SATELLITE-AIDED MOBILE RADIO CONCEPTS STUDY

Concept Definition of a Satellite-Aided Mobile and Personal Radio Communication System

R. E. Anderson
General Electric Company
Corporate Research and Development
Schenectady, NY

R. T. Milton
General Electric Company
Space Division, Valley Forge Space Center
P.O. Box 8555, Philadelphia, PA 19101

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16. Abstract

The objectives of this study were to determine the contribution satellite systems can make to the mobile radio service and identify technology developments needed to implement a satellite-aided system. An examination of present mobile systems and the proposed cellular systems indicate they are compatible with a satellite-aided service and can benefit from its use. Satellites can provide economical coverage in thinly populated areas not generally covered by terrestrial systems. Analysis indicates a large potential market outside the urban areas.

The satellite system requires the use of a large (70- to 140-foot) satellite antenna and spacecraft array power of about 12 kW or more depending on the operating frequency. Technology developments needed include large offset reflector multibeam antennas, satellite electrical power subsystems providing greater than 12 kW of power, signal switching hardware and linearized efficient solid state amplifiers for the satellite-aided mobile band. Presentally there is no frequency assignment for this service, and it is recommended that an allocation be pursued. The satellite system appears to be within reasonable extrapolation of the state-of-the-art. It is further recommended that the satellite-aided system spacecraft definition studies and supporting technology development be initiated.

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PREFACE

Study Objective

The objective of this study was to evaluate the contributions satellite systems can make to mobile and personal radio communication applications, whether the contributions satisfy recognized needs and do so in a cost-effective manner, and to identify the technology developments needed for the implementing of a useful, cost-effective satellite system.

Scope of Work

Present and developmental land mobile and personal communication systems were studied, satellite system concepts compatible with existing and developmental land mobile systems defined and their costs estimated. Satellite payload requirements were defined and needed technology developments identified.

Conclusions

Satellite systems can, indeed, uniquely provide a needed contribution to land mobile and personal communications and do so cost-effectively. Technology developments needed are within reasonable extension of the current state-of-the-art.

Satellite systems can augment the current land mobile radio services and provide service in thinly populated areas where terrestrial systems are not economically attractive. The future of land mobile radio telephone systems appears to be largely with the cellular systems being developed. The satellite system is not only compatible with such systems but a synergism exists between them. The development of the terrestrial cellular system will create a demand for the service which the satellite system can satisfy nationwide, outside the urban areas and can support even in the urban areas during the initial installation phases of the terrestrial system. The nationwide availability of the service further increases its utility and the demand for it.

Although well suited to augmenting the terrestrial cellular system, the satellite system can also support the more traditional land mobile radio services. Earth stations communicating through the satellite with the mobile units replace the traditional base station. Otherwise dispatch and radio telephone services can be provided in the present manner.

Terrestrial systems, when fully implemented, will service about 80% of the U.S. population which lives on about 10% of the nation's land area. This leaves 90% of the land area and about 40 million people to be serviced by the satellite system. Wide area coverage at relatively low cost is a unique capability of satellite systems. Such systems can make the mobile radio service economically available in remote areas for public safety, industrial and transportation needs. The estimated space segment cost of the satellite aided system is about $25 per month per subscriber.

Distinguishing characteristics of the satellite supporting the mobile radio service are an antenna of approximately 140 foot diameter and a power requirement of about 12 kW. The antenna is a reflector type to operate in the UHF band and is about 4 times the diameter of the ATS-6 reflector. The power requirement is an order of magnitude larger than that of the DSCS III spacecraft currently being developed. While the reflector diameter and power requirements exceed those of any NASA has put into geostationary orbit they are achievable within the current state-of-the-art.

<u>Recommendations</u>

Since a near term, mid-1980's, need for the satellite system can be identified, i.e., extension of coverage area and support of the terrestrial cellular system, it is recommended that NASA support the development of critical technologies. These include large multiple beam antennas in the range of 70 to 200 feet in diameter; spacecraft power subsystems in the range of 12 kW; linear and efficient solid state power amplifiers; and switches for the satellite payload to permit the interconnection of channels at the spacecraft.

Currently there is no frequency assignment for the satellite-aided mobile radio service. One is needed before the system development can proceed and it is recommended that NASA continue to support the allocation of frequencies to that service.

ACKNOWLEDGMENTS

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INTRODUCTION

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INTRODUCTION

Satellites offer something new to the users of mobile radio. They make it possible for a user to communicate with the user's own vehicles anywhere in the nation at any time. In addition, if the vehicles are properly equipped, they can be located automatically.

Federal and state agencies and some commercial enterprises have recognized the potential advantages of satellites. A federal law enforcement agency stated that it can communicate with its vehicles over seven percent of the country's area, but it needs to increase that coverage to 85%. Civil defense, search and rescue agencies have tested satellite communications and have expressed their need for them, as have state departments of emergency health services. A major food chain is interested in voice bandwidth data transmissions from trucks to a central computer for inventory control. A data systems company believes that a satellite-aided mobile communication position and surveillance system would make possible a nationwide cargo brokering service, and would fulfill a need for tracking valuable cargos on trucks and railroads. All of these applications and many others can be fulfilled by the use of a satellite, but few are likely to be fully satisfied without one.

Present day mobile radio is essential in our society. As it has grown to its present large size, it has retained much of the lack of coordination in regulation and procedures that characterized its early development. As a result, its assigned radio frequency spectrum is used less efficiently than modern techniques make possible, and it is inconvenient or impossible for some types of users to communicate when necessary with related users. For example, teams from several agencies working together in a search and rescue effort sometimes find it necessary to interface through other services such as amateur radio, or through special manually operated equipment that receives on one band, transmits on another.

It is likely that satellites will play a role in future mobile communications. It is important that their role be examined and planned to insure that they are well coordinated into the whole scheme so that they are used to their full advantage but not used when inappropriate.

When the study team undertook to identify the role of satellites it recognized that people have a nearly insatiable desire to communicate. In the United States there is a telephone for 1.3 persons. Each main telephone (not including extensions) is used 13 minutes per day. People also like to ride in automobiles. It is estimated that the average American spends about 40 minutes a day in an automotive vehicle. Except for a relatively insignificant number of mobile telephone subscribers, people are separated from the telephone service when they are in their automobiles. The recent explosive growth in the use of citizen's band radio demonstrates that people want to have communications with the world outside when they are in their automobiles.

Citizen's band provides a "party line" that serves many useful functions by enabling the interchange between occupants of nearby automobiles or base stations. It is a service limited by range, quality of communication and function. It cannot be used like the telephone to call anyone, anywhere at any time.

About 140,000 Americans subscribe to a mobile telephone service that gives them access to the public telephone network from their automobile. Present day mobile telephone service is expensive and uncoordinated. An average monthly cost of about $130 enables a subscriber to place calls within limited areas. Operational mobile telephone services are available from three types of enterprises, in three radio frequency bands of limited capacity. Each subscriber can use his mobile telephone only in the area served by the enterprise from which he subscribed and on the few channels within the one band for which his mobile phone is equipped. Despite the limitations of the present mobile telephone service, the demand far exceeds the capacity in many metropolitan areas.

A new approach, the cellular system, is now under development to increase the capacity and provide better service, potentially at lower cost. When full implemented, cellular systems will provide telephone service to millions of automobiles in metropolitan areas and along major highways. Every subscriber will be able to use his mobile phone whenever he is within range of the fixed transmitter-receivers of the system.

Plans for the cellular system do not now include the use of satellites. Without them, the terrestrial system will serve about eighty percent of the nation's population on ten percent of its land area. Extension of the terrestrial system to serve the rest of the nation would not be cost effective.

Recognizing that satellites could extend the service to all areas of the nation, this study considered the feasibility and probable cost effectiveness of augmenting the terrestrial cellular mobile telephone system with a compatible satellite-aided system. It concludes that a satellite could add needed services, attract additional subscribers and that it is likely to be cost effective.

By far the largest proportion of the five million commercial mobile radios in the United States are not connected to the public telephone network. They are in the public service, public safety and business-industrial services and use their radios almost exclusively in the dispatch mode in which a mobile and base station exchange short messages, one talking while the other listens, alternating use of a single assigned channel. Many mobiles and several base stations may share a channel.

Demand has grown to exceed capacity in many locations, and new procedures are being tested to improve capacity. One procedure is trunking. When a call is placed, the caller is assigned an available channel by a computer that serves as a central coordinator.

Most studies and experiments relating the application of satellite to mobile radio have emphasized the public service business applications. They may well be the most important societal applications. Federal and state agencies have needs for long range mobile communications that could justify the cost of a satellite.

It is against government policy to become a communication common carrier. If a satellite were to be placed in orbit for government needs, it would likely be done by a commercial enterprise that would then lease service to the government.

It was an early conclusion of this study that the best, most profitable use of a satellite would be as an augmentation of the planned terrestrial cellular mobile radio system. The public service-public safety requirements can be met by the use of single digit dialing and priority channel assignment within the public telephone network, terrestrially or through the satellite.

A concept for a satellite-aided mobile radio system was outlined. System and signaling parameter values were selected for evaluating the concept. The values are not to be regarded as suggestions for a final design. They are believed to be reasonable estimates for studying the concept, but they are subject to change when specific information is available on factors such as customer demand and frequency allocation.

The growth of mobile radio has been uncoordinated, resulting in an inefficient use of spectrum and incompatibility even within services of the same kind. The cellular and trunking approaches will bring a much needed coordination and compatibility to the mobile telephone service and bring the service to millions of subscribers. In parallel, advances in space technology now in progress could bring a new dimension to the system. Together the advances in terrestrial systems and space technology can bring forward an ubiquitous telephone service that will fulfill needs that cannot be met in other ways.

SECTION 2

CRITERIA FOR ACCEPTABILITY OF SATELLITE-AIDED SYSTEMS

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CRITERIA FOR ACCEPTABILITY OF SATELLITE-AIDED SYSTEMS

Any plan to implement a satellite-aided mobile radio system must be evaluated in its relationship to terrestrial mobile systems.

Present and planned terrestrial systems serve important needs. Demand for their service grows quickly to fill capacity whenever an engineering advance or a new frequency allocation provides an increase in the capacity. It is a healthy and profitable business that will remain so whether or not satellites are used. It follows that satellites, if they are to be used, must add a valuable service that is not likely to be provided without them. This study concludes that satellites can add the valuable service at acceptable cost within the following criteria:

- Satellites should not be used unless they can provide a needed service that cannot be provided in any other cost effective way.

Radio frequency spectrum and orbit positions are limited and precious resources that must be reserved for important applications that cannot be met without them. The large capacity of the mobile radio service within its limited spectrum is made possible by geographical frequency re-use; taking advantage of the range limitation imposed by the earth's curvature. Over continental or ocean basin areas, signalling range by satellite is not limited to the same extent by earth's curvature - a fact that gives satellites their greatest advantage. In the mobile radio service, the longer range advantage of satellites reduces frequency reuse, hence total capacity of the service that is available within a radio frequency band.

The limited range of terrestrial services restricts, and in some places, prohibits their use in areas that could benefit from them. Due to their extended range, satellite links can serve areas not likely to ever be served by terrestrial links. There is no plan for a terrestrial system that will serve all the nation's land area. The great majority of mobile radio users are presently limited to service within a few miles range from a base station. While this may satisfy their immediate needs, a single system serving all the land area would be attractive to many existing users and add many new users.

- A Satellite-aided land mobile radio system must be a profitable venture.

The system will be implemented and operated by a private enterprise. Government policy prohibits it from becoming a common carrier for communications. It follows that the satellite aided mobile radio system must have large capacity and attracts a large number of subscribers in order to justify the cost of the satellite, the ground terminal network, and operation.

There are precedents for the Federal government to obtain satellite communications from private sources even though the communications are solely for the government's purposes. Examples are the Navy's lease of a transponder on MARISAT, NASA's lease on the Tracking and Data Relay Satellite, and LEASAT. An exception to the need for profitability may exist if it is determined that public service requirements justify a government subsidy to support a satellite system implemented by a private enterprise.

For purposes of this study it is assumed that the system must be profitable. It is apparent that the system must attract hundreds of thousands of subscribers in order to recover its cost.

SECTION 3

PRESENT MOBILE RADIO SYSTEMS

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PRESENT MOBILE RADIO SYSTEMS

Mobile Radio is of great societal value in public safety and public service (Appendix G). Needs in these areas created the initial demand for mobile communications. More than five million commercial mobile and personal radios are in use in the United States. Worldwide, more than two billion dollars are spent on commercial mobile equipment annually, and the business is growing at an annual rate greater than 10%.

Business and industrial applications are also important and probably comprise the largest potential for growth of mobile radio. The ability to manage is determined by the ability to communicate. Services such as taxi and delivery services make constant use of mobile radio. Their needs are met by dispatch type communications. Other applications in mining, agriculture, construction and other businesses use mobile radio, and will increase their use when the two-way conversational mode is conveniently available (Appendix A).

Nationwide transportation services, rail and highway, have needs for the tracking of hazardous and high value cargoes. A nationwide cargo brokering service, especially between non-regulated carriers, would improve efficiency of the distribution system. An automatic cargo location surveillance system is the key element needed for implementation of the service. Federal law enforcement and search and rescue services also need a position location system. Satellites can be used to provide the surveillance function (Appendix H).

3.1 TYPES OF MOBILE RADIO SYSTEMS

Mobile radio systems are of three types:

- Dispatch
- Radio Telephone
- Paging

Dispatch service is the most widely used type in mobile two-way radio. A dispatcher at a central radio station location receives calls from the public or other customers or management and gives orders and information to people dispersed in vehicles or with radios carried on their persons. A simplex "push-to-talk" mode is used. Up to 100 business vehicles, or up to 40 police cars or fire engines are served per channel.

Radio telephone service is more recent and provides an extension of the public switched telephone network to a person in a vehicle. Ordinary two-way, full duplex, conversation is provided. About 30 subscribers can be accommodated on a channel pair. Average message length is longer than for dispatch service.

Paging is a one-way service that is sometimes offered in association with other two-way services. A subscriber carries a pocket-size "pager" containing a radio receiver, and a decoder for its own address number. When a person wishes to contact the subscriber, he calls the pager's number on the telephone. Depending on the type of service, the subscriber may hear an audio tone indicating he should call the paging service for the message, he may be instructed by the paging service operator to dial the caller's number, or he may hear the voice of the caller stating his message. The paging subscriber cannot respond by radio. Five hundred to one thousand subscribers may be accommodated on a paging channel.

A two-way radiotelephone channel serves fewer than 30 radiotelephone subscribers, but can serve up to 1000 pager subscribers at $20 to $30 per month. Equipment cost for a pager subscriber is about one-tenth that of a two-way radiotelephone subscriber. Income per radiotelephone subscriber is only 5 to 6 times higher than a pager subscriber. With limited number of channels there is a tendency by some radiotelephone common carriers to discourage mobile telephone subscribers, thus tending to reduce capacity available for the mobile telephone service.

Detailed descriptions and comments on the present mobile and personal radio systems are included in Appendix A which is summarized below.

3.2 MOBILE RADIO OPERATIONAL METHODS

Direct from Local Base

Dispatch type communications directly between an antenna on top of an office building and the vehicles.

Direct with Remote Base

Dispatch type communications with dispatcher control of a remote transmitter and receiver by way of telephone lines, microwave or other radio link.

Remote Repeater

Dispatch type communications with two-frequency simplex: one channel for transmitting and another for receiving.

Community Repeater

Dispatch type communications in which several small businesses share a remote repeater. Mobile radios of all the users are alike except that each individual business is assigned a sub-audible continuous tone so that only its vehicles and base are activated when the assigned tone is present. Each business appears to have its own repeater system, except that the channels are often busy and not available.

Private Interconnection to Telephone Network

Legal interconnection of a private business mobile radio system with the public switched telephone network. The person on the landline telephone has full duplex; someone can talk to him from the mobile radio while he is talking in return, but in the mobile it is not possible to listen while the other person is talking.

Radio Telephone (Common Carrier)

Radio telephone service extends the public telephone system telephones in vehicles. Two types of common carriers furnish mobile radio telephone service:

- Radio Common Carriers
- Wire Line Telephone Companies

Radio common carriers are companies that are organized to furnish service to mobile radio telephones. They do not provide wireline telephone service, but they do interconnect into a regular telephone network. From the standpoint of the regular wireline telephone companies, a radio common carrier appears as an independent telephone company. The radio telephone common carrier shares in the toll revenue which it generates via its customers. It also pays the wireline telephone company charges for its lines and services.

The second category, wireline telephone companies, furnish telephone service to homes and industry as well as mobile radio telephone service. For them the radio telephone interconnect appears in their hierarchy as either a small central office or as a private branch exchange.

3.3 CUSTOMER PERCEPTION OF MOBILE TELEPHONE SERVICE

The total capacity of the various mobile telephone systems across the continent is not available to any mobile telephone subscriber as he roams from one area to another. The company that installs the vehicle equipment assures service only in its local service area. Limited "roamer" capability exists, especially among the systems of the "wireline common carriers", but is limited by access protocol of the equipment and the frequency band for the customer equipment.

Various access protocols include the following:

- Manual service with access to an operator
- Improved mobile telephone system (IMTS) 2-way dial service with automatic channel selection and access to an operator.
- IMTS 2-way dial service; equipped roamers may dial all station-to-station calls, service to manual units not available
- 2-way dial service with access to an operator
- 2-way dial service without access to an operator

Various bands available include the following:

- Low band — 30-44 MHz; some channels wireline carrier, some channels radio common carrier.
- High band — 152-162 MHz; some channels wireline carrier, some channels radio common carrier.
- UHF band — 450-460 MHz; some channels wireline carrier, some channels radio common carrier.
- UHF band — Radio common carrier (additional channels in some cities).

A customer will have one of the seven sub-bands, created by the division of the above bands between wireline and radio common carrier, in his installed mobile equipment, and one or two of the five access protocols. It would take seven different radiotelephones installed across the front of the dash to cover the different bands... and seven telephone bills each month.

There is no uniform method of exchange billing among all the common carriers, especially the radiotelephone common carriers; thus many systems would not accept the call from a roamer since he could not be billed.

3.4 MOBILE TELEPHONE SERVICE IN NEW YORK STATE

For the purpose of depicting present-day mobile telephone services, we describe in some detail the services in New York State where they are typical of the service as it exists throughout the nation.

New York is just under the average of the contiguous states in area. Nine percent of the nation's population live within its borders. It contains the nation's largest city and several other major metropolitan areas. It includes one of the nation's largest wilderness areas and extensive agricultural lands. Its varied terrain includes mountains, plains and seacoast.

Like the nation as a whole, mobile radio services in the state are provided competitively by wireline carriers and radio common carriers in the populated areas. They do not provide service in areas far removed from cities.

The wireline carriers are further divided into the major carriers, such as the Bell System, and the independents. Therefore there are three types of suppliers to the service. A subscriber is served only by the type to which he subscribes. If it is an independent wireline or a radio common carrier, he may not have his calls accepted by other operators of the same type.

Service is provided in three mobile radio bands. The Improved Mobile Telephone Service of the Bell System's New York Telephone Company operates in the 152-162 MHz band and provides coverage shown in Figure 3-1. The outlines of the coverage areas show how terrain affects mobile radio service. More than one repeater site is often needed to serve an area. For example, the Capital District (Albany, Schenectady, Troy) area shown as the upper right service area has three sites. There are four channels to serve the area.

When the independent wireline carriers are added to the Bell System, their 152-162 MHz service is approximately as shown in Figure 3-2. Actual plots of coverage were not available, so each independent wireline site was assumed to serve a 25 mile radius.

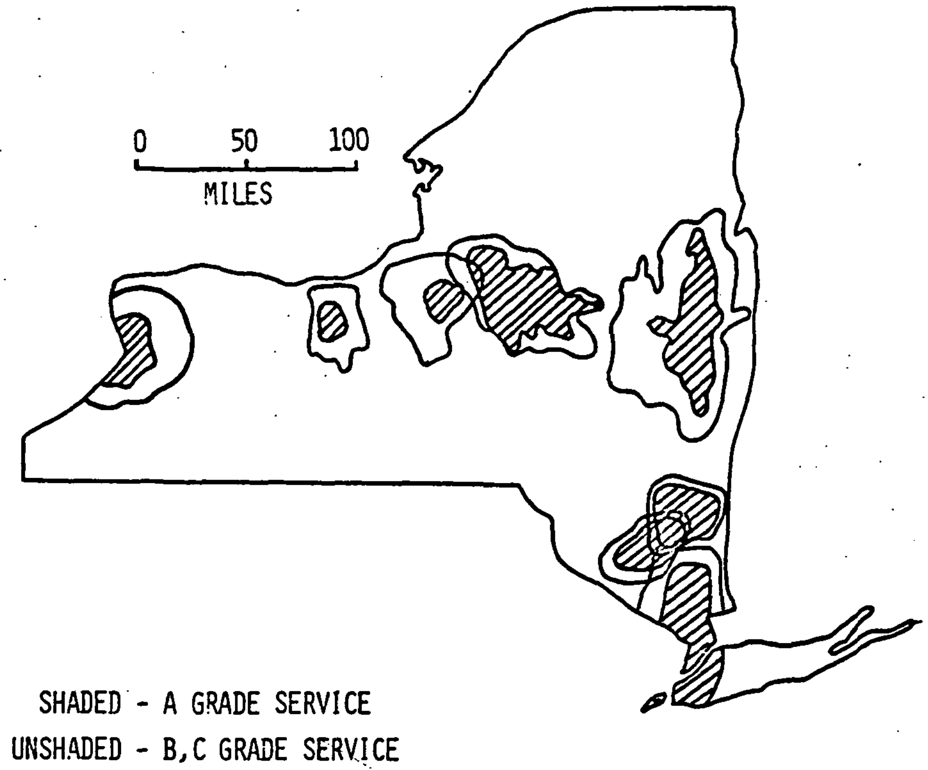


Figure 3-1. New York State Mobile Telephone Coverage
(Bell System - N. Y. Telephone Co. 152-162 MHz Band)

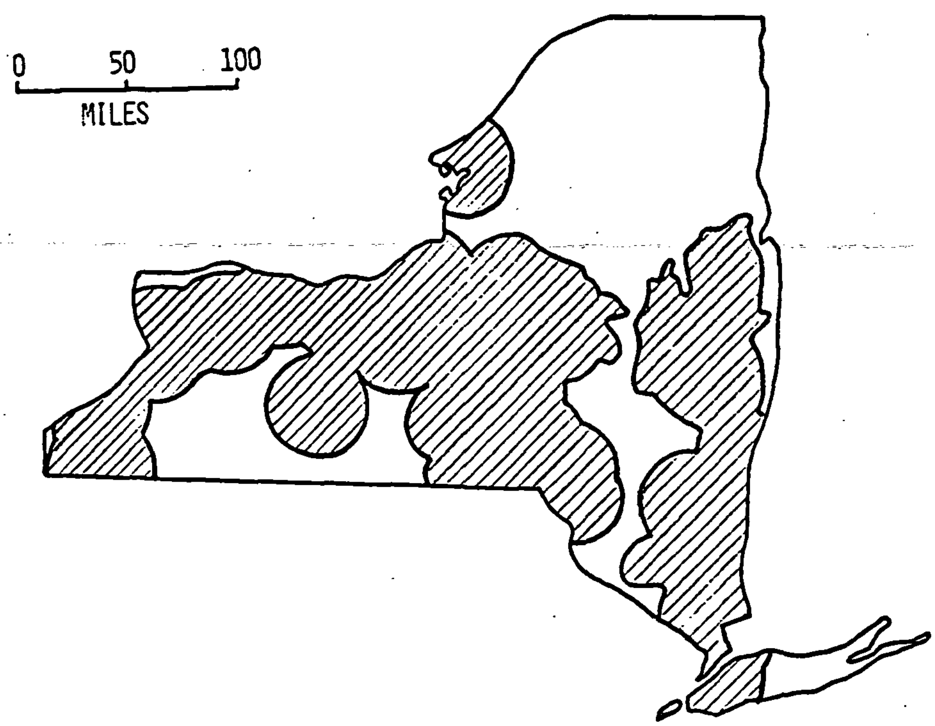


Figure 3-2. New York State Mobile Telephone Coverage
(All Wireline Telephone Companies 152-162 MHz Band)

Figure 3-2 is therefore an optimistic estimate of the area served. The radio common carriers generally serve the same areas as the wireline companies and would add little to the service area shown in Figure 3-2.

Service in the 450-460 MHz band is provided by wireline companies, and is shown in Figure 3-3. It is limited almost exclusively to the New York City metropolitan area and Long Island.

Service in the 30-44 MHz band is shown in Figure 3-4, again assuming that coverage extends a radius of 25 miles from the radio sites. Service is available, as with the Bell Systems, at cities along the New York State Thruway.

In New York State as throughout the nation, a subscriber to mobile telephone service is provided in one of the three bands. The number of channels available in the bands are:

35 - 44 MHz	10 channels
152 - 158 MHz	11 channels, wireline carrier 7 channels, radio common carrier
454 - 460 MHz	12 channels, wireline carrier 14 channels, radio common carrier In 13 cities throughout the USA an additional 12 to 24 channels are available.

The subscriber's equipment works in only one of the bands. It may work only on the channels served by the local carrier who sells the service to the subscriber. Typical cost to the subscriber for his equipment is about $2000 if he purchases it, or $100 per month if he leases it. In addition, there is a "readiness to serve charge" of about $30 per month. He is usually allowed a number of local calls for the readiness to serve charge, but pays additionally for local calls over that number and for long distance calls.

Mobile telephone services are operated as shown in Figure 3-5. The public wireline mobile telephone service, the Bell System's New York Telephone Company in New York, operates

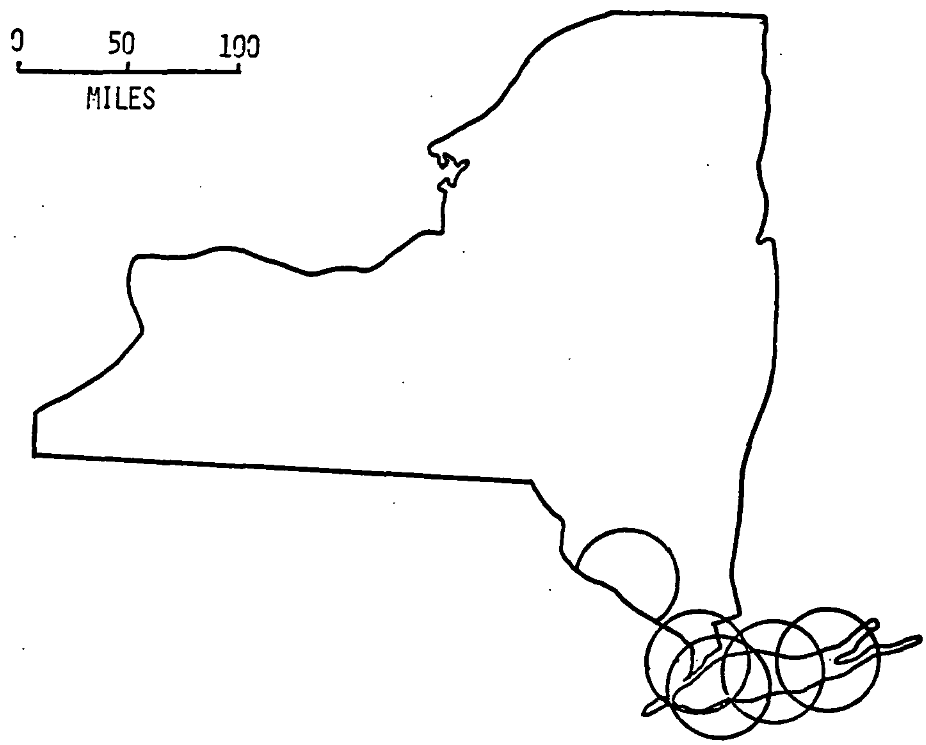


Figure 3-3. New York State Mobile Telephone Coverage (Wireline Telephone Companies 450-460 MHz Band)

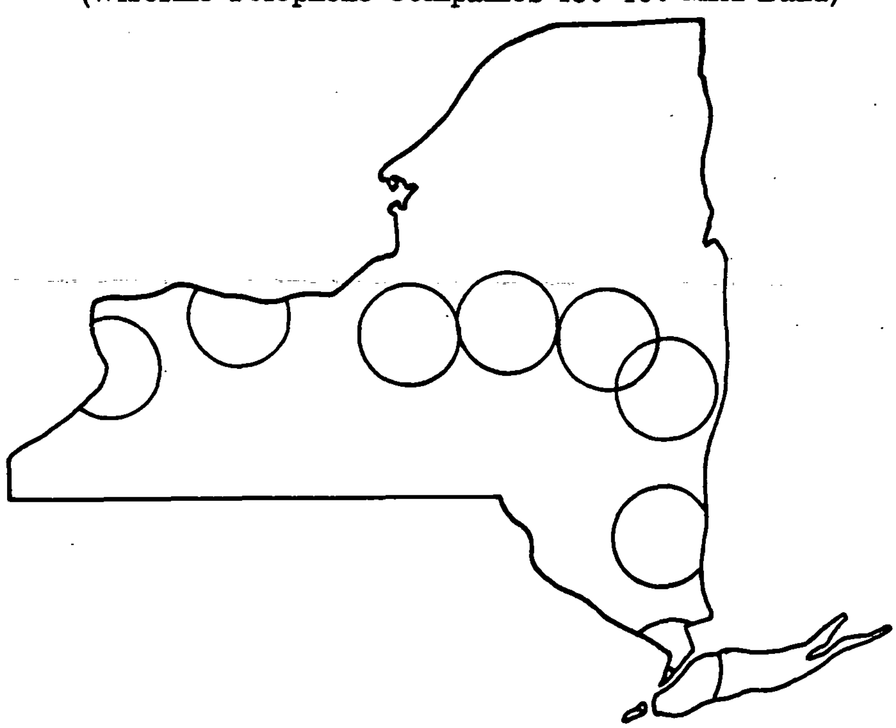


Figure 3-4. New York State Mobile Telephone Coverage (Wireline Telephone Companies 30-44 MHz Band)

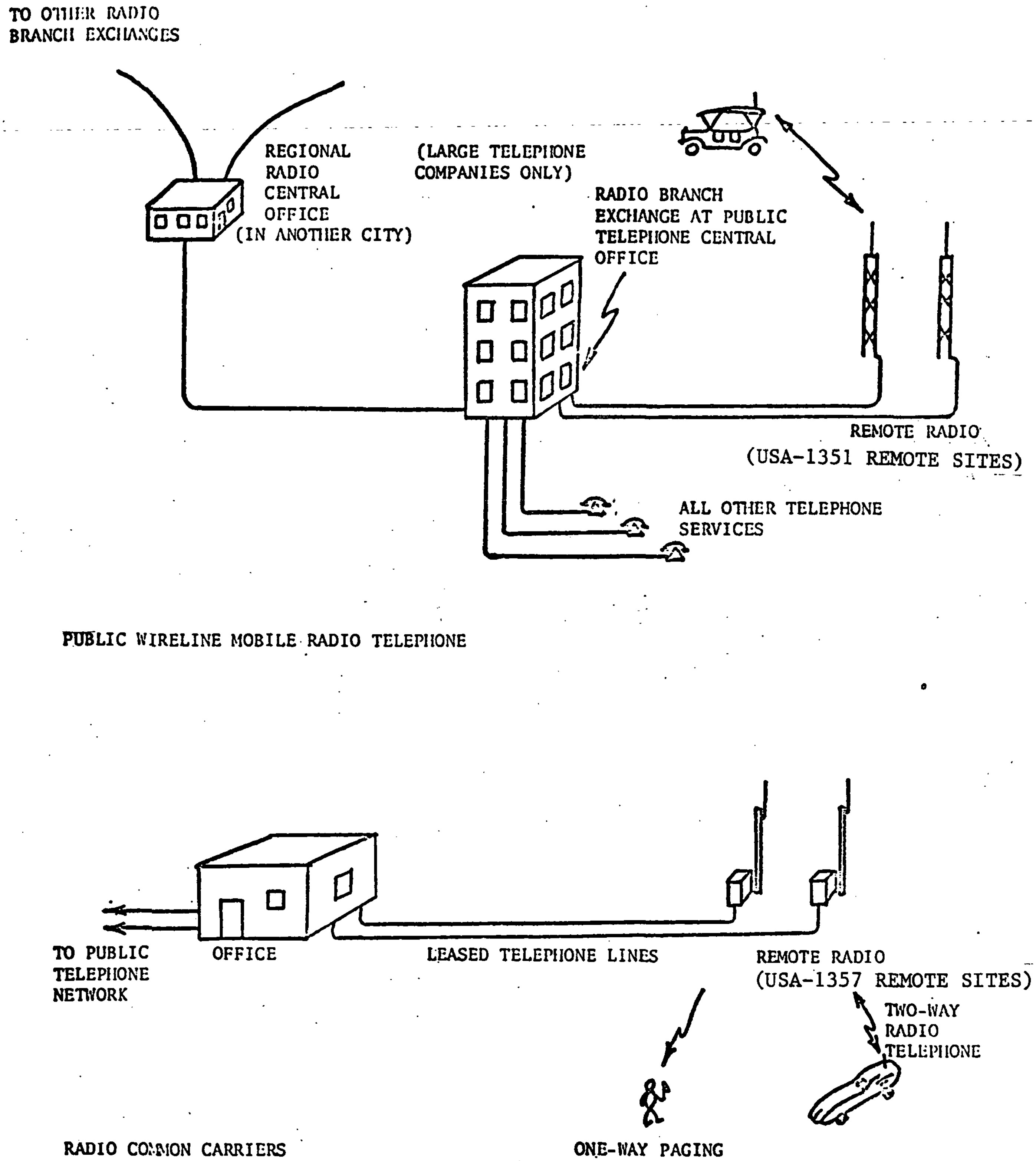


Figure 3-5. Mobile Telephone Service Operation

in the area shown in Figure 3-1 with a radio branch exchange at the public telephone central office in a city. Radio contact with subscriber's vehicles is from towers at favorably elevated locations. More than one site may be needed for a service area, as noted above for the capital district of New York. A wireline connection to a regional central office at Syracuse in New York coordinates operation of the state-wide system including switching and billing. Nationwide there are more than 1351 remote sites for all the wireline carriers, serving about 60,000 subscribers.

Independent radio common carriers who provide mobile telephone service but not other telephone services each have their own facility in the area they serve, as shown in Figure 3-5b. Leased telephone lines connect the office in the city with the remote radio site, one leased pair for each channel. The radio calls are connected to the public telephone network, usually by an operator. Nationwide the radio carriers have about 1357 remote sites and serve a total of 80,000 subscribers. Many radio common carriers find it more lucrative to use their facilities for paging rather than mobile telephone because a channel can handle many more short one-way paging calls than two-way conversations.

Present day mobile telephone service is poorly coordinated, limited in capacity, and limited in service area for any subscriber. Demand in many areas far exceeds the capacity. The deficiencies of the service and the unmet demand were incentives for the development of cellular systems. They hold the promise of meeting the demand in cities by reducing cost to subscribers, increasing system capacity, improving performance, and standardizing equipment and procedures.

Cellular systems will not serve the needs of persons who live outside the standard metropolitan statistical areas (SMSA). It is expected that terrestrial services compatible with cellular systems will be available in many areas outside the SMSA's where population densities are large enough to attract investment of radio common carriers. Much of the nation's area, and a large total population lives in areas that have little prospect of terrestrially based mobile telephone service. As shown in Section 5 that population is estimated to be 44 million persons who could be served by a satellite system designed to augment the cellular system. The combination of cellular systems in cities, cellular-compatible service in areas with moderate population density, and satellite service in the remaining area would achieve the goal of an "ubiquitous telephone service" of high quality.

3.5 CELLULAR MOBILE RADIO TELEPHONE SYSTEMS

A new development in mobile radio telephone systems is the cellular concept by AT&T. It is now in its test phases in Chicago and Newark by AT&T. Motorola and a radio common carrier, American Radio Telephone Service, are testing another version of cellular systems in the Washington/Baltimore area. Cellular systems use computer control of a 900 MHz system to achieve a high degree of frequency reuse in a small area. Based on the intensive studies over several years by AT&T, the Federal Communications Commission has set aside 666 duplex channel pairs in the 900 MHz region. The basic system design is intended to provide full radio telephone service to the general public.

Each area to be covered is divided into a honeycomb array of hexagonally shaped cells. A fraction of the total available channels (typically 1/7) is assigned to each cell. The size of a cell is determined by the total number of customers expected to be served within it. The cell size is not determined by technicalities of possible range from a given location, but is determined by expected density of customers and usage. The cellular approach thus uses a design philosophy opposite from that of conventional mobile radio where range is extended as far as possible by placing the transmitter-receivers on the tallest building or tallest hill in the area. By using many short range radio relays and program control, the cellular system reuses a given frequency at a distance which is only a small fraction of that of conventional systems. The cellular system achieves good communications without annoying interference and at high spectrum efficiency.

Operation of a cellular mobile radio telephone is illustrated by describing how a call is placed from a vehicle to a standard landline connected telephone. As the vehicle drives within a metropolitan area with its radio telephone instrument "on hook", there is some transmission interchange between it and the central computer. The mobile equipment searches through the orderlines for the best received set of channels; i.e., the channel set best used in the cell the vehicle is in.

In addition to the talking channels, there are channels dedicated to handling the control signals for the system similar to the order wire channels used in conventional landline toll telephone systems. Each cell is controlled by a programmed computer switch. The array of cells is controlled by a central office type of switch.

Each cell is assigned up to three orderline channels for "broadcast" paging of a mobile's telephone number. There may be a total of 21 paging channels in the system. The mobile radio telephone scans all 21 channels and selects the one that is the strongest. The selected orderline channel is kept in memory until another orderline channel becomes consistently stronger at which time the new orderline channel will be placed in the mobile radio telephone equipment memory. Periodic "overhead" words keep mobile's equipment informed as to access channels and paging channels being used in particular area.

When the subscriber in the car goes "off hook", picks up his telephone and dials the number with a conventional touchtone pad, the number is accumulated in a memory register. One unit now being tested shows that number on a liquid crystal on the instrument. If that is the desired number, the caller pushes a send button. If the orderline is not busy, it is used to transmit the number to the local cell computer that forwards the called information to the nearest landline central office for making the connection to the landline customer. The central office computer then assigns a channel pair for the conversation to the mobile radio telephone from the cell station. When the called landline customer comes off hook, the connection is completed to the mobile radio telephone and the channel put into busy conditions for all other users.

The telephone conversation is carried on in normal back and forth duplex fashion no different than a standard landline telephone connection. As the mobile radio telephone car proceeds from one area to another, it may traverse the edge of a cell, in which case two things occur. The cell computer tracks the signal strength received from the car and assesses its position in the cell. As it enters the next cell, the computer at central control hands off the vehicle from one channel pair to a new channel pair in the new cell. The handoff is accomplished by digital data inserted automatically on the voice channel during a 50 millisecond blanking of speech; a time sufficiently short that the handoff is usually not detected by either the landline or mobile customer. The channel pair originally in use is then available for use by any other customer in that assigned cell.

A second illustration of cellular use is the placement of a call from a landline station to a mobile radio telephone. The call is placed to the metropolitan area in which the mobile radio telephone is expected and his number is broadcast over all 21 orderline paging channels. As each available mobile radio telephone scans the orderlines, it detects its own address or telephone number. It then responds on the orderline held in its memory as the best that it receives. The computer then assigns a channel pair for use in the cell in which the mobile is located, resets the mobile radio telephone via the orderline to that channel pair, and rings the bell of the telephone in the car. When the mobile subscriber lifts the instrument off hook, the connections are made via the radio channel pair and the landline switching.

As the cellular system grows in usage so that the number of customers in each cell becomes higher than the cell size can handle with the channels available to it, the cell size is decreased so that the new cell size has the desired number of subscribers. A cell can be as small as one mile across. One additional requirement; when a mobile radio telephone enters one of the new small cells, it is necessary to decrease the range of the mobile so it does not interfere with a cell that uses the same channels two or more cells distant. Range is decreased by reducing the power output from the mobile radio telephone by computer control via digital message to the mobile radio telephone when it enters the small cell.

The cellular system carefully controls radiation in power and direction from the cellular fixed stations and also controls power output of the mobiles. Power output is a maximum of 12 watts for mobiles in the Chicago experimental cellular system and a maximum of 40 watts from the fixed stations. After transmission line and multiplexer losses (for site station), this provides equal signal quality for both fixed and mobile receivers.

The Improved Mobile Telephone Systems (IMTS) now in operational use by radio common carriers and wireline common carriers in the radio telephone service is a non-cellular system that employs power outputs of 20 to 30 watts for mobiles and up to 300 watts for base stations. The power requirements for the vehicle for a cellular mobile radio telephone are thus far lower than for the present day mobile radio telephones. Although transmitted power is controlled in the cellular mobile radio telephone system, there remains a large variation in received signal strength. The minimum received signal strength is kept high enough to insure full commercial grade service. For the AMPS cellular system design this is a carrier-to-interference plus noise ratio of 18 dB. As one drives past a cellular land station, the receive signal is extremely strong from adjacent channels radiated from that station. It is necessary that the cellular mobile radio telephone system receiver be able to handle a large dynamic range of simultaneous signals with low intermodulation product generation. At least 70 - 90 dB of signal variation in receive signal is encountered. The cellular system has the advantage that when the desired receive signal is weak, the undesired signals from that same station are also weak, although signals from the next cellular station are becoming stronger. As one approaches a cellular land station with the mobile radio telephone, not only the adjacent channel but the desired channel signal becomes stronger at the same rate. The problem of receiver design from the standpoint of dynamic range is easier with a cellular system than it is for the conventional system.

SECTION 4

SATELLITE AUGMENTATION OF TERRESTRIAL CELLULAR SYSTEMS

SECTION 4

SATELLITE AUGMENTATION OF TERRESTRIAL CELLULAR SYSTEMS

Over the years, mobile radio systems and operating protocols have developed step-by-step with advances in technology, increasing variety of applications, and growth in demand. The result is a mixture of unrelated procedures, techniques and equipments that does not realize the full potential of the art.

Recent advances in technology are coming into limited use. In the past, it was necessary for each radio to have a crystal to control the frequency of each channel. Frequency synthesizers now make it practical to set transmitters and receivers quickly and accurately to any one of hundreds of channels. Inexpensive and compact solid state logic circuits make it practical to have centralized control of mobile transmitter-receivers. These advances are combined to provide "trunking" operation of mobile users. When a mobile wants to talk it is assigned any unused channel from the set of allocated channels. Demand assignment increases the capacity of the channel set beyond the capacity that was available when each mobile was always constrained to talk on one or a few channels because it could afford only a few crystals.

Centralized control can further improve total system capacity by controlling mobile transmitter power, thus restricting range only to that needed at the time by the mobile. A channel can then be used simultaneously by several mobiles within line-of-sight range instead of depending on curvature of the earth to determine frequency reuse distances.

Cellular systems are an attempt to combine trunking and centralized control, and in addition to provide an interface with the public switched telephone network. An objective is to make all cellular systems compatible so that a user can obtain service anywhere that it is offered. Mobile radio users would then enjoy a system that takes advantage of all the technological advances and gives better service at lower cost.

As cellular systems become available, it is expected that they will attract many subscribers from businesses and the general public. Current users of dispatch type services will probably continue to use their facilities until they become obsolete. New customers that are candidates for dispatch type services will have the choice of purchasing their own mobile and base equipment for the traditional dispatch service, or subscribing to the cellular system, which will probably have a dispatch mode as well as convenient access to the public telephone network. The equipment purchase requires the investment of several thousands of dollars for the base station and one to two thousand for each mobile. It also requires that the owner be licensed for its use. Access to the cellular system does not require an investment nor the licensing procedure, but does require payment of monthly service charges for each mobile. It is likely that most new users would select the cellular service, and that many current users would subscribe to it when they can justify the phase out of their equipment.

Any consideration of satellite-aided mobile radio must consider the use of the best available mobile radio techniques as the designers of cellular systems have done in their attempt to combine the best available techniques into a well coordinated service. Terrestrially based cellular systems retain one serious omission - they will not provide service in thinly populated areas. Satellites offer the potential of correcting that omission. They can do it best if they also take advantage of the best mobile radio technology as well as the best of space technology. Terrestrially based and satellite-aided cellular type mobile radio systems may together accomplish a revolutionary advance in the mobile communication art.

Satellite augmentation of terrestrial systems is useful only if the cost is acceptable. As space technology progresses, there is little doubt that cost will eventually be low enough. It would be especially advantageous if a cost-effective space system could be implemented within the next five to ten years because the satellite-aided system could then advance the cellular concept by providing service everywhere, including smaller metropolitan areas that would otherwise have to wait for the installation of terrestrial services. As demand grows in such areas, the satellite service would eventually be replaced with terrestrially based systems.

The following sections examine potential demand for satellite-aided mobile service on a state-by-state basis, then present a concept and a sample design of a system that appears to be a practical approach to a satellite-aided cellular system that could be implemented well within the next decade by extension of present space technology.

SECTION 5

DISTRIBUTION AND SIZE OF POPULATION SERVED BY SATELLITE

SECTION 5

DISTRIBUTION AND SIZE OF POPULATION SERVED BY SATELLITE

The concept of a satellite-aided system for the nation is much like the cellular concept for an urban area. A multibeam antenna on the satellite forms many independent beam "footprints" on the earth, each footprint corresponding to a cell. The multibeam antenna permits frequency reuse on a geographical basis, and thus provides large total capacity within a limited radio frequency spectrum allocation.

The population that would be served by a satellite-aided mobile telephone system is distributed more uniformly than the general population. Densely populated areas will be served almost exclusively by terrestrial systems, hence their populations are not candidates for the satellite. Areas with very thin population densities will be served by a satellite or not at all. Areas with intermediate population densities may be served in part by terrestrial, in part by the satellite.

The distribution of the "served population density" that will use the satellite is estimated because it affects the relative demand for service in the various footprints. A uniform distribution of served population would contribute to an efficient use of the satellite total capacity. An uneven distribution affects the design of the satellite, perhaps requiring that some footprints be larger than others, or that some footprints have more channels than others.

The estimate of the served population and its distribution is made in several steps. For each of the 48 contiguous states the populations of metropolitan areas greater than 200, 000 is subtracted from the total population, as shown in Table 5-1. It is assumed that terrestrial urban cellular systems will serve the metropolitan areas.

The non-metropolitan population is divided by the area of the state to determine the average population density, D_p, in persons per square mile, Table 5-2. A minor inaccuracy is introduced in this step because the total areas of the states were used. For most states, the metropolitan areas are small compared to total area. For the smaller states, Rhode Island and Delaware, the metropolitan areas are such a large part of the total that is is assumed that they are not candidates for the satellite.

A satellite system "use factor", P_S, for the non-metropolitan area was determined for each state. It takes into account the states' differences in area, population density and population distribution, and is determined from statewide patterns of terrestrial system availability. It is assumed that a terrestrial system is almost certainly available if the resident population density exceeds 200 persons per square mile. The average 20-mile radius of a terrestrial system would then include a total population of 251,000 persons. A community of that size would almost certainly attract the investment in a terrestrial system. If the average non-urban population density of a state exceeds 200 per square mile, it is assumed that the entire state is served terrestrially, and there is zero probability of a call being placed through the satellite. Figure 5-1 illustrates the satellite system use factor.

As population density decreases, the probability that it is served entirely by terrestrial systems also decreases. It does not decrease linearly with population because service from a terrestrial system usually extends beyond concentrations of population that are large enough to attract investment in a terrestrial system. On a statewide basis, $P_S = \left[\frac{200 - D_p}{200}\right]^n$ where $n = 2$. Other values for n, or other functions for P_S may be assumed, but the values selected appear to agree with the present availability of terrestrial services within limits to make the result valid for estimates of relative usage in the various states, and hence in the footprints of the satellite.

When P_S is multiplied by D_p to yield the average population density served by the satellite, as opposed to resident population density, the result, as expected, shows that densely populated states such as Massachusetts, Connecticut and New Jersey do not use the satellite because the entire state is served by terrestrial systems, Table 5-3. Thinly populated states, like Nevada, depend on the satellite, but place few calls per square mile because there are few subscribers per square mile. States such as New York and Pennsylvania, which have large cities but also large rural and wilderness areas, are among the most active users of the satellite because they have extensive areas with fairly high populations.

Table 5-1. State Area and Population

State	Area	Population	Population Less Urban Areas Over 200,000	State	Area	Population	Population Less Urban Areas Over 200,000
Arizona	113,909	1,772,482	453,293	Missouri	69,686	4,677,399	1,807,295
Alabama	51,609	3,444,165	824,773	Montana	147,138	694,409	694,409
Arkansas	53,104	1,923,295	845,642	Nebraska	77,227	1,483,791	943,649
California	158,693	19,953,134	2,265,463	Nevada	110,540	448,738	175,450
Colorado	104,247	2,207,259	743,758	New Hampshire	9,304	737,681	737,681
Connecticut	5,009	3,032,217	1,000,048	Vermont	9,609	444,732	444,732
Florida	58,560	6,789,443	2,340,261	New Jersey	7,836	7,168,164	2,812,580
Geogria	58,876	4,589,575	2,501,025	New Mexico	121,666	1,016,000	700,226
Idaho	83,557	713,008	713,008	New York	49,576	18,241,266	2,495,024
Illinois	56,400	11,113,976	3,158,349	North Carolina	52,586	5,082,059	3,628,299
Indiana	36,291	5,193,669	2,889,952	North Dakota	70,665	617,761	617,761
Iowa	56,290	2,825,041	2,538,940	Ohio	41,222	10,652,017	2,663,405
Kansas	82,264	2,249,071	605,803	Oklahoma	69,919	2,559,253	1,441,419
Kentucky	40,395	3,219,311	2,139,015	Oregon	96,981	2,091,385	868,898
Tennessee	42,244	3,924,164	1,907,798	Pennsylvania	45,333	11,753,909	1,453,400
Louisiana	48,523	3,643,180	2,017,501	South Carolina	31,055	2,590,516	1,664,285
Maine	33,215	993,663	993,663	South Dakota	77,047	666,257	666,257
Maryland	10,577	3,922,399	1,851,729	Texas	267,339	11,196,730	4,744,067
Delaware	2,057	548,104	49,127	Utah	84,916	1,059,273	501,638
Massachusetts	8,257	5,689,170	1,960,294	Virginia	40,817	4,648,494	3,157,416
Rhode Island	1,214	949,723	44,534	Washington	68,192	3,409,169	1,288,786
Michigan	58,216	8,875,083	2,596,450	West Virginia	24,181	1,744,237	1,260,979
Minnesota	84,068	3,805,069	1,726,072	Wisconsin	56,154	4,417,933	2,446,881
Mississippi	47,716	2,216,912	1,958,006	Wyoming	97,914	332,416	332,416

Table 5-2. State Population Density

State	Population Density, Persons Per Square Mile Outside Metropolitan Areas Over 200,000	State	Population Density, Persons Per Square Mile Outside Metropolitan Areas Over 200,000
Arizona	3.98	Missouri	25.9
Alabama	16.0	Montana	4.72
Arkansas	15.9	Nebraska	12.2
California	14.3	Nevada	1.59
Colorado	7.13	New Hampshire	79.3
Connecticut	200	Vermont	46.3
Florida	40.0	New Jersey	359
Georgia	42.5	New Mexico	5.76
Idaho	8.53	New York	50.3
Illinois	56.0	North Carolina	69
Indiana	79.6	North Dakota	8.74
Iowa	45.1	Ohio	64.6
Kansas	7.36	Oklahoma	20.6
Kentucky	52.6	Oregon	8.96
Tennesse	45.2	Pennsylvania	32.1
Louisiana	41.6	South Carolina	53.6
Maine	29.9	South Dakota	8.65
Maryland	175.	Texas	17.9
Delaware	23.9	Utah	5.91
Massachusetts	237	Virginia	77.4
Rhode Island	36.7	Washington	18.9
Michigan	44.6	West Virginia	52.2
Minnesota	20.5	Wisconsin	43.6
Mississippi	41.0	Wyoming	3.39

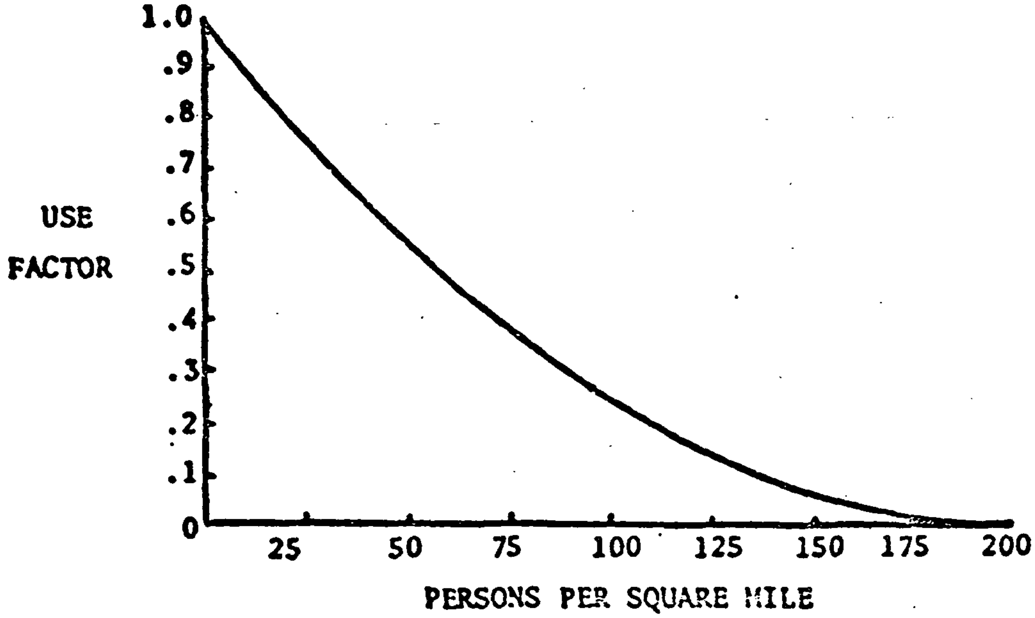


Figure 5-1. Satellite System Use Factor

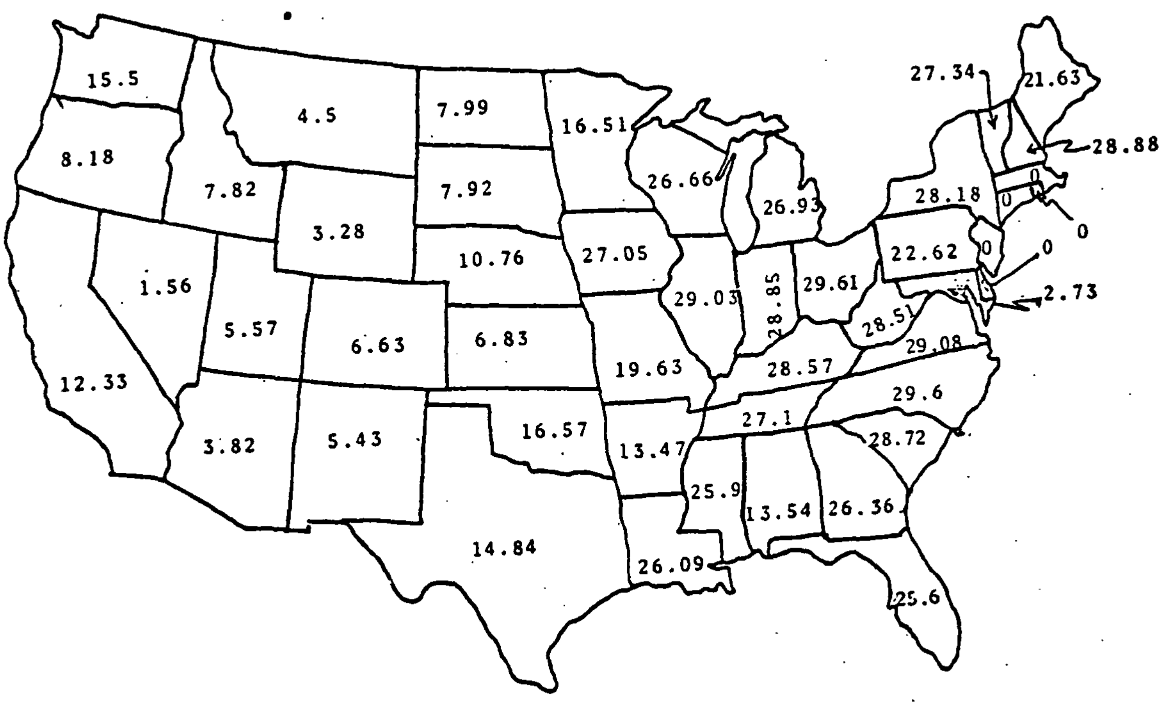


Figure 5-2. Served Population Density - Persons/Square Mile

Table 5-3. Served Population Density

State	Use Factor	Served Population Density	State	Use Factor	Served Population Density
Arizona	0.96	3.82	Missouri	0.76	19.63
Alabama	0.85	13.54	Montana	0.95	4.5
Arkansas	0.85	13.47	Nebraska	0.88	10.76
California	0.86	12.33	Nevada	0.98	1.56
Colorado	0.93	6.63	New Hampshire	0.36	28.88
Connecticut	0	0	Vermont	0.59	27.34
Florida	0.64	25.6	New Jersey	0	0
Georgia	0.62	26.36	New Mexico	0.94	5.43
Idaho	0.92	7.82	New York	0.56	28.18
Illinois	0.52	29.03	North Carolina	0.43	29.6
Indiana	0.36	28.85	North Dakota	0.91	7.99
Iowa	0.60	27.05	Ohio	0.46	29.61
Kansas	0.93	6.83	Oklahoma	0.80	16.57
Kentucky	0.54	28.57	Oregon	0.91	8.18
Tennessee	0.60	27.1	Pennsylvania	0.70	22.62
Louisiana	0.63	26.09	South Carolina	0.54	28.72
Maine	0.72	21.63	South Dakota	0.92	7.92
Maryland	0.02	2.73	Texas	0.83	14.84
Delaware	0	0	Utah	0.94	5.57
Massachusetts	0	0	Virginia	0.38	29.08
Rhode Island	0	0	Washington	0.82	15.50
Michigan	0.6	26.93	West Virginia	0.55	28.51
Minnesota	0.81	16.51	Wisconsin	0.61	26.66
Mississippi	0.63	25.9	Wyoming	0.97	3.28

The result suggests that the demand for satellite service will be more uniformly distributed over the continent than the general population, but varies over a range of about 19 to 1.

The data indicate which satellite beams can be combined, if desired, to produce large footprints and thus further equalize the number of calls per footprint. Figure 5-2 is a map of the contiguous States showing the served population density by state.

A factor that may affect the 19:1 ratio of demand in the footprints is difference in need as a function of living style and business activities in the various parts of the country. No attempt was made to estimate the effect of differences in need because we lacked a justifiable basis for an estimate.

Multiplication of each state's population outside of the urban areas by the use factor gives the estimated population served in each state, as shown in Table 5-4. This shows that nationwide population served is an estimated 44 million persons.

Service to areas other than the contiguous U.S. is discussed in Appendix I.

Table 5-4. Served Population

State	Served Population (Pop. less urban multiplied by use factor)	State	Served Population (Pop. less urban multiplied by use factor)
Arizona	435,161	Missouri	1,373,544
Alabama	701,057	Montana	659,688
Arkansas	718,795	Nebraska	830,411
California	1.948,298	Nevada	171,941
Colorado	691,694	New Hampshire	265,565
Connecticut	0	Vermont	262,391
Florida	1,497,767	New Jersey	0
Georgia	1,550,635	New Mexico	658,212
Idaho	655,967	New York	1,397,213
Illinois	1,642,341	North Carolina	1,560,168
Indiana	1,040,382	North Dakota	562,162
Iowa	1,523,364	Ohio	1,225,166
Kansas	563,396	Oklahoma	1,153,135
Kentucky	1,155,068	Oregon	790,669
Tennessee	1,144,678	Pennsylvania	1,017,380
Louisiana	1,271,025	South Carolina	898,713
Maine	715,437	South Dakota	612,956
Maryland	37,034	Texas	3,962,475
Delaware	0	Utah	471,539
Massachusetts	0	Virginia	1,199,818
Rhode Island	0	Washington	1,056,804
Michigan	1,557,870	West Virginia	693,538
Minnesota	1,398,118	Wisconsin	1,492,597
Mississippi	1,233,543	Wyoming	322,443
		Total	44,120,158

SECTION 6

SYSTEM CONCEPT

SECTION 6
SYSTEM CONCEPT

The foregoing sections described existing terrestrial systems and their planned development, and identified needed functions that satellite-aided mobile radio can fulfill as an augmentation of terrestrial systems. Having defined the role, we now portray a system concept that could fulfill the role.

The system functions as a mobile telephone service patterned after the cellular concept first proposed by the Bell System and now under test by Bell in Chicago and Newark, and by Motorola and American Radio Telephone in Washington-Baltimore.

The advanced features of terrestrial cellular systems are included in the satellite-aided cellular concept. Frequency reuse and trunking insure highly efficient use of the radio frequency channels. When demand grows, capacity can be increased within the allocation by orbiting a satellite that forms a larger number of smaller beams, thus increasing the reuse of the channels. Operating protocols are compatible with the terrestrial systems, and portions, if not all of the vehicle equipment can be used over the satellite links as well as in the terrestrial systems so that a subscriber can have the advantages of both systems.

W.R. Young[1] lists the objectives of the (terrestrial) Bell System Advanced Mobile Phone Service as follows:

(i) Large Subscriber Capacity

(ii) Efficient Use of Spectrum

(III) Nationwide Compatibility

(iv) Widespread Availability

(v) Adaptability to Traffic Density

(vi) Service to Vehicles and Portables

(vii) Regular Telephone Service and Special Services, Including "Dispatch"

(viii) "Telephone" Quality of Service

(ix) Affordability

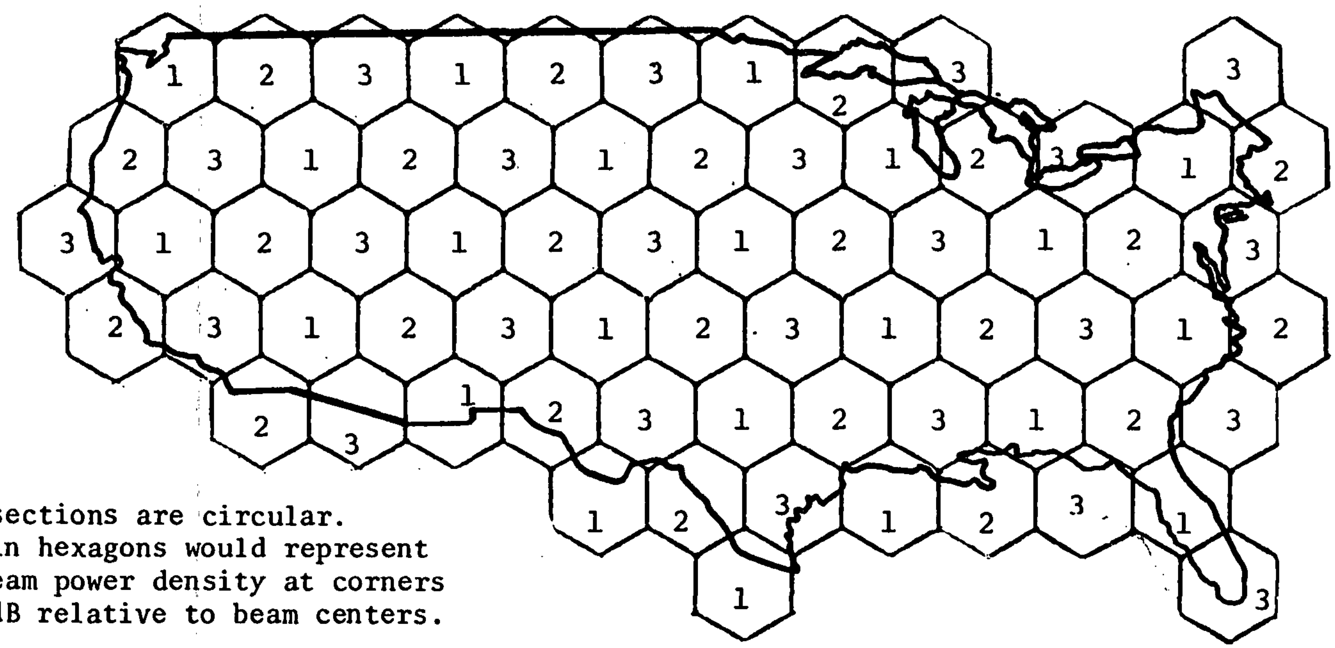
All of these objectives pertain to the satellite augmentation of the terrestrial systems. Under "Widespread Availability" (of the terrestrial systems) Young(1) states

> "Neither this characteristic nor nationwide compatiblity necessarily implies universal coverage. Wide-area coverage will be achieved gradually as metropolitan systems extend their coverage into surrounding suburbs, and finally along the principal road and rail routes between metropolitan centers."

It is the purpose of the satellite augmentation to provide the universal coverage except when a structure or terrain feature blocks the path from the vehicle to the satellite. Implementation of the satellite system would make the universal coverage immediately available, serving the early demand in areas where the gradual extension of the metropolitan systems will eventually take place, and continuing to provide the service in areas that cannot be served in as cost effective a manner by terrestrial means.

Most present-day mobile radio is in the dispatch mode whereby a vehicle talks directly to a base directly or through a repeater. The dispatch mode can be made available together with other services and features that offer advantages beyond the dispatch mode. An important service is access to the public switched telephone network.

The satellite aided mobile telephone system employs a satellite with a multibeam antenna. Each beam illuminates a "footprint" of limited extent within the total service area. The hexagons in Figure 6-1 represent the "cells" of the satellite system. The numerous cells or footprints are formed to permit frequency reuse in the manner of a terrestrial cellular system. The number of cells is proportional to the area of the satellite antenna. An early implementation may use relatively few footprints. As demand for service grows, satellites with larger antennas may be placed in orbit to form more footprints and permit greater frequency reuse. Figure 6-1 shows the contiguous states covered with 69 footprints.



Actual beam cross sections are circular. Circles inscribed in hexagons would represent 0.5° beamwidth. Beam power density at corners of hexagons is -4 dB relative to beam centers.

Numbers in hexagons refer to channel sets of frequency reuse pattern.

Figure 6-1. Satellite Antenna Beam Footprints

The channels within the allocated spectrum are divided into sets. Adjacent cells are assigned different sets of channels to avoid cochannel interference at the edges of the cells. The smaller the number of channel sets, the greater is the number of channels within each footprint, hence the greater the system capacity. It appears practical to control satellite antenna side lobes sufficiently that only three channel sets are needed - a smaller number than are needed in a terrestrial system. The numbers within the circles of Figure 6-1 refer to the channel sets.

Every vehicle that uses the system is capable of operating on all channels in all sets of frequencies. Within each set of frequencies there is at least one paired "calling" and one "control" channel. The remaining channels in each set are "talking" channels. When a subscriber's mobile telephone is activated, it automatically searches for and locks to a control channel. When the subscriber dials a number, the request is transmitted over the calling channel. An earth station assigns a talking channel pair to the vehicle via the control channel, and connects the call to the called party through the public switched telephone network.

As shown in Figure 6-2, the vehicle talks on a channel in a mobile frequency band, the satellite relays the vehicle signals to the earth station on a channel in a microwave band. The signal of the other party is transmitted by the earth station on a microwave channel to the satellite that relays it on a mobile channel to the vehicle.

The earth station assignment of the talking channels insures efficient use of the channels allocated for the system. All switching and control are done automatically under computer control at the earth station. The subscriber's perception of the system is no different than his perception of a fixed telephone or the terrestrial cellular system, except that he may be aware of a 1/4-second signal delay when talking to a fixed telephone, and 1/2-second delay when talking to another mobile telephone that is also using the satellite. The equipment in his vehicle is turned on by the ignition switch. The subscriber places a call by dialing, and receives calls by picking up the phone when it rings.

When a call is placed to a mobile, the earth station first attempts to reach the vehicle by transmitting the call on the command channels in the home footprint of the vehicle. If no response is forthcoming, it repeats the call in other footprints and makes the connection through the footprint in which the vehicle responds.

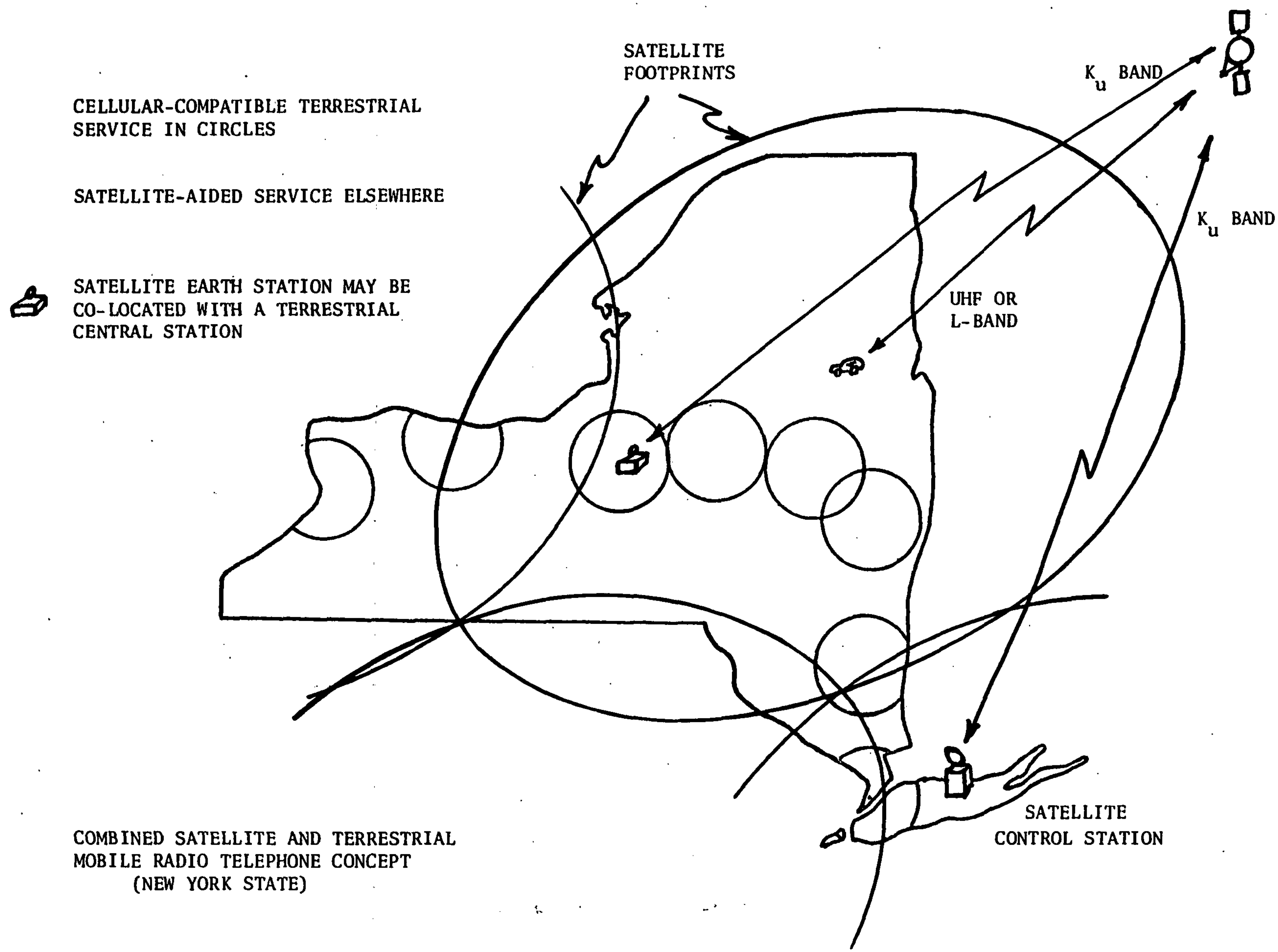


Figure 6-2. Combined Terrestrial and Satellite-Aided Mobile Telephone Systems

Operating protocols (Appendix A, Section A.5) and software are like those of terrestrial cellular systems. Vehicles that are equipped for terrestrial as well as satellite-aided mobile telephone service will first attempt to access the terrestrial system. When a vehicle fails to access the terrestrial system, it then scans for the satellite. No call setup delays are involved, because the scan and selection take place automatically within a few seconds after the ignition switch is turned on.

When a vehicle equipment determines that the average signal level received on the command channel that it is monitoring falls below a level adequate for the expected quality of service, it is an indication that the vehicle has entered a different footprint. It then automatically initiates another scan; first for terrestrial, then for a satellite command channel. The scan-relocking procedure need not take place during a conversation via the satellite. Handover procedures like those of the terrestrial systems are not needed with the satellite. Overlap of footprint service areas are large enough so that a vehicle is unlikely to traverse the entire overlap distance during a conversation. Should the unlikely event occur, the subscriber can redial the call through the satellite beam that serves the new footprint.

An automatic seek for terrestrial service at timed intervals may be advantageous so that if a vehicle enters a metropolitan area within a satellite footprint the equipment will transfer to the terrestrial system. The action will unload the satellite system, and perhaps reduce the chance of signal dropout by urban structures that could block the vehicle-to-satellite path.

Another option for the system is to allow the satellite to carry some of the load of a metropolitan cell when there is a sudden overload that might occur when a large crowd leaves a sporting event or a traffic jam occurs within the cell. If the event takes place during a slack period for the satellite footprint that includes the metropolitan area, vehicle call requests may be accommodated by switching the vehicle to satellite talking channels.

There are several possible arrangements for deployment of the radio equipped central-earth stations that interface the satellite with the public switched telephone network. Selection between the choices is affected by the combination of entities that operate the satellite-aided system. The choice has an influence on the cost of the satellite.

Figure 6-2 depicts an integrated land mobile system including terrestrial and satellite-aided service. The satellite footprints cover areas served by terrestrial systems, but the terrestrial service is preferred there in order to reduce demand on the satellite.

One version of the satellite-aided system places an earth station in each footprint. All calls between mobiles and fixed telephones, whether local or long distance, interconnect through the telephone network. Each footprint of the satellite is independent of all the others. The transponder in the satellite for each beam is likewise independent, so that no message switching in the satellite is necessary. The satellite is less costly than it would be if on-board message switching were required.

Complete independence of the beams could eliminate the need for the separate telephone system station shown in Figure 6-2. If that is done, each footprint earth central station must have a microwave transmitter-receiver to transmit signals from the telephone lines to the satellite and to receive mobile signals from the satellite. A ground station for satellite housekeeping and control must be provided regardless of the configuration of stations for the telephone system.

Figure 6-2 shows a separate control station as part of the telephone system. It may function at several levels. If the footprints operate independently, the control station performs record keeping functions for the system and may search the footprints for vehicles that are to receive calls when they are outside of their home footprints.

If the satellite contains a switch to transfer calls between beams, the separate control station may operate the switch within the satellite. If that is done, the two hop delay, 1/2 second for calls between two vehicles talking through the satellite, may be reduced to a one hop delay, 1/4 second. Long distance calls from a mobile may then be switched through the satellite rather than through the terrestrial network. If a single entity operates the whole system, the control station of Figure 6-2 could eliminate the need for an earth station in each beam.

If many independent entities participate in system operation, there may be a number of earth stations within each footprint with the set of channels divided between the entities. Each operating entity would then have its own specific assignment of channels and its own microwave interface between the satellite and the public switched telephone network.

SECTION 7

SYSTEM DESCRIPTION

SECTION 7
SYSTEM DESCRIPTION

Systems implementing the concepts discussed in the previous sections are described here along with some of the options and tradeoffs available. In the process important parameters are identified, discussed and quantified. Based on the work reported here, it is concluded that a satellite system to support the satellite-aided mobile radio concept is technically feasible; new technology required is a reasonable extension of the current art.

Because there is no current frequency allocation to the satellite-aided mobile radio service, spacecraft antenna designs and payload power requirements are derived for representative frequencies in the UHF and in the L-band. Within each of these bands two 10 MHz bandwidth allocations are assumed, one for a mobile transmit band and the other for a mobile receive band.

The establishment of primary frequency allocations for satellite-aided mobile radio is necessary for detailed design and for system capacity estimates. The 20 MHz, total, bandwidth assumed appears very conservative, at least in the long term. Trends in communications for purposes other than mobile are away from radio transmission. Edward C. Posner, (Reference 2), writing on "Communications In the 3rd Millennium" states:

"The trend to guided wave communications will mean that in many instances, bandwidth occupancy will no longer be the problem it has been. However, because of the wide use of mobile communications, there will still be a need for bandwidth-conserving modulation, data compression, and like techniques. This will be most true for mobile voice communication. Bandwidth conservation will, however, be less important in 2001 than at present."

The assumed bandwidth of 20 MHz in a mobile band for the satellite-aided service is modest compared to entertainment uses of the spectrum, being equivalent to 3-1/3 television channels. As television service moves toward the use of cable, its need for radio spectrum may be reduced. Reallocation of some UHF spectrum to the mobile telephone service, satellite as well as terrestrial, may be advantageous because the telephone has a societal value comparable with television.

Since system capacity is proportional to the available bandwidth, the capacity estimates given here, based on the assumed to 10 MHz allocations, will probable represent an initial value to be increased as the spectrum becomes available.

7.1 SYSTEM TECHNICAL OBJECTIVES AND REQUIREMENTS

System technical requirements follow from the objectives given below:

1. The system will provide voice bandwidth communications between mobile units and distant base stations, anywhere in the U.S.
2. Quality of the communications will equal that of the best non-satellite systems.
3. Except for special applications, planned mobile and personal radios will work through the satellites as well as with non-satellite systems. The required equipment modifications will be minimized.
4. All modern ancillary equipment and techniques and procedures, such as selective calling, will work through the satellites without modification.
5. The satellite system will not restrict the potential for growth in the number of users. Frequency reuse will be an important consideration.
6. The system will be cost effective.
7. The satellite system will fail-safe to insure communications reliability.
8. The satellite links are at least as resistant to jamming as present non-satellite links.
9. The system should incorporate means to prevent unauthorized use.

From these objectives the following systems requirements can be defined.

1. Coverage. Everywhere in the contiguous U.S. and Alaska that an unblocked direct path to the satellites exists.

2. Communications Quality:

   a. Service grade of P.02 (2% of offered calls blocked during the busy hours).

   b. Audio quality equivalent to a test tone to noise ratio of 50 dB in a 300 Hz to 3000 Hz audio band.

3. Satellite Transparent to Mobile Transmission. RF signals received by the mobile from the satellite should have the same modulation parameters as those received from the terrestrial transmitters. The satellite should accept RF signals from the mobile modulated as for use in the terrestrial system. However, translation of terrestrial system mobile transmit and receive frequencies is acceptable to permit satellite operation outside the frequency band of the terrestrial systems if required.

4. Support Ancillary Mobile Radio Equipment. The system should support the calling channel and control channels of terrestrial systems required to provide selective calling. It should also support inband signalling and supervisory tones and data transmission.

5. Non-restriction of Mobile Radio Growth. The satellite system should not restrict the growth of the number of users. Spectrum should be conserved and orbit space used efficiently. To this end frequency reuse is required.

6. Cost Effectiveness. Mobile and personal units for use with the satellite system should be of the same design as those for land use. Adapting the land units for satellite use should require no more than simple add-on's for frequency translation, power amplification and satellite reception (antennas).

   The satellite system cost per added subscriber should be a small part of the cost of the mobile radio service.

7. Communication Reliability. The satellite system space segment should include redundancy to assure continuous communications through the satellite.

8. Jamming Tolerance. The satellite receivers should have sufficient dynamic range and be overload protected so as to be able to tolerate large out-of-band signals without significant performance degradation.

9. Unauthorized Use. The system should include provisions to prevent call set-up for all land units not properly equipped and should provide means for unit identification.

7.2 SYSTEM CONFIGURATION

Two basic system configurations are described. One is based on the conventional satellite "Bent Pipe" transponder approach, the second incorporates switching in the spacecraft.

Subscriber perception of the service is substantially the same for both configurations. In either case, for the baseline system, the satellite is in geosynchronous orbit at 110 degrees west longitude. It illuminates the contiguous states with 69 beams.

Each spacecraft antenna beam services a hexagon cell as shown in Figure 7-1. The channels within the allocated frequency band are divided into three sets. The numbers within the cells represent the sets of channels assigned to the cells. To permit frequency reuse of the channels on a geographical basis while minimizing cochannel interference, no adjacent cells are assigned the same set of channels.

Consistent with the terrestrial cellular system design, the satellite system is designed to support narrowband FM channels having a 25 kHz IF bandwidth separated by 30 kHz. The assumed 10 MHz bandwidth allocation for vehicle to satellite, and 10 MHz satellite to vehicles permits a total of 333 duplex voice channels. The three frequency sets assigned to cells as shown in Figure 7-1 gives a frequency reuse factor of 23 for the 69 cells.

One hundred and eleven channels are available in each footprint. If three transmit and three receive channels in each cell are assigned to calling and control, there remain 108 talking channels in each footprint.

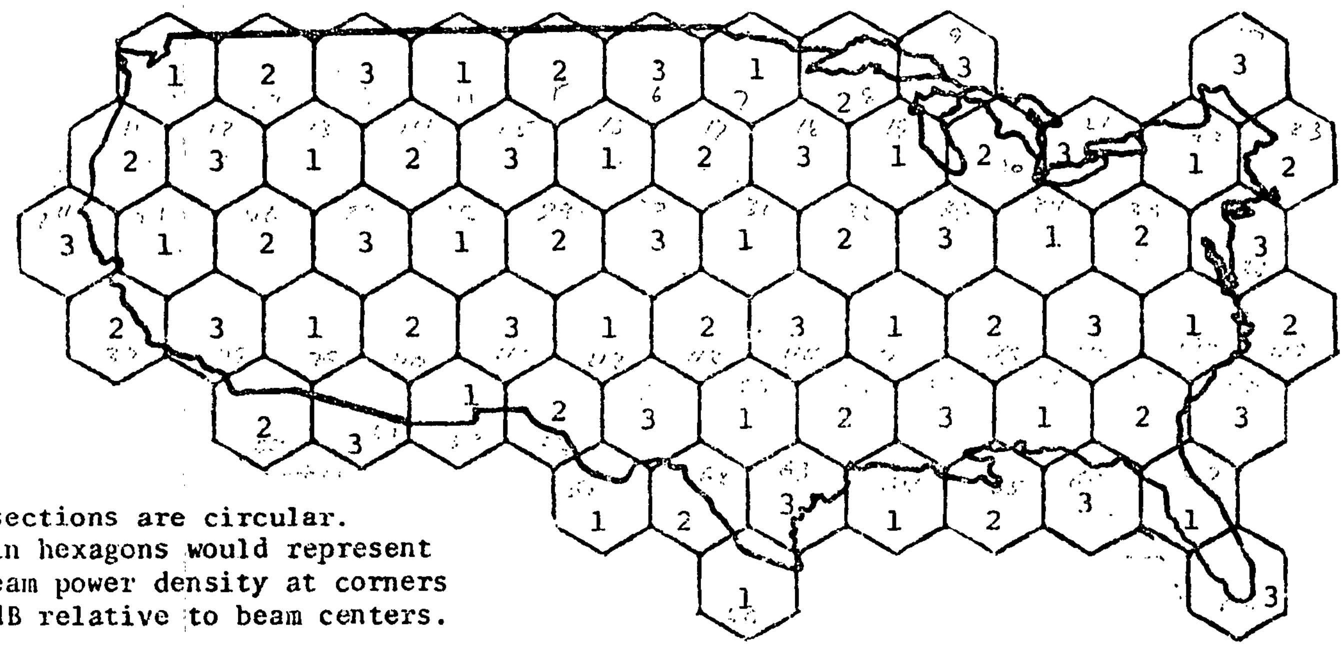
Numbering the 333 channels consecutively from one edge of the band to the other, the allocation of channels in the three sets is as follows:

Set 1: 1, 4, 7, 10, 13 331

Set 2: 2, 5, 8, 11, 14 332

Set 3: 3, 6, 9, 12, 15 333

The arrangement is chosen to maximize system capacity with tolerable adjacent channel and cochannel interference. Any three channels of each group may be selected for calling and control.



Actual beam cross sections are circular. Circles inscribed in hexagons would represent 0.5° beamwidth. Beam power density at corners of hexagons is -4 dB relative to beam centers.

Numbers in hexagons refer to channel sets of frequency reuse pattern.

Figure 7-1. Satellite "Cells" Serving Contiguous States

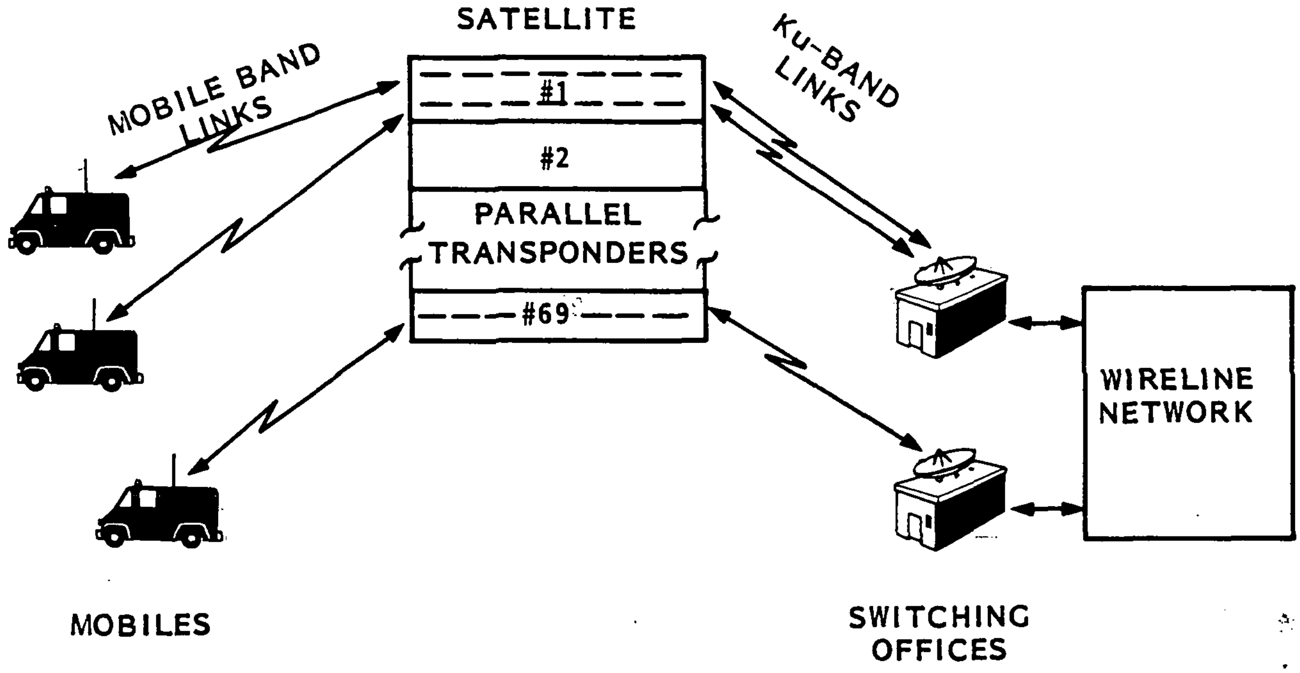
Analyses of possible frequency reuse patterns have been carried out (Appendix C) and, for the most promising patterns, analyses of cochannel interference resulting from their use estimated (Appendix B). These studies indicate the reuse pattern shown in Figure 7-1 can be used. This is the pattern that maximizes the system capacity. That is, only three sets of channels are required. This is the smallest number of sets that can be arranged so that no two adjacent cells carry the same set. Thus, there are one-third of the total number of channels in the system available at all points. Other frequency reuse patterns require dividing the total available channels into four or more sets. This means that any point in the system has available one-fourth or less of the total channels available to the system.

Dividing the available channels into larger numbers of sets has the advantage that the separation of cells using the same set can be increased. This can be used to reduce cochannel interference. However, the analyses done to-date indicate that the cochannel interference from the three frequency set pattern is acceptable. That arrangement is assumed for the baseline systems.

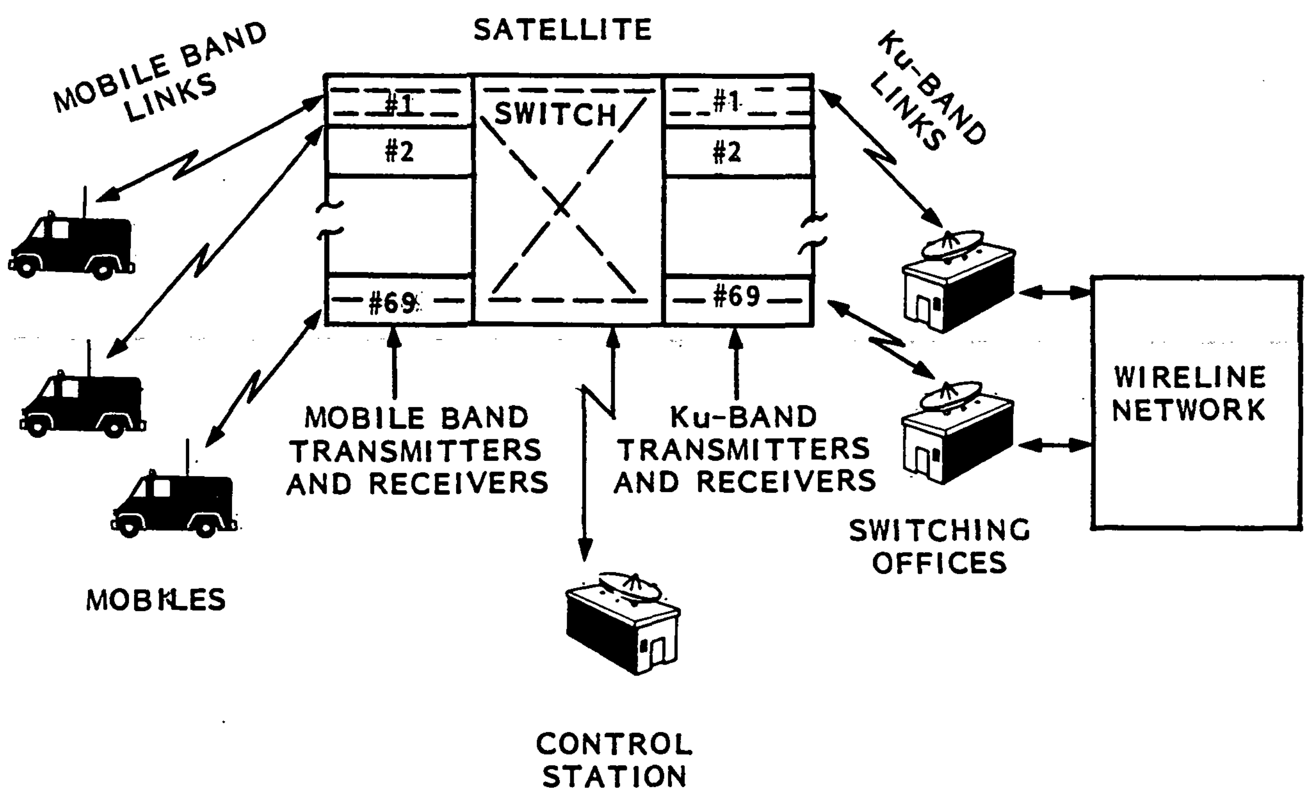
Figure 7-2 illustrates the two system configurations in simplified form.

7.2.1 BENT-PIPE TRANSPONDER

In the Bent-Pipe configuration the satellite carries 69 two-way, frequency translation transponders. Each has a 10 MHz bandwidth each way and is uniquely associated with a cell on the earth by the antenna beam servicing that cell. All transponders have the same center frequency. The satellite carries two multibeam antennas. One operates in the mobile band and generates the 69 beams that define the cells. The second operates at a higher frequency, the 12/14 GHz band is assumed for the baseline system. This antenna is used to establish links between the satellite and fixed earth stations. Depending on the amount of traffic and its distribution, there may be one or more earth stations in a cell or, if there are little used cells, some may not contain an earth station, in which case the cell could be served by a station in another cell. It is assumed that there will be at least one earth station in each cell and the Ku-band multibeam antenna beams coincide with those of the mobile band antenna. The Ku-band antenna makes possible frequency reuse in that band, also.



A. Bent-Pipe Transponder



B. Satellite Switching

Figure 7-2. Configurations in Basic Forms

Frequency division multiplex is used on the Ku-band links between the satellite and the earth stations. This is the natural type of mulitplex for the Bent-Pipe transponder because the channels are received from the mobiles and transmitted to them on separate carriers.

Each transponder and associated antenna beams is, in effect, independent of the others; there is no switching or interconnection between beams in the satellite. A mobile subscriber talks on one of the 108 channels assigned to the uplink mobile channels. His voice is relayed on a Ku-band channel to the earth station, thence through the telephone network to the other party, whose voice is passed through the public telephone network to the earth station, on Ku-band to the satellite, thence on a mobile band downlink channel to the vehicle. The call is carried from the earth station to the fixed telephone via the public switched telephone network whether it is local or long distance. Mobile-to-fixed telephone involves only one satellite "hop", introducing about 1/4 second path delay. Many overseas and long distance calls are now via satellite, and involve the one hop delay.

If the call is from a mobile in one footprint to a mobile in another footprint, the call is passed from one earth station to an earth station in the other footprint via the wireline network, thence by satellite through the other beam. The conversation is subject to a two-hop delay, approximately one-half second, that some subscribers might find annoying. It is expected that only a small percentage of the calls will be between mobiles that are both communicating through the satellite.

With the Bent-Pipe configuration all switching is done at the earth station and in the wireline network. Interconnection of mobiles in the same cell is done at the associated earth station. Interconnection with mobiles in other cells or to fixed telephones involves the wireline network.

Although the preceding discussion considered the mobile radio telephone application only, it is apparent that the satellite system will support the dispatch mode also, either by the use of an earth station as a base station or by sharing an earth station with the mobile radio telephone service.

7.2.2 SATELLITE SWITCHING

The second system configuration employs a switch in the satellite. The switch enables the system to interconnect mobiles in the same or different cells and to establish connections between mobiles and earth stations in the same or different cells. No call in this configuration need experience more than a one hop ground-to-space-to-ground delay, about 1/4 second. There is a separate mobile band transmitter and receiver for each beam and similarily a separate Ku-band transmitter and receiver. This configuration minimizes the switch requirements of the earth stations. An interface to the wireline network is required at the earth stations but little switching equipment. System switching is done at the satellite under the control of a central control station. Mobile and Ku-band antennas, receivers and transmitters are similar to those of the Bent-Pipe approach. The major difference is the addition of the satellite switch, the use of which requires channelizing (demultiplexing) equipment at the spacecraft to separate the channels for switching and multiplexing equipment for transmission.

Since there is channelization at the spacecraft and the satellite switch is controlled from the central control station, the calling channels from both the mobile and earth stations are stripped out at the satellite and transmitted to the control station via the Ku-band beam serving the cell it is in. Mobile and earth station control data are also generated at the control station, transmitted to the satellite and multiplexed into the appropriate beam. Any inbound signalling information between the mobile and earth station would also be transmitted by the earth station to the control station.

As in the case of the Bent-Pipe transponder, placement of earth stations depends on the traffic patterns. If, as is presumably the case, the majority of the traffic originates and terminates within the same cell and there is sufficient traffic, the use of one or more earth stations in each cell would minimize the number of long distance connections required through the landline network. The placement of earth stations, therefore, becomes a matter of trading earth station cost against the cost of using the landline network. It is assumed for the baseline system that there is an earth station in each cell.

Several options are available for the Ku-band link multiplexing, depending on the switch design. For baseband analog and for digital switching, digital time division multiplexing may give the best combination of performance and cost. For analog IF switching, frequency division multiplexing appears to be the preferred approach.

This configuration is particularly useful if there will be significant intra-cell mobile-to-mobile traffic or inter-cell traffic to either mobiles or earth sations.

7.3 SPACECRAFT DESCRIPTION

A baseline spacecraft is described for definiteness. Variations to that spacecraft resulting from the use of a different number of beams, incorporation of means of reducing voice channel carrier power, the use of a different mobile band carrier frequency, and different transponder type are related to the baseline configuration.

The baseline spacecraft operates at UHF mobile band frequencies, provides 69 beams to cover the contiguous United States and uses Bent-Pipe transponders. It is believed to be the most readily realized spacecraft, that is, the configuration closest to the current state-of-the-art.

7.3.1 SPACECRAFT CONFIGURATION

Figure 7-3 illustrates the baseline satellite and Table 7-1 summarizes technical data describing it. The spacecraft is configured for a shuttle launch: The UHF antenna uses a wrap-rib construction for the reflector which enables it to be wrapped around the antenna hub and stored within the 15-foot diameter of the shuttle bay. The antenna is positioned when in orbit by a combination of extendable and foldable members that, when collapsed, fit within the 60-foot long shuttle bay. Spacecraft weight is less than 5000 pounds and can be taken from low earth orbit to synchronous altitude by means of an IUS.

A major alternative to the use of UHF as the mobile band is to use L-band and this has a significant effect on the spacecraft. Table 7-2 summarizes the spacecraft data for this alternative. The main reflector size decreases from 139 feet to 75 feet effective diameter. Because of the smaller mobile unit antenna effective aperture area at L-band, the spacecraft EIRP has to be increased by about 3.4 times. This is reflected in an approximately equal increase in the required solar array area because the primary use of power aboard the spacecraft is for RF power generation. Also, since the power dissipated in the spacecraft increases proportionally, the radiating surface area has to be increased. The additional solar array area and radiating surface area results in a substantial spacecraft weight increase. Estimated spacecraft weights are listed in Table 7-3.

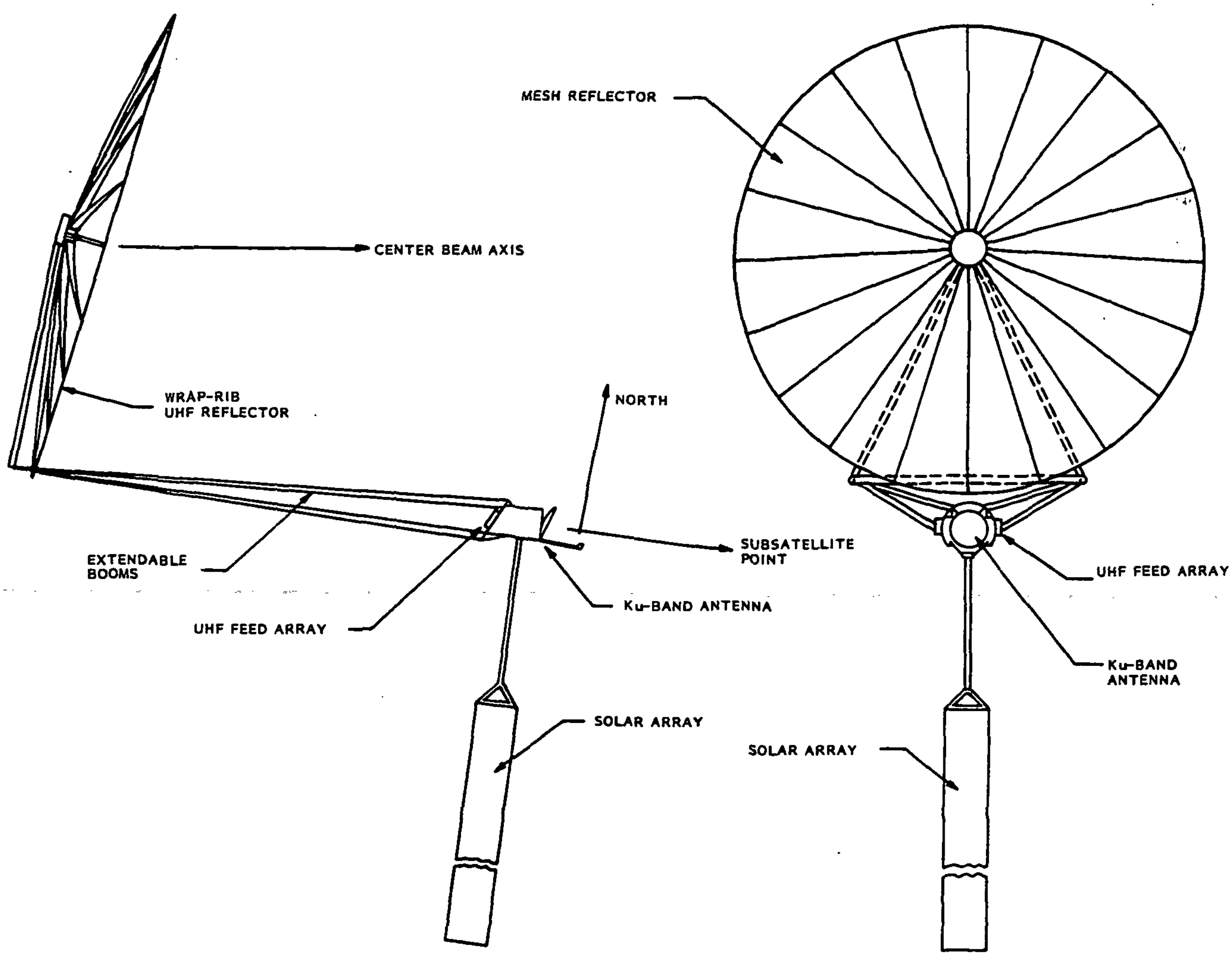


Figure 7-3. Spacecraft for Satellite-Aided Mobile Communications at UHF

Table 7-1. UHF Spacecraft Technical Data

Payload	
Forward Transponders	69 Parallel Redundant Units, Ku-Band to UHF Frequency Conversion
Return Transponders	69 Parallel Redundant Units, UHF to Ku-band Frequency Conversion
Transponder Type	Double Frequency Conversion
EIRP per Voice Channel	39.9 dBW
EIRP per Beam (Transponder)	60.4 dBW
Number of Beams	69 - For Contiguous U.S. Coverage
Voice Channels per Beam	111
Antenna Gain	44 dBic - At Corner of Cell
RF Radiated Power per Beam	16.4 dBW, 43.2 Watts
G/T	16.4 dB/^{o}K - At Corner of Cell
Bandwidth per Beam	10 MHz - each way
UHF Antenna	
Type	Offset Parabolic Reflector Multibeam, F/D = 1
Effective Aperture	139 ft. Diameter
Spacecraft	
Size	15 ft L, 9 ft H, 15 ft W
Weight	4000 lbs
Electrical Power S/S	12.5 kW Array Power 1560 ft^2 Solar Array
Thermal S/S	360 ft^2 Radiating Surface Combined North and South Panels

Table 7-2. L-band Spacecraft Technical Data

Payload	
Forward Transponder	69 Parallel Redundant Units Ku-band to Ku-band Frequency Conversion
Return Transponders	69 Parallel Redundant Units L-band to Ku-band Frequency Conversion
Transponder Type	Double Frequency Conversion
EIRP per Voice Channel	45.2 dBW
EIRP per Beam (Transponder)	65.7 dBW
Number of Beams	69
Voice Channels per Beam	111
Antenna Gain	44 d Bic - At Corner of Cell
RF Radiated Power per Beam	21.7 dBW, 148 Watts
G/T	16.4 dB/^{o}K
Bandwidth per Beam	10 MHz each way
L-band Antenna	
Type	Offset Parabolic Reflector Multibeam, F/D = 1
Effective Aperture	75 ft Diameter
Spacecraft	
Size	15 ft L, 9 ft H, 15 ft W
Weight	5515 lbs
Electrical Power S/S	41 kW Array Power 5130 ft^2 Solar Array
Thermal S/S	1200 ft^2 Radiating Surface

Table 7-3. Spacecraft Weight Estimates (Pound)

	UHF	L-band
Mobile Band Antenna		
- Reflector	500	250
- Supports	250	125
- Feed Array	330	160
Transponder		
- Mobile Band Diplexers	35	35
- Mobile Band Power Amplifiers	80	140
- IF Components	100	100
- Ku-band Power Amplifiers	15	15
- Ku-band Diplexers	15	15
- Cabling	50	50
Ku-band Antenna		
- Reflector (solid)	35	35
- Supports	10	10
- Feed Array	5	5
Spacecraft Structure	600	700
Propulsion	1100	1200
Electrical Power Subsystem		
- Solar Array	625	2100
- Electronics	50	75
- Battery	150	450
TT&C	50	50
Estimated Weight-pounds	4000	5515

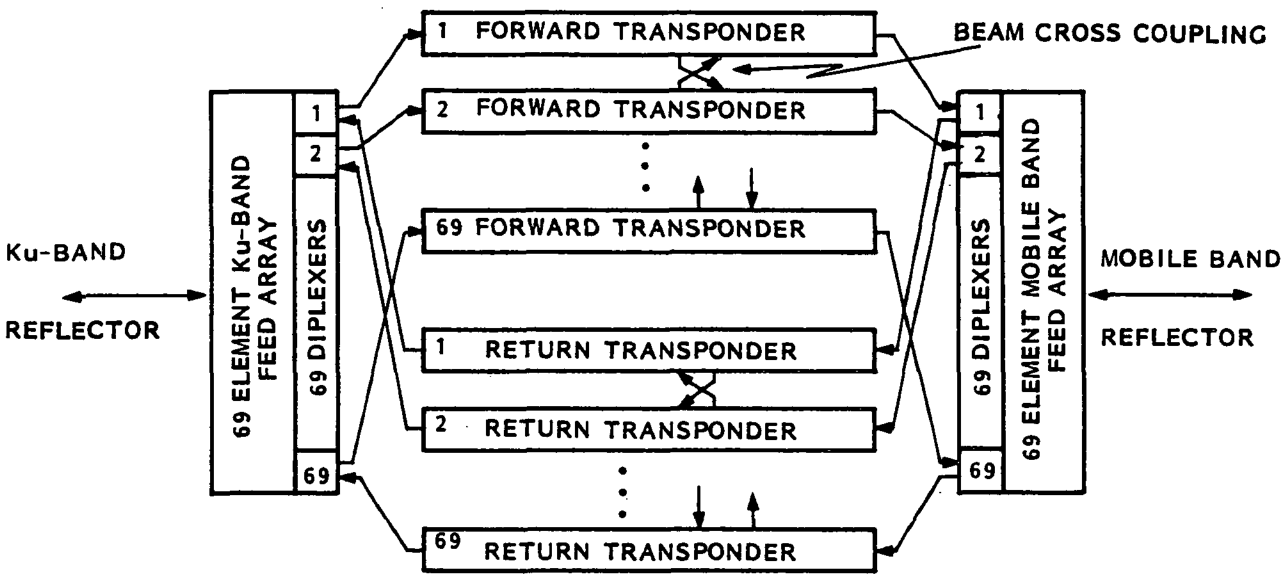
A second alternative to the baseline spacecraft payload is the use of a switch in the satellite to route traffic there rather than at the earth stations. Figure 7-4 gives simplified block diagrams of the baseline frequency translating transponders and the alternative switching transponder.

In the baseline transponder there are 69 parallel transponders each having the same center frequency. Carriers received from the earth stations are down converted, amplified, up-converted and retransmitted at UHF. The transponders are cross-connected for sidelobe level control. A similar process is carried out in the return direction. All transponders are redundant.

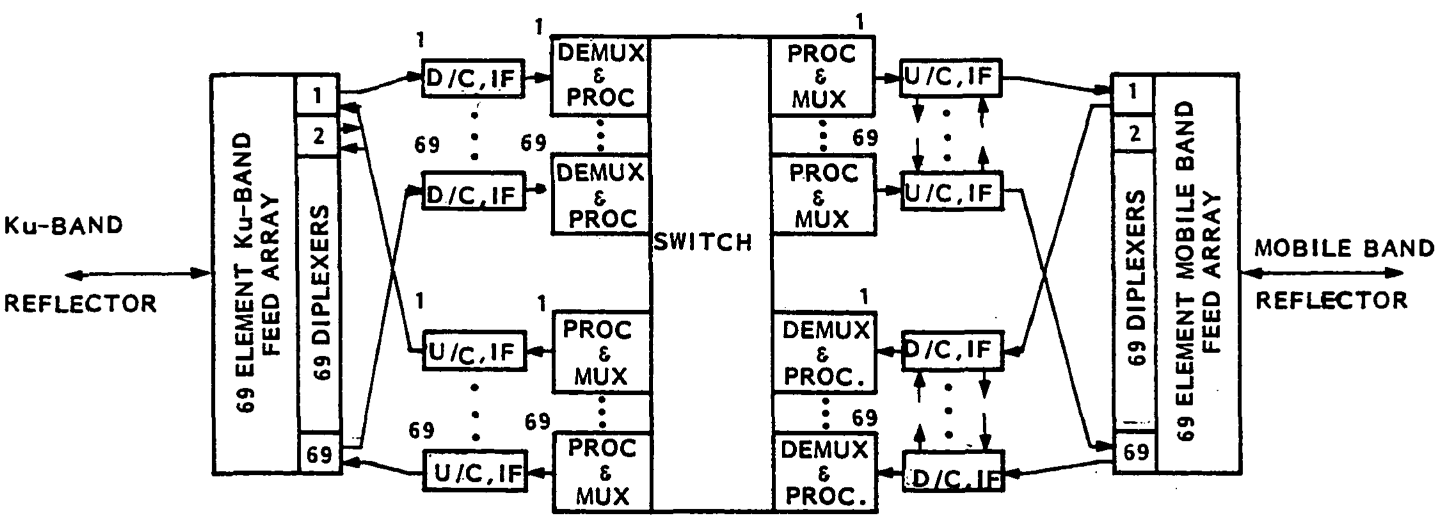
In the alternative configuration, with switching, the same operations are performed. In addition, there are processors at IF to demultiplex the multiplexed signals from the earth station. The demultiplexing is required to separate the voice channels so that the switch can route each of them separately. After switching, the voice channels are again multiplexed for transmission to the mobile units. The processing required ahead of the switching can range from down converting to a convenient IF and separating the channels with filters to demodulation of each channel followed by analog-to-digital conversion, digital switching, digital to analog conversion, remodulation and multiplexing, for transmission to the mobiles. With the switch, as in the baseline, there are cross-connections between channels for sidelobe control.

The alternative configuration contains all the elements of the baseline plus the processing associated with the switch and the switch itself. If there is significant traffic between cells or between mobiles within a cell, the switch offers the advantage of avoiding the double hop delay. Also, for inter-cell traffic, it minimizes the toll charges. Another benefit the switch offers is that it could reduce or eliminate the switching required at the earth stations and that may be a significant economic advantage, depending on the number of earth stations in the system. There are not sufficient data on traffic patterns, earth station switching costs or satellite switch costs to make the tradeoff at this time. Also, the design of the frequency translating transponder is relatively straight forward whereas the switch requires extensive development. At least for the initial deployment the Bent Pipe, frequency translating, transponder appears to be the preferred approach and for that reason is incorporated in the baseline system.

The major elements of the payload are discussed further in the following sections.



A. BASELINE FREQUENCY TRANSLATION TRANSPONDERS



B. ALTERNATE TRANSPONDER - WITH SWITCHING

Figure 7-4. Baseline and Alternative Transponders

7.3.2 PAYLOAD DESCRIPTION

General objectives in the selection of the baseline system component designs are the following:

1. Maximize system capacity.
2. The spacecraft should be compatible with a shuttle launch.
3. The designs should be such that they can be made available by the mid-1980's.

Although developments are required, the components discussed here are consistent with those objectives.

7.3.2.1 Antennas

With respect to the antenna the first objective governs the antenna beamwidth and sidelobe level control, the second places constraints on the antenna elements size and construction and the third dictates that the design should not be far beyond the current state of the art.

Three antenna types that can potentially satisfy the first two requirements are the offset parabolic reflector, lens and array antennas. These types are necessary to avoid radiating aperture blockage which causes increased sidelobe levels and, consequently, degrades the isolation between beams necessary for frequency reuse.

Reflector type antennas are the closest to the state of the art. A 10 meter reflector has been flow on ATS-6. Depending on the frequency used, the satellite aided mobile telephone system requires a reflector about two to four times that of the ATS-6 and appears to be within the state of the art.

Lens and array antennas can provide somewhat better performance than the reflector type at wide scan angles, i.e., greater than about 10 beamwidths. Other than beam broadening effects and a small loss of gain, the array antenna can be designed to cover very wide scan angles, much wider than required to cover the contiguous U.S., with little pattern degradation.

A brief examination of lens and array type antennas indicated that both types would require much more development, would be significantly heavier and would present more difficult packaging problems than the reflector type. Since the reflector type appears capable of giving adequate performance, lens and array antennas were not pursued further.

Figure 7-5 shows calculated offset parabolic antenna patterns as a function of D/λ for a feed angle of $\theta_f = 40^o$*. This feed angle is smaller than that of the baseline antenna but has little effect on the on-axis patterns. The figure indicates the tradeoffs available. It is seen that a D/λ of about 135 to 169 maximizes gain at the cell edge. However, a smaller D/λ of 120 to 135 maximizes the gain at the corner of the cell. Also, for $D/\lambda = 120$ the first sidelobe is in the next cochannel cell. This fact can be used to advantage: By coupling energy from the main beam into the beam serving that cell a partial concellation of the sidelobe is achieved, as shown in Figure 7-6.

To get satisfactory cochannel interference levels, effective sidelobe levels of about 25 dB below the peak gain are required, as discussed in Appendix B. It is noticed that the first sidelobes of all the patterns in Figure 7-5 are about 20 dB below the peak. A means of lowering the sidelobes then is necessary for the use of the offset reflector antenna. The method suggested above is such a technique. Further analyses of the cochannel interference resulting from the use of this form of sidelobe cancelling is required to demonstrate that it works satisfactorily. Since it looks promising, minimizes aperture size, and maximizes gain at the cell edge it is adopted for the baseline system.

The baseline system has cell sizes 0.5^o across. Analyses indicate that an offset reflector having an F/D of unity will give satisfactory pattern performance at scan angles of more than 6 beamwidths from the parabola axis. Since the contiguous U.S. is encompassed by a cone of 6.4^o apex angle, the total scan range is $\pm 3.2^o$ or ± 6.4 half degree beamwidths. This is consistent with an F/D of unity - the baseline value.

*Appendix F contains a description of the offset parabolic antenna including defining parameters.

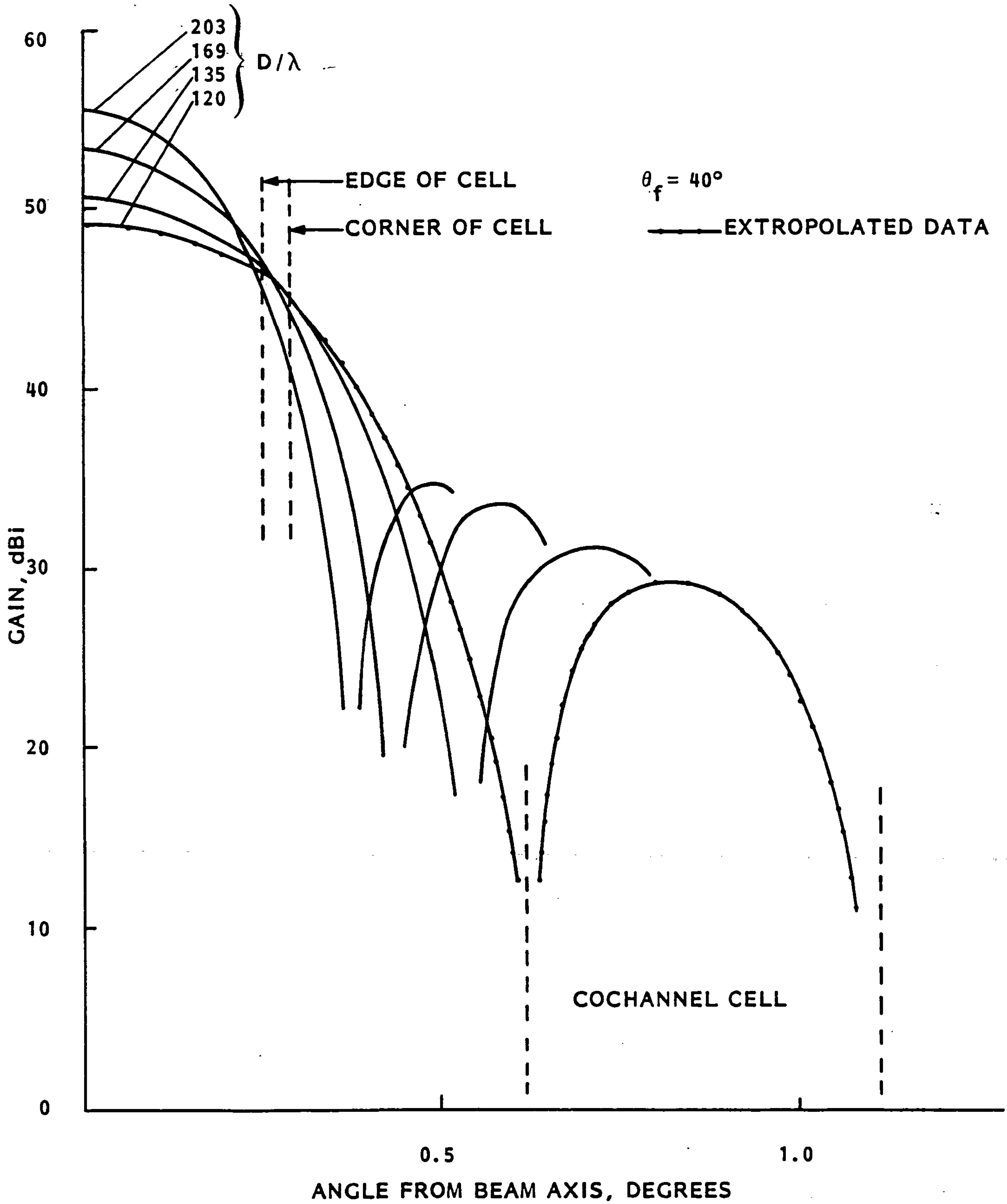


Figure 7-5. Offset Parabolic Antenna Patterns

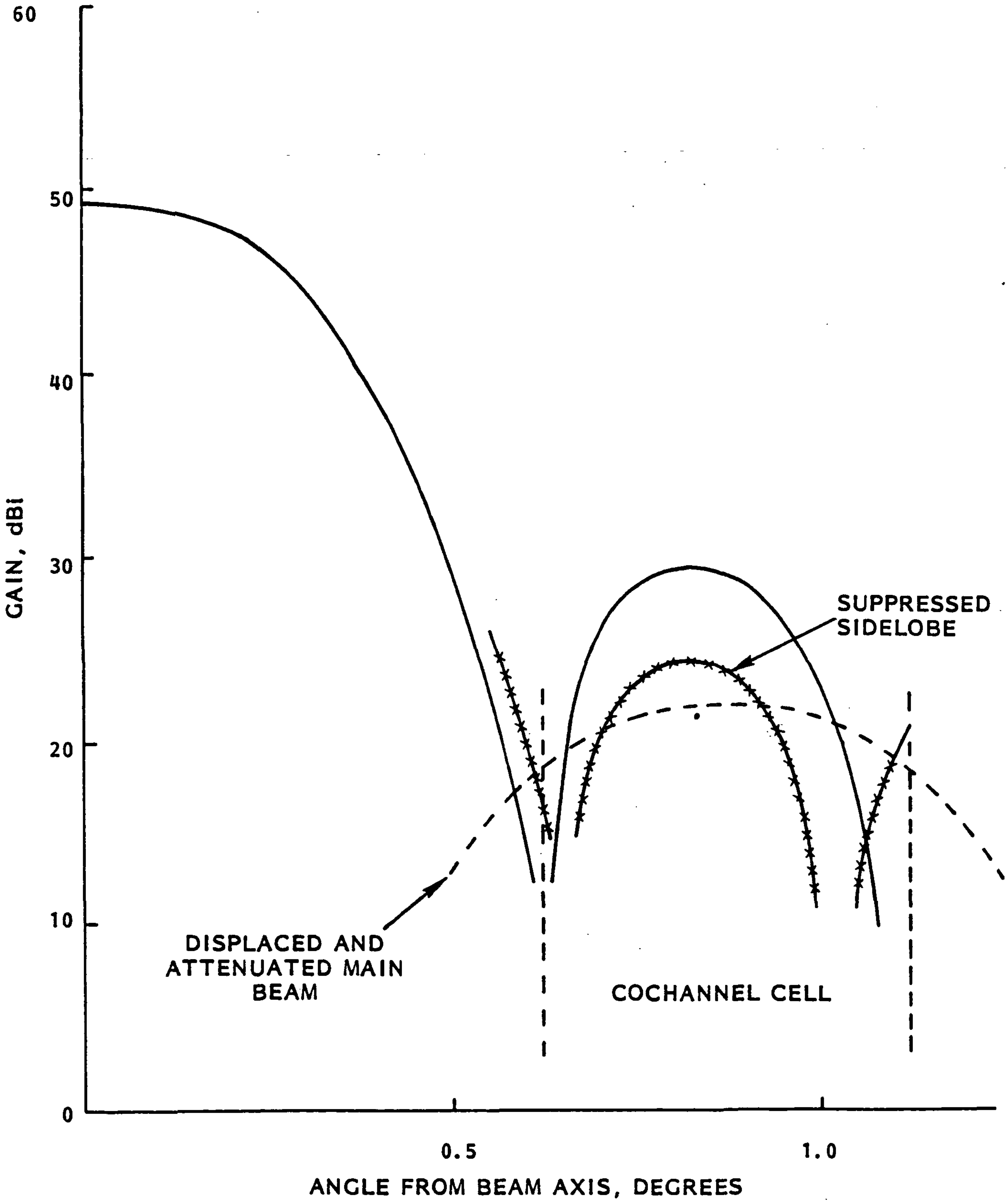


Figure 7-6. Sidelobe Cancellation

For this F/D and an aperture of $D/\lambda = 120$, at 850 MHz the aperture is 139 ft. The effective focal length, as explained in Appendix F, is 150 ft giving a maximum feed array dimension of 18 ft in the E-W direction. This is too large to fit across the shuttle bay which is 15 ft in diameter, and the feed array would have to be folded such as shown in Figure 7-7.

Although the baseline system uses 0.5° beams it is possible to use smaller beams for greater frequency reuse. Scan angles of ±10 beamwidths from the antenna axis can be achieved with antennas having an F/D of 1.355. To encompass the contiguous U. S. with ±10 beamwidths the beamwidth would be 0.32° giving a required aperture of about 190λ, or 220 ft at 850 MHz. The maximum feed array dimension then becomes about 37.4 ft in the E-W direction. There would be about 168 feed elements in the feed array corresponding to 168 cells on the contiguous U. S.

It is expected that a spacecraft configured for this antenna would present difficult packaging and weight problems for a single shuttle launch.

To achieve this many frequency reuses, it would probably be necessary to go to L-band operation which, unless means are found to reduce the RF power requirements, represents a potential weight problem due to the electrical power subsystem.

7.3.2.2 Transponder

This section gives more detail and discussion of the two types of transponders studied: the frequency translating Bent-Pipe and the Switch Transponder.

Figure 7-8 illustrates the forward bent pipe transponder and Figure 7-9 gives the return link transponder. Double conversion is shown in all transponders to reduce the gain needed at a single IF and thereby minimize the potential instabilities. It may be possible to use a single IF at the mobile band frequency. In the forward transponder, after down conversion (D/C) and amplification, the signals from the Ku-band antenna are power divided and part continues on and is amplified in the same transponder and transmitted as the principal signal

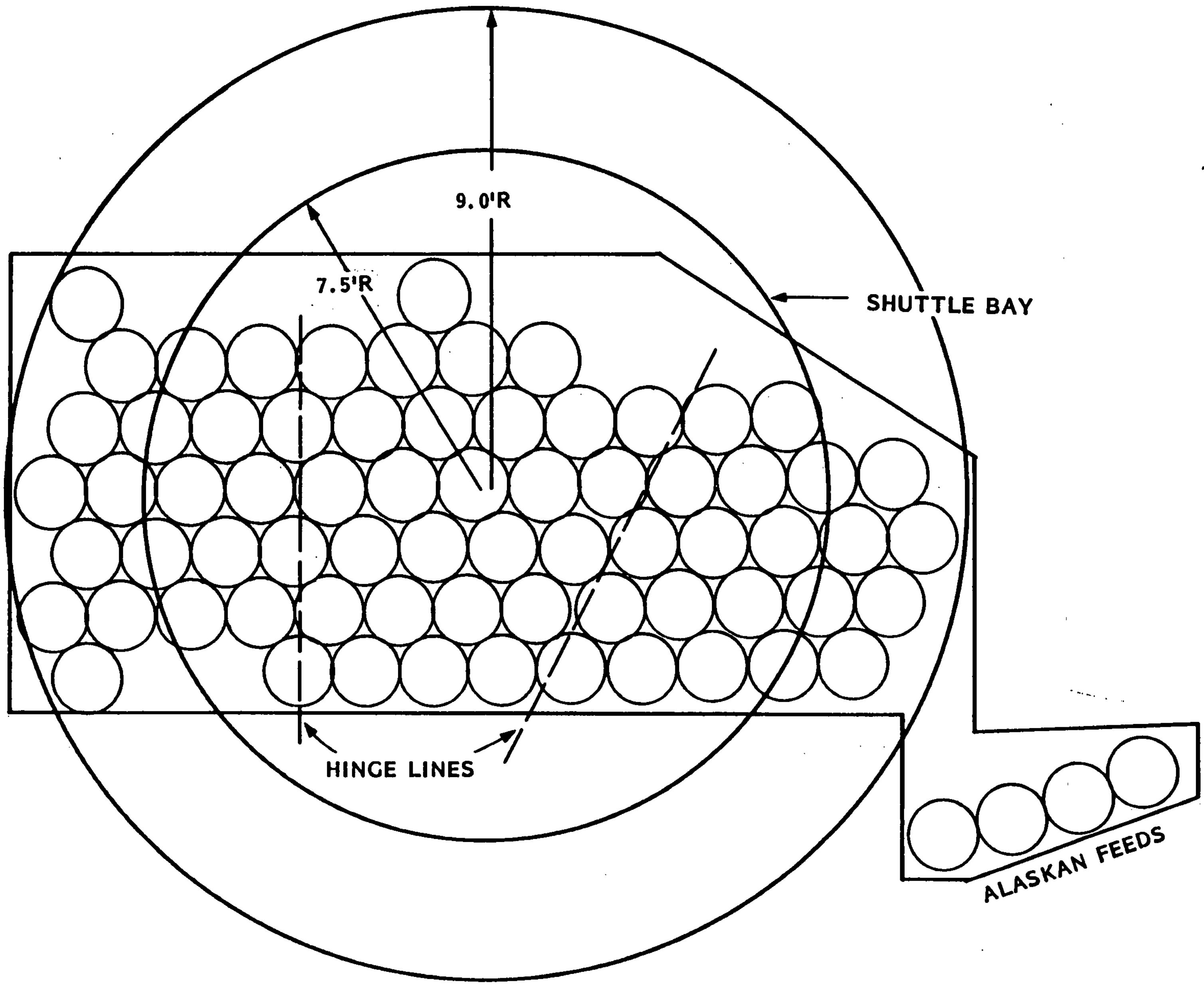


Figure 7-7. UHF Feed Array

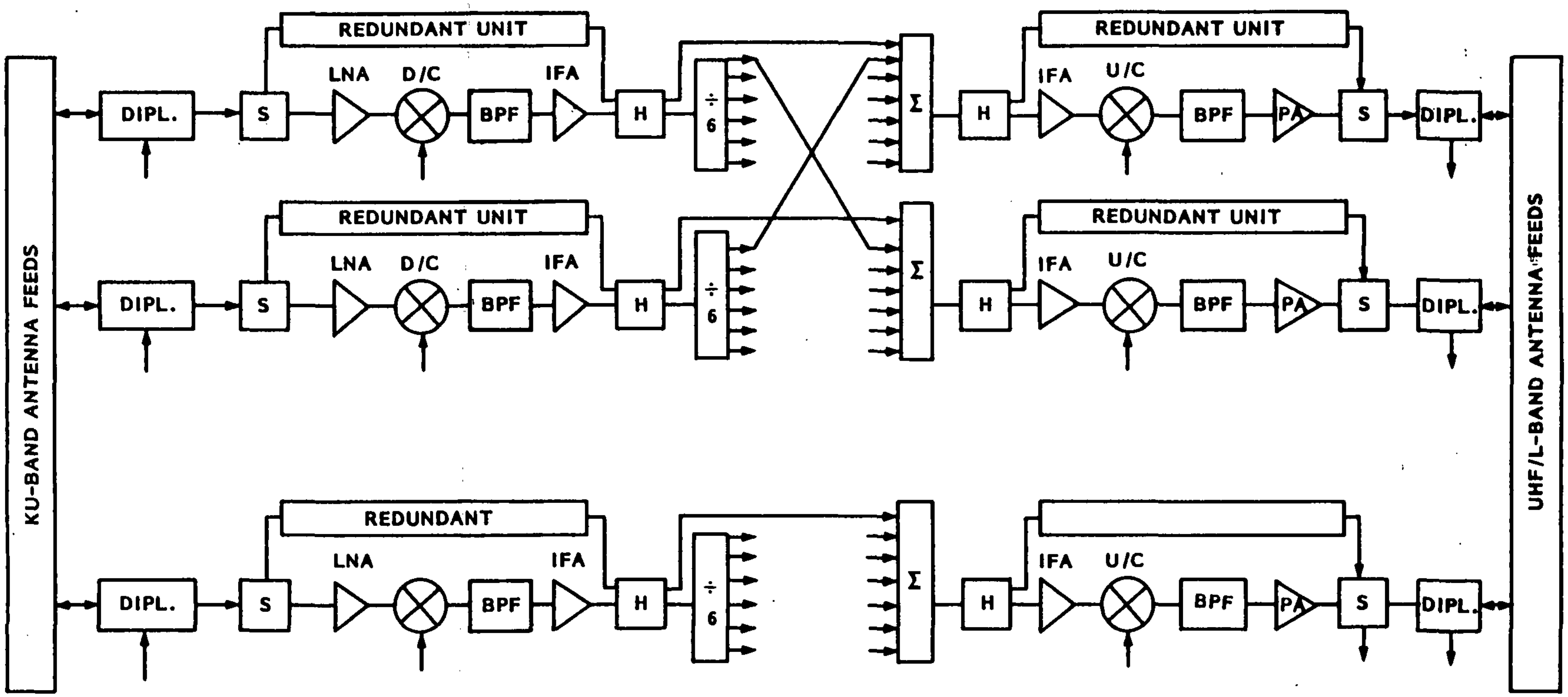


Figure 7-8. Forward Bent-Pipe Transponder

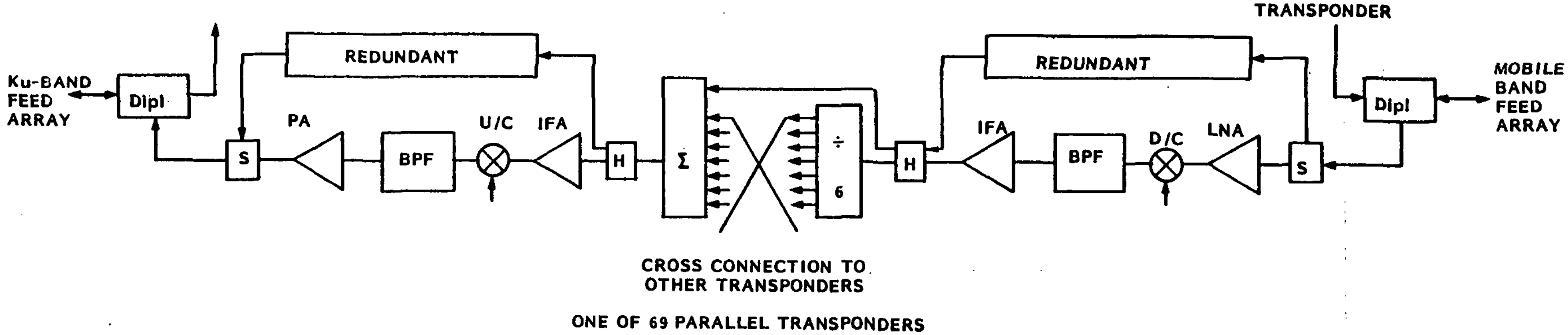


Figure 7-9. Return Link Bent-Pipe Transponder

in that transponder. The other part is sent to a 6-way divider and distributed to the transponders feeding the closest adjacent cochannel transponders. The signal fed into the adjacent cochannel transponders is about 27 dB down from the original signal and 180^{o} out of phase to give the 5 dB sidelobe cancellation.

The sidelobe cancellation is done at IF to avoid the power loss at RF had it been done there. Since the RF power requirements are already large, additional losses should be avoided. Operating at IF accomplishes this but adds the requirement that the phase length of all paths from the input to the IF power dividers through the antenna feeds stay constant within several degrees.

For the baseline UHF system, the power amplifiers must be linearized units capable of giving about 20 dB carrier to intermodulation ratios at 25% efficiency. Currently about 16% efficiency is obtained in solid state amplifiers at that carrier-to-intermodulation ratio. Thus, the mobile band power amplifiers are an item needing further development.

The return transponder operates in much the same manner. The Ku-band multibeam antenna might be designed such that sidelobe cancellation is not needed. This depends on the location of earth stations and the beam crossover levels permitted. For the baseline no sidelobe cancellation is assumed. The RF power amplifiers at Ku-band have low power requirements - about one Watt. It could be a solid state transistor amplifier and could be operated well backed off to minimize intermodulation product generation.

The alternative to the bent-pipe baseline is the satellite switch transponder. The switch could be digital or analog IF, analog baseband and sampled analog. It is instructive to analyze the switch complexity in terms of the number of crosspoints required. If it is assumed that any voice channel from a vehicle should be able to be connected to any channel to another mobile or to any earth station and similarily any earth station connected to any mobile or other earth station channel, the number of crosspoints in a continuous analog switch is

$$NCP = [(MB)(CPM) + (KB)(CPK)]^2$$

where NCP is the number of crosspoints, MB is the number of mobile band beams, CPM is the number of voice channels per mobile beam, KB is the number of Ku-band beams, and CPK is the number of voice channels per Ku-band beam. For the baseline system this becomes

$$NCP = [(69)(108) + (69)(108)]^2 = 222 \times 10^6 \text{ crosspoints}$$

which indicates that full switching between channels would require a very large switch.

If 10 channels per beam were made switchable then the number of crosspoints becomes about 2×10^6 which is more reasonable.

Other alternatives involve exchanging switching speed of transistors for crosspoints. For example the voice channels in a beam could be demodulated and sampled with 1 microsecond pulses at a rate of 8000 samples per second on each channel. These analog samples could be time division multiplexed to a single line for each beam. Then the number of crosspoints becomes $(2 \times 69)^2$, approximately 20 thousand. But now the switch must operate at microsecond rates and there is the probability that two or more input lines would try to connect simultaneously to the same output line. This can be minimized by controlling the sampling sequence of the multiplexers, but some traffic would be rejected. Making the sample pulse shorter so that each input beam has a time slot during which it has exclusive access to each of the output lines is a means of avoiding the interference between pulses, but requires that the voice channels be sampled with about 7 nanosecond pulses and the switch operate at 140 MHz rates. This too presents sever design problems especially for analog switching.

The final alternatives involve digital switching to relieve the need to preserve pulse amplitudes. Digital switches are available to operate at hundreds of megahertz rates. If each voice channel were sampled at 8000 Hz and converted to 7 bits per sample, the data rate associated with each beam would be 6 MBPS. If these were fed serially on a single line to the switch and if each of the 138 input lines were given a time slot during which it had exclusive access to each output line, data rates of about 980 MBPS would result. Instead of serial readout of each beam, a 7-bit parallel readout could be used. This increases the number of digital crosspoints from 20 thousand to about 1 million and reduces the data rate to 140 MBPS, which is still an impressive switch.

Although the above bounds represent worst cases in several respects; it is doubtful that full switching between earth stations would be required and some traffic blockage would be tolerable, it does show that the switch gets complicated very rapidly as the traffic capacity requirements increase. It therefore seems that the system design should be such that only the minimum switching be incorporated in the satellite with overflow being taken care of at the earth stations. What this minimum is depends on the amount of traffic that can benefit from satellite switching and the relative system costs of providing it at the earth stations and at the satellite. These questions need further study to resolve the switch design.

7.3.3 LINK BUDGETS AND POWER REQUIREMENTS

From the link budgets tabulated in Appendix E, the spacecraft, earth station and mobile RF power requirements are derived. It is found that in all cases, the RF power requirements are modest on a per channel basis. The aggregate requires special consideration, however, particularly for the L-band spacecraft.

Table 7-4 summarizes the RF power requirements of the system. The last column is added to show the advantage of using voice actived carriers (about 3 dB). Use of VOX does not appear compatible with current mobile radio designs. However, its use has significant advantages for the satellite system and the possibility of incorporating it into the mobile radios should be examined

Factors in the link budgets discussed here are the following:

1. Carrier-to-noise + Interference + Intermodulation, C/X_o
2. Second half of tandem link degradation

Table 7-4. RF Power Requirements Summary

Link	RF Power Requirements in dBW			
	Per Channel	Per Beam*	Per Spacecraft+	Per Spacecraft with VOX
Mobile to ES Links				
UHF Mobile to S/C	- 5.8	NA	-	-
UHF S/C to Mobile	- 4.7	16.3	34.8 (3 KW)	31.8 (1.5 KW)
L-Band Mobile to S/C	- 0.5	NA	-	-
L-Band S/C to Mobile	+ 0.6	21.7	42.4 (16.6 KW)	39.2 (8.3 KW)
Ku-Band S/C to ES	-20.1	0.4	18.7 (74 W)	15.7 (37 W)
Ku-Band ES to S/C	-16.5	4.0	NA	-
Mobile-to-Mobile Links				
UHF Mobile to S/C	10.0			
UHF S/C to Mobile	- 4.1			
L-Band Mobile to S/C	15.3			
L-Band S/C to Mobile	1.2			

* 111 Voice Channels per beam and 0.5 dB losses at UHF and 0.6 dB at L-band are included

\+ 69 Beams per spacecraft

3. Link degradation due to interference
4. Propagation loss
5. Margin
6. Receiver antenna gain
7. Receiver noise and interference

Carrier to noise and interference ratio is a major factor in determining the system power requirements. Figure 7-10 plots the IF bandwidth and threshold C/X_0 as a function of lowest talker subjective SNR in the audio band. Lowest talker SNR lower than 20 dB is usable. However, to be compatible with the developmental terrestrial systems an IF bandwidth of 25 kHz is required. For this bandwidth the audio SNR is greater than 20 dB and the threshold C/X_0 is 53.3 dB. Thus the system RF bandwidth requirement sets the C/X_0 and hence is a major factor in determining the various transmitter power requirements.

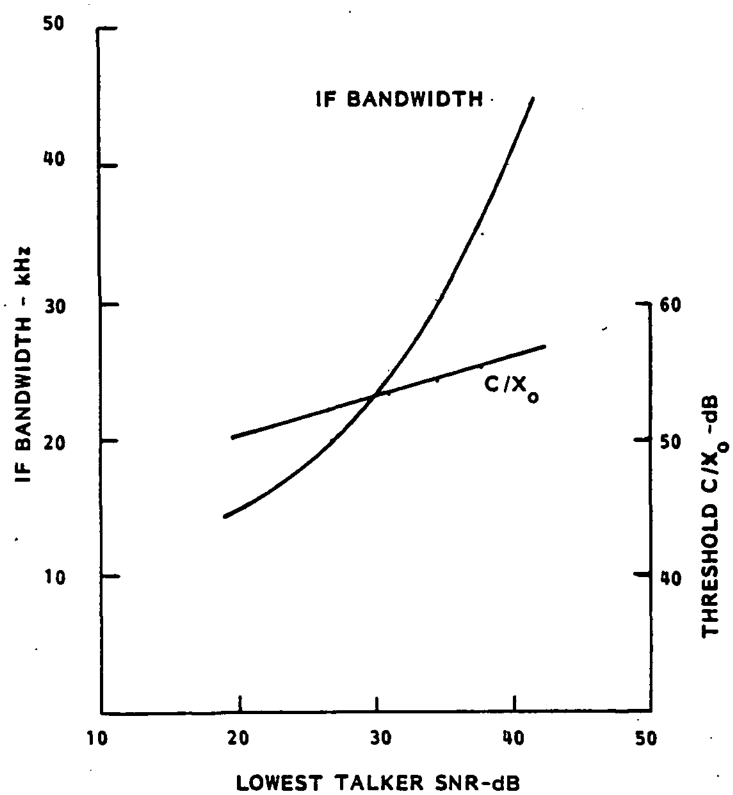


Figure 7-10. IF Bandwidth and Threshold Carrier-to-Noise vs. Lowest Talker SNR

Since there are two links in tandem providing communications to the mobile units, the performance of the link to the satellite determines the carrier-to-noise transmitted by it and hence the additional power needed to overcome the noise added in the uplink. For the ku-band uplink the links are designed so as to degrade the downlink to the mobile by less than 0.5 dB. It is important to keep that degradation small to minimize the spacecraft power required. The large uplink C/X required can be readily achieved on the Ku-band link. For mobile-to-mobile communications through the satellite a larger, a 0.9 dB, degradation of the downlink due to the mobile band uplink is included. It is expected that few of the voice channels will be devoted to mobile-to-mobile circuits and hence the added spacecraft power requirement will be negligible.

Link degradation due to interference is the additional RF power required because of the presence of cochannel, adjacent channel and intermodulation interference on the channel.

The principal contributors are cochannel and intermodulation. For the critical, because of the effect on spacecraft power, link from the spacecraft to the mobile, cochannel interference levels giving C/I of 17 dB and intermodulation levels giving C/IM of 20 dB are included in the design. These levels increase the required C/N_o by 1.5 dB and hence the spacecraft power by the same amount. Because of the large spacecraft power requirements these interference sources should be examined further to determine if the degradation can be reduced. The cochannel interference is due to cochannel transmissions reaching the receiver via sidelobes of beams serving cochannel cells. Sidelobe reduction techniques have been discussed and require closer examination using more accurate antenna pattern models. The methods used to determine the cochannel interference levels are discussed in Appendix B and these methods, particularly the computer analysis program, are an efficient means of evaluating the effect. Multicarrier intermodulation noise levels of 20 dB below the carriers (at 25% amplifier efficiency) represents an advancement in current solid state amplifier performance but one that appears achievable within a few years.

Propagation loss, beside being a function of the path length, is depending on frequency through the effective absorption area of an isotropic antenna. This accounts for the increased power requirements for L-band operation. If it is necessary to restrict the mobile antenna to be of a simple type, the propagation loss variation with frequency squared suggests that the mobile band should be as low in frequency as possible. If more complex antennas can be used, such as multiple element arrays, then higher frequencies become more attractive.

The margin of 5 dB on the links between the satellite and mobile is based on experience in radio communications to trucks via the ATS-6 satellite. It represents a satisfactory margin for operation when the mobile has a relatively clear path to the spacecraft. Loss due to blockage by buildings or dense foliage is not included in the margin.

A 2.8 dBic mobile antenna gain has been used in the link calculations. This is based on work done with a crossed dipole above a shaped ground plane which gives this gain. While that is a relatively simple antenna it is complicated compared to the whip antenna commonly used in mobile radio applications. Note that the gain is that to a circularly polarized wave. With a whip antenna the gain would be near zero dBic which would add about 2.8 dB to the already large spacecraft power requirements.

Mobile antenna design is an area needing further examination.

Noise temperatures used throughout the system are based on receiver LNAs having noise figures of 2 to 3 dB. This appears to be well within the capabilities of FET devices.

7.4 SYSTEM CAPACITY ESTIMATE

Capacity is a function of service grade and the number of channels. The "Erlang" is the international dimensionless unit of traffic intensity defined as the intensity in a traffic path continuously occupied. Erlang B is based on the assumption that calls not immediately satisfied are cleared and do not reappear during the period under consideration (Reference 3).

$$B(C, A) = \frac{A^c/C!}{\sum_{k=o}^{c} A^k/k!}$$

where

$B(C, A)$ = Probability of a call being blocked

A = Traffic intensity to be served, in Erlangs

C = Total number of circuits in the trunk group

The grade of service, P, is the percentage of calls that are not satisfied because all channels are occupied. For a service grade of P. 02, the probability is 2% that an offered call is blocked.

System parameters suggested for illustration include a service grade of P. 02 and 108 talking channels in each of 69 footprints. Traffic intensity is 95 Erlangs for the selected parameters. The average duration of calls on the present wireline connected mobile telephone service is 90 seconds. If we assume that more personal use of the system extends the average duration to 120 seconds, 95 calls can be satisfied in one footprint every 120 seconds, or 2850 calls during the busy hour.

There is no technical reason for limiting the number of calls; the system can handle a larger number, but the service grade will be lower. Leased telephone systems frequently offer service that is much poorer than P. 02.

The number of 2850 calls per busy hour in a footprint can be used as a starting value to estimate the number of subscribers that can be accommodated by the system. If, on the average, there is one call per subscriber during the busy hour, the system will accommodate 2850 subscribers per footprint, or 196, 659 subscribers.

SECTION 8

SPACE SEGMENT COST ESTIMATE

SECTION 8

SPACE SEGMENT COSTS ESTIMATE

Space segment costs have been developed (Reference 4) for a variety of satellite missions including the satellite-aided mobile radio service. The spacecraft model used for the mobile radio application closely approximates that spacecraft described in this report. For that reason the costs are representative of those expected.

Table 8-1 summarizes the cost factors included in the model. Table 8-2 gives the estimated annual cost of the space segments for several possible spacecraft configurations. Included in the costs are the development costs in a program in which three flight satellites are produced, including the deployable antenna development. The spacecraft, as characterized by the antenna size and power, required for this satellite aided mobile radio system falls between the top two entries. The annual cost is taken to be about $60 million (1979).

Table 8-1. Satellite Cost Factors

	NRC	RC	Expense
Launch Vehicle Cost[(1)]		X	
Launch Vehicle Construction Cost		X	
Launch Vehicle Insurance		X	
Satellite Control Center	X[(2)]		
TT&C Facility	X[(2)]		
Spare Parts Plus O&M Personnel			X
Data Lines/Computer Lease		X	
Launch Team/Incl. Rehearsals	X		
PAM	X	X	
Satellite Cost[(3)]	X	X	
Satellite Construction Cost	X	X	
Satellite Storage Cost			X
Satellite Launch Insurance		X	
Satellite On-Orbit Insurance			X
Rates			
Return on Investment = 10%			
Overhead = 100%			
General and Administrative = 25%			
Profit = 15%			

Notes

(1) Two Launches Plus One-Half for Backup

(2) Depreciated over two Generations

(3) Three Satellites

Table 8-2. Space Segment Annual Cost

Launch Vehicle	Antenna Diameter	RF Power (kW)	Space Segment Annual Cost
Shuttle/IUS	(210 Ft)	5.2	$ 61M
Shuttle/IUS	(120 Ft)	8.8	58
Shuttle/IUS	(60 Ft)	11.7	55
Shuttle/IUS	(30 Ft)	11.7	53
Shuttle/SSUS-A	(120 Ft)	2.5	43
Shuttle/SSUS-A	(60 Ft)	4.5	37
Shuttle/SSUS-A	(30 Ft)	5.0	35

SECTION 9

NEW TECHNOLOGY

SECTION 9

NEW TECHNOLOGY

No new technology was developed during this study.

SECTION 10

CONCLUSIONS AND RECOMMENDATIONS

SECTION 10

CONCLUSION AND RECOMMENDATIONS

In general, it is concluded on the basis of the current study that satellites can provide mobile radio services economically and provide them in areas that terrestrial systems will either not service or not service in the near future. Satellite and terrestrial systems are viewed not as competing approaches but rather as complimentary.

Specific conclusions are the following:

1. Satellites can provide a needed mobile telephone service for the general public and many public safety and service agencies. The role of satellites is to augment terrestrial systems in thinly populated areas where terrestrial systems are not cost effective. Satellites can fulfill the role at an acceptable cost.

2. Present mobile telephone systems operate in several radio frequency bands with several system protocols so that the service area available to any subscriber is limited.

3. A terrestrial "cellular" type mobile telephone system, now under development, will provide well coordinated service to millions of subscribers in urban areas and thus provide mobile telephone service to a large market that is now small and poorly served.

4. A demand for an "ubiquitous" telephone service may develop as a result of the market expansion.

5. Terrestrial systems are cost effective in densely populated areas. Satellites are cost effective in thinly populated areas.

6. The ubiquitous telephone service can be provided by a combined terrestrial and satellite system using common software and compatible vehicle equipment.

7. A satellite-aided mobile telephone system can augment and be compatible with terrestrial cellular type mobile telephone systems.

8. The satellite-aided mobile telephone system would add subscribers to terrestrial systems and provide cost effective service in areas that are not likely to be served by terrestrial systems.

9. Forty-four million persons live in areas of the contiguous states that are not likely to be served by terrestrial systems and are therefore candidates for the satellite-aided systems.

10. Total cost is $60 million for the space segment to serve 200,000 subscribers, or about $25 per month per added subscriber. User equipment and other systems costs are in addition.

11. The satellite must have a multibeam antenna and a solar array larger than any that have been placed in geostationary orbit by NASA, but they are feasible extensions of present technology.

Being economical and providing a needed service, it is recommended that the application be actively promoted. To that end it is particularly necessary to get frequency spectrum allocated to the service as this may affect the direction of technology developments. Specific recommendations include the following:

1. Consult with carriers who will implement terrestrial cellular systems to obtain information:

   a. Compatibility requirements, satellite and terrestrial systems
   b. Design features desired
   c. Time scale for implementation
   d. Financing
   e. Amount and distribution of traffic

2. Use results of marketing studies to determine:

   a. Capacity requirements
   b. Revenue potential

3. Formulate an implementation plan from information derived from 1 and 2 above including:

   a. A first generation satellite-aided system employing current technology to meet initial demand.
   b. A follow-on system to satisfy predicted mature demand.

4. Investigate ways to reduce power requirements in the satellites including:

   a. Mobile antenna design
   b. Control of power transmitted to the mobiles based on satellite-received signal strength.
   c. Possible reduction in fading margin specification based on experimental data.
   d. Possible use of Voice Operated Transmission (VOX) in satellite downlink.
   e. Matching power drain to instantaneous traffic load.
   f. The use of linear, power efficient RF power amplifiers.

5. Develop initial and follow-on satellite designs to accommodate initial and mature demands.

6. Develop UHF or L-band multibeam antennas, satellite switches, efficient linear amplifiers, and high power spacecraft electrical subsystems.

7. Conduct related studies and experiments in propagation, modulation, and data communications over mobile-satellite links.

8. Investigate possibilities of channel sharing between terrestrial and satellite-aided links including channel interleaving.

9. Investigate bandwidth compression and privacy techniques for voice communications including analog as well as digital signal processing.

SECTION 11

REFERENCES

SECTION 11

REFERENCES

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APPENDIX A

MOBILE AND PERSONAL RADIO SYSTEMS

APPENDIX A

MOBILE AND PERSONAL RADIO SYSTEMS

Mobile and personal radio systems touch the lives of nearly every citizen. Driving down the roads and streets one sees a large number of two-way radio antennas displayed on cars, trucks, and buses. In hospitals, airports and offices people carry paging units in their shirt pockets and two-way radios snapped to belt clips. At work the forklift trucks and the over-the-road trucks are dispatched by radio. It is hard to conceive that a police department or a fire department could function without constant use of two-way mobile radio. Children think it odd if a school bus is without two-way radio. About five million commercial mobile and personal radios are in use in the United States, and the 28 million citizen band radios add confirmation to the need for communication by people who are in motion.

Two-way mobile and personal radio started in the late 1920's and received a large impetus with the installation of a VHF FM system for Connecticut State Police before the second World War. After the war there was a rapid expansion that has continued as frequencies were added for the service between 26 and 916 MHz.

The use of high frequency, two to thirty MHz, for two-way mobile has been important for the military but of less importance for the civilian community and its local government. Present high frequency uses of two-way mobile radio is chiefly over the large ranges in the Southwest and Mexico. Some western states and Canadian provinces also place reliance on high frequency radio where VHF or UHF systems have not been installed.

A.1 TYPES OF MOBILE RADIO SYSTEMS

Mobile radio systems are of three types:

- Dispatch
- Radio/Telephone
- Paging

Dispatch service is the most widely used mode of mobile two-way radio. A dispatcher at a central radio station location receives calls from the public or other customers or management and gives orders and information to people dispersed in automobiles or with radios carried on their persons. This is the mode used by fire, police, taxis, contractors and other similar organizations. It features high channel efficiency, short messages and capability for many mobile customers being served by a single dispatch channel. Up to 100 business vehicles, or up to 40 police cars or fire engines are served per channel.

Radio telephone service is more recent and provides an extension of the normal public telephone system to a person in a vehicle. Ordinary two-way conversation or duplex is provided. It is of low channel efficiency because people tend to "chat" and because it uses two channel frequencies simultaneously. About 30 subscribers can be accommodated on a channel pair. Average message length is longer than for dispatch service.

Paging is a one-way service that is sometimes offered in association with other two-way services. It most often is used to initiate a landline telephone call, or response via subscriber's two-way radio. One concept is that of carrying the telephone bell in one's pocket without the telephone.

Most of the radio services use paging on their usual dispatch channels, but with some constraints for use on emergency services channels. The largest paging service is offered by the common carriers, either radio common carrier companies, or the landline (wireline) common carrier telephone companies. The common carriers offer the service to any individual or company. A typical common carrier subscriber carries a pocket-size "pager" containing a radio receiver, and a decoder for its own address number. When a person wishes to contact the subscriber, he calls the pager's number on the telephone. Depending on the type of service, the subscriber may hear an audio tone indicating he should call the paging service for the message, he may be instructed by the paging service operator to dial the caller's number, or he may hear the voice of the caller stating his message. The paging subscriber cannot respond by radio.

Paging makes very efficient use of a channel and is able to serve a very large number of customers, between 500 to 1000 per paging channel. The paging station must have an effective radiated power much higher than either dispatch or radio-telephone service since paging receivers have inherently poor receiving sensitivity and are often located inside buildings with high attenuation.

Radio and wireline common carriers can use their assigned two-way radiotelephone channels for paging, usually on their central station output frequency. There is a growing number of channels being set aside for one-way paging by radio common carriers serving the general public.

A two-way radiotelephone channel services less than 30 radiotelephone subscribers, but can serve up to 1000 pager subscribers at $20 to $30 per month. Equipment cost for a pager subscriber is about one-tenth that of a two-way radiotelephone subscriber. Income per radiotelephone subscriber is only 5 to 6 times higher than a pager subscriber.

With limited number of channels there is a tendency by some ratiotelephone common carriers to discourage radiotelephone subscribers.

A.2 MOBILE RADIO CUSTOMERS

Present mobile radio customers are:

- Public safety and service
- Utilities
- Emergency organizations
- Business and industrial
- Agriculture and mining
- Personal

A.2.1 PUBLIC SAFETY AND SERVICE

The present mobile radio service grew around the need for communications in public safety and service. It is difficult to find a police or fire organization that does not depend upon two-way radio. Local government uses radio to dispatch snow plows, trucks and highway equipment of all kinds. The management of our public forests and lands is carried out in the field through the use of two-way radio. For power and telephone utilities the use of mobile radio is vital and universal.

Although emergency organizations have used radio communications for many years, there is a new and growing use of radio by coordinated agencies in the emergency medical service and by National Red Cross. The whole concept and system of quick emergency medical service and disaster service is being affected by new two-way mobile radio systems.

A.2.2 BUSINESS AND INDUSTRIAL

The ability to manage is determined by the ability to communicate. For those industries where mobility is a factor, communications are critical. These include:

- Transportation and trucking
- Taxis
- Construction
- Service businesses
- Manufacturing

Although business and industrial users probably comprise the largest potential set of users for mobile radio, they are not highly equipped for such communications. An exception is the taxi industry with its obvious requirements.

Most businesses today are organized for communications based on hand carried papers, orders given face-to-face, and the use of the telephone and telegraph. A striking example of the way radio can improve operations is in the highway and landscaping businesses. Direct radio communication between an engineer looking through a transit and the operator of a large earth mover enables a more efficient but different way of grading where the blade or bucket depth is adjusted while the earth mover is underway. This is a different organization of the way that the engineer and the machinery operators and crews have worked in the past. Because of the ease with which reorganizing a business to achieve more efficient forms with efficient communications, availability of the service determines the rapidity with which such reorganization and uses of communications occurs. Thus we have seen that the business and industrial market is only now starting to assimilate two-way mobile radio communications. Taxi and transportation type users fall into the dispatch service mode quite easily, but much of the work of the rest of business and industry requires a two-way conversational mode much like standard business telephone communications (A-1).

A.2.3 AGRICULTURE AND MINING

Agriculture and mining require communication with people spread over a very large area. Difficulties with getting communications over long distances to a small number of stations is the reason that HF radio (3 to 30 MHz) is still used in this activity. It is difficult to get adequate service at VHF and UHF over the large distances involved for typical customers.

A.2.4 PERSONAL RADIO

The Citizen's Band (CB) Radio Service has drawn attention to a desire on the part of the general public for personal radio communications on the road, in the air, and on inland waterways. The Federal Communications Commission has three categories of services they consider under the broad heading of personal radio.

- Aeronautical and marine
- Citizens Radio Service
- Amateur and experimental

A fourth category, "New Service" is under study. An official Notice of Inquiry is being prepared by order of the full commission. It is contemplated that this will be a personal radio service for the general public for use over short distances in the 900 MHz band.

General aviation and pleasure boating use radio for personal usage and are both classified in this category. Formerly, most of the radio communications for personal aeronautical and marine radio service was carried on at the high frequencies. It is now almost completely converted to VHF.

The CB Radio Service has received much attention in the last few years of its sensational growth. It is difficult to realize that this service has been with us for over 27 years, but it is only in the past two or three years that is has come to the attention of the general public. The response was overwhelming but a large disappointment with quality of service has followed. It has demonstrated that the general public has a pent-up desire for personal communications on the road and for recreational activities. As with all items for the general consumer market, price is a major factor in acceptance.

The amateur and experimental service is one of the oldest, if not the oldest, radio service. The service uses portions of the spectrum spread from 1.8 MHz through the microwave ranges. These services demonstrate the desire for personal communications but will be little effected by satellite-aided mobile radio.

A.3 MOBILE RADIO OPERATIONAL SYSTEMS

Services in the VHF and UHF bands employ a variety of systems:

- Direct from local base
- Direct with remote base
- Remote repeater
- Remote community repeater
- Radio telephone (common carrier)
- Private interconnection to telephone network

A.3.1 DIRECT FROM LOCAL BASE

The most elementary radio system is direct from local base. An example is a dispatcher of a local taxi company with an antenna on top of the business office. Transmission and reception are directly between the antenna on top of the business office and the taxi cabs.

A.3.2 DIRECT WITH REMOTE BASE

If distance, hills, mountains, or tall structures prevent sufficient range, the radio transmitter, receiver and antenna may be located on a high hill or building different than the dispatcher's location. The dispatcher controls the remote transmitter and receiver by way of telephone lines, microwave or other radio link. The mobile units talk back to the elevated transmitter/receiver. Communications are between the dispatcher and a specified vehicle.

A.3.3 REMOTE REPEATER

A remote automatic repeater on a hill or tall building may be used if it is desired that one mobile be able to talk to another mobile, as well as to a dispatcher. Two frequency simplex is used; one channel for transmitting and another for receiving. All mobile and base units use the same channel pair. The repeater receives the signals on one channel and automatically retransmits them on the other. If Car 1 wants to talk to Car 2, he transmits on the talking channel which is received at the hill top automatic repeater; his signal is automatically re-transmitted simultaneously on the other (receive) channel. Car 2 is listening on that other channel and hears Car 1 by way of the powerful hilltop repeater. A dispatcher can use a radio transmitter and receiver as a vehicle would do, or he could use a land line to transmit and receive through the repeater station.

A.3.4 COMMUNITY REPEATER

Several small businesses may use a common remote repeater as a "community repeater". Each business that is using a community repeater obtains a license for his mobiles plus a remote repeater. Mobile radios of all the users are alike except that each individual business is assigned a sub-audible continuous tone (low frequency tone below the audio normal range). When a user wants to call one of its own mobiles, that user is assigned a sub-audible tone that is automatically transmitted along with his voice. Only those receivers fitted to receive that tone frequency will be operated. Each business appears to have its own repeater system and can hear only its own mobiles. Two different businesses cannot use the same repeater at the same time. A community repeater operator usually places the repeater at the highest possible site for maximum range so that he can offer his customers the widest possible range in the area and have the largest possible number of potential customers for the service. Community repeaters are noted for power struggles in which each business tries to maximize its share of channel time regardless of other users requirements. Control of channel usage resembles the same "jungle philosophy" found in crowded citizens radio service channels.

A.3.5 RADIOTELEPHONE (COMMON CARRIER)

Radiotelephone service extends the public telephone system telephones in vehicles. The present Improved Mobile Telephone Systems (IMTS) makes it possible to place calls from a vehicle and to receive calls in that vehicle to any phone in the world telephone system. The subscriber in the vehicle selects a channel which is not busy as shown by busy lights on his channel switches. As he drives from one territory to another, he must switch his channel to that served in the new territory. It is the stated objective of at least one major telephone company to furnish radio telephone service to mobiles on the interstate highways and in the major cities. Forest preserves, parks and extensive farmland areas are not intended to be covered by the service due to economic considerations.

There are two types of common carriers furnishing mobile radio telephone service:

- Radio Common Carriers
- Wire Line Telephone Companies

Radio common carriers are companies that are organized to furnish service to mobile radio telephones. They do not provide wire line telephone service, but they do interconnect into a regular telephone network. From the standpoint of the regular wireline telephone companies, a radio common carrier appears as an independent telephone company. The radio telephone common carrier shares in the toll revenue which it generates via its customers. It also pays the wireline telephone company charges for its lines and services.

The second category, wireline telephone companies, furnish telephone service to homes and industry as well as mobile radio telephone service. For them the radio telephone interconnect appears in their hierarchy as either a small central office or as a private branch exchange.

A.4 CUSTOMER PERCEPTION OF RADIOTELEPHONE

The total capacity of the various radiotelephone systems across the continent is not available to any radiotelephone customer as he roams from one area to another. The company from whom he subscribes to the radiotelephone service installs equipment in his car that allows him to use that particular company's system in his "home" area. Limited "roamer" capability exists, especially among the systems of the "wireline common carriers", but is limited by access protocol of the equipment and the frequency band for the customer equipment.

Various access protocols include the following:

- Manual service with access to an operator
- Improved mobile telephone systems (IMTS) 2-way dial service with automatic channel selection and access to an operator
- IMTS 2-way dial service; equipped roamers may dial all station-to-station calls; service to manual units not available
- 2-way dial service with access to an operator
- 2-way dial service without access to an operator

Various bands and carrier combinations available include the following:

•	Low band	30 - 44 MHz	Wireline carrier
•	High Band	152 - 162 MHz	Wireline carrier
•	UHF	450 - 460 MHz	Wireline carrier
•	Low Band		Radio common carrier
•	High band		Radio common carrier

- UHF band — Radio common carrier
- UHF band (special cities) — Radio common carrier

A customer will have one of the 7 particular bands, and one or two of the 5 protocols, in his installed mobile equipment. It would take 7 different radiotelephones installed across the front of the dash to just cover the different bands ... and 7 full telephone bills each month!

A customer who roams from one area to another, and who was motivated to have all 7 radiotelephones for each band, multiplied by up to 5 different protocols, still could not use all the radiotelephone systems across the continent. There is no uniform method of exchange billing among all the common carriers, especially the radiotelephone common carriers; thus many systems would not accept the call from a roamer since he could not be billed.

The present state of radiotelephone service is reminiscent of the early days of landline telephone when a businessman would have several telephones on his desk in order to talk to all the various telephone customers in a city.

A.5 PRIVATE INTERCONNECTION

As a result of the Carter radiotelephone hallmark court decisions, it is now possible for a business to interconnect their mobile radio system with the public switched telephone network. For example, the dispatcher for a business can dial a number for one of its mobiles and have the mobile talk through his radio and the interconnection to the public telephone and thence to a person who is talking on his landline telephone. The system is a peculiar mixture of half duplex and full duplex. The person on the landline telephone has full duplex; someone can talk to him from the mobile radio while he is talking in return, but in the mobile it is not possible to listen while the person is talking. Thus, the mobile radio is working with half duplex type operation.

Private interconnection to the telephone network is growing rapidly, especially in the business and industrial market. Many public safety (fire and police) systems are now designed for interconnection to the public switched network under dispatcher control.

A.6 REFERENCES

A-1 Reply comments to FCC Docket 20846 by Utilities Telecommunications Council and also by American Petroleum Institute.

APPENDIX B

COCHANNEL INTERFERENCE

APPENDIX B
COCHANNEL INTERFERENCE

Cochannel interference, and its control is a major consideration in the design of frequency reuse systems employing multibeam antennas, particularily, as in the present study, where contiguous beams are employed to provide continuous coverage.

This appendix discusses investigations made to determine the effect of antenna patterns on cochannel interference levels, interference experienced in several different arrangements of cochannel cells, and the reduction of interference attainable through the use of voice activated carrier (VOX).

B.1 STATISTICS OF COCHANNEL INTERFERENCE

The statistics of cochannel interference for the mobile transmit and mobile receive cases both with and without VOX are derived. These results are used in a computer program, COCELL, developed to evaluate cochannel interference levels.

B.1.1 MOBILE RECEIVE CASE

In the mobile receive case without VOX the fully loaded C/I is deterministic because all channels are assumed to be transmitted from the satellite continually and at the same level, neglecting call set-up.

If VOX is used on all transmitters, any occupied channel will have a carrier actually present only 40% of the time.

Cochannel interference statistics are derived below assuming that each cochannel channel is occupied and is using VOX, i.e., interference power is present with probability $p = 0.4$. The maximum possible cochannel interference to any given point is:

$$\text{Peak Interference} = \sum_{i=1}^{N} I_i$$

where I_i is the cochannel interference power from the i^{th} cell and there are N cochannel cells. If X is defined as the random variable representing the actual interference power observed,

$$X = \Sigma\, a_i\, I_i$$

where $P\,(a_i = 1) = p = 0.4$ and $P\,(a_i = 0) = q = 1-p$

The mean and variance of X can be derived as follows:

Using the notation $E[\cdot\,]$ to represent the expectation of the quantity in brackets and $E[a_i] = p$

$$E[X] = \Sigma\; E\,[a_i\, I_i] = \Sigma I_i\, E(a_i) = p\, \Sigma\, I_i \qquad \text{B1}$$

That is, the mean interference is reduced by p from the peak interference. For $p = 0.4$, the average interference is 4 db below the peak interference.

The variance is derived as follows: $\mathrm{Var}\,(X) = E\,(X - E(X))^2 = E\,(\Sigma\,(a_i I_i - p\Sigma\, I_i))^2 =$
$E\,(\Sigma\,(a_i-p)I_i)^2$

Defining a new random variable, $b_i = a_i - p$ then $P(b_i = q) = P(a_i = 1) = p$ and
$P(b_i = -p) = P(a_i = 0) = q$

giving

$$E\,(b_i) = qp - pq = 0 \qquad \text{B2}$$

$$E\,(b_i^2) = q^2 p + p^2 q = pq \qquad \text{B3}$$

The variance is obtained from $\mathrm{Var}\,(X) = E\,(\Sigma\, b_i I_i)^2$. Writing the square of the sum as:

$$(\Sigma\, b_i I_i)^2 = \sum_i b_i^2 I_i^2 + 2\sum_j \sum_k b_j b_k I_j I_k\,(1-\delta_{jk})$$

where δ_{jk} is the kronecker delta function, the expected value of the above expression is

$$E\left(\Sigma\, b_i I_i\right)^2 = \sum_i I_i^2\, E\, b_i^2 + 2 \sum_j \sum_k I_j I_k (1-\delta_{jk})\, E\, b_j\, E\, b_k$$

Substituting in equations B2 and B3, and noting that all cross product terms are zero, gives:

$$\mathrm{Var}\,(X) = pq\, \Sigma\, I_i^2 \qquad \text{B-4}$$

Except for special cases, the distribution of X is difficult to obtain. One such special case occurs when the point of interest is equally distance from all significant interferers, which then contribute equal interference levels. For example, at the center of a cell. The distribution of interference is then exactly binominal. However, the edge of the cell is of more interest. At the cell edge, even the closest six cells are not longer equidistant. To calculate the exact distribution there, the net interference is approximated as normally distributed with mean and variance given by equations 1 and 4 respectively.

The normal approximation has been implemented in a program which calculates the cochannel interference for cell sites covering the United States.

B.1.2 MOBILE TRANSMIT CASE

The case without VOX is considered first. Interference in the mobile transmit case is the result of the interferers transmitting in cochannel cells being received at the satellite via wanted signal cell antenna sidelobes. With one cochannel interferer per cochannel cell and assuming that the interferer may be positioned anywhere in the hexagonal cell with equal probability, the average interference received at the satellite is the sum over all cochannel cells of the average sidelobe level of the wanted beam across each cochannel cell.

Explicitly:

$$E\,(X) = \mu_{TX} = \Sigma\, \bar{I}_i \qquad \text{B5}$$

where $\bar{I}_i$ is the average interference power across the i^{th} cell due to the wanted signal antenna.

The program for the calculation of interference levels, called COCELL, calculates the interference at each of 191 points across a hexagonal cell and estimates $\bar{I}_i$ by the estimator:

$$I_i = \frac{1}{N} \sum_j I_{ij}$$

where N is the number of points calculated for each cell.

The variance for the mobile transmit case without VOX is the sum of the variances for each individual cochannel cell. The variance over each individual cell of N=191 points is provided by the unbiased estimator:

$$\text{Var }(X) = \sigma_i^2 = \frac{1}{N-1} (\sum_j I_{ij}^2 - N\bar{I}_i^2)$$

Summing over all cells:

$$\sigma_{TX}^2 = \Sigma \sigma_i^2$$

$$\text{Var }(X) = \sigma_{TX}^2 = \frac{1}{N-1} \sum_i \sum_j I_{ij}^2 - \frac{1}{N-1} \Sigma\, I_i^2 \qquad \text{B6}$$

Since the interference at the satellite is the sum of independent random variables, it is approximated as being normally distributed with mean μ_{TX} and variance σ_{TX}^2 given by equations 5 and 6 respectively.

To determine the distribution of interference from each individual cochannel cell assuming VOX is in use, the normal distribution assumption is used.

From Bayes' theorem

$$P(A) = P(A|B_1)\,P(B_1) + P(A|B_2)\,P(B_2) \qquad \text{B7}$$

Define the event A as the event $I_i < X$, the event B_1 as the event that the interferer is transmitting (with probability $p = 0.4$) and the event B_2 as the event the interferer is not transmitting (with probability $p = 0.6$).

Note that:

$$P(A|B_1) = P(I_i < X|\text{interferer transmitting})$$

$$= \int_{-\infty}^{X} N(\bar{I}_i, \sigma_i)\,dx$$

$$P(A|B_2) = P(I_i < X|\text{interferer off})$$

$$= 1$$

where the normal distribution is defined as:

$$N(I_i, \sigma_i) = \frac{1}{\sqrt{2\pi}\,\sigma_i}\,\epsilon^{-\frac{1}{2\sigma_i^2}(X - \bar{I}_i)^2}$$

Rewriting equation B7:

$$P(I_i < X) = q + p\int_{-\infty}^{X} N(\bar{I}_i, \sigma_i)\,dx$$

The probability distribution function (p. d. f.) is:

$$f_i(X) = q\,\delta(X) + pN(\bar{I}_i, \sigma_i) \qquad \text{B8}$$

In words, if the interferer is off (with probability $q = 0.6$) the interference is zero. This generates the delta function at $X = 0$ of area q and if the interferer is transmitting (with probability $p = 0.4$) the interference is normal with mean $= \mu_i$ and standard deviation $= \sigma_i$.

Since the total interference is the sum of the interference from each cochannel cell, the distribution of the total interference is the convolution of probability density functions $f_i(X)$:

$$f(X) = f_1(X) * f_2(X) * \ldots * f_n(X)$$

Instead of performing the convolutions, again the normal distribution approximation is made and the interference at the satellite is taken as being distributed with mean equal to the sum of the means and variance equal to the sum of the variances.

First we need to evaluate the mean and variance of the individual distributions, equation B8.

$$f_i(X) = q\,\delta(X) + pN(\bar{I}_i, \sigma_i)$$

$$E(X)_i = \int X f_i(X)\,dx$$

$$= \int X(q\,\delta(X) + pN(\bar{I}_i, \sigma_i))\,dx$$

$$E(X)_i = p\mu_i \qquad \text{B9}$$

$$E(X^2)_i = \int X^2 f_i(X)\,dx$$

$$= \int X^2 (q\,\delta(X) + pN(\bar{I}_i, \sigma_i))\,dx$$

$$= p\int X^2 N(\bar{I}_i, \sigma_i)\,dx$$

$$E(X^2)_i = p(\bar{I}_i^2 + \sigma_i^2)$$

$$\mathrm{Var}\ (X) = EX_i^2 - E^2X_i = pq\ \bar{I}_i^2 + p\,\sigma_i^2 \qquad \text{B10}$$

The mean of the total interference will be the sum of the mean interference from each cell (equation B9):

$$E\ (X) = p \sum \bar{I}_i$$

$$E\ (X) = p\,\mu_{TX} \qquad \text{B11}$$

And the variance is the sum of the individual variances (equation B10):

$$\mathrm{Var}\ (X) = pq \sum \bar{I}_i^2 + p \sum \sigma_i^2$$

$$\mathrm{Var}\ (X) = pq\,\mu_{TX}^2 + p\,\sigma_{TX}^2 \qquad \text{B12}$$

B.2 ANALYSIS OF COCHANNEL INTERFERENCE

Analyses have been made of the cochannel interference experienced in the system for the mobile transmit and receive cases. Several arrangements of cochannel cells have been considered along with the use of VOX. The analyses were carried out using an arrangement of 66 cells to cover the contiguous United States as shown in Figure B-1. Although, this is a different arrangement from the 69 cells adopted, the results apply to the latter case and to most regular cell arrangements.

For the purposes of these analyses the antenna patterns were approximated by Hansen Functions (B-1).

B.2.1 MOBILE RECEIVE CASE ANALYSES

Nine different configurations were analyzed using COCELL, and are discussed in this section.

Four system configurations studied used a 3 frequency scheme. With a 3 frequency scheme, the entire available band is split into 3 sets of channels (not necessarily equal) and each cell is assigned a set such that no adjacent cell uses a cochannel frequency. This configuration results in maximum frequency reuse and thus maximum capacity. It also has the closest cochannel cell spacing which implies relatively high cochannel interference. In order to determine the impact of cochannel interference on the 3 frequency scheme, COCELL was run for a series of different antenna patterns.

Two parameters of the antenna pattern were determined to be of primary importance. The first parameter is the level of the main beam at the edge of the cell. The second parameter is the level of the first sidelobe.

B.2.1.1 Three Frequency Reuse Patterns

Using an antenna pattern with 25 dB sidelobes and with a main beam 3 dB down at the cell edge, the results shown in Table B-1 for each of the 66 cells were obtained. In the table, column 1 gives the cell number, corresponding to the number given in Figure B-1. The second column, labelled "peak" refers to the largest interference level and hence the lowest C/I ratio found

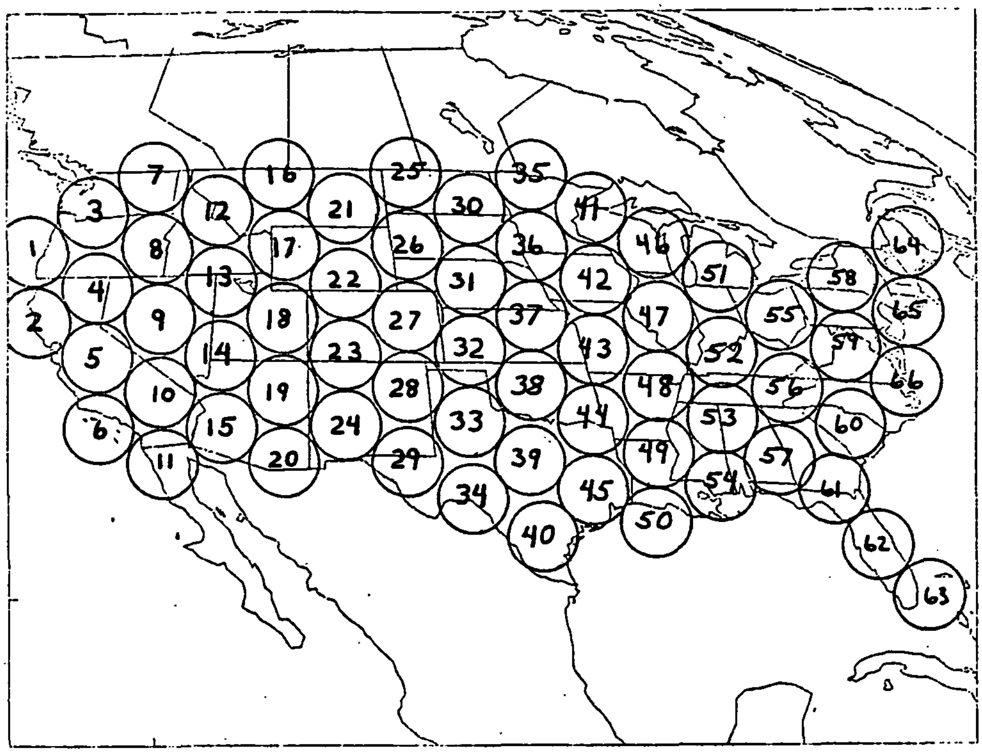


Figure B-1. Cell Site Positions

in the cell. The C/I ratio is tabulated for 191 points in each cell considering the interference from all beams within 6 cell diameters and "peak" is the lowest C/I of the 191 calculated. The second column, labelled 99%, is the C/I level exceeded by 99% of points in the cell, and so on. The C/I values are in dB. It is assumed that all channels are transmitting simultaneously which gives the maximum interference levels.

The data for peak interference at cell sites 40, 47 and 55 should be ignored because they are the result of misplaced beams. Nonetheless the data show poor C/I values at the 99% level but acceptable at the 95% level.

Table B-2 shows the C/I for the same cell arrangement but for 30 dB sidelobes. The C/I values in this case are considerably improved (but not by the 5 dB of the lowered sidelobes) and generally acceptable at the 99% level and all are useful at the 95% level. However, achieving the 30 dB sidelobes represents a difficult antenna design. The relatively small improvement in C/I indicates the main beam, as well as sidelobes, are contributing to cochannel interference, i.e., the main beam intrudes into the frequency reuse cells.

Table B-3 gives the C/I data for, again, the three frequency cell arrangement but for this case the beam is narrowed to make the gain at the cell edge 4 dB below the peak gain. This significantly improves the worst case C/I and gives generally acceptable C/I at the 99% level.

Table B-4 shows the case like the previous except that the sidelobes are 30 dB below the peak gain. Here there is a very significant improvement in C/I indicating that the sidelobes in this case are the major contributor to the interference. Figure B-2 illustrates the variation of C/I across cell 37.

A notable result of changing the beamwidth to give a 4 dB level at the cell edge is that the C/I values show only small changes between the 99%, 95% and 90% levels.

In Tables B-3 through B-7 there is a second set of columns labelled "Probability Statics; Worst case Point." This set of data refers only to the worst point in each cell and can be interpreted as the variation of C/I for that worst point as a function of time, in contrast to the first set of data that refer to statistics over the cell area. The time variation is due to the use of VOX. In the second set of data the column label 99% should be ignored because the normal distribution assumption used is not valid at the tails of the C/I distribution.

The above results illustrate a sensitivity to antenna pattern shape that show careful analysis of C/I for the actual patterns to be used is necessary to assure acceptable performance.

Table B-1. 3 Frequency Scheme, 3 dB Edge, 25 dB Sidelobes

****MAXIMUM POSSIBLE COCHANNEL INTERFERENCE****

CELL	PEAK	99%	95%	90%	NUMCOCH
1	14.5	16.8	20.1	21.3	8
2	13.7	14.6	18.1	19.8	9
3	14.4	16.2	18.9	19.5	10
4	17.0	17.9	18.8	19.6	9
5	14.5	16.5	18.2	18.7	10
6	14.4	16.2	18.9	19.5	10
7	14.5	16.7	19.0	19.5	10
8	14.4	16.2	18.2	18.8	11
9	13.5	16.5	17.3	17.6	12
10	16.0	16.7	18.9	19.3	11
11	15.9	16.5	18.9	19.2	11
12	15.8	17.3	18.3	18.5	13
13	13.4	15.4	16.9	17.6	13
14	13.3	15.2	16.9	17.7	13
15	14.1	17.2	18.2	18.5	14
16	13.6	15.5	18.2	18.9	13
17	13.5	15.3	17.9	18.5	14
18	13.3	15.8	17.0	17.6	16
19	15.9	16.8	18.2	18.3	15
20	15.9	16.4	18.5	18.8	14
21	15.7	15.9	18.2	18.8	16
22	13.4	15.8	16.7	17.5	16
23	14.7	15.7	16.9	17.7	16
24	14.2	16.8	17.9	18.2	18
25	15.6	16.1	18.3	19.0	16
26	15.8	16.6	18.0	18.5	16
27	15.5	15.9	16.5	17.7	19
28	15.3	15.6	17.4	18.0	18
29	15.6	16.5	18.2	18.7	16
30	15.6	16.1	18.4	19.0	17
31	15.5	15.8	16.7	17.9	19
32	15.7	15.7	16.7	18.0	17
33	15.4	15.8	17.7	18.1	18
34	16.8	18.0	18.6	19.1	17
35	14.1	15.9	18.6	19.1	16
36	13.3	15.5	17.6	18.9	16
37	13.2	15.2	16.7	17.6	18
38	13.3	15.2	16.8	17.3	19
39	15.7	16.5	18.0	18.5	16
40	11.0	15.2	17.9	18.6	17
41	16.7	17.7	18.5	19.0	16
42	14.1	16.0	17.2	17.7	18
43	13.5	13.6	17.0	17.6	16
44	13.1	13.5	16.7	17.5	17
45	13.4	14.1	17.3	18.7	16
46	13.5	14.2	18.1	19.6	14
47	11.0	13.7	15.6	17.8	16
48	13.2	14.4	16.8	17.4	16
49	13.3	15.3	17.9	18.5	14
50	11.0	15.2	17.9	18.9	14
51	13.5	15.5	18.0	18.3	15
52	13.6	14.7	17.3	18.4	13
53	13.7	14.1	16.7	18.1	14
54	18.7	19.5	19.9	20.1	12
55	10.8	14.7	17.5	18.3	13
56	12.4	14.7	17.6	18.0	13
57	16.0	17.4	18.2	18.7	11
58	16.2	17.9	18.6	19.2	11
59	16.3	17.5	18.6	19.4	10
60	14.6	17.2	18.5	18.9	11
61	12.7	14.9	19.0	19.4	10
62	20.5	21.0	21.7	22.3	8
63	25.7	25.7	26.9	27.6	8
64	18.1	20.2	21.7	22.6	8
65	14.7	17.4	19.9	20.4	10
66	15.3	17.8	19.5	19.9	9

Table B-2. 3 Frequency Scheme, 3 dB Edge, 30 dB Sidelobes

****MAXIMUM POSSIBLE COCHANNEL INTERFERENCE****

CELL	PEAK	99%	95%	90%	NUMCOCH
1	14.5	16.8	19.9	25.3	8
2	14.4	14.5	19.2	22.1	9
3	14.4	16.9	21.7	24.5	10
4	18.3	18.8	24.1	24.6	9
5	14.4	16.8	20.6	23.5	10
6	14.4	16.8	21.7	24.5	10
7	14.5	18.4	20.2	24.2	10
8	14.4	17.8	19.4	20.8	11
9	14.1	17.7	18.3	20.8	12
10	16.3	18.4	20.5	24.3	11
11	16.3	18.3	20.4	24.1	11
12	16.2	19.2	21.9	23.9	13
13	14.1	16.3	16.6	20.3	13
14	14.0	16.2	18.6	20.3	13
15	14.4	19.2	21.8	23.8	14
16	14.2	16.4	19.4	22.6	13
17	14.1	16.3	19.6	23.3	14
18	14.1	17.8	19.4	21.9	16
19	16.2	19.2	21.8	23.7	15
20	16.2	18.1	20.3	23.9	14
21	16.2	17.7	20.2	22.9	16
22	14.1	17.5	18.9	20.7	16
23	15.8	17.5	19.6	22.1	16
24	14.3	19.1	22.5	23.7	18
25	17.5	17.9	22.2	24.0	16
26	17.6	20.0	22.7	24.0	16
27	17.4	17.5	19.9	22.2	19
28	17.4	17.7	21.7	22.6	18
29	17.5	19.9	22.9	24.1	16
30	17.5	17.9	22.2	24.3	17
31	17.4	17.5	19.3	22.0	19
32	17.4	17.5	20.0	22.1	17
33	17.4	17.8	21.9	22.9	18
34	20.5	22.4	24.1	24.6	17
35	12.6	14.9	19.8	22.9	16
36	12.4	14.6	19.3	22.4	16
37	12.4	14.5	18.9	20.5	18
38	12.4	14.5	19.2	21.2	19
39	17.5	20.0	22.5	24.0	16
40	11.1	15.3	20.2	23.3	17
41	20.4	22.0	24.0	24.6	16
42	12.6	14.8	19.3	21.8	18
43	12.5	14.3	18.6	19.2	16
44	12.4	14.3	18.6	19.0	17
45	12.5	14.3	19.1	21.3	16
46	12.6	14.4	19.3	22.0	14
47	11.2	14.4	16.3	19.0	16
48	12.6	14.5	19.3	21.3	16
49	14.0	16.3	20.3	23.2	14
50	11.2	15.2	18.3	21.6	14
51	14.1	16.3	19.3	22.1	15
52	14.1	15.9	18.3	19.5	13
53	14.3	14.3	18.6	19.3	14
54	24.1	24.6	25.1	25.5	12
55	11.1	15.0	18.4	20.4	13
56	12.6	14.7	19.3	22.1	13
57	16.2	19.2	23.2	23.8	11
58	16.4	19.2	24.2	24.5	11
59	16.3	17.0	22.2	23.9	10
60	14.4	16.8	23.5	24.3	11
61	12.7	14.9	22.2	24.6	10
62	25.9	26.1	27.2	28.0	8
63	31.8	31.8	32.9	33.2	8
64	16.8	19.7	26.1	27.2	8
65	14.5	17.0	25.0	25.7	10
66	16.0	19.0	24.4	25.2	9

Table B-3. 3 Frequency Scheme, 4 dB Edge, 25 dB Sidelobes

	****MAXIMUM POSSIBLE COCHANNEL INTERFERENCE****					*** PROBABILITY STATISTICS; WORST CASE POINT***				
CELL	PEAK	99%	95%	90%	NUMCOCH	99%	95%	90%	MEAN	SIGMA
1	18.6	18.5	19.4	20.0	8	17.9	18.9	19.4	0.554E-02	0.455E-02
2	18.1	18.4	18.7	18.3	9	17.5	18.4	19.0	0.620E-02	0.493E-02
3	17.7	18.1	18.5	18.9	10	17.1	18.0	18.6	0.682E-02	0.544E-02
4	17.0	17.5	18.6	18.8	9	16.8	17.7	18.2	0.803E-02	0.545E-02
5	16.5	17.3	17.7	18.2	10	16.6	17.4	17.9	0.895E-02	0.558E-02
6	17.7	18.1	18.5	18.9	10	17.1	18.0	18.6	0.682E-02	0.544E-02
7	17.6	17.8	18.4	18.7	10	17.4	18.2	18.8	0.695E-02	0.487E-02
8	17.2	17.4	17.8	17.9	11	17.2	18.0	18.5	0.768E-02	0.493E-02
9	15.5	15.6	16.6	17.1	12	15.8	16.6	17.1	0.111E-01	0.644E-02
10	17.8	17.8	18.3	18.8	11	17.3	18.2	18.8	0.660E-02	0.524E-02
11	17.7	17.7	18.2	18.8	11	17.2	18.1	18.7	0.680E-02	0.518E-02
12	16.2	16.4	17.4	17.9	13	16.3	17.1	17.7	0.969E-02	0.584E-02
13	15.8	16.1	16.9	17.1	13	16.2	17.0	17.5	0.105E-01	0.575E-02
14	15.6	16.0	16.8	17.0	13	15.9	16.7	17.2	0.110E-01	0.637E-02
15	16.1	16.5	17.3	17.9	14	16.3	17.1	17.6	0.975E-02	0.586E-02
16	17.1	17.2	17.7	18.0	13	17.1	18.0	18.5	0.778E-02	0.498E-02
17	15.9	16.5	17.7	18.0	14	16.0	16.8	17.4	0.102E-01	0.637E-02
18	15.9	16.0	16.6	16.8	16	16.3	17.0	17.5	0.104E-01	0.569E-02
19	16.2	16.3	17.3	17.8	15	16.3	17.2	17.7	0.961E-02	0.583E-02
20	16.1	16.6	17.4	17.9	14	16.1	17.0	17.5	0.974E-02	0.624E-02
21	17.0	17.3	17.5	17.9	16	16.8	17.7	18.2	0.791E-02	0.553E-02
22	15.4	15.6	16.6	16.8	16	15.7	16.5	17.0	0.115E-01	0.648E-02
23	15.4	15.9	16.7	16.9	16	15.7	16.5	17.0	0.116E-01	0.665E-02
24	16.2	16.7	17.2	17.8	18	16.3	17.1	17.6	0.951E-02	0.605E-02
25	17.2	17.4	17.6	18.1	16	16.9	17.8	18.3	0.769E-02	0.549E-02
26	16.5	17.0	17.5	18.0	16	16.4	17.3	17.8	0.889E-02	0.594E-02
27	15.7	16.2	16.7	16.8	19	16.2	17.0	17.4	0.107E-01	0.572E-02
28	16.4	16.7	17.1	17.4	18	16.4	17.2	17.7	0.921E-02	0.592E-02
29	16.4	16.5	17.4	18.0	16	16.6	17.4	17.9	0.917E-02	0.541E-02
30	17.1	17.3	17.6	18.2	17	16.9	17.7	18.3	0.777E-02	0.549E-02
31	15.7	16.3	16.7	16.8	19	16.2	16.9	17.4	0.108E-01	0.574E-02
32	15.8	16.0	16.7	16.9	17	16.2	17.0	17.5	0.106E-01	0.573E-02
33	16.3	16.9	17.3	17.4	18	16.3	17.1	17.6	0.940E-02	0.613E-02
34	17.0	17.3	17.9	18.8	17	16.9	17.7	18.3	0.800E-02	0.540E-02
35	17.5	17.7	18.2	18.6	16	17.0	17.9	18.5	0.716E-02	0.545E-02
36	17.2	17.3	17.6	18.1	16	17.1	17.9	18.5	0.757E-02	0.520E-02
37	15.9	16.1	16.6	16.8	18	16.3	17.0	17.5	0.104E-01	0.570E-02
38	15.7	16.0	16.6	16.8	19	16.0	16.8	17.3	0.108E-01	0.618E-02
39	16.6	16.9	17.5	18.1	16	16.5	17.3	17.9	0.874E-02	0.591E-02
40	16.8	16.9	18.0	18.8	17	16.3	17.2	17.8	0.831E-02	0.648E-02
41	17.3	17.3	17.9	18.9	16	17.2	18.1	18.6	0.747E-02	0.492E-02
42	15.6	16.1	16.7	17.1	18	15.8	16.6	17.1	0.109E-01	0.657E-02
43	15.4	16.0	16.5	16.8	16	15.7	16.5	17.0	0.115E-01	0.665E-02
44	15.0	15.7	16.6	17.0	17	15.4	16.2	16.7	0.126E-01	0.694E-02
45	16.9	17.4	18.0	18.6	16	16.7	17.6	18.1	0.815E-02	0.566E-02
46	17.3	17.7	18.7	18.9	14	16.9	17.8	18.4	0.741E-02	0.549E-02
47	16.2	16.4	16.9	17.3	16	16.4	17.2	17.7	0.956E-02	0.575E-02
48	15.6	15.9	16.9	17.1	16	16.0	16.8	17.3	0.109E-01	0.616E-02
49	15.9	16.4	17.7	18.0	14	16.0	16.8	17.4	0.102E-01	0.637E-02
50	15.6	16.1	18.0	18.7	14	15.5	16.3	16.9	0.110E-01	0.744E-02
51	15.2	15.7	17.4	17.9	15	15.4	16.2	16.7	0.122E-01	0.729E-02
52	15.4	15.9	16.9	17.6	13	15.6	16.4	16.9	0.115E-01	0.677E-02
53	16.0	16.5	17.4	17.7	14	16.0	16.9	17.4	0.101E-01	0.638E-02
54	17.5	18.4	20.2	20.7	12	17.2	18.0	18.6	0.705E-02	0.524E-02
55	16.5	16.9	17.8	18.6	13	16.3	17.1	17.7	0.898E-02	0.632E-02
56	15.7	16.1	16.8	17.6	13	15.9	16.7	17.2	0.107E-01	0.648E-02
57	16.4	16.9	17.5	18.5	11	16.2	17.1	17.6	0.915E-02	0.639E-02
58	17.0	17.1	18.1	18.8	11	16.4	17.3	17.9	0.799E-02	0.648E-02
59	16.4	17.2	18.3	19.3	10	16.0	16.9	17.4	0.917E-02	0.690E-02
60	17.0	17.4	18.5	19.1	11	16.5	17.4	17.9	0.802E-02	0.627E-02
61	16.6	16.9	18.3	18.9	10	16.0	16.9	17.5	0.882E-02	0.698E-02
62	19.3	19.8	20.8	22.4	8	18.0	19.0	19.6	0.469E-02	0.485E-02
63	24.5	25.2	28.0	29.3	8	23.6	24.5	25.2	0.142E-02	0.125E-02
64	19.6	20.6	21.7	22.3	8	18.1	19.1	19.8	0.440E-02	0.482E-02
65	17.3	18.0	19.5	20.7	10	16.6	17.6	18.2	0.741E-02	0.612E-02
66	16.4	16.7	17.9	18.8	9	16.0	16.9	17.4	0.911E-02	0.695E-02

Table B-4. 3 Frequency Scheme, 4 dB Edge, 30 dB Sidelobes

	****MAXIMUM POSSIBLE COCHANNEL INTERFERENCE****					*** PROBABILITY STATISTICS: WORST CASE POINT***				
CELL	PEAK	99%	95%	90%	NUMCOCH	99%	95%	90%	MEAN	SIGMA
1	22.1	24.1	24.7	25.3	8	21.4	22.3	22.9	0.248E-02	0.204E-02
2	21.6	22.3	24.2	24.4	9	21.2	22.1	22.7	0.277E-02	0.208E-02
3	22.5	23.0	23.8	24.1	10	22.0	22.9	23.5	0.224E-02	0.175E-02
4	22.8	22.9	23.4	24.1	9	22.2	23.2	23.7	0.210E-02	0.166E-02
5	22.2	22.6	22.9	23.4	10	22.1	23.0	23.5	0.239E-02	0.162E-02
6	22.5	23.0	23.8	24.1	10	22.0	22.9	23.5	0.223E-02	0.175E-02
7	23.0	23.1	23.8	24.1	10	22.4	23.3	23.9	0.201E-02	0.162E-02
8	22.3	22.8	23.1	23.3	11	22.0	22.9	23.5	0.237E-02	0.167E-02
9	21.4	21.6	21.8	22.3	12	21.6	22.4	22.9	0.287E-02	0.175E-02
10	23.1	23.1	23.8	24.0	11	22.5	23.4	24.0	0.198E-02	0.156E-02
11	23.0	23.1	23.8	24.1	11	22.5	23.4	24.0	0.199E-02	0.156E-02
12	22.1	22.3	22.5	23.1	13	21.7	22.6	23.2	0.244E-02	0.184E-02
13	20.4	21.8	22.2	22.5	13	20.5	21.3	21.8	0.366E-02	0.225E-02
14	20.6	21.5	22.1	22.3	13	20.8	21.6	22.1	0.346E-02	0.210E-02
15	22.1	22.3	22.7	23.0	14	21.7	22.6	23.2	0.245E-02	0.184E-02
16	20.5	22.4	22.9	23.5	13	20.6	21.4	21.9	0.358E-02	0.224E-02
17	20.9	21.8	22.7	23.6	14	20.9	21.8	22.3	0.321E-02	0.210E-02
18	21.8	21.8	22.1	22.3	16	21.7	22.6	23.1	0.265E-02	0.176E-02
19	21.9	22.1	22.5	23.0	15	21.6	22.5	23.0	0.260E-02	0.185E-02
20	21.8	22.2	22.7	23.2	14	21.6	22.5	23.0	0.262E-02	0.183E-02
21	22.3	22.6	23.1	23.3	16	22.0	22.9	23.5	0.235E-02	0.168E-02
22	21.3	21.3	21.9	22.2	16	21.6	22.4	22.9	0.299E-02	0.167E-02
23	21.5	21.6	22.1	22.3	16	21.5	22.3	22.8	0.282E-02	0.186E-02
24	21.8	22.2	22.4	22.9	18	21.6	22.5	23.0	0.263E-02	0.185E-02
25	22.5	22.5	23.0	23.6	16	22.1	23.0	23.6	0.225E-02	0.167E-02
26	22.0	22.3	22.7	23.3	16	21.8	22.7	23.2	0.251E-02	0.176E-02
27	21.6	21.8	22.0	22.3	19	21.6	22.4	23.0	0.278E-02	0.178E-02
28	22.0	22.2	22.6	22.9	18	21.7	22.6	23.1	0.252E-02	0.184E-02
29	22.0	22.1	22.6	23.2	16	21.8	22.7	23.2	0.253E-02	0.176E-02
30	22.4	22.6	23.0	23.6	17	22.1	23.0	23.5	0.231E-02	0.168E-02
31	21.4	21.9	22.0	22.4	19	21.6	22.4	22.9	0.290E-02	0.170E-02
32	21.4	21.7	22.0	22.3	17	21.7	22.5	23.0	0.288E-02	0.168E-02
33	21.5	22.1	22.6	22.9	18	21.4	22.3	22.8	0.280E-02	0.192E-02
34	22.0	22.5	23.1	24.1	17	21.7	22.6	23.1	0.250E-02	0.184E-02
35	19.7	22.8	23.7	23.8	16	18.8	19.7	20.4	0.424E-02	0.388E-02
36	19.3	22.5	23.0	23.3	16	18.6	19.5	20.1	0.475E-02	0.393E-02
37	19.1	21.7	22.0	22.2	18	18.5	19.4	20.0	0.497E-02	0.394E-02
38	19.5	21.6	21.9	22.2	19	18.7	19.7	20.3	0.444E-02	0.386E-02
39	22.1	22.2	22.7	23.3	16	21.8	22.7	23.3	0.246E-02	0.176E-02
40	18.1	22.3	23.1	23.9	17	16.3	17.3	18.0	0.626E-02	0.748E-02
41	22.1	22.6	23.2	24.1	16	21.7	22.6	23.2	0.248E-02	0.184E-02
42	19.9	21.7	22.0	22.4	18	18.9	19.8	20.5	0.410E-02	0.382E-02
43	18.6	21.0	21.7	22.0	16	18.1	19.0	19.6	0.556E-02	0.419E-02
→44	18.5	20.7	21.6	22.2	17	18.1	19.0	19.6	0.567E-02	0.419E-02
45	19.1	21.9	23.4	23.9	16	18.5	19.4	20.0	0.488E-02	0.404E-02
46	19.0	21.6	23.5	24.3	14	18.4	19.3	19.9	0.503E-02	0.407E-02
47	17.2	19.7	22.1	22.5	16	16.0	17.0	17.6	0.767E-02	0.757E-02
48	19.6	21.4	22.1	22.3	16	18.7	19.7	20.3	0.442E-02	0.385E-02
49	21.4	21.9	22.7	23.4	14	21.3	22.2	22.7	0.288E-02	0.194E-02
50	17.6	21.6	22.7	23.8	14	16.1	17.2	17.8	0.688E-02	0.750E-02
51	20.4	21.0	22.8	23.3	15	20.6	21.4	21.9	0.361E-02	0.222E-02
52	20.9	21.1	22.1	22.6	13	20.7	21.6	22.1	0.328E-02	0.225E-02
53	19.8	21.5	22.6	23.2	14	19.9	20.7	21.2	0.420E-02	0.261E-02
54	22.8	23.7	25.5	26.4	12	22.2	23.1	23.7	0.209E-02	0.168E-02
55	17.4	22.0	22.8	23.4	13	16.0	17.1	17.7	0.725E-02	0.756E-02
56	19.6	21.3	21.8	22.6	13	18.7	19.6	20.3	0.436E-02	0.395E-02
57	22.4	22.6	22.9	23.9	11	22.2	23.1	23.6	0.230E-02	0.157E-02
58	22.3	22.5	23.3	24.2	11	21.8	22.7	23.3	0.236E-02	0.182E-02
59	21.7	22.4	23.6	24.7	10	21.2	22.1	22.7	0.270E-02	0.211E-02
60	22.0	22.5	23.4	24.3	11	21.5	22.4	23.0	0.252E-02	0.199E-02
61	20.4	21.9	23.5	24.3	10	19.0	20.1	20.7	0.362E-02	0.380E-02
62	24.5	25.2	26.2	27.3	8	23.0	24.0	24.7	0.143E-02	0.155E-02
63	30.4	32.1	35.3	36.8	8	29.6	30.6	31.2	0.368E-03	0.310E-03
64	24.4	25.6	26.8	27.5	8	23.0	24.0	24.7	0.144E-02	0.155E-02
65	22.5	22.9	24.7	26.0	10	21.8	22.7	23.3	0.224E-02	0.187E-02
66	21.7	22.0	23.2	24.2	9	21.1	22.1	22.6	0.272E-02	0.213E-02

Table B-5. 3/6 Hybrid Scheme, 3 dB Edge, 25 dB Sidelobes

	MAXIMUM POSSIBLE COCHANNEL INTERFERENCE*					*** PROBABILITY STATISTICS: WORST CASE POINT***				
CELL	PEAK	99%	95%	90%	NUMCOCH	99%	95%	90%	MEAN	SIGMA
1	24.0	24.4	25.3	26.1	5	23.7	24.6	25.1	0.161E-02	0.115E-02
2	24.8	25.8	27.0	27.8	5	24.0	24.9	25.5	0.132E-02	0.115E-02
3	20.1	20.4	21.4	22.1	4	18.9	19.9	20.5	0.392E-02	0.383E-02
4	24.4	24.9	26.1	26.5	5	23.9	24.8	25.3	0.146E-02	0.114E-02
5	19.7	20.4	21.4	22.4	5	18.8	19.7	20.4	0.432E-02	0.382E-02
6	20.5	20.8	21.7	22.3	5	19.1	20.1	20.8	0.355E-02	0.377E-02
7	19.7	20.0	21.0	21.6	6	18.8	19.7	20.4	0.428E-02	0.385E-02
8	20.1	20.4	21.4	22.1	5	18.9	19.9	20.5	0.392E-02	0.383E-02
9	19.0	19.4	20.3	20.7	7	18.5	19.4	20.0	0.500E-02	0.398E-02
10	19.7	20.4	21.4	22.4	5	18.8	19.7	20.4	0.432E-02	0.382E-02
11	25.9	26.3	26.6	26.7	6	25.1	26.0	26.6	0.102E-02	0.900E-03
12	19.7	20.0	21.1	21.7	6	18.7	19.7	20.3	0.429E-02	0.397E-02
13	19.8	20.1	21.3	21.8	7	18.7	19.7	20.3	0.420E-02	0.396E-02
14	18.9	19.6	20.5	20.9	7	18.3	19.2	19.8	0.517E-02	0.409E-02
15	19.4	19.9	21.6	22.6	7	18.6	19.5	20.1	0.459E-02	0.401E-02
16	19.6	20.2	21.2	21.8	7	18.7	19.7	20.3	0.438E-02	0.388E-02
17	19.4	20.0	21.3	22.2	6	18.6	19.5	20.1	0.456E-02	0.403E-02
18	19.6	19.7	20.8	21.5	8	18.8	19.7	20.3	0.443E-02	0.378E-02
19	19.5	19.9	21.2	22.3	7	18.6	19.6	20.2	0.453E-02	0.398E-02
20	19.7	20.2	21.0	21.7	8	18.8	19.7	20.3	0.432E-02	0.384E-02
21	19.1	19.6	20.9	21.9	9	18.4	19.4	19.9	0.496E-02	0.404E-02
22	19.2	19.9	21.0	22.0	7	18.5	19.4	20.0	0.479E-02	0.401E-02
23	18.9	19.2	20.1	20.5	10	18.4	19.4	19.9	0.514E-02	0.393E-02
24	19.4	19.8	21.1	22.2	8	18.6	19.5	20.1	0.460E-02	0.398E-02
25	19.7	20.1	21.1	21.8	8	18.8	19.7	20.3	0.430E-02	0.387E-02
26	19.5	19.6	20.8	21.7	8	18.7	19.7	20.3	0.450E-02	0.383E-02
27	18.7	19.0	19.7	20.3	9	18.3	19.2	19.7	0.538E-02	0.409E-02
28	19.5	19.8	20.8	21.8	9	18.7	19.6	20.2	0.454E-02	0.386E-02
29	19.4	19.9	21.0	22.2	9	18.6	19.5	20.1	0.458E-02	0.398E-02
30	19.2	19.7	20.9	21.7	10	18.6	19.5	20.1	0.478E-02	0.390E-02
31	19.3	19.8	20.9	21.8	9	18.6	19.5	20.1	0.475E-02	0.390E-02
32	18.5	19.0	19.6	20.2	10	18.2	19.1	19.7	0.559E-02	0.410E-02
33	19.4	19.6	20.8	21.8	8	18.6	19.6	20.2	0.463E-02	0.390E-02
34	19.8	20.4	21.5	22.7	10	18.8	19.7	20.4	0.417E-02	0.391E-02
35	20.2	20.4	21.6	22.1	7	19.0	20.0	20.6	0.380E-02	0.379E-02
36	19.4	19.8	20.8	21.6	11	18.7	19.6	20.2	0.461E-02	0.386E-02
37	19.1	19.2	19.7	20.3	9	18.5	19.4	20.0	0.492E-02	0.396E-02
38	18.7	18.9	19.7	20.2	10	18.4	19.3	19.8	0.536E-02	0.391E-02
39	19.5	19.9	20.9	21.7	8	18.7	19.6	20.3	0.447E-02	0.388E-02
40	20.1	20.5	21.4	22.6	9	19.0	20.0	20.6	0.388E-02	0.370E-02
41	19.8	19.9	21.4	22.0	8	18.9	19.8	20.4	0.424E-02	0.377E-02
42	18.0	18.5	19.7	20.4	8	17.6	18.5	19.0	0.638E-02	0.479E-02
43	18.8	19.0	19.6	20.3	10	18.4	19.3	19.9	0.525E-02	0.397E-02
44	19.1	19.5	20.8	21.5	7	18.5	19.4	20.0	0.498E-02	0.398E-02
45	19.7	20.2	21.2	21.9	9	18.7	19.7	20.3	0.433E-02	0.388E-02
46	18.5	18.9	19.6	20.3	10	17.9	18.8	19.4	0.567E-02	0.449E-02
47	11.5	16.4	19.4	20.0	8	9.8	10.8	11.5	0.281E-01	0.333E-01
48	18.1	18.5	18.8	19.2	9	17.7	18.6	19.2	0.620E-02	0.455E-02
49	19.1	19.7	20.6	21.4	7	18.5	19.4	20.0	0.491E-02	0.398E-02
50	19.3	19.8	21.0	21.8	8	18.6	19.6	20.1	0.469E-02	0.389E-02
51	17.8	18.4	19.6	20.4	8	17.2	18.1	18.7	0.665E-02	0.531E-02
52	22.6	24.0	25.0	25.5	7	22.6	23.4	24.0	0.222E-02	0.140E-02
53	19.0	19.4	20.0	20.5	7	18.5	19.4	20.0	0.504E-02	0.395E-02
54	24.5	25.5	27.1	28.0	5	23.9	24.9	25.4	0.142E-02	0.112E-02
55	19.0	19.2	19.6	20.2	8	18.7	19.6	20.1	0.499E-02	0.369E-02
56	20.1	21.0	21.7	22.1	7	18.9	19.9	20.5	0.387E-02	0.391E-02

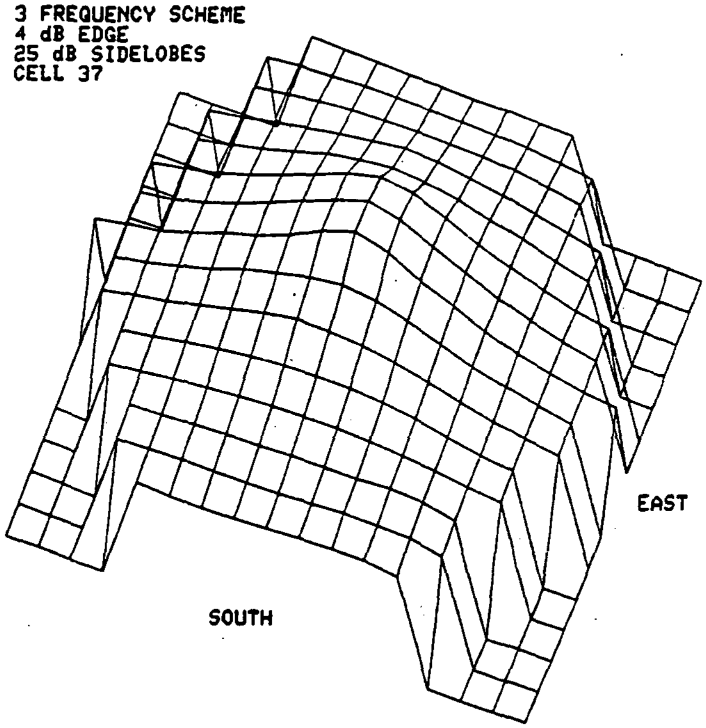
57	19.6	20.3	21.3	22.1	5	18.6	19.6	20.2	0.441E-02	0.399E-02
58	18.1	20.9	21.8	22.5	6	16.8	17.8	18.5	0.621E-02	0.623E-02
59	18.5	19.2	20.4	20.9	4	17.8	18.8	19.4	0.565E-02	0.465E-02
60	20.2	21.0	21.6	22.3	6	18.9	19.9	20.5	0.383E-02	0.392E-02
61	20.1	20.9	21.7	22.4	6	18.9	19.9	20.5	0.391E-02	0.391E-02
62	22.7	24.1	25.7	27.0	6	21.6	22.6	23.2	0.214E-02	0.204E-02
63	29.7	30.8	31.8	32.6	4	28.7	29.7	30.3	0.433E-03	0.389E-03
64	20.2	20.8	22.0	23.3	4	19.1	20.1	20.7	0.386E-02	0.363E-02
65	20.6	21.2	21.9	22.7	5	19.0	20.1	20.7	0.349E-02	0.388E-02
66	20.4	21.0	22.0	23.3	5	19.2	20.2	20.8	0.363E-02	0.361E-02
67	20.0	20.6	21.4	22.4	5	18.8	19.8	20.4	0.400E-02	0.399E-02
68	17.9	20.1	20.7	21.0	6	16.8	17.8	18.4	0.644E-02	0.624E-02
69	11.5	16.2	18.8	19.6	6	9.7	10.8	11.5	0.285E-01	0.333E-01
70	27.0	27.5	28.2	28.7	5	25.3	26.3	27.0	0.804E-03	0.931E-03

Table B-6. 4/8 Hybrid Homogeneous, 3 dB Edge, 25 dB Sidelobes

	MAXIMUM POSSIBLE COCHANNEL INTERFERENCE					PROBABILITY STATISTICS: WORST CASE POINT				
CELL	PEAK	99%	95%	90%	NUMCOCH	99%	95%	90%	MEAN	SIGMA
1	26.9	27.4	28.5	29.2	3	25.5	26.6	27.2	0.812E-03	0.851E-03
2	26.5	27.1	27.2	27.5	3	25.2	26.2	26.9	0.895E-03	0.905E-03
3	25.9	26.0	26.5	27.0	3	25.0	25.9	26.5	0.104E-02	0.924E-03
4	20.3	20.7	21.9	22.5	4	19.0	20.0	20.6	0.374E-02	0.383E-02
5	27.5	27.9	28.8	29.5	2	25.6	26.7	27.4	0.714E-03	0.874E-03
6	20.6	21.0	21.8	22.3	3	19.1	20.1	20.8	0.352E-02	0.377E-02
7	26.7	26.8	26.9	27.1	3	25.3	26.3	27.0	0.862E-03	0.898E-03
8	24.9	25.3	26.1	26.8	4	24.2	25.1	25.7	0.131E-02	0.107E-02
9	20.3	20.7	21.9	22.5	4	19.0	20.0	20.6	0.374E-02	0.383E-02
10	24.7	25.2	25.9	26.6	4	23.9	24.8	25.4	0.136E-02	0.118E-02
11	20.6	21.0	21.8	22.3	3	19.1	20.1	20.8	0.352E-02	0.377E-02
12	24.1	24.7	25.6	26.1	4	23.8	24.7	25.2	0.155E-02	0.114E-02
13	23.7	24.6	25.3	25.9	5	23.4	24.3	24.8	0.172E-02	0.124E-02
14	24.3	24.7	25.6	26.2	5	23.7	24.6	25.2	0.150E-02	0.119E-02
15	24.5	24.9	25.9	26.6	5	23.8	24.7	25.3	0.144E-02	0.119E-02
16	24.2	24.7	25.9	26.6	4	23.6	24.5	25.1	0.152E-02	0.122E-02
17	23.1	23.9	24.8	25.4	5	23.1	23.9	24.4	0.196E-02	0.128E-02
18	25.7	25.9	26.9	27.5	4	24.8	25.7	26.4	0.107E-02	0.969E-03
19	23.5	24.0	24.8	25.4	6	23.2	24.0	24.6	0.180E-02	0.130E-02
20	24.0	24.5	25.9	26.6	6	23.4	24.3	24.9	0.160E-02	0.129E-02
21	23.5	23.9	25.0	25.4	6	23.3	24.2	24.7	0.179E-02	0.123E-02
22	23.1	23.9	24.7	25.4	5	23.0	23.9	24.4	0.197E-02	0.128E-02
23	23.2	23.9	25.0	25.6	6	23.0	23.8	24.4	0.193E-02	0.135E-02
24	23.4	24.1	25.7	26.1	6	23.1	24.0	24.5	0.181E-02	0.133E-02
25	24.0	24.5	25.5	26.1	6	23.6	24.5	25.0	0.161E-02	0.120E-02
26	23.2	23.8	24.6	25.3	7	23.2	24.0	24.6	0.190E-02	0.125E-02
27	23.1	24.1	24.9	25.4	7	23.1	23.9	24.4	0.195E-02	0.128E-02
28	22.8	23.5	24.6	25.0	7	22.9	23.7	24.2	0.208E-02	0.133E-02
29	23.4	24.2	25.7	26.1	6	23.1	24.0	24.5	0.181E-02	0.133E-02
30	23.6	24.2	25.5	26.3	6	23.2	24.1	24.7	0.175E-02	0.130E-02
31	23.3	24.1	24.9	25.6	5	23.0	23.9	24.5	0.188E-02	0.133E-02
32	22.6	23.1	24.1	24.3	8	22.7	23.5	24.0	0.219E-02	0.138E-02
33	22.7	23.4	24.4	24.9	7	22.7	23.6	24.1	0.217E-02	0.136E-02
34	23.3	24.0	25.7	26.6	6	23.0	23.9	24.4	0.188E-02	0.135E-02
35	23.7	24.3	25.1	25.6	7	23.4	24.3	24.8	0.169E-02	0.124E-02
36	24.2	24.5	25.4	26.4	6	23.7	24.6	25.2	0.154E-02	0.118E-02
37	23.5	24.2	25.3	25.9	7	23.3	24.2	24.7	0.180E-02	0.122E-02
38	23.2	23.8	25.0	25.6	6	23.2	24.0	24.6	0.190E-02	0.125E-02
39	24.2	24.8	25.7	26.2	6	23.7	24.6	25.2	0.152E-02	0.119E-02
40	24.5	24.7	25.7	26.5	6	24.0	24.9	25.5	0.142E-02	0.110E-02
41	23.7	24.2	24.9	25.6	7	23.2	24.1	24.7	0.172E-02	0.133E-02
42	23.2	23.8	24.6	25.4	6	23.0	23.8	24.4	0.191E-02	0.135E-02
43	20.3	20.7	21.5	21.7	7	19.3	20.3	20.9	0.370E-02	0.342E-02
44	23.3	24.0	24.7	25.4	5	23.2	24.1	24.6	0.185E-02	0.123E-02
45	24.4	25.3	26.0	26.6	5	24.0	24.9	25.4	0.144E-02	0.111E-02
46	24.3	24.7	25.7	26.3	5	23.7	24.6	25.2	0.149E-02	0.121E-02
47	24.5	25.3	25.9	26.3	6	24.2	25.1	25.6	0.143E-02	0.103E-02
48	20.4	20.5	21.5	22.1	6	19.4	20.3	21.0	0.368E-02	0.338E-02
49	23.1	23.7	24.3	24.8	5	22.9	23.7	24.3	0.198E-02	0.137E-02
50	25.7	26.1	27.1	27.4	5	24.8	25.8	26.4	0.108E-02	0.958E-03
51	23.7	24.2	25.0	25.6	5	23.3	24.2	24.8	0.172E-02	0.126E-02
52	20.3	21.1	21.8	22.6	5	18.9	19.9	20.6	0.373E-02	0.390E-02
53	23.8	25.1	25.5	26.1	5	23.7	24.5	25.1	0.167E-02	0.113E-02
54	25.9	26.0	26.8	27.5	4	24.9	25.9	26.5	0.102E-02	0.936E-03
55	20.7	21.1	22.1	22.5	5	19.0	20.1	20.8	0.342E-02	0.388E-02
56	20.6	21.1	21.9	22.9	4	19.0	20.1	20.7	0.347E-02	0.389E-02
57	24.7	25.1	25.8	26.3	4	24.2	25.1	25.7	0.135E-02	0.104E-02
58	20.7	21.2	22.0	22.9	4	19.0	20.1	20.8	0.344E-02	0.388E-02
59	26.9	27.5	28.1	28.7	4	25.2	26.3	27.0	0.825E-03	0.932E-03
60	20.7	21.4	21.9	22.7	4	19.0	20.1	20.8	0.341E-02	0.388E-02
61	25.2	25.3	26.5	27.4	4	24.3	25.3	25.9	0.121E-02	0.106E-02
62	30.2	30.3	31.6	32.1	3	29.4	30.3	30.9	0.381E-03	0.334E-03
63	30.6	31.9	33.3	34.3	3	29.6	30.6	31.2	0.345E-03	0.319E-03
64	26.6	27.2	27.9	28.2	4	25.1	26.1	26.8	0.885E-03	0.942E-03
65	27.0	27.7	29.0	30.1	4	26.5	27.4	28.0	0.790E-03	0.615E-03
66	27.2	28.4	30.3	31.4	3	26.4	27.3	28.0	0.754E-03	0.663E-03
67	26.9	27.2	28.0	28.5	4	25.4	26.4	27.1	0.811E-03	0.886E-03
68	20.8	21.1	21.8	22.3	6	19.5	20.5	21.2	0.334E-02	0.335E-02
69	20.5	20.7	21.6	22.3	5	19.4	20.4	21.1	0.354E-02	0.337E-02
70	20.8	21.4	22.2	23.0	3	19.1	20.1	20.8	0.330E-02	0.388E-02

Table B-7. 4/8 Hybrid Homogeneous, 3 dB Edge, 30 dB Sidelobes

MAXIMUM POSSIBLE COCHANNEL INTERFERENCE						PROBABILITY STATISTICS; WORST CASE POINT				
CELL	PEAK	99%	95%	90%	NUMCOCH	99%	95%	90%	MEAN	SIGMA
1	31.9	32.8	33.6	34.5	3	30.3	31.3	32.0	0.261E-03	0.292E-03
2	31.2	31.4	31.7	32.1	3	30.4	31.3	31.9	0.304E-03	0.263E-03
3	30.2	30.6	31.3	31.8	3	29.4	30.4	31.0	0.380E-03	0.326E-03
4	25.4	26.2	27.0	27.6	4	24.1	25.1	25.8	0.114E-02	0.118E-02
5	32.3	33.1	33.8	34.6	2	30.4	31.5	32.2	0.237E-03	0.290E-03
6	25.6	26.3	27.2	27.7	3	24.2	25.2	25.9	0.111E-02	0.117E-02
7	30.7	30.9	31.4	32.0	3	30.2	31.1	31.7	0.339E-03	0.266E-03
8	30.1	30.3	31.3	32.0	4	29.3	30.2	30.8	0.393E-03	0.340E-03
9	25.4	26.2	27.0	27.6	4	24.1	25.1	25.8	0.114E-02	0.118E-02
10	29.0	29.7	31.0	31.8	4	28.4	29.3	29.9	0.501E-03	0.412E-03
11	25.6	26.3	27.2	27.7	3	24.2	25.2	25.9	0.111E-02	0.117E-02
12	29.5	30.3	31.1	31.5	4	28.7	29.7	30.3	0.451E-03	0.380E-03
13	29.1	29.4	30.4	30.9	5	28.8	29.6	30.2	0.494E-03	0.359E-03
14	28.8	29.6	30.5	30.8	5	28.3	29.2	29.8	0.528E-03	0.414E-03
15	29.0	29.8	31.3	32.1	5	28.5	29.4	30.0	0.503E-03	0.392E-03
16	29.2	29.8	31.3	31.6	4	28.6	29.5	30.1	0.476E-03	0.386E-03
17	28.0	28.9	30.0	30.4	5	28.0	28.8	29.4	0.629E-03	0.415E-03
18	30.8	31.1	31.7	32.0	4	29.9	30.8	31.4	0.335E-03	0.298E-03
19	28.6	29.1	30.1	30.5	6	28.5	29.4	29.9	0.553E-03	0.363E-03
20	28.8	29.8	31.4	32.0	6	28.3	29.2	29.8	0.531E-03	0.401E-03
21	28.0	28.8	29.7	30.1	6	27.9	28.7	29.3	0.633E-03	0.431E-03
22	28.0	28.9	29.9	30.4	5	28.0	28.8	29.3	0.634E-03	0.415E-03
23	28.7	29.2	30.0	30.7	6	28.5	29.4	29.9	0.545E-03	0.375E-03
24	28.6	29.3	30.8	31.3	6	28.4	29.3	29.8	0.558E-03	0.377E-03
25	28.5	29.4	30.8	31.7	6	28.1	29.0	29.6	0.564E-03	0.423E-03
26	27.9	28.7	29.7	30.1	7	27.8	28.7	29.2	0.645E-03	0.435E-03
27	28.6	29.5	30.1	30.8	7	28.3	29.2	29.7	0.554E-03	0.398E-03
28	28.0	28.8	29.7	30.2	7	28.0	28.9	29.4	0.630E-03	0.409E-03
29	28.6	29.3	30.8	31.3	6	28.4	29.3	29.8	0.558E-03	0.377E-03
30	28.6	29.5	31.3	31.9	6	28.3	29.2	29.7	0.552E-03	0.400E-03
31	28.6	29.5	30.3	30.8	5	28.3	29.2	29.7	0.556E-03	0.401E-03
32	28.2	28.7	29.3	29.7	8	28.1	28.9	29.5	0.611E-03	0.407E-03
33	27.9	28.7	29.8	30.5	7	27.9	28.8	29.3	0.643E-03	0.412E-03
34	28.8	29.7	31.6	32.0	6	28.5	29.4	30.0	0.522E-03	0.375E-03
35	28.3	29.0	30.2	31.2	7	28.1	29.0	29.5	0.591E-03	0.410E-03
36	28.8	29.5	31.1	31.8	6	28.3	29.2	29.8	0.532E-03	0.403E-03
37	28.5	29.3	30.2	30.7	7	28.2	29.1	29.7	0.563E-03	0.406E-03
38	28.5	29.3	29.9	30.6	6	28.1	29.0	29.6	0.566E-03	0.422E-03
39	28.7	29.5	30.8	31.6	6	28.2	29.1	29.7	0.539E-03	0.417E-03
40	29.7	29.9	31.0	31.9	6	29.2	30.1	30.7	0.428E-03	0.334E-03
41	28.5	29.3	30.3	31.2	7	28.3	29.2	29.7	0.571E-03	0.383E-03
42	28.9	29.3	30.1	30.5	6	28.6	29.5	30.0	0.511E-03	0.375E-03
43	25.5	25.7	26.5	27.5	7	24.5	25.5	26.1	0.114E-02	0.103E-02
44	28.9	29.4	30.3	30.7	5	28.4	29.3	29.9	0.512E-03	0.396E-03
45	29.5	29.8	31.0	31.7	5	28.8	29.7	30.3	0.450E-03	0.375E-03
46	28.7	29.4	30.9	31.3	5	28.4	29.3	29.8	0.539E-03	0.392E-03
47	29.8	30.2	30.7	31.0	6	29.6	30.5	31.0	0.424E-03	0.286E-03
→48	25.5	25.5	26.7	27.7	6	24.7	25.6	26.2	0.114E-02	0.979E-03
49	29.0	29.0	29.6	29.9	5	28.6	29.5	30.1	0.506E-03	0.371E-03
50	30.9	31.0	31.8	32.5	5	30.3	31.2	31.8	0.324E-03	0.266E-03
51	28.7	29.3	30.0	30.7	5	28.3	29.2	29.8	0.535E-03	0.400E-03
52	25.6	25.9	26.8	27.6	5	24.1	25.1	25.8	0.110E-02	0.121E-02
53	29.9	30.0	30.8	31.3	5	29.6	30.4	31.0	0.411E-03	0.299E-03
54	30.7	30.9	32.0	32.8	4	30.2	31.1	31.7	0.337E-03	0.266E-03
55	25.3	26.0	27.1	27.6	5	24.2	25.2	25.8	0.117E-02	0.113E-02
56	25.9	26.1	27.0	27.6	4	24.2	25.2	25.9	0.103E-02	0.121E-02
57	29.8	30.2	30.8	31.3	4	29.1	30.0	30.6	0.416E-03	0.352E-03
58	25.9	26.5	27.3	27.8	4	24.1	25.2	25.9	0.103E-02	0.121E-02
59	31.3	31.7	32.6	33.6	4	30.2	31.1	31.8	0.297E-03	0.286E-03
60	25.4	26.2	27.0	27.7	4	24.0	25.0	25.7	0.116E-02	0.122E-02
61	30.3	30.8	31.9	33.2	4	29.5	30.4	31.0	0.372E-03	0.323E-03
62	36.1	36.5	37.3	38.4	3	34.4	35.5	36.2	0.990E-04	0.112E-03
63	39.0	39.1	39.6	40.1	3	38.1	39.1	39.7	0.505E-04	0.443E-04
64	31.2	31.8	32.9	33.6	4	30.0	31.0	31.7	0.306E-03	0.293E-03
65	34.1	34.4	35.6	36.4	4	33.3	34.2	34.8	0.156E-03	0.135E-03
66	35.2	35.5	36.8	37.6	3	34.8	35.7	36.3	0.122E-03	0.896E-04
67	30.9	31.7	32.8	33.4	4	29.8	30.8	31.4	0.322E-03	0.308E-03
68	25.7	26.1	27.1	27.9	6	24.6	25.6	26.2	0.107E-02	0.103E-02
69	25.7	25.8	27.2	28.0	5	24.6	25.5	26.2	0.107E-02	0.104E-02
70	26.0	26.5	27.3	28.0	3	24.2	25.2	25.9	0.100E-02	0.121E-02



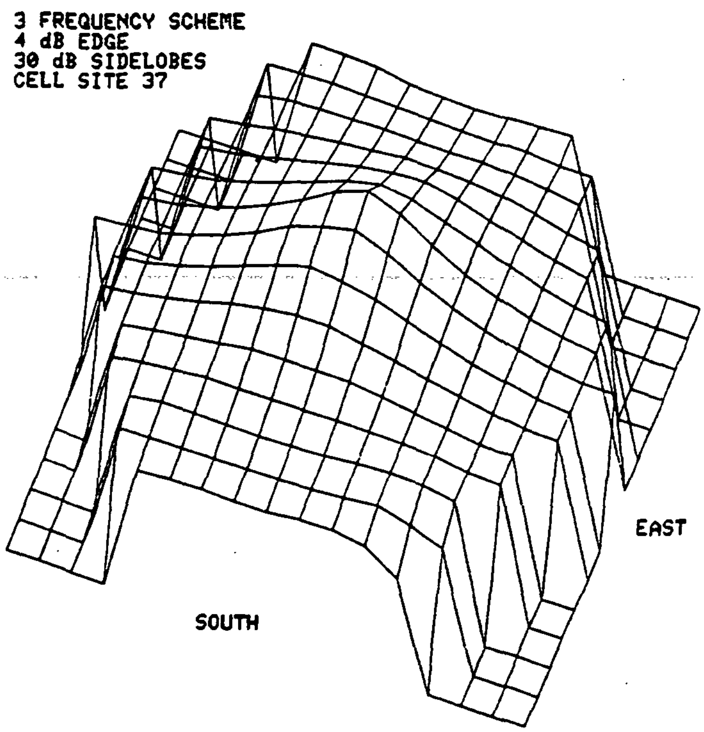


Figure B-2. Variation of C/I Across Cell 37

B.2.1.2 3/6 Hybrid Frequency Reuse Pattern

In the 3/6 hybrid scheme the entire available band is split into six sets. Four high population cell sites are each assigned two of the six sets resulting in the capacity of a 3 frequency scheme configuration for those cells. All other cells are assigned only one of the six frequency bands resulting in the cochannel interference properties of a 6 frequency scheme configuration.

Note that while there are 66 cell sites, the listing for the 3/6 hybrid scheme in Table B-5 lists data for 70 cell sites. The four additional cell sites, 67-70, implement the second band assigned to each of the four thickly populated cells (cells 6, 51, 55, and 65, respectively).

The average 99% worst point C/I is 20.54 dB as opposed to 17.07 dB experienced with the corresponding straight 3 frequency scheme. Thus we have essentially a 3 dB improvement in C/I for an approximately 3 dB reduction in capacity. The significant consideration remains, of course, that there is no reduction of capacity for cells with high population density.

C/I is relatively constant across the cell only rarely falling below 19 dB.

B.2.1.3. 4/8 Hybrid Frequency Reuse Pattern

The 4/8 hybrid scheme is similar to the 3/6 hybrid scheme except that the available frequencies are split up into eight bands instead of six. Again, four thickly populated cells are assigned two frequency bands and all other cell sites may use one band.

There are two distinct types of 8 frequency scheme assignments, homogeneous and inhomogeneous. Both were investigated. In all cases the homogeneous scheme averaged 0.5 dB better than the inhomogeneous scheme. For this reason, only the homogeneous scheme will be discussed further. However, the inhomogeneous arrangement may give better performance in different assumed population density distributions. An advantage of the inhomogeneous scheme is that it gives a certain degree of control over the distribution of cochannel interference across the country.

The results of COCELL for the 4/8 hybrid homogeneous frequency scheme with 25 dB sidelobes are listed in Table B-6. The average 99% worst point C/I is 24.36 dB as opposed to 20.54 dB for the 3/6 hybrid. This is nearly a 4 dB improvement in C/I in exchange for a 25% reduction in capacity.

The C/I across the cell site does not fall below 23.5 dB as compared with 19.1 dB for the 3/16 hybrid scheme and the C/I is relatively flat across the entire cell.

A sidelobe level 30 dB below the peak gain gives the results listed in Table B-7. Here the average 99% worst point C/I has increased to nearly 30 dB, the expected 5 dB improvement. The smallest C/I over the entire site is 28.5 dB as compared with 23.5 dB for 25 dB sidelobes. Again, we experience the maximum possible benefit from decreased sidelobes.

It should be noted that with all of the hybrid frequency schemes discussed above, main beam intrusion is no longer a problem. This is due to the greater spacing between cochannel cell sites. Since there is no main beam intrusion, tightening up the main beam by reducing the power at the cell edge from 3 dB down to 4 dB down will be of little consequence. Thus only 3 dB edge configurations were considered for hybrid schemes.

B.2.2 MOBILE TRANSMIT CASE

Cochannel interference in a cellular satellite based system for the case where the mobile station is transmitting and the satellite is receiving is analyzed for specific cellular configurations. Factors considered include voice controlled operation (VOX) and randomly distributed cochannel interferers.

In the mobile transmit case interference experienced is independent of the mobile station's position in the wanted signal cell. Consequently the C/I will be worst at the cell corner where signal strength (the C of C/I) is a minimum.

Further, the interference will be distributed in time if VOX is used and due to the fact that each cochannel interferer is equally likely to be at any given position in the cochannel cell within the sidelobes of the wanted signal cell antenna.

This analysis of cochannel interference assumes that the mobile station in the wanted signal cell is transmitting, the satellite is receiving and all cochannel mobile stations are transmitting. Further, the system is assumed to be operating at maximum capacity with every channel in each cell fully occupied. Since cochannel interference results when the interferer is received via a sidelobe of the wanted signal cell beam, the essentially random positions of the cochannel interferers within the sidelobe pattern of the wanted signal cell beam will cause the interference to be randomly distributed. For the mobile transmit case, interference is independent of the mobile position within the wanted signal cell. To obtain the worst case C/I we simply position the mobile station at the point of minimum signal -- the cell corner.

Analyses were made of the 3, 3/6 and 4/8 frequency schemes. The C/I statistics, given the mobile station is at the worst point in the cell (i.e., cell corner), were calculated. Figure B-3 plots the 90% level C/I of the cell corner averaged over all 66 cells for each of the three configurations. The 90% level C/I is the C/I which will be equaled or exceeded 90% of the time. From Figure B-3, it can be seen that for the lowest C/I configuration considered (3 frequency scheme, 25 dB sidelobes), the average 90% level C/I will be 18 dB in the cell corner. Note that this is 90% of the time at the worst point in the cell . Since 18 dB C/I 90% of the time is

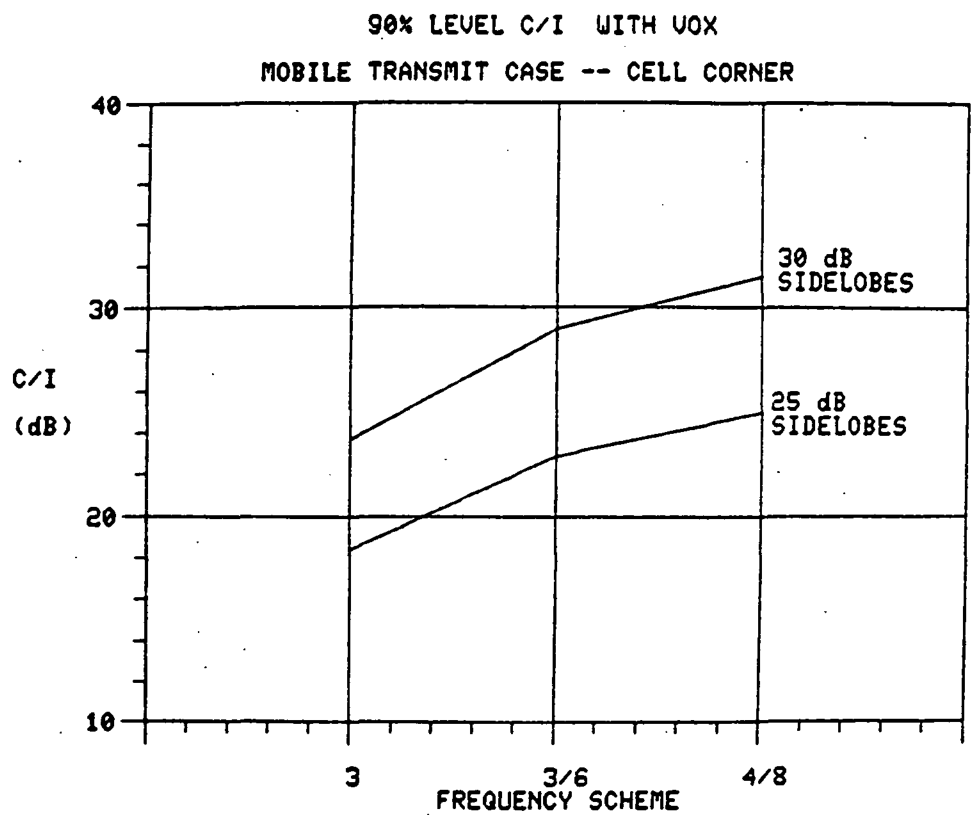


Figure B-3. Mobile Transmit Case - Cell Corner (90% Level C/I with VOX)

acceptable, the 3 frequency scheme will be usable provided sidelobes can be kept below 25 dB. The 3/6 or 4/8 hybrids schemes can be used to trade capacity for C/I. These systems provide up to 31 dB C/I in the cell corner under ideal conditions.

In the above statistics, it is assumed that VOX is used. If VOX is not used, 90% C/I is usually about 1.5 dB lower.

Tables B-8 through B-13 list the output of the program COCELL for the mobile transmit case for six system configurations. There are two sets of statistics for C/I, i.e., with and without VOX. The first column labeled "CELL" lists the cell site for which the statistics have been calculated. The next column under "NO VOX" labeled "PEAK" lists the C/I in dB for the peak interference case at the cell center. There is no way C/I may be poorer than this at the cell center. Since only signal strength (not interference) changes as the mobile station is moved away from the cell center, statistics for any other point in the cell are reduced from the listed C/I by the amount of signal has decreased. To obtain statistics for the cell corner for the 3/6 and 4/8 hybrid systems, C/I must be reduced by 4 dB. The 3 frequency scheme statistics must be reduced by 5.4 dB for the cell corner for the Hansen Function beam shape assumed in the analysis, as the 3 frequency scheme requires narrower beams to compensate for main beam intrusion into cochannel cells. As discussed elsewhere, through the use of sidelobe suppression for a specific antenna design, an antenna beam that drops off by 4 dB to the cell corner can be used which means the C/I values calculated for the 3 frequency scheme also drop by 4 dB at the cell corners. This means the C/I in that case degrades by 4 dB rather than the 5.4 dB assumed above.

The columns under the VOX heading have essentially identical descriptions, except that VOX is now taken into consideration.

The two statements at the bottom of the page indicate the average (in dB) of the 90% levels of C/I with and without VOX.

Figure B-3 shows the C/I for 25 dB and 30 dB sidelobe levels. These results were extrapolated to determine the sidelobe levels required for 18 dB C/I at the cell corner for each system. The 3 frequency scheme requires 25 dB sidelobes for 18 dB C/I without extrapolation. The 3/6 frequency scheme requires 22 dB sidelobes and the 4/8 hybrid scheme requires 20 dB sidelobes for 18 dB C/I assuming linear extrapolation.

The column labeled "99%" indicates the C/I which will be exceeded in the given cell 99% of the time. The 95% and 90% columns are similar to the 99% column. There are two columns labeled "MEAN." The first provides the mean C/I in dB, the second provides the mean I/C (not C/I), before conversion to dB. The final column in the section labeled "SIGMA" provides the standard deviation of I/C.

Table B-8. 3 Frequency, 25 dB Sidelobes, 4 dB Edge

MOBILE TRANSMIT CASE

CELL	NO VOX PEAK	NO VOX 99%	NO VOX 95%	NO VOX 90%	NO VOX MEAN(DB)	NO VOX MEAN(PWR)	NO VOX SIGMA	VOX PEAK	VOX 99%	VOX 95%	VOX 90%	VOX MEAN(DB)	VOX MEAN(PWR)	VOX SIGMA
1	21.41	22.32	23.13	23.63	25.09	0.246E-02	0.146E-02	21.41	23.45	24.58	25.34	30.07	0.984E-03	0.152E-02
2	19.83	21.13	21.85	22.31	24.44	0.359E-02	0.179E-02	19.83	22.00	23.12	23.86	28.42	0.144E-02	0.209E-02
3	19.81	21.35	22.10	22.56	24.71	0.338E-02	0.170E-02	19.81	22.26	23.38	24.12	28.69	0.135E-02	0.197E-02
4	19.86	21.45	22.20	22.67	24.87	0.326E-02	0.168E-02	19.86	22.39	23.51	24.25	28.85	0.130E-02	0.192E-02
5	18.71	20.49	21.20	21.64	23.62	0.434E-02	0.197E-02	18.71	21.26	22.37	23.10	27.60	0.174E-02	0.247E-02
6	19.79	21.35	22.10	22.56	24.71	0.336E-02	0.170E-02	19.79	22.26	23.36	24.12	28.69	0.135E-02	0.197E-02
7	19.76	21.22	21.96	22.42	24.57	0.349E-02	0.174E-02	19.76	22.12	23.24	23.98	28.55	0.140E-02	0.204E-02
8	18.63	20.31	21.01	21.44	23.39	0.458E-02	0.203E-02	18.63	21.05	22.16	22.89	27.37	0.183E-02	0.259E-02
9	17.03	19.29	19.94	20.33	22.06	0.623E-02	0.238E-02	17.03	19.82	20.92	21.64	26.04	0.249E-02	0.340E-02
10	19.74	21.21	21.96	22.42	24.56	0.350E-02	0.174E-02	19.74	22.11	23.23	23.97	28.53	0.140E-02	0.204E-02
11	19.62	21.17	21.91	22.36	24.46	0.358E-02	0.174E-02	19.62	22.03	23.15	23.89	28.44	0.143E-02	0.207E-02
12	18.53	20.57	21.27	21.69	23.62	0.435E-02	0.190E-02	18.53	21.29	22.39	23.13	27.60	0.174E-02	0.245E-02
13	17.03	19.21	19.85	20.24	21.95	0.636E-02	0.241E-02	17.03	19.72	20.62	21.55	25.93	0.255E-02	0.348E-02
14	16.97	19.16	19.80	20.18	21.87	0.650E-02	0.241E-02	16.97	19.65	20.75	21.47	25.85	0.260E-02	0.353E-02
15	18.50	20.56	21.26	21.68	23.61	0.436E-02	0.190E-02	18.50	21.28	22.39	23.12	27.59	0.174E-02	0.245E-02
16	18.48	20.30	20.97	21.40	23.29	0.468E-02	0.200E-02	18.48	20.98	22.09	22.82	27.27	0.187E-02	0.262E-02
17	18.43	20.39	21.03	21.49	23.37	0.460E-02	0.195E-02	18.43	21.07	22.17	22.90	27.35	0.184E-02	0.257E-02
18	16.87	19.26	19.89	20.27	21.94	0.640E-02	0.235E-02	16.87	19.73	20.83	21.55	25.92	0.256E-02	0.347E-02
19	18.44	20.50	21.19	21.61	23.49	0.447E-02	0.190E-02	18.44	21.18	22.29	23.02	27.47	0.179E-02	0.250E-02
20	16.52	20.42	21.12	21.53	23.45	0.452E-02	0.195E-02	16.52	21.12	22.23	22.96	27.43	0.161E-02	0.254E-02
21	18.40	20.35	21.01	21.43	23.31	0.467E-02	0.198E-02	18.40	21.00	22.11	22.84	27.29	0.187E-02	0.261E-02
22	16.85	19.16	19.79	20.16	21.82	0.658E-02	0.238E-02	16.85	19.62	20.71	21.43	25.80	0.263E-02	0.356E-02
23	16.88	19.29	19.92	20.30	21.97	0.635E-02	0.234E-02	16.88	19.76	20.86	21.58	25.95	0.254E-02	0.344E-02
24	18.39	20.55	21.24	21.65	23.54	0.443E-02	0.188E-02	18.39	21.23	22.33	23.06	27.52	0.177E-02	0.247E-02
25	18.47	20.51	21.20	21.62	23.54	0.442E-02	0.192E-02	18.47	21.22	22.32	23.05	27.52	0.177E-02	0.248E-02
26	18.42	20.61	21.30	21.72	23.63	0.433E-02	0.187E-02	18.42	21.31	22.42	23.15	27.61	0.173E-02	0.243E-02
27	16.84	19.26	19.89	20.27	21.93	0.641E-02	0.233E-02	16.84	19.73	20.63	21.55	25.91	0.256E-02	0.347E-02
28	17.46	19.64	20.49	20.66	22.63	0.546E-02	0.211E-02	17.46	20.39	21.49	22.21	26.61	0.218E-02	0.299E-02
29	18.48	20.63	21.32	21.74	23.66	0.431E-02	0.187E-02	18.48	21.33	22.44	23.17	27.64	0.172E-02	0.242E-02
30	18.46	20.51	21.20	21.62	23.54	0.443E-02	0.192E-02	18.46	21.22	22.32	23.05	27.52	0.177E-02	0.248E-02
31	16.80	19.17	19.79	20.17	21.81	0.659E-02	0.237E-02	16.80	19.61	20.71	21.43	25.79	0.264E-02	0.356E-02
32	16.86	19.30	19.95	20.31	21.98	0.633E-02	0.233E-02	16.86	19.77	20.87	21.59	25.96	0.253E-02	0.343E-02
33	17.48	20.03	20.68	21.08	22.83	0.521E-02	0.203E-02	17.48	20.59	21.69	22.41	26.81	0.208E-02	0.286E-02
34	19.68	21.69	22.43	22.89	25.02	0.315E-02	0.156E-02	19.68	22.58	23.70	24.44	29.00	0.126E-02	0.163E-02
35	19.55	21.17	21.90	22.34	24.41	0.362E-02	0.173E-02	19.55	22.01	23.12	23.86	28.39	0.145E-02	0.208E-02
36	18.50	20.42	21.11	21.53	23.45	0.452E-02	0.196E-02	18.50	21.12	22.23	22.96	27.42	0.181E-02	0.254E-02
37	16.83	19.19	19.82	20.20	21.85	0.653E-02	0.237E-02	16.83	19.65	20.75	21.47	25.83	0.261E-02	0.353E-02
38	16.86	19.31	19.95	20.33	22.01	0.630E-02	0.233E-02	16.86	19.80	20.89	21.62	25.99	0.252E-02	0.342E-02
39	18.40	20.62	21.31	21.73	23.64	0.432E-02	0.187E-02	18.40	21.32	22.43	23.16	27.62	0.173E-02	0.242E-02
40	19.67	21.65	22.40	22.66	25.02	0.315E-02	0.158E-02	19.67	22.56	23.68	24.42	29.00	0.126E-02	0.184E-02
41	19.64	21.67	22.41	22.87	25.00	0.317E-02	0.156E-02	19.64	22.56	23.67	24.41	28.97	0.127E-02	0.164E-02
42	17.55	19.76	20.43	20.63	22.59	0.551E-02	0.215E-02	17.55	20.34	21.44	22.17	26.57	0.220E-02	0.302E-02
43	16.93	19.20	19.83	20.21	21.90	0.645E-02	0.240E-02	16.93	19.69	20.79	21.51	25.88	0.258E-02	0.350E-02
44	16.89	19.17	19.81	20.19	21.86	0.651E-02	0.240E-02	16.89	19.65	20.75	21.47	25.84	0.260E-02	0.353E-02
45	18.59	20.73	21.42	21.83	23.74	0.423E-02	0.182E-02	18.59	21.42	22.53	23.26	27.72	0.169E-02	0.237E-02
46	19.50	21.06	21.78	22.22	24.25	0.376E-02	0.175E-02	19.50	21.86	22.98	23.71	28.23	0.150E-02	0.215E-02
47	17.55	19.62	20.27	20.66	22.40	0.575E-02	0.222E-02	17.55	20.16	21.26	21.98	26.38	0.230E-02	0.315E-02
48	17.37	19.65	20.29	20.67	22.38	0.578E-02	0.217E-02	17.37	20.15	21.25	21.98	26.36	0.231E-02	0.315E-02
49	16.47	20.42	21.11	21.53	23.44	0.453E-02	0.195E-02	16.47	21.12	22.23	22.96	27.42	0.181E-02	0.254E-02
50	19.57	21.09	21.82	22.26	24.33	0.369E-02	0.176E-02	19.57	21.92	23.04	23.78	28.31	0.148E-02	0.212E-02
51	18.40	20.36	21.05	21.47	23.35	0.462E-02	0.197E-02	18.40	21.04	22.15	22.88	27.33	0.185E-02	0.258E-02
52	17.68	19.61	20.27	20.67	22.45	0.569E-02	0.225E-02	17.68	20.19	21.29	22.02	26.42	0.228E-02	0.313E-02
53	17.63	19.76	20.42	20.81	22.59	0.551E-02	0.217E-02	17.63	20.33	21.43	22.16	26.57	0.221E-02	0.303E-02
54	21.12	24.11	24.85	25.31	27.45	0.180E-02	0.896E-03	21.12	25.01	26.12	26.86	31.43	0.719E-03	0.105E-02
55	16.59	20.52	21.23	21.66	23.63	0.433E-02	0.195E-02	16.59	21.28	22.39	23.12	27.61	0.173E-02	0.245E-02
56	17.63	19.92	20.59	21.00	22.81	0.523E-02	0.212E-02	17.63	20.54	21.64	22.37	26.79	0.209E-02	0.289E-02
57	18.69	20.91	21.64	22.08	24.14	0.385E-02	0.183E-02	18.69	21.74	22.85	23.59	28.12	0.154E-02	0.221E-02
58	19.81	21.74	22.51	22.98	25.23	0.300E-02	0.159E-02	19.81	22.72	23.84	24.59	29.21	0.120E-02	0.178E-02
59	19.71	21.39	22.13	22.59	24.74	0.336E-02	0.168E-02	19.71	22.29	23.41	24.15	28.72	0.134E-02	0.196E-02
60	19.63	21.65	22.40	22.85	25.00	0.316E-02	0.158E-02	19.63	22.55	23.67	24.41	28.98	0.127E-02	0.184E-02
61	19.76	21.90	22.66	23.13	25.34	0.292E-02	0.152E-02	19.76	22.85	23.97	24.71	29.32	0.117E-02	0.172E-02
62	24.06	24.93	25.66	26.44	29.53	0.111E-02	0.901E-03	24.06	26.41	27.59	28.37	33.51	0.445E-03	0.789E-03
63	29.37	31.80	32.61	33.10	35.51	0.281E-03	0.163E-03	29.37	32.90	34.03	34.78	39.49	0.112E-03	0.172E-03
64	24.05	24.32	25.23	25.81	28.82	0.131E-02	0.102E-02	24.05	25.77	26.93	27.71	32.80	0.524E-03	0.913E-03
65	21.53	22.63	23.46	23.93	26.53	0.223E-02	0.139E-02	21.53	23.82	24.96	25.72	30.51	0.890E-03	0.140E-02
66	19.93	21.95	22.73	23.22	25.52	0.280E-02	0.154E-02	19.93	22.98	24.10	24.85	29.50	0.112E-02	0.168E-02

90% AVERAGE, NO VOX=21.9508   90% AVERAGE WITH VOX=23.4208

Table B-9. 3 Frequency, 30 dB Sidelobes, 4 dB Edge

MOBILE TRANSMIT CASE

CELL	NO VOX PEAK	NO VOX 99%	NO VOX 95%	NO VOX 90%	NO VOX MEAN(DB)	NO VOX MEAN(PWR)	NO VOX SIGMA	VOX PEAK	VOX 99%	VOX 95%	VOX 90%	VOX MEAN(DB)	VOX MEAN(PWR)	VOX SIGMA
1	26.63	27.52	28.34	28.85	31.36	0.731E-03	0.447E-03	26.63	28.68	29.82	30.57	35.34	0.292E-03	0.456E-03
2	24.93	26.30	27.05	27.51	29.69	0.108E-02	0.545E-03	24.93	27.22	28.34	29.06	33.67	0.430E-03	0.630E-03
3	24.69	26.51	27.26	27.74	29.96	0.101E-02	0.524E-03	24.89	27.47	28.59	29.33	33.94	0.404E-03	0.596E-03
4	24.95	26.61	27.38	27.86	30.14	0.969E-03	0.521E-03	24.95	27.61	28.73	29.48	34.12	0.388E-03	0.578E-03
5	23.78	25.67	26.39	26.83	28.88	0.130E-02	0.607E-03	23.78	26.48	27.60	28.33	32.86	0.518E-03	0.742E-03
6	24.89	26.52	27.28	27.74	29.96	0.101E-02	0.524E-03	24.89	27.47	28.59	29.33	33.94	0.404E-03	0.596E-03
7	24.89	26.40	27.16	27.62	29.82	0.104E-02	0.537E-03	24.89	27.34	28.46	29.20	33.80	0.417E-03	0.613E-03
8	23.73	25.49	26.20	26.63	28.62	0.137E-02	0.624E-03	23.73	26.26	27.37	28.11	32.60	0.549E-03	0.780E-03
9	22.09	24.48	25.14	25.54	27.32	0.185E-02	0.733E-03	22.09	25.06	26.16	26.89	31.30	0.741E-03	0.102E-02
10	24.69	26.41	27.17	27.63	29.63	0.104E-02	0.536E-03	24.89	27.35	28.47	29.21	33.81	0.416E-03	0.612E-03
11	24.83	26.37	27.13	27.59	29.76	0.106E-02	0.536E-03	24.83	27.29	28.41	29.15	33.74	0.423E-03	0.619E-03
12	23.59	25.76	26.48	26.91	28.92	0.128E-02	0.588E-03	23.59	26.55	27.66	28.39	32.90	0.513E-03	0.730E-03
13	22.09	24.38	25.04	25.43	27.19	0.191E-02	0.746E-03	22.09	24.94	26.04	26.77	31.17	0.764E-03	0.105E-02
14	22.03	24.34	24.99	25.38	27.12	0.194E-02	0.745E-03	22.03	24.88	25.98	26.70	31.10	0.777E-03	0.106E-02
15	23.59	25.75	26.47	26.90	28.90	0.129E-02	0.589E-03	23.59	26.53	27.64	28.38	32.88	0.515E-03	0.733E-03
16	23.59	25.49	26.19	26.61	28.56	0.139E-02	0.615E-03	23.59	26.22	27.33	28.06	32.54	0.557E-03	0.765E-03
17	23.54	25.60	26.30	26.73	26.67	0.136E-02	0.600E-03	23.54	26.33	27.44	28.17	32.65	0.543E-03	0.766E-03
18	21.93	24.45	25.09	25.48	27.21	0.190E-02	0.727E-03	21.93	24.98	26.08	26.80	31.19	0.760E-03	0.104E-02
19	23.50	25.70	26.40	26.83	28.79	0.132E-02	0.589E-03	23.50	26.45	27.56	28.29	32.77	0.528E-03	0.746E-03
20	23.59	25.61	26.32	26.75	28.73	0.134E-02	0.605E-03	23.59	26.37	27.49	28.22	32.71	0.535E-03	0.759E-03
21	23.55	25.52	26.23	26.65	28.60	0.138E-02	0.611E-03	23.55	26.26	27.37	28.10	32.58	0.552E-03	0.778E-03
22	21.91	24.36	25.00	25.38	27.09	0.195E-02	0.736E-03	21.91	24.87	25.97	26.69	31.07	0.781E-03	0.106E-02
23	21.93	24.49	25.14	25.53	27.26	0.188E-02	0.721E-03	21.93	25.02	26.12	26.85	31.24	0.752E-03	0.103E-02
24	23.47	25.77	26.46	26.91	26.67	0.130E-02	0.579E-03	23.47	26.52	27.63	28.37	32.85	0.518E-03	0.733E-03
25	23.60	25.67	26.38	26.82	28.81	0.132E-02	0.598E-03	23.60	26.44	27.56	28.29	32.79	0.526E-03	0.747E-03
26	23.55	25.79	26.51	26.94	28.94	0.128E-02	0.583E-03	23.55	26.57	27.68	28.42	32.92	0.511E-03	0.726E-03
27	21.91	24.46	25.11	25.50	27.23	0.189E-02	0.725E-03	21.91	25.03	26.09	26.82	31.21	0.757E-03	0.103E-02
28	22.60	25.03	25.70	26.10	27.92	0.161E-02	0.656E-03	22.60	25.65	26.75	27.48	31.90	0.645E-03	0.893E-03
29	23.55	25.82	26.53	26.97	28.98	0.127E-02	0.581E-03	23.55	26.60	27.72	28.45	32.96	0.506E-03	0.721E-03
30	23.58	25.68	26.40	26.83	28.82	0.131E-02	0.596E-03	23.58	26.46	27.57	28.30	32.80	0.525E-03	0.745E-03
31	21.90	24.37	25.01	25.39	27.11	0.195E-02	0.736E-03	21.90	24.68	25.98	26.70	31.09	0.778E-03	0.106E-02
32	21.93	24.49	25.14	25.53	27.27	0.187E-02	0.721E-03	21.93	25.03	26.13	26.86	31.25	0.750E-03	0.103E-02
33	22.59	25.20	25.87	26.28	28.12	0.154E-02	0.634E-03	22.59	25.83	26.94	27.67	32.10	0.617E-03	0.855E-03
34	24.71	26.91	27.68	28.15	33.40	0.913E-03	0.483E-03	24.71	27.89	29.01	29.76	34.38	0.365E-03	0.541E-03
35	23.37	26.25	27.00	27.46	29.64	0.109E-02	0.552E-03	23.37	27.17	28.29	29.03	33.62	0.435E-03	0.637E-03
36	22.52	25.51	26.22	26.66	28.67	0.136E-02	0.624E-03	22.52	26.29	27.41	28.14	32.65	0.544E-03	0.774E-03
37	21.15	24.34	24.99	25.38	27.12	0.194E-02	0.747E-03	21.15	24.88	25.98	26.70	31.10	0.777E-03	0.106E-02
38	21.18	24.46	25.11	25.51	27.27	0.167E-02	0.734E-03	21.18	25.02	26.12	26.85	31.25	0.749E-03	0.103E-02
39	23.55	25.80	26.51	26.94	28.93	0.128E-02	0.581E-03	23.55	26.57	27.68	28.41	32.91	0.512E-03	0.726E-03
40	21.66	26.41	27.23	27.74	30.23	0.949E-03	0.574E-03	21.66	27.56	28.70	29.45	34.21	0.380E-03	0.590E-03
41	24.71	26.87	27.64	28.11	30.33	0.926E-03	0.484E-03	24.71	27.84	28.96	29.70	34.31	0.371E-03	0.547E-03
42	21.74	24.93	25.61	26.02	27.86	0.164E-02	0.678E-03	21.74	25.57	26.68	27.41	31.84	0.654E-03	0.908E-03
43	20.57	24.30	24.96	25.36	27.13	0.194E-02	0.763E-03	20.57	24.88	25.98	26.70	31.11	0.774E-03	0.106E-02
44	20.54	24.27	24.92	25.31	27.07	0.196E-02	0.764E-03	20.54	24.82	25.92	26.65	31.05	0.766E-03	0.106E-02
45	21.74	25.76	26.46	26.92	26.96	0.127E-02	0.595E-03	21.74	26.57	27.68	28.42	32.94	0.509E-03	0.728E-03
46	23.33	26.15	26.89	27.35	29.48	0.113E-02	0.557E-03	23.33	27.04	28.16	28.89	33.46	0.451E-03	0.655E-03
47	21.75	24.75	25.42	25.82	27.63	0.172E-02	0.697E-03	21.75	25.36	26.46	27.19	31.61	0.690E-03	0.953E-03
48	21.61	24.79	25.46	25.86	27.65	0.172E-02	0.685E-03	21.61	25.38	26.49	27.21	31.63	0.688E-03	0.947E-03
49	23.58	25.63	26.33	26.76	28.72	0.134E-02	0.599E-03	23.58	26.37	27.48	28.22	32.70	0.537E-03	0.759E-03
50	21.63	25.94	26.73	27.22	29.54	0.111E-02	0.615E-03	21.63	26.98	28.11	28.86	33.52	0.444E-03	0.669E-03
51	23.53	25.56	26.27	26.69	28.64	0.137E-02	0.605E-03	23.53	26.30	27.41	28.14	32.62	0.547E-03	0.771E-03
52	22.74	24.82	25.49	25.69	27.70	0.170E-02	0.666E-03	22.74	25.43	26.53	27.26	31.68	0.680E-03	0.939E-03
53	22.70	24.98	25.65	26.06	27.88	0.163E-02	0.666E-03	22.70	25.60	26.71	27.43	31.86	0.651E-03	0.902E-03
54	26.15	29.48	30.28	30.77	33.17	0.482E-03	0.277E-03	26.15	30.57	31.70	32.45	37.15	0.193E-03	0.294E-03
55	23.73	25.70	26.42	26.86	28.89	0.129E-02	0.602E-03	23.73	26.51	27.62	28.36	32.87	0.516E-03	0.738E-03
56	21.77	25.04	25.73	26.15	28.05	0.157E-02	0.674E-03	21.77	25.73	26.84	27.57	32.03	0.626E-03	0.878E-03
57	23.78	26.09	26.84	27.29	29.45	0.114E-02	0.569E-03	23.78	26.99	28.11	28.85	33.43	0.454E-03	0.663E-03
58	24.93	26.92	27.71	26.20	30.54	0.662E-03	0.493E-03	24.93	27.97	29.10	29.85	34.52	0.353E-03	0.533E-03
59	24.81	26.58	27.34	27.81	30.01	0.997E-03	0.516E-03	24.81	27.53	28.65	29.39	33.99	0.399E-03	0.587E-03
60	24.72	26.88	27.64	28.12	30.35	0.922E-03	0.485E-03	24.72	27.85	28.97	29.71	34.33	0.369E-03	0.546E-03
61	23.48	26.93	27.72	28.21	30.59	0.874E-03	0.496E-03	23.48	28.00	29.13	29.88	34.57	0.349E-03	0.531E-03
62	29.25	30.05	31.01	31.61	34.87	0.326E-03	0.284E-03	29.25	31.61	32.79	33.58	38.85	0.130E-03	0.240E-03
63	35.35	38.51	39.40	39.96	42.82	0.523E-04	0.380E-04	35.35	39.88	41.04	41.81	46.80	0.209E-04	0.351E-04
64	29.29	29.59	30.52	31.11	34.21	0.379E-03	0.309E-03	29.29	31.08	32.25	33.04	38.19	0.152E-03	0.270E-03
65	26.68	27.82	28.66	29.19	31.63	0.657E-03	0.426E-03	26.68	29.06	30.20	30.96	35.80	0.263E-03	0.420E-03
66	25.01	27.09	27.89	28.39	30.81	0.830E-03	0.483E-03	25.01	28.19	29.32	30.07	34.79	0.332E-03	0.509E-03

90% AVERAGE, NO VOX=27.19DB

90% AVERAGE WITH VOX=28.69DB

Table B-10. 3/6 Hybrid, 25 dB Sidelobes, 3 dB Edge

CELL	NO VOX PEAK	NO VOX 99%	NO VOX 95%	NO VOX 90%	NO VOX MEAN(DB)	NO VOX MEAN(PWR)	NO VOX SIGMA	VOX PEAK	VOX 99%	VOX 95%	VOX 90%	VOX MEAN(DB)	VOX MEAN(PWR)	VOX SIGMA
1	26.52	27.30	28.23	28.68	33.77	0.837E-03	0.404E-03	26.52	28.35	29.47	30.21	34.75	0.335E-03	0.483E-03
2	28.52	29.23	30.04	30.55	32.99	0.503E-03	0.296E-03	28.52	30.35	31.49	32.24	36.97	0.201E-03	0.309E-03
3	23.77	24.03	24.93	25.49	28.38	0.145E-02	0.107E-02	23.77	25.42	26.58	27.36	32.36	0.580E-03	0.982E-03
4	26.58	27.50	28.23	28.68	33.76	0.839E-03	0.404E-03	26.58	28.35	29.46	30.20	34.74	0.336E-03	0.484E-03
5	23.36	23.93	24.81	25.36	28.15	0.153E-02	0.108E-02	23.36	25.26	26.42	27.19	32.13	0.613E-03	0.101E-02
6	23.35	23.32	24.15	24.66	27.21	0.190E-02	0.118E-02	23.35	24.50	25.64	26.40	31.19	0.761E-03	0.120E-02
7	23.35	23.84	24.69	25.23	27.91	0.162E-02	0.108E-02	23.35	25.11	26.26	27.02	31.89	0.648E-03	0.105E-02
8	23.77	24.03	24.93	25.49	28.38	0.145E-02	0.107E-02	23.77	25.42	26.58	27.36	32.36	0.580E-03	0.982E-03
9	20.70	21.63	22.38	22.84	25.00	0.316E-02	0.159E-02	20.70	22.54	23.66	24.40	28.98	0.126E-02	0.185E-02
10	23.36	23.93	24.81	25.36	28.15	0.153E-02	0.108E-02	23.36	25.26	26.42	27.19	32.13	0.613E-03	0.101E-02
11	27.18	27.79	28.54	29.00	31.15	0.768E-03	0.384E-03	27.18	28.70	29.82	30.55	35.13	0.307E-03	0.448E-03
12	22.86	24.12	24.91	25.40	27.76	0.168E-02	0.942E-03	22.86	25.18	26.31	27.06	31.74	0.671E-03	0.101E-02
13	22.52	24.00	24.77	25.25	27.53	0.176E-02	0.952E-03	22.52	25.00	26.13	26.87	31.51	0.706E-03	0.105E-02
14	20.75	22.66	23.44	23.92	26.21	0.239E-02	0.130E-02	20.75	23.67	24.80	25.54	30.19	0.958E-03	0.143E-02
15	22.79	24.35	25.16	25.67	28.12	0.154E-02	0.916E-03	22.79	25.48	26.61	27.37	32.10	0.616E-03	0.951E-03
16	22.98	23.76	24.61	25.13	27.74	0.168E-02	0.108E-02	22.98	24.99	26.13	26.89	31.72	0.673E-03	0.107E-02
17	22.52	24.03	24.81	25.29	27.59	0.174E-02	0.948E-03	22.52	25.05	26.18	26.92	31.57	0.697E-03	0.104E-02
18	22.06	23.11	23.87	24.33	26.51	0.223E-02	0.114E-02	22.06	24.04	25.16	25.90	30.49	0.893E-03	0.131E-02
19	22.75	24.10	24.89	25.37	27.70	0.170E-02	0.942E-03	22.75	25.14	26.27	27.01	31.68	0.679E-03	0.102E-02
20	22.42	22.91	23.68	24.16	26.40	0.229E-02	0.121E-02	22.42	23.89	25.02	25.76	30.38	0.916E-03	0.136E-02
21	22.20	23.87	24.63	25.09	27.27	0.188E-02	0.953E-03	22.20	24.80	25.92	26.66	31.25	0.751E-03	0.110E-02
22	22.13	23.83	24.58	25.04	27.19	0.191E-02	0.955E-03	22.13	24.74	25.85	26.59	31.17	0.764E-03	0.111E-02
23	20.44	21.74	22.46	22.90	24.91	0.323E-02	0.149E-02	20.44	22.54	23.65	24.38	28.89	0.129E-02	0.184E-02
24	22.63	24.05	24.83	25.31	27.60	0.174E-02	0.943E-03	22.63	25.06	26.19	26.93	31.58	0.695E-03	0.104E-02
25	22.83	23.69	24.52	25.03	27.57	0.175E-02	0.108E-02	22.83	24.87	26.01	26.76	31.54	0.701E-03	0.110E-02
26	22.33	23.37	24.16	24.64	26.98	0.201E-02	0.111E-02	22.33	24.41	25.54	26.29	30.96	0.803E-03	0.121E-02
27	20.39	22.09	22.82	23.27	25.36	0.291E-02	0.141E-02	20.39	22.94	24.06	24.80	29.34	0.116E-02	0.168E-02
28	22.48	23.40	24.19	24.68	27.03	0.198E-02	0.111E-02	22.48	24.46	25.58	26.33	31.01	0.793E-03	0.120E-02
29	22.61	23.98	24.75	25.22	27.46	0.180E-02	0.946E-03	22.61	24.95	26.08	26.82	31.44	0.718E-03	0.106E-02
30	22.38	23.41	24.20	24.68	27.02	0.198E-02	0.111E-02	22.38	24.46	25.58	26.33	31.00	0.794E-03	0.120E-02
31	22.59	23.46	24.26	24.75	27.14	0.193E-02	0.111E-02	22.59	24.54	25.67	26.42	31.11	0.774E-03	0.118E-02
32	20.39	22.11	22.84	23.29	25.39	0.289E-02	0.140E-02	20.39	22.97	24.09	24.82	29.37	0.116E-02	0.167E-02
33	22.50	23.47	24.27	24.76	27.16	0.192E-02	0.111E-02	22.50	24.56	25.69	26.44	31.14	0.769E-03	0.117E-02
34	23.00	24.39	25.20	25.70	28.16	0.153E-02	0.908E-03	23.00	25.52	26.65	27.40	32.14	0.611E-03	0.943E-03
35	23.70	24.14	25.03	25.59	28.49	0.142E-02	0.105E-02	23.70	25.52	26.69	27.46	32.47	0.566E-03	0.960E-03
36	22.38	23.34	24.11	24.59	26.88	0.205E-02	0.111E-02	22.38	24.34	25.47	26.22	30.86	0.821E-03	0.123E-02
37	20.77	21.94	22.71	23.18	25.42	0.287E-02	0.151E-02	20.77	22.92	24.04	24.78	29.40	0.115E-02	0.170E-02
38	20.31	22.12	22.85	23.30	25.39	0.289E-02	0.139E-02	20.31	22.97	24.09	24.82	29.36	0.116E-02	0.167E-02
39	22.41	23.52	24.32	24.82	27.22	0.190E-02	0.109E-02	22.41	24.61	25.74	26.49	31.20	0.759E-03	0.116E-02
40	23.20	24.68	25.51	26.03	28.58	0.139E-02	0.867E-03	23.20	25.87	27.01	27.77	32.56	0.555E-03	0.873E-03
41	22.98	23.77	24.61	25.13	27.73	0.169E-02	0.108E-02	22.98	24.99	26.13	26.89	31.71	0.675E-03	0.107E-02
42	20.03	21.66	22.43	22.90	25.11	0.308E-02	0.160E-02	20.03	22.62	23.74	24.48	29.09	0.123E-02	0.182E-02
43	20.68	21.89	22.65	23.12	25.32	0.294E-02	0.151E-02	20.68	22.84	23.96	24.70	29.30	0.118E-02	0.173E-02
44	22.24	23.13	23.89	24.36	26.56	0.221E-02	0.114E-02	22.24	24.08	25.20	25.94	30.54	0.883E-03	0.130E-02
45	22.90	23.72	24.56	25.08	27.65	0.172E-02	0.108E-02	22.90	24.93	26.07	26.83	31.63	0.687E-03	0.109E-02
46	20.96	22.07	22.86	23.35	25.68	0.270E-02	0.150E-02	20.96	23.12	24.24	24.99	29.66	0.108E-02	0.163E-02
47	18.21	21.65	22.22	22.70	24.94	0.320E-02	0.170E-02	18.21	22.43	23.56	24.30	28.92	0.128E-02	0.190E-02
48	19.40	20.91	21.64	22.08	24.15	0.385E-02	0.183E-02	19.40	21.74	22.86	23.59	28.12	0.154E-02	0.221E-02
49	22.35	23.27	24.05	24.53	26.83	0.208E-02	0.113E-02	22.35	24.28	25.41	26.16	30.80	0.831E-03	0.124E-02
50	22.73	23.58	24.39	24.89	27.31	0.186E-02	0.108E-02	22.73	24.69	25.82	26.57	31.29	0.744E-03	0.114E-02
51	19.98	21.65	22.41	22.87	25.08	0.310E-02	0.161E-02	19.98	22.60	23.72	24.46	29.06	0.124E-02	0.183E-02
52	25.06	26.65	27.30	27.69	29.43	0.114E-02	0.439E-03	25.06	27.19	28.29	29.01	33.41	0.456E-03	0.624E-03
53	20.53	21.92	22.67	23.13	25.30	0.295E-02	0.149E-02	20.53	22.84	23.96	24.70	29.28	0.118E-02	0.173E-02
54	27.91	29.80	30.52	30.96	32.96	0.506E-03	0.232E-03	27.91	30.59	31.70	32.44	36.94	0.202E-03	0.288E-03
55	19.85	21.34	22.12	22.60	24.87	0.326E-02	0.175E-02	19.85	22.34	23.47	24.21	28.85	0.130E-02	0.194E-02
56	22.85	23.96	24.77	25.29	27.86	0.164E-02	0.103E-02	22.85	25.14	26.28	27.04	31.84	0.654E-03	0.103E-02
57	23.06	23.36	24.18	24.70	27.21	0.190E-02	0.116E-02	23.06	24.53	25.66	26.42	31.19	0.761E-03	0.119E-02
58	21.98	23.22	24.06	24.58	27.17	0.192E-02	0.122E-02	21.98	24.43	25.58	26.33	31.14	0.768E-03	0.122E-02
59	21.62	22.11	22.94	23.45	25.94	0.254E-02	0.155E-02	21.62	23.27	24.41	25.16	29.92	0.102E-02	0.158E-02
60	22.85	23.12	23.94	24.44	26.89	0.205E-02	0.121E-02	22.85	24.25	25.38	26.14	30.87	0.819E-03	0.126E-02
61	23.96	24.41	25.32	25.89	28.86	0.130E-02	0.995E-03	23.96	25.84	27.01	27.78	32.84	0.520E-03	0.895E-03
62	25.70	28.01	28.72	29.15	31.11	0.775E-03	0.345E-03	25.70	28.76	29.87	30.60	35.09	0.310E-03	0.438E-03
63	33.39	33.39	34.19	34.68	37.05	0.197E-03	0.112E-03	33.39	34.46	35.59	36.34	41.03	0.790E-04	0.120E-03
64	23.63	24.48	25.37	25.92	28.77	0.133E-02	0.959E-03	23.63	25.84	27.00	27.77	32.75	0.531E-03	0.890E-03
65	24.43	24.72	25.69	26.31	29.68	0.108E-02	0.986E-03	24.43	26.32	27.51	28.31	33.66	0.431E-03	0.817E-03
66	22.73	24.19	25.02	25.54	28.12	0.154E-02	0.974E-03	22.73	25.39	26.53	27.29	32.09	0.617E-03	0.975E-03
67	23.60	24.44	25.32	25.87	28.66	0.136E-02	0.960E-03	23.60	25.78	26.93	27.70	32.64	0.544E-03	0.902E-03
68	20.02	21.34	22.30	22.77	24.97	0.319E-02	0.164E-02	20.02	22.48	23.61	24.35	28.95	0.127E-02	0.188E-02
69	17.65	20.67	21.42	21.88	24.04	0.395E-02	0.198E-02	17.65	21.58	22.70	23.44	28.02	0.158E-02	0.230E-02
70	30.52	30.20	31.10	31.66	34.55	0.351E-03	0.259E-03	30.52	31.59	32.75	33.53	38.53	0.140E-03	0.237E-03

90% AVERAGE, NO VOX=25.2200

90% AVERAGE WITH VOX=26.8800

Table B-11. 3/6 Hybrid, 30 dB Sidelobes, 3 dB Edge

CELL	PEAK	99%	95%	90%	MEAN(DB)	MEAN(PWR)	SIGMA	PEAK	99%	95%	90%	MEAN(DB)	MEAN(PWR)	SIGMA
1	32.11	32.73	33.48	34.18	36.22	0.239E-03	0.119E-03	32.15	33.80	34.92	35.65	40.19	0.956E-04	0.158E-03
2	34.71	34.71	35.53	36.04	38.51	0.141E-03	0.844E-04	34.71	35.85	36.99	37.74	42.49	0.563E-04	0.673E-04
3	28.81	29.16	30.06	30.65	33.58	0.439E-03	0.330E-03	28.81	30.59	31.75	32.53	37.56	0.175E-03	0.300E-03
4	32.13	32.94	33.67	34.12	36.20	0.240E-03	0.115E-03	32.13	33.79	34.90	35.64	40.18	0.960E-04	0.138E-03
5	28.64	29.10	29.98	30.54	33.38	0.459E-03	0.331E-03	28.64	30.46	31.61	32.38	37.36	0.184E-03	0.308E-03
6	23.38	27.06	28.04	28.67	32.14	0.611E-03	0.583E-03	23.08	28.69	29.89	30.69	36.12	0.244E-03	0.475E-03
7	28.38	29.04	29.92	30.47	33.24	0.474E-03	0.331E-03	28.38	30.37	31.52	32.29	37.22	0.190E-03	0.313E-03
8	28.81	29.18	30.08	30.65	33.58	0.439E-03	0.330E-03	28.81	30.59	31.75	32.53	37.56	0.175E-03	0.300E-03
9	22.16	25.91	26.76	27.30	29.98	0.101E-02	0.669E-03	22.16	27.18	28.32	29.09	33.96	0.402E-03	0.650E-03
10	28.64	29.10	29.98	30.54	33.36	0.459E-03	0.331E-03	26.64	30.46	31.61	32.38	37.36	0.184E-03	0.308E-03
11	32.37	33.35	34.13	34.61	36.91	0.204E-03	0.111E-03	32.37	34.37	35.49	36.24	40.89	0.815E-04	0.122E-03
12	27.84	29.25	30.07	30.57	33.04	0.497E-03	0.297E-03	27.84	30.39	31.52	32.28	37.02	0.199E-03	0.307E-03
13	27.72	29.15	29.96	30.45	32.85	0.519E-03	0.299E-03	27.72	30.24	31.37	32.12	36.83	0.208E-03	0.317E-03
14	26.03	27.76	28.56	29.05	31.44	0.718E-03	0.411E-03	26.03	28.84	29.97	30.72	35.42	0.287E-03	0.437E-03
15	28.31	29.52	30.37	30.90	33.54	0.443E-03	0.289E-03	28.31	30.77	31.91	32.67	37.52	0.177E-03	0.284E-03
16	28.24	29.00	29.87	30.41	33.13	0.487E-03	0.331E-03	28.24	30.30	31.45	32.21	37.11	0.195E-03	0.317E-03
17	27.72	29.21	30.01	30.51	32.94	0.506E-03	0.297E-03	27.72	30.32	31.45	32.20	36.92	0.203E-03	0.312E-03
18	27.27	28.33	29.10	29.57	31.82	0.658E-03	0.348E-03	27.27	29.31	30.43	31.18	35.80	0.263E-03	0.390E-03
19	27.84	29.25	30.06	30.56	33.02	0.499E-03	0.296E-03	27.84	30.38	31.51	32.26	37.00	0.200E-03	0.308E-03
20	22.84	26.82	27.75	28.34	31.47	0.712E-03	0.587E-03	22.84	28.32	29.49	30.28	35.45	0.285E-03	0.510E-03
21	27.46	29.11	29.90	30.38	32.72	0.535E-03	0.297E-03	27.46	30.15	31.28	32.03	36.70	0.214E-03	0.323E-03
22	27.49	29.04	29.82	30.30	32.59	0.551E-03	0.299E-03	27.49	30.05	31.18	31.92	36.57	0.220E-03	0.329E-03
23	22.03	25.99	26.83	27.36	29.97	0.101E-02	0.649E-03	22.03	27.22	28.36	29.12	33.95	0.403E-03	0.642E-03
24	27.73	29.23	30.04	30.55	32.99	0.502E-03	0.296E-03	27.73	30.35	31.49	32.24	36.97	0.201E-03	0.309E-03
25	28.11	28.94	29.79	30.32	32.97	0.505E-03	0.332E-03	28.11	30.19	31.34	32.10	36.95	0.202E-03	0.324E-03
26	27.60	28.62	29.43	29.93	32.35	0.581E-03	0.340E-03	27.60	29.73	30.86	31.62	36.33	0.233E-03	0.357E-03
27	25.62	27.24	27.99	28.46	33.62	0.866E-03	0.438E-03	25.62	28.16	29.28	30.02	34.60	0.347E-03	0.507E-03
28	27.68	28.65	29.47	29.97	32.43	0.572E-03	0.340E-03	27.68	29.78	30.92	31.67	36.41	0.229E-03	0.353E-03
29	27.65	29.16	29.96	30.46	32.84	0.520E-03	0.297E-03	27.65	30.24	31.38	32.13	36.82	0.208E-03	0.316E-03
30	27.68	28.66	29.47	29.98	32.42	0.573E-03	0.338E-03	27.68	29.78	30.92	31.67	36.40	0.229E-03	0.353E-03
31	27.72	28.71	29.53	30.04	32.53	0.559E-03	0.336E-03	27.72	29.86	31.00	31.75	36.51	0.223E-03	0.347E-03
32	25.55	27.32	28.08	28.55	30.76	0.839E-03	0.436E-03	25.55	28.27	29.39	30.13	34.74	0.336E-03	0.495E-03
33	27.79	28.71	29.53	30.04	32.53	0.558E-03	0.338E-03	27.79	29.86	31.00	31.76	36.51	0.223E-03	0.347E-03
34	28.16	29.61	30.46	31.00	33.70	0.427E-03	0.287E-03	28.16	30.88	32.03	32.80	37.68	0.171E-03	0.277E-03
35	29.00	29.34	30.25	30.84	33.86	0.411E-03	0.323E-03	29.00	30.79	31.96	32.74	37.84	0.164E-03	0.287E-03
36	27.59	28.58	29.38	29.87	32.26	0.594E-03	0.340E-03	27.59	29.66	30.79	31.54	36.24	0.238E-03	0.362E-03
37	25.86	27.10	27.88	28.36	30.65	0.862E-03	0.466E-03	25.86	28.11	29.24	29.98	34.63	0.345E-03	0.515E-03
38	25.53	27.33	28.08	28.55	30.73	0.845E-03	0.432E-03	25.53	28.26	29.36	30.12	34.71	0.338E-03	0.496E-03
39	27.86	26.76	29.60	30.11	32.61	0.548E-03	0.333E-03	27.86	29.94	31.08	31.83	36.59	0.219E-03	0.341E-03
40	28.38	29.88	30.75	31.30	34.08	0.391E-03	0.274E-03	28.38	31.20	32.36	33.13	38.06	0.156E-03	0.258E-03
41	28.35	29.01	29.87	30.42	33.14	0.485E-03	0.331E-03	28.35	30.31	31.46	32.22	37.12	0.194E-03	0.317E-03
42	20.24	24.89	25.85	26.47	29.79	0.105E-02	0.941E-03	20.24	26.47	27.66	28.46	33.77	0.420E-03	0.787E-03
43	25.71	27.08	27.86	28.33	30.59	0.873E-03	0.465E-03	25.71	28.07	29.20	29.94	34.57	0.349E-03	0.519E-03
44	27.25	28.34	29.11	29.58	31.84	0.655E-03	0.348E-03	27.25	29.32	30.45	31.19	35.82	0.262E-03	0.389E-03
45	28.23	28.94	29.80	30.33	32.99	0.503E-03	0.332E-03	26.23	30.20	31.35	32.11	36.97	0.201E-03	0.323E-03
46	26.12	27.29	28.09	28.58	30.96	0.802E-03	0.457E-03	26.12	28.36	29.49	30.24	34.94	0.321E-03	0.488E-03
47	18.38	24.04	25.08	25.75	29.57	0.111E-02	0.122E-02	18.38	25.79	27.01	27.83	33.54	0.442E-03	0.941E-03
48	24.53	26.08	26.82	27.27	29.35	0.116E-02	0.559E-03	24.53	26.94	28.05	28.79	33.33	0.465E-03	0.670E-03
49	27.41	28.50	29.29	29.79	32.15	0.609E-03	0.345E-03	27.41	29.57	30.70	31.45	36.13	0.244E-03	0.370E-03
50	27.96	28.80	29.62	30.13	32.64	0.545E-03	0.332E-03	27.96	29.96	31.10	31.85	36.62	0.218E-03	0.340E-03
51	20.23	24.88	25.85	26.46	29.77	0.105E-02	0.942E-03	20.23	26.46	27.65	28.45	33.75	0.421E-03	0.788E-03
52	30.75	32.30	32.95	33.34	35.08	0.310E-03	0.120E-03	30.75	32.84	33.94	34.67	39.06	0.124E-03	0.170E-03
53	25.55	27.07	27.83	28.30	30.50	0.891E-03	0.461E-03	25.55	28.02	29.14	29.88	34.48	0.356E-03	0.525E-03
54	34.38	36.15	36.90	37.35	39.47	0.113E-03	0.556E-04	34.38	37.03	38.15	38.89	43.45	0.452E-04	0.656E-04
55	24.92	26.51	27.29	27.77	33.06	0.986E-03	0.535E-03	24.92	27.53	28.65	29.40	34.04	0.394E-03	0.589E-03
56	28.20	29.13	29.99	30.52	33.19	0.479E-03	0.319E-03	28.20	30.40	31.54	32.31	37.17	0.192E-03	0.309E-03
57	28.11	28.59	29.43	29.95	32.54	0.557E-03	0.354E-03	26.11	29.81	30.95	31.71	36.52	0.223E-03	0.353E-03
58	20.77	25.61	26.69	27.40	31.63	0.687E-03	0.885E-03	20.77	27.46	28.70	29.54	35.61	0.275E-03	0.653E-03
59	26.64	27.32	28.14	28.66	31.18	0.761E-03	0.470E-03	26.64	28.49	29.63	30.39	35.16	0.305E-03	0.477E-03
60	25.56	28.00	28.85	29.38	32.04	0.626E-03	0.412E-03	25.56	29.25	30.40	31.16	36.02	0.250E-03	0.402E-03
61	29.06	29.54	30.47	31.05	34.13	0.386E-03	0.311E-03	29.06	31.02	32.19	32.98	38.11	0.154E-03	0.273E-03
62	31.32	33.43	34.18	34.64	36.81	0.209E-03	0.105E-03	31.32	34.34	35.46	36.20	40.79	0.835E-04	0.122E-03
63	38.67	39.01	39.82	40.32	42.76	0.529E-04	0.312E-04	38.67	40.13	41.26	42.01	46.74	0.212E-04	0.326E-04
64	28.72	29.58	30.48	31.05	34.01	0.396E-03	0.302E-03	26.72	31.00	32.16	32.94	37.99	0.159E-03	0.273E-03
65	29.62	29.84	30.83	31.47	34.97	0.318E-03	0.309E-03	29.62	31.49	32.69	33.50	38.95	0.127E-03	0.250E-03
66	27.77	29.29	30.15	30.69	33.38	0.459E-03	0.309E-03	27.77	30.57	31.72	32.48	37.36	0.184E-03	0.298E-03
67	28.55	29.55	30.45	31.01	33.93	0.405E-03	0.303E-03	28.65	30.95	32.11	32.89	37.91	0.162E-03	0.275E-03
68	20.22	24.85	25.81	26.42	29.70	0.107E-02	0.945E-03	20.22	26.42	27.60	28.40	33.68	0.429E-03	0.796E-03
69	17.81	23.63	24.61	25.24	28.65	0.136E-02	0.127E-02	17.81	25.25	26.45	27.25	32.63	0.546E-03	0.105E-02
70	35.51	35.90	36.82	37.40	40.43	0.905E-04	0.715E-04	35.51	37.36	38.53	39.31	44.41	0.362E-04	0.633E-04

90% AVERAGE, NO VOX=30.26DB

90% AVERAGE WITH VOX=32.03DB

Table B-12. 4/8 Hybrid, 25 dB Sidelobes, 3 dB Edge

	NO VOX							VOX						
CELL	PEAK	99%	95%	90%	MEAN(DB)	MEAN(PWR)	SIGMA	PEAK	99%	95%	90%	MEAN(DB)	MEAN(PWR)	SIGMA
1	30.38	30.08	30.99	31.57	34.54	0.351E-03	0.270E-03	30.38	31.52	32.68	33.46	38.57	0.140E-03	0.242E-03
2	28.18	28.16	28.97	29.47	31.90	0.646E-03	0.378E-03	28.18	29.27	30.40	31.16	35.88	0.258E-03	0.397E-03
3	27.87	27.99	28.76	29.24	31.49	0.710E-03	0.377E-03	27.87	28.98	30.10	30.84	35.47	0.284E-03	0.422E-03
4	23.93	24.09	24.99	25.56	28.51	0.141E-02	0.107E-02	23.93	25.50	26.67	27.45	32.49	0.563E-03	0.967E-03
5	31.27	30.25	31.18	31.78	34.91	0.323E-03	0.267E-03	31.27	31.75	32.93	33.72	38.89	0.129E-03	0.231E-03
6	24.28	24.32	25.25	25.85	28.98	0.126E-02	0.104E-02	24.28	25.82	27.00	27.79	32.96	0.506E-03	0.906E-03
7	27.87	27.98	28.75	29.23	31.48	0.712E-03	0.378E-03	27.87	28.96	30.09	30.83	35.46	0.285E-03	0.423E-03
8	27.87	28.09	28.86	29.33	31.59	0.693E-03	0.369E-03	27.87	29.08	30.20	30.95	35.57	0.277E-03	0.412E-03
9	23.93	24.09	24.99	25.56	28.51	0.141E-02	0.107E-02	23.93	25.50	26.67	27.45	32.49	0.563E-03	0.967E-03
10	27.49	27.75	28.50	28.96	31.12	0.773E-03	0.389E-03	27.49	28.66	29.78	30.52	35.10	0.309E-03	0.452E-03
11	24.28	24.32	25.25	25.85	28.98	0.126E-02	0.104E-02	24.28	25.82	27.00	27.79	32.96	0.506E-03	0.906E-03
12	27.16	27.78	28.51	28.95	31.00	0.794E-03	0.374E-03	27.16	28.61	29.72	30.45	34.98	0.318E-03	0.455E-03
13	26.23	26.80	27.50	27.93	29.90	0.102E-02	0.458E-03	26.23	27.55	28.66	29.39	33.87	0.410E-03	0.579E-03
14	26.23	26.76	27.47	27.90	29.86	0.103E-02	0.462E-03	26.23	27.51	28.62	29.35	33.84	0.413E-03	0.584E-03
15	27.49	27.91	28.66	29.12	31.30	0.742E-03	0.376E-03	27.49	28.83	29.95	30.69	35.27	0.297E-03	0.434E-03
16	27.16	27.66	28.38	28.83	30.87	0.819E-03	0.384E-03	27.16	28.48	29.59	30.33	34.85	0.328E-03	0.469E-03
17	25.73	26.62	27.30	27.71	29.55	0.111E-02	0.458E-03	25.73	27.27	28.37	29.10	33.53	0.443E-03	0.615E-03
18	27.87	28.08	28.86	29.33	31.61	0.690E-03	0.372E-03	27.87	29.08	30.21	30.95	35.59	0.276E-03	0.412E-03
19	25.73	26.72	27.41	27.82	29.68	0.108E-02	0.450E-03	25.73	27.38	28.49	29.21	33.66	0.431E-03	0.600E-03
20	27.16	27.91	28.66	29.11	31.25	0.750E-03	0.372E-03	27.16	28.81	29.92	30.66	35.23	0.300E-03	0.436E-03
21	25.73	26.54	27.21	27.61	29.44	0.114E-02	0.465E-03	25.73	27.16	28.27	28.99	33.42	0.455E-03	0.630E-03
22	25.73	26.62	27.30	27.71	29.55	0.111E-02	0.458E-03	25.73	27.26	28.36	29.09	33.53	0.444E-03	0.616E-03
23	25.98	26.77	27.46	27.88	29.77	0.105E-02	0.450E-03	25.98	27.46	28.56	29.29	33.75	0.422E-03	0.590E-03
24	26.55	27.43	28.12	28.53	30.41	0.910E-03	0.384E-03	26.55	28.10	29.21	29.94	34.39	0.364E-03	0.508E-03
25	27.16	27.59	28.31	28.75	30.79	0.834E-03	0.391E-03	27.16	28.40	29.51	30.25	34.77	0.333E-03	0.477E-03
26	25.69	26.57	27.25	27.66	29.50	0.112E-02	0.463E-03	25.69	27.21	28.31	29.04	33.48	0.449E-03	0.623E-03
27	25.93	26.78	27.47	27.89	29.78	0.105E-02	0.449E-03	25.93	27.47	28.57	29.30	33.76	0.421E-03	0.588E-03
28	25.30	26.39	27.04	27.43	29.16	0.121E-02	0.465E-03	25.30	26.93	28.03	28.75	33.14	0.485E-03	0.663E-03
29	26.55	27.47	28.15	28.56	30.44	0.904E-03	0.381E-03	26.55	28.14	29.24	29.97	34.42	0.362E-03	0.504E-03
30	27.16	27.70	28.42	28.87	30.91	0.812E-03	0.380E-03	27.16	28.52	29.63	30.36	34.89	0.325E-03	0.465E-03
31	26.23	26.92	27.63	28.07	30.05	0.989E-03	0.447E-03	26.23	27.69	28.80	29.53	34.03	0.396E-03	0.561E-03
32	24.82	26.10	26.76	27.16	28.93	0.128E-02	0.504E-03	24.82	26.67	27.77	28.50	32.91	0.512E-03	0.703E-03
33	25.51	26.60	27.27	27.67	29.49	0.112E-02	0.457E-03	25.51	27.22	28.32	29.05	33.47	0.450E-03	0.622E-03
34	27.10	27.87	28.60	29.05	31.12	0.773E-03	0.368E-03	27.10	28.71	29.83	30.56	35.10	0.309E-03	0.445E-03
35	26.04	27.17	27.87	28.29	30.21	0.954E-03	0.414E-03	26.04	27.88	28.99	29.72	34.18	0.382E-03	0.536E-03
36	27.16	27.65	28.38	28.82	30.88	0.817E-03	0.386E-03	27.16	28.48	29.59	30.33	34.86	0.327E-03	0.469E-03
37	25.98	26.68	27.37	27.78	29.68	0.108E-02	0.460E-03	25.98	27.36	28.47	29.20	33.66	0.431E-03	0.603E-03
38	25.98	26.80	27.51	27.93	29.88	0.103E-02	0.455E-03	25.98	27.54	28.65	29.38	33.86	0.411E-03	0.580E-03
39	27.16	27.58	28.30	28.74	30.78	0.836E-03	0.391E-03	27.16	28.39	29.50	30.24	34.76	0.335E-03	0.478E-03
40	27.09	27.72	28.43	28.87	30.87	0.819E-03	0.375E-03	27.09	28.50	29.61	30.34	34.85	0.328E-03	0.466E-03
41	26.17	27.45	28.15	28.57	30.49	0.892E-03	0.389E-03	26.17	28.17	29.27	30.00	34.47	0.357E-03	0.502E-03
42	25.73	26.70	27.38	27.79	29.64	0.109E-02	0.452E-03	25.73	27.35	28.45	29.18	33.62	0.434E-03	0.604E-03
43	22.46	23.14	23.92	24.40	26.69	0.214E-02	0.116E-02	22.46	24.15	25.28	26.03	30.67	0.856E-03	0.128E-02
44	25.98	26.84	27.54	27.97	29.93	0.102E-02	0.453E-03	25.98	27.58	28.69	29.43	33.91	0.406E-03	0.574E-03
45	27.16	27.47	28.19	28.63	30.66	0.858E-03	0.399E-03	27.16	28.28	29.39	30.13	34.64	0.343E-03	0.491E-03
46	26.84	27.49	28.20	28.64	30.63	0.865E-03	0.393E-03	26.84	28.26	29.38	30.11	34.61	0.346E-03	0.491E-03
47	26.55	27.24	27.92	28.34	30.21	0.953E-03	0.401E-03	26.55	27.91	29.01	29.74	34.19	0.381E-03	0.531E-03
48	22.57	23.44	24.25	24.75	27.18	0.191E-02	0.112E-02	22.57	24.55	25.69	26.44	31.16	0.765E-03	0.118E-02
49	25.05	26.06	26.72	27.13	28.93	0.128E-02	0.514E-03	25.05	26.66	27.76	28.49	32.91	0.512E-03	0.707E-03
50	28.80	29.19	29.93	30.39	32.53	0.558E-03	0.278E-03	28.80	30.08	31.20	31.94	36.51	0.223E-03	0.325E-03
51	25.97	26.74	27.43	27.85	29.77	0.105E-02	0.458E-03	25.97	27.45	28.55	29.28	33.75	0.421E-03	0.592E-03
52	23.63	24.17	25.04	25.60	28.40	0.145E-02	0.102E-02	23.63	25.51	26.66	27.43	32.38	0.579E-03	0.960E-03
53	26.19	27.21	27.89	28.30	30.16	0.965E-03	0.401E-03	26.19	27.86	28.97	29.70	34.14	0.386E-03	0.536E-03
54	28.34	28.73	29.47	29.92	32.03	0.626E-03	0.306E-03	28.34	29.60	30.72	31.46	36.01	0.251E-03	0.363E-03
55	23.30	23.27	24.11	24.63	27.22	0.190E-02	0.121E-02	23.30	24.48	25.63	26.39	31.20	0.759E-03	0.120E-02
56	23.93	24.34	25.25	25.83	28.82	0.131E-02	0.102E-02	23.93	25.78	26.95	27.72	32.80	0.525E-03	0.909E-03
57	27.16	27.66	28.38	28.82	30.87	0.819E-03	0.385E-03	27.16	28.47	29.59	30.32	34.85	0.328E-03	0.469E-03
58	24.57	24.77	25.75	26.38	29.83	0.104E-02	0.985E-03	24.57	26.40	27.59	28.40	33.81	0.416E-03	0.805E-03
59	29.61	29.42	30.25	30.77	33.32	0.465E-03	0.291E-03	29.61	30.61	31.75	32.51	37.30	0.186E-03	0.293E-03
60	23.93	23.60	24.49	25.05	27.90	0.162E-02	0.118E-02	23.93	24.97	26.13	26.90	31.88	0.649E-03	0.109E-02
61	28.26	29.07	29.89	30.39	32.85	0.519E-03	0.308E-03	28.26	30.20	31.34	32.09	36.82	0.208E-03	0.321E-03
62	33.17	33.57	34.35	34.84	37.16	0.193E-03	0.106E-03	33.17	34.60	35.73	36.48	41.13	0.770E-04	0.116E-03
63	34.29	34.95	35.69	36.14	38.25	0.150E-03	0.729E-04	34.29	35.82	36.94	37.67	42.22	0.599E-04	0.867E-04
64	29.85	29.77	30.61	31.13	33.74	0.423E-03	0.271E-03	29.85	30.99	32.14	32.90	37.72	0.169E-03	0.269E-03
65	30.15	31.43	32.13	32.56	34.51	0.354E-03	0.157E-03	30.15	32.17	33.27	34.01	38.49	0.142E-03	0.200E-03
66	30.87	32.17	32.90	33.34	35.41	0.288E-03	0.137E-03	30.87	33.00	34.12	34.85	39.39	0.115E-03	0.165E-03
67	29.85	29.56	30.38	30.90	33.49	0.448E-03	0.285E-03	29.85	30.75	31.89	32.65	37.47	0.179E-03	0.284E-03
68	23.16	23.80	24.66	25.20	27.92	0.162E-02	0.110E-02	23.16	25.09	26.24	27.01	31.90	0.646E-03	0.105E-02
69	23.30	23.89	24.77	25.32	28.11	0.154E-02	0.109E-02	23.30	25.23	26.38	27.15	32.09	0.618E-03	0.102E-02
70	24.82	24.88	25.89	26.54	30.17	0.962E-03	0.983E-03	24.82	26.57	27.78	28.59	34.15	0.385E-03	0.780E-03

90% AVERAGE, NO VOX=28.61DB 90% AVERAGE WITH VOX=29.9ADA

Table B-13. 4/8 Hybrid, 30 dB Sidelobes, 3 dB Edge

CELL	PEAK	99%	95%	90%	MEAN(DB)	MEAN(PWR)	SIGMA	PEAK	99%	95%	90%	MEAN(DB)	MEAN(PWR)	SIGMA
1	35.84	35.57	36.49	37.09	43.15	0.966E-04	0.777E-04	35.84	37.04	38.21	39.00	44.13	0.386E-04	0.682E-04
2	33.24	33.49	34.29	34.77	37.20	0.191E-03	0.110E-03	33.24	34.59	35.72	36.47	41.10	[illegible]	[illegible]
3	32.85	33.33	34.10	34.50	36.04	0.207E-03	0.110E-03	32.85	34.32	35.44	36.19	40.82	0.829E-04	0.123E-03
4	28.95	29.22	30.12	30.70	33.68	0.429E-03	0.330E-03	28.95	30.65	31.81	32.59	37.66	0.172E-03	0.296E-03
5	36.25	35.59	36.52	37.11	40.20	0.954E-04	0.776E-04	36.25	37.08	38.25	39.03	44.16	0.362E-04	0.678E-04
6	29.30	29.45	30.39	30.99	34.17	0.383E-03	0.322E-03	29.30	30.98	32.15	32.94	38.15	0.153E-03	0.277E-03
7	32.85	33.31	34.09	34.56	35.82	0.208E-03	0.111E-03	32.85	34.31	35.43	36.17	40.80	0.831E-04	0.124E-03
8	32.85	33.51	34.28	34.76	37.02	0.199E-03	0.106E-03	32.85	34.50	35.62	36.37	41.00	0.794E-04	0.118E-03
9	28.95	29.22	30.12	30.70	33.68	0.429E-03	0.330E-03	28.95	30.65	31.81	32.59	37.66	0.172E-03	0.296E-03
10	32.48	33.07	33.81	34.27	36.39	0.230E-03	0.113E-03	32.48	33.95	35.07	35.81	40.37	0.918E-04	0.133E-03
11	29.30	29.45	30.39	30.99	34.17	0.383E-03	0.322E-03	29.30	30.98	32.15	32.94	38.15	0.153E-03	0.277E-03
12	32.15	33.31	34.04	34.48	36.55	0.221E-03	0.105E-03	32.15	34.15	35.26	36.00	40.53	0.665E-04	0.127E-03
13	31.22	32.16	32.67	33.30	35.27	0.297E-03	0.133E-03	31.22	32.92	34.03	34.76	39.24	0.119E-03	0.168E-03
14	31.22	32.10	32.80	33.23	35.19	0.303E-03	0.135E-03	31.22	32.84	33.95	34.69	39.17	0.121E-03	0.171E-03
15	32.48	33.35	34.10	34.56	36.72	0.213E-03	0.107E-03	32.48	34.26	35.38	36.12	40.70	0.851E-04	0.124E-03
16	32.15	33.09	33.81	34.25	36.29	0.235E-03	0.110E-03	32.15	33.90	35.01	35.75	40.27	0.940E-04	0.134E-03
17	30.72	32.12	32.79	33.20	35.06	0.312E-03	0.130E-03	30.72	32.76	33.87	34.60	39.04	0.125E-03	0.174E-03
18	32.85	33.53	34.30	34.78	37.07	0.196E-03	0.106E-03	32.85	34.53	35.66	36.41	41.05	0.786E-04	0.117E-03
19	30.72	32.29	32.98	33.40	35.28	0.296E-03	0.126E-03	30.72	32.97	34.08	34.81	39.26	0.119E-03	0.166E-03
20	32.30	33.52	34.27	34.74	36.92	0.203E-03	0.104E-03	32.30	34.45	35.57	36.31	40.90	0.813E-04	0.119E-03
21	30.72	31.95	32.63	33.03	34.86	0.327E-03	0.134E-03	30.72	32.58	33.68	34.41	38.84	0.131E-03	0.181E-03
22	30.72	32.11	32.79	33.19	35.04	0.313E-03	0.130E-03	30.72	32.75	33.86	34.58	39.02	0.125E-03	0.174E-03
23	30.97	32.24	32.93	33.34	35.25	0.299E-03	0.128E-03	30.97	32.93	34.04	34.77	39.23	0.119E-03	0.167E-03
24	31.54	33.01	33.69	34.11	35.99	0.252E-03	0.107E-03	31.54	33.68	34.79	35.52	39.97	0.101E-03	0.141E-03
25	32.15	32.98	33.70	34.15	35.21	0.240E-03	0.113E-03	32.15	33.81	34.92	35.66	40.19	0.958E-04	0.138E-03
26	30.72	32.02	32.69	33.10	34.95	0.320E-03	0.432E-03	30.72	32.66	33.76	34.49	38.93	0.126E-03	0.176E-03
27	30.97	32.26	32.95	33.37	35.26	0.296E-03	0.126E-03	30.97	32.96	34.07	34.80	39.26	0.119E-03	0.166E-03
28	30.42	31.86	32.52	32.91	34.68	0.341E-03	0.133E-03	30.42	32.43	33.53	34.25	38.66	0.136E-03	0.187E-03
29	31.54	33.03	33.76	34.18	36.05	0.248E-03	0.105E-03	31.54	33.75	34.85	35.58	40.03	0.993E-04	0.139E-03
30	32.15	33.18	33.90	34.34	35.40	0.229E-03	0.108E-03	32.15	34.03	35.11	35.85	40.38	0.917E-04	0.132E-03
31	31.22	32.38	33.09	33.52	35.49	0.282E-03	0.127E-03	31.22	33.14	34.25	34.98	39.47	0.113E-03	0.160E-03
32	29.93	31.66	32.33	32.73	34.52	0.354E-03	0.141E-03	29.93	32.25	33.35	34.08	38.49	0.141E-03	0.195E-03
33	30.57	32.13	32.81	33.21	35.05	0.313E-03	0.128E-03	30.57	32.76	33.87	34.59	39.03	0.125E-03	0.173E-03
34	32.15	33.48	34.21	34.66	36.76	0.211E-03	0.102E-03	32.15	34.34	35.45	36.19	40.74	0.843E-04	0.122E-03
35	31.53	32.66	33.36	33.78	35.70	0.269E-03	0.117E-03	31.53	33.37	34.48	35.21	39.68	0.108E-03	0.151E-03
36	32.15	33.10	33.84	34.29	36.39	0.230E-03	0.112E-03	32.15	33.96	35.08	35.82	40.37	0.919E-04	0.133E-03
37	30.97	32.07	32.76	33.19	35.11	0.309E-03	0.134E-03	30.97	32.78	33.89	34.62	39.08	0.123E-03	0.173E-03
38	31.09	32.27	32.98	33.41	35.39	0.289E-03	0.130E-03	31.09	33.03	34.14	34.87	39.36	0.116E-03	0.164E-03
39	32.15	32.95	33.67	34.11	36.15	0.243E-03	0.114E-03	32.15	33.76	34.87	35.61	40.13	0.970E-04	0.139E-03
40	32.12	33.17	33.92	34.38	36.53	0.222E-03	0.112E-03	32.12	34.08	35.20	35.94	40.51	0.889E-04	0.130E-03
41	31.14	32.95	33.64	34.06	35.99	0.252E-03	0.110E-03	31.14	33.66	34.77	35.50	39.97	0.101E-03	0.142E-03
42	30.72	32.14	32.82	33.24	35.13	0.307E-03	0.130E-03	30.72	32.82	33.92	34.65	39.11	0.123E-03	0.172E-03
43	27.47	28.43	29.22	29.71	32.06	0.623E-03	0.349E-03	27.47	29.48	30.61	31.36	36.04	0.249E-03	0.376E-03
44	31.12	32.35	33.06	33.50	35.49	0.283E-03	0.128E-03	31.12	33.12	34.23	34.97	39.46	0.113E-03	0.161E-03
45	32.15	32.76	33.48	33.92	35.96	0.254E-03	0.119E-03	32.15	33.57	34.68	35.42	39.94	0.101E-03	0.145E-03
46	31.83	32.98	33.69	34.12	36.09	0.246E-03	0.111E-03	31.83	33.74	34.85	35.58	40.07	0.983E-04	0.139E-03
47	31.54	32.66	33.35	33.77	35.69	0.270E-03	0.117E-03	31.54	33.37	34.48	35.21	39.67	0.108E-03	0.151E-03
48	27.66	28.56	29.37	29.88	32.36	0.561E-03	0.349E-03	27.66	29.70	30.64	31.59	36.34	0.232E-03	0.360E-03
49	30.03	31.50	32.17	32.57	34.37	0.365E-03	0.147E-03	30.03	32.10	33.21	33.93	38.35	0.146E-03	0.202E-03
50	33.80	34.76	35.52	35.99	38.20	0.151E-03	0.784E-04	33.80	35.71	36.84	37.58	42.18	0.605E-04	0.892E-04
51	30.96	32.16	32.85	33.26	35.15	0.305E-03	0.130E-03	30.96	32.84	33.95	34.68	39.13	0.122E-03	0.171E-03
52	28.65	29.28	30.17	30.73	33.59	0.438E-03	0.319E-03	28.65	30.65	31.81	32.58	37.57	0.175E-03	0.294E-03
53	31.84	32.64	33.33	33.75	35.65	0.272E-03	0.117E-03	31.84	33.34	34.44	35.17	39.63	0.109E-03	0.152E-03
54	33.53	34.13	34.92	35.40	37.74	0.168E-03	0.938E-04	33.53	35.18	36.30	37.05	41.72	0.672E-04	0.101E-03
55	28.34	28.54	29.39	29.91	32.54	0.557E-03	0.361E-03	28.34	29.78	30.92	31.68	36.52	0.223E-03	0.356E-03
56	28.95	29.45	30.37	30.95	34.00	0.398E-03	0.317E-03	28.95	30.91	32.08	32.87	37.98	0.159E-03	0.279E-03
57	32.15	33.12	33.85	34.29	35.35	0.232E-03	0.110E-03	32.15	33.95	35.07	35.80	40.33	0.926E-04	0.133E-03
58	29.75	29.86	30.85	31.49	35.02	0.315E-03	0.308E-03	29.75	31.52	32.72	33.53	39.00	0.126E-03	0.249E-03
59	34.78	34.69	35.54	36.07	38.72	0.134E-03	0.880E-04	34.78	35.94	37.09	37.85	42.70	0.537E-04	0.862E-04
60	23.95	28.94	29.84	30.41	33.36	0.461E-03	0.350E-03	28.95	30.36	31.52	32.30	37.34	0.164E-03	0.316E-03
61	33.56	34.83	35.64	36.14	36.59	0.136E-03	0.617E-04	33.56	35.95	37.09	37.84	42.57	0.554E-04	0.852E-04
62	38.67	39.44	40.25	40.74	43.15	0.484E-04	0.280E-04	38.67	40.54	41.67	42.42	47.13	0.194E-04	0.296E-04
63	40.51	40.37	41.19	41.71	44.23	0.377E-04	0.232E-04	40.51	41.54	42.68	43.44	48.21	0.151E-04	0.236E-04
64	34.84	35.37	36.21	36.74	39.33	0.117E-03	0.745E-04	34.84	36.59	37.73	38.49	43.31	0.467E-04	0.741E-04
65	36.44	37.26	37.98	38.43	40.48	0.895E-04	0.423E-04	36.44	38.08	39.20	39.93	44.46	0.358E-04	0.514E-04
66	37.46	38.13	38.93	39.43	41.84	0.655E-04	0.380E-04	37.46	39.22	40.36	41.11	45.82	0.262E-04	0.401E-04
67	34.84	34.95	35.79	36.32	38.91	0.129E-03	0.819E-04	34.84	36.17	37.31	38.07	42.89	0.514E-04	0.616E-04
68	26.76	29.11	29.99	30.55	33.36	0.461E-03	0.326E-03	26.76	30.46	31.62	32.39	37.34	0.184E-03	0.307E-03
69	28.35	25.94	29.81	30.37	33.17	0.482E-03	0.342E-03	28.35	30.28	31.43	32.20	37.15	0.193E-03	0.320E-03
70	29.96	29.94	30.96	31.61	35.29	0.296E-03	0.308E-03	29.96	31.65	32.86	33.68	39.27	0.118E-03	0.243E-03

90% AVERAGE, NO VOX=33.84DB

90% AVERAGE WITH VOX=35.43DB

B.3 CONCLUSIONS

The 3 frequency scheme may be used if all sidelobes may be kept better than 25 dB down. The 3/6 hybrid scheme allows sidelobes of up to 22 dB. Going to the 4/8 hybrid, geographical cochannel separation increases to the point where the 1st sidelobe is no longer of consequence. Here one may use any antenna where the second and higher order sidelobes correspond to those of an ideal Hansen pattern of only 20 dB sidelobes. However, the first sidelobe (since it rarely falls over cochannel cells) may be virtually any value. Elimination of the first sidelobe restriction should be of immense value in the design of a multi-beam antenna.

B.4 REFERENCES

B-1 Hansen, R.C., "Circular Aperture Distribution with One Parameter", Electronics Letters, Vol 11, No. 8, 17 April 1975

APPENDIX C

COCHANNEL CELL PATTERNS

APPENDIX C

COCHANNEL CELL PATTERNS

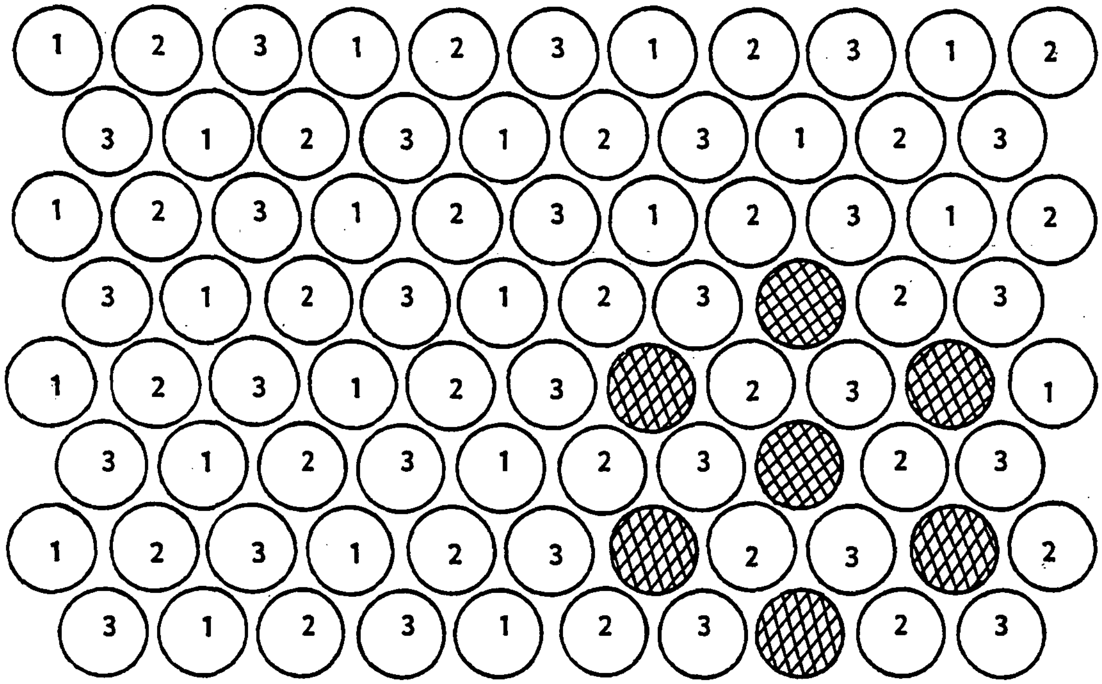
C.1 GENERAL

Since in both the mobile transmit and mobile receive cases, whether the mobiles are transmitting or receiving, the cochannel interference is related to the satellite antenna side lobe structure, and possibly the main beam. The pattern of assignment of cochannel frequencies to the cells defined by the beams of the satellite multibeam antenna is an important means of controlling cochannel interference. When the mobile is receiving, the interference it experiences is due to the sidelobes in the direction of other beams carrying cochannel signals. When the mobile is transmitting, the interference the satellite receives is due to the sidelobes of the satellite antenna in the direction of the cochannel mobile transmitters. Because each cell is uniquely associated with a satellite antenna beam, the assignment of frequencies to the cells determines the angular separation of the interference source from the beam axis and, hence, the allowable sidelobe level.

This appendix describes several cell arrangements of most interest and discusses the relative advantage with regard to system capacity and interference rejection.

Cell arrangements for frequency reuse in the 900 MHz land mobile band have been investigated (C-1, C-2, C-3, C-4). Examples of the cases already studied are presented in Figures C-1, C-2, C-7 and C-11. Figure C-1 shows a three frequency cell site arrangement. The darkened cells consist of a central cell and the six closest cells which occupy the same frequency pattern. This cochannel interference pattern is approximately isotropic (independent of direction from the central cell) and homogeneous (independent of the location of the central cell). Cases which have been considered in the literature concern only those cell site arrangements whose cochannel interference pattern is both homogeneous and isotropic.

The pattern of Figure C-1 was generated by starting the top row with a repeating pattern. The second row uses an identical pattern shifted 1.5 cell diameters which avoids contiguous cells of the same frequency to minimize cochannel interference. This pattern is then repeated for the entire cell site matrix.

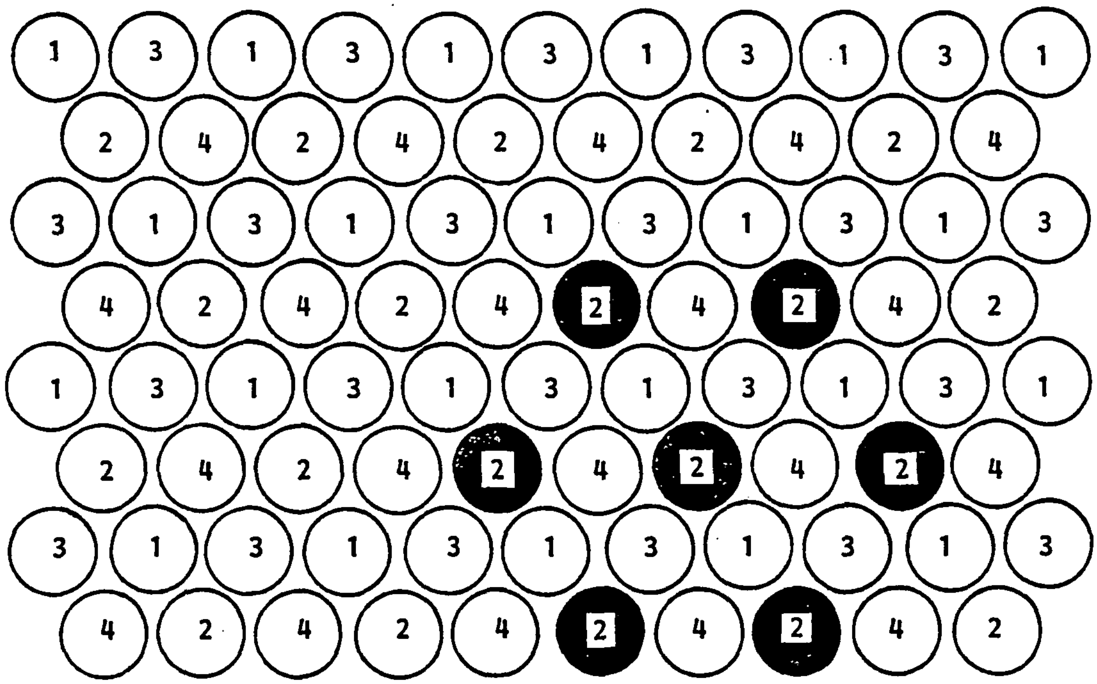


COCHANNEL
SEPARATION:
6 at 1.73d

Figure C-1. Three Frequency Cell Site Arrangement

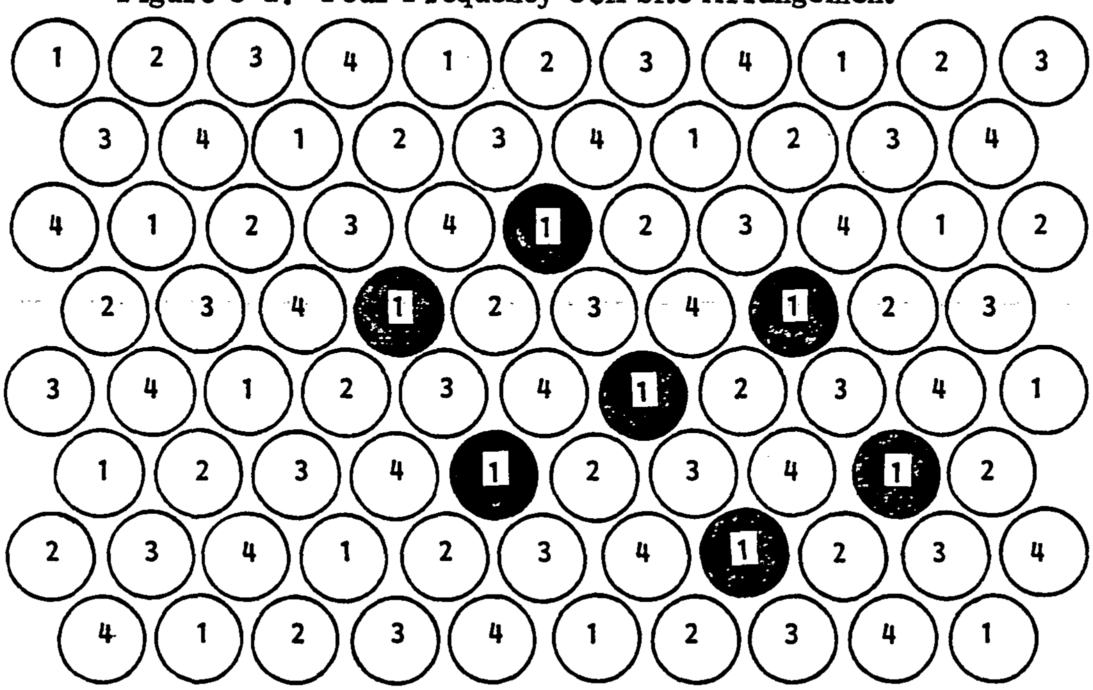
Figure C-2 illustrates a four frequency arrangement. The four available frequencies are split into two groups. The first group is assigned in sequence to the first row and the second group to the second row. The pattern of the first two rows is then shifted one cell diameter and duplicated in the next two rows. The entire matrix is generated in this manner. The cochannel interference pattern, Figure C-2, is isotropic and homogenous. Note also that the separation between cochannel cells is greater than in the 3 frequency case.

Figure C-3 shows a second way in which a four frequency arrangement may be realized. All four frequencies are placed in sequence in the first row and repeated. The first row is copied in the second row and then shifted 2.5 cell diameters to minimize cochannel interference. There are two possible phases which the second row may be shifted to and still maintain minimum cochannel interference. This gives a number of possible cochannel interference pattern orientations and configurations in the cell matrix. By appropriately choosing the phase of each row as the matrix is generated, the closer cochannel cells may be placed in lightly used areas,



COCHANNEL
SEPARATION:
6 at 2d

Figure C-2. Four Frequency Cell Site Arrangement

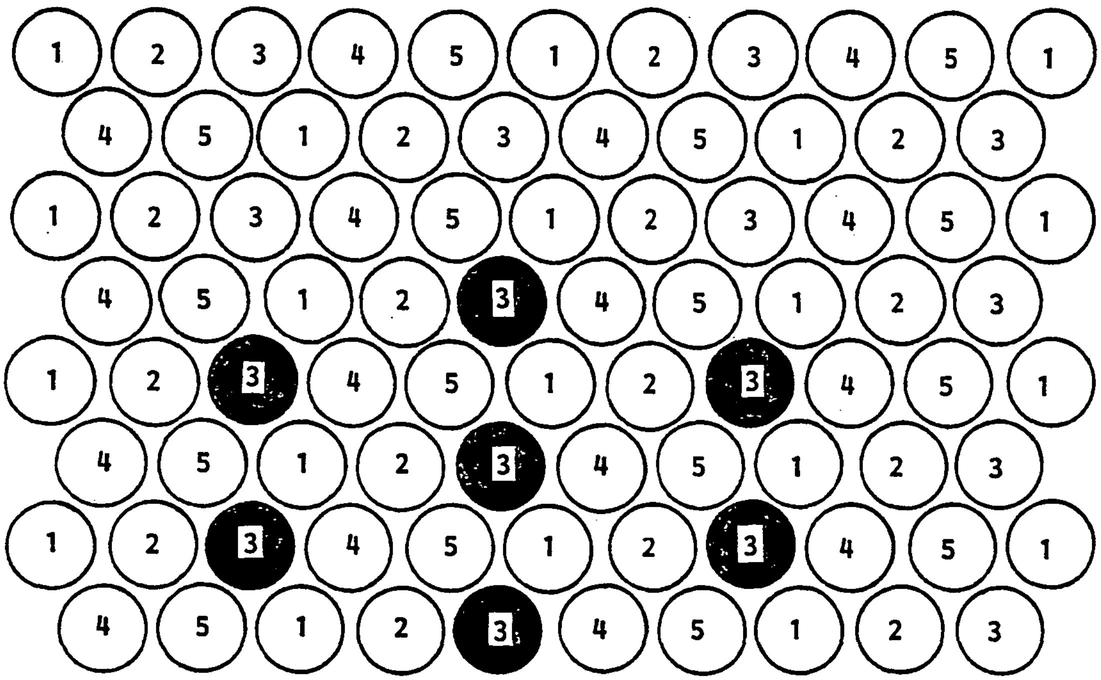


COCHANNEL SEPARATION
2 at 1.73d
2 at 2d
2 at 2.65d

Figure C-3. Four Frequency Cell Site Arrangement minimizing average cochannel interference. If the central cell in question is close to the edge of the coverage area cochannel cells may be placed outside the area; i.e., not used, and therefore contribute no interference.

The cochannel interference pattern in Figure C-3 is one of many possible patterns. If all cells are fully loaded the anisotropic pattern in Figure C-3 will usually have less cochannel interference than the isotropic pattern in Figure C-2, depending on how rapidly the antenna sidelobes fall off.

Figure C-4 shows the five frequency homogenous (and anisotropic) arrangement. Note that the second row now has three possible positions allowing further control over the cochannel interference pattern.

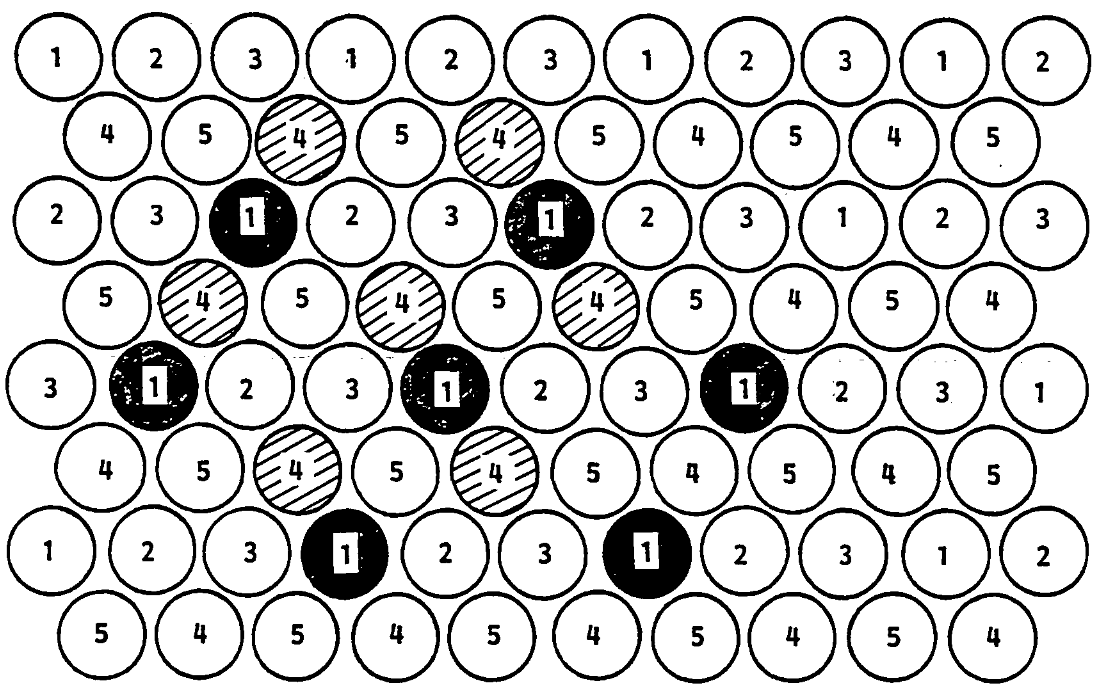


COCHANNEL SEPARATION
2 at 1.73d
4 at 2.65d

Figure C-4. Five Frequency Cell Site Arrangement

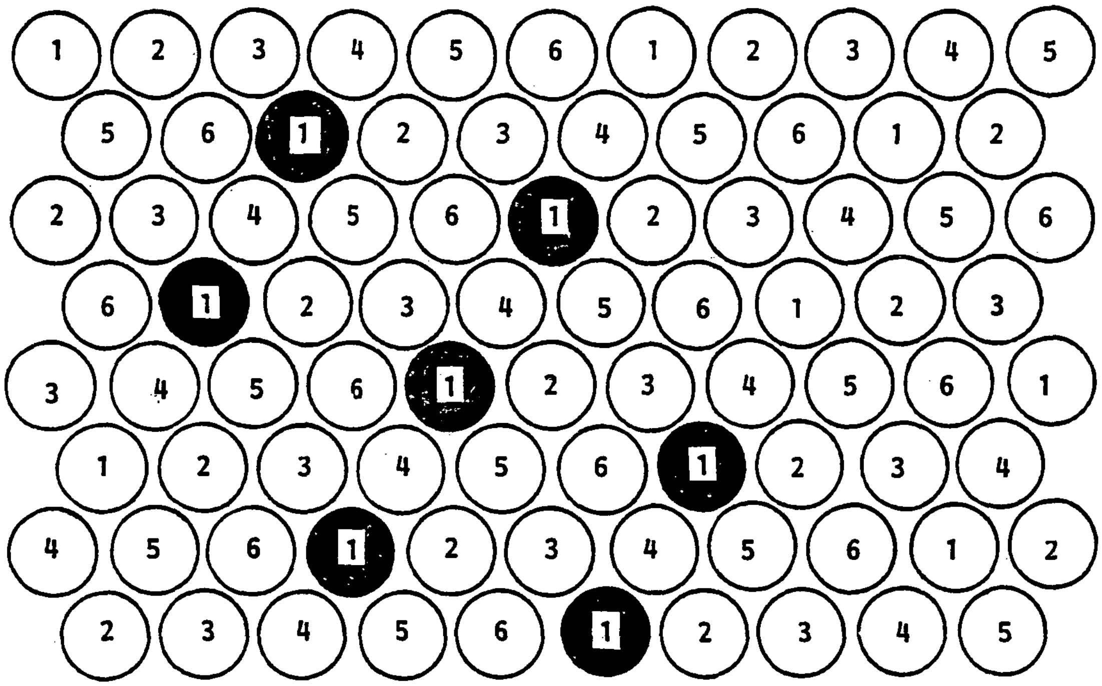
Figure C-5 shows the inhomogenous five frequency arrangement. This matrix was generated by restricting the first row to the first three frequencies and the second row to the last two frequencies. There is some latitude in positioning the rows, but not as much as in the five frequency homogenous case. Figure C-5 shows the widely spaced anisotropic cochannel interference pattern for frequency sets 1, 2 and 3. Frequency sets 4 and 5 show the same isotropic pattern as a four frequency isotropic arrangement.

Figure C-6 shows a six frequency set arrangement. This is anisotropic and homogenous. The orientation of the pattern may be modified by changing the phase of individual rows. There is no acceptable isotropic or inhomogenous pattern for the six cell arrangement. The six frequency arrangement shown in Figure C-6 is generated by assigning all six frequencies in sequence to the first row and repeating to fill the first row. The second row is merely a shifted version of the first. Restricting the first row to the first three frequency sets, the second row to the last three frequency sets and so on generates an identical cochannel interference pattern.



COCHANNEL SEPARATION
2 at 2d
2 at 2.65d
2 at 3d
or
6 at 2d

Figure C-5. Five Frequency Cell Site Arrangement



COCHANNEL SEPARATION
2 at 2d
2 at 2.65d
2 at 3d

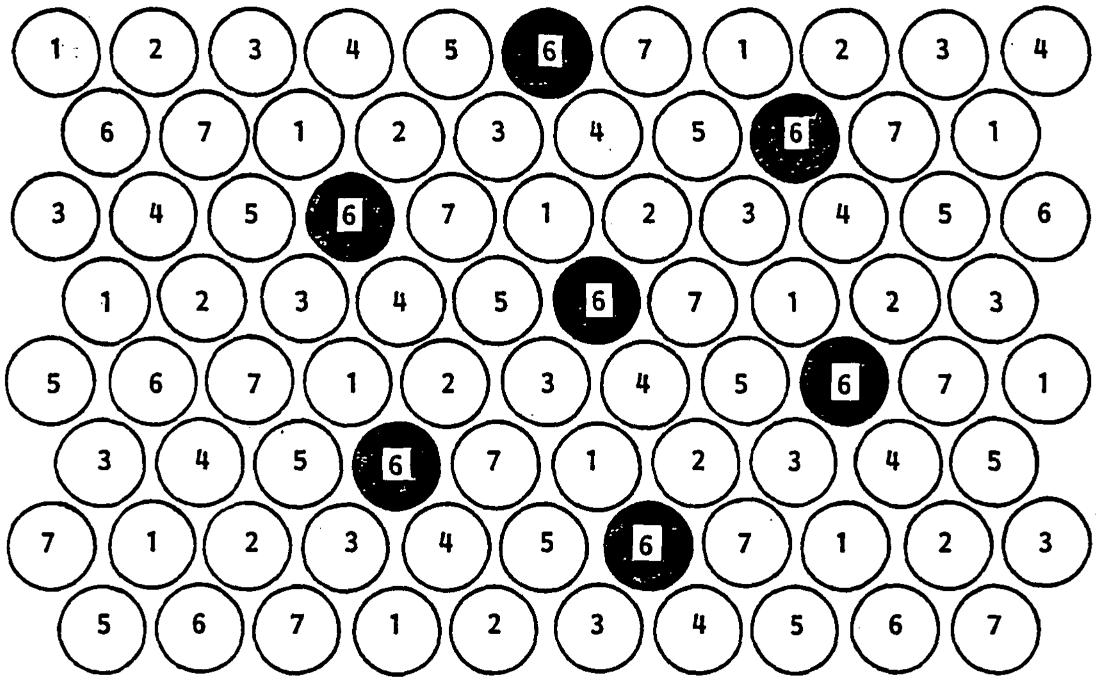
Figure C-6. Six Frequency Cell Site Arrangement

Figure C-7 shows the seven frequency homogenous, isotropic arrangement. Restricting the first row to the first four frequency sets produces the inhomogenous pattern of Figure C-8,

It is noted that for the seven (or more) frequency set arrangements, it is no longer necessary to assign adjacent frequencies to adjacent cells. For example, in the blacked in cells in Figure C-8, if all frequencies in Set 3 are adjacent to all frequencies in Set 1, the adjacent channel interference due to Set 1 is at least 0.866 cell diameter distant.

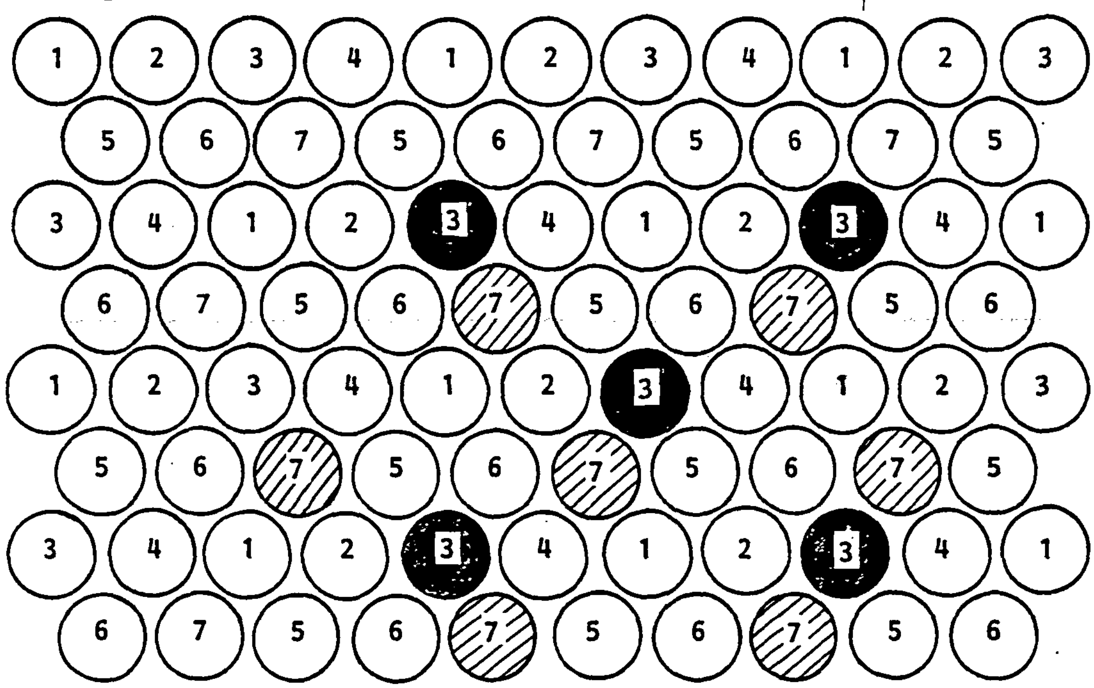
C.2 HYBRID COCHANNEL CELL PATTERNS

A significant advantage of the three frequency arrangement is that maximum frequency reuse is realized. However it, as well as any regular pattern of cell frequency assignment, allots the same amount of the spectrum to lightly populated areas as to heavily populated areas. Hybrid assignment methods offer a means of varying the spectral assignment.



COCHANNEL SEPARATION
6 at 2.65d

Figure C-7. Seven Frequency Cell Site Arrangement



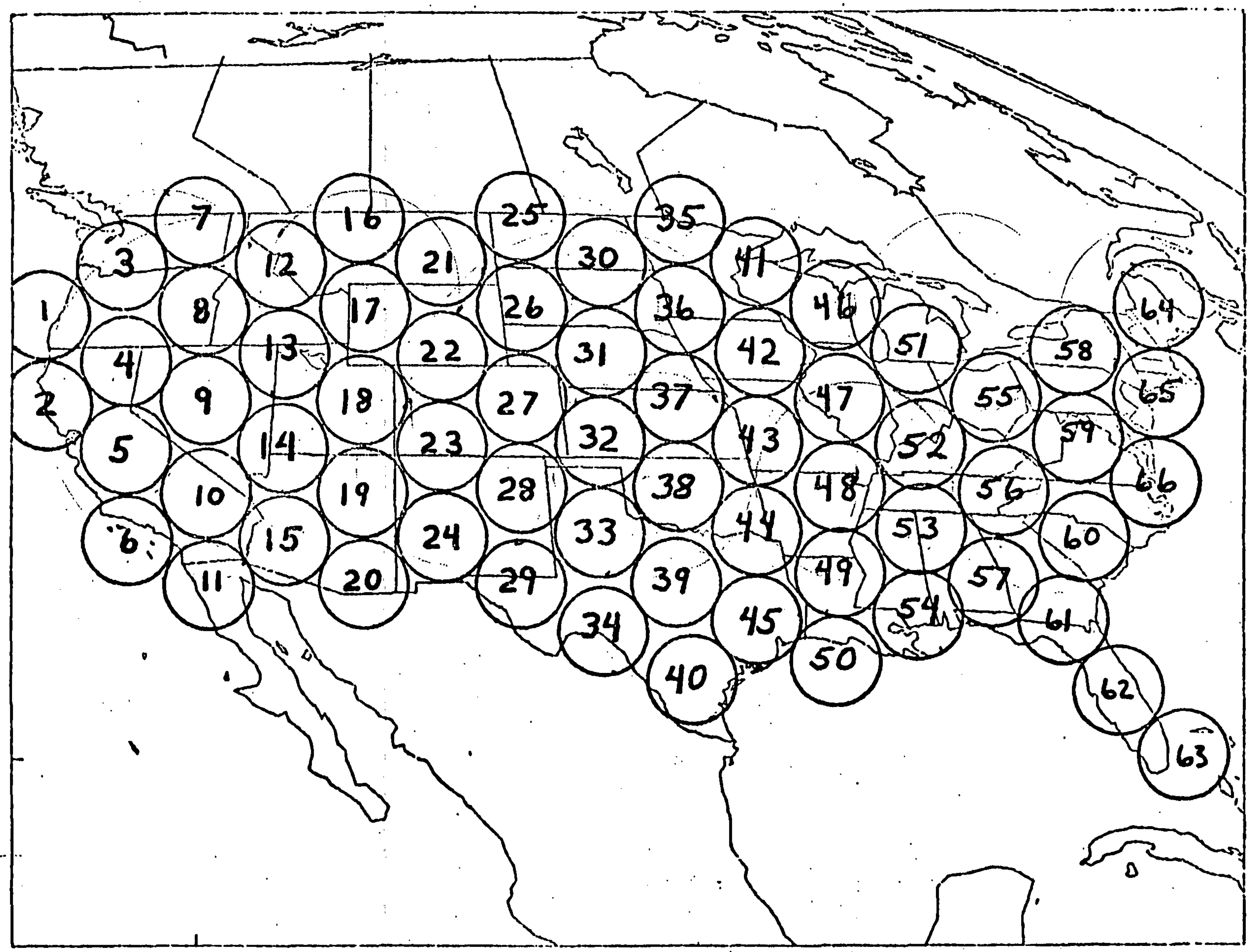
COCHANNEL SEPARATION
4 at 2.65d
or
2 at 2d
2 at 2.65d
2 at 3d

Figure C-8. Seven Frequency Cell Site Arrangement

Figure C-9 shows pattern of $1/2^{o}$ cells over the U.S. and Figure C-10 shows a hybrid 3/6 frequency cell site arrangement for this pattern. The entire available band is divided into six separate bands: 1a, 1b, 2a, 2b, 3a, 3c. Four cell sites are given a full third of the entire available band, as indicated in Figure C-10. For illustration these are taken as cells 65 near NYC, 51 near Chicago, 6 near Los Angeles and 55 covering Ohio.

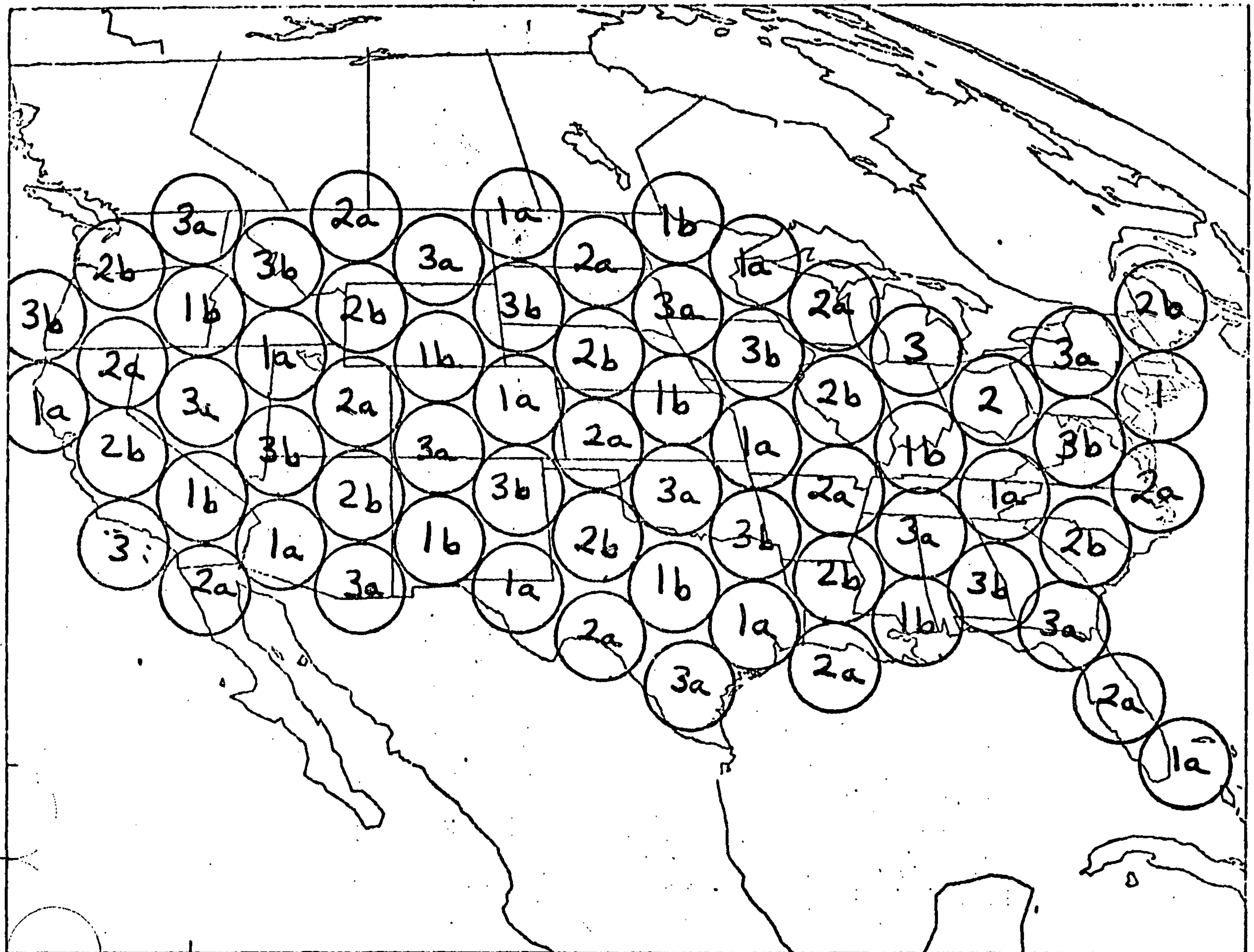
All other cell sites receive only one of the six bands mentioned before. Assignment of these frequencies starts in Maine with band 2b given to site 64. Frequencies are assigned as well as possible around the Chicago, Ohio and NYC cell sites. After these are assigned a transition is made to the standard 6 frequency cell site arrangement for the rest of the country. The "phase" of rows may be shifted in order to place cochannel cell sites in lightly used areas or even outside of the United States. For example, consider the vertical row starting with cell site 25 and ending with cell site 29. That column has frequencies in the sequence: 1a, 3b, 1a, 3b, 1a. There are three cell sites on frequency 1a and only two on frequence 3b. If the average cochannel interference on frequency 1a is greater than desirable in some neighboring cells (cells 13, 15, 41, 43, 45) and more interference on frequency 3b is tolerable, the row can be shifted by one to: 3b, 1a, 3b, 1a, 3b. Now there will be only two cochannel interfering cells on frequency 1a, while frequence 3b will have an additional cochannel interferer. Using a multitude of such "phase" changes, and a knowledge of expected traffic loads for each cell site, the average cochannel interference can be minimized by controlling the number and the location of cochannel cells. Cochannel cells may be placed over thinly populated areas, or even outside of the United States, minimizing the average interference to heavily used cells.

The 3/6 hybrid approach has adjacent channels assigned to adjacent cells for every cell. This characteristic can be avoided in the hybrid 4/8 frequency cell site arrangement. Here, 1/4 of the available band is given to each major population center. All other cell sites receive 1/8th of the available band. Thus, most of the country will have an eight frequency cell site arrangement. Eight frequency arrangements can be divided into two major groups, homogenous (cochannel interference does not depend on the central cell site location) and inhomogenous (cochannel interference does depend on the central cell site location). These arrangements applied to the hybrid 4/8 frequency cell site arrangement, are shown in Figures C-11 and C-12, respectively.



SYNCHRONOUS VIEW AT -110.00 DEGREES LONGITUDE

Figure C-9. Cell Site Positions



SYNCHRONOUS VIEW AT -110.00 DEGREES LONGITUDE

Figure C-10. Hybrid 3/6 Frequency Cell Site Arrangement

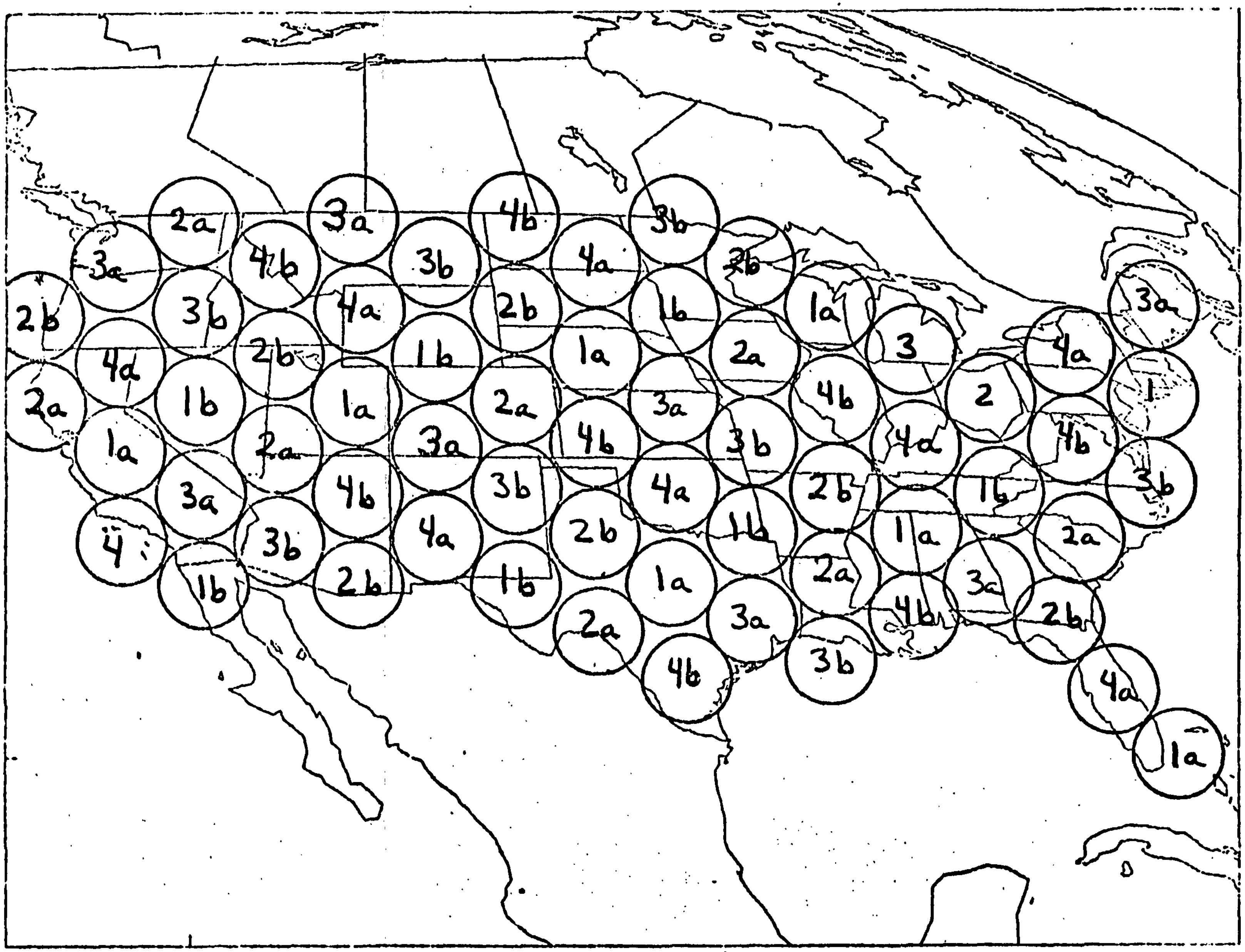
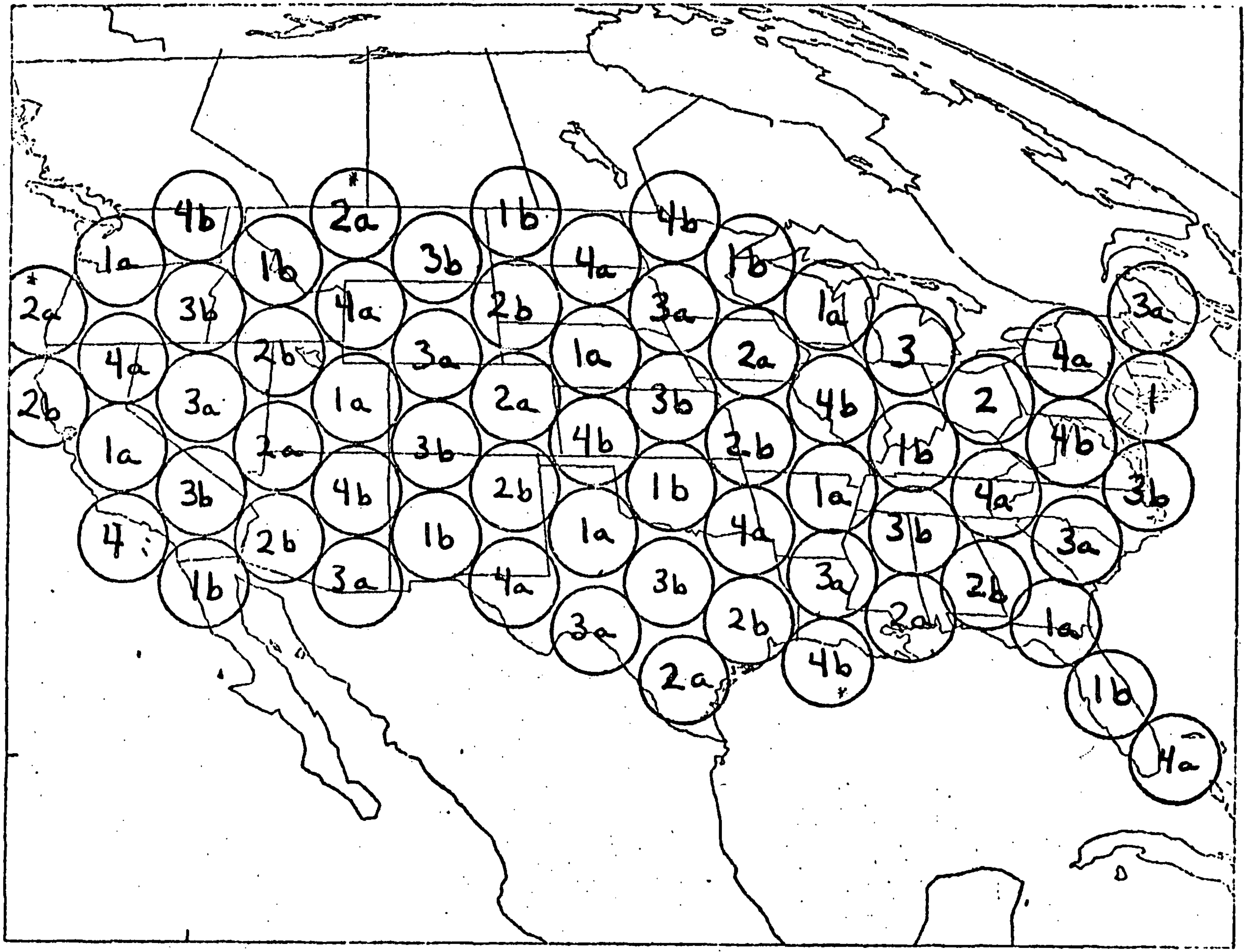


Figure C-11. Hybrid 4/8 Frequency Cell Site Arrangement (Homogenous)



SYNCHRONOUS VIEW AT -110.00 DEGREES LONGITUDE

Figure C-12. Hybrid 4/8 Frequency Cell Site Arrangement (Inhomogenous)

Around the edges of the cell site configurations in Figures C-11 and C-12, some cell site frequencies do not conform to the eight frequency arrangement. This is because, after all frequency assignments are made, it is necessary to check each edge cell site for other, possibly better, frequency assignments.

A multitude of permutations on this arrangement are possible just as they were on the hybrid 3/6 arrangement, allowing control over interference.

The cochannel interference statistics for all three of the above cell site arrangements has been extensively investigated assuming the antenna pattern shown in Figure C-13. Results are presented in Appendix B.

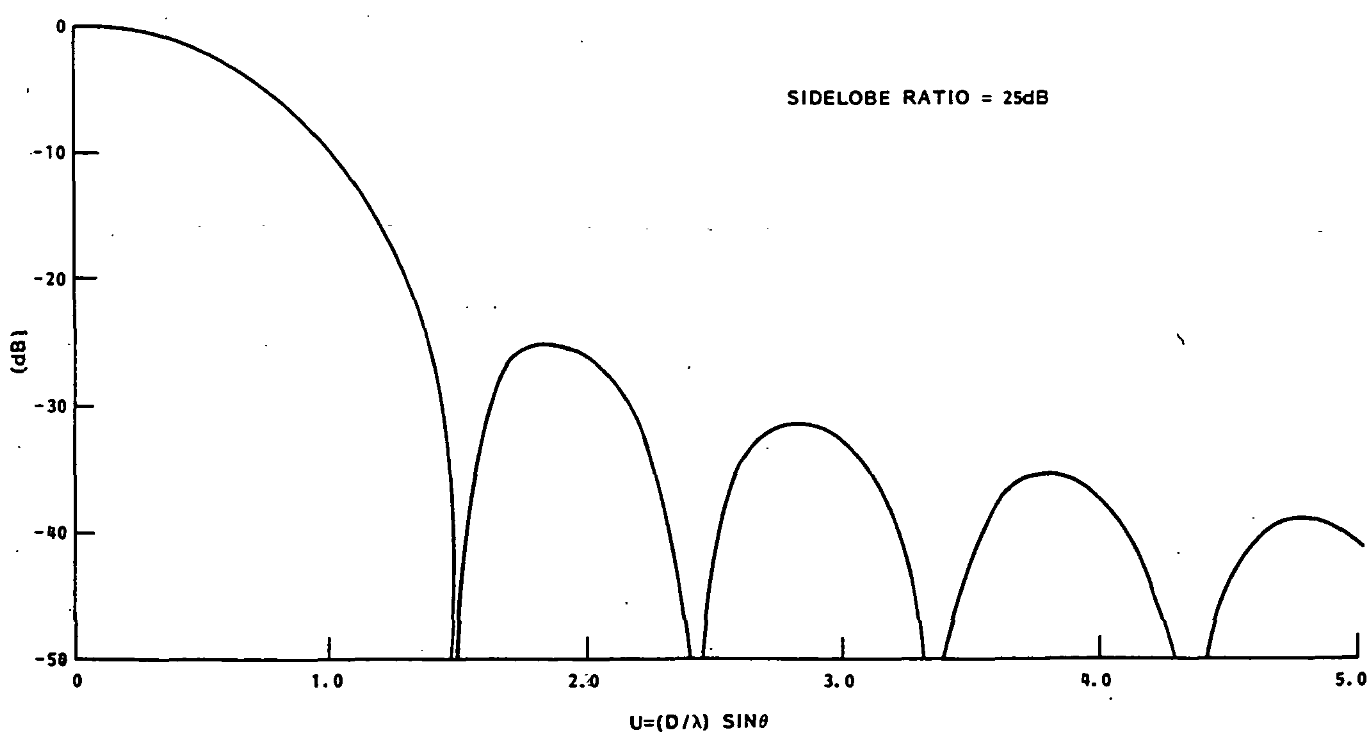


Figure C-13. Hansen Function Pattern

C.3 REFERENCES

C-1. Cornell, W. A. and Schulte, H. J., "Multi-Area Mobile Telephone System," IEEE Trans. Vehicular Communications, Vol. VC-9, pp. 43-48, May 1960.

C-2. Lewis, W. D., "Coordinated Broadband Mobile Telephone Systems," IEEE Trans. Vehicular Communications, Vol. VC-9, pp. 43-48, May 1960.

C-3. Frenkiel, R. H., "A High-Capacity Mobile Radiotelephone System Model Using a Coordinated Small-Zone Approach," IEEE Trans. Vehicular Technology, Vol. VT-19, pp. 173-177, May 1970.

C-4. Mikulski, J. J., "A System Plan for a 900-MHz Portable Radio Telephone," IEEE Trans. Vehicular Technology, Vol. VT-26, pp. 76-81, February 1977.

C-5. Hansen, R. C., "Circular Aperture Distribution with One Parameter," Electronics Letters, Vol. II, No. 8, 17 April 1975.

APPENDIX D

FREQUENCY MODULATION CHANNEL PARAMETERS

APPENDIX D

FREQUENCY MODULATION CHANNEL PARAMETERS

Frequency modulation is the obvious choice for the satellite system since it is widely used in the current mobile radio systems; it is the modulation method of the cellular systems currently undergoing evaluation, with which the satellite must be compatible; and, considering alternative modulation techniques, it appears to be less expensive and to perform better than the narrow band AM techniques proposed[D-1] and less expensive to implement than digital techniques.

This appendix discusses the performance achievable with frequency modulation and some of the tradeoffs available between performance, modulation parameters and voice processing.

D.1 VOICE CHANNEL QUALITY OBJECTIVES

Voice channel quality is highly subjective, a characteristic that is used to minimize the satellite and mobile terminal RF power and receiver sensitivity requirements. This is achieved through the use of companding which provides an objective advantage in that it increases the frequency deviation of the FM transmission from the lowest level talkers. In addition the expandor circuit at the receiver suppresses noise during periods of no talking and during inter-syllabic pauses which provides a subjective improvement in speech quality.

Additional improvement in channel quality is obtainable through the use of speech pre-emphasis at the transmitter and de-emphasis at the receivers. These filtering operations take advantage of the speech frequency spectrum to reduce the channel noise and interference effects relative to the speech signal carried.

The system modulation parameters in combination with the speech processing operations of emphasis and companding are used to provide a channel with a subjective performance equivalent to that of one with a test tone to noise ratio of greater than 50 dB.

D.1.1 DEVELOPMENT OF TEST TONE TO NOISE REQUIREMENT

Ignoring for the moment the specific implementation, the channel noise and dynamic range requirements can be derived as follows. From (D-2, page 50) it can be shown that an 18.4 dB talker volume-to-C-message-weighted-noise ratio gives telephone noise quality judged fair or better by 50% of the listeners. This is taken as the SNR that must be provided to the lowest level talker serviced. Any lower level talker would be asked to talk louder.

To determine the dynamic range required data is needed on the distribution of talker levels. Talker levels measured in dBm, are taken to be normally distributed with a standard deviation (σ) of from 5 dB to 6.5 dB (D-2, page 234). A standard deviation of 5 dB is somewhat less than that measured on the direct dial network intertoll trunks but about the same as that experienced on the long distance trunks. This smaller value, which gives a smaller dynamic range requirement, is adopted for the present system and justified on the basis that system designed to that standard deviation will support long distance calls and in the mobile radio application it is anticipated that the people will speak louder than in home use.

For a normal distribution of talker levels (in dB) 99.5% of the talker levels will be higher than a level 2.56 σ dB below the mean, 0.5% will be higher than a level 2.56 σ dB above the mean. These levels are taken as the extremes of the talker levels serviced and encompass 99% of the talkers. Talkers outside this range can be asked to adjust their level to fall withing the range. For the value of $\sigma = 5$ dB, the range of talker levels is 25.6 dB.

Another channel parameter of importance is the clipping level. A clipper to limit the speech amplitude into the frequency modulator is required to prevent excessive RF energy from being spread into adjacent channels. The clipping level is taken as 10 dB above the average level of the loudest speaker. At this clipping level noticeable, but not seriously objectionable distortion of the loudest talkers is experienced.

Figure D-1 illustrates and summarizes the channel signal levels for $\sigma = 5$ dB.

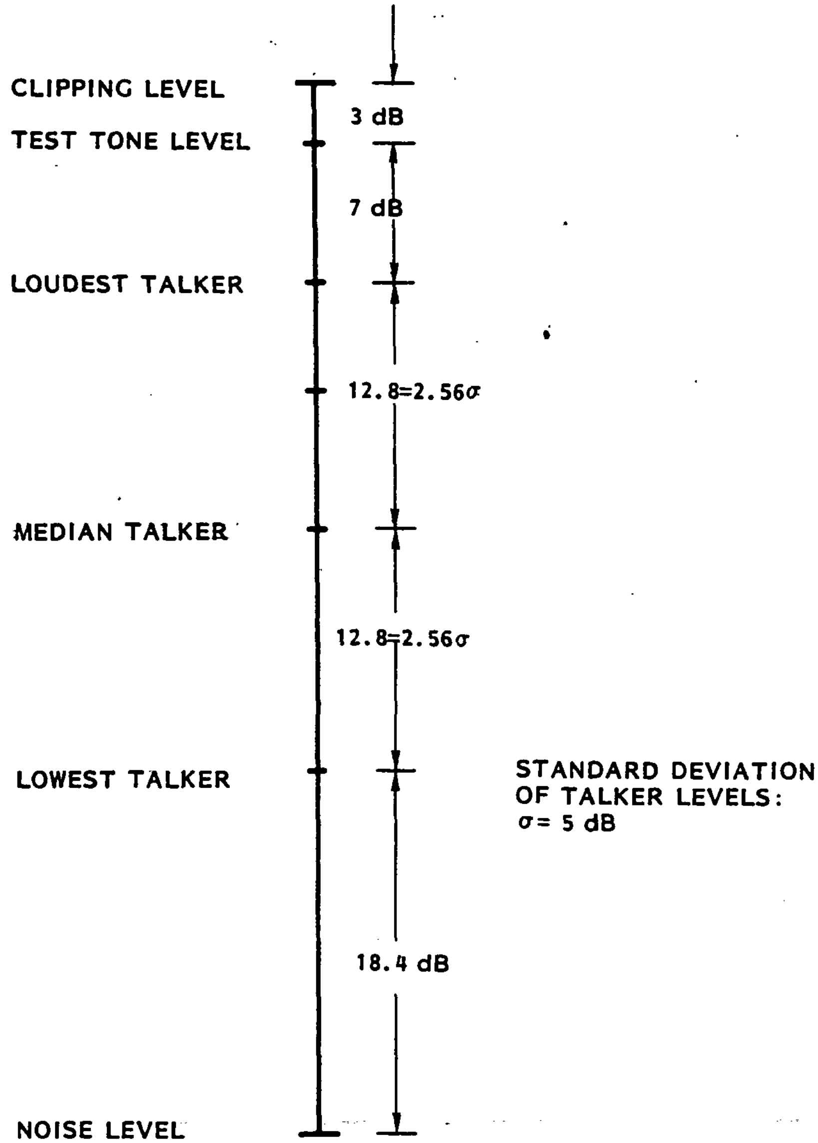


Figure D-1. Voice Channel Signal Level Distribution

D.1.2 AUDIO CHANNEL BANDWIDTH

In addition to channel dynamic range and SNR, the audio channel bandwidth is of importance. This directly affects the intelligibility of speech and hence should be as large as practical up to about 4000 Hz. Higher bandwidths restrict the allowable frequency deviation of carrier and reduce the SNR improvement of the link. A secondary effect is to increase the discriminator threshold C/No. A bandwidth from 300 to 3000 Hz is chosen for the baseline system. This bandwidth provides almost perfect sentence and word intelligibility.

D.2 AUDIO SIGNAL PROCESSING

The FM link is designed to provide the equivalent of a 50 dB Test Tone to Noise Ratio (TTNR). Use is made of emphasis circuits and companding to achieve the equivalent 50 dB TTNR with minimum system EIRP and G/T requirements.

Figure D-2 shows the audio processing elements of the baseline system, which are the same as those of the AMPS. These are discussed here. It is noted that at the transmitter the compressor portion of the compandor precedes the pre-emphasis network and at the receiver the de-emphasis network precedes the expandor. The complimentary relative positions of the emphasis and compandor circuits provides the proper signal levels at the two ends of the compondor to assure the expansion action of the receiver circuit matches the compression introduced at the transmitter. The specific order of the circuits, i.e., compressor-pre-emphasis-de-emphasis-expandor, is chosen so that the noise reduction and, hence, SNR improvement provided by the de-emphasis network is obtained before the expandor. The expander improvement is dependent on the SNR at the input to it: larger SNR's provide greater improvement.

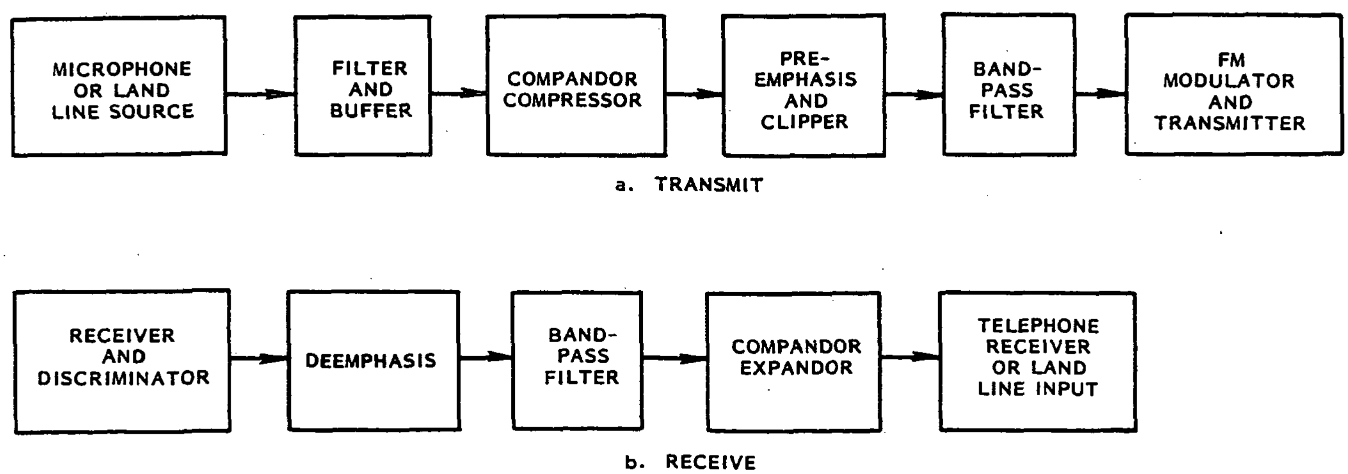


Figure D-2. Audio Processor

Filtering is included to limit extraneous signal inputs to the compander circuits and to confine the audio signal bandwidth.

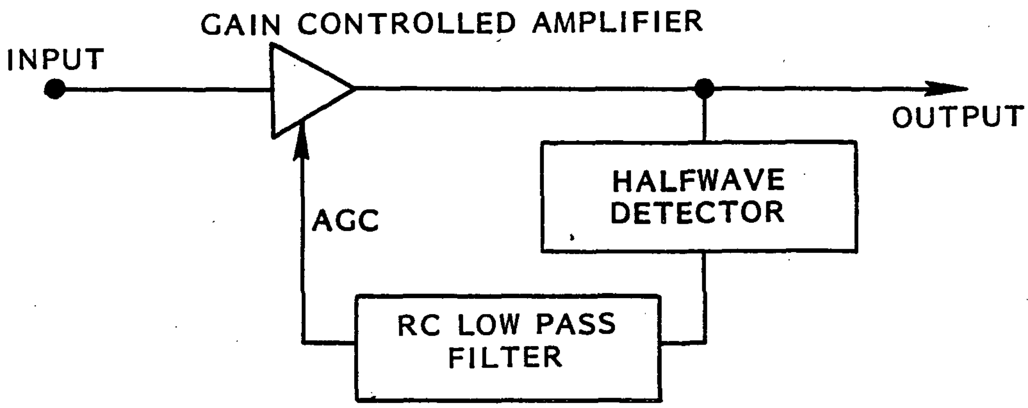
Clipping is included to prevent overmodulation of the frequency modulator which would introduce adjacent RF channel interference.

D.2.1 AMPLITUDE COMPANDING

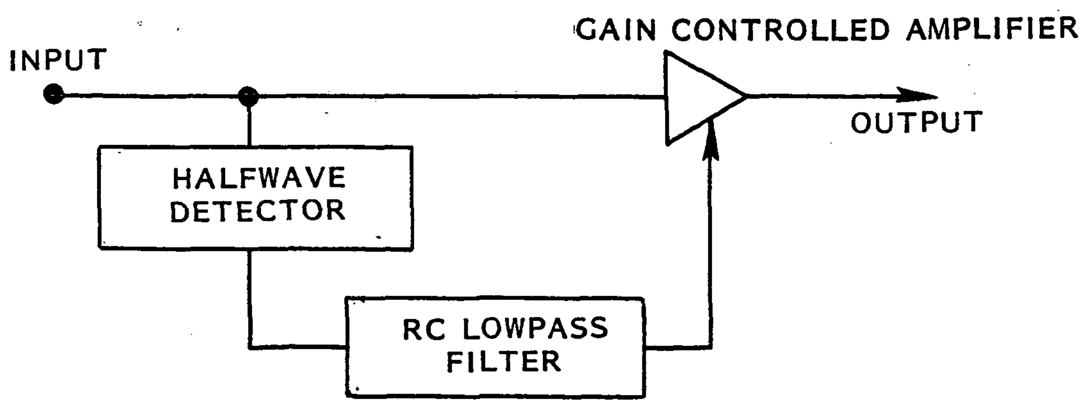
Syllabic amplitude companding introduces a number of benefits. It increases the level of softer speakers at the frequency modulator resulting in greater frequency deviation and greater SNR at the discriminator output. During speech pauses and intersyllabic pauses, noise introduced by the transmission is attenuated thereby giving a significant subjective SNR improvement. This is true for any low level disturbances introduced in the transmission path such as hum, spurious FM of system oscillators and cochannel interference.

In addition the expandor reduces the effect of large amplitude, short duration impulse-like disturbances. The expandor gain has a response time controlled by an RC low bandpass filter operating on a halfwave rectifier driven by the audio from the de-emphasis circuit. The RC drive constant is 20 ms. When in the high loss state, impulsive noise significantly shorter than the 20 ms response time of the integrator has little effect on the gain and hence is attenuated.

Considerable experience indicates that a 2:1 compandor is about optimum. The compressor in this case reduces the slow, slower than syllabic rate, input level variations by 2:1 in dB. A compensating expansion of the input levels to the receiver expandor restores the original levels. Figure D-3 is a block diagram of the compandor circuits and Figure D-4 illustrates the compandor effects for representative signal levels. It is noted that the relative audio signal levels (in dBm) applied to the frequency modulator are one-half those at the input to the compressor. In particular, the lowest level talkers audio signal level is increased by 12.8 dB giving that much signal to noise improvement over what it would have had without companding.



a. Compressor Circuit



b. Expandor Circuit

Figure D-3. Compandor Circuits

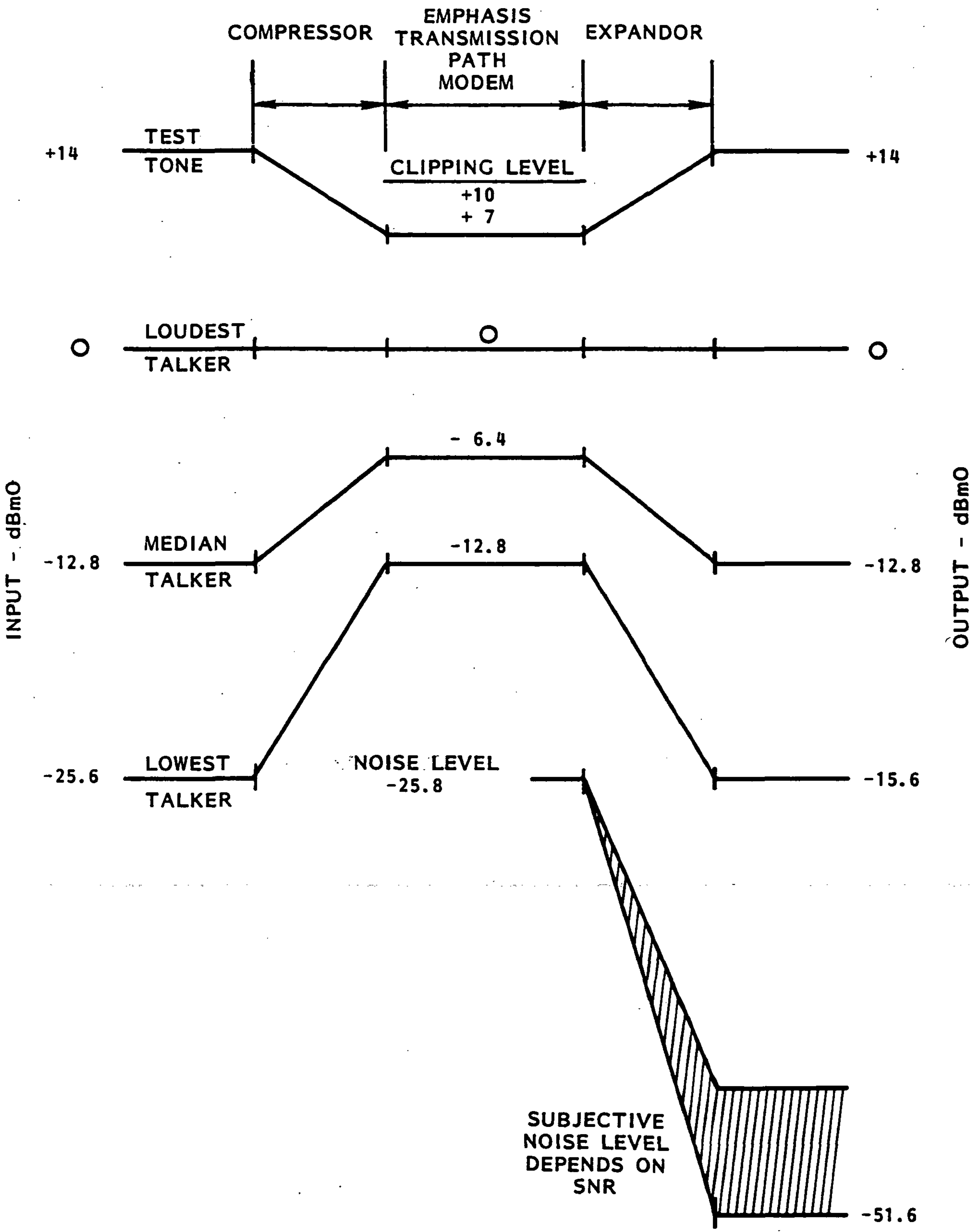


Figure D-4. Signal Levels in Compandored Channel

The channel noise level shown has been reduced by the noise improvement contributed by the de-emphasis network. For the channel noise level shown, the expandor circuit will reduce it to the -51.6 dBm0 level during periods of no talking giving substantial channel quieting. However, during speech the subjective noise level is higher than during speech pauses. Experiments[D-1] indicate the subjective improvement is dependent on the SNR at the expandor input as shown in Figure D-5.

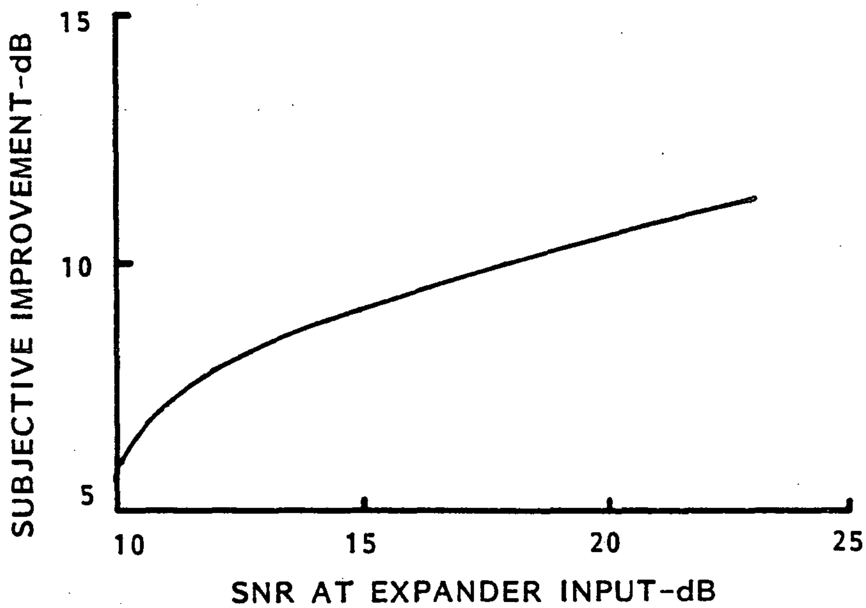


Figure D-5. Subjective SNR Improvement Due to the Expandor

D.2.2 EMPHASIS

Pre-emphasis circuits are used in the transmitter to modify the transmitted spectrum according to the shape of the noise spectrum experience in the transmission path. If, as in the case of speech transmitted by FM, the signal spectrum decreases with frequency and the noise spectrum increases with frequency, an improvement is obtained in the SNR at de-emphasis network.

Ideally, for large carrier-to-noise ratios (CNR), the power spectrum of noise from a frequency discriminator is of the form

$$N_d(f) = (1/k^2)\ (N_o/C) f^2 \ \text{watts/Hz}$$

where $1/k$ = the discriminator constant in volts per Hertz of frequency deviation from the carrier, f = baseband frequency, C = carrier power, N_o = noise density in watts/Hz. In practice, oscillator instabilities, impulsive noise at the discriminator output and interference tend to add a constant noise level to the f^2 variation of the ideal case. Consequently pre-emphasis of the form

$$| H_p(f) |^2 = K [1 + f^2/f_o^2]$$

is used to match the pre-emphasis to the noise spectrum. f_o is the corner frequency where the f^2 term becomes dominant in the noise spectrum and K is a constant chosen to keep the signal power to the frequency modulator the same as without pre-emphasis. For speech spectral power density S(f) this requires that

$$\int_{f_\ell}^{B} S(f)\, df = \int_{f_\ell}^{B} S(f) \cdot | H(f) |^2 df = K \int_{f_\ell}^{B} S(f) \; [1 + f^2/f_o^{\,2}] \; df$$

from which the value of K can be determined. B is the maximum audio frequency and f_ℓ is the minimum frequency. K depends on both the speech power spectrum and the corner frequency of the pre-emphasis network.

At the output of the receiver discriminator the de-emphasis network is added which has a transfer function of the form

$$| H_d (f) |^2 = 1/K [1 + f^2/f_o^{\,2}]$$

which reduces the noise in the audio band by the ratio

$$N/N_d = \int_{f_\ell}^{B} f^2\, df \Big/ \int_{f_\ell}^{B} f^2 \; [1/K (1 + f^2/f_o^{\,2})] \; df$$

The improvement obtained depends on the speech power spectrum, through the constant K, and on the noise spectrum, through f_o which is chosen so that the pre-emphasis network power transfer function approximates the noise spectrum of the transmission path. Boudreau and Davis[D-3] have calculated the improvement for the several cases shown in Table D-1. For subsequent work the conservative value of 7.0 dB emphasis improvement will be assumed. This leaves a potential implementation margin of up to 2.3 dB.

Table D-1. Emphasis Improvement

f_o Hz	Emphasis Improvement - dB	
	Flat Speech	Telephone Speech
30	8.1	9.3
300	7.9	8.2
600	7.0	8.0

Also it will be assumed that 1000 Hz is the crossover frequency of the emphasis networks. The crossover frequency is the audio band frequency that passes through the emphasis circuits without a change in level. This assumption is made to avoid having to keep track of the level changes of the 1000 Hz test tone discussed later and implies an emphasis circuit corner frequency between 300 and 600 Hz.

D.2.3 CLIPPING

A clipping level 10 dB above the average level of the loudest talker is assumed. Clipping is necessary to prevent over modulation of the frequency modulation which could contribute to adjacent channel interference. For unfiltered speech clipping at 10 dB above the average level introduces noticeable but not too objectionable distortion. This relatively low clipping level is chosen to minimize the link dynamic range requirements.

D.3 FM LINK CARRIER TO NOISE REQUIREMENTS

Using the previously discussed data the FM link Carrier to Noise Ratio (CNR) requirements are developed and available tradeoffs presented. The CNR's form the basis for the link budgets from which the mobile and satellite power requirements are derived.

At the discriminator output, before the de-emphasis and expander circuits, the audio SNR is given by

$$SNR = 10 \log_{10} [3(C/N_o)f^2_{rms}/B^3] \text{ - dB} \qquad D1$$

where:

SNR = the signal to noise ratio in the audio band having a high cut off frequency of B Hz

C = Carrier power at IF

N_o = Noise plus interference density at IF - watts/Hz

f_{rms} = RMS carrier frequency deviation due to the audio signal

B = Maximum audio frequency transmitted.

This equation applies when the FM link is above the noise improvement threshold which is given by (D-1):

$$(C/N_o)_T = 6.64 + 12.9 \log W - 2.9 \log B \qquad D2$$

where:

W = IF bandwidth - Hz

B = Maximum audio frequency - Hz

With these equations the FM link bandwidth and carrier-to-noise requirements can be derived.

It is convenient to consider the use of a test tone TT in the link performance description. The TT is at a frequency of 1000 Hz and its level is such as to drive the modulator to the clipping level, i.e., the maximum allowable deviation, at the tone peaks. This is illustrated in Figure D-4. It is noted that the TT rms level is 3 dB below the peak.

With this definition of the TT, the subjective audio SNR of the lowest talker can be related to the TTNR as shown in Figure D-6. This curve is based on the expander and de-emphasis

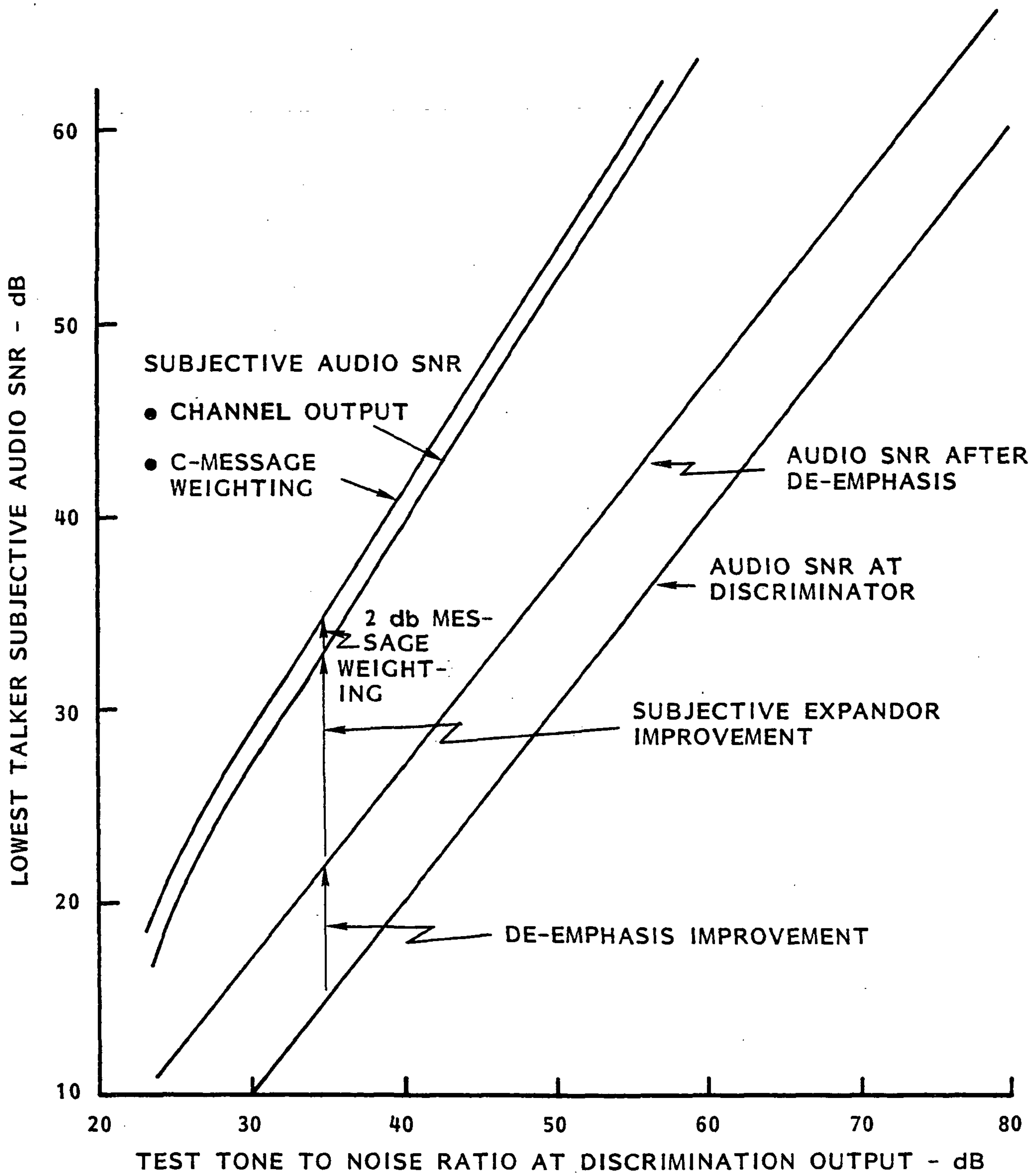


Figure D-6. Lowest Talker Subjective Audio Signal to Noise Ratio at Channel Output vs. TTNR at Discriminator Output

SNR improvement data given previously and on the distribution of talker levels described by $\sigma = 5$ dB and loudest and lowest talking being $2.56\,\sigma$ above and below the median talker, respectively. That distribution defines the lowest talker SNR at the discriminator output.

From the data of Figure D-6, the required IF bandwidth (W), lowest talker subjective SNR and threshold IF can be related to the TTNR through the use of equations 1 and 2. This is shown in Figure D-7.

D.4 REFERENCES

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D-3. P.M. Boudreau, N.C. Davies, "Modulation and Speech Processing for Single Channel per Carrier Satellite Communications" 1971 International Communications Conference Record, pp 19-6 to 19-15.

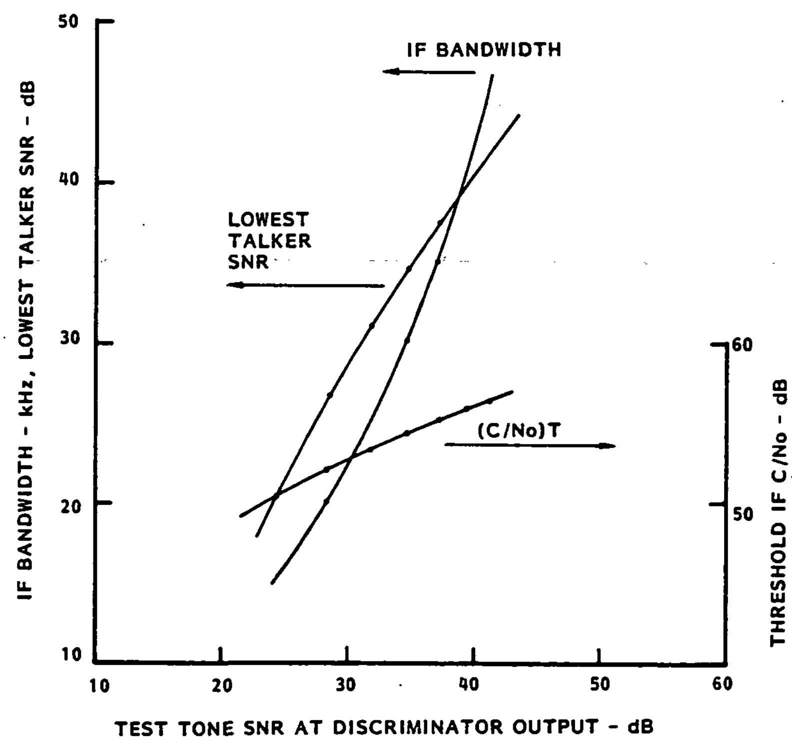

Figure D-7. IF Bandwidth, Lowest Talker SNR and Threshold Carrier to Noise Density (C/No) T vs. Test Tone SNR at Discriminator

APPENDIX E

LINK POWER BUDGETS

APPENDIX E

LINK POWER BUDGETS

For the purposes of this study, since there are no frequency allocations to the service, the satellite aided mobile radio service is assumed to operate at either UHF or L-band and link power budgets are developed for both cases. In addition, the use of the Ku-band for links between the satellite and fixed earth station is assumed and for that frequency band, the link budgets are developed.

The following cases are considered:

<u>Links Between Mobiles and Fixed Earth Stations</u>

• Mobile to Satellite	UHF and L-band
• Satellite to Earth Station	Ku-band
• Earth Station to Satellite	Ku-band
• Satellite to Mobile	UHF and L-band

<u>Links Between Mobiles (Direct)</u>

• Mobile to Satellite	UHF and L-band
• Satellite to Mobile	UHF and L-band

A frequency separation between uplinks and downlinks in the mobile band (UHF and L-band) of about 6% is assumed. The frequency separation in practice should be made as small as possible, to minimize the difference between transmit and receive beam shapes, within the constraints of transponder duplexer design requirements and eventual frequency allocations. The use of the 12/14 GHz Ku-band is assumed for the satellite - earth station link.

Symbols used are defined as follows:

C = Carrier power per channel

N_o = Noise power density

I_o = Interference, cochannel or adjacent channel, power density

IM_o = Intermodulation product power density

$X_o = (N_o + I_o + IM_o)$

= Sum of thermal noise, interference and intermodulation power densities.

Power densities are in watts per Hz. Unsubscripted symbols refer to power in a defined bandwidth, usually the 25 kHz IF bandwidth.

Figure E-1 illustrates the interfaces in the links where carrier-to-noise ratios are defined in the link budgets. It is noted that although the intermodulation products are generated in the satellite power amplifier they are treated as additive interference. That interference, like adjacent channel and cochannel, is proportioned to the carrier power. That is, it depends on the power amplifier design and operating point, and system design. For fixed designs and operating points increasing the carrier power does not increase the carrier-to-interference ratio. It does increase the carrier-to-thermal noise ratio, however.

In the presentation of link budgets, the tabulation begins by deriving the requirements of the link under consideration from the system requirement and the effect of the other half of the tandem link. The effect of the other half is entered as a degradation, in dB. This yields the link C/X_o required. Adding to C/X_o the degradation (in dB) due to interference and intermodulation, where necessary, gives the link carrier-to-thermal noise, C/N_o, requirement from which carrier power is derived.

The degradation factors, in numerical rather than dB units, are as follows. The tandem link C/X_o is specified to satisfy the system requirement. Designating it as $(C/X_o)_s$ and the carrier-to-noise plus interference plus intermodulation on the two halves of the links as $(C/X_o)_1$ and

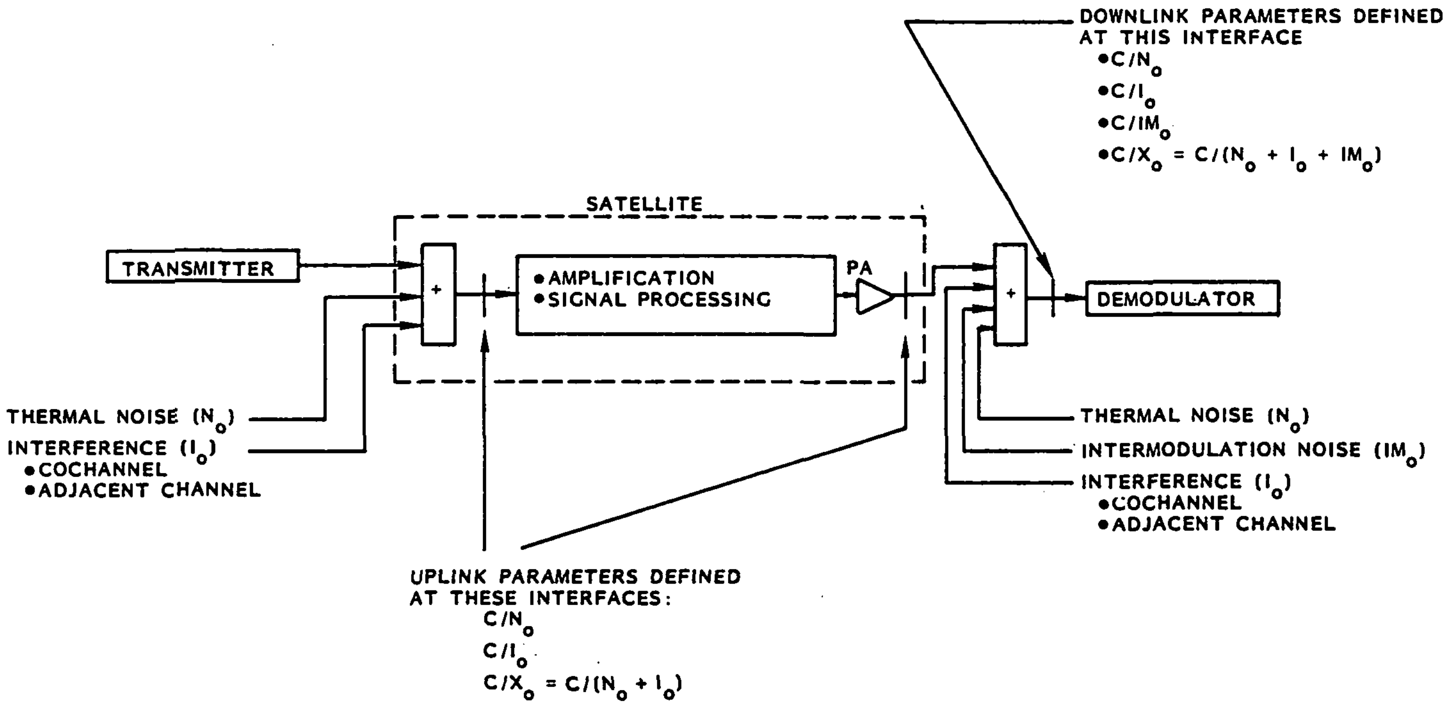

Figure E-1. Definition of Link Budget Parameters

$(C/X_o)_2$, the reciprocals of these quantities are related by:

$$(X_o/C)_s = (X_o/C)_1 + (X_o/C)_2$$

Letting the subscript 1 designate the link under consideration, subscript 2 the other half of the link, and D be the degradation of the system C/X_o by the other half of the link, then:

$$(C/X_o)_1 = D\,(C/X_o)_s$$

i. e., the link under consideration has to have a C/X_o that is D times as large as the system C/X_o.

The second link requirement, $(C/X_o)_2$, is related to the system requirement by:

$$(C/X_o)_2 = \frac{D}{D-1} (C/X_o)_s$$

D, after conversion to dB, is entered on the second line of the link budgets, and $(C/X_o)_2$ as defined above is entered in the notes at the bottom of the budgets.

The effects of interference are handled in a similar manner. For the link under consideration

$$(X_o/C)_1 = (N_o/C) + ((I_o+IM_o)/C)$$

Let ID designate the degradation due to interference and intermodulation.
Then

$$(C/N_o) = ID \cdot (C/X_o)_1$$

and

$$(C/(I_o + IM_o)) = \left(\frac{ID}{ID-1}\right) (C/X_o)_1$$

The quantity ID, in dB form, is entered on the fourth line of the budgets and $C/(I_o + IM_o)$ is entered in the note at the bottom of the listing.

Tables E-1 through E-6 give the link budgets for the case where the mobile band is at UHF and the circuits are between a mobile and an earth station. Tables E-1 and E-4 are the UHF uplink and downlink, respectively. E-2 and E-3 are the associated Ku-band down and up links.

It is noted that all the budgets are on a per channel basis, that is, they are for a single half-circuit. In the tables positive quantities that should be subtracted when forming the sum (e.g., antenna gains) are in parentheses. Tables E-5 and E-6 are the budgets for the case where the circuits are between mobiles directly, without going through an earth station.

Table E-1. Power Budget for UHF Mobile-to-Satellite Link for Mobile-to-Earth Station Half-Circuit

Carrier-to-(Noise + Interference + IM) at ES Receiver	(C/X_o) ES	53.3	dB
Downlink Degradation (1)		0.5	dB
Uplink C/X_o Required	$(C/X_o)_u$	53.8	dB
Uplink C/X_o Degradation Due to Interference (2)		0.9	dB
Uplink C/N_o Required	$(C/N_o)_u$	54.7	dB
Propagation Loss	L	182.3	dB
Uplink Margin	M_u	5.0	dB
Satellite Antenna Gain	G_S	(44.0)	dBic
Satellite Receive Noise Temperatures	T_s	27.6	dB°K
Boltzmann's Constant	k	-228.6	dBw/Hz/°K
Mobile EIRP Required	$EIRP_m$	-3.0	dBW
Mobile Antenna Gain	G_m	(2.8)	dBic
Mobile Power	P_m	-5.8	dBW

(1) Downlink $C/X_o \geq 62.9$ dB Required

(2) Cochannel plus Adjacent Channel Interference: $C/I_o \geq 61$ dB

$C/I \geq 17$ dB

Table E-2. Power Budget for Ku-Band Satellite-to-Earth Station Link of Mobile-to-Earth Station Half-Circuit

Carrier-to-(Noise + Interference + IM) at ES Receiver	$(C/X_o)_{ES}$	53.3	dB
Uplink Degradation (1)		9.6	dB
Downlink C/X_o Required	$(C/X_o)_{dK}$	62.9	dB
Downlink Degradation due to Interference (2)		4.2	dB
Downlink C/N_o required	$(C/N_o)_{dK}$	67.1	dB
Propagation Loss (12GHz)	L	205.4	dB
Margin	M_{dK}	4.0	dB
Earth Station Gain (4.5 meter, 50% Eff)	G_{ES}	(52.0)	dBic
Earth Station Noise Temperature	T_{ES}	30.0	$dB^{o}K$
Boltzmann's Constant	k	-228.6	$dBw/Hz/^{o}K$
Satellite EIRP Required	$EIRP_s$	25.9	dBW
Satellite Antenna Gain	G_{SK}	(46.0)	dBic
Satellite Power	P_S	-20.1	dBW

(1) Uplink $C/X_o \geq 53.8$ dB

(2) Carrier-to-(Cochannel + Adjacent Channel + IM_o): $C/I_o > 65$ dB

Table E-3. Power Budget for Ku-Band Earth Station-to-Satellite Link of Earth Station-to-Mobile Half-Circuit

Carrier-to-(Noise + Interference + IM) at Mobile Receiver	$(C/X_o)_m$	53.3	dB
Downlink Degradation (1)		9.6	dB
Uplink C/X_o Required	$(C/X_o)_{uK}$	62.9	dB
Uplink Degradation due to Interference (2)		6.6	dB
Uplink C/N_o Required	$(C/N_o)_{uK}$	69.5	dB
Propagation Loss	L	206.7	dB
Margin	M_{uK}	4.0	dB
Satellite Antenna Gain	G_{SK}	(46.0)	dBic
Satellite Receiver Noise Temperature	T_S	30.0	dB^{o}K
Boltzmann's Constant	k	-228.6	dBw/Hz/^{o}K
Earth Station EIRP Required	$EIRP_{ES}$	35.5	dBW
Earth Station Gain	G_{ES}	(52.0)	dBic
Earth Station Power	P_{Sk}	-16.5	dBW

(1) UHF Downlink $C/X_o \geq 53.8$

(2) K-band Uplink Carrier-to-(Cochannel +Adjacent Channel+ IM); $C/I_o \geq 64$ dB

Table E-4. Power Budget for UHF Satellite-to-Mobile Link of Earth Station-to-Mobile Half-Circuit

Carrier-to-(Noise + Interference + IM) at Mobile Receiver	$(C/X_o)_m$	53.3	dB
Uplink Degradation (1)		0.5	dB
Downlink C/X_o Required		53.8	dB
Downlink C/X_o Degradation Due to Interference and IM (2)		1.5	dB
Downlink C/N_o Required	$(C/N_o)_d$	55.3	dB
Propagation Loss	L	182.8	dB
Downlink Margin	M_o	5.0	dB
Mobile Antenna Gain	G_m	(2.8)	dBic
Mobile Receive Noise Temperature	T_m	27.6	dB^oK
Boltzmann's Constant	k	-228.6	$dB/Hz/^oK$
Satellite EIRP Required	$EIRP_S$	39.3	dBW
Satellite Antenna Gain	G_S	(44.0)	dBic
Satellite Power	P_S	-4.7	dBW

(1) Uplink $C/X_o \geq 62.9$ dB Required

(2) Downlink $C/I = 17$ dB and $C/IM = 20$ dB Giving $C/X_o = 59.2$ dB

Table E-5. Power Budget for UHF Mobile-to-Satellite Link of Mobile-to-Mobile Half-Circuit

Carrier-to-(Noise + Interference + IM) at Mobile Receiver	$(C/X_o)_m$	53.3	dB
Downlink Degradation (1)		7.2	dB
Uplink C/X_o Required	$(C/X_o)_u$	60.5	dB
Uplink Degradation Due to Interference (2)		10.0	dB
Uplink C/N_o Required	$(C/N_o)_u$	70.5	dB
Propagation Loss	L	182.3	dB
Uplink Margin	M_u	5.0	dB
Satellite Antenna Gain	G_S	(44.0)	dBic
Satellite Receive Noise Temperature	T_S	27.6	dB°K
Boltzmann's Constant	k	-228.6	dB/Hz/°K
Mobile EIRP Required	$EIRP_m$	12.8	dBW
Mobile Antenna Gain	G_m	(2.8)	dBic
Mobile Power Required	P_m	10.0	dBW

(1) Downlink $C/X_o \geq 54.2$ dB; C/X_o at Mobile Receiver Output due to Downlink Impairments

(2) Uplink Cochannel + Adjacent Channel Interference: $C/I_o \geq 61$ dB

Table E-6. Power Budget for UHF Satellite-to-Mobile Link of Mobile-to-Mobile Half-Circuit

Carrier-to-(Noise + Interference + IM) at Mobile Receiver	$(C/X_o)_m$	53.3	dB
Uplink Degradation (1)		0.9	dB
Downlink C/X_o Required	$(C/X_o)_d$	54.2	dB
Downlink C/X_o Degradation Due to Interference and IM (2)		1.7	dB
Downlink C/N_o Required	$(C/N_o)_d$	55.9	dB
Propagation Loss	L	182.8	dB
Downlink Margin	M_d	5.0	dB
Mobile Antenna Gain	G_m	(2.8)	dBic
Mobile Receive Noise Temperature	T_S	27.6	dB°K
Boltzmann's Constant	k	-228.6	dBw/Hz/°K
Satellite EIRP Required	$EIRP_S$	33.9	dBW
Satellite Antenna Gain	G_S	(44.0)	dBic
Satellite Power Required	P_S	-4.1	dBW

(1) Uplink $C/X_o = 60.5$ dB; C/X_o at Satellite Receiver Output

(2) Downlink $C/I = 17$ dB, $C/IM = 20$ dB Giving $C/X_o = 59.2$ dB

In all links the uplink portion is made relatively strong to minimize the satellite power required. Even so the uplink power requirements are modest.

If the mobile band is at L-band, the link budgets can be obtained by modifying the UHF budgets as follows:

	UHF	Change	L-Band
Uplink Propagation Loss-dB	182.3	5.3	187.6
Downlink Propagation Loss-dB	182.8	5.3	188.1
Mobile/Earth Station Circuit			
Mobile Transmit Power-dBW	-5.8	5.3	-0.5
Satellite Transmit Power-dBW	-4.7	5.3	+0.6
Mobile/Mobile Circuit			
Mobile Transmit Power-dBW	10.0	5.3	15.3
Satellite Transmit Power-dBW	-4.1	5.3	1.2

All other parameters remain substantially the same as for the UHF case. The satellite antenna gain remains the same because the same area of the earth must be covered. Similarily, the mobile antenna gain is the same because the same angular coverage is acquired to keep the satellite within the beam. Only the propagation losses change because the mobile and satellite antenna effective apertures are proportional to the reciprocal of the frequency squared.

APPENDIX F

OFFSET PARABOLIC REFLECTOR ANTENNAS

APPENDIX F

OFFSET PARABOLIC REFLECTOR ANTENNAS

Extensive effort has been devoted recently to the design of multiple beam antennas. Because of its relative simplicity and light weight, the offset reflector has received considerable atten- for large space structures (Reference F-1). Detailed analyses of the scanning performance of offset parabolic antennas has been done under a study for NASA/LeRC (References F-2 and F-3). Affifi (Reference F-2) has shown that with an offset reflector having focal length to diameter ratio (F/D) of unity, the mainbeam and sidelobe structure stays very nearly constant at scan angles of more than 6 beamwidth, although there is some loss of gain. Going to an F/D of 1.335, Affifi (Reference F-3) obtained similarily good scanning performance at scan angles of more than 10 beamwidths.

Although good scanning performance has been achieved, there is a fundamental constraint in the use of offset parabolic reflectors for generating multiple contiguous beams for frequency reuse. That is, there is a rigid relationship between the focal length, feed aperture and beam-to-beam offset angle. This relationship restricts the reflector illumination edge taper achievable, and hence the suppression of sidelobes. Sidelobes lower than about 20 dB below the peak gain have not been obtained without special feed techniques. These techniques involve the excitation of feeds surrounding the feed of the beam of interest to suppress the sidelobes. The mobile radio application requires sidelobes approximately 25 dB below the peak gain. Analyses indicate this is achievable, in effect, in the areas containing the frequency reuse cells.

Because of the relatively light weight and advanced state of development of the offset parabolic antenna and the availability of means to control the sidelobe levels, they are good candidates for this application.

The most significant parameters of the offset parabolic reflector antenna are shown in Figure F-1. Tables F-1 through F-3 give numerical values for the several parameters for representative UHF and L-band frequencies and F/D ratios of 0.75, 1.0 and 1.355. Also indicated are the feed array dimensions.

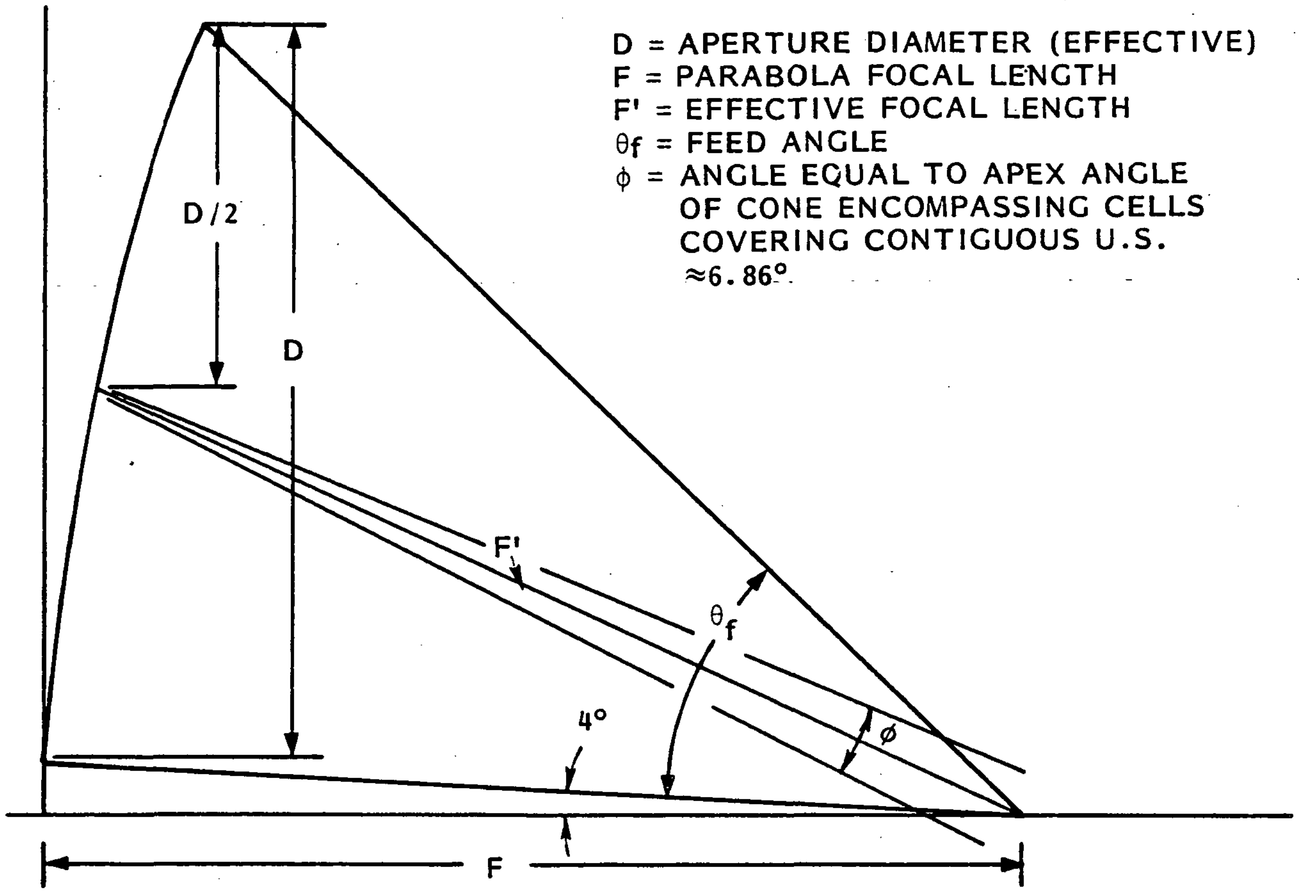

Figure F-1. Offset Parabolic Reflector Parameters

Table F-1. Reflector Parameters for F/D = 0.75

		850 MHz	1585 MHz
Aperture (D) - meters (ft)	120λ	42.35 (138.9)	22.71 (74.5)
F' = 1.136F - meters (ft)	102.2λ	36.0 (118.1)	19.31 (63.4)
Feed Dimension, Max. - meters (ft)	0.89λ	0.314 (1.0)	0.168 (0.55)
Feed Array Diameter - meters (ft)	2F'tan (φ/2)	4.32 (14.2)	2.31 (7.59)
Feed Angle (Θ_f) degrees	66.1°		
F/D	0.75		

Table F-2. Reflector Parameters for F/D = 1.0

		850 MHz	1585 MHz
Aperture (D) - meters (ft)	120λ	42.35 (138.9)	22.71 (74.5)
F' = 1.081F - meters (ft)	129.74λ	45.79 (150.2)	24.56 (80.6)
Feed Dimension, Max - meters (ft)	1.13λ	0.399 (1.31)	0.214 (0.702)
Feed Array Diameter - meters (ft)	2F' tan (φ/2)	5.49 (18.0)	3.124 (9.66)
Feed Angle (Θ_f) - degrees	52.29°		
F/D	1.0		

Table F-3. Reflector Parameters for F/D = 1.355

		850 MHz	1585 MHz
Aperture (D) - meters (ft)	120λ14	42.35 (138.9)	22.71 (74.5)
F' = 1.048F - meters (ft)	170.4λ	60.14 (197.3)	32.25 (105.8)
Feed Dimension, Max. - meters (ft)	1.487λ	0.525 (1.72)	0.281 (.922)
Feed Array Diameter - meters (ft)	2F' tan (φ/2)	7.21 (23.65)	3.87 (12.68)
Feed Angle (Θ_f) - degrees	40°		
F/D	1.355		

Table F-4 gives the same data for a reflector to be used at Ku-band.

Table F-4. Ku-Band Reflector Parameters for F/D = 1.0

		11.7 GHz
Aperture (D) - meters (ft)	120λ	3.08 (10.1)
F' = 1.081F - meters (ft)	129.74λ	3.33 (10.9)
Feed Dimension - meters (ft)	1.13λ	0.029 (0.095)
Feed Array Diameter - meters (ft)	2F' tan (φ/2)	0.4 (1.31)
Feed Angle - degrees	52.29°	
F/D	1.0	

For offset parabolic reflectors, the feed plane is perpendicular to the line labelled F' and is located at the point where F' intersects the parabola axis, i.e., at the focal point of the parabola. The angle a beam is displaced from the axis of the parabola is approximately $\beta = \tan^{-1}(d/F')$ where d is the linear displacement from the focal point of the parabola and F' is the effective focal length of the offset parabola. This is equal to the angle formed by a line from the phase center of the feed horn to the point on the reflector where F' intersects it and the line F'. The feedhorn phase center, F' and the beam axis all lie on the same plane. The angle β is restricted to the range of $\beta \leqslant (\varphi - BW/2)$ where BW is the antenna beamwidth.

As viewed looking toward the earth, the feed array would appear as shown in Figure F-2, assuming 0.5° beamwidth beams. The circles represent the feedhorn aperture. The appearance is like that of the beam footprints on the earth as viewed from orbit except that the pattern is rotated 180°. The angular displacement of several feeds, corresponding to the beam axis displacement from the parabolic antenna axis, is shown. For the contiguous U.S. the maximum angular displacement is about 3.2° corresponding to 6.4 beamwidths. Maximum beam displacement for the Alaskan beams is about 5.1° or more than 10 beamwidths. If an antenna F/D = 1 is used there may be pattern degradation at scan angles of 10 beamwidths. However, the group of Alaskan beams is isolated and cochannel interference may not be serious even with degraded patterns.

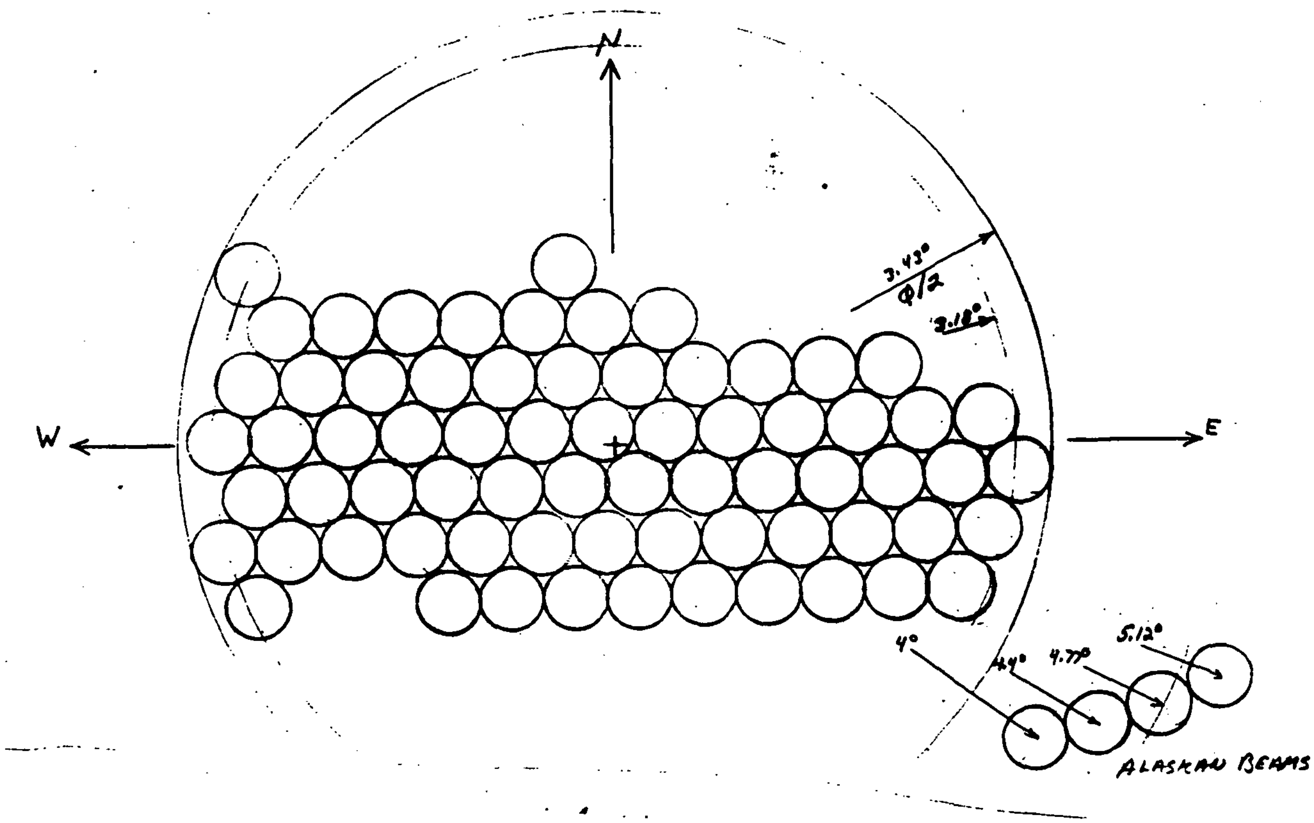

Figure F-2. Feed Array

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F-3 Affifi, M., "Antenna Design Considerations (Part II) and Frequency and Spectrum Re-use Coverage Planning," General Electric Co. Internal Report 1J52LeRC289, June 1979

APPENDIX G

PUBLIC SAFETY AND PUBLIC SERVICE USES OF SATELLITE-AIDED MOBILE RADIO

APPENDIX G

PUBLIC SAFETY AND PUBLIC SERVICE USES OF SATELLITE-AIDED MOBILE RADIO

The two-way land mobile radio service came into being as a result of the needs of the Public Safety sector. Today it would be unusual to find a police car or a fire fighting vehicle without radio. Ambulances, forrestry service and national Red Cross all are extensive users of two-way mobile radio. The terrestrial radio services serve all these groups but there are certain communications requirements which are difficult to serve adequately with two-way radio. Problems are especially severe for those organizations that cover every wide territories, operate in thinly populated areas, and rugged terrains or have need for intensive communications in an area of the country which cannot be easily predicted beforehand.

Table G-1 is a matrix of various public safety organizations and how they match with the unique characteristics of satellite-aided/mobile radio service. Also included is the need for secure voice communications or need for rapid access to a central data bank. Public safety organizations are typified by the following:

- State Police Departments
- Federal Bureau of Investigation
- County Sheriff
- Drug Enforcement Agency
- Internal Revenue Service
- Immigration and Naturalization Service
- Federal Communications Commission - Field Operations Bureau
- Parks Commissions
- State Fire Marshalls
- Search and Rescue
- Defense Civil Preparedness Agency

Table G-1. Public Safety Needs of Satellite Land Mobile Radio

Public Safety Organization	Suburban & Rural	Statewide or Nationwide	Secure Voice	Data
State Police Department				
• Investigators	X	X	X	X
• Supervisors			X	
• Patrol				X
Federal Bureau of Investigation	X	X	X	X
County Sheriff				
• Prisoner transport	X	X		
• Patrol				X
Drug Enforcement Agency	X	X	X	X
Federal Marshalls	X	X		
IRS	X	X		
Border Patrol	X	X		
FCC/FOB		X		X
Parks Commission	X	X		
State Fire Marshalls				
• Forest fire fighting	X	X		
Search and Rescue				
• DCPA, etc.	X	X		
• Red Cross	X	X		X
- Party line				
- Radiotelephone				

DISPATCH VERSUS RADIO TELEPHONE SWITCH SERVICE

Public Safety uses of radio have traditionally been a conventional dispatch service. The dispatcher runs a master station and contacts a group of people via their mobile radios, usually in vehicles, but sometimes personally carried. Requests and orders are tersely passed through a central dispatcher or operator.

In the case of a wide area service such as might be served with satellite land mobile, there is a frequent need to access the public switched telephone network in order to contact all segments of the same organization and also other organizations with which these wide-area groups interact. It is contemplated that communications in locally concentrated limited areas will continue to be served by the terrestrial services. In the case of urban areas, the terrestrial systems will provide this concentrated service.

The demarcation between dispatch channels and radio telephone channels becomes less clear when they are implemented in software. For example, the differences could be more administrative than technical. A dispatcher when he operates his push-to-talk button could in fact be setting up a group of channels for specific address or telephone numbers, either in party line or group calling arrangement. This could be arranged in software for that particular supervisor for the particular button which he pushes. The only further requirements is that an access code be sent when the dispatcher pushes the button. This is identical to the radiotelephone requirement for sending the number or identification of the calling party as well as the called party. Software could give priority to channels for such usages. As an example, if this were made part of the same block of channels used in the ordinary public radio telephone satellite service, it would be possible to reserve a certain number of channels for use in priority public service. Another possibility is the use of a priority takeover. This is similar to that used in military communications where a high level priority message can be initiated and circuits seized from less important communications.

It would not be necessary to have all channels that might be used during a rush period on the public safety channels set aside from the ordinary public switched network. The effect to the public safety user would be the same as having a number of dedicated channels at all times. Maximum use would be made of all channels. This type of versatility is allowed in systems which set up all communications via a rapid order wire channel set aside for that purpose.

If the arrangement for accessing dispatched vehicles is identical in hardware to that used for accessing the public switched network, then it is possible to have a combination system where a mobile in the field could call either his dispatcher or call in through the public switch network to any person served by either satellite radio telephone, terrestrial radio telephone, or terrestrial landline system.

Public safety use of radio increasingly needs better provisions for secure voice communications. This is true of data usages as well. In the case of secure voice transmissions, most techniques presently require a wider bandwidth to obtain high intelligibility and voice recognition when digital encoding is used than with ordinary analog voice. To obtain secure voice channels it might be necessary to use pairs of channels at increased bandwidth for those circuits that require secure voice and digital encoding. Data can be sent either within the baseband along with voice (low data rates) or occupy the full channel for bursts of high data rate communications. Most data transmissions by public safety organizations are brief in nature, such as identification of license plates and individuals. It is conceivable that for search and rescue Red Cross, or Civil Defense, personnel with need for accurate conditions and survivor data, that the total data to be sent might be quite large. In this case a data channel could use the entire bandwidth whereas for some of the other applications it might be possible to use a narrow slice of the baseband for the background data along with the voice.

TYPICAL PUBLIC SAFETY USERS

Representative public safety users were listed in Table G-1. Each of these organizations has its own terrestrial system but also has a need for improved coverage and service that a satellite might best give them.

State Police Department

State police agencies are organized in various ways. In some states the State Police Agency is limited to patrolling state roads and interstate highways. In most states they are the overall agency that handles cases which are regional in nature and cover more than several counties, or that provide the police service to remote parts of the state. For example, a manhunt through mountainous areas is almost always directed by state police.

The need for communications by state police has overbalanced the economics in most instances. Most states have a state police radio network. In some instances the effectiveness is not as high as it could be, but it is generally felt to be reasonably good.

There are state police officers, such as investigators and supervisors, who have special communication needs. They require, but do not now have, access into a wider range of direct communication from their mobiles than they can get through their normal police systems. This could be handled either by an interconnection into a public switch network from the ordinary system or by means of a separate radio telephone system. Investigation officers often work in suburban or rural areas and have need for secure voice when discussing sensitive information. Knowledge of easy communications intercept of an investigator's communication could adversely affect jury trials later on. They also have the need to obtain data from their central data files or from the National Criminal data files. This means that they could benefit from a special secure voice and data channel which could be accessed from anywhere in the state. Satellite mobile communications could fulfill these requirements in a unique manner. Digital encryption, coupled with modern digital voice techniques developed for landline telephone, could provide secure voice communication. It would be necessary to use more than one voice channel with present technology to obtain high quality secure voice communication if good voice recognition and intelligibility were demanded. For digital data, a satellite would enable direct access to a central data file, at either state of national levels, expeditiously and without intermediate steps.

Federal Bureau of Investigation

The Federal Bureau of Investigation operates a very extensive network of radio communications over the country. The cost is exceedingly high, and the effectiveness in areas outside the urban parts of the country is either poor or nonextient. The total number of agents in the field at any one time would hardly justify the system that is in place without their urgent need for communications in much of the nation. Due to their investigative nature, they should also have secure voice channels, but they could use the normal switched satellite channels by reason of the priority availability possible with order wire techniques.

County Sheriff

The role of the County Sheriff varies widely. In some areas sheriff's deputies are the major police force. This is true in such places as Dade County, Florida, and Los Angeles. In other areas they only provide a central lockup or jail service for surrounding communities. In some states they provide the main police service and operate over a wide area. There might be some specific requirements for patrols of sheriffs in the areas where they furnish police protection to isolated and difficult (mountainous) terrain. As a minimum for a county patrol, the availability to directly access state central data would be very useful.

One activity that is common to many sheriff departments is that of prisoner transport. They are the official group to transport dangerous prisoners to the various county, state, and sometimes federal penitentiaries. In New York Sate, for example, County Sheriff deputies are furnished with the most powerful radios that can be procured, and sometimes employ special vehicular repeaters in an effort to provide communications in remote regions, and to provide coordinated communications to other law enforcement agencies as they pass through with dangerous prisoners in transport. They often encounter long stretches of the road during which they have no communications and are then at especially high risk.

Federal Marshalls

Federal Marshalls operate over wide areas and are involved in such prosaic but dangerous duties as transporting prisoners between federal penitentiaries. The numbers of Federal

Marshalls are not high and they are distributed across the entire country. A satellite could provide them with economically feasible communications. They would not need the high degree of voice security that other agencies would routinely require for investigative purposes.

Immigration and Naturalization Service

This agency, in common with the following two agencies, has the problem of proividing closely coordinated operations over the long stretches of our country's borders. It has not been feasible to provide them with continuous communications over this entire area. Similar to the Federal Marshalls, the total number of units involved is small, but the area in which they operate is large. This is the type of application where a satellite-aided/land mobile system could provide excellent communications regardless of the area in which specific people were operating. They also could benefit greatly by being connected into the public switched network for much of their operations, especially those that require coordination with other agencies.

Drug Enforcement Agency and Internal Revenue Service

There are two separate agencies that have communications needs like the Immigration and Naturalization Service. The Drug Enforcement Agency has the additional need to operate in the coastal waters as well as along the land borders. They also operate in all sections of the country. Communications requirements are of a similar nature of IRS and the Drug Enforcement Agency. Due to the difficult nature of their operation, it is necessary that secure voice be considered for many of the operations of the Drug Enforcement Agency. They also need access to central data files during field operations. At the present time it is probable that satellite-aided land mobile radio is the only economical way that such an agency could be served.

Federal Communications Commission - Field Operations Bureau

Although not considered as "Public Safety", the Federal Communications Commission Field Operations Bureau typifies a government agency which could substantially benefit from a viable satellite land mobile radio service. Various field units of the FOB are shunted among all field offices as enforcement actions are strategically employed. During these operations they could benefit from being tied into the switched landline network as well as having access to central data files. It is to be noted that in the case of Federal Agencies like this, the switched landline network could be into the Federal landline system with shortest inter-tie to a satellite ground station.

Parks Commissions

National Parks are often located in remote areas and with many environmental constraints to terrestrial radio installations. They often cover very wide areas. Since they only constitute a relatively small number of users but need to cover a wide area, they could benefit from use of a satellite land mobile service. They also need to be tied into the public switched network for direct communications to other agencies. This is needed especially in times of emergency, such as forest fires or during search and rescue missions.

State Fire Marshalls

Many states have fire marshalls whose job it is to furnish fire protection to sparsely populated areas that have no other fire fighting service. Most states have only a few fire marshalls whose main function (in terms of fighting large brush fires and forest fires) becomes one of leading the efforts of many agencies. It becomes necessary that their communications be able to interact with other systems. It is believed that this could be done best by having radio telephones which would be part of the public switched network itself with special calling features. They have no large amount of data requirements nor does it seem that they have a need for a high degree of voice security.

Search, Rescue, and Disaster Relief

There are at least two major national organizations involved in emergency work with a need for specialized communications. Defense Civil Preparedness Agency (DCPA) and the American National Red Cross. They have to deploy their people and equipment with high speed into areas that are not known in advance. Thus, they need good communications under stressful conditions to any place, and in any environment that exists in the United States. The three functions of these organizations can be separated as:

- Go find people and rescue them (search and rescue)
- Bring equipment and people to bear to prevent physical harm to person and property (Defense Civil Preparedness Agency), and to
- Provide direct relief of both short term and long term nature to people in emergency situations (charter of the American National Red Cross).

None of these organizations has an effective national communications systems in operation. American National Red Cross, for example, uses one common frequency for all their vehicles in an attempt to be able to communicate with each other at the scene of the emergency. Most of the wide area requirements of these organizations could be served by a priority radio telephone system which accesses other mobiles and the public switched network.

Priority Channel Needs for Public Safety

In the foregoing examples it was shown that public safety services need quick and sure access to a communication channel. Dedicated channels are often used in present terrestrial systems, but may be dedicated in either hardware or software. With the satellite communication system being considered in this study, there would be an orderwire channel for system control. Priorities for channel access could be transmitted by this channel, and software could recognize the assigned priority. For example, if an agency needed a channel, even though all channels were occupied, it would be possible to clear the channel immediately for this high priority traffic.

Systems strategy would be a matter of program control algorithms, and could be changed according to the requirements that developed. For example, one strategy could be to leave a specified number of channels remaining after non-priority, general service channel capacity started filling at a particular time period. With such versatility, it would be possible to fulfill the stringent needs of public safety services without impacting overall system efficiency.

Priority users could be recognized by the calling party identification automatically sent by the calling station. This identification is also normally used for automatic machine accounting by the commercial organization.

With this system it is seen that requirements of both public safety and the general public could be handled in a single system by use of the software that assigns channels.

By using a calling party identification number at the beginning of a series of transmissions when a specific party or parties is required, it would be possible to automatically group call (in the fashion of ordinary dispatch operations) or to access a specific called party with a repertoire dialer, for example. When a person came "off hook" his dispatcher, or designated communication point, would be automatically dialed with whatever priority needs are assigned to him to assure channel space.

"911" Button

Situations could arise in any of these services (possibly including ordinary public use of satellite via switched network) where there is an overriding need which can be seen by the calling party for emergency service. An emergency priority button could be provided on the controlled unit of a mobile user to be activated only in case of an emergency that involved safety of life or property being in imminent danger. Upon activation of this "panic button" the subsequent communications could be recorded for legal purposes along with the identification automatically sent by the calling parties. This would minimize frivolous uses of the emergency panic button.

A software/hardware design can be provided to give a degree of service to many public safety agencies via land mobile satellite that it is not technically feasible or economically possible to do in the foreseeable future via the terrestrial system by itself.

SATELLITES FOR PUBLIC SAFETY USE

This study emphasizes the use of satellites to augment terrestrial mobile telephone systems. Eventually the greatest return on the investment in the satellite portion of the ubiquitous telephone system will derive from its use by the general public. In the short term, however, its most prominent use may be for public services. The dispatch mode that is now used almost exclusively by public services in their terrestrial mobile communications. That mode attempts to insure channel access by the use of dedicated hardware and the assignment of exclusive use of channels. As noted above, the wireline connected mobile telephone appears to have the potential for equal or better assurance of channel access through the use of dedicated software and the assignment of channels by trucking. The dispatch mode is less efficient in its use of the spectrum and would also be less efficient in its use of the satellite than trucking.

Whenever a new service is offered to an existing operational enterprise, it must be made to mesh with the current way of doing things or it becomes a disruption and its acceptance is delayed. For this reason, some provision for dispatch use of a satellite should be considered. In parallel, the use of the wireline connected service using trunking techniques should be introduced. Rapid, reliable and convenient access to the communication links can be achieved by the use of single digit dialing, conference calling for simultaneously accessing a number of mobiles by the dispatcher and by the use of priority assignment of channels based on source and destination identification by calling and called numbers. These techniques are in use when telephone systems are used by public safety organizations.

In view of the expressed needs for satellite-aided mobile communications for public service and public safety applications, the need to develop technologies and to experiment with operational options and uses, it may be advantageous to launch an experimental satellite with capacity sufficient for the public service needs and a limited use for public telephone but with less capacity than would be required for a fully operational mobile telephone service.

The interim satellite would have fewer, larger footprints and a smaller number of channels than the later, fully operational satellite. The larger footprints of the interim satellite would limit frequency reuse when the demand for the service grows beyond its capacity.

As an example, an interim satellite with one degree beams would serve the contiguous states with 17 footprints. Ten channels per footprint would accommodate approximately 15,000 subscribers with 0.02 grade service. Cost per subscriber would be greater than for the larger satellite, but initial investment would be more attractive.

Following the precendent of the Tracking and Data Relay Satellite, Marisat and Leasat, it is conceivable that the Federal Government might support the development of the interim satellite to advance technology development and guarantee a return on investment by purchasing service on the satellite in support of the needs of federal public service and public safety agencies.

The larger footprints would permit the use of an antenna with smaller aperture, and the reduced number of channels would enable a corresponding reduction in required power. Technology would be demonstrated and initial user requirements met in a cost effective way by the interim satellite.

APPENDIX H

AUTOMATIC VEHICLE POSITION MONITORING

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A simple, automatic means to locate vehicles is desired by a variety of enterprises. Police departments are required to record the locations of accidents to an accuracy of 100 feet in cities, 0.1 mile in rural areas. A convenient way to locate a patrol car at an accident scene would save time and cost. A federal law enforcement agency would like to track an agency automobile that follows a suspect. A nationwide bus company finds it difficult to keep records for maintaining and licensing of individual busses as they are diverted to different routes or used for charter. Tracking hazardous and high value truck and rail cargos is now inconvenient and sometimes difficult. Automatic location of hijacked vehicles could save drivers and property.

Several satellite-aided techniques for automatic surveillance of vehicle positions have been demonstrated. A base station can interrogate a vehicle, receive its response and compute the vehicle's position within one second to an accuracy better than 0.1 mile.

One technique employs tone-code ranging to determine one line of position from the communication satellite, and the time of arrival of signals from an independent satellite. A vehicle that is to be located by the system satellite-aided mobile telephone is equipped with a separate receiver and timing circuit in addition to its mobile radio. The separate receiver receives timing signals from a satellite such as the NOAA GOES satellite. The timing signals appear as "ticks" once per second. When the vehicle is to be located, a telephone call is placed to the vehicle from the central station. A tone-code signal, a fraction of a second in duration, is transmitted to the vehicle. The central station listens directly to the satellite as the signal leaves the satellite on its way to the vehicle. The vehicle responds, and sends with its response a digital message stating the time interval from the last received time tick until its reception of the tone code interrogation. The central station listens directly to the satellite as it relays the vehicle's response. The time interval between the satellite relay of the interrogation and the vehicle response, minus known vehicle equipment delay, yields range from the communication satellite to the vehicle. The time interval sent as a digital message by the vehicle enables the central station to determine range from the independent satellite to the vehicle. The two range measurements from the known locations of the satellites determine two large circles on the earth that intersect at the vehicle location.

The method of determining the vehicle location is illustrated in Figure H-1. When R_3 and R_4 are measured, the location of the vehicle on the earth's surface can be computed from the known locations of the two satellites in space. R_3 is determined by active ranging, R_4 by measuring the time of arrival of a signal from S (GOES) relative to the active ranging interrogation from S_R. In Figure H-1:

O = Fixed earth station

V = Vessel

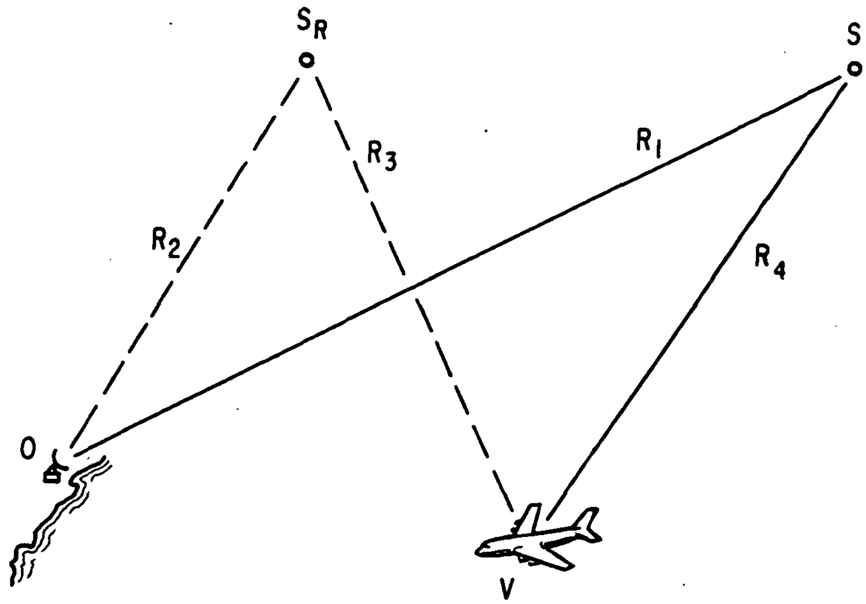
S_R = Active ranging satellite

S = Time distribution satellite

C = Velocity of light

Certain time delays that are known constants are omitted to simplify this explanation of the process. Start time, T_S, represents the instant when a time tick is transmitted from S. When the time tick is received at 0, it immediately transmits a tone-code ranging interrogation containing the address of the vehicle, V. The tone-code signal is repeated by S_R and received at O and V. Time for the signal to go from O to S_R and return determines R_2. The vehicle repeats the tone-code signal, and it is relayed back to O by S_R. The two-way travel time is measured at O to determine R_2 plus R_3. Since R_2 is known, R_3 is determined.

The vehicle receives time ticks at regular intervals, such as once per second, from S. Its on-board time-tick generator is maintained in synchronism with the received ticks. A time interval count starts at each tick from the generator. If no interrogation is received from S_R, the counter returns to zero and starts over at each tick. If an interrogation is received, the counter stops, and the interval from tick to interrogation is sent as a digital message along with the tone-code response of the vessel. That interval is $(T_{VO} - T_{VS})$ in the expression



$$T_{VO} = T_S + \frac{R_1 + R_2 + R_3}{C}$$

Where: R_1 is known from tracking S. Time intervals $\frac{R_2}{C}$ and $\frac{R_3}{C}$ are known from active ranging on vehicle.

$$T_S = T_{VO} - \frac{R_1 + R_2 + R_3}{C}$$

also

$$T_{VS} = T_S + \frac{R_4}{C} \; ; \; \frac{R_4}{C} = T_{VS} - T_S$$

Then

$$\frac{R_4}{C} = T_{VS} - \left(T_{VO} - \frac{R_1 + R_2 + R_3}{C}\right)$$

$$= \frac{R_1 + R_2 + R_3}{C} - (T_{VO} - T_{VS})$$

but $T_{VO} - T_{VS} = X$ is interval measured on vehicle and returned as data during ranging interrogation

$$R_4 = R_1 + R_2 + R_3 - CX$$

Ranges R_3 and R_4 from known positions of satellite determine vehicle fix.

Figure H-1. Vehicle Position Fix Determination for $\frac{R_4}{C}$ in Figure H-1. The ranges R_3 and R_4 from the known positions of the satellite are then used to determine two lines of position on the earth that intersect in the ship location.

There is one ambiguity with geostationary satellites. Two fixes are determined; one in the northern and one in the southern hemisphere. Apriori knowledge of the hemisphere in which the vehicle is located resolves that ambiguity.

A second technique for vehicle location is the relay of LORAN-C signals through the communication satellite to the base, where the position is computed with reference to LORAN-C timing data and corrections are applied for propagation distortions in the locality of the vehicle. LORAN-C, an operational navigation aid operated by the U.S. Coast Guard, is a non-satellite hyperbolic navigation system operating at 100 kHz carrier frequency. Timing signals are transmitted from pairs of fixed ground stations. The difference in arrival times of the signals at a LORAN-C receiver identifies a hyperbolic line of position passing through the receiver's location. Another hyperbolic line, determined from a different station pair, intersects the first line to provide a position fix.

LORAN-C is precise, and accurate if corrections are applied for local distortions in propagation due to factors such as changes in ground conductivity and reflections from large structures. Tests have shown that it is practical for a vehicle to carry a LORAN-C receiver, send the signal measurements automatically to a central station over a radio communication link, make an initial computation of the vehicle position, then apply corrections stored in the computer to refine the position fix to achieve accuracy to a small fraction of a mile.

It is expected that LORAN-C service will cover the contiguous United States within the next few years.

A third technique determines vehicle position from measurements of the doppler shift on signals transmitted from low orbit satellites as they pass within view of the vehicle. The rate of doppler frequency shift vs time is a function of the distance of the vehicle from the subsatellite track, hence, one line of position is produced parallel to the track. The time of zero crossing of the doppler shift, i. e., when the received frequency exactly equals the satellite transmitted frequency, identifies a line of position at right angles to the track.

The Navy's TRANSIT passive navigation system uses the doppler shift technique. It is accurate provided that vehicle velocity is known accurately. The technique can be used to determine fixes only during passes of the TRANSIT satellites.

A reverse doppler technique has been demonstrated by NASA and will be implemented as a search and rescue aid. A device that is to be located transmits a radio signal that is received by a passing low orbit satellite. The doppler shift observed by the satellite is transmitted to a central ground station that computes the position fix. Accuracy is affected by frequency stability of the device, and its velocity. Capacity is limited by the number of signals the passing satellite can observe at one time within its field of view.

APPENDIX I

SERVICE TO AREAS OTHER THAN THE CONTIGUOUS STATES

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Areas other than the contiguous states could benefit from satellite-aided mobile telephone service. The areas include Alaska, Canada, Central and South America and probably Hawaii and Puerto Rico.

Alaska

The longitude, 110 west, chosen for the candidate design of this report was selected to include mainland Alaska and much of the Aluetian Chain within view of the satellite. The state sees the satellite at a low elevation angle for the chosen longitude, but a further westward location of the satellite would improve the elevation in Alaska only a small amount while seriously lowering the satellite elevation for the northeastern contiguous states.

Elevation angles for some reference locations are:

Location	Latitude	Longitude	Elevation
Ketchikan	55N	130W	24^o
Kodiak	57.5N	152.5W	15^o
Anchorage	61.5N	150W	13^o
Prudhoe Bay	71N	148W	6.3^o
Nome	64.5N	165W	5.7^o
Little Island (Aluetians)	52N	180W	3.5^o
Pt. Barrow	73N	157W	2.8^o

The low elevation angles will result in signal blockage by mountains and forests to a greater extent than would be experienced if the satellite were at a higher elevation. Communications will be possible in all regions of the state except the most distant Aleutian Islands, but in most regions it will be necessary to be on the sides of mountains toward the satellite and to be clear of tall trees. No attempt was made to estimate the proportion of land area that will be blocked.

The state may be served by a single beam, shaped to 2^o x $3/4^o$. Alternatively the state may be served by five beams using frequency reuse patterns used in the contiguous states. There need be no adjacent beams unless the northwest territories of Canada are served by the same satellite. For that reason, the frequency reuse pattern of the contiguous states beam is not required and all of the assigned channels, three times the number of a contiguous states beam, can be used in Alaska. The shaped beam may be achieved by a single feed illuminating a portion of the satellite reflector. The power required per channel is larger because of the larger beam, but it is slightly less than the power required if the state were served by several smaller beams.

Alternatively, the state, not including the Aluetians, may be served by five beams, using a frequency reuse pattern as in the contiguous states. An advantage of the smaller beam for reception of mobiles at the satellite is the larger aperture used for each beam. If a single beam is used, vehicle transmitter power must be 60 Watts instead of 10 Watts if several smaller beams are used. Alternatively, vehicle antennas with higher gain may be used to reduce the vehicle transmitted power requirement.

A special advantage to Alaska would result from the availability of the communications in the offshore fishing waters. Heavy seas and bad weather are hazards to small fishing vessels in that area. Communications by high frequency (short wave) radio are often disrupted or impossible, and the vessels cannot afford the present MARISAT terminals. The ubiquitous telephone service would provide much improved, affordable communications to the Alaskan fishing industry. The technical possibility of adding position surveillance to the communications could add a safety feature by making it possible to rendezvous quickly with a stricken craft.

Canada

The present-day mobile telephone service has at least as much acceptance in Canada as in the United States. For example, an informal report states that there are 15,000 subscribers in Alberta which has a population of about 1.5 million. One percent of Alberta's population are subscribers, compared to .05% for the United States.

Most of Canada's population is within a narrow strip north of the border with the United States. That portion of Canada would be well served by the use of terrestrial cellular systems in the cities, and a row of 0.5° beamwidth satellite footprints added to the pattern that serves the contiguous states, Figure I-1. The less populated, large areas of northern Canada might be served by a smaller number of larger beams as suggested for Alaska.

The foreshortening effect enables Canada to be served with a total radiated power of 6 k Watts, compared to 11.8 k Watts for the contiguous states, even though the area of Canada is larger by 27 percent.

Mexico

An additional 24, 0.5 degree beam footprints would cover Mexico. Although the area of Mexico, is approximately one-fourth that of the contiguous states the foreshortening effect is also smaller and the number of footprints correspondingly larger. The radiated power from the satellite for Mexican coverage becomes 4 k Watts at UHF or 14 k Watts at L-band.

North American Coverage

Coverage of all North America, including Canada and Mexico requires a total radiated power of 23 k Watts at UHF or 77 k Watts at L-band. The size of the satellite antenna reflector does not change compared to the size for the contiguous states only, but the number of transponders and antenna feeds increases. Figure I-1 shows the North American served with 133 cells.

Feasibility of serving the entire continent from a single satellite depends on total demand and is affected by the distribution of demand and grade of service that is offered.

Quality of service, primarily affected by signal-to-noise ratio, is a function of radio frequency and area served. Vehicle antenna patterns must be omnidirectional in azimuth and have an elevation pattern that includes the change in elevation to the satellite throughout the area in which the vehicle travels plus an allowance for tilt of the vehicle antenna as the vehicle goes up and down hills. The pattern should have a null below the horizontal plane to reduce the effects of multipath reflections from the ground.

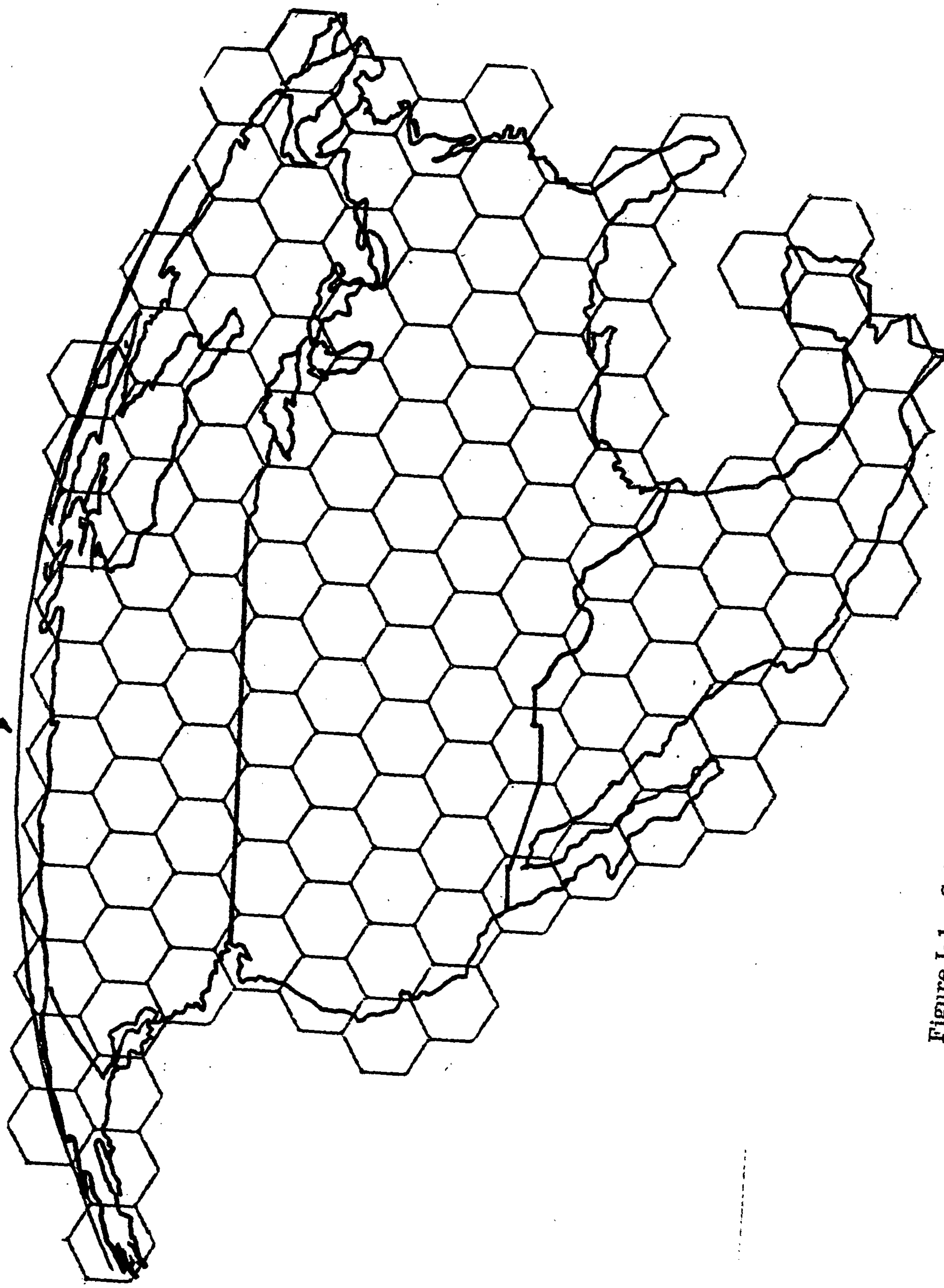

Figure I-1. Satellite Beam Pattern to Serve North America

For the contiguous states, the elevation to the satellite is between 23° and 56°. With allowance for vehicle tilt, the gain for the vehicle antenna may be 4 dB. For Alaska, elevation angles are from 3° to 24°. Canada, including Baffin Island but not Ellsmere Island, angles are from about 5° to 49° at Windsor, Ontario. The most heavily populated portions of Canada lie within an elevating angle of 21° to 49°. For Mexico, elevation angles are between 51° and 63°.

It would seem unnecessary to use the same antenna on vehicles in all parts of North America if the satellite were to serve the whole continent. The same basic design can be used with a low elevation pattern for users in Alaska and northern Canada, an intermediate elevation for southern Canada and the contiguous states, and a high elevation pattern for Mexico. If that were done, the satellite can be designed for use with 4 dB gain vehicle antennas in all locations. That assumption was used in calculating the power required in the satellite to serve each of the North American countries.

Hawaii

The Hawaiian chain extends from approximately 155 W, 19 N to 180 W, 28 N. The larger islands, Hawaii to Niihau, lie between 155 W, 19 N and 160 W and 22 N. The area that includes the larger islands and the surrounding sea is approximately 280 by 120 nautical miles. The small sizes of the islands compared to continental areas suggests that the state would be better served by a terrestrial system than by satellite. A satellite link between the mobile telephone system and the mainland can be through a domestic satellite or cables that interconnect the fixed telephone network of the islands with that of the mainland.

The elevation angle to the satellite is approximately 29°. It may be that the satellite would provide less shadowing by mountains in some areas of the state than would be experienced with the terrestrial system. This is conjectural and of dubious value if true.

It is recommended that Hawaii not be served by the satellite.

Puerto Rico and Virgin Islands

Puerto Rico has an area of about 3500 square miles, a population of 2,712,000 or a population density of 775 persons per square mile. The Virgin Islands are small in area, each one easily covered by a terrestrial installation. It is recommended that they be served by terrestrial systems.

Central and South America

South America has many large, modern cities. It also has vast, thinly populated areas that contain important resources that are under development. Wireline communications do not cover South America as well as they do North America. A satellite-aided mobile telephone service could fulfill important needs in most countries of South America.

The scope of this study did not include a detailed examination of South American needs for the service, or the configuration of a system for that continent. The similarities with North America in area, population distribution between urban, rural and remote lands, suggest that the configuration described for the contiguous United States would be adaptable to the nations of South America.