

DEVELOPMENT CONCERNS FOR  
SATELLITE-BASED AIR TRAFFIC CONTROL SURVEILLANCE SYSTEMS

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Large Space Antenna Systems Technology - 1984

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## Abstract

This paper describes some preliminary results of an investigation directed toward the configuration of a practical system design which can form the baseline for assessing the applications and value of a satellite-based air traffic surveillance system for future use in the National Airspace System (NAS). This work has initially studied the characteristics and capabilities of a satellite configuration which would operate compatibly with the signal structure and avionics of the next generation air traffic control secondary surveillance radar system, the Mode S system. A compatible satellite surveillance system concept is described and an analysis is presented of the link budgets for the various transmission paths. From this, the satellite characteristics are established involving a large multiple feed L-band antenna of approximately 50 meter aperture dimension. Trade-offs involved in several of the alternative large aperture antennas considered are presented as well as the influence of various antenna configurations on the performance capabilities of the surveillance system. The features and limitations of the use of large aperture antenna systems for air traffic surveillance are discussed. Tentative results of this continuing effort are summarized with a brief description of follow-on investigations involving other space-based antenna systems concepts.

## INTRODUCTION

With the increasingly widespread use of satellites for communications, navigation, and surveillance, it has appeared appropriate from time to time to investigate their application to various air traffic control functions in the National Airspace System. The Federal Aviation Administration (FAA) has participated in investigations of this area since about 1965 and a number of successful and useful applications have been identified. However, the use of satellites in the National Airspace System has been minimal to date primarily because of economic considerations.

The principal technique currently used for the surveillance of air traffic is radar which was introduced into the ATC system shortly after World War II. To improve coverage reliability and to provide a means for aircraft to transmit encoded altitude information to the air traffic control (ATC) system, transponders which receive interrogations from the ground-based ATC radars at 1030 MHz and reply at 1090 MHz have been implemented on board aircraft. This cooperative radar system is called a secondary surveillance system; the secondary surveillance system for ATC in the United States is the air traffic control radar beacon system (ATCRBS). An upgrading of the radar beacon system is planned which provides for the selective addressing of all aircraft in the airspace. This selective address capability, by agreement of the International Civil Aviation Organization (ICAO), is referred to as the Mode Select, or the Mode S system. A national standard for the Mode S system has been published recently specifying its performance, capabilities, and data transmission formats (Ref. 1).

With the introduction of the Mode S concept, the possible compatibility of this technology with satellite systems has been considered. Basically, the question is if a space-based surveillance system can be configured that would be compatible with the Mode S signal structure and the Mode S transponder avionics that are planned for implementation, and would such a system have capabilities and benefits of sufficient merit to consider it further. The initial results of an investigation of these questions are addressed in this paper. The investigation is essentially a feasibility study, and in no way is meant to indicate FAA plans for implementation or current considerations for incorporation of a satellite-based surveillance system into the National Airspace System. However, there appear to be a number of advantages and benefits which are inherent in the use of a space-based surveillance system. It is to investigate the technical feasibility, identify an exemplary system configuration and determine preliminary operating parameters that this investigation was conducted.

## OBJECTIVES OF THE STUDY

Figure 1 lists the objectives of the study, which were to assess technical feasibility and obtain an indication of the cost involved in developing and implementing a compatible satellite surveillance system (CSSS). It was desired to configure a representative system design or designs, and to analyze the performance capabilities for the system in its various modes of operation. It was also desired to identify the critical concerns which require additional development in technology, or other activities to be accomplished, to provide a viable candidate system for consideration. It was recognized at the outset that certain limitations of the Mode S ground-based system design and the transponder characteristics in particular placed serious constraints on the compatible use of space-based systems and that these factors might preclude the development of any satellite configuration that was practical and economically viable.

1. DETERMINE TECHNICAL FEASIBILITY AND COST
  - o SATELLITE-BASED ATC SURVEILLANCE AND DATA LINK SYSTEM
  - o COVERAGE OF CONUS, ALASKA, HAWAII, ADJACENT AREAS
  - o USE OF MODE S SIGNAL STRUCTURE AND AVIONICS
2. CONFIGURE REPRESENTATIVE SYSTEM DESIGNS
  - o ESTABLISH PERFORMANCE
  - o ESTIMATE COST
3. DETERMINE SYSTEM PERFORMANCE CAPABILITIES
  - o EN ROUTE AND TERMINAL AREA
  - o SURVEILLANCE AND DATA LINK
  - o ALTITUDE ACCURACY
  - o COMPARISON WITH ALTERNATIVES
4. IDENTIFY CRITICAL AREAS OF CONCERN
  - o ISSUES
  - o ACTIVITIES
  - o RESOURCES
  - o SCHEDULE
  - o COORDINATION

Figure 1

## EN ROUTE RADAR SURVEILLANCE SYSTEM SENSOR DISTRIBUTION

Figure 2 illustrates the approximate distribution of en route surveillance resources throughout the United States, Canada, and Alaska, including Hawaii and Puerto Rico. As of 1984, there were 130 en route and 197 terminal area sensors for a total of 327 sensors. By the turn of the century, acquisition plans for Mode S call for about 151 en route and 239 terminal sensors for a total of 390. The current Mode S buy is for 137 sensors which are to be in service by about 1990.

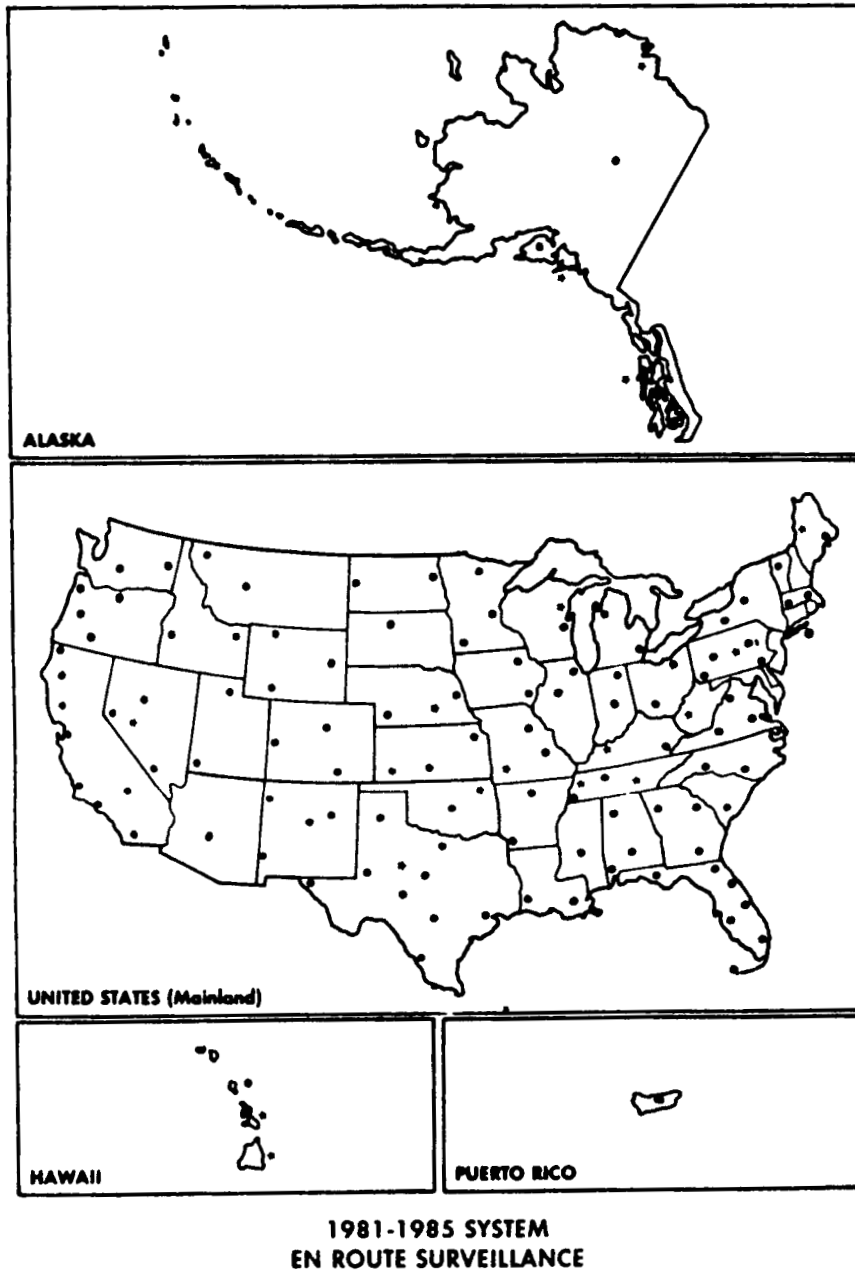
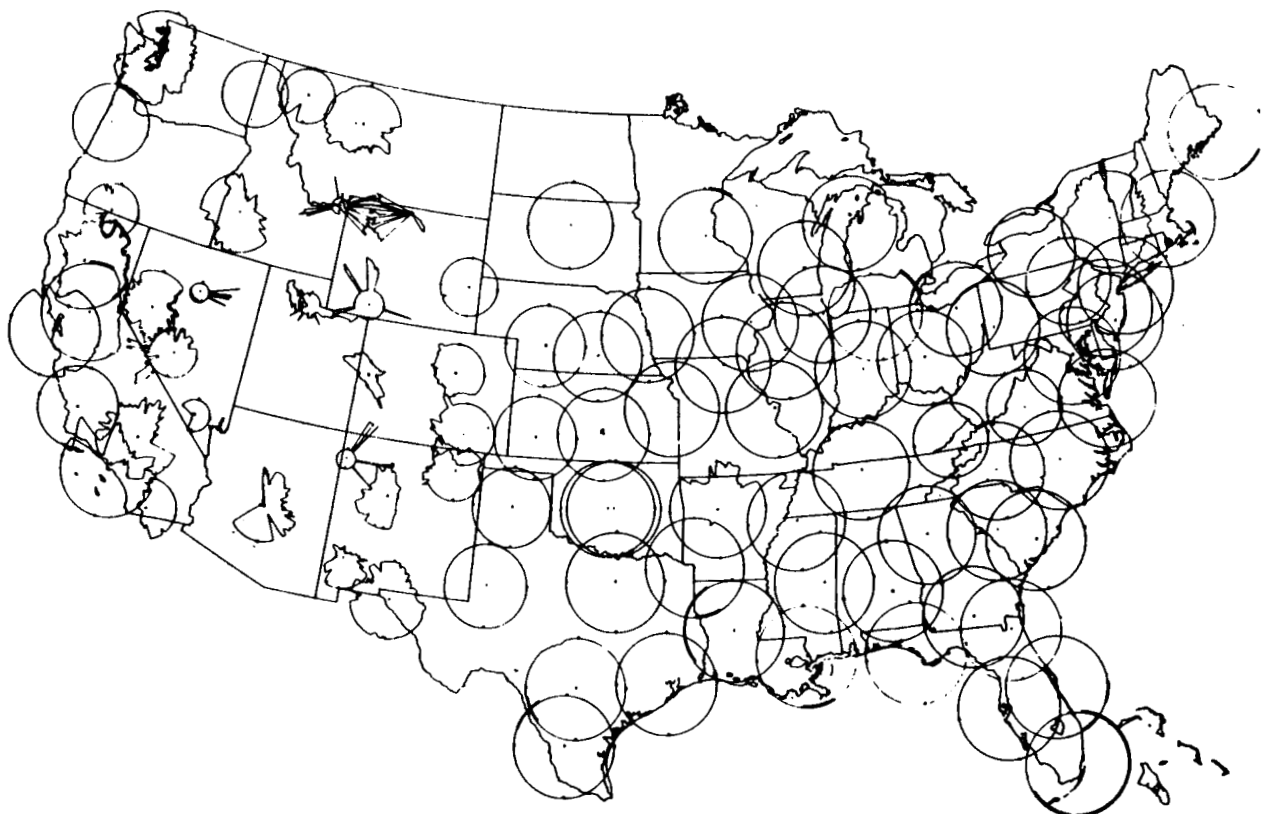


Figure 2

### ARSR COMPOSITE COVERAGE MAP

Figure 3 shows the air route surveillance radar coverage. This map is based on a 10,000-foot mean sea level (MSL) contour. As is apparent from the map, visibility in the western part of the country is severely restricted by the terrain. It is also apparent that the eastern part of the country is very well covered with secondary surveillance radar facilities.



10,000 FT. MSL, MAXIMUM RANGE  $R_{\max}$  = 100 n.mi.

Figure 3

## ASSUMPTIONS AND CONSTRAINTS

The assumptions and constraints for the compatible satellite surveillance system study are shown in Figure 4. The coverage would be basically the United States, including Alaska and Hawaii, as well as adjacent areas, such as the nearer coastal regions of the Atlantic, Pacific, and the Gulf of Mexico, and the adjoining borders with Mexico and Canada. The capacity of the system is sized to handle an instantaneous airborne count (IAC) of 50,000 aircraft which is believed to correspond to that which may be realistic sometime beyond the turn of the century. The current maximum IAC is approximately one-third of this number. The system is to provide three-dimensional position determination and data link (DL) capabilities consistent with those provided by the Mode S system. The user update rate is to correspond with the current system with the exception that more frequent updates are to be provided on an adaptable basis so that update intervals of one to ten seconds are obtainable. The system is to be continuously available and will require top-mounted antennas on the aircraft to provide the reliable link with the satellite constellation. One of the principal features of the system is that it is to provide access to low-altitude aircraft, many substantially below the current 6-10,000 foot minimums generally associated with the current ground-based radar systems operating in the continental United States (CONUS). Access to near-ground level is to be provided over the entire CONUS if possible. It was recognized that the interference and garble effects associated with the operation of the current radar beacon system may be a significant constraining factor and therefore these interference effects are considered in the study. The potential implementation time frame is for the late 1990's.

### COMPATIBLE SATELLITE SURVEILLANCE SYSTEM STUDY

#### ASSUMPTIONS AND CONSTRAINTS

1. COVERAGE OF UNITED STATES AND ADJACENT AREAS
2. INSTANTANEOUS AIRBORNE COUNT (IAC) OF 50,000 AIRCRAFT
3. 3D POSITION DETERMINATION AND DATA LINK
4. MODE S SIGNAL AND AVIONICS COMPATIBLE
5. USER UPDATE RATE OF ONCE EVERY 1-10 SECONDS
6. CONTINUOUS SYSTEM AVAILABILITY
7. TOP MOUNTED ANTENNAS ON AIRCRAFT
8. ACCESS TO LOW ALTITUDE AIRCRAFT
9. INTERFERENCE AND GARBLE EFFECTS TO BE CONSIDERED
10. POTENTIAL IMPLEMENTATION TIME FRAME OF LATE 1990's

Figure 4

## POTENTIAL BENEFITS AND CONCERNS

The potential benefits and concerns of the system are indicated on Figure 5. These items occur in three general areas: first, the operational improvements which may be feasible using the satellite-based system; second, the cost considerations involved, primarily directed toward the eventual replacement or elimination of some of the ground-based facilities by the satellite system; and third, the operational limitations that may be associated with the system, in particular those which may arise due to the interference and garbling problems associated with the signal environment of the ATCRBS and the Mode S systems.

1. OPERATIONAL IMPROVEMENTS
  - o IMPROVED COVERAGE; 3D; LOW ALTITUDE
  - o OFF-SHORE COVERAGE
  - o SURVEILLANCE ALTITUDE INDEPENDENT OF AIRCRAFT ALTIMETER
  - o ATMOSPHERIC AND ALTIMETRY CALIBRATION FEASIBLE
  - o ACCURACY IMPROVEMENT POTENTIAL
2. COST CONSIDERATIONS
  - o POSSIBLY LESS EXTENSIVE NETWORK OF TERRESTRIAL FACILITIES
  - o ELIMINATION OF RADARS DEPENDENT ON PRIMARY RADAR REQUIREMENTS
3. OPERATIONAL LIMITATIONS
  - o INTERFERENCE ENVIRONMENT DURING ATCRBS TO MODE S TRANSITION MAY LIMIT SYSTEM PERFORMANCE

Figure 5



## COMPATIBLE SURVEILLANCE SATELLITE SYSTEM CONCEPT

Figure 6 indicates the system concept in pictorial form for the compatible surveillance satellite system. A constellation of five satellites is indicated in the figure, four of which are "receive only" satellites and one of which provides transmissions to the Mode S transponder equipped aircraft. As indicated in the figure, the central ground station (CGS) is provided with a backlink from all of the receive satellites and provides the surveillance and datalink information to the various area control facilities. There may be any number of CGS's; however the computing capability and the antenna systems necessary for these stations will probably restrict their number to possibly three or four throughout the country.

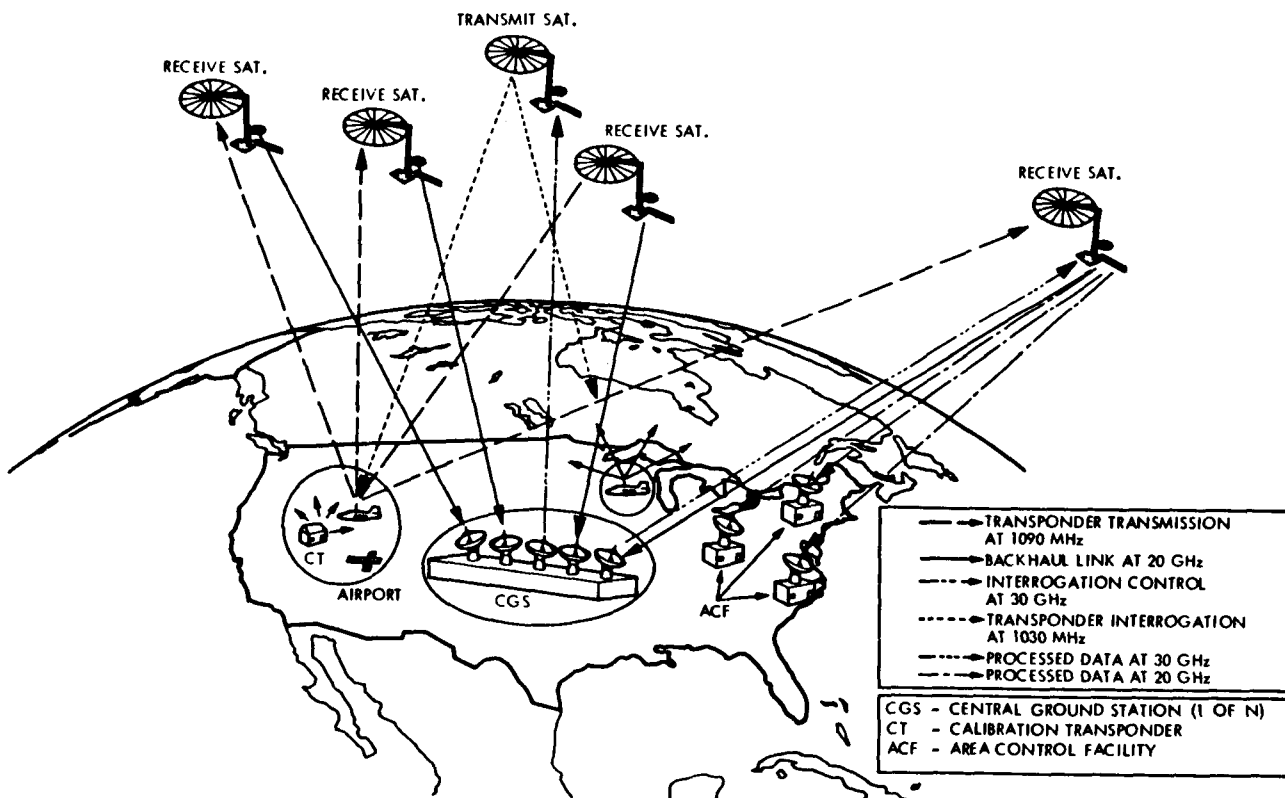


Figure 6

## CSSS SYSTEM CONCEPT

Figure 7 provides some of the basic information relating to the system concept. The satellite receive system constellation receives the signals from each transponder and by means of a translating repeater (transponder) retransmits that information at another convenient downlink frequency to the CGS, where the various signals are separated by the identification (ID) codes placed on the transmissions by the aircraft originally. The ranges from the satellites to the aircraft are then determined by the computer system which enables the determination of aircraft positions. The transmissions from the aircraft transponder can be either as replies to a transmit satellite interrogation or as "squitter" replies similar to those associated with the ATCRBS and Mode S transponders. The squitter transmission occurs approximately every second spontaneously from each aircraft transponder.

1. AIRCRAFT MODE S TRANSPONDER TRANSMISSIONS ARE PICKED UP BY CONSTELLATION OF GEOSYNCHRONOUS RECEIVE SATELLITES WITH FAVORABLE GEOMETRY
2. TRANSPONDER TRANSMISSIONS CAN BE SPONTANEOUS (SQUITTER) OR IN RESPONSE TO AN INTERROGATION FROM A SATELLITE
3. SATELLITE SENDS RECEIVED SIGNALS DOWN OVER A BACKHAUL LINK TO TWO OR MORE GEOGRAPHICALLY SEPARATED CENTRAL GROUND STATIONS (CGS)
4. CENTRAL GROUND STATIONS NORMALLY COMPUTE TRANSPONDER LOCATION FROM AIRCRAFT -SATELLITE-CGS SIGNAL TIME OF ARRIVAL DIFFERENCES
5. SYSTEM CAN ALSO MEASURE CGS-AIRCRAFT TWO WAY RANGE BY INTERROGATING
6. CENTRAL GROUND STATIONS ALSO MANAGE THE DATA LINK WHICH INCLUDES THE SCHEDULING OF DATA MESSAGE TRAFFIC TO AND FROM AIRCRAFT
7. PROCESSED AIRCRAFT POSITION INFORMATION, AS WELL AS DATA LINK INFORMATION, IS DISTRIBUTED BY THE GROUND STATIONS VIA SATELLITE (AND OTHER MEANS) TO THE APPROPRIATE FACILITIES (I.E. ACF'S)

Figure 7

## AIRCRAFT REPLY PATHS TO SATELLITES

The reply paths from the aircraft to the satellite constellation are shown in Figure 8. This illustrates the requirement for three or four satellites to receive each aircraft's reply. Four satellites are required for operation of the system in the squitter mode. The advantage of utilizing the squitter transmission is that the transmit satellite is only required to provide interrogations for datalink messages from the aircraft. This would require a "message waiting" bit in the squitter reply format, which is a change from the current Mode S signal structure. In the squitter mode of operation, it is necessary to measure the times of arrival from the four satellites; however, it avoids the transponder delay associated with the aircraft transponder and provides an accurate means for determining aircraft position.

If the interrogation/reply technique is used with a transmit satellite interrogating for a reply message, then only three receive satellites are required to obtain a position determination. However, the transponder "jitter" and the cable length delays associated with the aircraft transponder must be incorporated in the position accuracy error budget, and some additional degradation in the position determination accuracy occurs. The central ground stations manage the datalink transmissions to the aircraft and the distribution of the datalink messages from the aircraft. Reliability of the datalink messages should be excellent since they normally are received over three or four independent links.

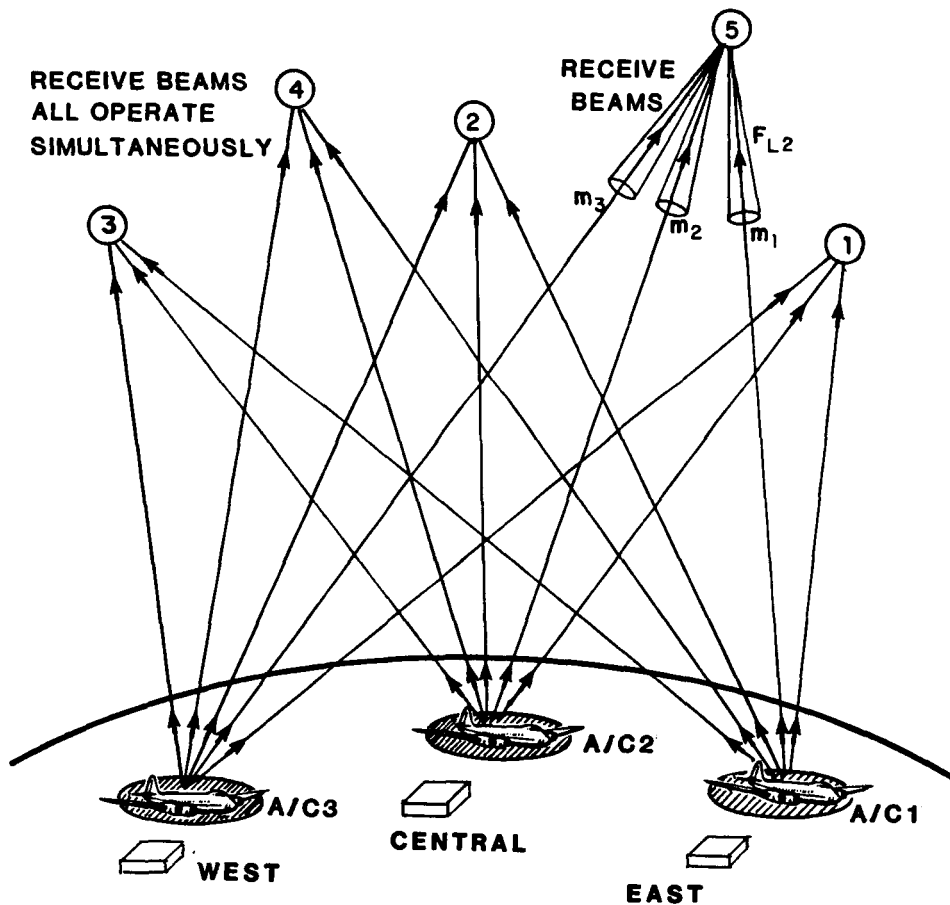


Figure 8

## CSSS AIRCRAFT-TO-SATELLITE LINK BUDGET

Figures 9 and 10 provide preliminary link budgets for the aircraft-to-satellite and the satellite-to-aircraft links of the compatible satellite surveillance system. The aircraft-to-satellite link is based upon an aircraft transponder transmitter power of 70 watts peak, corresponding to the minimum power required for operation in the ATC system. An antenna gain of unity is assumed for the circularly polarized top-mounted aircraft antenna. The spacecraft receiver system noise temperature is estimated at about 360 Kelvin, somewhat higher than the noise temperature of the radiation from the earth contained in the antenna beam width. A spacecraft receiver system bandwidth of about 10 MHz is assumed, which is somewhat liberal, and a signal-to-noise ratio of about 14 dB is obtained. The corresponding signal energy to noise density value is about 21.0 dB, which is approximately 5 dB above that required for a bit error rate (BER) of 1 part in  $10^5$ . The time of arrival measurement error for these values considering a demodulation loss of about 6 dB is approximately 30 nanoseconds, corresponding to a 30-foot ranging error. Since the satellite constellation provides a position dilution of precision (PDOP) factor of about 3, the position determination accuracy is about 100 ft. in three dimensions.

It should be recognized that the link budget closure requires a spacecraft antenna gain of approximately 52 dB which translates to a 50-meter diameter antenna at the 1030-1090 MHz operating frequencies. The principal driver leading to this large aperture antenna is the 70 watt aircraft transmitter power available from the minimal Mode S transponder.

A/C TRANSMITTER POWER; MINIMUM OF 70 WATTS PEAK	18.5 dBw	
A/C ANTENNA GAIN	0.0 dB	
EIRP	18.5 dBw	on-axis
FREQUENCY: 1090 MHz		
RANGE LOSS: 40,000 Km	185.2 dB	
S/C ANTENNA GAIN (D = 50 METERS)	52.0 dB	
S/C RECEIVER CIRCUIT LOSS	0.3 dB	
S/C ANTENNA POINTING LOSS (TRIPLE CROSSOVER)	4.0 dB	
POLARIZATION LOSS	0.0	
S/C RECEIVED SIGNAL POWER	-119.0 dBw	
S/C RECEIVER SYSTEM NOISE TEMP: 360 K	-203.0 dBw	$N_o$
S/C RECEIVER SYSTEM BW: 10 MHz	70.0 dBHz	
S/C RECEIVER SYSTEM NOISE POWER	-133.0 dBw	
SIGNAL TO NOISE RATIO, SNR	14.0 dB	RF SNR
DATA DETECTION, BIT RATE: 1Mbps	60.0 dB	
DEMODULATION LOSS	3.0 dB	
$E_b/N_o$	21.0 dB	AVAILABLE
$E_b/N_o$ REQUIRED FOR BER OF $10^{-5}$	16.0 dB	BER: 1E-5
AVAILABLE MARGIN	5.0 dB	
TIME OF ARRIVAL, PREAMBLE RATE: 2 Mbps	63.0 dB	
DEMODULATION LOSS	6.0 dB	
CARRIER ENERGY TO NOISE DENSITY, $E_b/N_o$	15.0	AVAILABLE
$E_b/N_o$ REQUIRED FOR TOA < 30 n. SEC.	15.0	
AVAILABLE MARGIN	0.0	

Figure 9

## CSSS SATELLITE-TO-AIRCRAFT LINK BUDGET

The satellite-to-aircraft link shown in Figure 10 also requires the 50-meter aperture antenna, primarily due to the poor sensitivity of the transponder receiver. The specified receiver sensitivity is -74 dBm, which corresponds to a noise temperature for the receiver of approximately 9,000 Kelvin. Assuming a spacecraft transmitter power of 5 kilowatts peak and the 50-meter antenna aperture, a carrier energy to noise density of 21.4 dB is obtained at the user transponder. This is about 9 dB above that required for a BER of 1 part in  $10^5$ . The available margin is essentially zero for the minimum triggering level required for the Mode S transponder.

S/C TRANSMITTER POWER (5 K WATTS PEAK)	37.0 dBw	
S/C TRANSMITTER CIRCUIT LOSSES	1.0 dB	
S/C ANTENNA GAIN (D = 50 m.)	<u>52.0 dB</u>	
EIRP	88.0 dBw	on-axis
FREQUENCY: 1030 MHz		
RANGE LOSS; 40,000 km	184.7 dB	
S/C TRANSMIT ANTENNA POINTING LOSS	<u>4.0 dB</u>	TRIPLE CROSSOVER
RECEIVED SIGNAL POWER	-100.7 dBw	
RECEIVER SYSTEM NOISE TEMPERATURE; 9000 K	-189.1 dBw	$N_o$
BIT RATE; 4 Mbps	66.0 dB	
DEMODULATION LOSS	1.0 dB	
CARRIER ENERGY TO NOISE DENSITY, $E_b/N_o$	21.4 dB	AVAILABLE
$E_b/N_o$ REQUIRED FOR BER OF $1E-5$	<u>12.0 dB</u>	REQUIRED
AVAILABLE MARGIN	9.4 dB	
MINIMUM TRIGGERING LEVEL	<u>-101.0 dBw</u>	WORST CASE
AVAILABLE MARGIN	0.3 dB	ABOVE MTL

Figure 10

## SATELLITE SYSTEM LINK DESIGN REQUIREMENTS

Satellite system link design requirements are tabulated in Figure 11. The 50-meter antenna aperture requires approximately 100 beams to cover the United States and the other areas under consideration. Therefore, a reasonably complex feed structure is required in addition to the large aperture antenna system. The normal operation of the CSSS is to use the "squitter" mode from the aircraft transponders. In this mode of operation, spontaneous reply transmissions containing the aircraft ID occur approximately once a second. These replies provide the basis for obtaining position determination from the system. The replies are received by each satellite in the constellation and relayed to the central ground station for position determination. A message waiting pulse is incorporated in the squitter transmission which informs the CGS if a data link message is waiting to be transmitted by an aircraft. An interrogation through the transmitter satellite to the aircraft transponder allows the datalink message to be sent. This mode of operation minimizes the prime power and size of the transmit satellites in the system. Transmissions may occur simultaneously on a number of beams depending on the traffic requirements for the aircraft in the ATC system. The duty cycle for the transmissions from satellite to aircraft is estimated to be in the order of 1 to 10 percent.

### RECEIVE

- o RECEIVE ON ~ 100 BEAMS SIMULTANEOUSLY
- o MAXIMIZE RECEIVER LISTENING TIME IF SQUITTERS ARE OF PRIME INTEREST
- o RECEIVE NOISE TEMPERATURE 360 K

### TRANSMIT

- o TRANSMIT ON FROM 1 TO (TBD) BEAMS SIMULTANEOUSLY
- o 5 KW PEAK RF POWER FOR THE  $\frac{\text{CONUS}}{100}$  BEAM SIZE
- o 18  $\mu$ SEC PULSES (OCCASIONAL 32  $\mu$ SEC PULSES) TRANSMITTED
- o DUTY CYCLE OF ABOUT LESS THAN 1% TO 10% (TBD)

Figure 11

## PHASED ARRAY TRANSMIT ANTENNA TRADE-OFFS

The advantages and disadvantages of a phased array transmit antenna are summarized in Figure 12. If a phased array transmit antenna is used, a smaller antenna is feasible because the beam agility of the phased array technique allows directing the antenna boresight toward the aircraft under surveillance. This avoids the triple crossover beam pointing loss of 4 dB in the previous power budgets. This factor combined with the greater ease with which high power levels can be generated with the phased array allows the substantial decrease in antenna dimension. It appears that a 14.5 meter array would be adequate; however, substantially increased prime power would be required for its operation.

### 14.5M ARRAY VS 50M REFLECTOR

#### ADVANTAGES

- GRACEFUL DEGRADATION
- POINT BEAM ANYWHERE  
MINIMIZE POINTING LOSS
- AVOID FAILURE OF SPECIFIC  
BEAMS DUE TO SEVERAL LOCALIZED  
FAILURES
- RECEIVE SATELLITES LISTEN ON  
ALL BEAMS ALL THE TIME
- NO LNA PROTECTION CIRCUITRY  
OR DIPLEXERS IN RECEIVE SATELLITES
- MINIMAL DESIGN WORK TO AVOID  
BREAKDOWN (PA's ARE LESS THAN  
A FEW HUNDRED WATTS)

#### DISADVANTAGES

- SEPARATE S/C DESIGN
- SEPARATE SAT-GROUND STATION  
2-WAY KU BAND LINK
- LARGER SOLAR-POWER SYSTEM
- LARGER SPOT BEAM
- TRANSMIT ON ONLY ONE BEAM  
AT A TIME
- ARRAY DISTORTION CORRECTION  
SYSTEM REQUIRED

Figure 12

## STRAWMAN SYSTEM DESIGN

The strawman system design characteristics are shown in Figure 13. The satellite constellation is to include both geostationary and synchronous inclined orbit satellites. A constellation of five inclined and two geostationary satellites would provide a system with redundancy in both the inclined and equatorial orbital planes. This arrangement would normally provide four satellites in view of the United States with five in view half of the time. The spacecraft commonality concerns relating to the use of independent transmit satellites or combined transmit-receive spacecraft are yet to be determined. In any case, the satellite RF systems basically consist of translating transponders which form a "bent pipe" return link to the ground for transponder replies. The system would require top-mounted circularly polarized aircraft antennas.

- o SATELLITES CONSTELLATION TO INCLUDE BOTH GEOSTATIONARY AND NON-GEOSTATIONARY SATELLITES
- o TOP-MOUNTED CIRCULARLY POLARIZED AIRCRAFT ANTENNA
- o SATELLITES (OPERATING UNDER A MIXED ATCRBS/MODE S ENVIRONMENT) BASED ON 50 M WRAP RIB OFFSET FED ANTENNA
- o APPROXIMATELY 100 RECEIVE BEAMS
- o TRANSMIT-RECEIVE S/C COMMONALITY TO BE DETERMINED
- o COMBINATION OF ACTIVE AND PASSIVE SURVEILLANCE MODES
- o RECEIVE SATELLITE BENT PIPE FOR TRANSPONDER REPLIES

Figure 13



## OFFSET-FED WRAPPED RIB LARGE APERTURE ANTENNA

Figure 14 illustrates a typical offset-fed wrapped-rib large aperture antenna similar to the type developed for the land mobile satellite system.

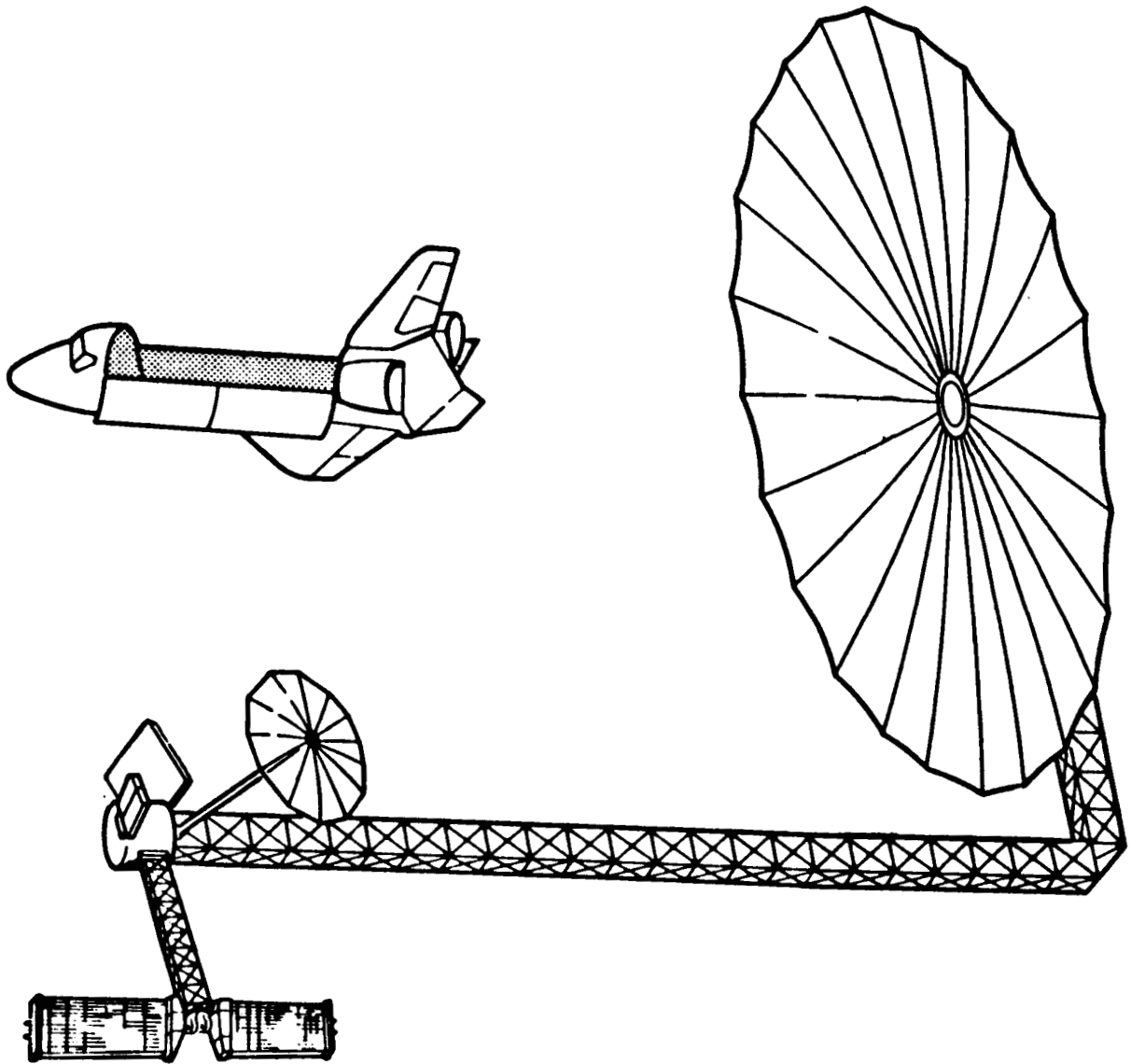
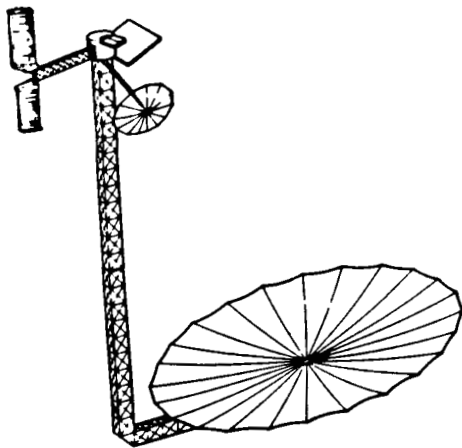


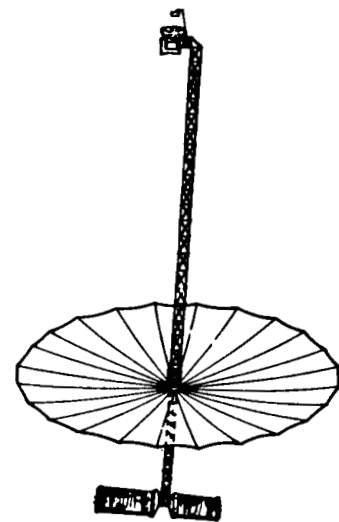
Figure 14

## PRINCIPAL ANTENNA CONFIGURATIONS CONSIDERED

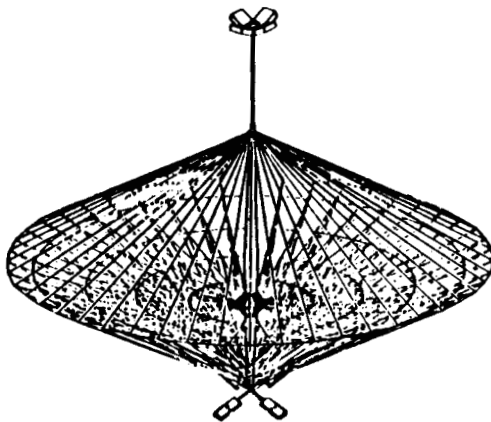
Other approaches which appear feasible for obtaining the aperture dimensions required are shown in Figure 15 and include the offset and axisymmetric wrapped-rib designs, the offset-fed quadruple aperture hoop column antenna, and the phased array transmit antenna which has been described.



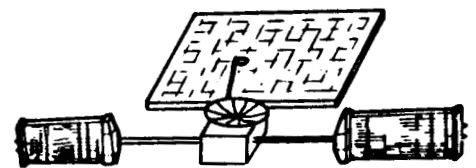
**OFFSET-FED WRAPPED RIB**



**AXISYMMETRIC WRAPPED RIB**



**OFFSET-FED CONFIGURATION BASED UPON HARRIS REFLECTOR**



**PHASED ARRAY TRANSMIT SATELLITE**

Figure 15

## REPRESENTATIVE MULTI-BEAM SURVEILLANCE SATELLITE CONFIGURATION

Figure 16 shows a representative multi-beam antenna surveillance satellite system which could be configured for the receive mode or for the combined transmit-receive modes of operation with the CSSS.

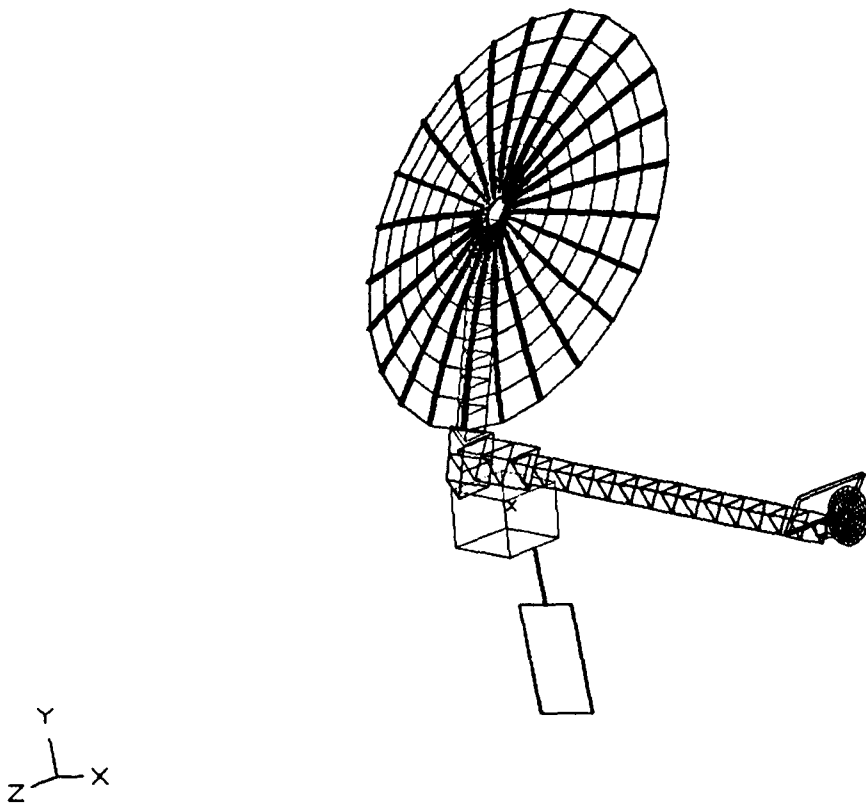
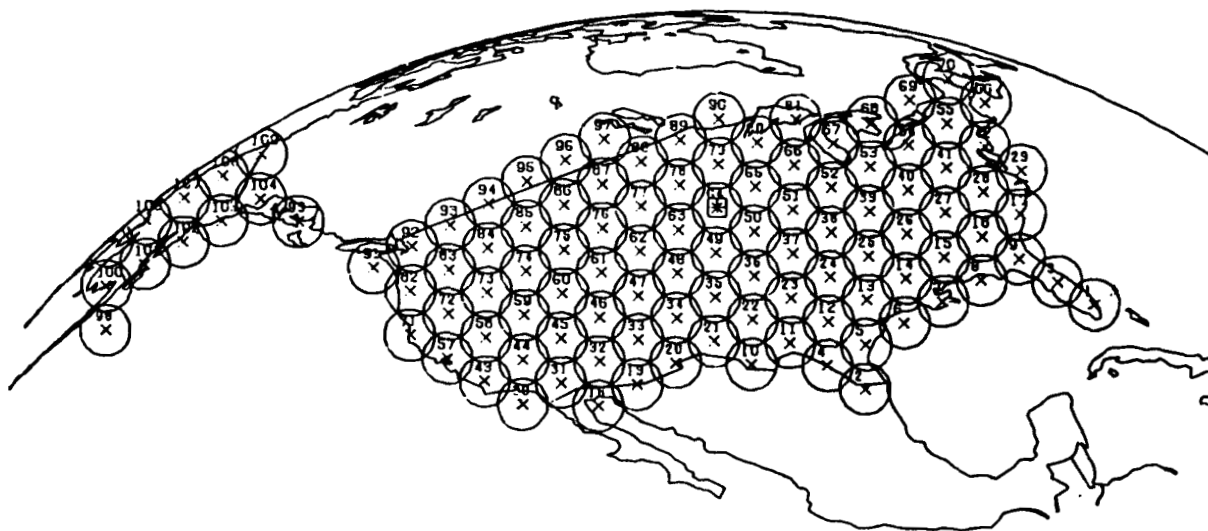


Figure 16

## SURVEILLANCE SATELLITE ANTENNA BEAM LAYOUT - SATELLITE PERSPECTIVE

The surveillance satellite antenna beam layout is shown in Figure 17 for a satellite in geostationary orbit at a location of 120 degrees West Longitude. This figure provides a satellite perspective of both the earth and the coverage beams.



SURVEILLANCE SATELLITE ANTENNA BEAM LAYOUT

SATELLITE POSITION: 120°W LONGITUDE GEOSTATIONARY ORBIT

Figure 17

# SURVEILLANCE SATELLITE ANTENNA BEAM LAYOUT - MERCATOR PROJECTION

The CSSS antenna patterns shown in Figure 18 illustrate the coverage of the beams on a mercator projection of the earth. The lengthening of the beams near the limb of the earth is clearly indicated.

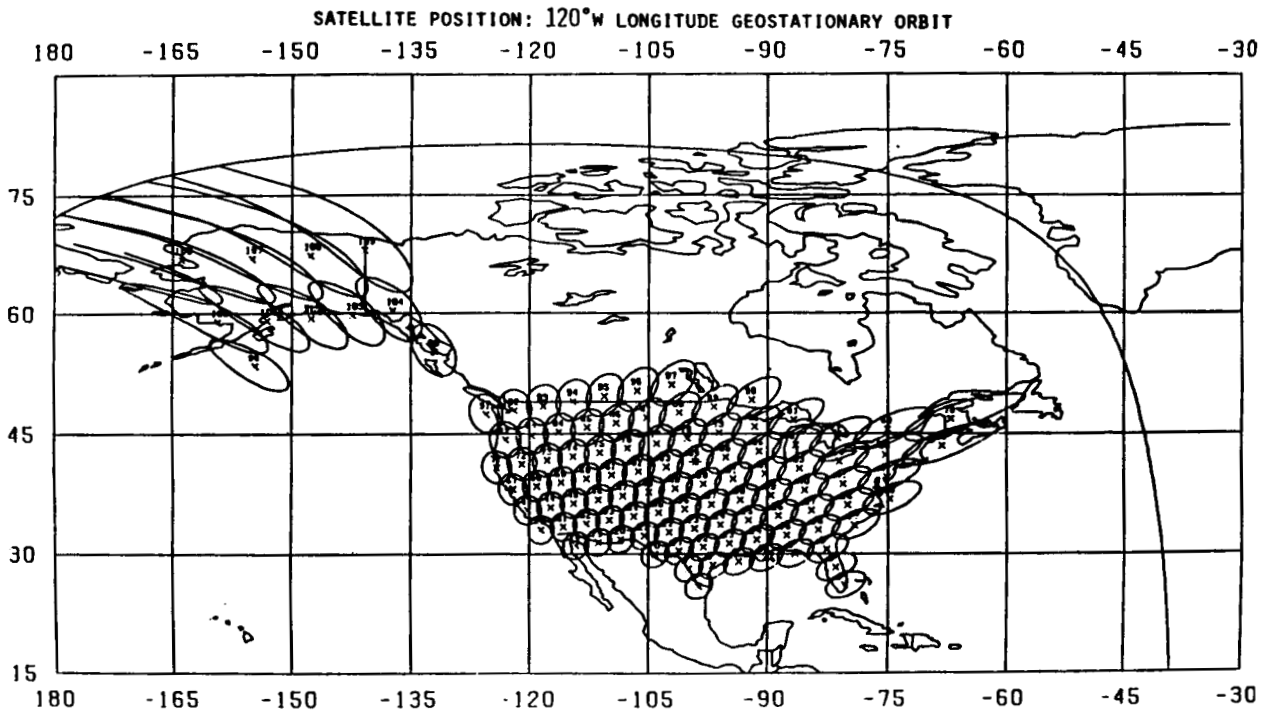


Figure 18

## DEPLOYABLE ANTENNA TECHNOLOGY READINESS DATES

Figure 19 is a chart (Ref. 2) illustrating the projected technology readiness dates for antenna reflector sizes which are deployed by satellite. This chart addresses precision deployables, advanced concepts, and existing concepts. As indicated, the existing concepts should be mature and available in the 1993-1995 time frame. The surface tolerance estimates for 50-meter antenna apertures indicated on the chart are considerably beyond those required for the 50-meter aperture antenna employed in the CSSS.

## DEPLOYABLE ANTENNA TECHNOLOGY READINESS DATES

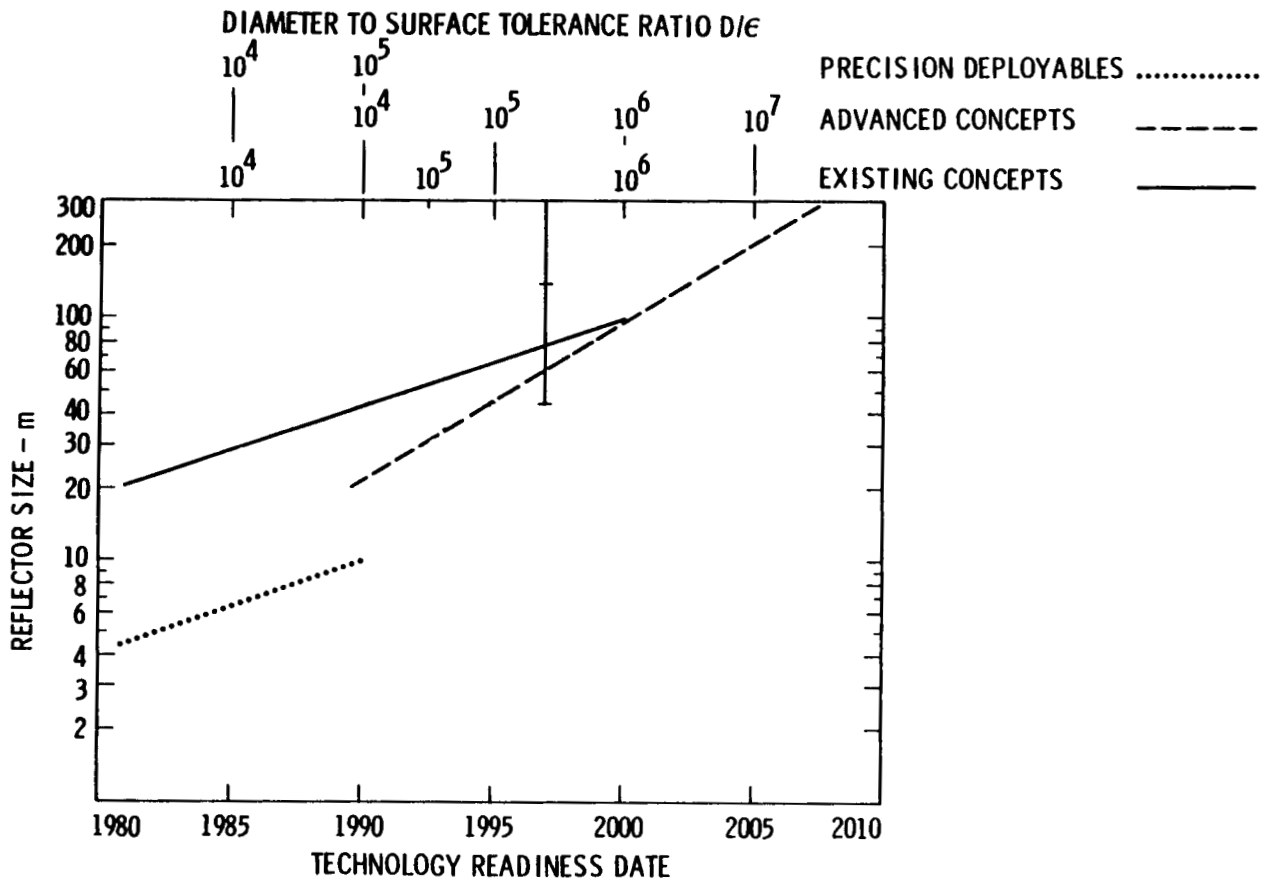


Figure 19

## CONCLUSIONS

The basic conclusions relating to the technical feasibility, practicality, and viability of the Mode S compatible surveillance satellite system are presented in Figure 20. Unless a number of applications for large aperture antenna and feed systems occur in the next few years, it does not appear likely that antennas in the 50-meter class will be economically viable even though several types appear technically feasible.

Investigation of this technology is continuing with the analysis of concepts and techniques which combine a) the use of smaller and more economically viable antenna apertures in space, b) the operation of the system in the aeronautical L-band where authorized allocations for satellite-based systems for aeronautical applications exist, and c) the modification of the Mode S transponder to operate at L-band frequencies, including the incorporation of a more sensitive receiver and a more capable transmitter system.

The investigation reported in this paper demonstrated many of the features and concerns in using satellites for ATC applications in the national airspace system. It appears clear that their potential is substantial and that further effort is needed for an attractive, useful, viable system to be developed.

- o COMPLETE COMPATIBILITY WITH ALL MODE S TRANSPONDER PARAMETERS RESULTS IN AN EXPENSIVE SPACECRAFT DESIGN.
- o MODE S TRANSPONDER LOW OUTPUT POWER (70 W GENERAL AVIATION) AND THE INTERFERENCE ENVIRONMENT AT 1090 MHz DRIVE THE RECEIVE SATELLITE ANTENNA SIZE TO THE 50 METER DIAMETER RANGE.
- o MODE S TRANSPONDER HIGH MINIMUM TRIGGERING LEVEL (OF -74 DBM) RESULTS IN A VERY HIGH POWER SATELLITE TRANSMITTER. INTERROGATION RATES ABOVE A FEW THOUSAND PER SECOND CAN DRIVE TRANSMIT SATELLITE PRIME POWER REQUIREMENTS ABOVE PRACTICAL LEVELS.
- o THE STRAWMAN SYSTEM DESIGN CAN PROVIDE ACCURATE AIRCRAFT POSITION DETERMINATION AND DATA LINK OPERATION OVER AREAS OF CONUS WHERE THE ATRBS SENSOR COUNT IS IN THE RANGE OF 10 TO 20 OR LESS WITHIN A RECEIVE BEAM (ALSO IAC DEPENDENT).
- o THE MODE S COMPATIBLE SURVEILLANCE SATELLITE SYSTEM APPEARS TECHNICALLY FEASIBLE BUT CURRENT COST CONSIDERATIONS MAKE ITS IMPLEMENTATION QUESTIONABLE.
- o A COST EFFECTIVE SATELLITE SURVEILLANCE SYSTEM WHICH USES THE MODE S FORMAT WILL REQUIRE MODIFICATION TO THE MODE S TRANSPONDERS.

Figure 20

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