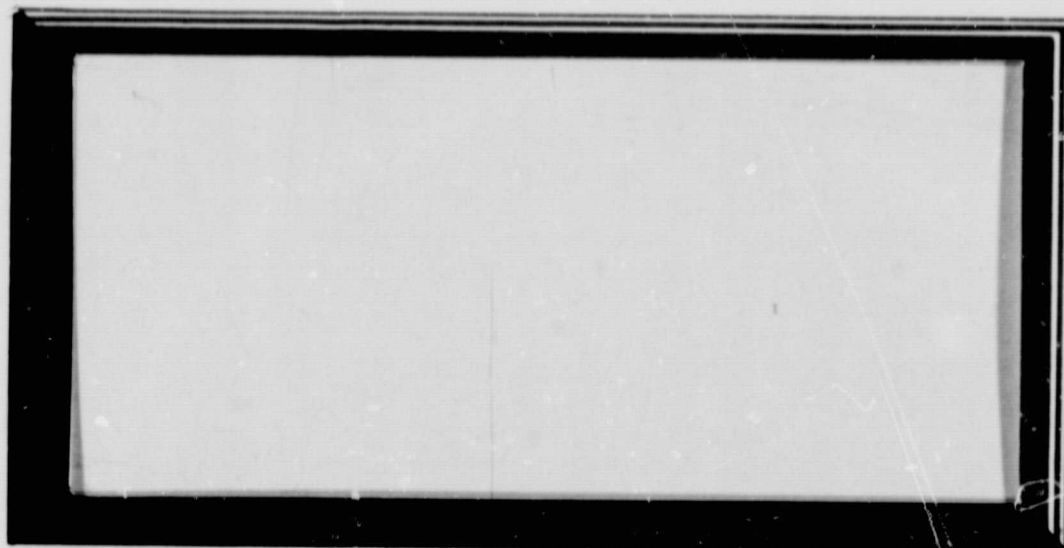


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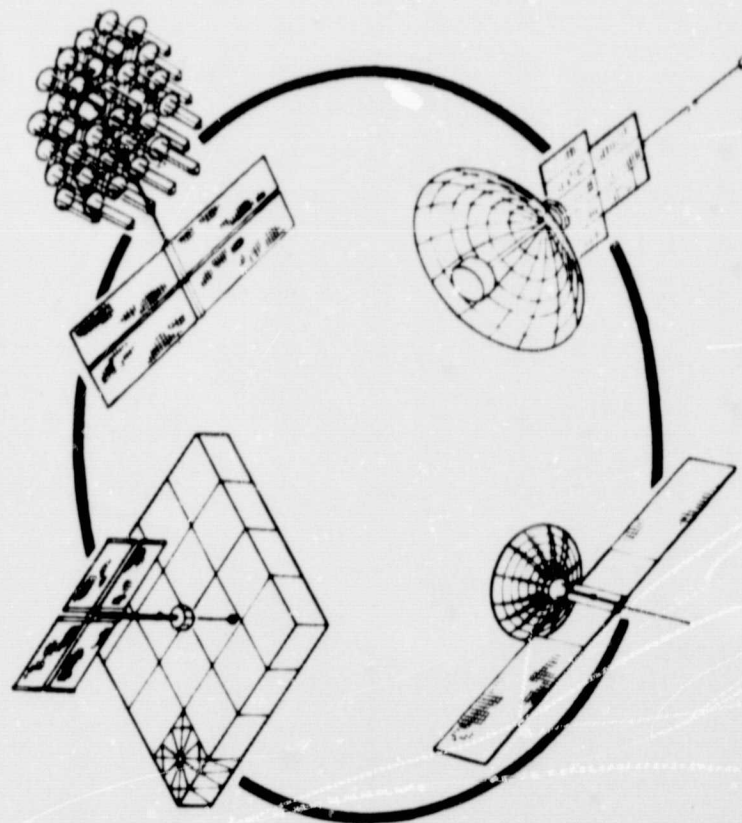
GENERAL  ELECTRIC

DOCUMENT NO. 67SD4330
SEPTEMBER 22, 1967

**VOICE BROADCAST MISSION STUDY
NASW 1475**

**VBMS
FINAL REPORT**

VOLUME I - SUMMARY



GENERAL  ELECTRIC

MISSILE AND SPACE DIVISION
Valley Forge Space Technology Center
P. O. Box 8555 • Philadelphia, Penna. 19101

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SECTION 1

INTRODUCTION

The Voice Broadcast Mission Study (VBMS) investigated the technological and cost factors associated with unmanned satellites for the direct broadcast of aural material to unmodified home receivers. The study was performed under a prime contract to the Missile and Space Division of the General Electric Company. The Goodyear Aerospace Corporation contributed to the study as a subcontractor in the area of spacecraft antennas. The study is summarized in this volume (Volume I). The detailed results are presented in Volume II, "Study Report," Document No. 67SD4330, 14 July 1967.

The variables involved in system selection are shown in Figure 1-1. All of these factors, with the exception of political and business differences, were considered in the selection of systems. Systems were evaluated and conceptually designed to be available in the early 1970's. Three frequency bands were considered:

- High Frequency (HF)/AM,
15 to 26 MHz
- Very High Frequency (VHF)/FM,
88 to 108 MHz
- Ultra High Frequency (UHF)/FM,
470 to 890 MHz

The study involved the evaluation of potential audience, in terms of the distribution of receivers, and the signal strength required to reach the audience in each of the frequency bands. A series of configurations were postulated and evaluated, leading to the definition and conceptual design of four Representative Systems. The performance and costs of these configurations were parametrically evaluated, and schedules and program plans were defined. Throughout this evaluation, design parametric and analysis tools were developed to permit rapid synthesis and evaluation of new systems as requirements become more fully defined.

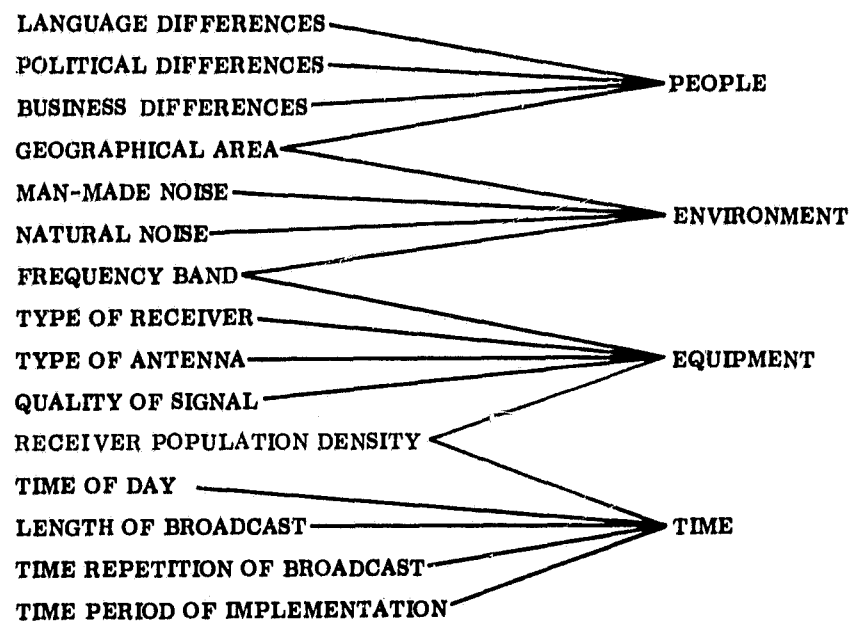


Figure 1-1. Variables For
System Selection

The characteristics of the Representative Systems developed are summarized in Table 1-1. Each of these systems was designed to perform a different specific mission and therefore direct comparison among the systems cannot be made. Vehicle concepts are shown in Figures 1-2 through 1-5.

Table 1-1. Representative Systems Summary

		HF	VHF 1	VHF 2	UHF
Orbit		4356 nm (4.8 hr circular equatorial)	19323 nm (Geostationary)	7556 nm (8hr circular equatorial)	19323 nm (Geostationary)
Satellite In-orbit Weight (lb)		4741	2560	171	1126
Booster		Titan III F/Stretched Transtage	Titan III F/Transtage	SLV-3A/Improved Agena D	SLV-3A/Improved Agena D + Apogee Kick Motor
Solar Power Supply	Array Type & Size	4 Section, roll out 38' x 12'	4 Section roll out 42' x 12'	8 Section fold out 4' x 9'	2 Section roll out 28.5 x 7.7
	Cell Area (ft ²)	1788	1968	326	438
	Power Out (end of 2 yrs) (kw)	15.4 kw with batteries 7 kw from array	11.38	1.36	2.54
Antenna	Size & Type	100' x 100' x 15' 16 element array	51' x 51' x 15' 32 element array	34.5' Dia.	22.5' Dia.
	Gain & HPBW	14.4 db, 20°	26.9 db, 7.5°	19 db, 18.5°	23 db, 3.75°
	Beam Pointing	Electronic Pointing referenced to local vertical	Electrical Pointing (interferometry)	Feed Positioning referenced to local vertical	Antenna fixed to vehicle, vehicle pointed using interferometer
ERP (dbw)		52.1	65.4	48.1	63.6
Performance	Coverage	1.8 million sq nm areas, 1 hr to 5 areas/day	Continental U.S. continuously (except shadow)	1.8 million sq nm areas, 1 hr to 3 areas/day	U.S. by time zone, 5 hr to each time zone each day
	Field Strength	158 to 433 μ v/m	204 to 273 μ v/m	77 to 99 μ v/m	99 to 144 μ v/m
	Potential Audience	37 million radios representing 13% of world total in 1970	98 million radios representing 74% of world total in 1970	15 million radios representing 12% of world total in 1970	36 million TV receivers representing 29% of world total in 1970

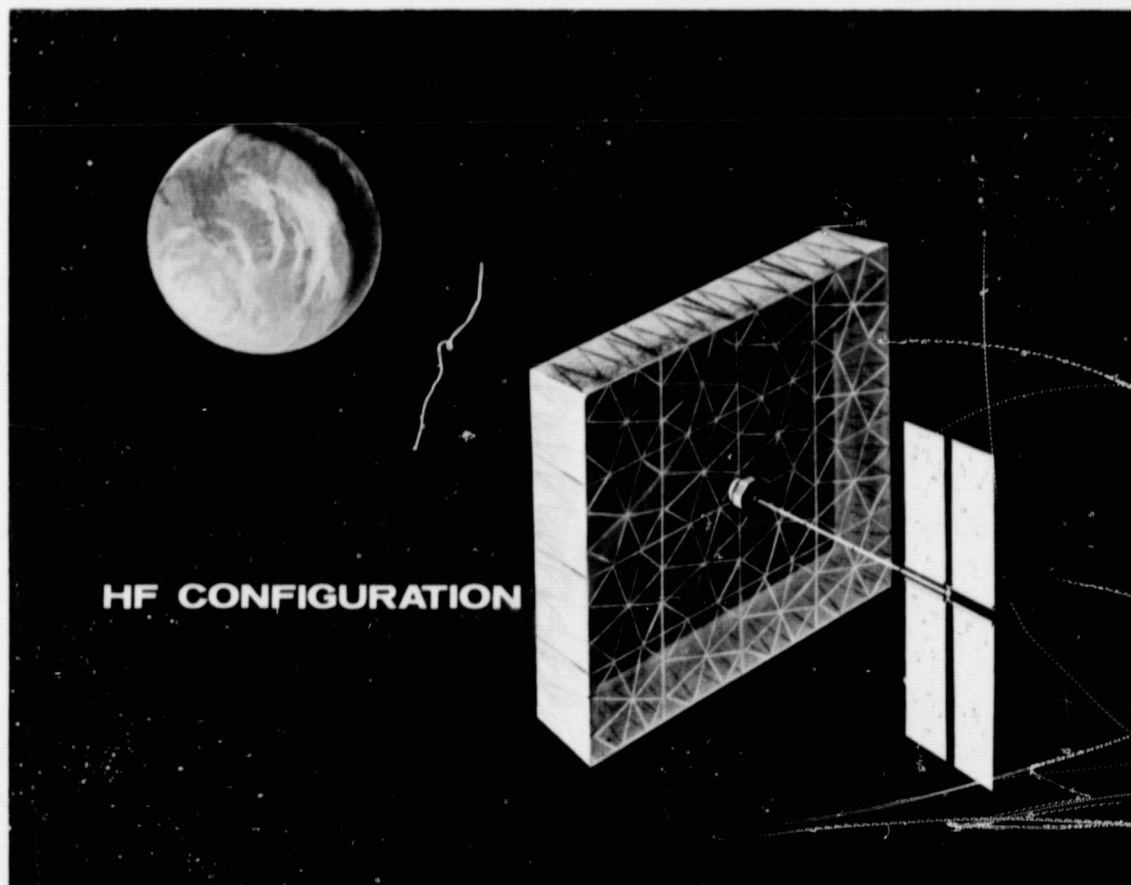


Figure 1-2. HF Configuration

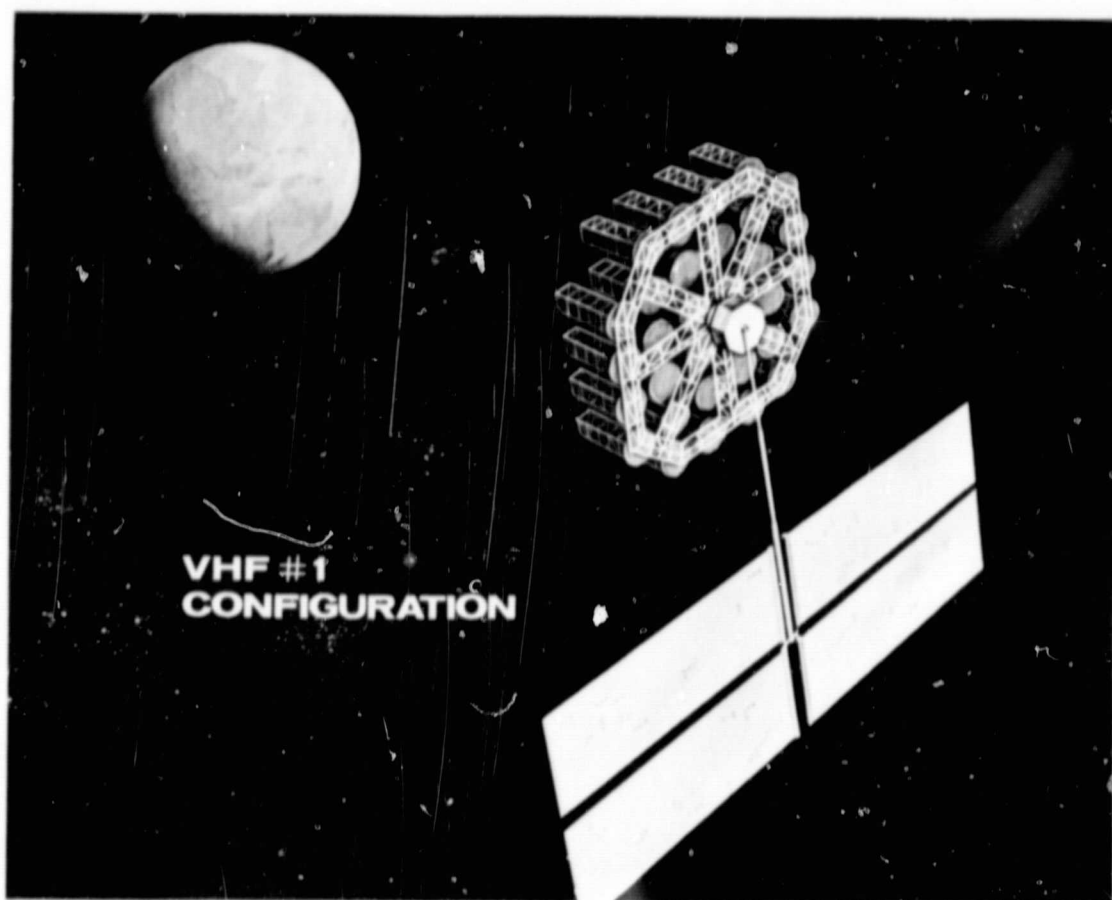


Figure 1-3. VHF 1 Configuration

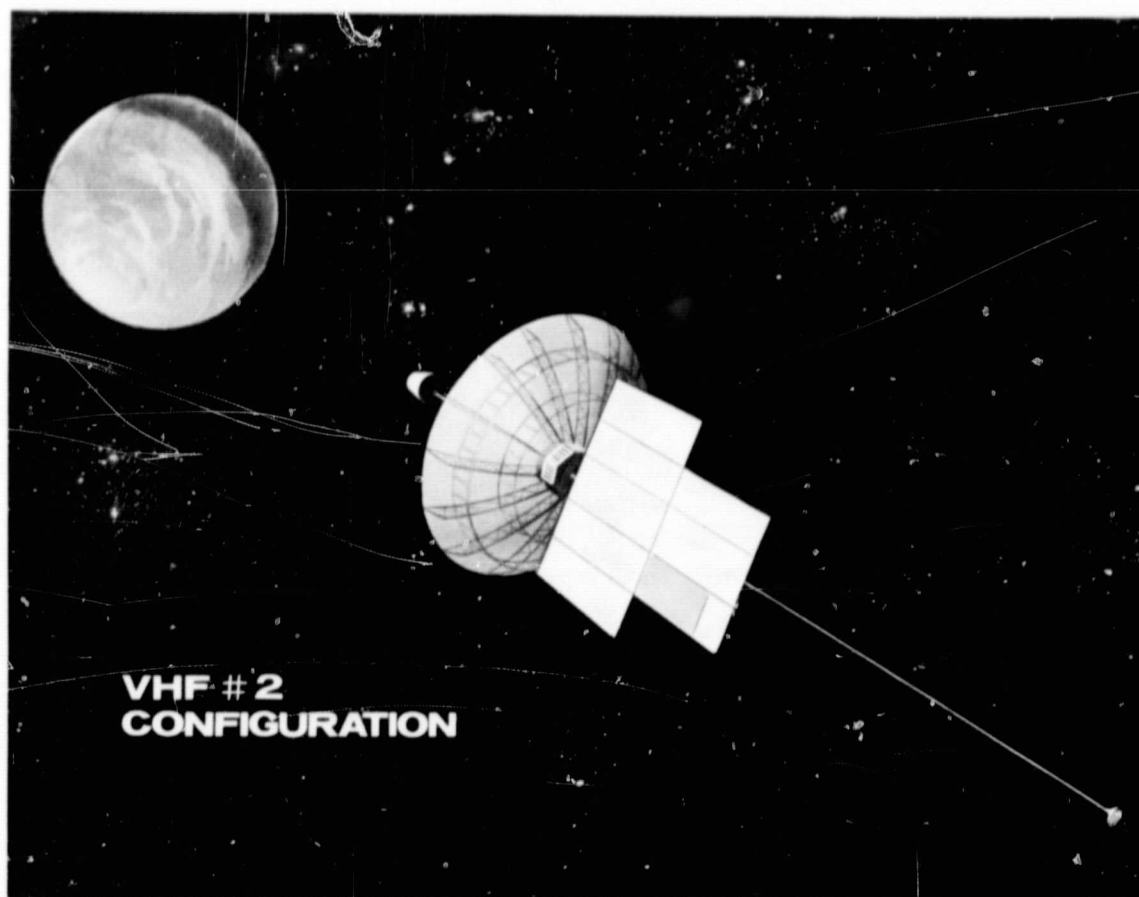


Figure 1-4. VHF 2 Configuration

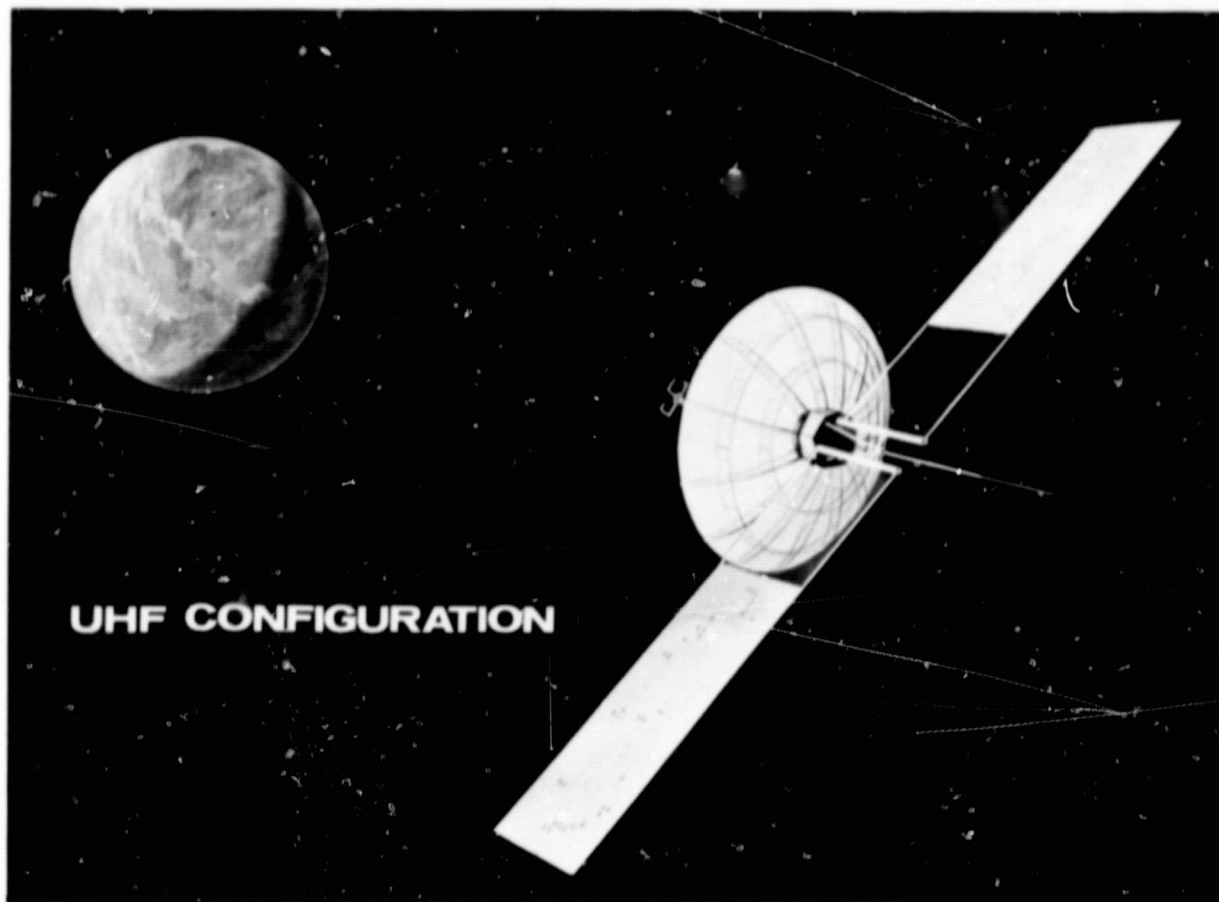


Figure 1-5. UHF Configuration

The most critical technology problems associated with these configurations, and in general with the whole class of configurations that can be anticipated for direct voice broadcast are:

- Large Solar Array Deployment
- Large Antenna Deployment
- Stabilization of Flexible Vehicles
- Long Life High Power Transmitters
- Long Life Space Systems (Minimum two years)

The study has shown that direct broadcast of aural material from satellites is feasible in the early 1970's. It has been determined that cost-effective systems are possible for certain combinations of population density, areas covered, and schedules of operation (duty cycle). This study has also provided an estimate of the vast radio audience available throughout the world (over 1/2 billion receivers by 1970 in the frequency bands investigated).

SECTION 2

STUDY PLAN

At the start of the VBMS, the range of objectives and systems requirements under investigation was very broad. In order to narrow down the possibilities to arrive at a basis for defining representative systems and to identify the technical problems associated with voice broadcast systems, a number of iterations were required. To accomplish this during the six month study period, a three phase program was defined. The study plan flow is shown in Figure 2-1.

During Phase I the potential audience was defined in terms of numbers of receivers and their locations. Representative receiver performance was developed to define ground signal requirements. Possible orbits capable of providing desired coverages were evaluated and ranges of system performance requirements identified. Technology limits were defined for the critical subsystems and candidate configurations were defined to cover the range of performance requirements. The results of the Phase I portion of the study were used to develop the performance requirements for the Phase II representative systems effort.

Phase II of the program concentrated on the conceptual design of four representative systems to meet the goals established at the end of Phase I. Preferred approaches to fulfilling the above requirements were developed through trade-off analyses. Minimization of costs and the feasibility of establishing on-orbit systems by the early 1970's were used as a basis for approach selection.

Phase III was devoted to a detailed performance and cost analysis of the representative systems. This included further analysis of the audience reachable and an evaluation of cost-effectiveness. Program plans and technology problem areas were also defined for each of the four systems.

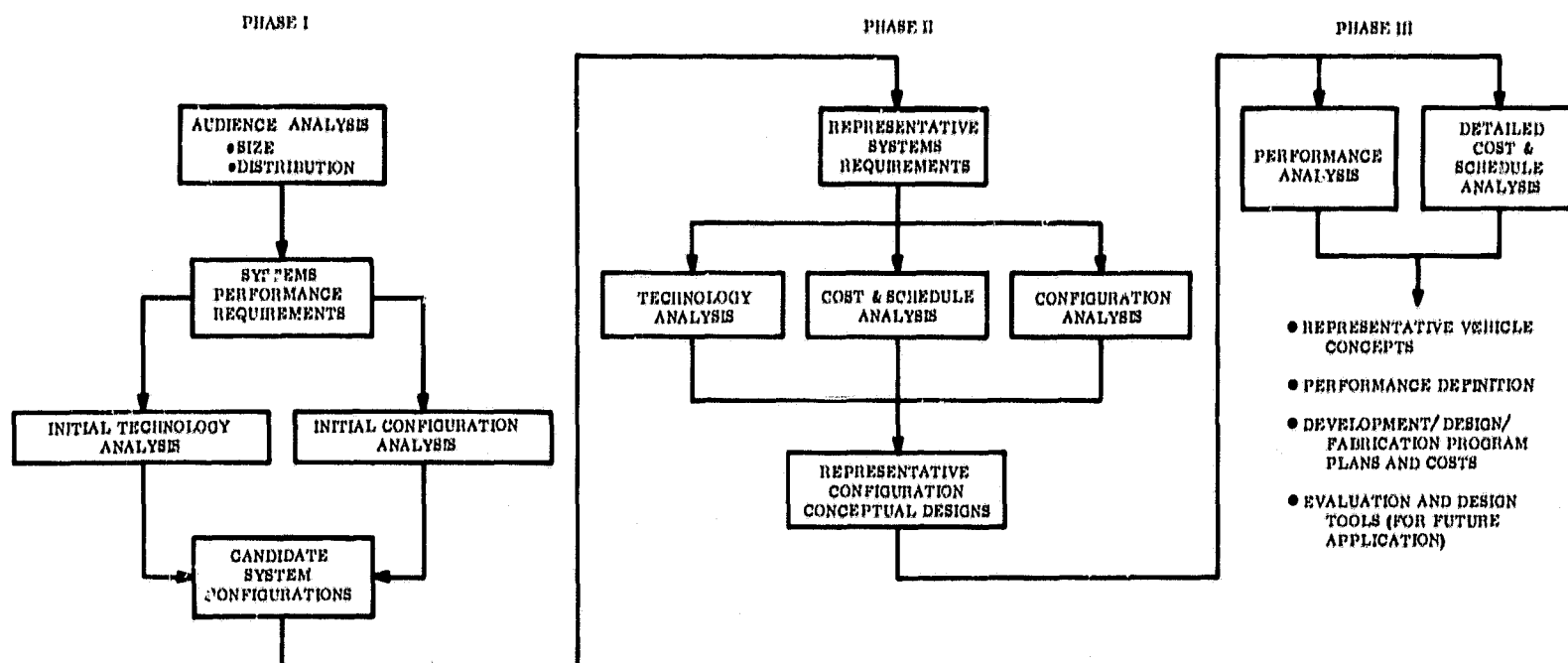


Figure 2-1. Study Plan

SECTION 3

SYSTEM PERFORMANCE REQUIREMENTS

To provide a basis for voice broadcast satellite performance it was necessary to define the radio audience and what signals are required to reach that audience. The areas of prime consideration in developing the system performance requirements are:

- World Audience Distribution
- Propagation Effects
- Ground Signal Requirements
- Audience Reachable

3.1 WORLD AUDIENCE DISTRIBUTION

The potential audience for the HF band is distributed widely throughout the world. This audience is unique in that nearly 50% of the receivers are found in newly emerging areas of the world. The audience in the United States is very small. Although there are short wave receivers in Russia, no data was available upon which to estimate the size of the potential audience. The distribution is shown in Figure 3-1. The percentages shown reflect the portion of the total world's receivers (excluding Russia) in each area.

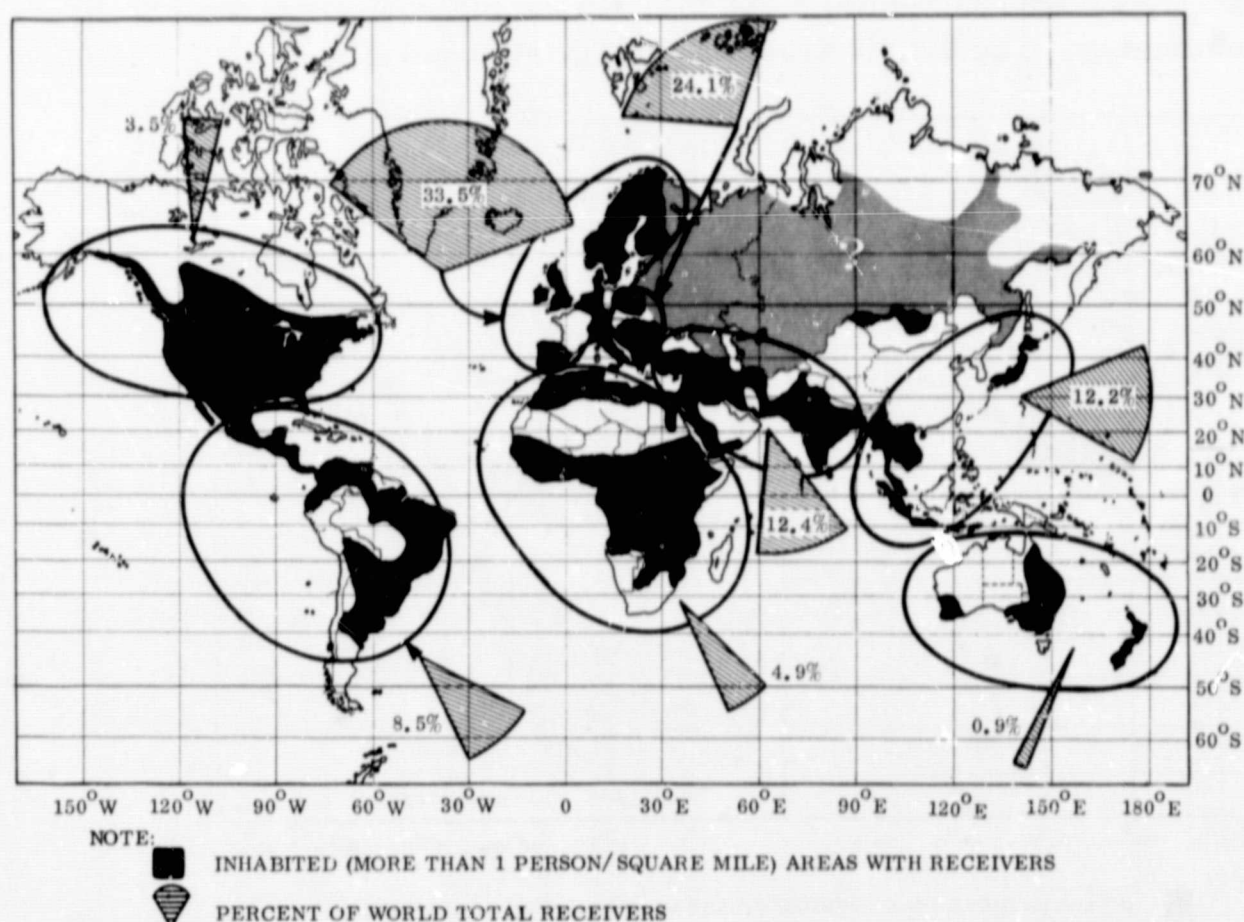


Figure 3-1. Distribution of Potential HF Audience (15 to 26 MHz)

The potential audience in the VHF band is also widely distributed throughout the world but the receivers in the United States account for almost 75% of the audience. More than 90% of the receivers are located in developed areas. This distribution is shown in Figure 3-2.



Figure 3-2. Distribution of Potential VHF Audience (88 to 108 MHz)

The UHF potential audience is very sparsely distributed throughout the world. UHF TV receivers are essentially found only in the United States, Western Europe, and the Far East, with the United States predominating. The distribution is shown in Figure 3-3.

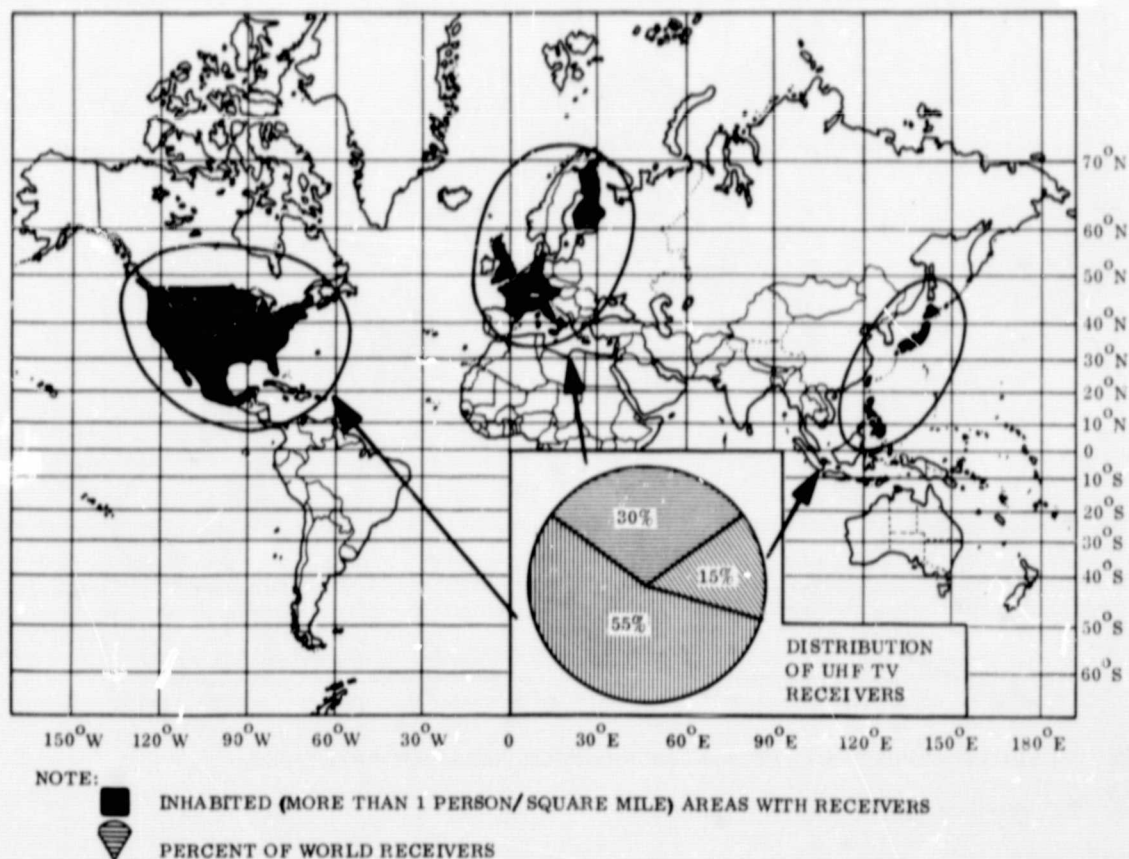


Figure 3-3. Distribution of Potential UHF Audience (470 to 890 MHz)

The total radio audience in the bands of interest to this study has been estimated to be over 1/2 billion by 1970. More than half of these receivers will be HF. The audience size, by world areas projected to 1970, is shown in Figure 3-4. All audience analyses conducted during this study were based on 1970 projections.

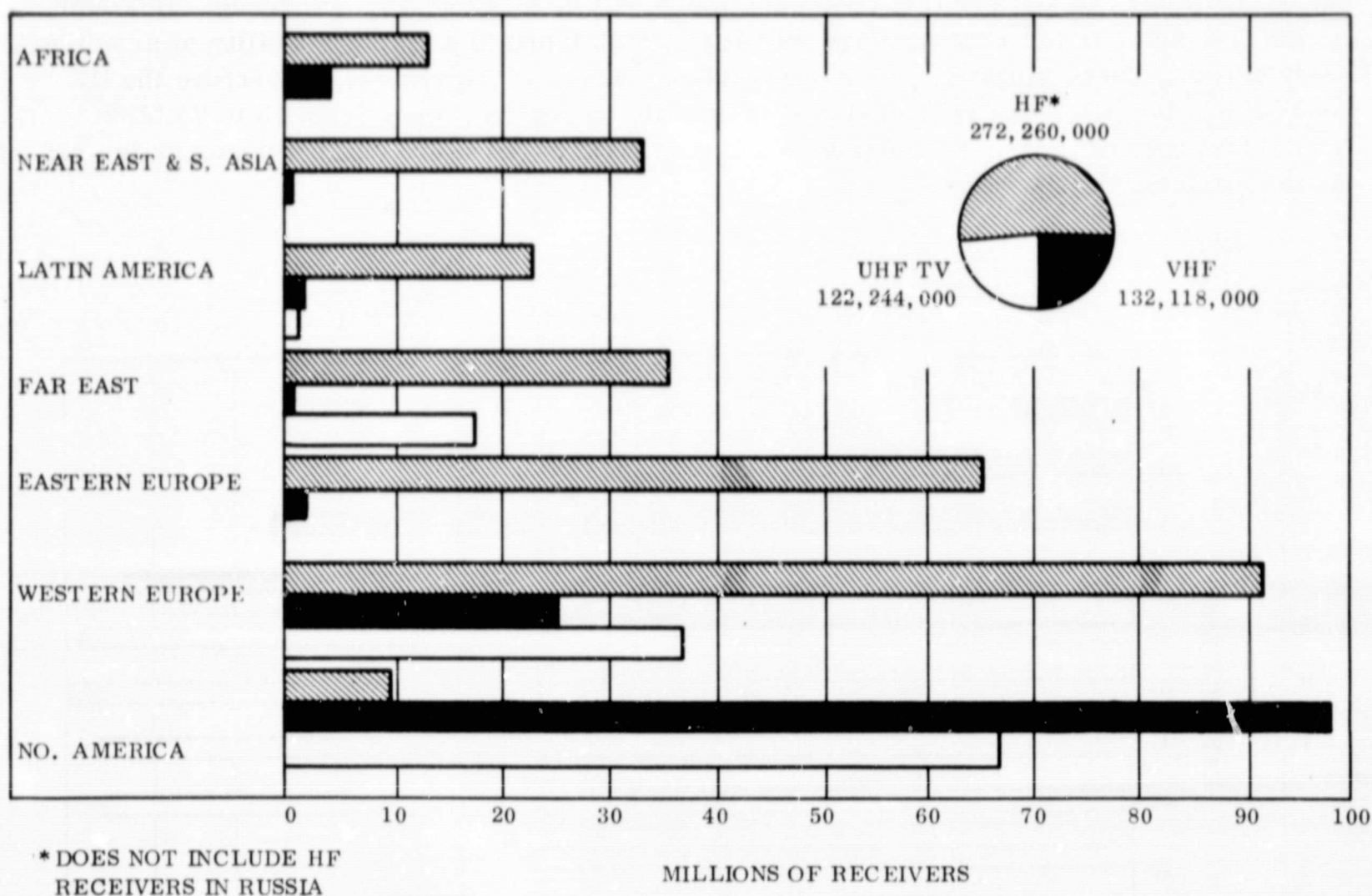


Figure 3-4. Types and Locations of Receivers (1970 Projection)

3.2 PROPAGATION EFFECTS

When defining the signal that must be generated by a satellite in order to provide a given signal on the earth's surface, the effects of the ionosphere must be considered in addition to the normal free space signal attenuation. The ionosphere absorbs some of the energy and also defocuses the beam. The short term variation in defocusing causes what is commonly called fading. These effects are most severe at low frequencies. Losses increase as the latitude of the target area increases. The ionospheric effects are of most significance for the HF band and must be considered in the same fashion as in present terrestrial broadcasting. (At the higher frequency bands these factors are still present but the effects are greatly reduced.) All of these effects vary as a function of time of day and year.

The ionosphere also causes rotation of the plane of polarization of transmitted waves. The amount of rotation varies as a function of frequency and ionospheric conditions. If linearly polarized antennas are used at both the satellite and the home, deep fades may be experienced. This fading can be limited by utilizing circular polarization at the spacecraft and accepting a 3 db (1/2 power) loss in the system.

There is a frequency above which ground transmitted signals will pass through the ionosphere (no bounce). This frequency usually occurs at the high end of the 15 to 26 MHz band. If the satellite operates above that frequency there will be no ground interference. However, as the frequency is increased toward values at which there is a high probability of avoiding interference, the potential audience decreases as shown in Figure 3-5. Therefore the HF system configuration has been designed to operate on any frequency from 15 to 26 MHz. The actual operating frequency assignments may be secured in the same manner as is presently in use for terrestrial systems.

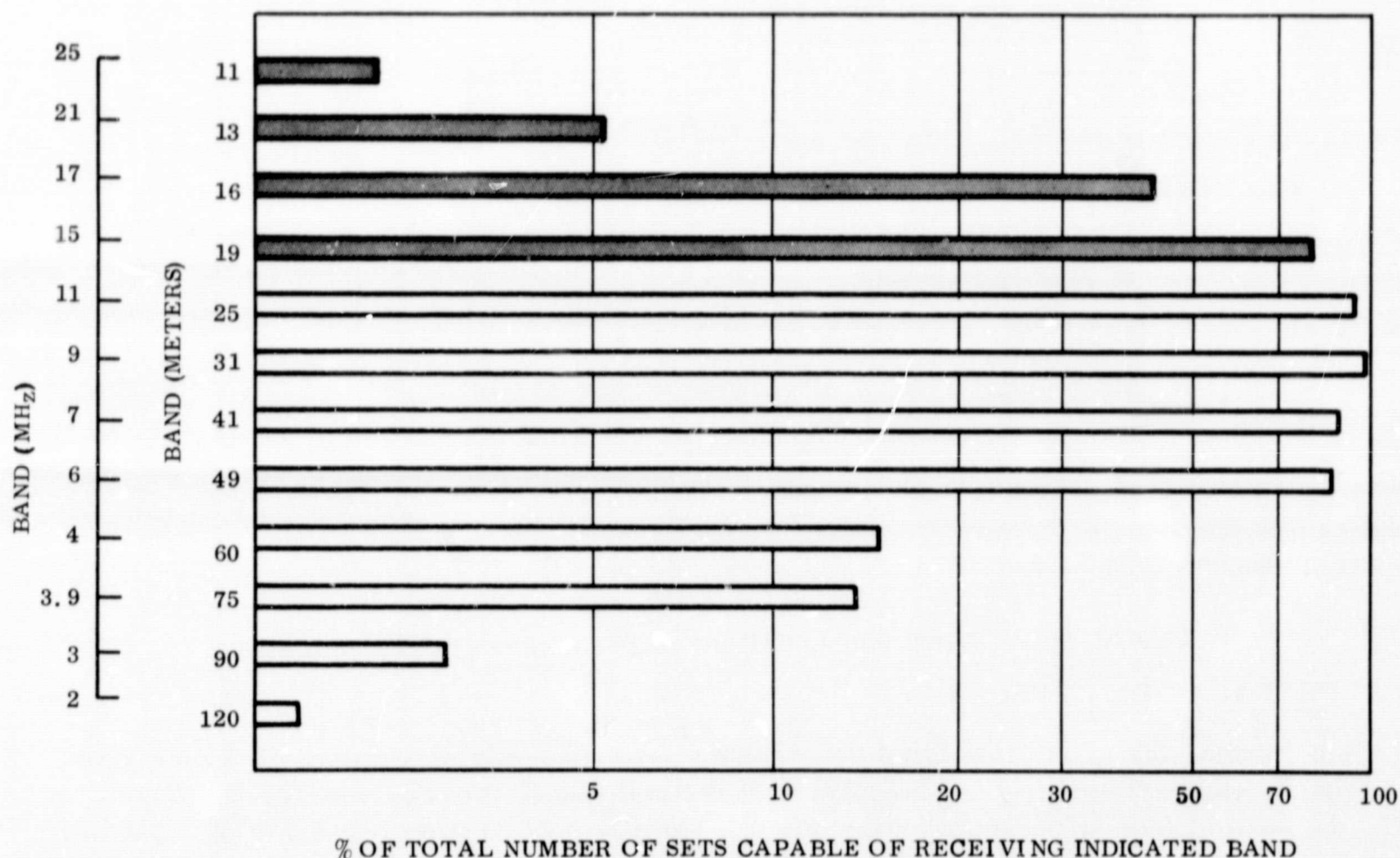


Figure 3-5. HF Receiver Band Selection Capability

3.3 GROUND SIGNAL REQUIREMENTS

In defining the signal levels that the satellite must place at the earth's surface to reach home radio receivers, the receiver sensitivity must be known or estimated. The distribution of sensitivity of receivers used for this study for the HF and VHF cases was derived from measurements made on selected receivers. This distribution was assumed to apply to the world's receiver population since the receivers were selected to be representative of the present market. For the case of HF reception, to obtain a reasonable audio quality, the signal strength to overcome the noise background exceeded the sensitivity point of all the types of HF radios. Thus, the HF sensitivity distribution did not modify the results of the signal level analysis. For the audio sensitivity of UHF TV receivers, theoretical performance (6 microvolts) was assumed for all sets since this is a parameter that is well controlled in TV sets. The assumed sensitivity for the VHF case is shown in Figure 3-6.

Three items have to be considered in addition to basic receiver performance. These items are: the type of antenna and its location (indoor/outdoor), the effect of building attenuation on indoor antennas, and the man-made noise environment in which the receivers exist.

For evaluation in this study, the antenna types assumed as representative of those expected to be in existence in the 1970's and the losses assumed are shown in Table 3-1.

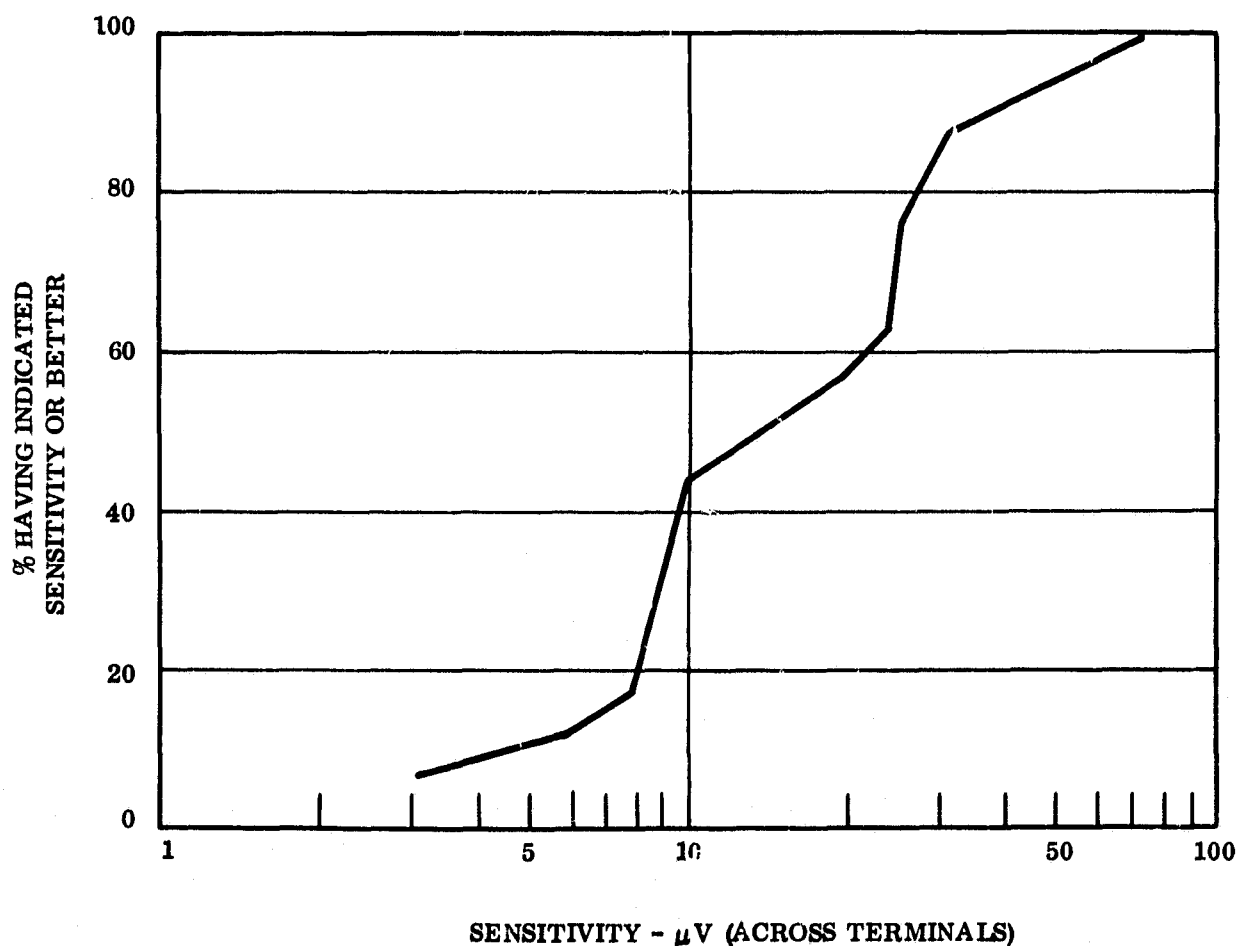


Figure 3-6. Measured Sensitivity, VHF (16 "Comparison Shopping" Receivers)

Table 3-1. Home Antenna Assumptions

Frequency	HF	VHF	UHF
<u>Antenna Type</u>			
Indoor	Whip	Whip	Loop
Outdoor Low Gain	Wire	Dipole	Dipole
Outdoor High Gain	← 3 Element Yagi →		
<u>Losses</u>			
Polarization	3 dB	3 dB	3 dB
Line	0 dB	0.5 dB	3 dB

The distribution of these antenna types is shown in Figure 3-7. The distribution shows that approximately 50% are indoor and 50% outdoor. These values are based on data gathered for UHF TV in the United States.

Estimates from world-wide users indicate that this distribution applies to all bands.

The effects of building attenuation on signal requirements for indoor antennas must be considered next. To provide an estimate of building attenuation, data was taken from the New York City survey on VHF and UHF television frequencies and extrapolated to the frequencies of interest in this study. The use of this data will produce conservative results since the data is based on ground measurements, where the structural effects of side walls and adjacent buildings will be generally more severe than in the case of satellite transmitted signals. (See Figure 3-8.) As a transition occurs from urban to suburban areas at a given frequency, the nature of the structures involved reduces the building attenuation significantly. As the frequency decreases for a given type of assumed structure, the building attenuation also decreases significantly.

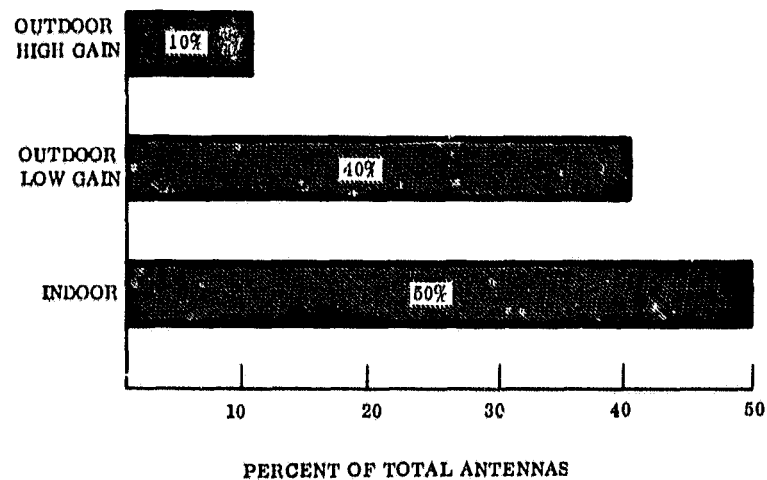


Figure 3-7. Antenna Distribution

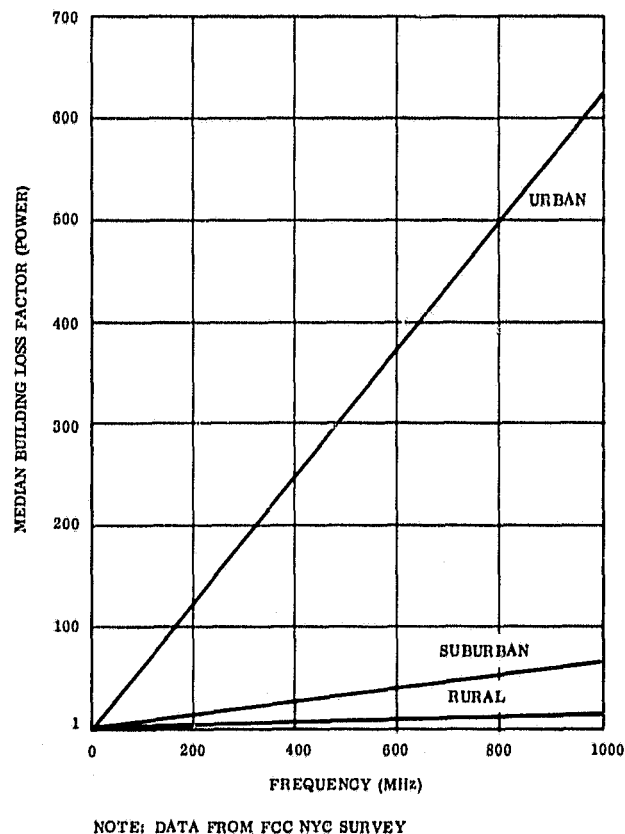


Figure 3-8. Building Attenuation

The design values used for building power losses are:

	<u>HF</u>	<u>VHF</u>	<u>UHF</u>
Urban	12.4 dB	17.7 dB	26.9 dB
Suburban	4.8 dB	9.5 dB	17.9 dB
Rural	0 dB	0 dB	10.4 dB

The third item to be evaluated was the man-made electrical noise environment in which the home receivers exist. Published data was not considered to be sufficient to properly define average noise power as a function of site location. As a part of the study, noise measurements were taken at three locations in the Philadelphia and Valley Forge, Pennsylvania area to provide additional information. The three sites were selected to be representative of urban, suburban and rural locations. The data taken confirmed the slope and the value (within 5 dB) of the Environmental Science and Services Administration (ESSA) data. See Figure 3-9.

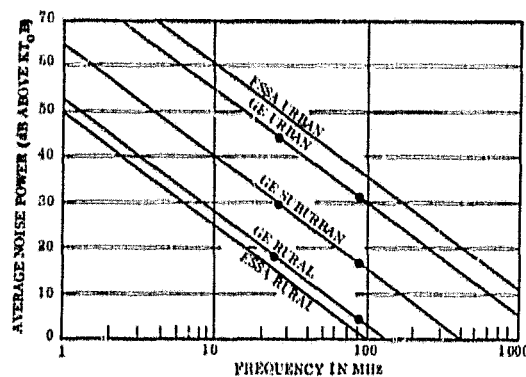


Figure 3-9. Man-Made Noise

The values derived from the curves and used in the study analysis are tabulated below.

	Urban	Suburban	Rural
15 MHz	55 dB $9.15 \times 10^{70} \text{K}$	35 dB $9.15 \times 10^{50} \text{K}$	20 dB $2.9 \times 10^{40} \text{K}$
100 MHz	35 dB $9.15 \times 10^{50} \text{K}$	15 dB $9.15 \times 10^{30} \text{K}$	0 dB 290^{0}K
890 MHz	11.5 dB $3.78 \times 10^{30} \text{K}$	-7.5 dB 51.5^{0}K	-23.5 dB 1.3^{0}K

As part of the noise measurement program, receiving antenna noise discrimination was measured. It was found that with a high gain antenna, at an elevation angle of 45° , the noise discrimination is approximately half the forward power gain of the antenna in dB.

3.4 AUDIENCE REACHABLE

To identify the potential audience as a function of signal level on the ground, the foregoing data must be combined with estimates of the distribution of receivers in urban, suburban and rural environments. It was assumed that receivers are distributed as the population is distributed. Because of the lack of data on population distribution of most countries, the following demographic rule was used.

$$\text{Population of } n^{\text{th}} \text{ largest city} = \frac{\text{Population of largest city}}{n}$$

The population was divided into the three classifications as follows:

Urban - total population in cities of 1 million or greater plus half the population in cities from 100,000 to 1 million.

Suburban - one half the population in cities from 2500 to 1 million.

Rural - total remaining population.

The results of this combination are shown in Figures 3-10, 3-11, and 3-12.

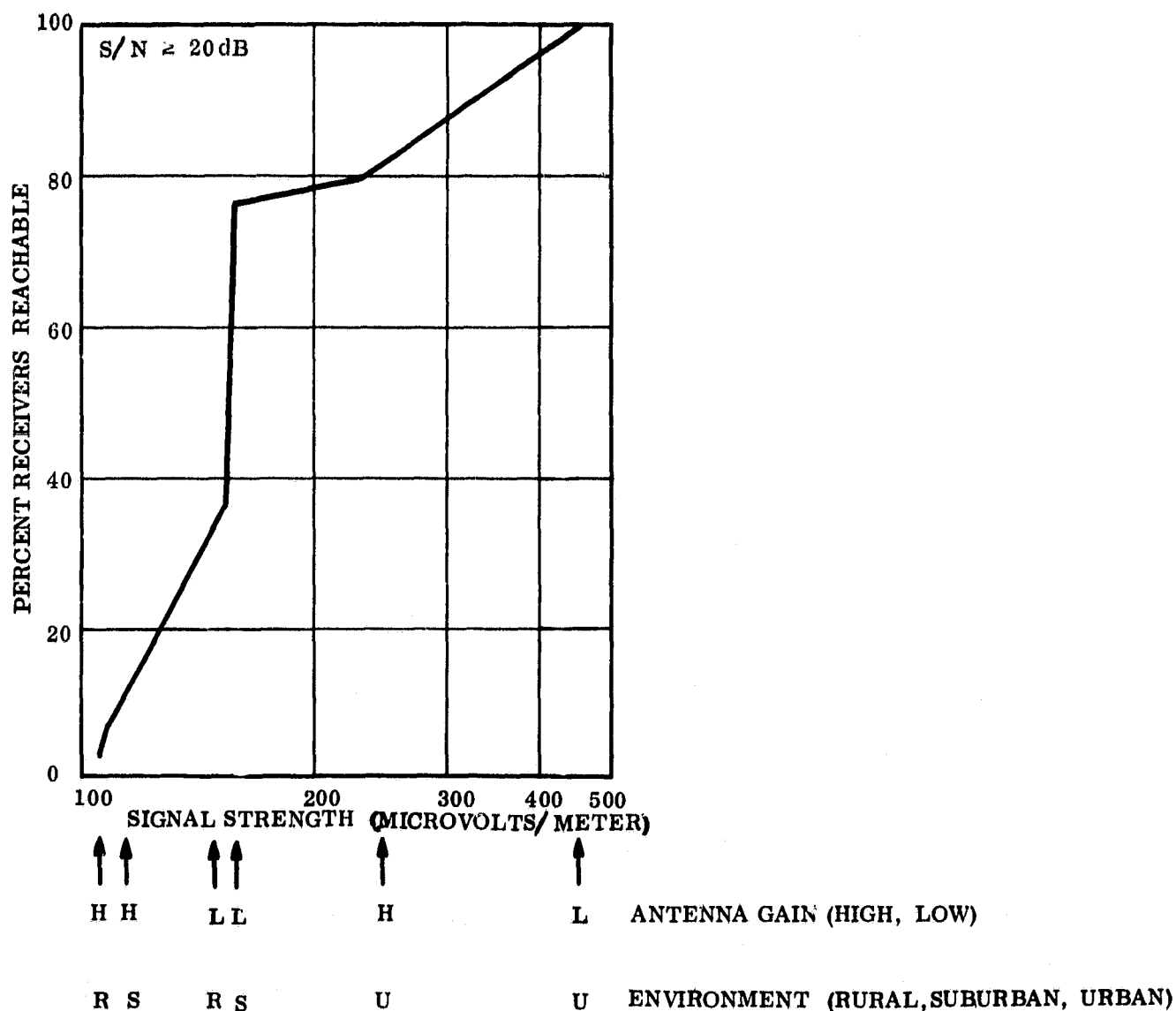


Figure 3-10. HF Potential Audience Versus Signal Strength

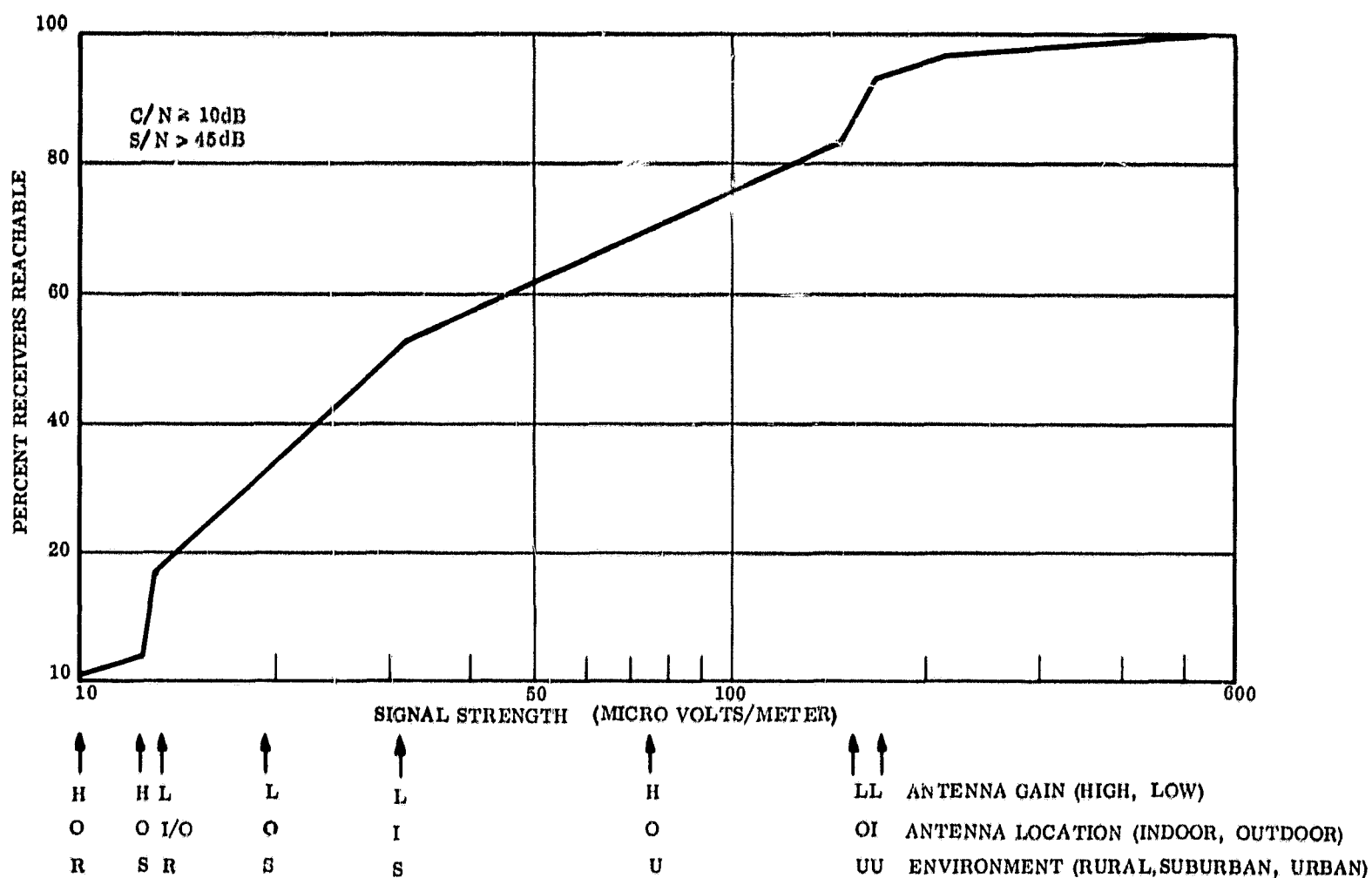


Figure 3-11. VHF Potential Audience Versus Signal Strength

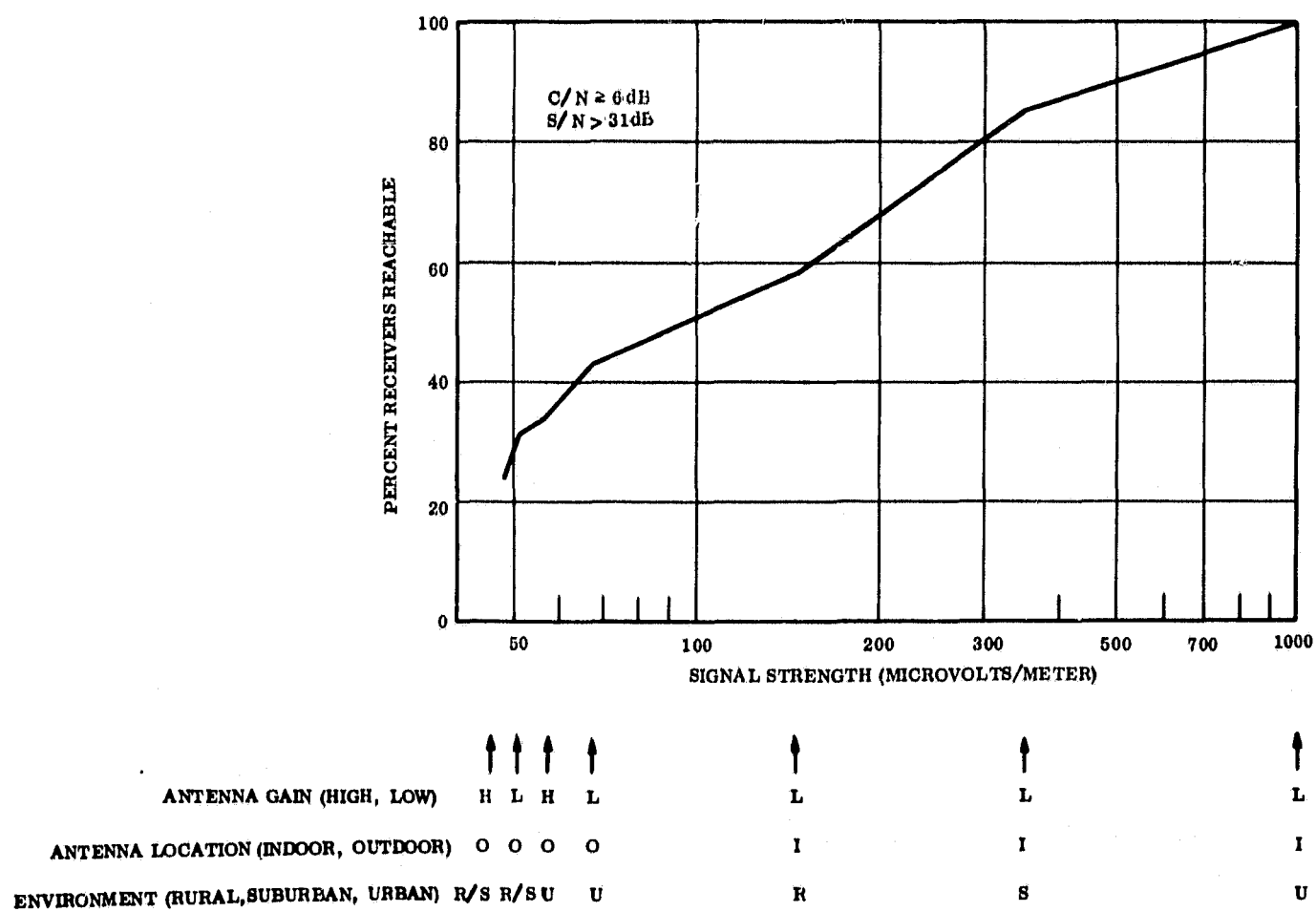


Figure 3-12. UHF Potential Audience Versus Signal Strength

The scales below each curve describe the receiver installation capable of receiving the various signal levels in terms of the type of antenna, its location and the environment. As the signal increases, it is possible to go from high to low gain antennas, or from outdoor to indoor installations, or from rural to suburban to urban noise environments. These scales show the signal break points at which these transitions occur.

In the HF band (Figure 3-10) there is a severe break in the curve, showing that a signal of 160 microvolts per meter reaches a significant portion of the audience. It is at 160 μ v/m where the background noise is overcome in all environments except urban. Beyond that point the rate of growth as a function of signal level is rather low. The antenna location is omitted from the plot since antenna location has no effect on the signal strength requirements. (Because of the high external noise environment in the HF band, the signal strength necessary to provide the required S/N exceeds the sensitivity of the poorest receiver whether or not building attenuation is included.)

For VHF/FM systems (Figure 3-11) approximately 50% of the audience can be reached with signals of 30 microvolts per meter. To reach 90% to 95% of the audience, signal levels must be in excess of 200 microvolts per meter. At approximately 160 microvolts per meter, radios with low gain indoor antennas in urban environments may receive the transmission. As 160 microvolts per meter is exceeded, the lower sensitivity radios may be reached. A threshold of 10 dB was assumed for these calculations.

For the UHF systems (Figure 3-12) a signal level of 100 microvolts per meter is required to reach about 50% of the receivers in any area. However, a signal level of approximately 1000 microvolts per meter is required to reach the sets with low gain indoor antennas in an urban environment. A threshold of 6 dB was assumed for these calculations.

SECTION 4

REPRESENTATIVE SYSTEMS

During Phases II and III of the study; four representative systems were developed and analyzed. These systems were based on design goals established in Phase I (with the concurrence of NASA), recognizing both desirable characteristics in terms of ability to reach large audiences and technology limitations of the early 1970's defined in the first phase of the study. Each of these systems is summarized below.

4.1 HF CONFIGURATION

For the HF configuration, a system capable of covering selected target areas on a world wide basis was chosen because the HF receivers are widely distributed throughout the world. Since man-made noise is critical in the design of an HF satellite system, a signal level capable of reaching receivers in at least the rural and suburban noise environments was defined as a minimum. Propagation losses were assumed to be negligible by limiting broadcasts to areas between latitudes 45°N and 45°S during early evening hours. The basic performance requirements and the corresponding implementation approach are summarized below.

<u>Requirement</u>	<u>Implementation Approach</u>
• Broadcast in the HF short wave bands	Transmit AM carrier at 15.1, 17.7, 21.45 or 25.85 MHz (switchable)
• Cover selected areas throughout the world between 45°N and 45°S latitudes.	Broadcast to 5 areas around the world (these areas contain 44 million sets - 16% of world total in 1970)
• Minimum 1 hour coverage	Transmit 1 hour per day to each area (5 hrs/day total)
• Reach all sets not in high noise environment	Deliver signal of at least 160 microvolts/meter (reach 70% of sets in covered area)

The configuration developed to meet these requirements is shown in Figure 4-1. The configuration employs an inflatable 16 element spiral array antenna of wire grid tube construction and a rollout solar array providing 7 kw at the end of two years of operation. Storage batteries are utilized to provide the remainder of the 15.4 kw required during broadcast time. The configuration, weighing 4741 pounds, would require a Titan IIF booster.

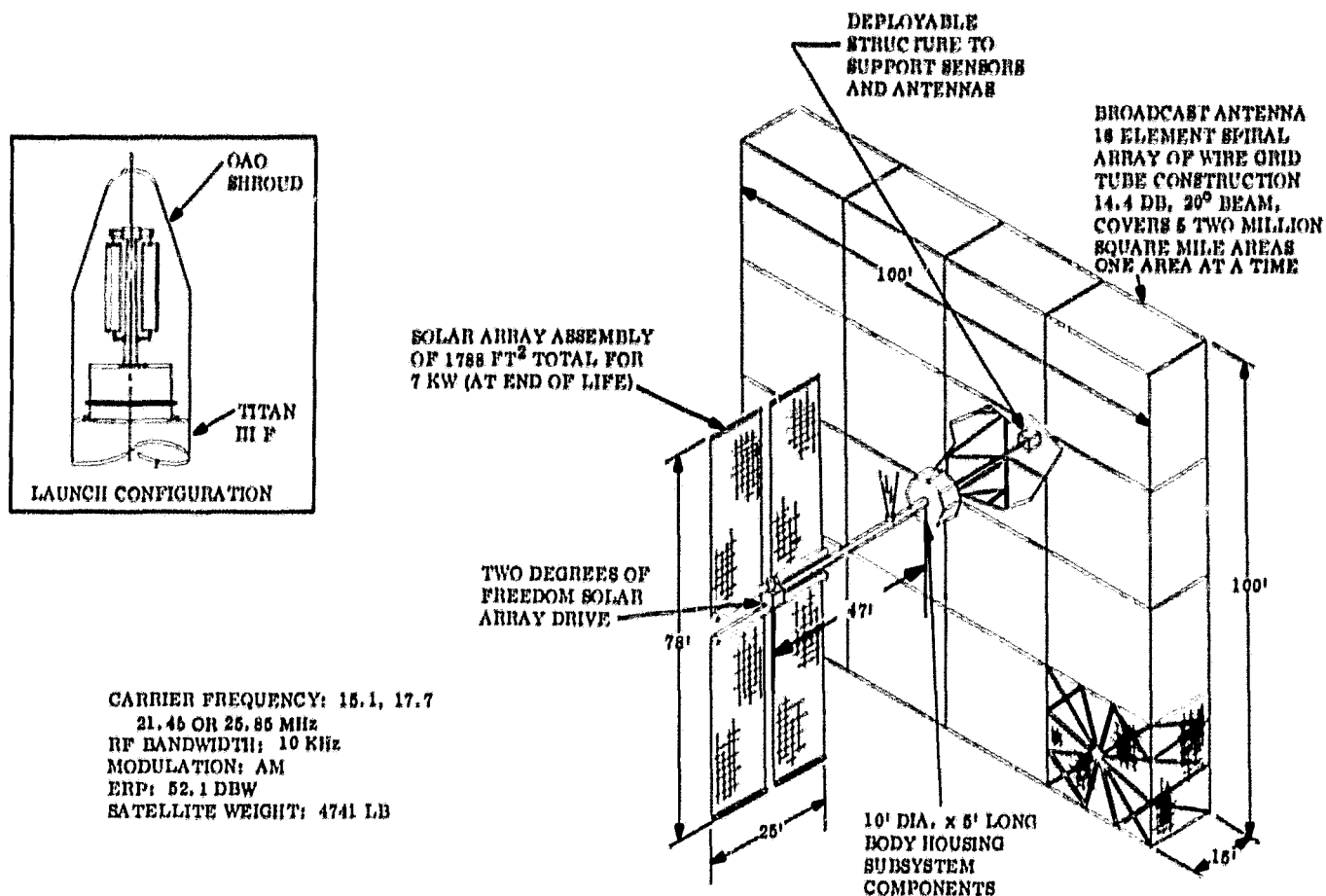


Figure 4-1. HF Configuration

The vehicle is designed to broadcast from a 4356 nm circular orbit. Vehicle motion during the orbit is shown in Figure 4-2.

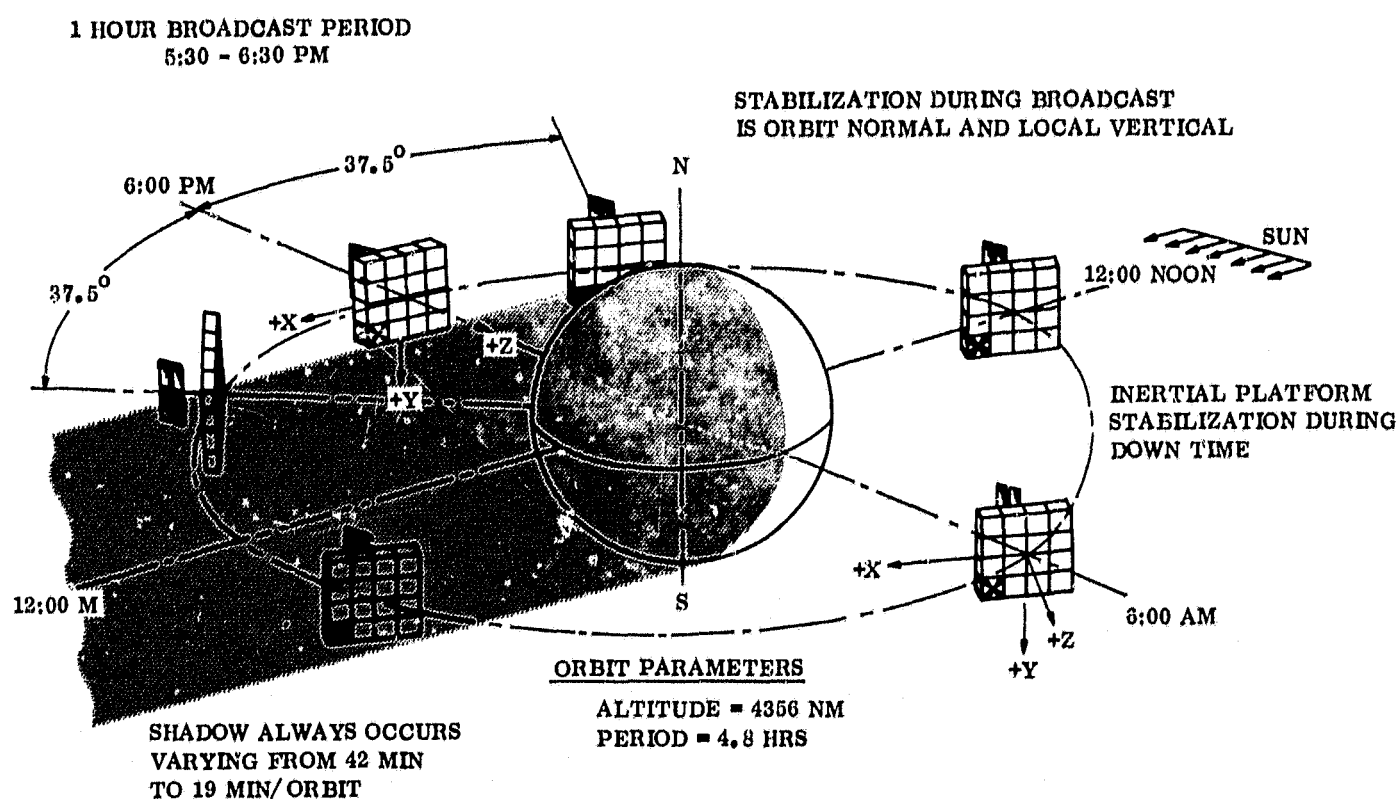


Figure 4-2. HF Configuration Orbital Motion

The system can broadcast to five areas in the world each day, reaching each area at the same local time and repeating both area and local time on a daily basis. The areas are located at 72° longitude spacing around the world. During broadcast times, the vehicle will be oriented to local vertical by active stabilization systems and the antenna beam will be electronically off-set to the area of interest. During the remainder of the orbit, the system will be stabilized in inertial space and the solar array sun-oriented to permit charging of the storage batteries.

The audience reachable for each of the four sample areas covered is shown in Figure 4-3. The fifth area covered by this system, not shown in the figure, is French Polynesia where there is not a significant number of receivers. Other sets of five areas may be selected for this system. The dashed lines indicate the range of signal level produced in the coverage areas. The number of receivers reachable corresponding to the mean ground signal strength in each area is also shown on the plot. While the audience in each area is small the total audience reachable per day is 37 million sets which is 13% of the total world HF receiver population in 1970.

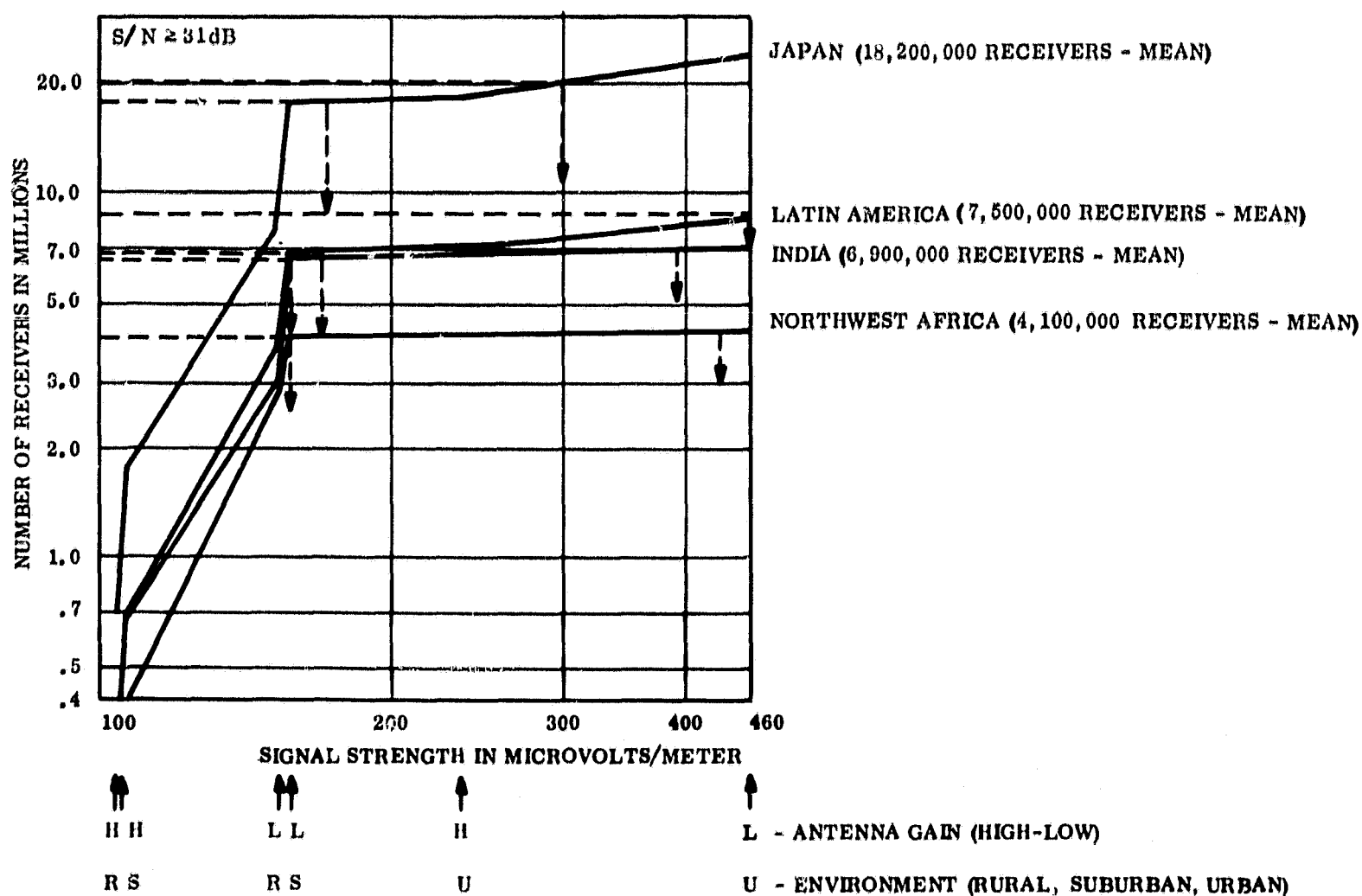


Figure 4-3. HF Potential Audience Versus Signal Strength

The total program cost for providing this system is \$101.5 million. This includes two vehicles, AGE and the operation of the ground station for two years. The investment costs include the launch pad modifications at ETR required for a Titan III F booster. Figure 4-4 shows the breakdown of these costs among the major cost categories. The schedule for development of this system is shown in Figure 4-5. The launch date is early 1972, assuming earlier phase activities occur as shown.

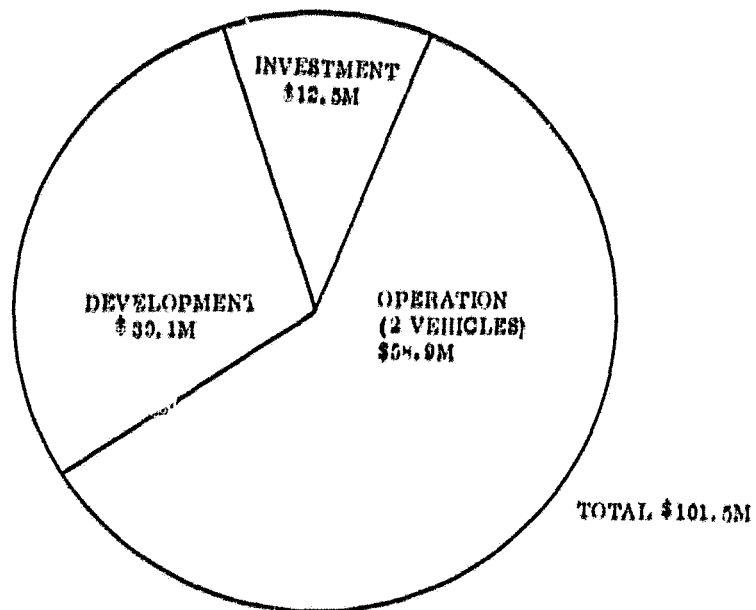


Figure 4-4. HF Program Costs

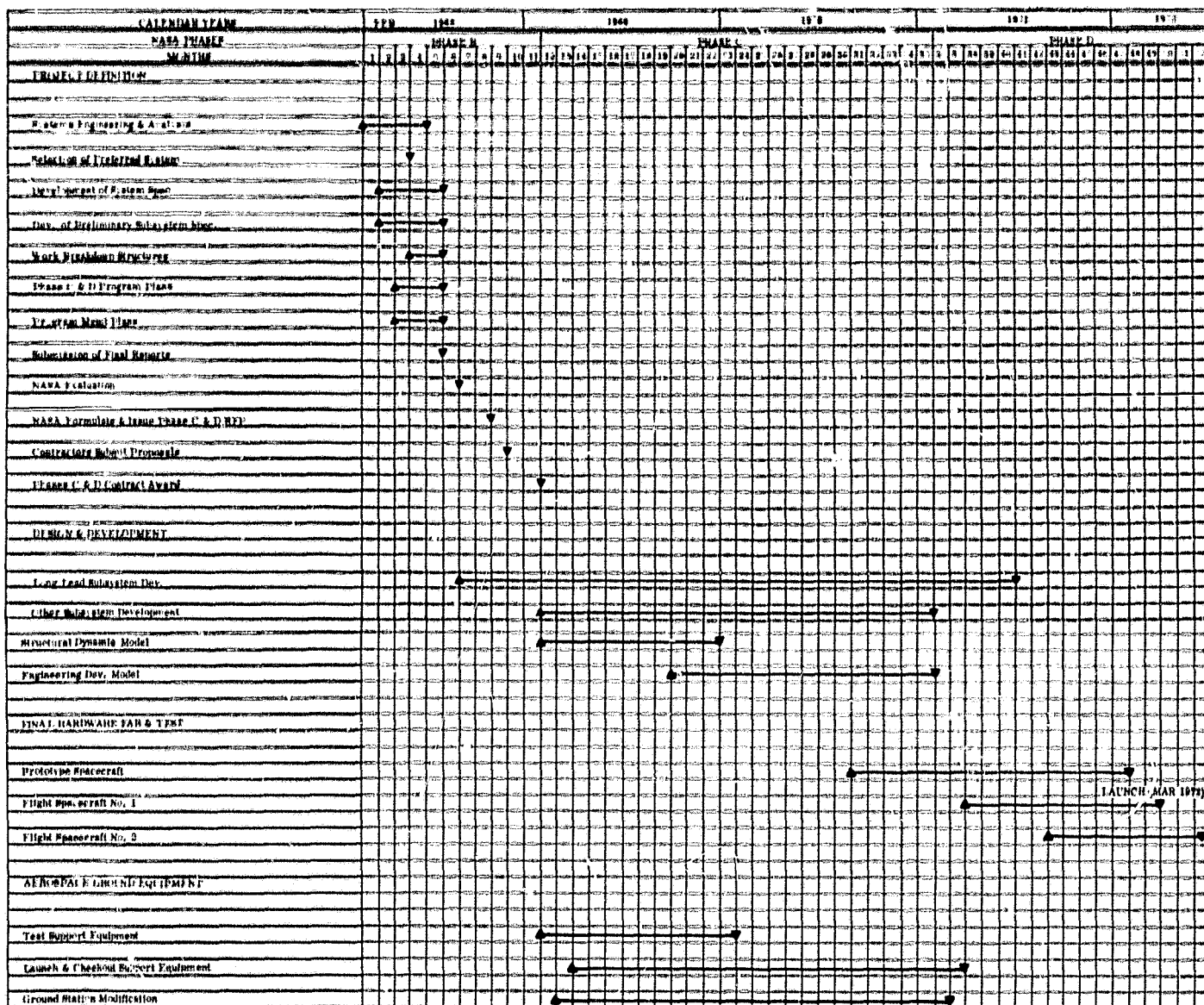


Figure 4-5. HF Schedule

The cost of the representative system was evaluated from a number of viewpoints. One was the cost of reaching each receiver in the target area for one hour; another was the total annual system operating costs based upon a two year satellite life. Cost curves were prepared as a function of microvolts per meter delivered to the ground, which is a direct indication of the size of the satellite. The curves present the variation in systems' costs as the ground signal is varied by adjusting the power system in the spacecraft and keeping all other sub-systems fixed. The cost of reaching a receiver is relatively high for this HF configuration, as shown in Figure 4-6.

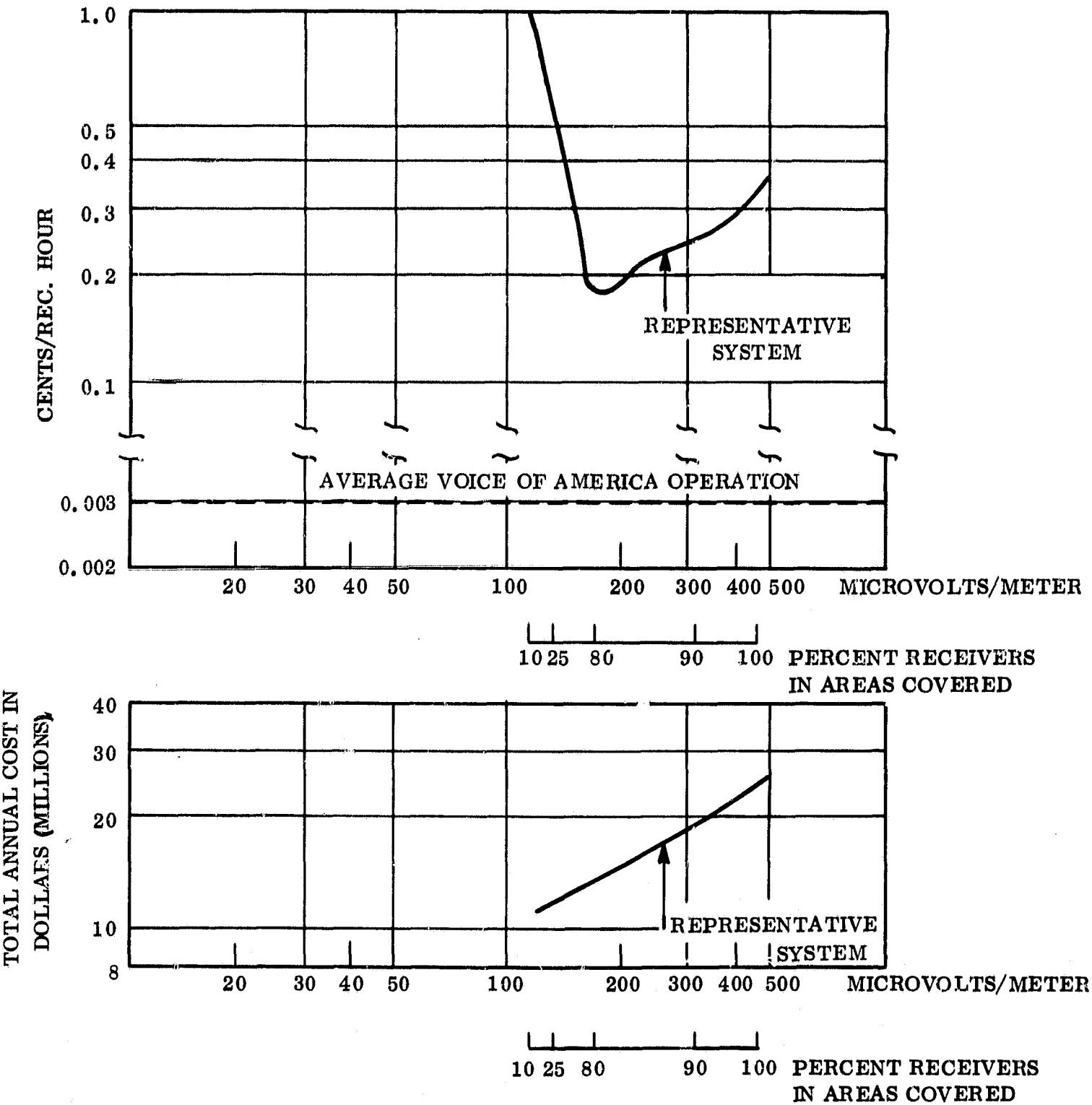


Figure 4-6. HF Cost-Effectiveness

This high cost is caused by the low duty cycle of the system (5 hours/day), the coverage of areas with relatively low receiver population density, the technical complexities associated with operating at these low frequencies, and the relatively short assumed satellite life of two years.

The approximate cost per receiver hour of present Voice of America (VOA) operations is shown for comparison. This value was derived from total operating budgets and estimates of total receivers covered by all of the VOA transmissions.

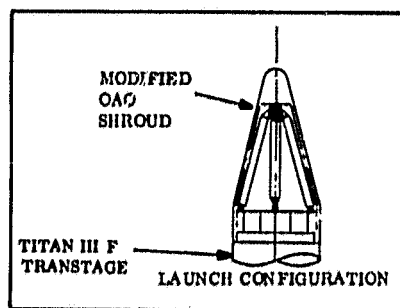
Considerable improvement is required in HIF space system cost-effectiveness before it could become competitive on this basis. The cost-effectiveness for this system and this mission, as shown by the curve, could be improved by reducing the size of the satellite to deliver an average signal of approximately 170 microvolts per meter. Overall cost-effectiveness of HF broadcast missions can be improved by operating during a longer period of time and broadcasting to higher density areas. This type of evaluation must be made for each system as requirements definitions become firm. It should be noted that cost comparisons may not be the best evaluation method for all systems. Other items that may have to be considered are: the ability to reach new audiences and interference-free operation.

4.2 VHIF 1 CONFIGURATION

For the VHIF 1 configuration, the United States was selected as the coverage area because it contains the largest potential audience, almost 75% of the world's FM receivers. The area is covered on a continuous basis and the signal level for the system is such that over 95% of receivers can be reached. The basic performance requirements and the corresponding implementation approach are summarized below.

<u>Requirement</u>	<u>Implementation Approach</u>
• Broadcast in standard FM band	Transmit FM carrier between 100 and 108 MHz.
• Cover area with largest potential audience	Broadcast to U.S. (U.S. will contain 98 million sets - 74.6% of world's total in 1970)
• Give continuous daily coverage	Transmit at least 22 hours per day, every day.
• Reach essentially all existing FM radios	Deliver signal of at least 170 microvolts per meter (reach 95% of sets in covered area)

The configuration developed to meet these requirements is shown in Figure 4-7. The configuration utilizes a 32 element helix array antenna of wire grid tube construction and a roll-out solar array providing 11.38 kw at the end of two years of operation. The configuration, weighing 2560 pounds, is designed to be launched on a Titan III F booster.



CARRIER FREQUENCY: ONE CHANNEL
IN 100-108 MHz BAND
RF BANDWIDTH: 180 MHz
MODULATION: FM
ERP: 65.4 DBW
TOTAL WEIGHT: 2561 LBS

BROADCAST ANTENNA
32 ELEMENT HELIX
ARRAY OF WIRE GRID
TUBE CONSTRUCTION.
(26.9 DB, 7.5° BEAM,
51' x 51' x 15') COVERS
CONTINENTAL U.S.
CONTINUOUSLY.

2.5' x 10' DIAM
BODY HOUSING
SUBSYSTEM
COMPONENTS

DEPLOYABLE
STRUCTURE TO
SUPPORT SENSORS
AND ANTENNAS.

2 DEGREE OF FREEDOM
GIMBAL

44.2'

25'

85'

SOLAR ARRAY ASSEMBLY OF
1968 FT² TOTAL AREA FOR
11.38 KW

Figure 4-7. VHF 1 Configuration

The vehicle is designed to broadcast from a 19323 nm geostationary orbit. Vehicle motion during the orbit is shown in Figure 4-8.

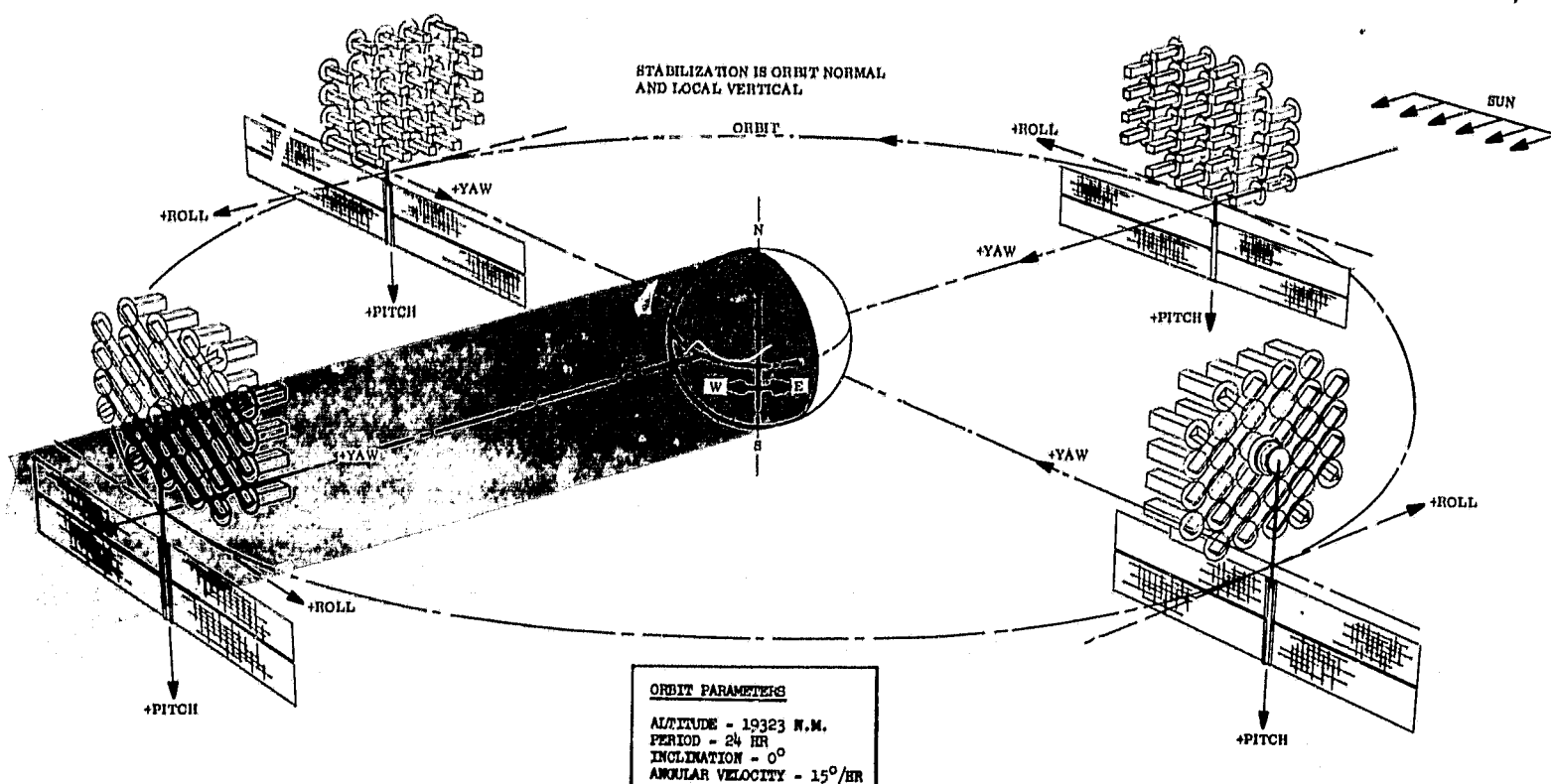


Figure 4-8. VHF 1 Configuration Orbital Motion

The antenna is oriented relative to the local vertical and the solar array is maintained broad-side to the sun throughout the orbit. The antenna is pointed to the area of interest using electronic pointing and an interferometer.

The audience reachable for this system is shown in Figure 4-9. The dashed lines show the range of signal strength provided. This signal range reaches in excess of 95% of the receivers in the area. All types of installations are reached, including low gain antennas in the indoor urban environment. Most low sensitivity portable receivers are included in the audience that can be reached with these signal levels.

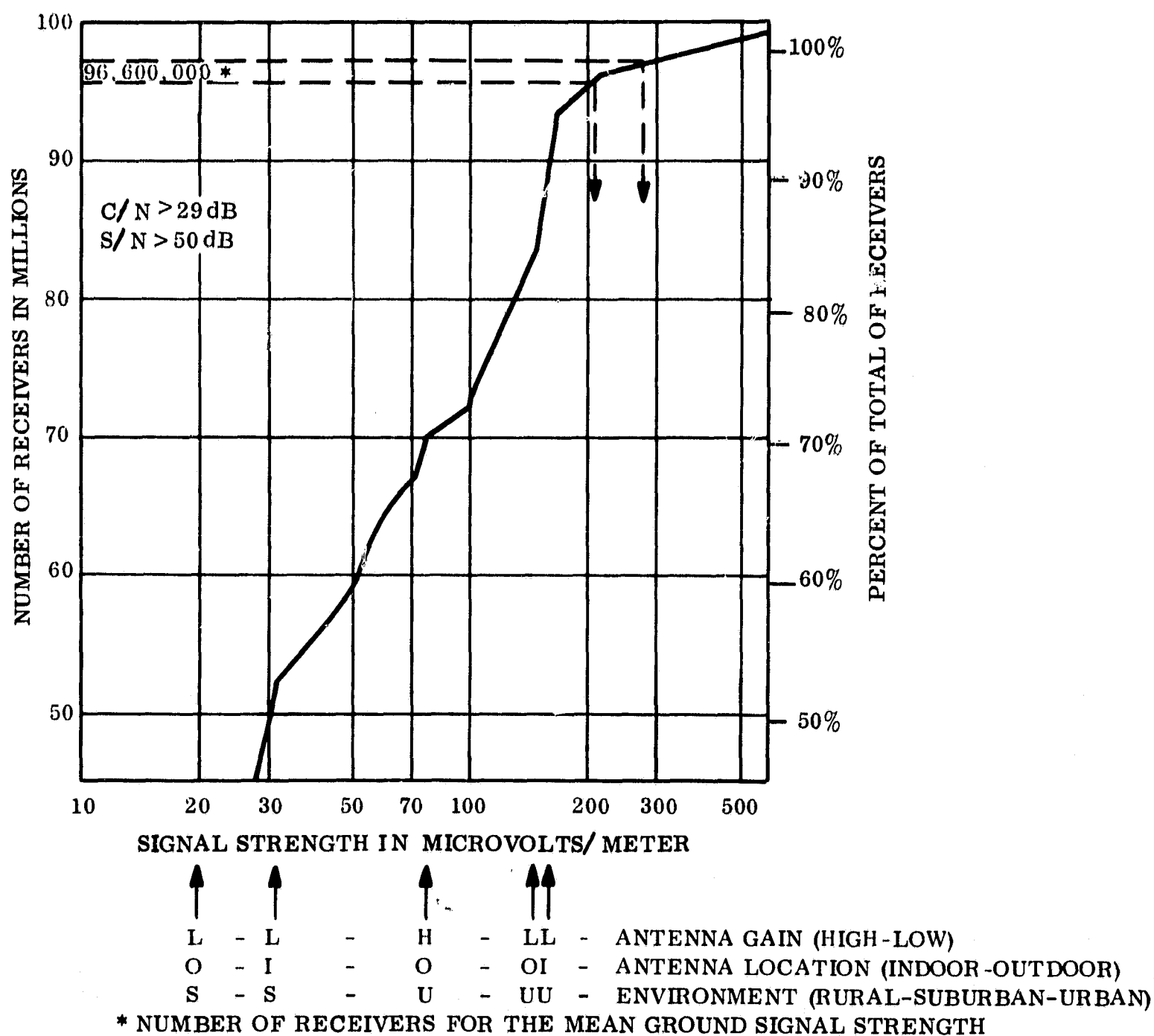


Figure 4-9. VHF 1 U.S. Potential Audience Versus Signal Strength

The total program cost for this system is \$99.1 million. This includes two vehicles, AGE, and the operation of the ground station for two years. Figure 4-10 shows the break-down of these costs among the major cost categories. The schedule for development of this system is shown in Figure 4-11. The launch date is early 1972, assuming earlier phase activities occur as shown.

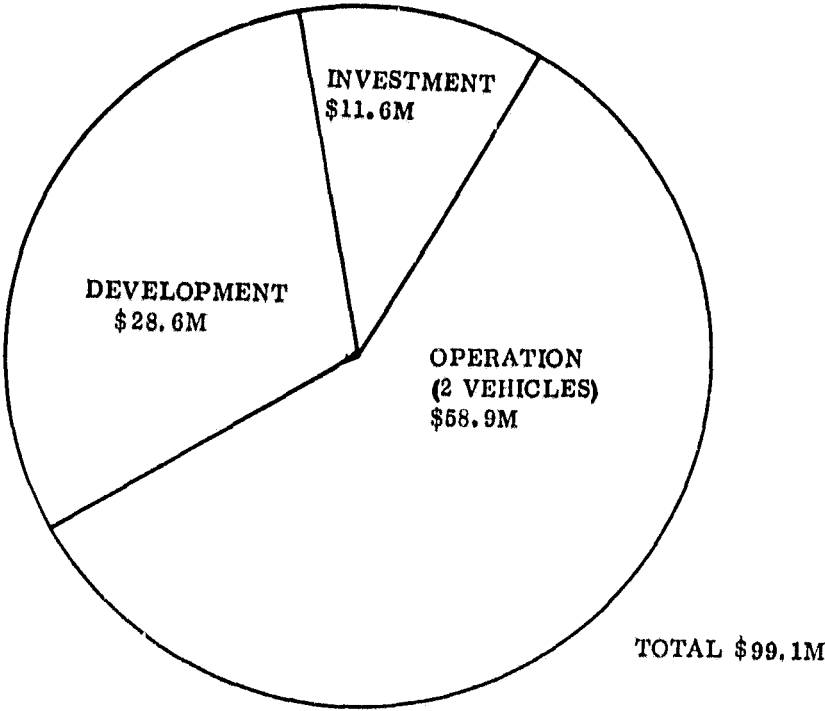


Figure 4-10. VHF 1 Program Cost

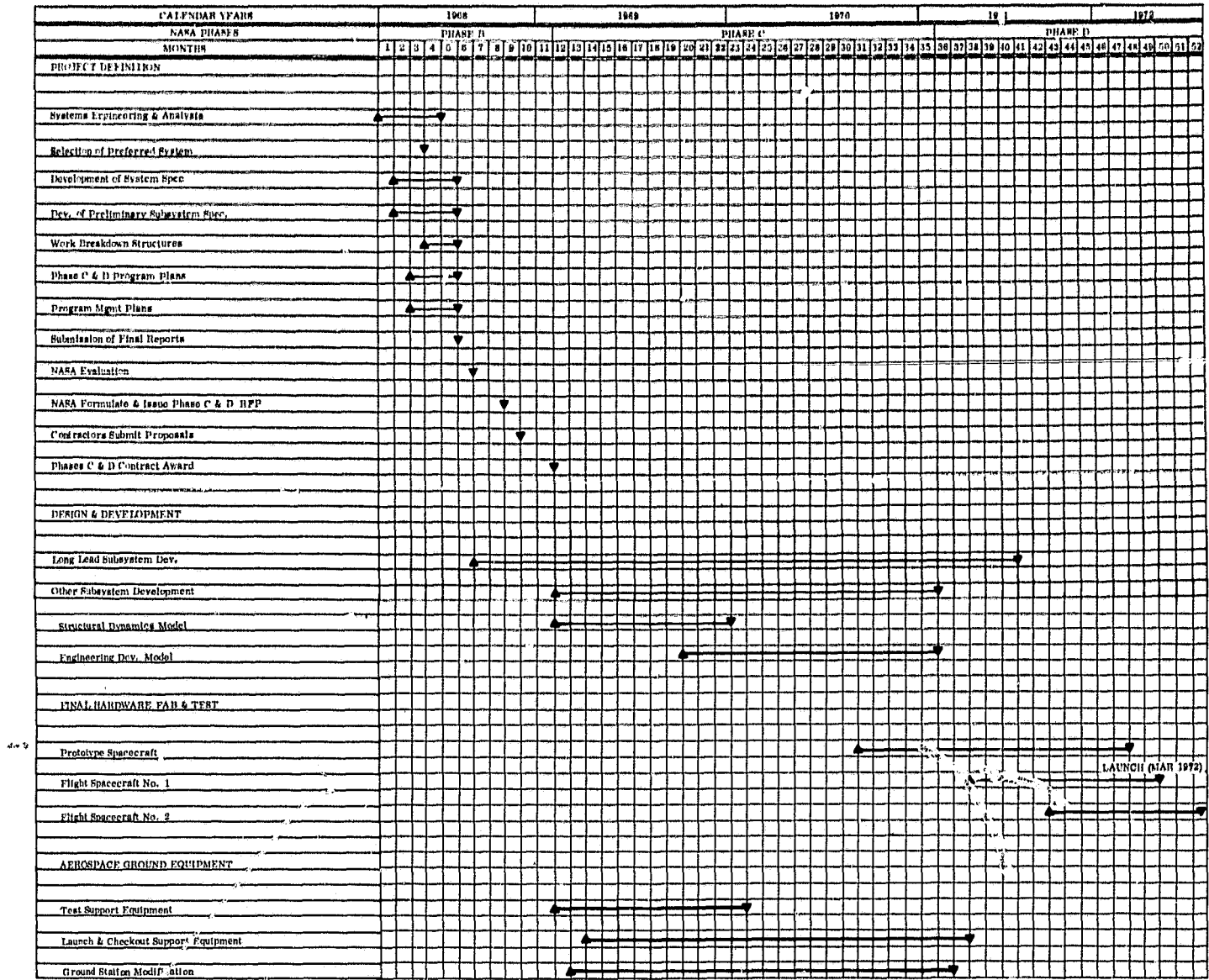


Figure 4-11. VHF 1 Schedule

The cost-effectiveness of this system was evaluated as previously described. See Figure 4-12. For this case comparison was made to costs of commercial FM broadcasting in the United States. This evaluation shows that a cost-effective system can be designed for FM missions of this type. Improvements in cost-effectiveness and reduction in operating costs can be realized by reducing system size to operate at the 100 microvolt per meter range. This improvement however, is made at the expense of losing some of the urban audience and all of the low priced FM portable receivers.

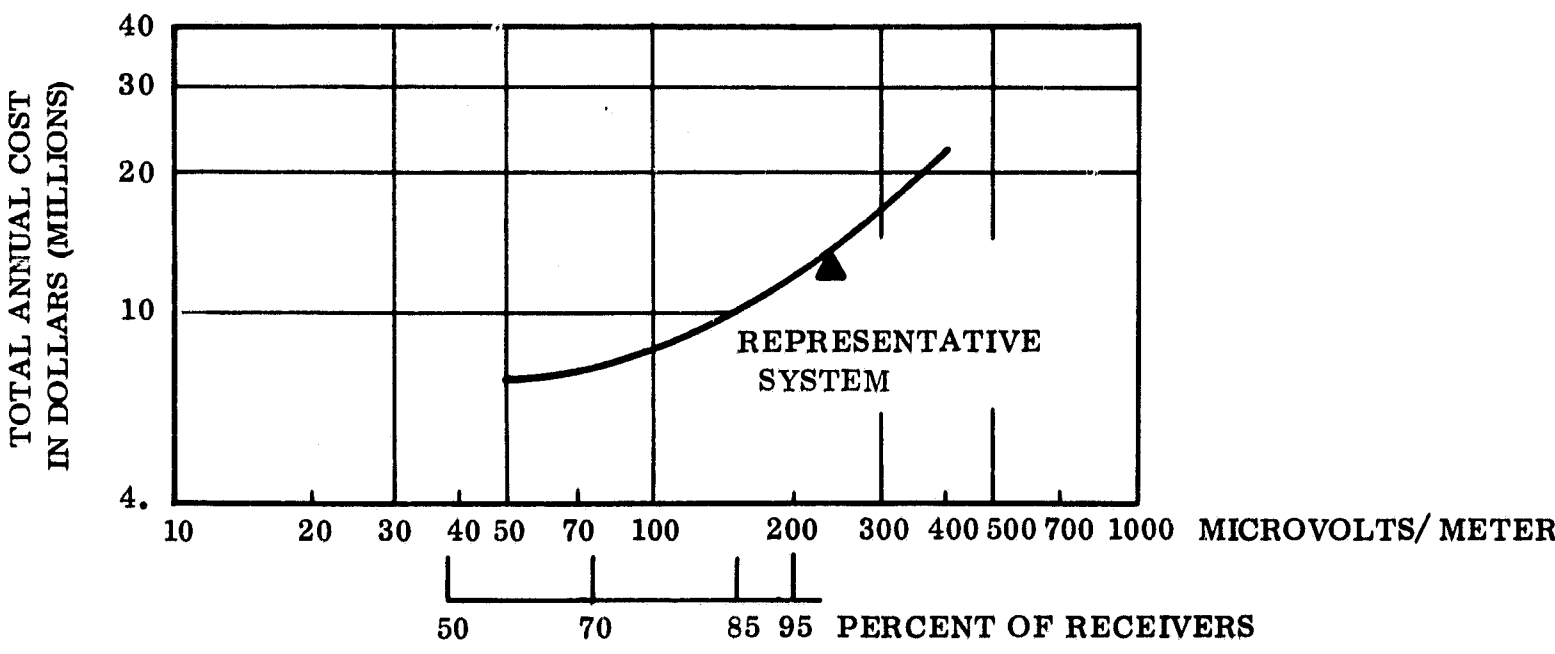
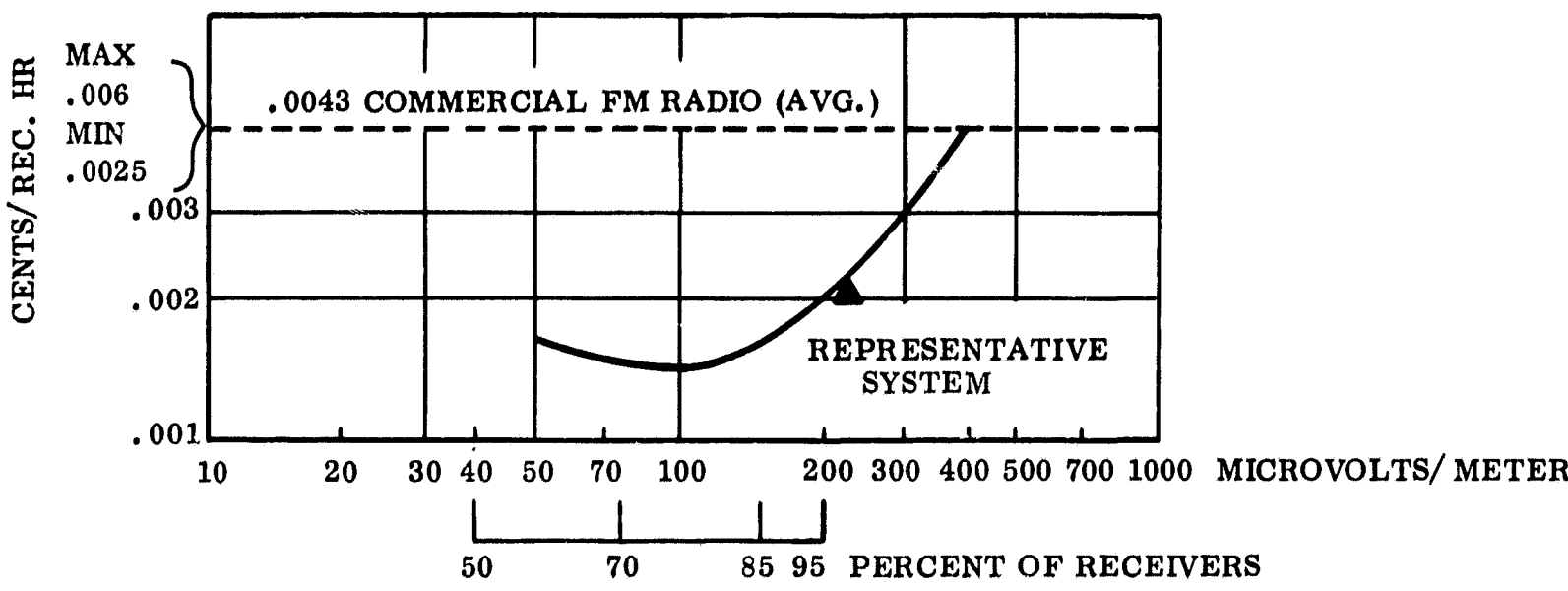


Figure 4-12. VHF 1 Cost-Effectiveness

4.3 VHF 2 CONFIGURATION

Since there is an FM radio audience in almost every nation in the world, a second lower cost VHF/FM system was investigated to reach selected areas of the world. The signal level for this system is designed to reach audiences with suitable outdoor antennas in all environments. The basic performance requirements and the corresponding implementation approach are summarized below.

<u>Requirement</u>	<u>Implementation Approach</u>
● Broadcast in standard FM band	Transmit FM carrier between 100 and 108 MHz.
● Cover selected areas of the world	Broadcast to 3 areas around the world (these areas contain 21.4 million sets - 16% of world total in 1970)
● Minimum 1 hour coverage	Transmit 1 hour per day to each area (3 hrs/day total)
● Reach all sets with high gain antennas	Deliver signal of at least 75 microvolts per meter (reach 70% of sets in covered area)

The configuration developed to meet these requirements is shown in Figure 4-13. The configuration employs a 34.5 foot inflatable parabola of wire grid construction and fold-out solar array panels to provide 1.36 kw (end of 2 years) during broadcast time. The configuration weighs 771 pounds and is launched on an Atlas/Improved Agena D.

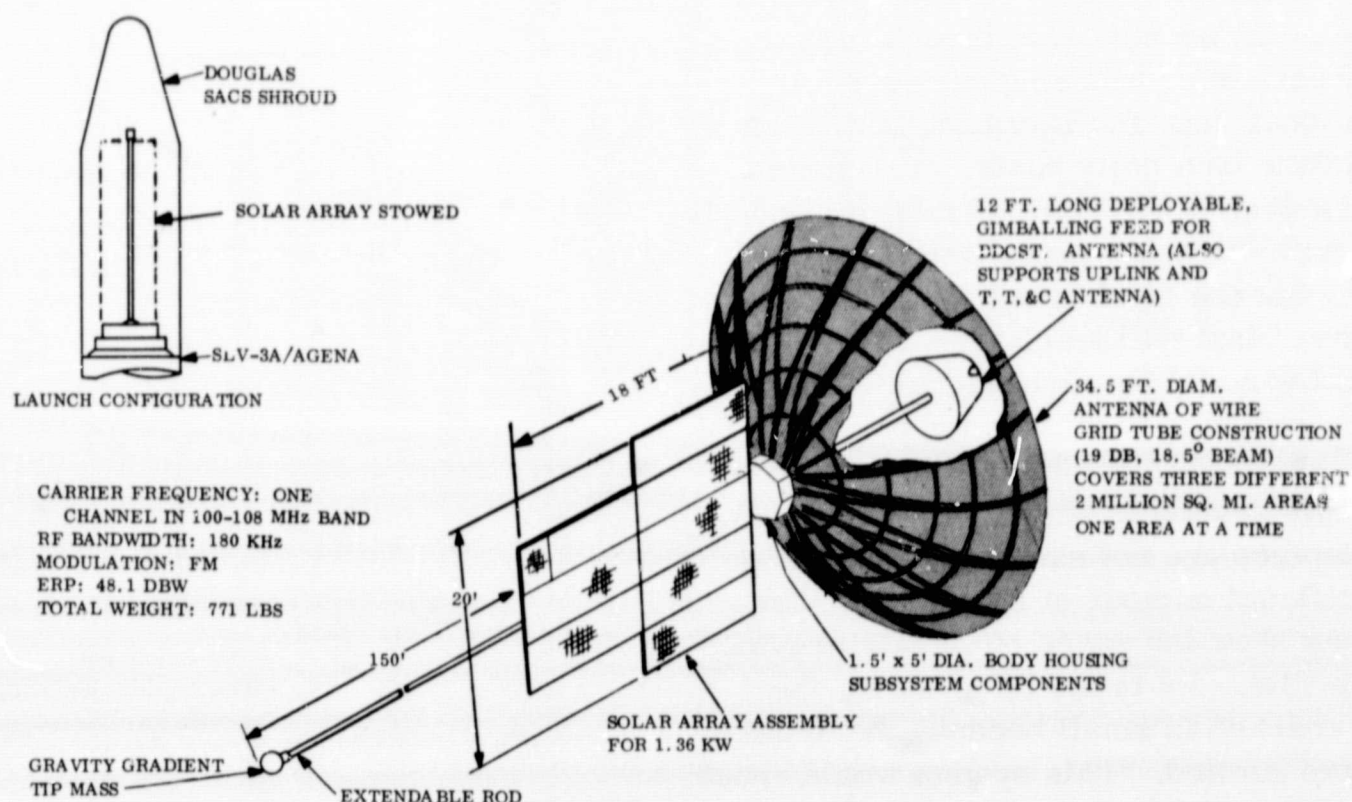


Figure 4-13. VHF 2 Configuration

The vehicle is designed to broadcast from a 7556 nm, 8 hour, circular, equatorial orbit. Vehicle motion during the orbit is shown in Figure 4-14.

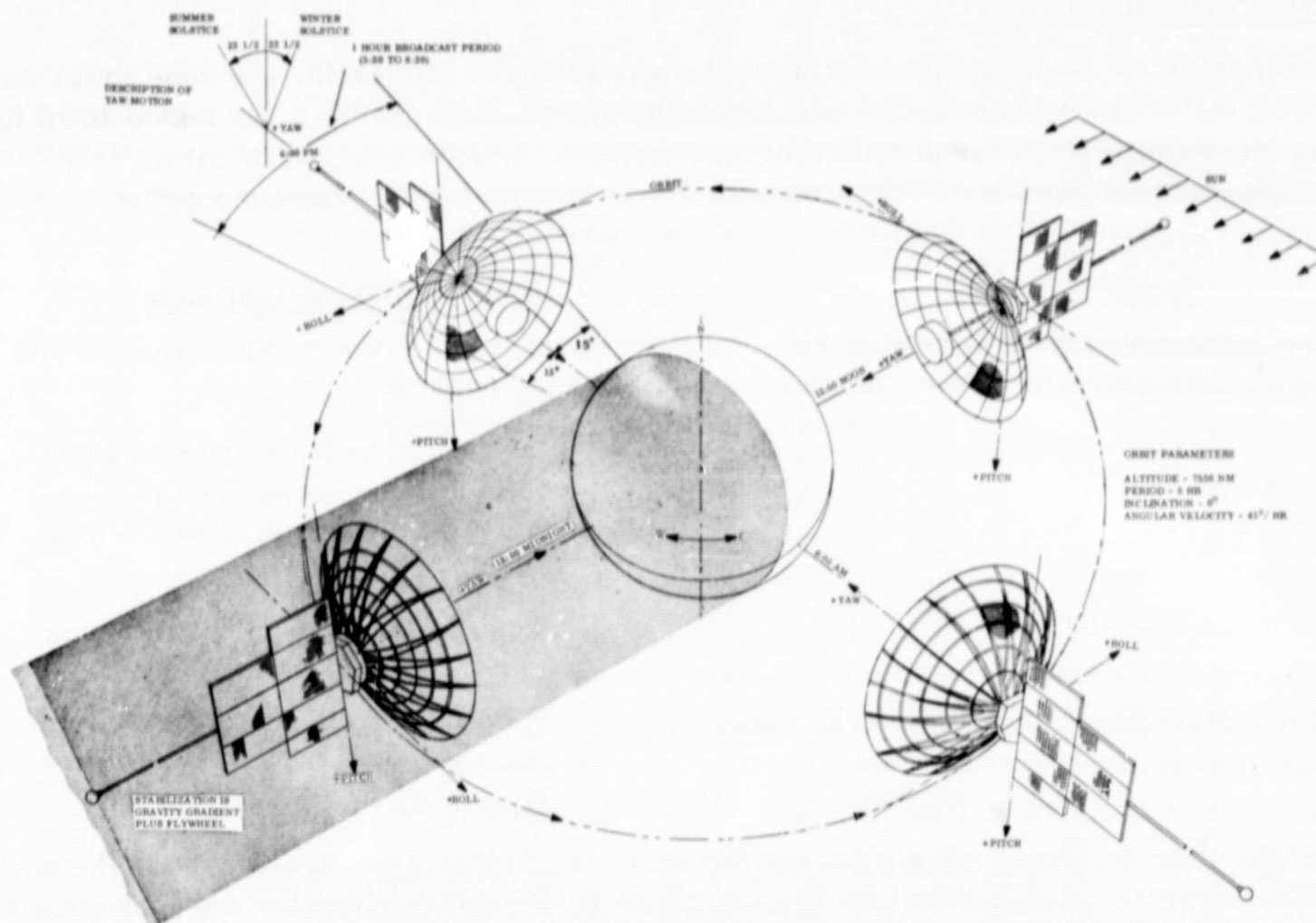


Figure 4-14. VHF 2 Configuration Orbital Motion

The system can broadcast to three areas in the world each day, reaching each area at the same local time and repeating both area and local time on a daily basis. The system will be oriented to the local vertical throughout the orbit with the solar array oriented to the sun during the one hour broadcast period. The antenna beam will be offset with respect to the local vertical by positioning the antenna feed. The audience reachable for two of the three sample areas with the signal range provided by this system is shown in Figure 4-15. The Philippines are not shown since there is not a significant number of receivers. The dotted lines show the range of signals provided by the satellite. As in the HF system, the audience reached is small because the areas covered are limited. This system would reach over 15 million sets per day which is 12% of the world FM receivers in 1970.

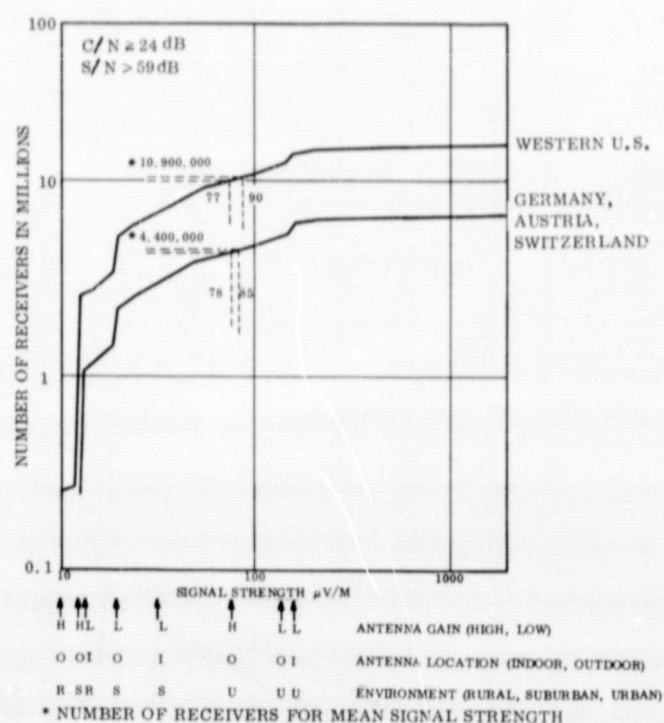


Figure 4-15. VHF 2 Potential Audience Versus Signal Strength

The total program cost for this system is \$48.2 million. This includes two vehicles, AGE, and the operation of the ground station for two years. Figure 4-16 shows the breakdown of these costs among the major cost categories. The schedule for development of this system is shown in Figure 4-17. The launch date is mid-1971, assuming earlier phase activities occur on the schedule shown.

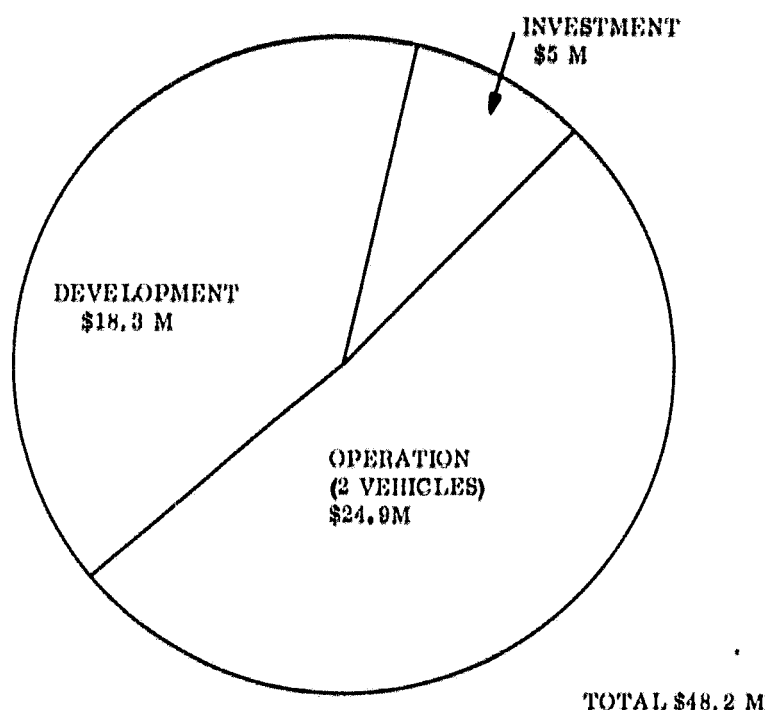


Figure 4-16. VHF 2 Program Cost

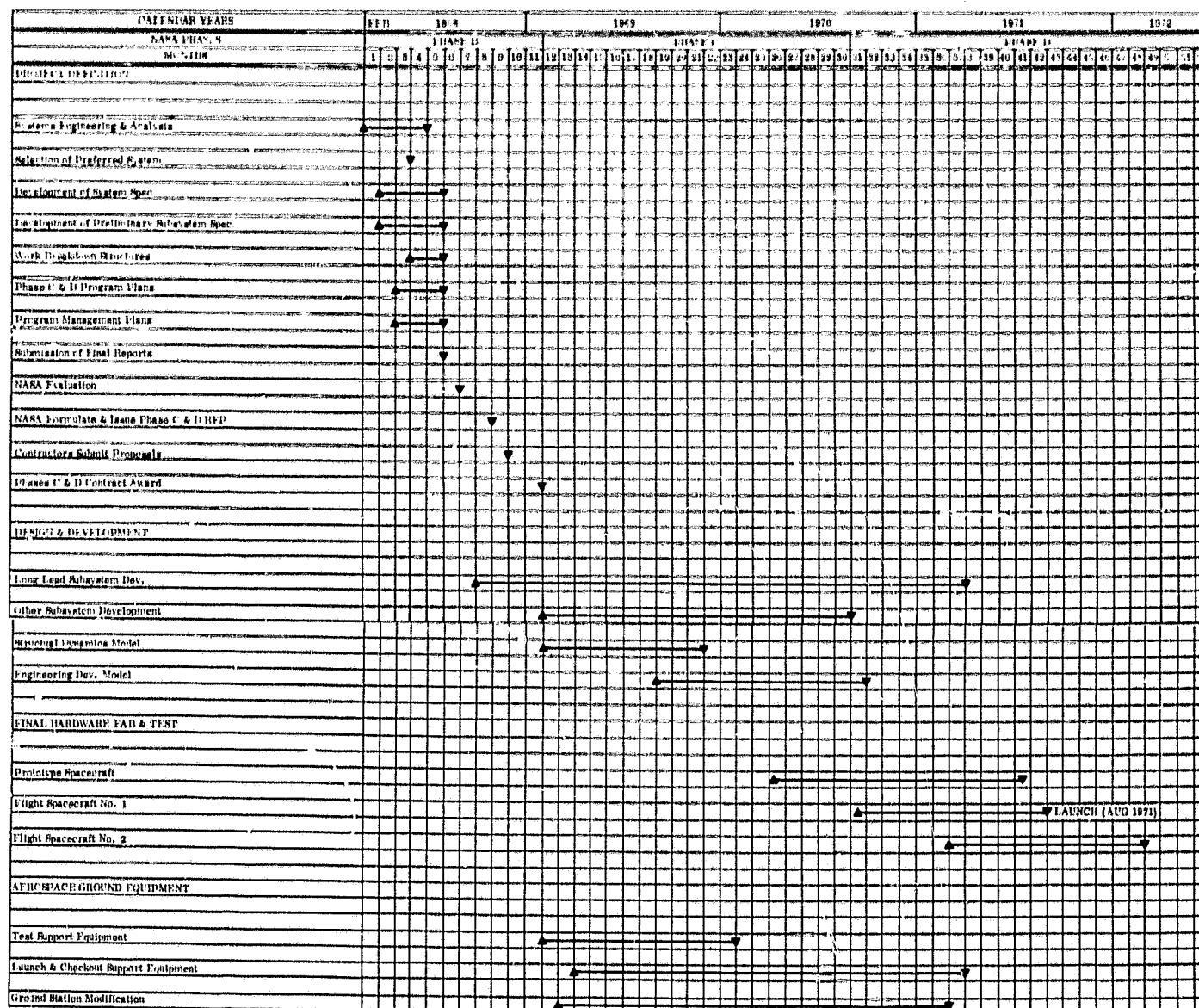


Figure 4-17. VHF 2 Schedule

The cost-effectiveness of this system falls considerably short of being competitive with commercial FM broadcast costs, for reasons similar to those applicable to the HF system. The cost curves are shown in Figure 4-18.

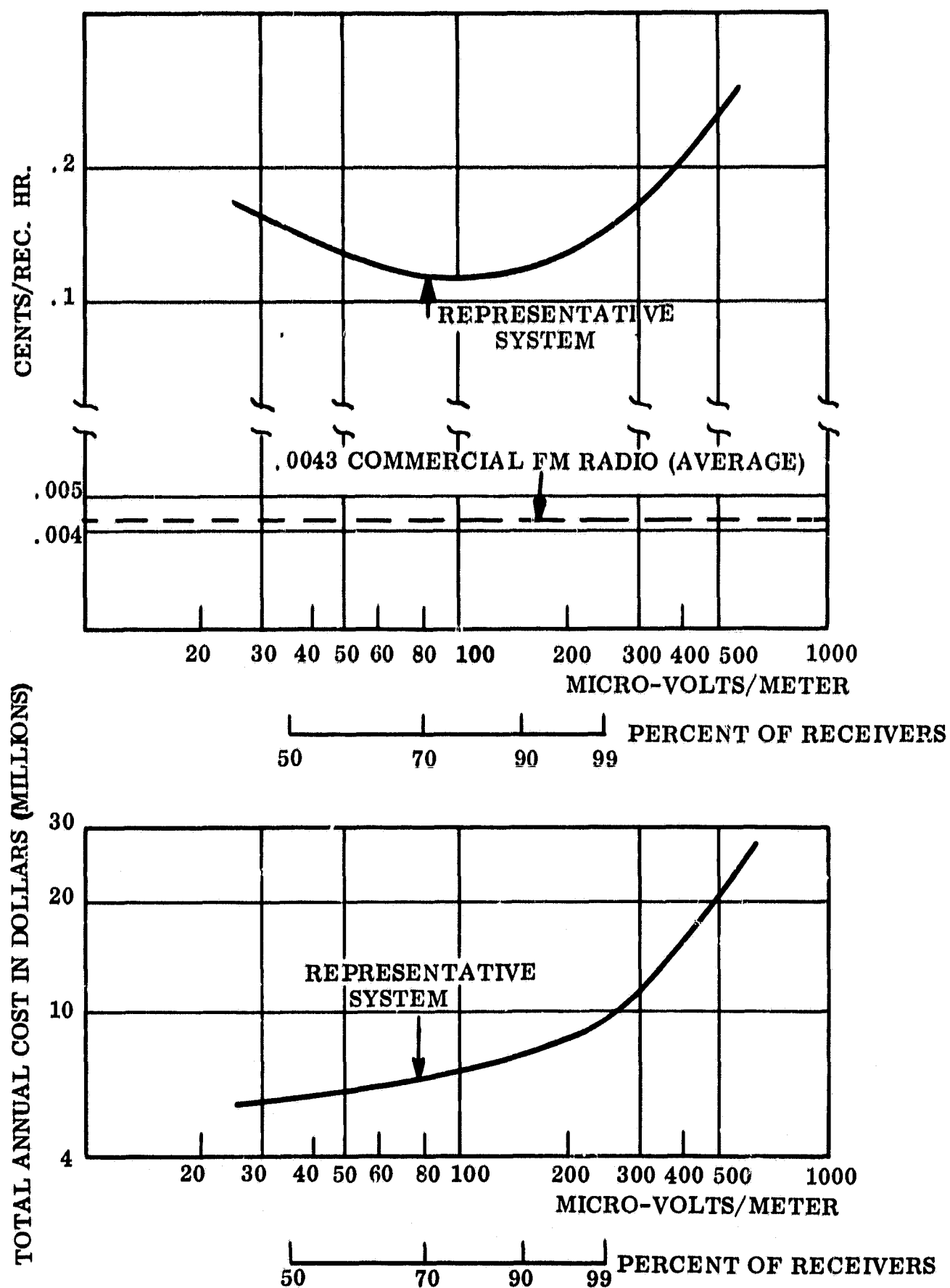


Figure 4-18. VHF 2 Cost-Effectiveness

4.4 UHF CONFIGURATION

The UHF system is designed to deliver audio material to UHF television receivers. This system was considered to take advantage of the possibility of voice broadcasting, at the higher frequency, to existing unmodified receivers. The receiver population is concentrated heavily in the U.S. The system was designed to cover each U.S. time zone sequentially. The basic performance requirements and the corresponding implementation approaches are summarized below.

<u>Requirement</u>	<u>Implementation Approach</u>
• Audio only to UHF/TV sets	Transmit sound carrier at 871.75 MHz and unmodulated picture carrier at 867.25 MHz.
• Cover area with largest potential audience	Broadcast to U.S. (U.S. contains 67 million sets - 55% of world total in 1970)
• Reach existing home TV sets	Deliver signal of at least 99 $\mu\text{v}/\text{m}$ per carrier (reach 50% of sets in coverage area).

The configuration developed to meet these requirements is shown in Figure 4-19. The configuration utilizes a 22-1/2 foot diameter inflatable parabola of wire grid construction and a roll-out solar array to provide the required 2.54 kw (end of 2 year operation). The configuration weighs 1126 pounds with a launch weight of 2641 pounds. An Atlas/Improved Agena D will launch the system with final orbit injection accomplished by a Surveyor-series apogee kick motor.

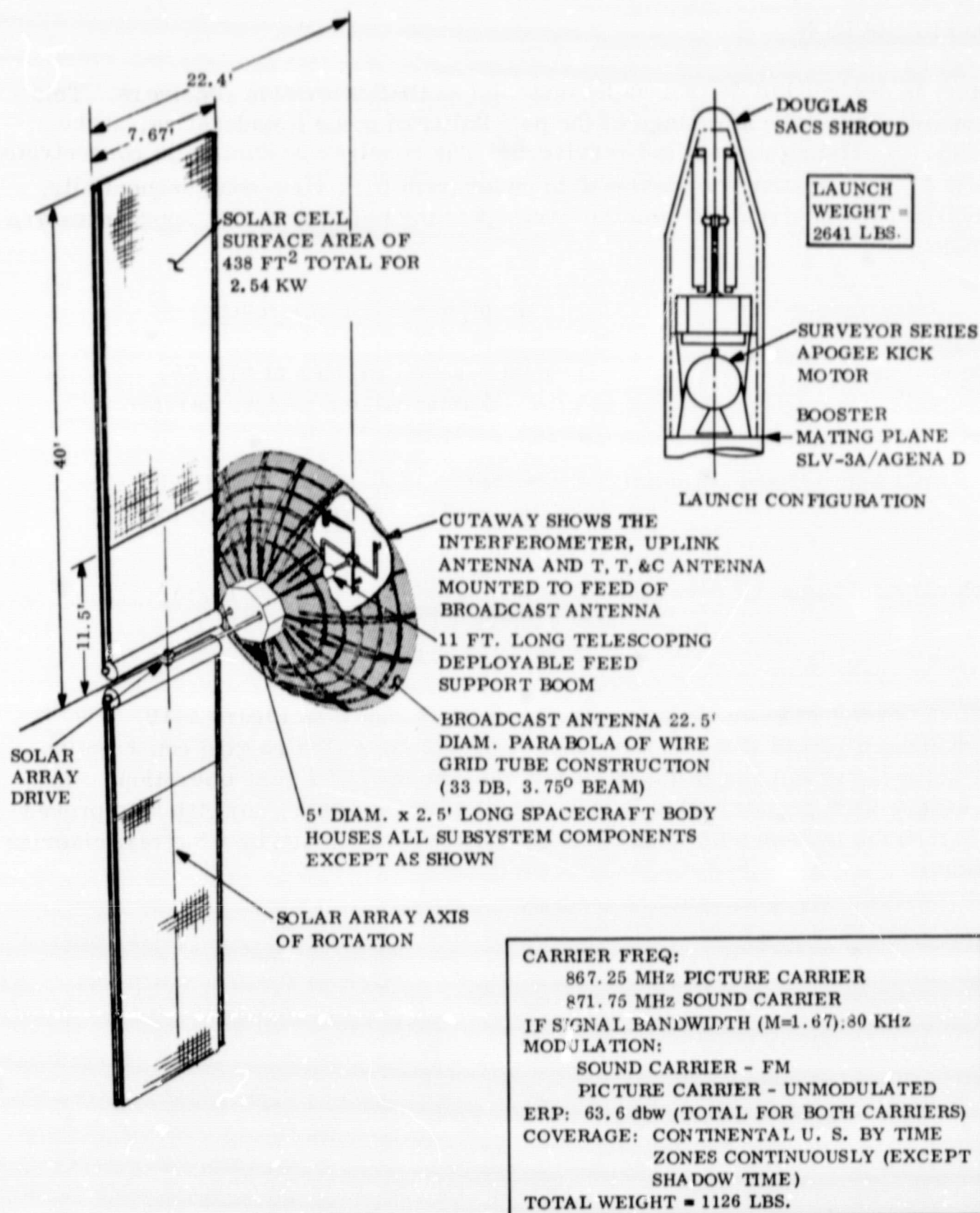


Figure 4-19. UHF Configuration

The vehicle will transmit at the high end of the UHF/TV broadcast band from a 19323 nm geostationary orbit. Vehicle motion during the orbit is shown in Figure 4-20. The vehicle body is continuously oriented to keep the antenna axis aimed at the area of interest (utilizing interferometer sensing). The solar array is continuously rotated (in a wind-unwind fashion, to eliminate slip-rings, to be normal to the sun line.

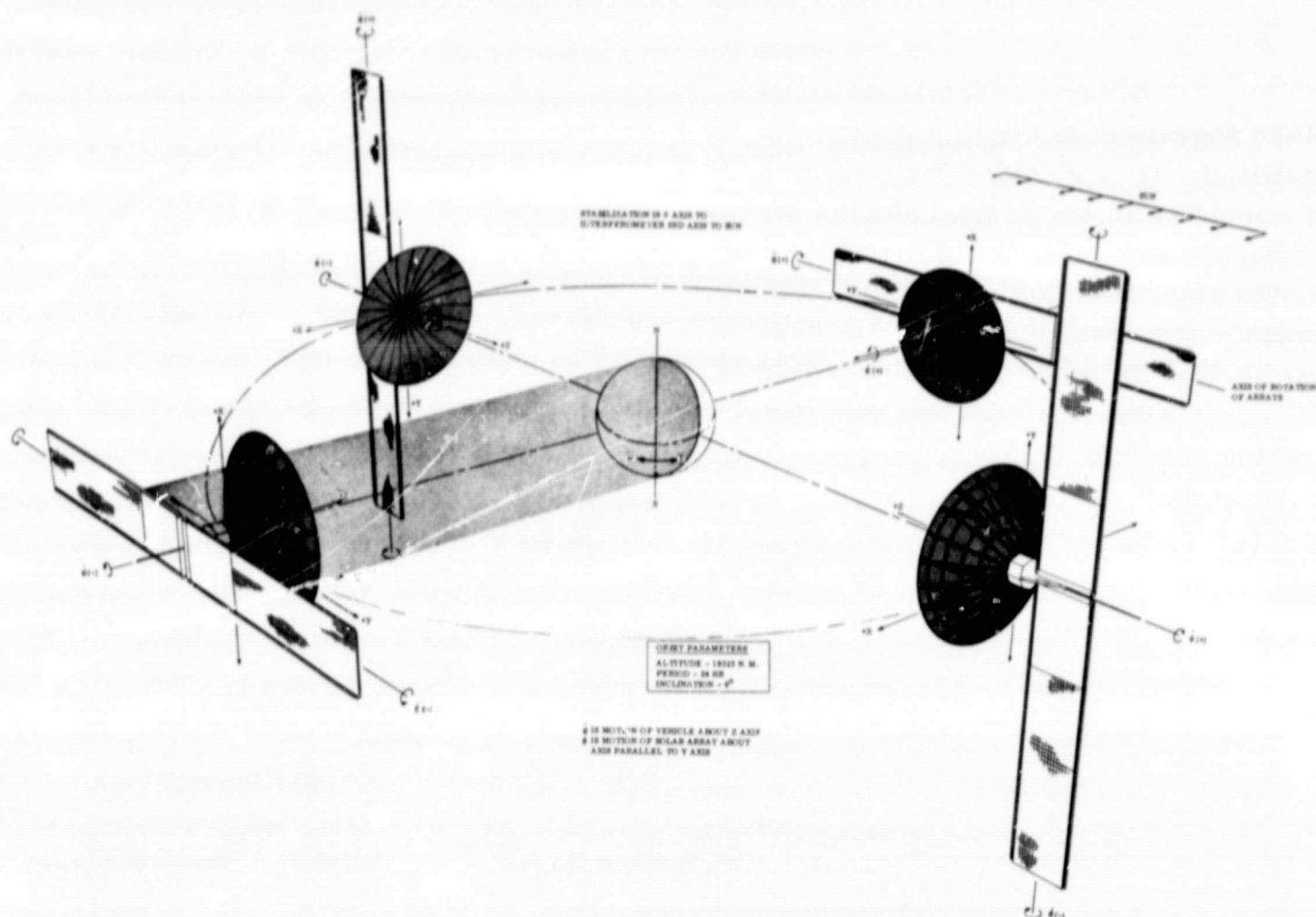


Figure 4-20. UHF Configuration Orbital Motion

The audience reachable in each time zone is shown in Figure 4-21. The dotted lines show the signal range provided by this configuration. For this signal level all receivers with outside antennas can be reached. Building attenuation is high enough at these frequencies that the signal cannot reach sets with indoor antennas. The system will reach over 35 million sets which is 29% of the world's UHF/TV receivers in 1970.

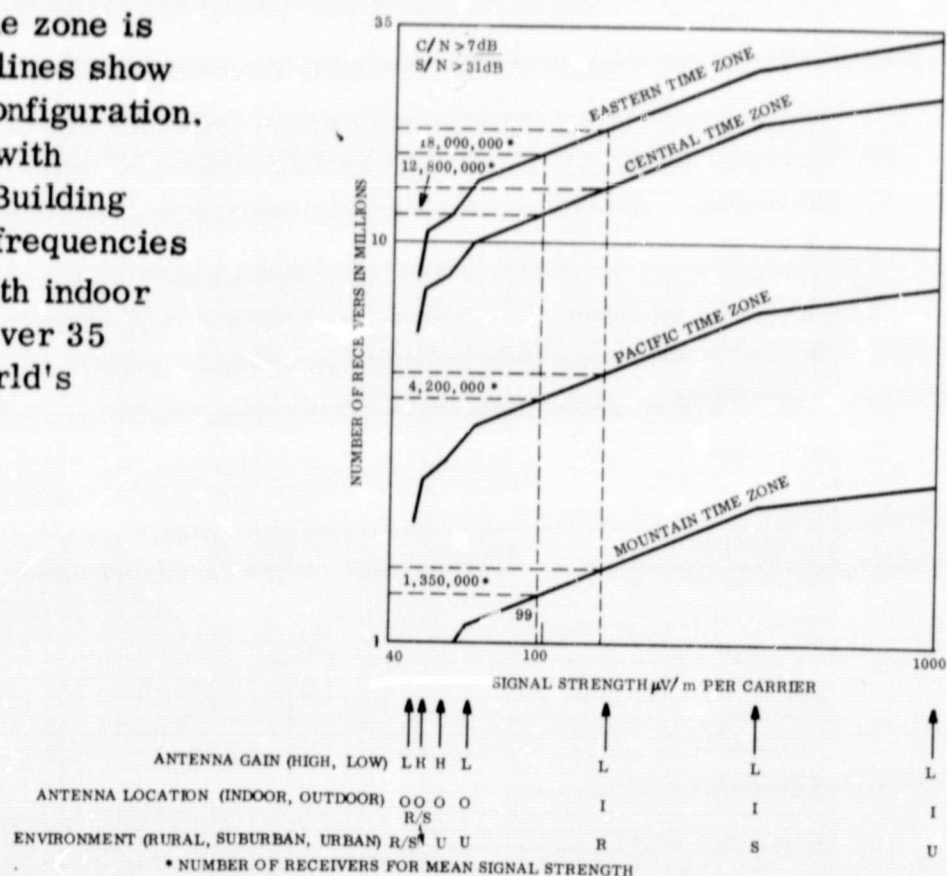


Figure 4-21. UHF U.S. Potential Audience Versus Signal Strength by Time Zones

The total program cost for this system is \$55.5 million. This includes two vehicles, AGE, and the operation of the ground station for two years. Figure 4-22 shows the breakdown of these costs among the major cost categories. The schedule for development of this system is shown in Figure 4-23. The launch date is late 1971, assuming earlier phase activities occur on the schedule shown.

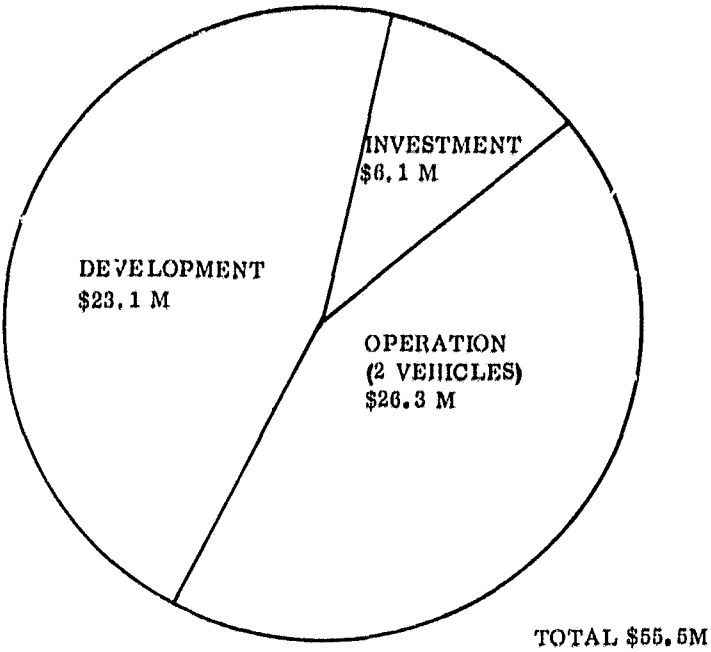


Figure 4-22. UHF Program Cost

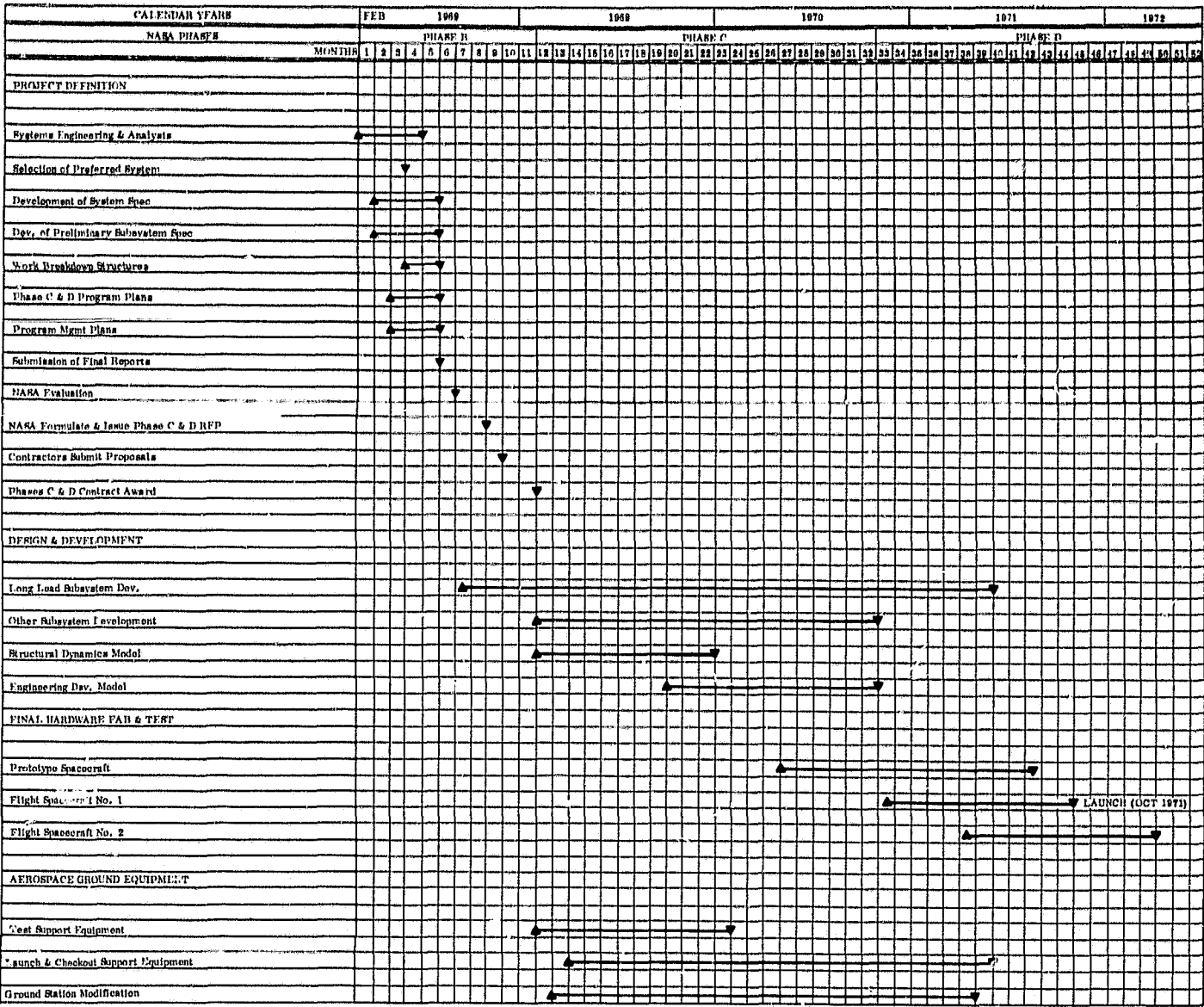


Figure 4-23. UHF Schedule

Cost curves for the UHF system are shown in Figure 4-24. The configuration developed is most cost-effective for this mission and approach. The cost-effectiveness comparison yields favorable results when evaluated against commercial VHF/TV broadcast costs, although the commercial costs include both video and audio and the system being evaluated is audio only. Another meaningful comparison for this system might be commercial FM costs.

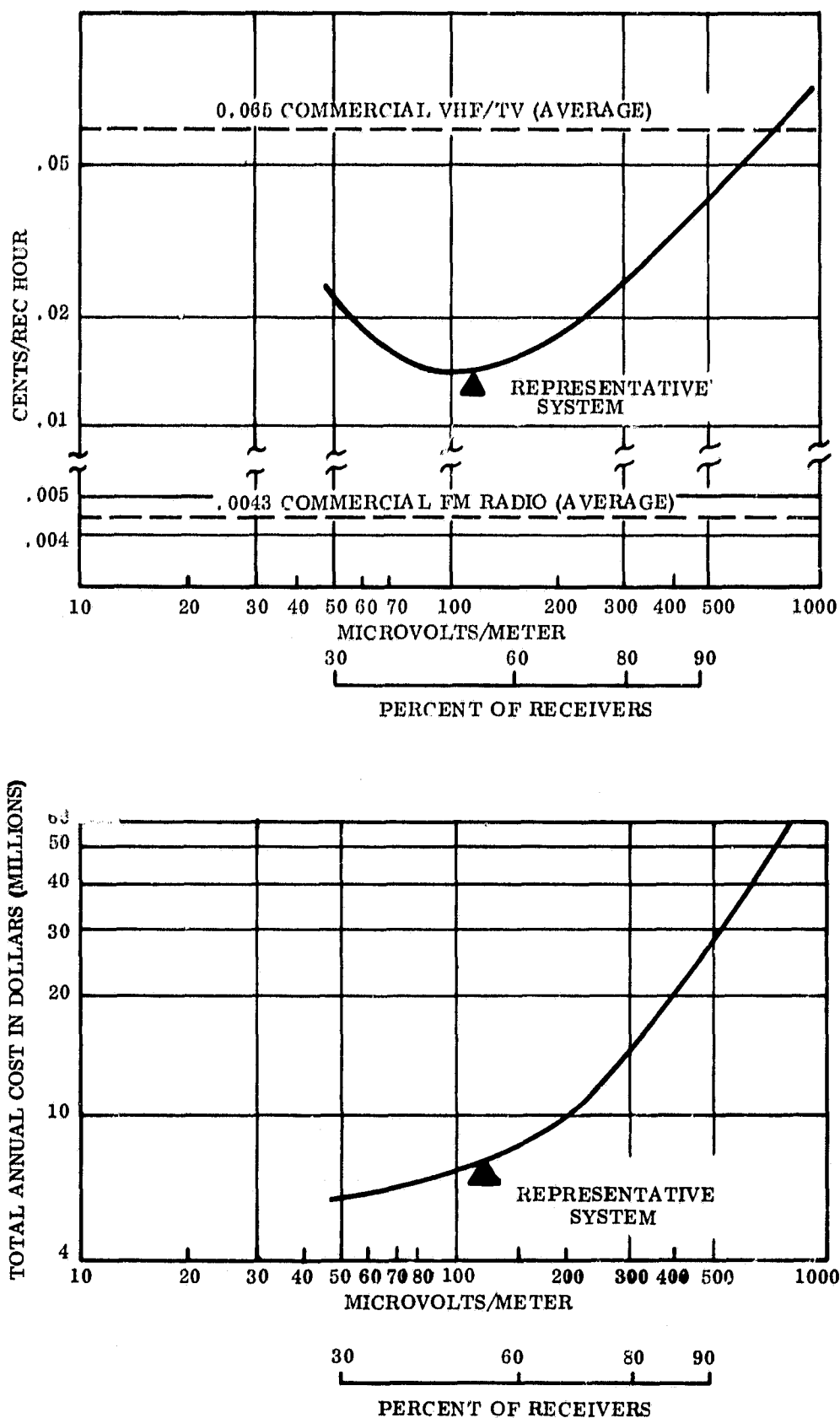


Figure 4-24. UHF Cost-Effectiveness

SECTION 5

TECHNOLOGY CONSIDERATIONS

In evaluating system approaches leading to definition of the representative configurations, a wide range of applicable technologies was investigated. The critical technologies considered are tabulated below. The representative configurations for which specific technologies were selected are shown in parentheses.

CRITICAL TECHNOLOGIES

<u>Transmitter</u>	Output Device:	Vacuum Tubes (UHF) Transistors (HF, VHF 1, 2)
	Circuits:	Final Stage Modulation: Class C Amplifier (UHF, VHF 1, 2) Digital Synthesis (HF)
<u>Antenna</u>	Types:	Aperture (UHF, VHF 2) Endfire (HF, VHF 1)
	Construction:	Rigid Folding Inflatable (All)
<u>Power</u>	Energy Source:	Solar (All) Nuclear Chemical
	Conversion:	Photovoltaic (All) Thermionic Thermoelectric
	Pointing:	Fully Oriented (UHF, HF, VHF 1) Fixed Panels (VHF 2) Body Mounted
<u>Attitude Control</u>	Types:	Passive
		Spin
		Hybrid (VHF 2)
		Active (VHF 1, HF, UHF)

Each of the technology areas considered critical to the design of a voice broadcast satellite was found to be within the state-of-art for early 1970 systems. However, extensive design is required for any particular satellite configuration. The following is a summary of the evaluation of the critical technologies as they affect voice broadcast satellites.

TECHNOLOGY EVALUATION

Transmitter	● Devices within state-of-the-art
Solar Array	● No extension of state-of-the-art needed in solar cells ● Large size & deployment techniques require design effort
Antenna	● Materials & elements are state-of-the-art ● Deployment is a design problem
Attitude Control	● Sensor & control components are state-of-the-art ● Stabilization of flexible vehicle is a design problem
Long Life	● To achieve long life requires design effort in every subsystem

The specific problems associated with each of the technology areas have been investigated and the scope and nature of the problems identified.

5.1 TRANSMITTER DESIGN

The main problem in the tube transmitter design (required for the UHF system) is the power output device. The problems and approaches are:

<u>Problem Areas</u>	<u>Solution Approaches</u>
● Tube life	Tube parameter derating and high reliability modifications
● Launch environment	Mechanical isolation, testing

The cost of the design program is approximately \$700 thousand over a 21 month period. The major risk area is the limited time for life tests which requires a program of accelerated life testing.

The three solid state transmitter designs require 11 to 18 month programs costing \$300 to \$500 thousand. The problems and approaches are:

<u>Problem Areas</u>	<u>Solution Approaches</u>
● Digital modulation technique	Breadboard testing
● Multi-element combining circuits	Breadboard testing
● High power device modification	Increase voltage capability

5.2 POWER SUBSYSTEM DESIGN

The prime power sources for the configurations under consideration are fold-out or roll-out arrays of standard silicon solar cells on flexible substrates. These are conservative designs in terms of systems currently being developed. The systems, however, require design

effort, particularly for the roll-out arrays. Programs ranging from 19 to 23 months expending \$2.0 to \$5.2 million are required. From an economic standpoint the manufacturing processes should be improved to reduce the costs since this is the high cost subsystem on each one of the configurations.

The problem areas and approaches are summarized below:

<u>Problem Areas</u>	<u>Solution Approaches</u>
● Deployment-erection system	Environment & performance testing of full scale models
● Manufacturing processes	Semi-automated technique required
● 450° temperature excursions of array	Design of compatible flexible electrical cell interconnections
● High reliability voltage converter (UHF)	Breadboard testing and analysis

5.3 ANTENNA DESIGN

The major problem in the antenna designs is assuring deployment.

Parabolic Antennas - For the parabolic antennas used in the UHF and VHF 2 configurations, programs costing approximately \$500 to \$700 thousand with 20 month durations are required.

Problem areas and solution approaches are summarized as follows:

<u>Problem Areas</u>	<u>Solution Approaches</u>
● Deployment	Full scale testing
● Electrical design	Model tests

The high risk area for inflatable antennas is the development of the ability to simulate weightlessness of large units when testing in a 1G environment on earth. The test specimen might be floated on water or filled with gases to overcome gravity loading during test.

Array Antennas - In all array antennas the design effort required is greater than in the case of parabolic antennas. Programs costing \$1.0 to \$1.3 million and requiring a 25 month period are needed. The major additional problem is dealing with the large number of individual segments. The size of the antennas makes full scale testing difficult. The testing of segments or small groups of segments of the antenna is a possible approach.

5.4 STABILIZATION SUBSYSTEM DESIGN

Active Systems - Programs for active systems to be used in the HF, VHF 1 and UHF configurations will require approximately 22 to 28 months and \$4.3 to \$7.3 million.

The problem areas and solution approaches are summarized below:

<u>Problem Areas</u>	<u>Solution Approaches</u>
● Solar array drive and gimbal	Full scale model testing
● Flexibility effects	Extensive analysis and model testing
● Articulation effects	Extensive analysis and simulation

The risk areas are in estimating the structural characteristics accurately. The magnitude and frequency of the vibrations and the modes of damping in a fairly complex mechanical design must be estimated.

Hybrid Systems - For a hybrid system of the type required for VHF 2 configuration, a design program cost of \$3.6 million and a period of 19 months is estimated. The major problem area is the ability to evaluate the disturbing torques due to the solar pressure on the gravity gradient system. This requires extensive analysis, the major risk being in the ability to simulate a particular disturbing torque for the given configuration.

5.5 LONG-LIFE TRANSMITTER DESIGN

In a broadcast satellite system, lifetime and failure-free operation become dominant design factors. The first reason for this is the relatively great cost of the satellite, which means that the satellite equipment must be considered as a long-term investment item. In addition, in many broadcast services, the penalties for outage in transmission time are severe. Thus, maintenance of scheduled operation is an important requirement of the system.

It is reasonable to achieve a two-year life vehicle. Three periods of major concern are the deployment, initial month of operation, and the remainder of the two years. The highest probability of failure will occur in the initial launch injection and the deployment of the solar array and antenna, followed by the infant mortality period in the first 30 days.

There are reasonable approaches to insure that long life is achieved. Sufficient margin must be provided in the early stages of the design effort, in particular in each of the critical areas that have been indicated. The program must include exhaustive ground testing and qualification prior to the launch of the vehicle to insure that the probability of infant mortality will be low. NIMBUS II was a typical successful example, where extensive ground testing was done prior to launch and the design goals were exceeded. This has also been done for other satellites that have exceeded the two-year life.

SECTION 6

CONCLUSIONS

This study has shown that:

- Voice broadcast satellite systems are feasible by the early 1970's.
- Cost-effective systems are possible for certain combinations of population density, areas covered, and schedules of operation (duty cycle).
- To be able to launch these systems by early 1970's, the design effort should begin in early 1968.
- Decisions regarding user requirements are necessary before specific operational or demonstration missions can be defined.

The ultimate goal of a Broadcast Satellite Program is to provide operational broadcast systems. Before this can happen a number of key events must occur as shown in Figure 6-1. The first satellite will probably be for demonstration purposes. For a demonstration to be meaningful, it is necessary that demonstration requirements be specified from a fusion of user needs and national objectives plus technical studies such as this Voice Broadcast Mission Study.

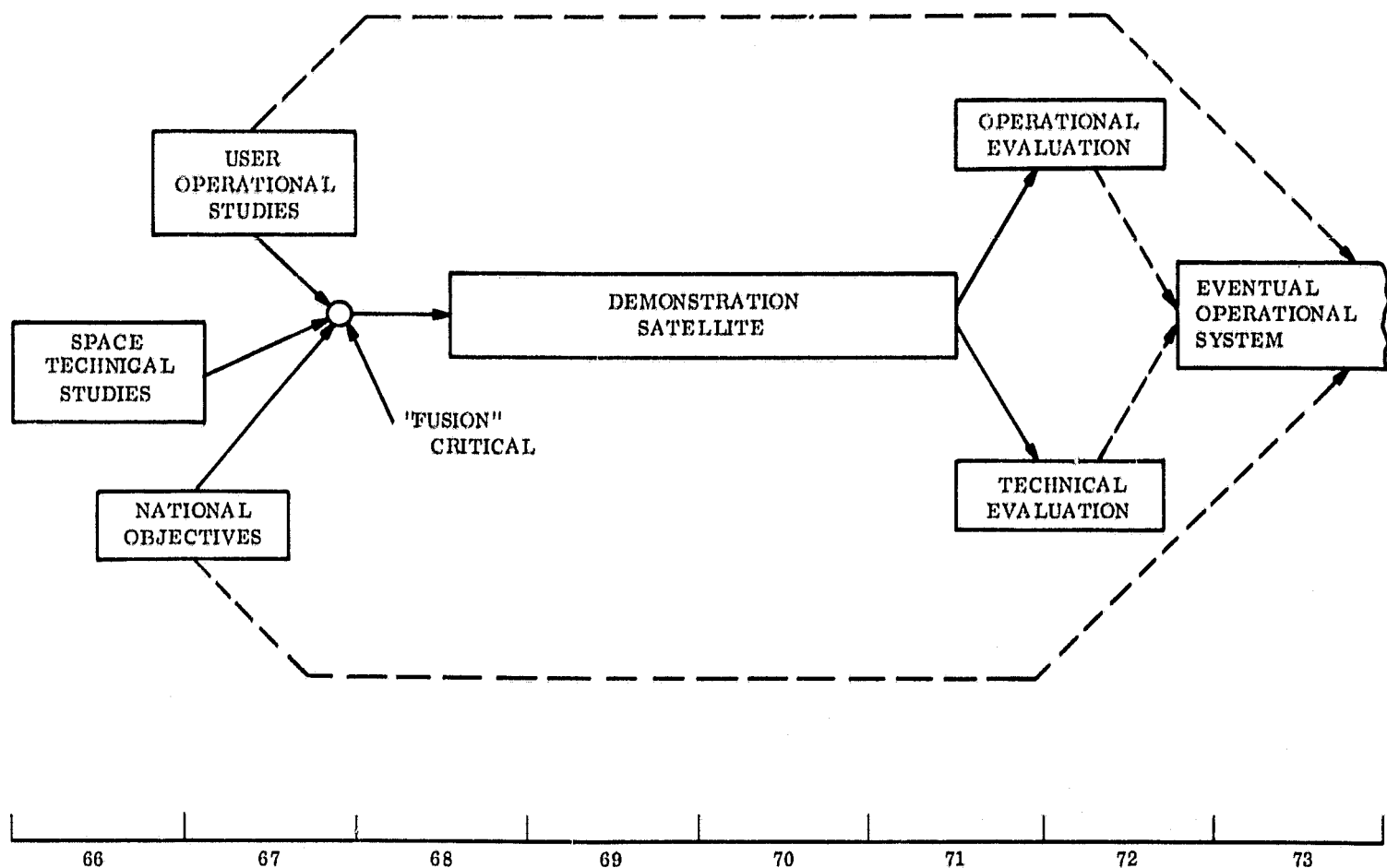


Figure 6-1. Space Broadcast Development Program