SUMMARY OF THE RESULTS OF FEASIBILITY STUDIES OF DIRECT VOICE BROADCASTING UNDERTAKEN FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Presented to study groups IV, X, and XI of the CCIR for information purposes concerning direct voice broadcast from space.

Introduction

Voice broadcast feasibility studies were performed for the NASA by the General Electric Company (1), and the Radio Corporation of America (2). The objectives of these studies were the following:

a. To determine the feasibility of direct broadcast of voice programs from an unmanned satellite with a minimum expected life of two years to home receivers in the early 1970's;

b. To evaluate the technological requirements of such a mission and the extent of advances in existing technology required;

c. To determine the cost factors for such missions.

For the feasibility study, three frequency bands were chosen:

Band 7, 15 to 25 MHz, AM
Band 8, 88 to 108 MHz, FM
Band 9, 470 to 890 MHz, FM

In addition, measurements of man-made noise were taken to aid in the determination of the spacecraft power requirements.

Considerations

The following were among the factors considered in this study.

1. Mission
   - Audience, including receiver distribution, language differences and geographic areas
   - Ground receivers and antennas
   - Signal quality
   - Noise, man-made and natural
   - Frequency
   - Broadcast time, duration and repetition
   - Time period for mission implementation
2. Technology
   - Propagation
   - Satellite antenna and transmitter
   - Satellite prime power source and thermal control
   - Satellite attitude control and station keeping
   - Launch vehicle and ascent trajectory
   - Ground to satellite communications

Method

Mission, communications and spacecraft technology, and spacecraft configuration analyses were performed to define feasible spacecraft configurations capable of meeting the mission objectives. Analyses of the performance capabilities provided by these configurations were made, the perferred approaches selected, and detailed analysis of all aspects of the selected configuration carried out.

An audience analysis was performed to define representative broadcast missions. The present worldwide distribution of receivers in the three frequency bands was evaluated and the numbers and their distribution were extrapolated to the early 1970's assuming that the number, distribution, and characteristics of these receivers were unaffected by any knowledge of a future space system.

The sensitivity of present receivers manufactured in the USA and in other world areas was evaluated using the present world standards where applicable and data obtained from the respective contractors consumer product divisions.

The time(s) of broadcast and duration(s) were used to define the required satellite orbits. The above analyses, together with a study of propagation effects, were used to define the satellite performance requirements.

A technology evaluation of the various satellite subsystems was performed and the results used to define conceptual configurations which could meet the above requirements and launch date and life constraints. Preferred approaches at each frequency were selected, and detailed analyses of the spacecraft designs, performance, and cost were made.

Configurations

A summary of the major characteristics of three of the four selected configurations of each contractor is given in Table I. The other configurations, which are not reviewed, were for a subsynchronous altitude band 8 satellite.

Band 7 Configurations

These configurations were designed to broadcast for a minimum of 1 hour to selected areas on a daily repeat. A sketch of one of the configurations is shown in figure 1. Weight optimization of the configuration with orbit altitude as a variable determined the optimum orbits in the medium altitude range. Since continuous transmission was neither necessary or possible, energy storage batteries could be used in one configuration lowering the size of the solar array and the attendant costs.

Scintillation, absorption, and reflection effects limit most of the broadcasting to the upper portion of band 7, where only a small fraction of present "short wave" receivers are usable and to latitudes between 45N and 45S. The result is that although these satellites are capable of reaching 80 percent of the receivers in the selected areas at a signal-to-noise ratio of 20 db under favorable conditions, the actual percentage reached under unfavorable conditions will be approximately 10 percent of the receivers in the selected areas. In addition the total number of receivers in the selected areas represents only 5 to 15 percent of the known world total in 1970. One contractor gained the higher potential listening audience by broadcasting to 4 areas per day and including frequency diversification in the configuration.

To use the solid state output devices at the highest efficiency digital switching techniques are used in the configurations to obtain AM modulation.

Band 8 Configurations

These configurations were designed to broadcast simultaneously to band 8 FM home receivers in the United States of America for a minimum of 22 hours daily. A sketch of one of the configurations is shown in figure 2.

It was determined from receiver growth studies that the United States would contain 98 million or 75 percent of the world total of FM home receivers in 1970, of which a substantial fraction (65 to 90 percent) could be reached by these configurations at an unweighted signal-to-noise ratio of 45 db. In addition, a substantial number of inexpensive transistor AM-FM portables could be reached when used outside.

Propagation losses are negligible at these frequencies; however, because of Faraday rotation in the ionosphere a 3 db loss was accepted for using linear polarized antennas to receive circularly polarized radiation.

Band 9 Configurations

The band 9 configurations were designed to broadcast audio material to unmodified UHF television sets in the United States of America. The instantaneous coverage area is a single time zone with each of the time zones covered sequentually. Broadcasting is continuous except when the satellite is in the Earth's shadow. Because the vast majority of UHF television sets in the United States use intercarrier sound IF amplification, both the video and audio carrier must be transmitted, resulting in a four-fold increase in power over the usual audio FM transmission. A sketch of one of the configurations is shown in figure 3.

From receiver growth analysis it was estimated that the United States would contain 67 million UHF TV sets in 1970, about 55 percent of the world total at that time. The UHF satellites configured were expected to be able to reach 30 to 55 percent of this audience with a signal satisfactory for an unweighted signal-to-noise ratio of 31 db.

Again propagation losses are negligible but a 3 db loss must be accepted for circularly polarized reception by linear polarized antennas.

Technology Evaluation

The present and projected (to early 1970's) technology status of the various satellite subsystems were evaluated. Several subsystems were found to require either a substantial extension of the present state-of-the-art or a long lead time for design, construction, and testing.

Solar Arrays

Solar arrays were considered the only practical power source for all of the configurations. The high powers to be used on all these configurations necessitates the lightest possible solar array which is consistent with deployment reliability and 2 year life. One contractor used a light weight roll out deployment array which mounts standard silicon cells on a thin flexible film. The other Contractor used a light weight fold out array. Both of these array types have packaging, deployment, and thermo-mechanical problems which must be solved by full scale modeling and testing before they can be considered reliable enough for space use. Present space tested solar arrays are limited to below a few kilowatts so that the extension of present solar arrays to the low powered Band 9 configuration would be practical and also would not place too a severe weight penalty on the spacecraft.

Antennas

To concentrate the radio frequency power in the desired coverage areas on Earth necessitates very large antennas at the frequencies considered. In order to minimize the weight of the spacecraft the lightest possible antenna structures must be used. One contractor used structures of an inflatable wire grid for all antennas. The other contractor used a light weight umbrella type parabola for two configurations and a long vee boom antenna for band 7. All these structures are large, and semiflexible and as yet untested at these sizes. Packaging, deployment, and thermomechanical problems must again be solved by large scale modeling and testing. At present 10 meter diameter space antennas are undergoing detailed study by the NASA and the technical problems involved with antennas of 10 meter diameter does not appear to be too severe.

Thermal Control

The two critical areas are the thermal control of the solar array and antenna structures and the cooling of the radio frequency output devices, especially if tubes are used. The problems of the first critical area are amenable to solution by passive methods used today and would be evaluated by large scale model testing. The problem of cooling of the r.f. tubes can probably best be solved by using heat pipes which have a very high effective thermal conductivity. Heat pipes are being studied experimentally for this purpose but have not yet been fully tested for this application under the conditions of space.

Transmitter Output Devices

Because the efficiency of the output device determines to a large extent the total spacecraft electrical efficiency and thus the spacecraft solar array power, the devices whether tube or solid state must have the highest efficiency which is achievable and which is consistent with a 2 year life. Output tubes of present satellites are below 100 watts. Solid state circuits of the same power level have been built and demonstrated on the ground. Thus, the power output of these configurations represents a 10 to 100 fold increase in output power.

This increased power plus the desirability of high efficiency and long life necessitates a strong development and long term life testing effort.

Attitude Control and Station Keeping

The configurations designed used active systems combining momentum wheels and jets. This type of system has been partially demonstrated in space but further development and testing is necessary. If the satellites are going to have a useful life beyond a few years, jets of higher impulse must be developed or the weight allocated for control propellant becomes excessive.

A problem which needs both analytical and experimental study is the question of the effects of the interacting motions of two large, light weight, semiflexible structures such as the solar array and the antennas.

Cost Evaluation

In estimating the costs of the programs leading to a voice broadcast satellite it was assumed that all necessary research, development and hardware not at present in hand was chargeable to the mission with the exception of development of necessary launch vehicles. Two costs are of interest; the research and development cost and the cost effectiveness of a fully developed voice broadcast satellite system.

The research and development costs included the costs of increasing the technology to the required level, testing and modification of components, testing facilities, and mechanical and thermal test models of the satellites. It did not include the costs of building the launched satellite. Although there was a wide variation in this cost, due to the contractors differing opinions as to the extent of development and testing necessary, the average development cost was approximately 25 million dollars plus 4 thousand dollars per kilogram of final configured satellite.

The cost effectiveness of a broadcast system can best be measured against similar terrestrial systems. For this three terrestrial system costs were available to the contractors:

a. The estimated operating cost per receiver-hour of the band 7 broadcasting system of the USIA - 0.002 cents per receiver-hour;

b. The estimated operating cost per receiver-hour of terrestrial FM broadcasters in the United States - 0.0025 to 0.006 cents per receiver-hour;

c. The estimated operating cost per receiver-hour of terrestrial band 8 - TV broadcasters in the United States - averaged at 0.065 cents per receiver-hour.

The operating cost per receiver-hour of the configured satellites was estimated to be:

a. Band 7 configurations - 0.15 to 0.30 cents per receiver-hour;

b. Band 8 configurations - 0.002 to 0.004 cents per receiver-hour;

c. Band 9 configurations - 0.015 to 0.035 cents per receiver-hour.

Noise Survey

A limited program of the measurement of man-made noise in bands 7, 8, and 9 was conducted as part of the voice broadcast mission study. The results are shown in figure 4.

One program consisted of measurements of absolute and relative levels of man-made noise in urban, suburban, and rural areas in the Philadelphia area. Noise discrimination by home antennas was also evaluated.

The equipment used for these measurements was the Noise Amplitude Distribution Measurement Equipment (NADME), which consists of eight solid state amplitude detectors and counters preceded by a receiver with approximately 10 KHz bandwidth.

Each amplitude detector is adjusted to respond when a preset amplitude is exceeded. The average number of noise pulses above a preset amplitude per unit time was then calculated. These values were then converted into RMS noise. The dipole antennas used were mounted 20 to 40 feet above the ground plans. These measurements were made at 25.8 MHz and 90.4 MHz over a two-week period at each of three sites, downtown Philadelphia (urban), Valley Forge (suburban), and near Bucktown, Pa. (rural). Measurements were made during both daytime and nighttime hours.

The other noise survey was performed at six major sites chosen in the New York - New Jersey metropolitan area. The sites varied from suburban (New Brunswick, N. J.) to urban (midtown Manhattan). Standard communication or RFI receivers were used with 6 to 20 KHz bandwidths at 20 and 109 MHz and 300 KHz bandwidth at 800 MHz. The noise parameters measured were true and weighted rms voltage from the detector output at the receiver. Both dipole and directive antennas were used and were mounted 10 to 20 feet above the ground plane.

Results of antenna discrimination measurements indicate that a high gain antenna elevated at 45° above the horizon may provide a reduction in man-made noise of approximately half the forward gain in db (an antenna with 10 db forward gain has 5 db noise discrimination).

Concluding Remarks

In general, the studies concluded that the voice broadcast missions were feasible from the technological standpoint for a luanch in the early 1970's providing design efforts on items needing long development and testing times are started in the immediate future.

As part of a continuing study of communication satellites, the NASA is presently conducting similar studies on the feasibility of television broadcasting from space.

Bibliography

1. Anon.: Voice Broadcast Mission Study. Rep. No. 67SD4330, General Electric Co., Missiles and Space Div., July 14, 1967.

2. Anon.: Voice Broadcast Mission Study. Rep. No. AED-R-3187, Radio Corp. of America, Astro-Electronics Div., May 1967.

TABLE I

	BAND 7 (15 - 20 MHz)		BAND 8 100 (MHz)		BAND 9 (800 MHz)	
	A	B	A	B	A	B
Orbit	Medium, 4.8 hr	Medium, 6 hr	Geostationary	Geostationary	Geostationary	Geostationary
Mass, Kg	2140	2500	1180	1090	500	1320
Prime power (KW)	15	15	11	5	2.5	10
Antenna type and size (m)	Array 30.4 × 30.4	Vee-Booms 60.8 long	Array 15.6 × 15.6	Parabola 23, diam.	Parabola 6.72, diam.	Parabola 9.15, diam.
Antenna gain (db)	14.4	15	26.9	25	33	35
Transmitter output (KW)	8.8	9.0	7.07	2.5	1.15	4.0
Transmitter type	Solid state	Solid state	Solid state	Solid state	Tube	Solid state or tube
Power supply type	Orientated solar array + batteries	ORIENTED SOLAR ARRAY				
Attitude control type	3 AXIS ACTIVE					
E. R. P. (dbw)	52	54.5	65	59	64	71
Field μ/m strength	158 - 433	150 - 430	204 - 273	100 - 140	99 - 144 per carrier	200 - 250 per carrier
Potential audience, 1970	300×10^6 Home receivers in the world		98×10^6 Home receivers in in the world		67×10^6 TV receivers in the USA	
Area of coverage	5×10^6 sq km		Continental US continuously except when S/C in shadow		US by time zone 5 hrs to each time zone each day	
% of audience reached	13 Maximum in 4 areas of the world	5 Maximum in 1 area of the world	90 of the USA	65 of the USA	35 of the USA	55 of the USA

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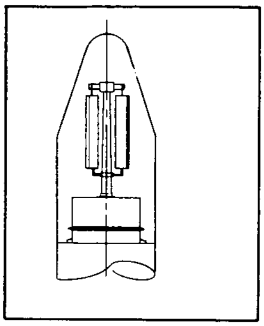

Launch configuration

Carrier frequency: 15.1, 17.7, 21.45 or 25.85 MHz
RF bandwidth: 10 KHz
Modulation: AM
ERP: 52.1 DBW
Satellite weight: 2140 kg

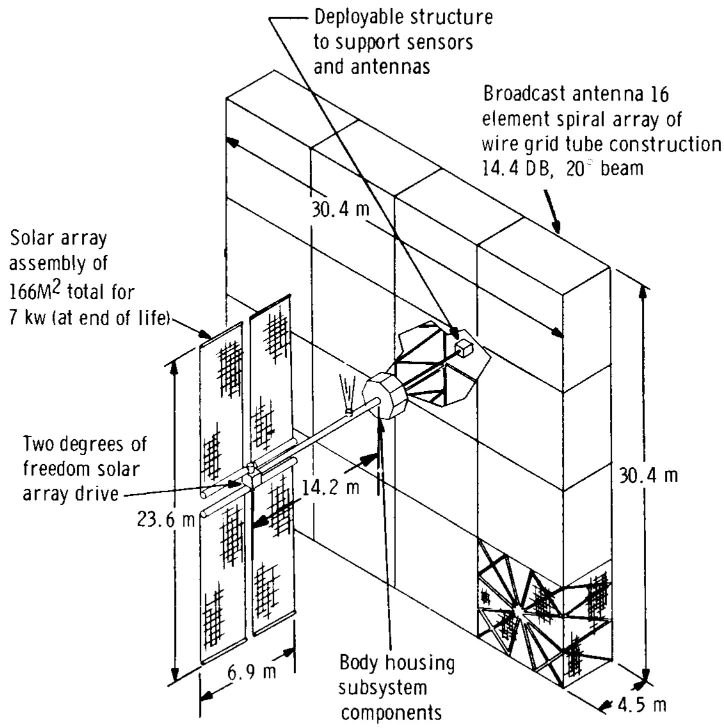

Figure 1. - Band 7 configuration.

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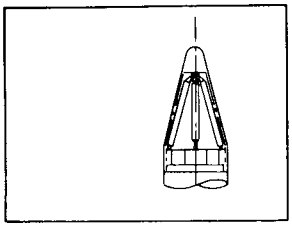

Launch configuration

Carrier frequency: One channel in 100-108 MH_z band
RF bandwidth: 180 KH_z
Modulation: 65.4 DBW
Total weight: 1180 kg

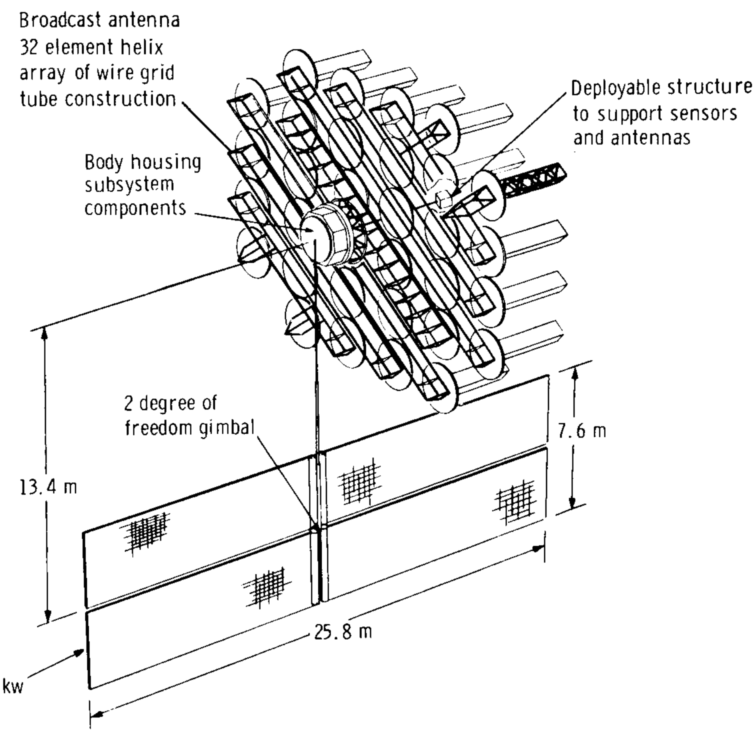

Figure 2. - Band 8 configuration.

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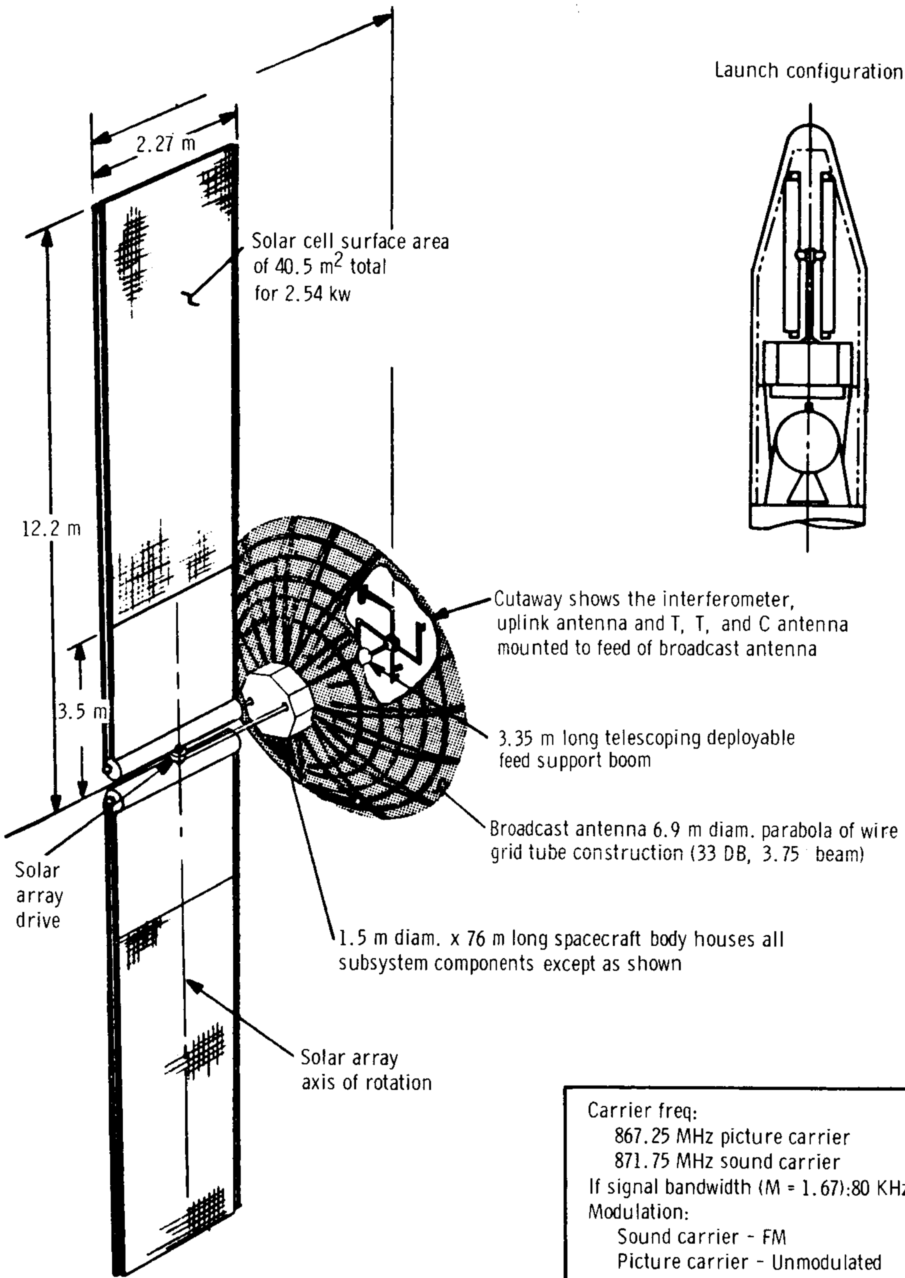

Carrier freq:
  867.25 MHz picture carrier
  871.75 MHz sound carrier
If signal bandwidth (M = 1.67):80 KHz
Modulation:
  Sound carrier - FM
  Picture carrier - Unmodulated
ERP: 63.6 dbw (total for both carriers)
Coverage: Continental U. S. by time zones continuously (except shadow time)
Total weight = 500 Kg

Figure 3. - Band 9 configuration.

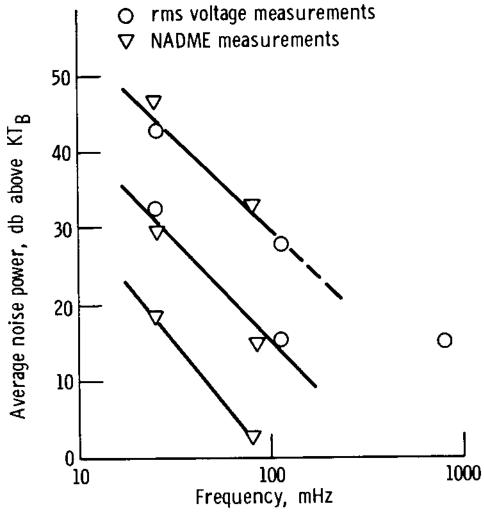

Figure 4. - Results of noise surveys.