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Final Report, Volume I

Television Broadcast Satellite Systems

Prepared By

Satellite Communications Laboratory

E. R. Graf, Project Leader

Contract NASA-24818 CR-123818
George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama

Approved By:

C. C. Carroll

C. C. Carroll
Professor and Head
Electrical Engineering

Submitted By:

ERGraf

E. R. Graf
Professor
Electrical Engineering

FOREWORD

This is Volume I of two volumes, which make up the final report of a study conducted by the Electrical Engineering Department under the auspices of the Engineering Experiment Station of Auburn University. This final report is submitted toward fulfillment of the requirements prescribed in NASA Contract NAS8-24818.

Problems of system weight and picture quality are discussed for a satellite television broadcast system in this first volume.

Volume II of the final report discusses coverage and weather attenuation in detail.

Two other technical reports were submitted during the contract period: Technical Report No. 1, "Receiver Antennas for Application in a Television Broadcast Relay System," dated 30 January 1970; Technical Report No. 2, "Television Broadcast Relay System," dated 30 November 1970.

ABSTRACT

Empirical expressions are derived to account for various components of the Television Satellite Broadcast System. Computer programs are developed to determine the system weight in any general design. The factors of picture quality, propagation losses and R. F. power requirements are discussed and determined for a particular case.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to the many members of the group from the Auburn University Electrical Engineering Department, both student and faculty, who contributed to the overall preparation of the study.

In addition, we are greatly indebted to Mr. Grady Saunders of NASA in Huntsville, Alabama, for his valuable assistance throughout the entire project.

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SYMBOLS

W = total system weight (lbs)

W_A = antenna system weight (lbs)

W_S = solar array system weight (lbs)

W_{TR} = weight of transmitter (lbs)

W_{PS} = weight of electrical power subsystem (lbs)

W_{Th} = weight of thermal control (lbs)

$W_T = W_{TR} + W_{PS} + W_{Th}$

W_{AO} = weight of attitude and orbit control (lbs)

W_{AST} = weight of antenna, solar array, transmitter, power subsystem and thermal control

W_{ST} = weight of structure (lbs)

K_1 = antenna weight factor (lbs/sq ft)

K_4 = solar cell array weight factor (lbs/kw)

K_5 = efficiency of transmitter

K_2, K_3 = constants that determine the weight of transmitter, power subsystems and thermal control equipment

K_6 = constant that determines weight of attitude, orbit control and structure

C = velocity of light $\frac{3 \times 10^{10}}{30.48}$ ft/sec

A_S = area of coverage on earth (sq. miles)

S = distance between transmitting and receiving antennas (miles)

f = frequency (Hz)

P = transmitter output power (kw)

Television Broadcast Satellite Systems

S. G. Chandra, H. V. Poor, D. G. Burks, E. R. Graf

I. Introduction

The television systems around the world have seen a very rapid growth in the last few years. The effects of television have been numerous. Most of the countries have adopted television as a means to achieve national unity, and mass communication.

The most important problem in any country, is that of ensuing a good ground coverage of the broadcasting signals so that the percentage of homes which can receive television without complex aerials or amplifying equipment approaches 100%. At the present time, to achieve close to 100% coverage with ground links requires a very large number of conventional transmitting stations and the increase in distribution costs to achieve this coverage would be very much higher than the increased revenue that would result. The most attractive alternate to this is to have one ground transmitting station for each channel and beam its output to a geostationary satellite and for the satellite responder to relay the signals direct to the home receiver. A geostationary satellite (altitude about 35870 km above the equator) would permit a continuous broadcast service to areas as small as individual countries or as large as continents up to about 1/3 of the earth's surface. A geostationary satellite also permits the use of a fixed receiving antenna of very high gain.

The development of a Television Broadcast Satellite (TVBS) is now accepted as technically feasible and economically profitable. Such as satellite system includes a large number of subsystems interrelated in a complex fashion. A number of different system configurations are possible and for each system, the design involves an examination of the interrelations among and the choice of a set of subsystems to optimize in some sense the resulting system.

The system weight is an important design consideration and an effort is made in this report to give simplified relationships for the subsystem weights, considering all possible variables. Also state-of-the art of the system components, attenuation of the signal and picture quality are discussed.

II. Antennas

An ideal television broadcast satellite transmitter antenna requires a minimum RF power to provide the required field strength over the entire area to be covered. Other aspects affecting the antenna design are side lobe level, beam pointing accuracy, power handling capability, multiple-beam capability, deployment and compatibility with satellite weight and size. Detailed analysis of these factors have been made in various reports [1,2,3,4].

Most high gain directional spacecraft antennas have been parabolic reflectors because they are simpler in design and lighter in weight for a given gain. They may be divided into two categories. Small antennas which can be launched in operating position and large antennas which due to shroud limitations must be folded for launch and then deployed in space.

C

An antenna diameter of approximately 10 ft. divides the two classes. This means that for all bandwidths at 0.9 GHZ and for bandwidths less than about 3^{o} at 2.5 GHZ, a deployable reflector is required.

Deployable parabolic antennas may be classified into three groups:

(1) Flexible reflector surfaces
(2) Rigid reflector surfaces
(3) Inflatable structures

Many concepts for deployable antennas have been described in the literature and a few typical of these are compared in Tables 1, 2, and 3 of Chapter IV in reference [1].

A flexible reflector surface such as metallized film or wire mesh can be supported by a system of ribs or cables which define and maintain the required parabolidal shape. For frequencies up to approximately 5 GHZ, antenna surface qualities and deviations from a true parabolid required to minimize reflector losses are such that a flexible reflector is preferred. The minimum weight design of such an antenna we found to be "Elastic Recovery Umbrella", a 6 ft. size model developed by TRW Systems, with a unit weight of 0.04 lbs/ft^2. The maximum weight design is an umbrella type reflector, 10 ft. model developed for solar concentrator by NASA Langley, with a unit weight of 0.312 lbs/ft^2, other developments are with unit weights of 0.1, 0.13, 0.2,and 0.25 lbs/ft^2.

A rigid reflector antenna is an assemblage of rigid segments of a circular paraboloid. These surfaces provide more accuracy, but are heavier and costly. Models varying from size of 4 ft. diameter to 52 ft.

diameter have been developed for frequencies up to 10 GHz. The unit weight varies from 0.26 to 0.96 lbs/ft^2 for these designs.

Inflatable antennas consist of a circular membrane that assumes the shape of a paraboloid of revolution when subjected to a uniform radial tension combined with uniform lateral pressure. Using this principle antennas up to 20 ft. in diameter have been constructed, with unit weight of the system varying from 0.4 to 2 lbs/ft^2. It is interesting to note in Table 3 of reference [1], about the design of a 200-400 ft. size inflatable reflector, with a unit weight of only 0.03 lbs/ft^2, for use at frequencies 10-30 MHZ. Many problems are yet to be solved in these designs, and hence the application of inflatable structures to spacecraft antennas is beyond the current state-of-the-art.

It is expected, however, that by 1975 some of the large deployable reflectors will have been successfully demonstrated in spacecraft applications.

At lower frequencies (say 0.9 GHZ), the active phased array antenna appears to be an attractive alternate to the reflector antenna, especially for multiple beam capability. TRW Systems [1] have developed a 30 foot array, with a total system weight of 396 lbs., resulting in a unit weight of 0.56 lb/ft^2. However, their complexity, heavy weight and difficulty in meeting launch vehicle fairing constraints have prevented their extensive use on spacecraft to date.

For frequencies above 8 GHZ, (max. size about 10 ft. diameter) the parabolic reflector offers the most promising design. A variety of small antennas have been used in space and pose no major technological problems for the broadcast satellite. The weight of the antenna system is no more significant in this case, and the typical system unit weight varies from about 0.7 to 1.13 lbs/ft^2.

The antenna system weight has been computed for all possible types by using the relation derived in [5].

$$W_A = K_1 \frac{c^2 s^2}{f^2 A_s}$$

where W_A = Antenna system weight in lbs.

Figure 1 [Table 1] is a family of curves of antenna system weight for the frequency range 1 to 4 GHZ, and for 8 antenna weight factors ranging from 0.04 to 0.635 lb/ft .

Figure 2 [Table 2] is a similar plot for the frequency range 8-12 GHZ and for 8 weight factors ranging from 0.13 to 1.13 lb/ft^2.

III. Power Supply

Reliability, long life and efficiency are the three major factors to be considered in the design of a satellite power system. Since the television broadcast satellite must operate for many months, the system's reliability becomes important. Power supply efficiency, measured by watts per pound, is a continuing goal because of the high cost per pound in orbit.

Three sources of energy may be exploited in a spacecraft; nuclear reactor, radio-isotope thermo-electric generator, and solar cell array.

TABLE 1

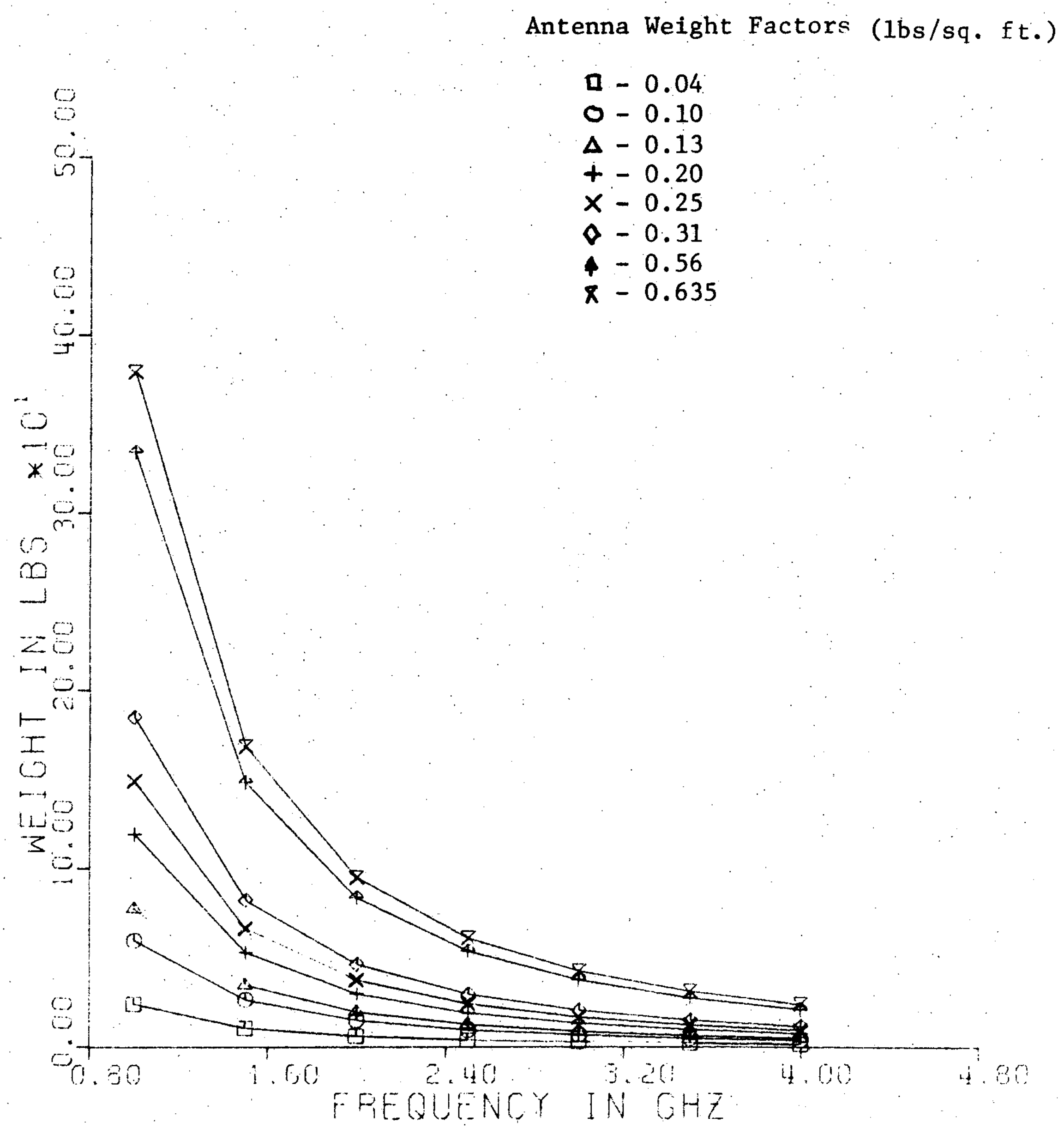
ANTENNA WEIGHT VS FREQ FOR EIGHT ANTENNA WEIGHT FACTORS (1 - 4GHZ)

Frequency (GHZ)	Antenna Weight Factors (lbs/sq. ft.)							
	0.04	0.10	0.13	0.20	0.25	0.31	0.56	0.635
1.0	23.88	59.71	77.62	119.41	149.26	185.09	334.35	379.13
1.5	10.61	26.54	34.50	53.07	66.34	82.26	148.60	168.50
2.0	5.97	14.93	19.40	29.85	37.32	46.27	83.59	94.78
2.5	3.82	9.56	12.42	19.11	23.88	29.61	53.50	60.66
3.0	2.65	6.63	8.62	13.27	16.58	20.57	37.15	42.13
3.5	1.95	4.87	6.34	9.75	12.18	15.11	27.29	30.95
4.0	1.49	3.73	4.85	7.46	9.33	11.57	20.90	23.70

TABLE 2

ANTENNA WEIGHT VS FREQ FOR EIGHT ANTENNA WEIGHT FACTORS (8 - 12GHZ)

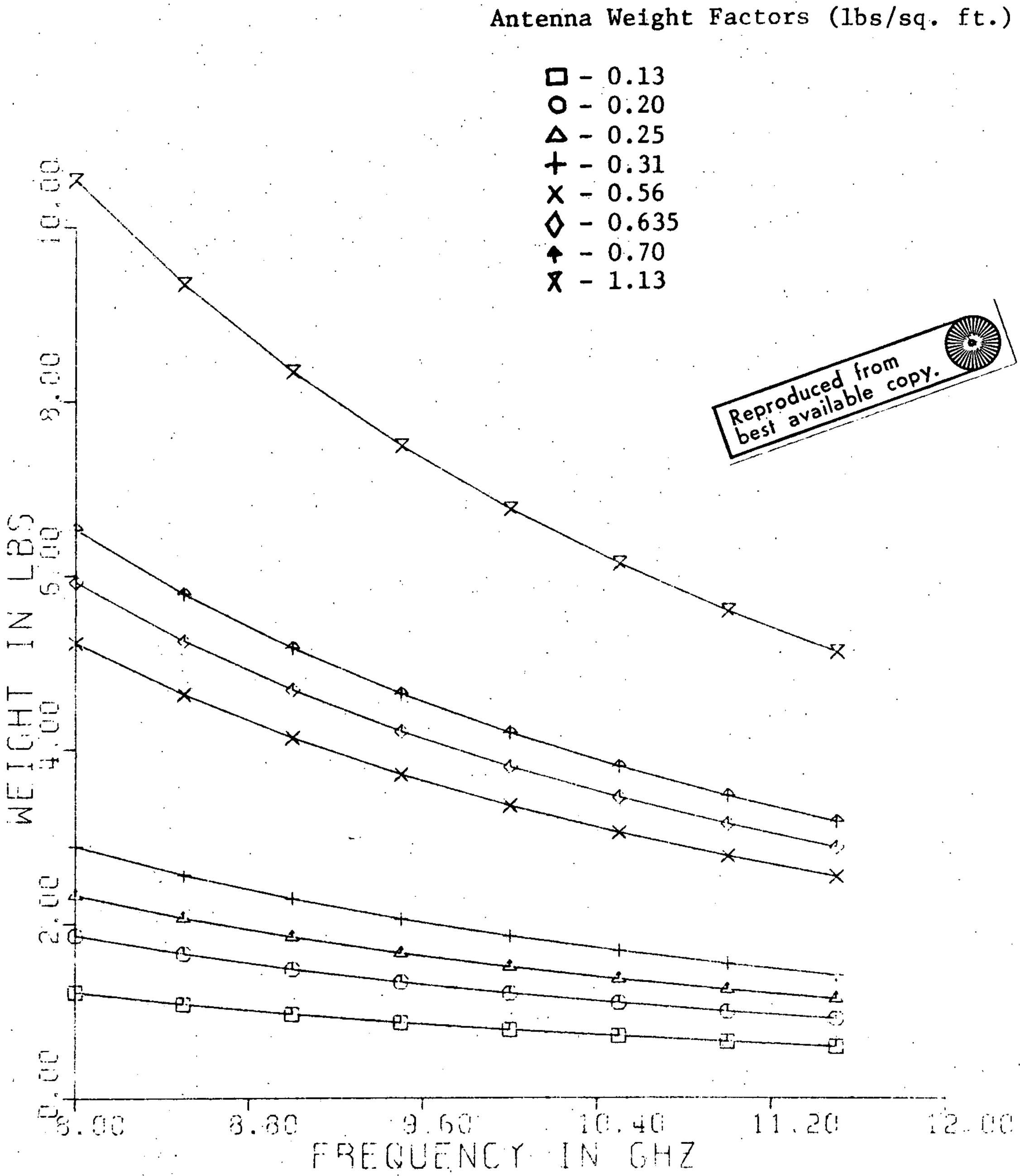
Frequency (GHZ)	Antenna Weight Factors (lbs/sq. ft.)							
	0.13	0.20	0.25	0.31	0.56	0.635	0.70	1.13
8.0	1.21	1.87	2.33	2.89	5.22	5.92	6.53	10.54
8.5	1.07	1.65	2.07	2.56	4.63	5.25	5.78	9.34
9.0	0.96	1.47	1.84	2.29	4.13	4.68	5.16	8.33
9.5	0.86	1.32	1.65	2.05	3.70	4.20	4.63	7.48
10.0	0.78	1.19	1.49	1.85	3.34	3.79	4.18	6.75
10.5	0.70	1.08	1.35	1.68	3.03	3.44	3.79	6.12
11.0	0.64	0.99	1.23	1.53	2.76	3.13	3.45	5.58
11.5	0.59	0.90	1.13	1.40	2.53	2.87	3.16	5.10



ANTENNA WT VS FREQUENCY

FOR EIGHT ANTENNA WT FACTORS (1 - 4GHZ)

Figure 1



ANTENNA WT VS FREQUENCY

FOR EIGHT ANTENNA WT FACTORS (8 - 12GHZ)

Figure 2

Nuclear reactor systems offer the greatest potential in terms of gross power capability. A growth potential for this system is projected up to 300 kw. The main problems associated with these systems are limited lifetime due to generation of helium in fuel casing, heavy shielding requirements in conversion equipment and low efficiency.

Isotope thermo-electric generator systems have been well researched and several low powered systems have been developed and flown. However, the technology base is still inadequate for the power range of interest in the TVBS systems.

The technology of solar cell systems is well in hand, primarily because of their continued use throughout the space program. In fact it appears that they offer the best source for an efficient, practical system for long durations.

Silicon solar cells have been commonly used and the manufacturing techniques for this material are far enough advanced. Silicon cells of polarity N-on-P are preferred to P-on-N because they are more radiation resistant and are readily available. These cells may be obtained in 1 x 2, 2 x 2, 3 x 3 and 2 x 6 cm sizes. However only 2 x 2 cm cells are mostly considered so far because of their cost advantage. The current state-of-the-art in silicon solar cells with some projections for 1975 and 1980 are given [2] below in Table 3.

Table 3
State of the art of silicon solar cells [2]

Parameter	1970	1975	1980
Size/type	2 x 2 cm N/P Silicon	2 x 6 cm N/P Silicon	4 x 6 cm N/P Silicon
Power/cell	72.8 mw	225 mw	450 mw
Weight*	48 w/lb (21 lb/kw)	55 w/lb (18 lb/kw)	60 w/lb (16.7 lb/kw)

(* Not including Substrate/Structure)

Cadmium sulfide solar cells have also been found to be the most promising in the thin film category. They seem to offer several advantages in the areas of cost, storage efficiency and radiation resistance. The following are their typical characteristics:

Power/cell	157 to 252 mw
Power/area	3.78 to 2.35 w/ft^2 (40.7 to 25.3 w/m^2)
Power/weight	37 to 75.7 lb/kw (16.7 to 34.3 kg/kw)

However, the disadvantages of these are larger area, low stability and are not readily available.

Many schemes have been considered for mounting assemblies of solar cells on a spacecraft. They may be mounted directly on the satellite body, but the disadvantage is low efficiency and difficulty in maintaining adequate temperature control, since the spacecraft interior needs to be kept close to 20°C and the solar cells below 0°C. The weight factor of such arrays is of the order of 60 lbs/kw.

Further as the spacecraft increases in size, the amount of electric power that can be supplied by surface mounted cells does not increase at the same rate as the payload volume. To keep power and size in step, certain deployment schemes have been proposed. The two important methods of deployment are roll-out and fold-out. The roll-out method differs from the fold-out scheme only in the manner in which the array/substrate is packaged. The roll-out winds the array on a drum approximately 10 inches in diameter, similar to a window shade. The fold-out method "zee" folds the array into a flat pack against the spacecraft body.

The best method from an efficiency standpoint is to mount the cells on a flat panel which is continuously oriented to face the sun. The oriented flexible solar array is a highly promising concept for large spacecraft power requirements (1 to 100 kw) in the 1970's. This fulfills a critical need for a reliable, low weight, low volume and high power electric power source.

NASA has concluded many study contracts about the feasibility of 30 watt/lb roll-up solar arrays and the results are encouraging. Typical characteristics of these and other developments [6,7,8,9] are given below in Table 4.

A GE study indicates that the utilization of 2 ohm-cm cells results in a calculated max. power of 2523 watts at 102 volts, where as for 10 ohm-cm cells this results in a max.power of 2294 watts at 90 volts. Based on this it is concluded that cells with a 2 ohm-cm base resistivity are required to meet the requirements of 10 watt/sq ft of module area.

Table 4
Low weight roll-up solar array developments

	Hughes[6]	Fairchild Hiller[7]	Boeing[8]	GE[9]
Type of cell	2 x 2 cm N/P 2 ohm-cm 7.2 mil thick	2 x 2 cm silicon cell 8 mil thick	2 x 2 cm 8 mil thick	2 x 2 cm 8 mil N/P 2 ohm-cm
Power/cell		49.5 mw		
Panel area	88 sq ft	277.4 sq ft	29 sq ft	
Number of cells/panel	34500	61,920	6480	55, 176
Power/panel	1500 w	2760 w	290 w	2469 w
Power/weight	21.5 w/lb	34.49 w/lb	20.6 w/lb	32.3 w/lb
Remarks	A 500 w model deployment and orientation system has been verified. A 1500 w model under development in 1970.	A full scale mechanical functioning model has been fabricated and has successfully demonstrated its ability to deploy and retract.	Total power of 1160 watts for 4 panels is achieved.	

However, TRW Systems [1] select 10 ohm-cm cells over 2 ohm-cm cells, because of their higher end-of-life performance.

From the above, it may be seen that the weight factor of the solar cell array varies from about 33 to 60 lbs/kw. Power system weight was computed for these weight factors and is given with respect to the transmitter output power (P). An efficiency of 65% is assumed for the transmitter in the 1-4 GHZ range and 58% for the 8-12 GHZ range. Futher it is assumed that the auxiliary power requirement of the spacecraft is 23% of the transmitter output power. Hence we may write

$$W_s = K_4\left(\frac{P}{K_5} + 0.23P\right)$$

where W_s = Solar cell array system weight (lbs)

The computed results are indicated in Figures 3 and 4, and also in Tables 5 and 6.

IV. Other System Parameters

1. Communications Electronics

The complexity and magnitude of the problems encountered in generating and transmitting high RF power levels in a space environment have been discussed in various reports. Useful discussions are made in [10] about the television broadcast satellite requirements and constraints, and their impact upon transmitter designs. It is anticipated that future trends will be toward multiple beam, multiple repeater configurations that generate sufficient power to allow the use of low-cost terrestrial

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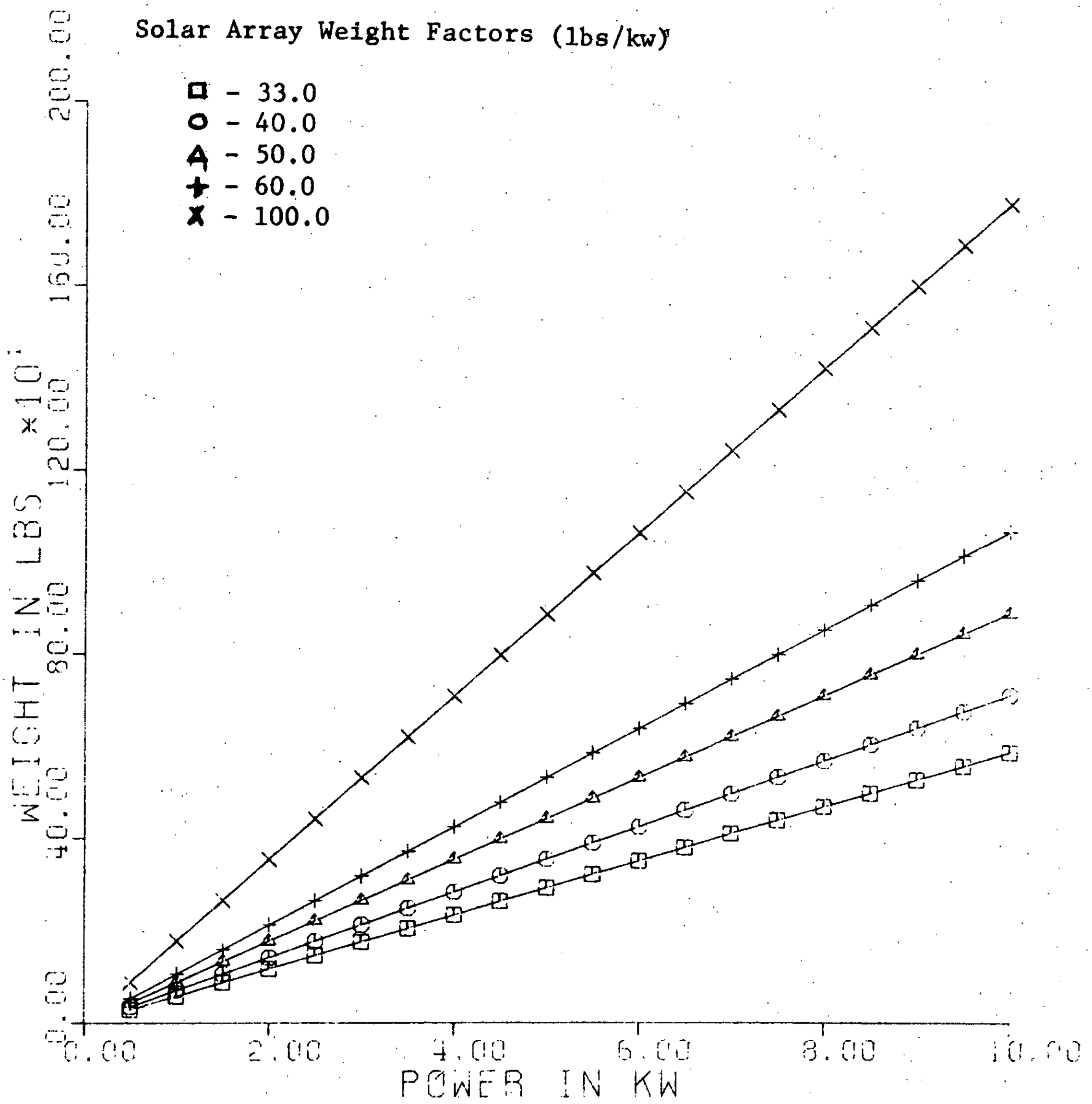
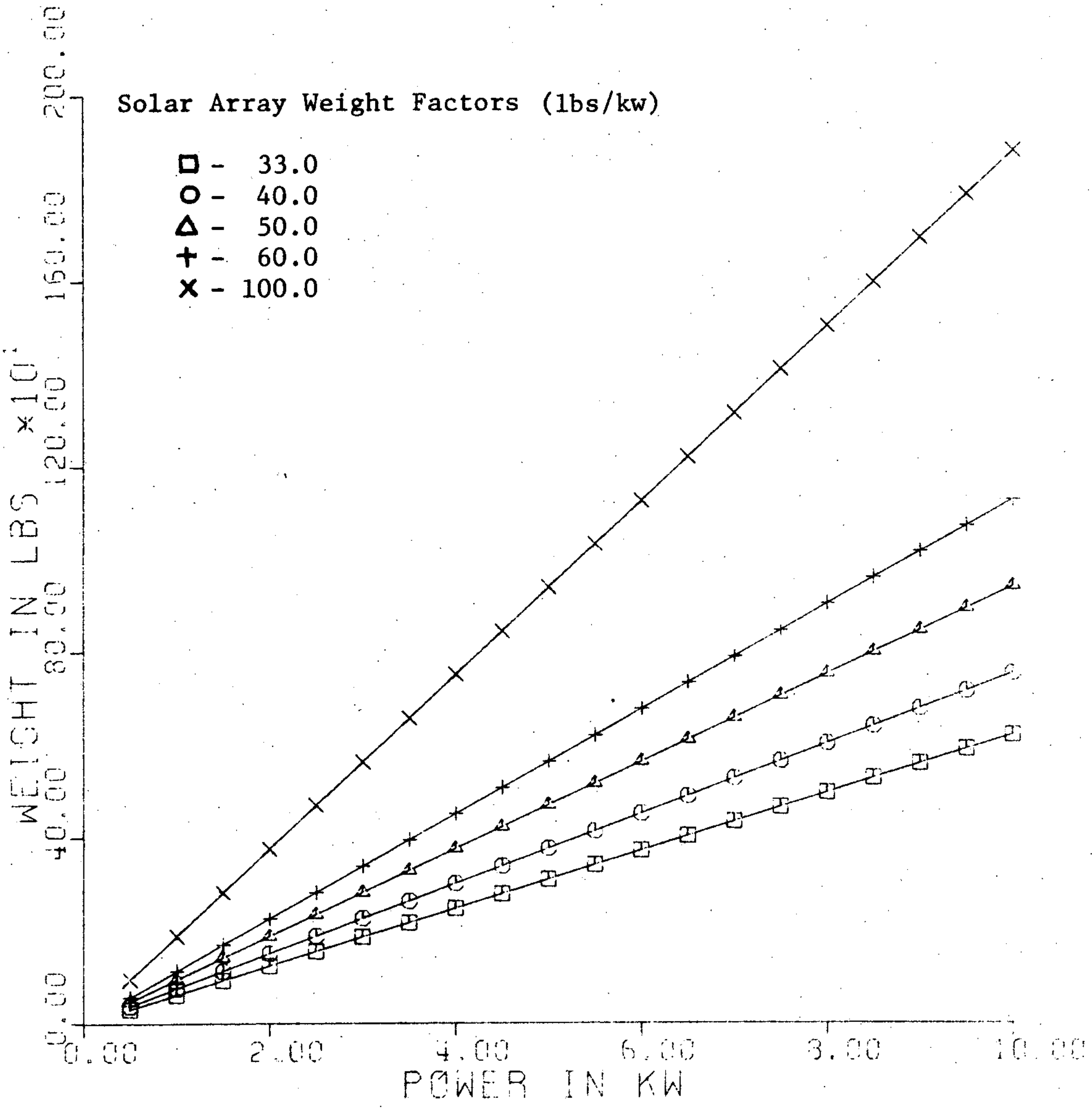


SOLAR CELL WEIGHT VS POWER

FREQ=1-4 GHZ

Figure 3



SOLAR CELL WEIGHT VS POWER

FREQ=8-12 GHZ

Figure 4

TABLE 5

SOLAR CELL ARRAY WEIGHT VS POWER FOR 1-4 GHZ

KW	Solar Array Weight Factors (lbs/KW)				
	33.0	40.0	50.0	60.0	100.0
0.5	29.1796	35.3692	44.2115	53.0538	88.4231
1.0	58.3592	70.7384	88.4230	106.1076	176.8460
1.5	87.5388	106.1076	132.6345	159.1615	265.2690
2.0	116.7184	141.4769	176.8461	212.2153	353.6921
2.5	145.8980	176.8461	221.0576	265.2690	442.1152
3.0	175.0777	212.2153	265.2690	318.3230	530.5383
3.5	204.2573	247.5846	309.4807	371.3767	618.9614
4.0	233.4369	282.9536	353.6921	424.4307	707.3843
4.5	262.6165	318.3230	397.9036	477.4844	795.8074
5.0	291.7959	353.6921	442.1152	530.5383	884.2305
5.5	320.9756	389.0613	486.3267	583.5920	972.6536
6.0	350.1553	424.4307	530.5383	636.6460	1061.0767
6.5	379.3350	459.7598	574.7498	689.6997	1149.4998
7.0	408.5144	495.1692	618.9614	742.7537	1237.9229
7.5	437.6941	530.5383	663.1729	795.8076	1326.3459
8.0	466.8738	565.9075	707.3845	848.8613	1414.7690
8.5	496.0532	601.2769	751.5959	901.9153	1503.1921
9.0	525.2329	636.6460	795.8076	954.9690	1591.6152
9.5	554.4126	672.0154	840.0190	1008.0229	1680.0383
10.0	583.5918	707.3840	884.2300	1061.0759	1768.4600

TABLE 6

SOLAR CELL ARRAY WEIGHT VS POWER FOR 8-12 GHZ

Power KW	Solar Array Weight Factors (lbs/KW)				
	33.0	40.0	50.0	60.0	100.0
0.5	30.9233	37.4828	46.8534	56.2241	93.7069
1.0	61.8465	74.9655	93.7068	112.4482	187.4137
1.5	92.7698	112.4482	140.5603	168.6723	281.1204
2.0	123.6931	149.9310	187.4137	224.8965	374.8274
2.5	154.6163	187.4137	234.2672	281.1206	468.5342
3.0	185.5396	224.8965	281.1206	337.3447	562.2412
3.5	216.4629	262.3792	327.9739	393.5688	655.9480
4.0	247.3862	299.8618	374.8274	449.7930	749.6550
4.5	278.3093	337.3447	421.6809	506.0171	843.3618
5.0	309.2327	374.8274	468.5342	562.2412	937.0686
5.5	340.1560	412.3103	515.3877	618.4653	1030.7756
6.0	371.0791	449.7930	562.2412	674.6895	1124.4827
6.5	402.0024	487.2756	609.0947	730.9136	1218.1895
7.0	432.9256	524.7585	655.9480	787.1377	1311.8962
7.5	463.8489	562.2412	702.8015	843.3618	1405.6033
8.0	494.7722	599.7241	749.6550	899.5862	1499.3103
8.5	525.6956	637.2068	796.5085	955.8103	1593.0171
9.0	556.6187	674.6892	843.3616	1012.0339	1686.7231
9.5	587.5415	712.1716	890.2144	1068.2573	1780.4290
10.0	618.4648	749.6545	937.0691	1124.4817	1874.1362

receiving systems. Details with regard to state-of-the-art of the RF amplifiers is discussed in another chapter.

An approximate weight of the communication system may be determined by the following relations derived from the curves given in [2]. For 1-4 GHZ range $W_{TR} = 28 + 7.5P$ and fro 8-12 GHZ range, $W_{TR} = 23 + 7.8P$ where W_{TR} = Weight of the transmitter (lbs).

2. Electrical Power Subsystem

This corresponds to the power conditioning equipment for housekeeping loads and for power amplifiers, batteries and battery control, power cables, and slip ring assembly. The weight of each of these components depend on the transmitter output power. From the relations given in [1], a simple formula may be approximated to obtain the power subsystem weight as below:

$$W_{PS} = 62 + 16.14P$$

where W_{PS} = Electrical power subsystem weight (lbs).

3. Thermal Control

The temperature of the spacecraft is affected by natural and induced environment, orientation and internal heat dissipation. Several thermal control concepts have been investigated. The weight of thermal control equipment in lbs may be assumed to be about 10 times the transmitter power in kw.

The weights of transmitter, power subsystem and thermal control equipment are computed as shown in Tables 7 and 8. The same are plotted in Figures 5 and 6.

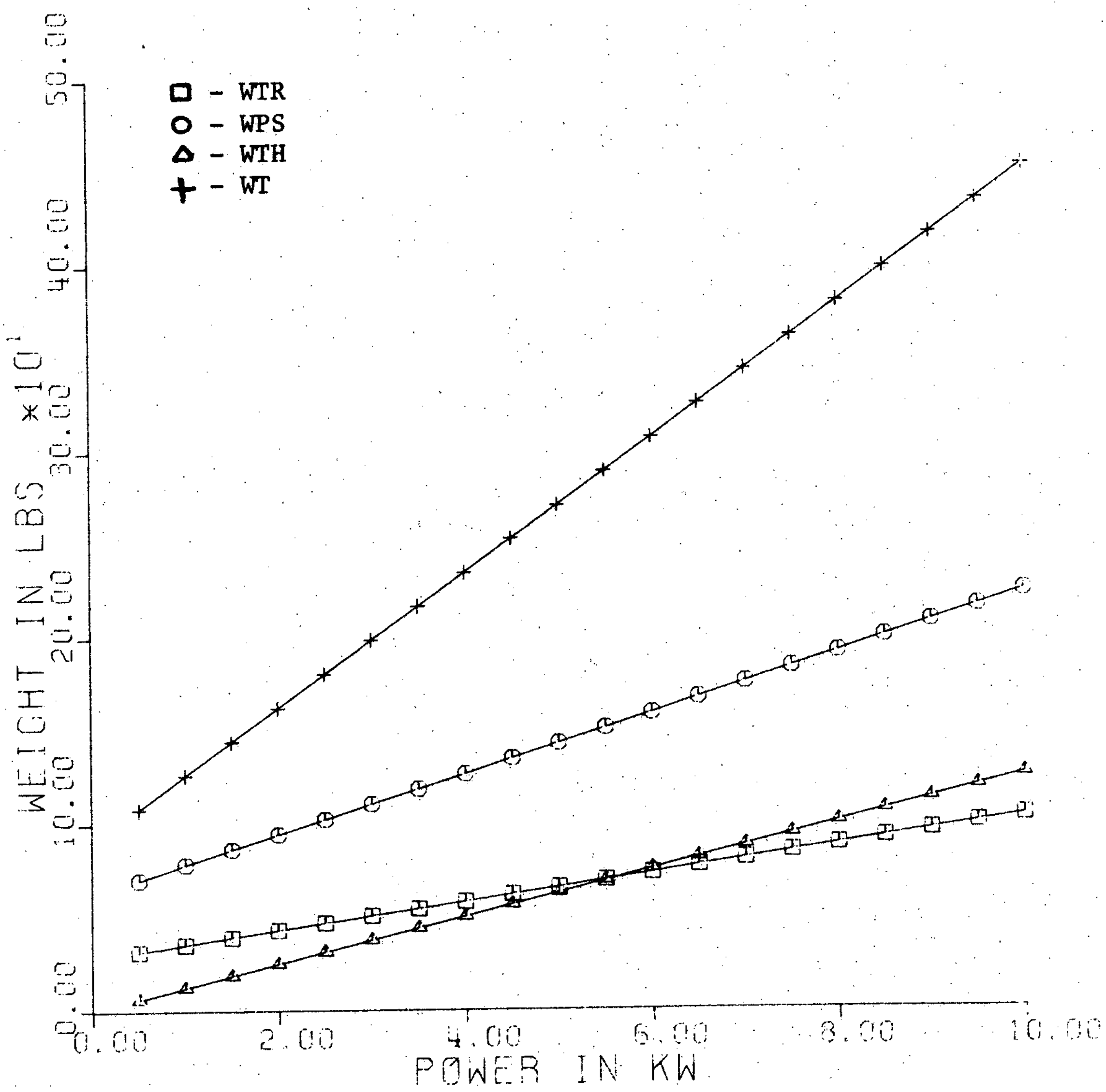
TABLE 7

COMM SYSTEM WEIGHT VS POWER (1 - 4GHZ)

P	WTR	WPS	WTH	WT
0.5	31.7500	70.0700	6.2500	108.0700
1.0	35.5000	78.1400	12.5000	126.1400
1.5	39.2500	86.2100	18.7500	144.2100
2.0	43.0000	94.2800	25.0000	162.2800
2.5	46.7500	102.3500	31.2500	180.3500
3.0	50.5000	110.4200	37.5000	198.4200
3.5	54.2500	118.4900	43.7500	216.4900
4.0	58.0000	126.5600	50.0000	234.5600
4.5	61.7500	134.6300	56.2500	252.6300
5.0	65.5000	142.7000	62.5000	270.7000
5.5	69.2500	150.7700	68.7500	288.7698
6.0	73.0000	158.8400	75.0000	306.8398
6.5	76.7500	166.9100	81.2500	324.9099
7.0	80.5000	174.9800	87.5000	342.9800
7.5	84.2500	183.0500	93.7500	361.0498
8.0	88.0000	191.1200	100.0000	379.1199
8.5	91.7500	199.1900	106.2500	397.1899
9.0	95.5000	207.2600	112.5000	415.2598
9.5	99.2500	215.3300	118.7500	433.3298
10.0	103.0000	223.4000	125.0000	451.3999

TABLE 8
COMM SYSTEM WEIGHT VS POWER (8 - 12GHZ)

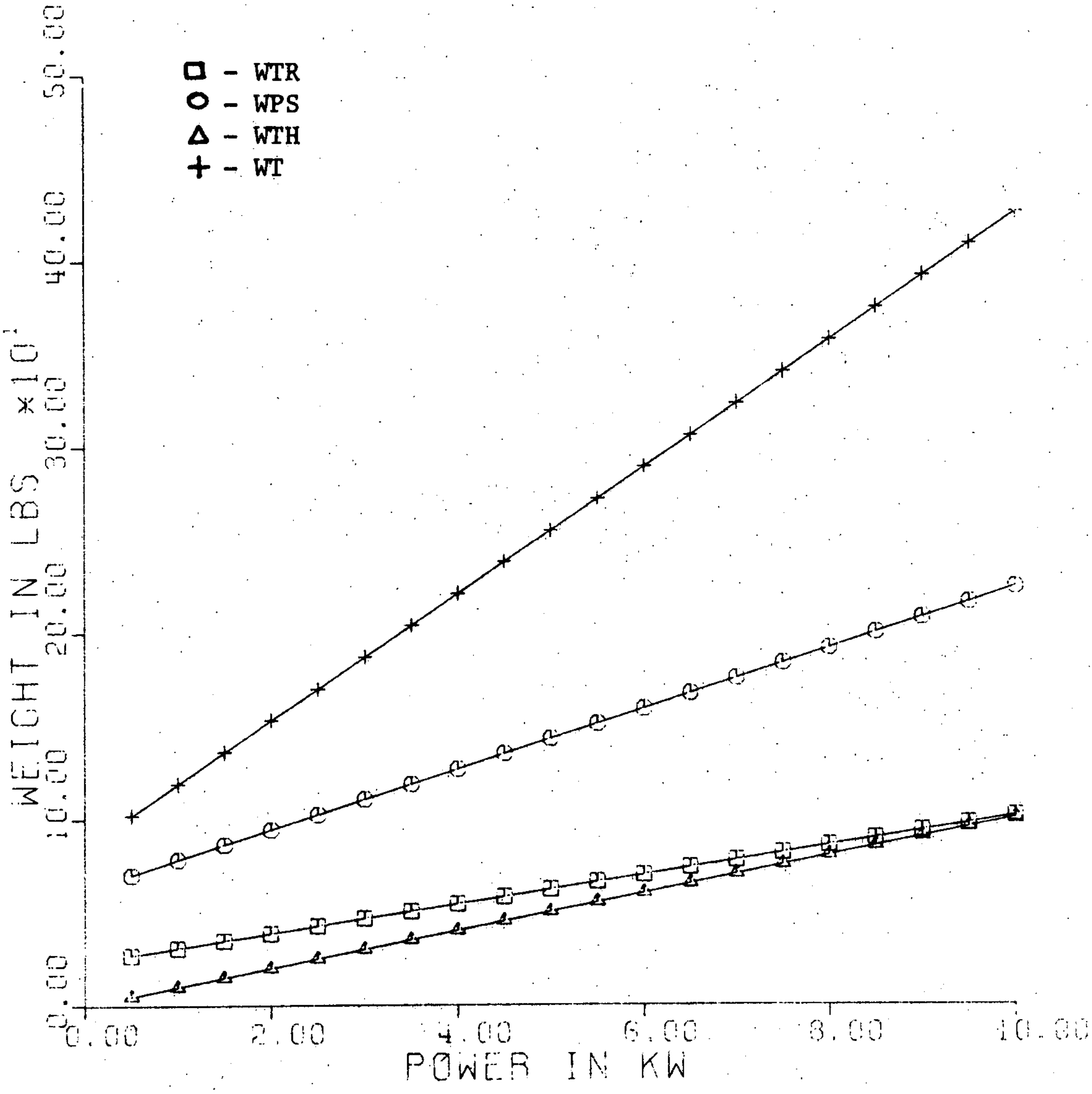
P	WTR	WPS	WTH	WT
0.5	26.9000	70.0700	5.0000	101.9700
1.0	30.8000	78.1400	10.0000	118.9400
1.5	34.7000	86.2100	15.0000	135.9100
2.0	38.6000	94.2800	20.0000	152.8800
2.5	42.5000	102.3500	25.0000	169.8500
3.0	46.4000	110.4200	30.0000	186.8200
3.5	50.3000	118.4900	35.0000	203.7900
4.0	54.2000	126.5600	40.0000	220.7600
4.5	58.1000	134.6300	45.0000	237.7300
5.0	62.0000	142.7000	50.0000	254.7000
5.5	65.9000	150.7700	55.0000	271.6699
6.0	69.8000	158.8400	60.0000	288.6399
6.5	73.7000	166.9100	65.0000	305.6099
7.0	77.6000	174.9800	70.0000	322.5798
7.5	81.5000	183.0500	75.0000	339.5498
8.0	85.4000	191.1200	80.0000	356.5198
8.5	89.3000	199.1900	85.0000	373.4897
9.0	93.2000	207.2600	90.0000	390.4600
9.5	97.1000	215.3300	95.0000	407.4299
10.0	101.0000	223.4000	100.0000	424.3999



COMM SYSTEM WEIGHT VS POWER

FREQ=1-4 GHZ

Figure 5



COMM SYSTEM WEIGHT VS POWER

FREQ=6-12 GHZ

Figure 6

4. Attitude, Orbit Control

The communication satellite, after it is in orbit, is still to be controlled to derive certain advantages. Two types of control are required: (1) Control of the location of the satellite in orbit, which in turn means the control of its orbital velocity, and (2) control of the attitude of the satellite which means having the capability of maintaining or adjusting the orientation of the satellite in a precise way with respect to one or more of three axes.

Various means of control have been discussed and from the information given in [1] and [11], we may write,

$W_{AO} = 0.234\ W_{AST}$ for 1-4 GHZ

$W_{AO} = 0.2\ W_{AST}$ for 8-12 GHZ

where W_{AO} = weight of attitude and orbit control W_{AST} = weight of antenna, solar array, transmitter, power subsystem and thermal control.

5. Structure

A number of factors influence the size and shape of the satellite.

The desired antenna, housing for the equipment and propulsion system, the interface with launch vehicle and fairing, type of attitude and thermal control used, mounting and deployment of solar cells, are the main factors that determine the type of structure. Hence the structure weight depends on all of the above factors and from the plot given in [11] a relation is derived as follows:

$W_{ST} = 28 + 0.272\ W_{AST}$ for 1-4 GHZ

$W_{ST} = 28 + 0.464\ W$ For 8-12 GHZ

where W_{ST} = weight of structure in lbs.

The weights of attitude and orbit control and structure are given in the following Tables 9 and 10 and also in Figures 7 and 8.

V. Total System Weight

Combining all the previously derived relationships, the total satellite system weight may be obtained by the following relationship:

$$W = 28 + (1 + K_6)\ K_1\frac{C^2S^2}{f^2A_S} + K_2 + P(K_3 + \frac{K_4}{K_5} + 0.23K_4)$$

where W = Total system weight in lbs.

A general comupter program is written for the above and is included in the appendix. A particular system example is choosen as follows to verify the program.

f = 2.5 GHZ

A_S = 1000 miles diameter

$K_1 = 0.2$

$K_4 = 40$

The total system weight is computed as a function of transmitter power and is given in Table II and also in Figure 9.

TABLE 9

ATTITUDE, ORBIT CONTROL AND STRUCTURE WEIGHT

(FREQ. 1 - 4GHZ)

WAST	WAC	WST	WAOST
0.0	0.0	28.000	28.000
1000.000	234.000	300.000	534.000
2000.000	468.000	572.000	1040.000
3000.000	702.000	844.000	1546.000
4000.000	936.000	1116.000	2052.000

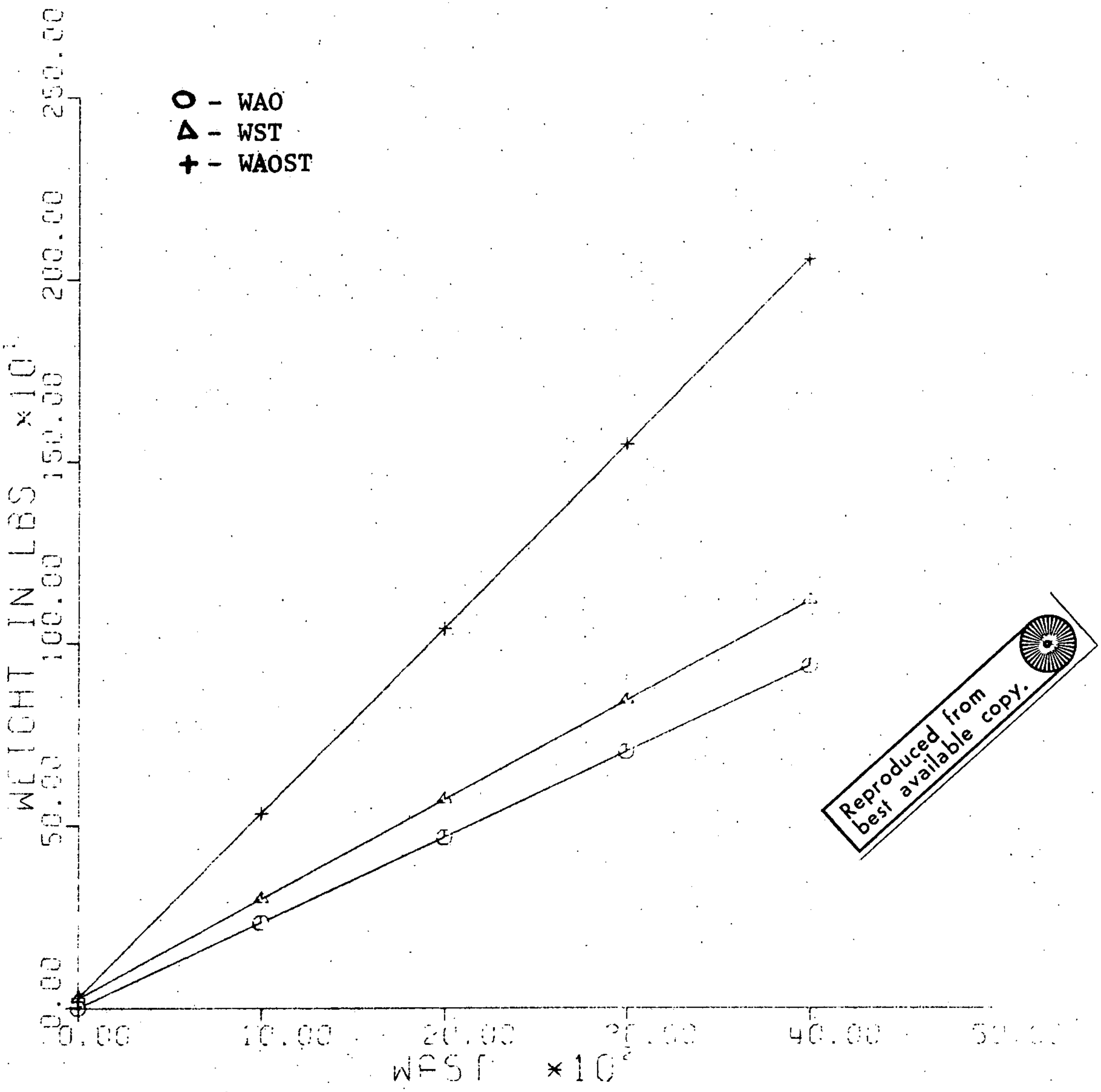
ε

TABLE 10

ATTITUDE, ORBIT CONTROL AND STRUCTURE WEIGHT

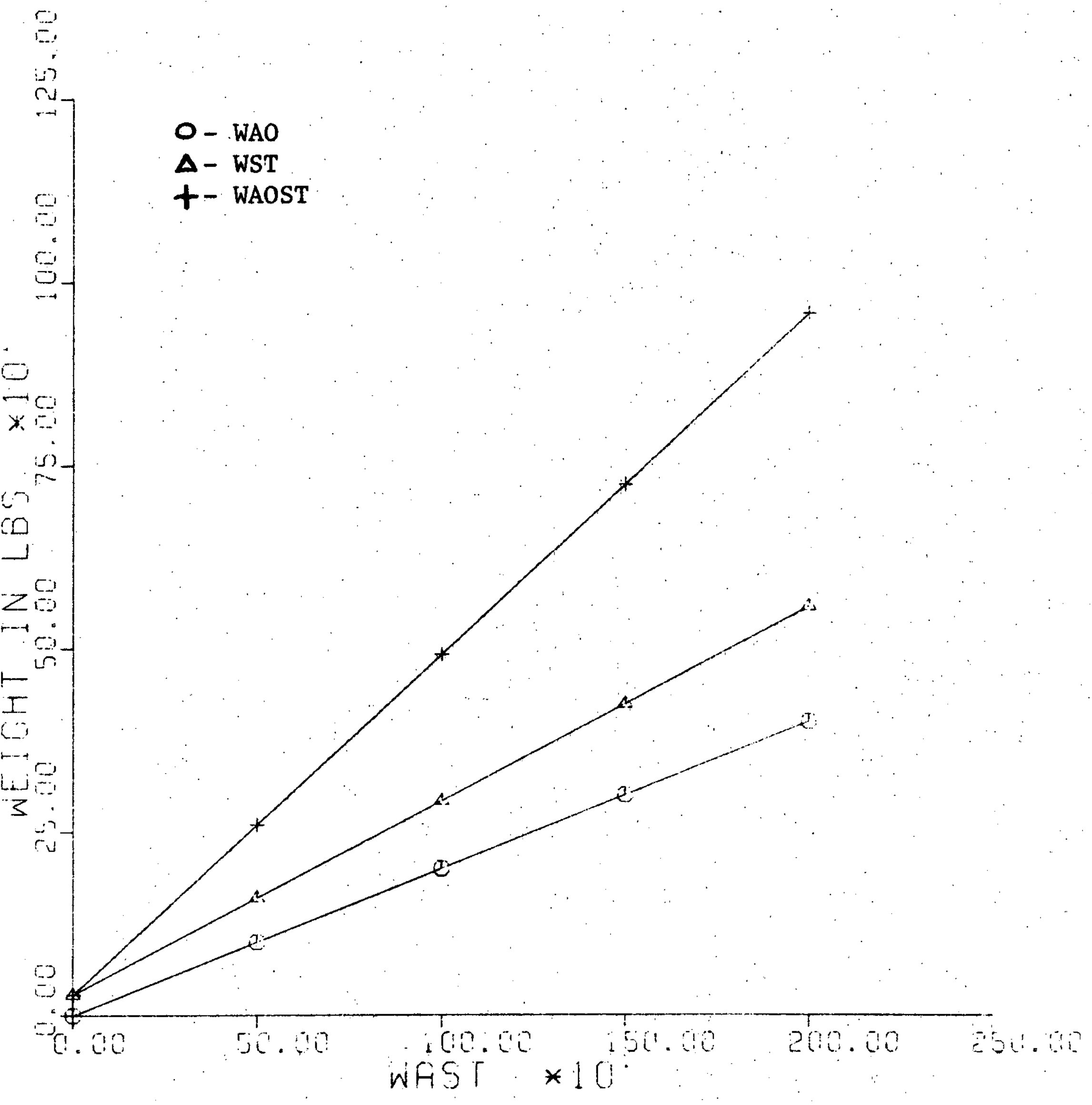
(FREQ. 8 - 12GHZ)

WAST	WAC	WST	WAOST
0.0	0.0	28.000	28.000
500.000	100.000	160.000	260.000
1000.000	200.000	292.000	492.000
1500.000	300.000	424.000	724.000
2000.000	400.000	556.000	956.000



ATTITUDE, ORBIT CONTROL AND STRUCTURE WT (1 - 4GHZ)

Figure 7

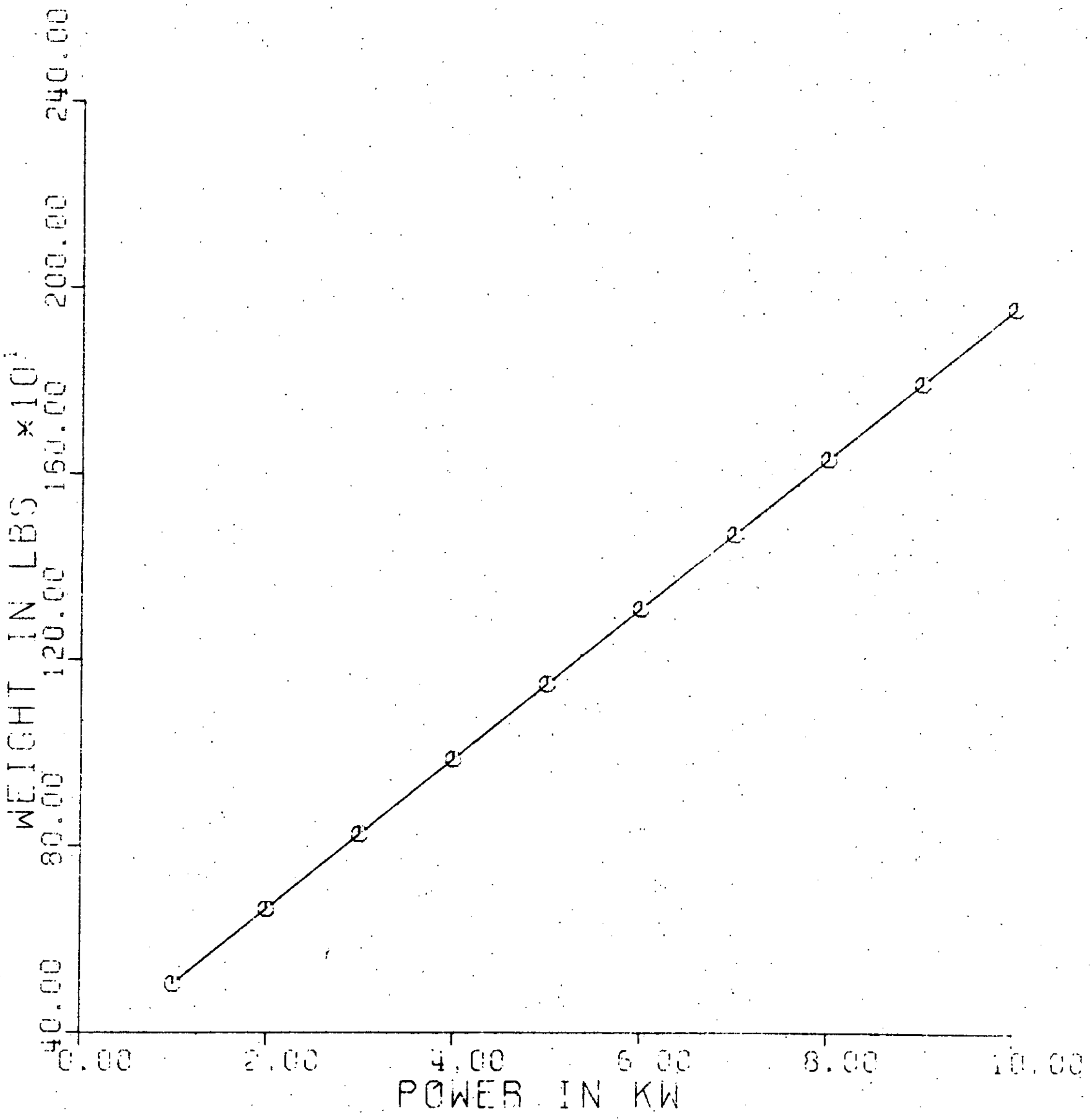


ATTITUDE, ORBIT CONTROL AND STRUCTURE WT (8 - 12GHZ)

Figure 8

TABLE 11

```
                         TOTAL WEIGHT OF SATELLITE

XMIT TO REC ANTENNA IN MILES                           =22000.0000

FREQUENCY IN GHZ                                       =    2.0000

DIAMETER OF COVERAGE IN MILES                          =  500.0000

COVERAGE AREA IN SQ MILES                              =   196349.

POWER IN KW                                            =    5.0000

ANTENNA WT FACTOR IN LBS/SQ FT                         =    0.2000

ELECTRICAL AND ELECTRONIC EQUIPMENT WT FACTOR          =   90.0000

ELECTRICAL AND THERMAL CONTROL WT FACTOR               =   36.1400

SOLAR CELL ARRAY WT FACTOR IN LBS/KW                   =   40.0000

XMITTER EFFICIENCY                                     =    0.6500

ATTITUDE CONTROL AND STRUCTURE WT FACTOR               =    0.5060

TOTAL WEIGHT OF SATELLITE                              = 1148.1477

                         TOTAL WEIGHT VS POWER


    POWER IN KW=     1.0000     TOTAL WEIGHT=   504.3123

    POWER IN KW=     2.0000     TOTAL WEIGHT=   665.2712

    POWER IN KW=     3.0000     TOTAL WEIGHT=   826.2300

    POWER IN KW=     4.0000     TOTAL WEIGHT=   987.1890

    POWER IN KW=     5.0000     TOTAL WEIGHT=  1148.1477

    POWER IN KW=     6.0000     TOTAL WEIGHT=  1309.1067

    POWER IN KW=     7.0000     TOTAL WEIGHT=  1470.0654

    POWER IN KW=     8.0000     TOTAL WEIGHT=  1631.0247

    POWER IN KW=     9.0000     TOTAL WEIGHT=  1791.9834

    POWER IN KW=    10.0000     TOTAL WEIGHT=  1952.9424
```



TOTAL WEIGHT VS POWER (2GHZ)

Figure 9

VI. SATELLITE TRANSMITTER POWER REQUIREMENTS

1. Picture Quality

The ultimate objectives of any TVBS System is to provide the required picture quality by the most economical system for the entire coverage area.

Quality of picture and sound is a subjective concept, since it is a measure of the degree to which deficiencies in the received signals are experienced by the viewers. The relation between this subjective quality and signal deficiency is, of course, an issue of vital importance. Noise performance requirements on broadcast transmissions have in the United States been the subject of extensive investigations by the TASO [12] established by the FCC in the last decade.

In the final report of TASO, the level of television service has been characterized by specifying the level of picture quality to be achieved or exceeded. The typical values shown in Table 12 represent the grade of service for random noise interference. (Based on 75% observers)

The numbers (C/N) TASO represent input carrier to noise ratio. Also they were made in conjunction with an AM-VSB receiver. Since only FM transmission is to be considered for satellite case, because of the lower power requirements, the numbers in Table 12 are to be suitably converted to determine FM signal level requirements. In this process, the carrier-noise ratio is first converted into weighted video signal-to-noise-ratio at the picture tube. TRW Systems [1] have derived analytically equivalent weighted picture-to-noise-ratios for the TASO grades, considering the effect of camera noise. These are shown as $(S/N)_w$dB in Table 12.

Table 12. TASO Picture Quality Grades

Grade	Name	(C/N) TASO dB	(S/N)w dB	C/T dBw/$^\circ$K
1	Excellent	46	49.5	-
2	Fine	38	40.3	-139.6
3	Passable	31	32.2	-141.2
4	Marginal	25	25.9	-
5	Inferior	19	19.9	-

Next, considering FM transmission, the required power and bandwidth are derived for cases of fine and passable picture quality. These values are given as (C/T) dBw/$^\circ$K in Table 12. They correspond to 525 line, color receiver, with a video bandwidth of 4.2 MHz. The required R. F. bandwidth is found to be 19.8 MHz for fine quality and 13.8 MHz for passable quality.

2. Propagation Medium

Attenuation of the signal results due to a variety of factors in the propagation medium from satellite to earth.

(a) Free space loss depends on the frequency and the slant range. This may be expressed as follows:

$$L_{FS} = 92.5 + 20\log_{10}F + 20\log_{10}R_S \ .$$

where L_{FS} = Free space loss in dB.

F = Frequency in Hz.

R_S = Slant range in Km.

For synchronous satellite, the slant range is expressed in terms of α, the zenith angle of the ground antenna [13], as

$$R_S = 44{,}100 \ \frac{\sin[\alpha - \sin^{-1}(0.193\sin\alpha)]}{\sin\alpha}$$

(b) At the frequencies of interest, viz 2.5 GHz and 12 GHz, the ionospheric effects are of no significance [14].

(c) The effects of atmosphere on the signal are discussed in [15]. They may be summarized by the following equations.

(i) Attenuation due to oxygen and water vapor.

$$A_1(F) = 1.4 + 0.09\text{x}10^{-9}F - 1.6\exp(-2.1\text{x}10^{-9}\text{x}F)$$

$$\therefore\ A_2(r) = 1-\exp(-0.0054\frac{20}{\sin\theta})$$

$$A_3(\theta) = \exp(-10\theta)$$

and $A_g = A_1(F) \cdot A_2(r) \cdot A_3(\theta)$

where A_g = total attenuation due to oxygen and water vapor in dB.

$A_1(F)$ = frequency dependent component of A_g.

$A_2(r)$ = component of A_g dependent on length of ray path

$A_3(\theta)$ = component of A_g dependent on elevation angle

F = frequency in Hz.

θ = elevation angle in radians.

(ii) Attenuation due to clouds and fog is given by the following:

$$A_C = k\rho r$$

where A_C = attenuation in dB

k = coefficient in dB/km/gm/m^3.

ρ = liquid water content (0.3 gm/m^3)

$r = \frac{6}{\sin\theta}$ (vertical cloud distance is assumed as 6km for temperate regions)

(iii) Attenuation due to precipitation may be expressed as follows:

$$A_p = qpR$$

where A_p = attenuation due to precipitation in dB.

q = coefficient (assumed 1×10^{-4} for 2.5GHz and 3×10^{-2} for 12GHz)

p = rainfall rate in mm/hr. (assume 10mm/hr)

and R is determined as follows:

Assuming that constant rainfall state of 10mm/hr. over a hypothetical area, the linear extent of that area may be obtained as,

$$E = 41.4 - 23.5\log_{10}p = 17.9\text{Km}.$$

Further, the height at which the precipitation begins in temperate zones may be taken as 3km and the length of the ray path is then $(\frac{3}{\sin\theta})$.

Then R is taken to be the smaller of the two values $(\frac{17.9}{\cos\theta})$ and $(\frac{3}{\sin\theta})$.

The total attenuation in the propagation medium is then the sum of all of the above factors. This is computed for frequencies 2.5GHz and 12GHz, and for elevation angles of 90°, 70°, 50°, 30°, and 10°.

3. Transmitter R. F. Power

The value of satellite transmitter R. F. power required per video channel at 2.5GHz and at 12GHz is computed as shown in the Tables 13 and 14, for the five elevation angles. The assumptions made in these computations are:

(1) Fine quality picture (TASO 2) at the edge of earth coverage area.

(2) Receiver system noise temperature of 800°k for 2.5GHz, for an adapter with preamplification by one bipolar transistor stage, and 1300°k for 12GHz assuming the noise figure attainable by 1975 to be 7 dB for a dual mixer with Schottky-barrier diodes in the receiver adapter, without R. F. preamplifier.

(3) Half-power beamwidth of 3° for the satellite transmitting antenna.

(4) Parabolic receiver antenna of 1 meter diameter, at the top of building.

(5) Uplink noise of 0.3 dB.

(6) Polarization loss of 0.5 dB.

(7) Circuit losses of 1.5 dB.

(8) Satellite antenna on-axis gain of 35 dB.

From the results, it may be seen that at 2.5 GHz, the required peak transmitter power is of the order of 310 watts/video channel, in most of the cases. For 12 GHz transmission, this is found to be about 700-750 watts/video channel.

Table 13. FM Broadcasting at 2.5 GHz
Transmitter Power Per Video-Channel.

			Elevation Angle in Degrees				
		Unit	90°	70°	50°	30°	10°
(i)	Required C/T for Fine Quality (TASO 2) Picture.	dBw/°K	-139.6	-139.6	-139.6	-139.6	-139.6
(ii)	Receiver System Noise Temp. (800°K).	dBw/°K	-29.0	-29.0	-29.0	-29.0	-29.0
(iii)	Uplink Noise. (dB)	dB	-0.3	-0.3	-0.3	-0.3	-0.3
(iv)	Power to be Received (i)-(ii)-(iii).	dBw	-110.3	-110.3	-110.3	-110.3	-110.3
(v)	Receiver Antenna Gain (1m).	dB	+25.8	+25.8	+25.8	+25.8	+25.8
(vi)	Required Flux. (iv)-(v).	dBw/m^2	-136.1	-136.1	-136.1	-136.1	-136.1
(vii)	Total Propagation Losses.	dB	-191.02	-191.02	-191.03	-191.04	-191.25
(viii)	Polarization Loss.	dB	-0.5	-0.5	-0.5	-0.5	-0.5
(ix)	Required e.i.r.p. at Beam Edge (vi)-(vii)-(viii).	dBw	+55.42	+55.42	+55.43	+56.44	+56.65
(x)	Satellite Antenna Gain at Beam Edge.	dB	+32	+32	+32	+32	+32
(xi)	Circuit Losses	dB	-1.5	-1.5	-1.5	-1.5	-1.5
(xii)	Required Peak Transmitter Power. (ix)-(x)-(xi)	dBw	+24.92	+24.92	+24.93	+25.94	+26.15
(xiii)	Required Peak Transmitter Power.	Watts	310	310	312	392	412
(xiv)	Area of Earth Coverage.	Million Sq. Miles	1.0	1.03	1.30	2.0	5.6

Table 14. FM Broadcasting at 12 GHz.
Transmitter Power/Video Channel.

		0=90°	70°	50°	30°	10°
(i)	Required C/T For Fine Quality Picture (TASO 2) (dBw/°K)	-139.6	-139.6	-139.6	-139.6	-139.6
(ii)	Receiver System Noise Temp. (1300°K). (dBw/°K)	-31.1	-31.1	-31.1	-31.1	-31.1
(iii)	Uplink Noise. (dB)	-0.3	-0.3	-0.3	-0.3	-0.3
(iv)	Power to be Received. (dBw)	-108.2	-108.2	-108.2	-108.2	-108.2
(v)	Receiver Antenna Gain (1m). (dB)	+39.5	+39.5	+39.5	+39.5	+39.5
(vi)	Required Flux (dBw/m^2)	-147.7	-147.7	-147.7	-147.7	-147.7
(vii)	Total Propagation Loss. (dB)	-206.13	-206.21	-206.48	-208.27	-212.73
(viii)	Polarization Loss. (dB)	-0.5	-0.5	-0.5	-0.5	-0.5
(ix)	Required e.r.i.p. at Beam Edge. (dBw)	+58.93	+59.01	+59.28	+61.07	+65.53
(x)	Satellite Aerial Gain at Beam Edge. (dB)	+32	+32	+32	+32	+32
(xi)	Circuit Losses. (dB)	-1.5	-1.5	-1.5	-1.5	-1.5
(xii)	Required Peak Transmitter Power (dBw)	+28.43	+28.51	+28.78	+30.57	35.03 dB
(xiii)	Required Peak Transmitter Power (Watts) (Watts)	697	710	755	1140	3184
(xiv)	Coverage (Million Square Miles)	1.0	1.03	1.30	2.0	5.6

VII. State-of-the-Art of Components

In order to assess the present and future state-of-the-art of system components for TVBS, questionnaires were sent to about 75 leading manufacturers of system components for space communications.

The format of the questionnaires are included in the appendix. Although most of them replied, very few were able to given the type of information required. After careful study of these, all important information with regard to the state-of-the-art of R. F. amplifiers, solar cells, solar arrays, and nickel cadmium batteries is compiled in the following tables.

Tables 15 and 18 give parameters of space qualified RF amplifiers that are being manufactured by four firms. In order to arrive at a relationship between weight and power output of these amplifiers for different frequency ranges, typical values are plotted in Figures 10 and 11. These reveal that in the extremely low power range from 1 - 10 watt, the Litton TWT's in the 8 - 12 GHZ range have a favorable power to weight ratio. At power outputs of 20 - 100 watts, Litton Klystrons operating in the 1 - 4GHZ range present good power to weight ratios. Good power-to-weight-ratios for all power outputs above 100 watts are obtained with Sperry and Varian TWT's and Klystron's operating in the 8 - 12GHZ range.

Tables 19 and 20 indicate the present and future state-of-the-art of solar cells as furnished by the manufactures. Similarly Tables 21 and 22, give solar cell array data. Finally information about nickel cadmium battery is given in Tables 23 and 24.

TABLE 15

RF AMP PARAMETERS VS POWER

POWER (WATTS)	FREQ RANGE (GHZ)	GAIN (DB)	WEIGHT (LBS)	COMPANY	PART NO	TYPE
1.	7.0-11.0	30.0	1.5	LITTON IND	L-5045	TWT
1.	8.2-10.0	60.0	1.5	LITTON IND	L-3972	TWT
1.	8.0-14.0	35.0	1.2	LITTON IND	L-5339	TWT
1.	1.0- 2.0	30.0	0.0	KELTEC	LR600-1	TWT
2.	7.0-11.0	36.0	1.5	LITTON IND	L-3998	TWT
2.	8.0-12.0	36.0	1.5	LITTON IND	L-5008	TWT
2.	8.0-14.0	65.0	1.5	LITTON IND	L-5322	TWT
2.	12.4-18.0	35.0	2.0	LITTON IND	L-5227	TWT
2.	5.4-11.0	60.0	1.5	LITTON IND	L-3957	TWT
10.	7.0-11.0	40.0	2.5	LITTON IND	L-3928	TWT
10.	7.0-11.0	60.0	2.5	LITTON IND	L-5043	TWT
10.	7.0-12.0	40.0	2.0	LITTON IND	L-5293	TWT
10.	1.0- 2.0	30.0	3.0	LITTON IND	L-5036	TWT
10.	2.0- 4.0	33.0	2.5	LITTON IND	L-5010	TWT
10.	3.7- 6.5	36.0	2.5	LITTON IND	L-5134	TWT
10.	4.0- 8.0	33.0	2.5	LITTON IND	L-5011	TWT
10.	1.7- 2.7	30.0	3.5	LITTON IND	L-5225	TWT
20.	2.3- 2.3	20.0	2.6	LITTON IND	L3910B	KLY
20.	1.0- 2.0	30.0	3.5	LITTON IND	L-5155	TWT
20.	4.0- 8.0	33.0	3.5	LITTON IND	L-5083	TWT
20.	2.0- 4.0	33.0	3.0	LITTON IND	L-5160	TWT
70.	12.4-18.0	33.0	7.0	SPERRY	STU-54312	TWT
100.	2.3- 2.3	29.0	5.0	LITTON IND	L-5044	KLY
100.	7.0-13.0	43.0	7.0	SPERRY	STX-5225	TWT

TABLE 15 (Cont'd)

POWER (WATTS)	FREQ RANGE (GHZ)	GAIN (DB)	WEIGHT (LBS)	COMPANY	PART NO	TYPE
100.	14.5-15.5	35.0	7.0	SPERRY	STU-52271	TWT
125.	7.0-12.0	33.0	6.0	SPERRY	STX-5224	TWT
125.	8.0-14.0	40.0	7.0	SPERRY	STX-52270	TWT
200.	2.6- 5.2	40.0	10.0	LITTON IND	L-5323	TWT
200.	5.0-10.0	40.0	7.0	LITTON IND	L-5324	TWT
200.	7.0-11.0	40.0	8.0	LITTON IND	L-5280	TWT
200.	7.4-11.0	36.0	6.0	SPERRY	STX-5220	TWT
200.	7.0-11.0	40.0	6.0	SPERRY	STX-5222	TWT
200.	7.0-11.0	38.0	7.0	SPERRY	STX-52260	TWT
200.	7.0-13.0	43.0	7.0	SPERRY	STX-52251	TWT
200.	7.0-13.0	40.0	7.0	SPERRY	STX-52261	TWT
250.	2.5- 2.7	29.0	11.0	LITTON IND	L5109	KLY
250.	2.0- 4.0	40.0	10.0	LITTON IND	L-5281	TWT
400.	8.0-12.0	42.0	12.0	SPERRY	STX-54400	TWT
500.	7.9- 8.4	48.0	16.0	VARIAN	VA-914	KLY
1000.	2.3- 2.3	30.0	12.0	LITTON IND	L-5101	KLY
1100.	5.9- 6.4	46.0	55.0	VARIAN	VA-936C	KLY
1200.	2.7- 2.8	30.0	35.0	LITTON IND	L3668H	KLY
3000.	5.9- 6.4	43.0	22.0	VARIAN	VA-9368	KLY
5200.	5.9- 6.4	47.1	18.0	VARIAN	VA-936A	KLY
8000.	3.1- 3.5	48.0	120.0	SPERRY	SAS5310	KLY

TABLE 16

RFAMP PARAMETERS VS FREQUENCY

POWER (WATTS)	FREQ RANGE (GHZ)	GAIN (DB)	WEIGHT (LBS)	COMPANY	PART NO	TYPE
1.	1.0- 2.0	30.0	0.0	KELTEC	LR600-1	TWT
10.	1.0- 2.0	30.0	3.0	LITTON IND	L-5036	TWT
20.	1.0- 2.0	30.0	3.5	LITTON IND	L-5155	TWT
10.	1.7- 2.7	30.0	3.5	LITTON IND	L-5225	TWT
20.	2.3- 2.3	20.0	2.6	LITTON IND	L3910B	KLY
100.	2.3- 2.3	29.0	5.0	LITTON IND	L-5044	KLY
1000.	2.3- 2.3	30.0	12.0	LITTON IND	L-5101	KLY
250.	2.5- 2.7	29.0	11.0	LITTON IND	L5109	KLY
1200.	2.7- 2.8	30.0	35.0	LITTON IND	L3668H	KLY
10.	2.0- 4.0	33.0	2.5	LITTON IND	L-5010	TWT
20.	2.0- 4.0	33.0	3.0	LITTON IND	L-5160	TWT
250.	2.0- 4.0	40.0	10.0	LITTON IND	L-5281	TWT
8000.	3.1- 3.5	48.0	120.0	SPERRY	SAS5310	KLY
200.	2.6- 5.2	40.0	10.0	LITTON IND	L-5323	TWT
10.	3.7- 6.5	36.0	2.5	LITTON IND	L-5134	TWT
10.	4.0- 8.0	33.0	2.5	LITTON IND	L-5011	TWT
20.	4.0- 8.0	33.0	3.5	LITTON IND	L-5083	TWT
1100.	5.9- 6.4	46.0	55.0	VARIAN	VA-936C	KLY
3000.	5.9- 6.4	43.0	22.0	VARIAN	VA-936B	KLY
5200.	5.9- 6.4	47.1	18.0	VARIAN	VA-936A	KLY
200.	5.0-10.0	40.0	7.0	LITTON IND	L-5324	TWT
500.	7.9- 8.4	48.0	16.0	VARIAN	VA-914	KLY
2.	5.4-11.0	60.0	1.5	LITTON IND	L-3957	TWT
1.	7.0-11.0	30.0	1.5	LITTON IND	L-5045	TWT

TABLE 16 (Cont'd)

POWER (WATTS)	FREQ RANGE (GHZ)	GAIN (DB)	WEIGHT (LBS)	COMPANY	PART NO	TYPE
2.	7.0-11.0	36.0	1.5	LITTON IND	L-3998	TWT
10.	7.0-11.0	40.0	2.5	LITTON IND	L-3928	TWT
10.	7.0-11.0	60.0	2.5	LITTON IND	L-5043	TWT
200.	7.0-11.0	40.0	8.0	LITTON IND	L-5280	TWT
200.	7.0-11.0	40.0	6.0	SPERRY	STX-5222	TWT
200.	7.0-11.0	38.0	7.0	SPERRY	STX-52260	TWT
1.	8.2-10.0	60.0	1.5	LITTON IND	L-3972	TWT
200.	7.4-11.0	36.0	6.0	SPERRY	STX-5220	TWT
10.	7.0-12.0	40.0	2.0	LITTON IND	L-5293	TWT
125.	7.0-12.0	33.0	6.0	SPERRY	STX-5224	TWT
2.	8.0-12.0	36.0	1.5	LITTON IND	L-5008	TWT
100.	7.0-13.0	43.0	7.0	SPERRY	STX-5225	TWT
200.	7.0-13.0	43.0	7.0	SPERRY	STX-52251	TWT
200.	7.0-13.0	40.0	7.0	SPERRY	STX-52261	TWT
400.	8.0-12.0	42.0	12.0	SPERRY	STX-54400	TWT
1.	8.0-14.0	35.0	1.2	LITTON IND	L-5339	TWT
2.	8.0-14.0	65.0	1.5	LITTON IND	L-5322	TWT
125.	8.0-14.0	40.0	7.0	SPERRY	STX-52270	TWT
100.	14.5-15.5	35.0	7.0	SPERRY	STU-52271	TWT
2.	12.4-18.0	35.0	2.0	LITTON IND	L-5227	TWT
70.	12.4-18.0	33.0	7.0	SPERRY	STU-54312	TWT

TABLE 17

RFAMP PARAMETERS VS GAIN

POWER (WATTS)	FREQ RANGE (GHZ)	GAIN (DB)	WEIGHT (LBS)	COMPANY	PART NO	TYPE
20.	2.3- 2.3	20.0	2.6	VARIAN	VA-936C	KLY
100.	2.3- 2.3	29.0	5.0	LITTON IND	L-3957	TWT
250.	2.5- 2.7	29.0	11.0	SPERRY	STX-5225	TWT
1.	7.0-11.0	30.0	1.5	KELTEC	LR600-1	TWT
1.	1.0- 2.0	30.0	0.0	LITTON IND	L-5225	TWT
10.	1.0- 2.0	30.0	3.0	SPERRY	SAS5310	KLY
10.	1.7- 2.7	30.0	3.5	LITTON IND	L-5083	TWT
20.	1.0- 2.0	30.0	3.5	VARIAN	VA-936B	KLY
1000.	2.3- 2.3	30.0	12.0	LITTON IND	L-5339	TWT
1200.	2.7- 2.8	30.0	35.0	SPERRY	STX-52270	TWT
10.	2.0- 4.0	33.0	2.5	LITTON IND	L-5323	TWT
10.	4.0- 8.0	33.0	2.5	LITTON IND	L-5011	TWT
20.	4.0- 8.0	33.0	3.5	VARIAN	VA-936A	KLY
20.	2.0- 4.0	33.0	3.0	LITTON IND	L-5324	TWT
70.	12.4-18.0	33.0	7.0	VARIAN	VA-914	KLY
125.	7.0-12.0	33.0	6.0	LITTON IND	L-3928	TWT
1.	8.0-14.0	35.0	1.2	LITTON IND	L-5155	TWT
2.	12.4-18.0	35.0	2.0	LITTON IND	L5109	KLY
100.	14.5-15.5	35.0	7.0	LITTON IND	L-3998	TWT
2.	7.0-11.0	36.0	1.5	LITTON IND	L3910B	KLY
2.	8.0-12.0	36.0	1.5	LITTON IND	L-5044	KLY
10.	3.7- 6.5	36.0	2.5	LITTON IND	L-5134	TWT
200.	7.4-11.0	36.0	6.0	LITTON IND	L-3972	TWT
200.	7.0-11.0	38.0	7.0	LITTON IND	L-5293	TWT

TABLE 17 (Cont'd)

POWER (WATTS)	FREQ RANGE (GHZ)	GAIN (DB)	WEIGHT (LBS)	COMPANY	PART NO	TYPE
10.	7.0-11.0	40.0	2.5	LITTON IND	L-5010	TWT
10.	7.0-12.0	40.0	2.0	LITTON IND	L-5281	TWT
125.	8.0-14.0	40.0	7.0	LITTON IND	L-5043	TWT
200.	2.6- 5.2	40.0	10.0	LITTON IND	L-5280	TWT
200.	5.0-10.0	40.0	7.0	SPERRY	STX-5222	TWT
200.	7.0-11.0	40.0	8.0	SPERRY	STX-52260	TWT
200.	7.0-11.0	40.0	6.0	SPERRY	STX-5220	TWT
200.	7.0-13.0	40.0	7.0	LITTON IND	L-5008	TWT
250.	2.0- 4.0	40.0	10.0	SPERRY	STX-52251	TWT
400.	8.0-12.0	42.0	12.0	SPERRY	STX-52261	TWT
100.	7.0-13.0	43.0	7.0	LITTON IND	L-5045	TWT
200.	7.0-13.0	43.0	7.0	SPERRY	STX-5224	TWT
3000.	5.9- 6.4	43.0	22.0	SPERRY	STU-52271	TWT
1100.	5.9- 6.4	46.0	55.0	LITTON IND	L-5322	TWT
5200.	5.9- 6.4	47.1	18.0	LITTON IND	L-5227	TWT
500.	7.9- 8.4	48.0	16.0	SPERRY	STX-54400	TWT
8000.	3.1- 3.5	48.0	120.0	SPERRY	STU-54312	TWT
1.	8.2-10.0	60.0	1.5	LITTON IND	L-5036	TWT
2.	5.4-11.0	60.0	1.5	LITTON IND	L3668H	KLY
10.	7.0-11.0	60.0	2.5	LITTON IND	L-5160	TWT
2.	8.0-14.0	65.0	1.5	LITTON IND	L-5101	KLY

TABLE 18

RFAMP PARAMETERS VS WEIGHT

POWER (WATTS)	FREQ RANGE (GHZ)	GAIN (DB)	WEIGHT (LBS)	COMPANY	PART NO	TYPE
1.	1.0- 2.0	30.0	0.0	LITTON IND	L-5225	TWT
1.	8.0-14.0	35.0	1.2	LITTON IND	L-5155	TWT
1.	7.0-11.0	30.0	1.5	KELTEC	LR600-1	TWT
2.	7.0-11.0	36.0	1.5	LITTON IND	L3910B	KLY
2.	8.0-12.0	36.0	1.5	LITTON IND	L-5044	KLY
1.	8.2-10.0	60.0	1.5	LITTON IND	L-5036	TWT
2.	5.4-11.0	60.0	1.5	LITTON IND	L3668H	KLY
2.	8.0-14.0	65.0	1.5	LITTON IND	L-5101	KLY
2.	12.4-18.0	35.0	2.0	LITTON IND	L5109	KLY
10.	7.0-12.0	40.0	2.0	LITTON IND	L-5281	TWT
10.	2.0- 4.0	33.0	2.5	LITTON IND	L-5323	TWT
10.	4.0- 8.0	33.0	2.5	LITTON IND	L-5011	TWT
10.	3.7- 6.5	36.0	2.5	LITTON IND	L-5134	TWT
10.	7.0-11.0	40.0	2.5	LITTON IND	L-5010	TWT
10.	7.0-11.0	60.0	2.5	LITTON IND	L-5160	TWT
20.	2.3- 2.3	20.0	2.6	VARIAN	VA-936C	KLY
10.	1.0- 2.0	30.0	3.0	SPERRY	SAS5310	KLY
20.	2.0- 4.0	33.0	3.0	LITTON IND	L-5324	TWT
10.	1.7- 2.7	30.0	3.5	LITTON IND	L-5083	TWT
20.	1.0- 2.0	30.0	3.5	VARIAN	VA-936B	KLY
20.	4.0- 8.0	33.0	3.5	VARIAN	VA-936A	KLY
100.	2.3- 2.3	29.0	5.0	LITTON IND	L-3957	TWT
125.	7.0-12.0	33.0	6.0	LITTON IND	L-3928	TWT
200.	7.4-11.0	36.0	6.0	LITTON IND	L-3972	TWT

TABLE 18 (Cont'd)

POWER (WATTS)	FREQ RANGE (GHZ)	GAIN (DB)	WEIGHT (LBS)	COMPANY	PART NO	TYPE
200.	7.0-11.0	40.0	6.0	SPERRY	STX-5220	TWT
70.	12.4-18.0	33.0	7.0	VARIAN	VA-914	KLY
100.	14.5-15.5	35.0	7.0	LITTON IND	L-3998	TWT
200.	7.0-11.0	38.0	7.0	LITTON IND	L-5293	TWT
125.	8.0-14.0	40.0	7.0	LITTON IND	L-5043	TWT
200.	5.0-10.0	40.0	7.0	SPERRY	STX-5222	TWT
200.	7.0-13.0	40.0	7.0	LITTON IND	L-5008	TWT
100.	7.0-13.0	43.0	7.0	LITTON IND	L-5045	TWT
200.	7.0-13.0	43.0	7.0	SPERRY	STX-5224	TWT
200.	7.0-11.0	40.0	8.0	SPERRY	STX-52260	TWT
200.	2.6- 5.2	40.0	10.0	LITTON IND	L-5280	TWT
250.	2.0- 4.0	40.0	10.0	SPERRY	STX-52251	TWT
250.	2.5- 2.7	29.0	11.0	SPERRY	STX-5225	TWT
1000.	2.3- 2.3	30.0	12.0	LITTON IND	L-5339	TWT
400.	8.0-12.0	42.0	12.0	SPERRY	STX-52261	TWT
500.	7.9- 8.4	48.0	16.0	SPERRY	STX-54400	TWT
5200.	5.9- 6.4	47.1	18.0	LITTON IND	L-5227	TWT
3000.	5.9- 6.4	43.0	22.0	SPERRY	STU-52271	TWT
1200.	2.7- 2.8	30.0	35.0	SPERRY	STX-52270	TWT
1100.	5.9- 6.4	46.0	55.0	LITTON IND	L-5322	TWT
8000.	3.1- 3.5	48.0	120.0	SPERRY	STU-54312	TWT

Figure 10. RF Amplifier Weight Vs Power.

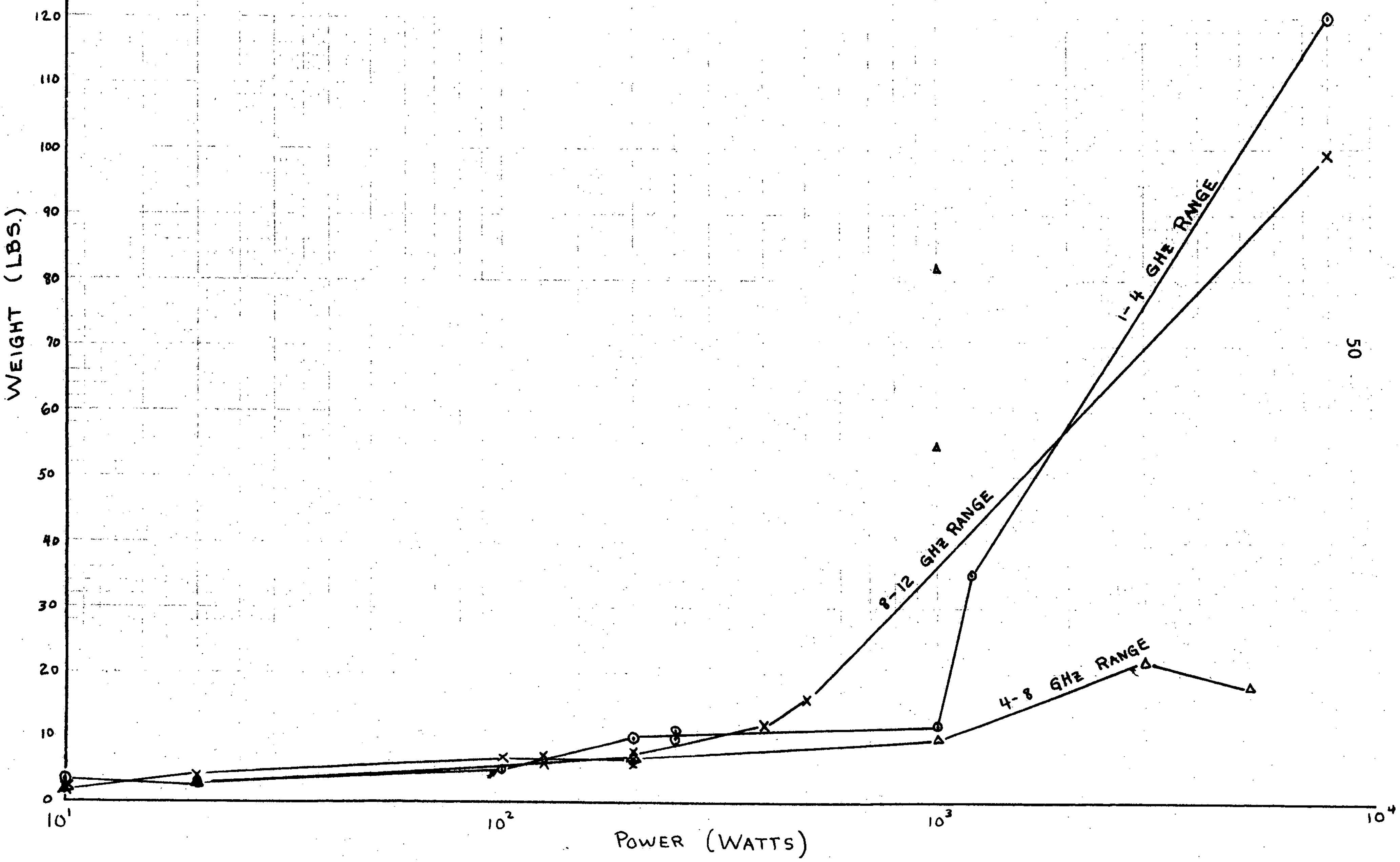


Figure 11. RF Amplifier Weight Vs Power.

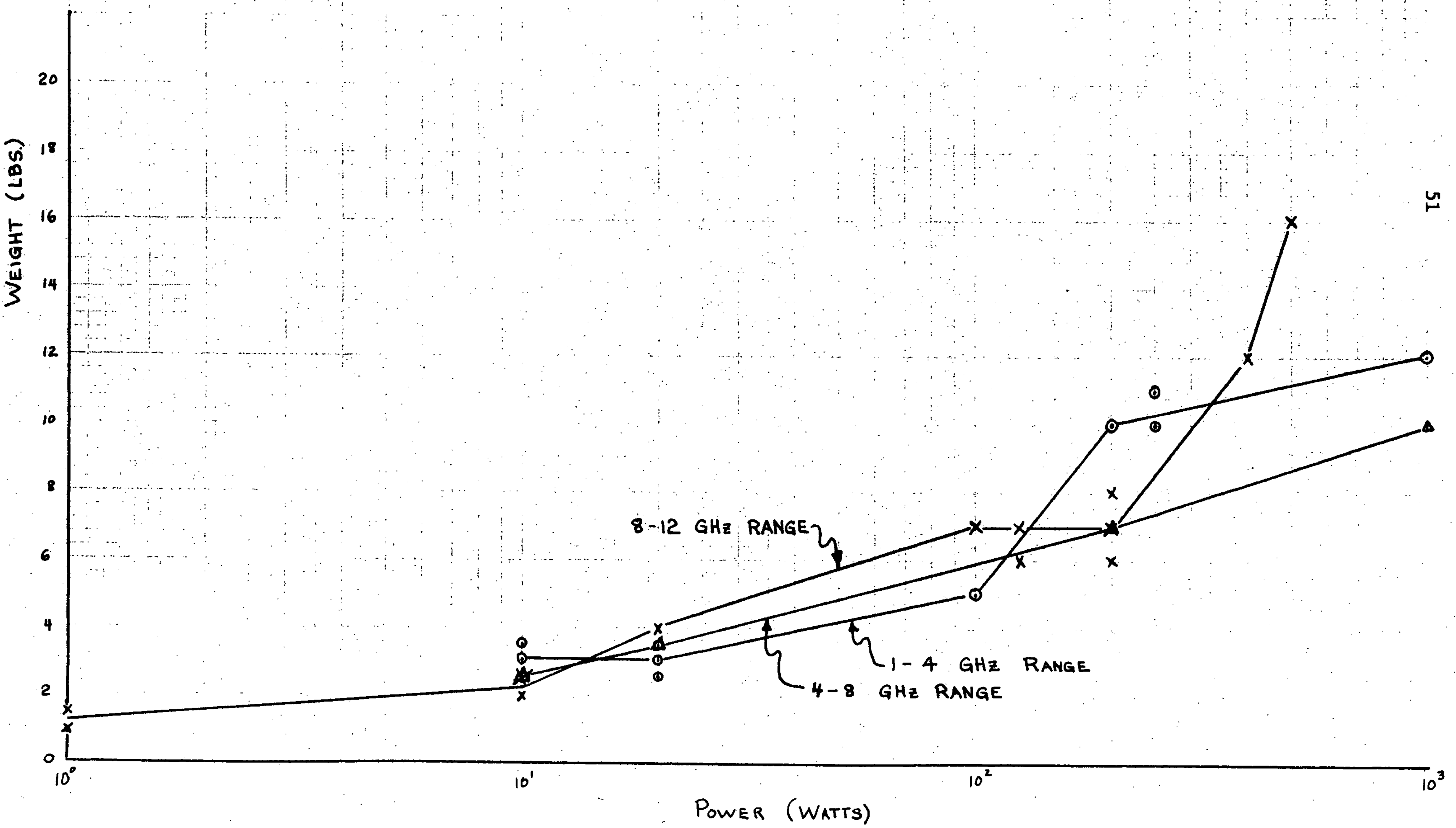


TABLE 19

Subject: SOLAR CELLS

INTERPRETATION OF BOEING COMPANY DATA

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART						
TYPE OF CELLS	SIZE	THICKNESS	EFFICIENCY	POWER/CELL	CELLS/KW	COST/KW
CADMIUM SULFIDE	3" x 3"	0.007"	2% UNKNOWN*	180MW UNKNOWN*	5550 UNKNOWN*	EXPERIMENTAL ONLY COST NOT ESTABLISHED
SILICON	1 x 2 cm 2 x 2 cm 2 x 4 cm 2 x 6 cm 2 x 8 cm	0.004" to 0.020" AVG.	9.5% to 10.5% AVG. @ STD. COND. 12% AVG.**	VARIABLE BY SIZE	VARIES GREATLY WITH CONFIG. DEGRAT, ETC. FOR FLAT EXTENDED PANEL @ 55°C 200-220/SQ.FT.	VARIES GREATLY WITH CONFIG, DEGRAD ETC.
					i.e. 2000-2200 /KW 2 x 2 cm cells	
					BODY MOUNTED CELLS WOULD BE LESS EFFICIENT BECAUSE OF THE LARGER NO. OF CELLS REQUIRED	

COMMENTS: *Cds technology has been discontinued in the industry - inadequate efficiency

**Technology work directed to improving solar cell efficiency

TABLE 20

Subject: SOLAR CELLS

INTERPRETATION OF FAIRCHILD INDUSTRIES DATA

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART						
TYPE OF CELLS	SIZE	THICKNESS	EFFICIENCY	POWER/CELL	CELLS/KW	COST/KW
ATS - SILICON, N ON P, F&G SILVER - TITANIUM CONTACTS, THIN-PRESSED SOLDER	2 x 4 cm (0.788 x 1.591 x 0.014 inch)	0.014 inch NOM.	11.0% AMO, IAU, 28°C	117.8 MW at 28°C	8500	$43,200
<u>COVERSLIDES</u> CORNING 0211 MICROSHEET	TO MATCH 2x4cm CELL (0.748 x 1.591 x 0.006 inch)	0.006 inch, NOM.			COVERSLIDES/KW 8500	$14,200

COMMENTS: The attachment, taken from Lockheed's LMSC-A981486, December 1970, is a good general summary of the future state-of-the-art and current development programs.

TABLE 21

Subject: SOLAR CELL ARRAYS

INTERPRETATION OF THE BOEING COMPANY DATA

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART						
	WEIGHT (lbs/kw)					
TYPE OF CELL	CELLS	ELECTRIC MISC.	STRUCTURE	TOTAL	POWER TO AREA RATIO (W/Ft^2)	POWER TO WEIGHT RATIO (W/lb)
SILICON	2 x 2 cm x 12 MIL + 6 MIL GLASS 18 lbs/KW	2.5 lbs/KW	ALUMINUM HONEYCOMB 79.5 lbs/KW	100 lbs/KW	TEMP 55°C FLAT EXTENDED PANEL 10 W/SQ. FT. AT BEGINNING OF LIFE.	HONEYCOMB SUBSTRATE FLAT, EXTENDED PANEL 10 W/LB AVG. AT BEGINNING OF LIFE.
SILICON	2 x 2 cm x 8 MIL + 3 MIL GLASS 552 lbs = 11 $\frac{\text{lbs}}{\text{KW}}$	124 lbs = 2.5 lbs/KW	1606 lbs = 30.5 lbs/KW incl. MECHANISMS.	* ≈ 44 lbs/KW	TEMP 55°C FLAT EXTENDED PANEL 10 W SQ. FT. AT BEGINNING OF LIFE	LIGHTWEIGHT FIBERGLASS SUBSTRATE BERYLLIUM FRAME > W/LB AT BEGINNING OF LIFE

COMMENTS: We have had no experience to date on lighter weight (Kapton) substrates such as for roll up and foldout arrays. *Developed in the large area solar array contract for JPL. (#951653) 59 KW array.

Subject: SOLAR ARRAYS

TABLE 22

INTERPRETATION FAIRCHILD INDUSTRIES DATA

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART						
	WEIGHT (lbs/kw)					
TYPE OF CELLS	CELLS	ELECTRIC MISC.	STRUCTURE*	TOTAL	POWER TO AREA RATIO (W/Ft^2)	POWER TO WEIGHT RATIO (W/lb)
ATS-F 2 x 4 cm N ON P 14 MIL, THIN-PRESSED SOLDER	EQUINOX 0 YEARS: 62	44	232	233	2.98	2.86
	SUMMER SOLSTICE 5 YEARS: 97	68	364	529	1.91	1.90
FUTURE 2 x 4 xm N ON P 8 MIL	EQUINOX 0 YEARS: 35	34	6	75	2.98	13.3

COMMENTS: *Does not include deployment mechanism or panel support beams.

TABLE 23

Subject: NICKEL CADMIUM BATTERY SPECIFICATIONS INTERPRETATION OF BOEING COMPANY DATA

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART

LOAD REQUIREMENTS (WATTS)	BATTERY CAPACITY (A-HR)	BATTERY WEIGHT (lbs)	BATTERY VOLUME (IN^3)
0 - 200	UP TO 16 A-HRS FOR 25 VOLTS SYSTEMS	40 LBS. 35 LBS.	340 in^3 300 in^3
200 - 400	UP TO 32 A-HRS.	76 LBS. 68 LBS.	650 in^3 585 in^3
400 - 600	UP TO 48 A-HRS.	108 LBS. 97 LBS.	920 in^3 830 in^3
600 - 800	UP TO 64 A-HRS (TWO OF 32 A-HRS SIZE)	152 LBS. 137 LBS.	1290 in^3 1180 in^3
800 - 1000	UP TO 100 A-HRS (TWO OF 50 A-HRS SIZE)	215 LBS. 194 LBS.	1830 in^3 1670 in^3

COMMENTS: These values are for sealed cells only. System parameters assumed were 25% max depth of discharge, cycling for less than 2 years. Information is based on the 'user' point of view

TABLE 24

Subject: NICKEL CADMIUM BATTERY SPECIFICATIONS INTERPRETATION OF FAIRCHILD INDUSTRIES DATA

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART			
LOAD REQUIREMENTS (WATTS)	BATTERY CAPACITY (A-HR)	BATTERY WEIGHT (lbs)	BATTERY VOLUME (IN^3)
0 - 200			
ATS-F 208 W CONDITIONED OUTPUT POWER 200 - 400	(2) 15 AHR BATTERIES 19 CELLS/BATTERY NOMINAL STORED ENERGY: 342 WHR/BATTERY	76 (TOTAL, 2 BATTERIES)	1152 (TOTAL, 2 BATTERIES)
400 - 600			
600 - 800			
800 - 1000			

COMMENTS: 50 AHR cells represent the practical limit of the state-of-the-art. 100 AHR cells, not presently made in production quantities for aerospace applications, have thermal problmes: when large cells are packaged together these problems become severe.

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APPENDIX

PROGRAM FOR FIGURE 1

```
C     SPACCI ANTENNA WT VS FREQUENCY
      DIMENSION YLA(10),YLB(10),YLC(10),YLD(10),YLE(10),YLF(10),
     1 YLG(10),YLH(10),F(10)
      CALL PLOT (4.0,3.0,-3)
      S=22000*1760*3
      AS=3.1416*(500*1760*3)**2.
      C=(3.*3.281)*10**8
      WRITE(6,1)
    1 FORMAT('1',/,'-',10X,'ANTENNA WEIGHT VS FREQ FOR EIGHT ANTENNA
     1GHT FACTORS')
      PRINT10
   10 FORMAT ('-',10X,'F',6X,'YLA',5X,'YLB',5X,'YLC',5X,'YLD',5X,
     1 'YLE',5X,'YLF',5X,'YLG',5X,'YLH')
      READ(5,3000)N1
 3000 FORMAT(I10)
      N2=N1+1
      N3=N1+2
      DO 100 I=1,N1
      F(I)=FLOAT(I+1)*3.5/FLOAT(N1)
      YLA(I)=0.04/AS*((C*S/F(I))**2)*10.**(-18)
      YLB(I)=0.10/AS*((C*S/F(I))**2)*10.**(-18)
      YLC(I)=0.13/AS*((C*S/F(I))**2)*10.**(-18)
      YLD(I)=0.20/AS*((C*S/F(I))**2)*10.**(-18)
      YLE(I)=0.25/AS*((C*S/F(I))**2)*10.**(-18)
      YLF(I)=0.31/AS*((C*S/F(I))**2)*10.**(-18)
      YLG(I)=0.56/AS*((C*S/F(I))**2)*10.**(-18)
      YLH(I)=0.635/AS*((C*S/F(I))**2)*10.**(-18)
  100 WRITE(6,30)F(I),YLA(I),YLB(I),YLC(I),YLD(I),YLE(I),YLF(I),
     1YLG(I),YLH(I)
   30 FORMAT('0',9X,F3.1,8F8.2)
      CALL SCALE (F,5.,N1,1)
      YLA(N2)=0.0
      YLA(N3)=100.0
      YLB(N2)=YLA(N2)
      YLB(N3)=YLA(N3)
      YLC(N2)=YLA(N2)
      YLC(N3)=YLA(N3)
      YLD(N2)=YLA(N2)
      YLD(N3)=YLA(N3)
      YLE(N2)=YLA(N2)
      YLE(N3)=YLA(N3)
      YLF(N2)=YLA(N2)
      YLF(N3)=YLA(N3)
      YLG(N2)=YLA(N2)
      YLG(N3)=YLA(N3)
      YLH(N2)=YLA(N2)
      YLH(N3)=YLA(N3)
      CALL AXIS (0.,0.,'FREQUENCY IN GHZ',-16,5.0,0.,F(N2),F(N3))
      CALL AXIS (0.,0.,'WEIGHT IN LBS',13,5.,90.,YLA(N2),YLA(N3))
      CALL LINE (F,YLA,N1,1,1,0)
      CALL LINE (F,YLB,N1,1,1,1)
      CALL LINE (F,YLC,N1,1,1,2)
      CALL LINE (F,YLD,N1,1,1,3)
      CALL LINE (F,YLE,N1,1,1,4)
      CALL LINE (F,YLF,N1,1,1,5)
      CALL LINE (F,YLG,N1,1,1,6)
      CALL LINE (F,YLH,N1,1,1,7)
      CALL SYMBOL(.1,-1.,.1,23HANTENNA WT VS FREQUENCY,0.0,23)
      CALL SYMBOL(.1,-1.3,.1,28HFOR EIGHT ANTENNA WT FACTORS,0.0,28)
      CALL PLOT (10.0,0.0,999)
      STOP
```

C

PROGRAM FOR FIGURE 2

```
C     SPACE4 ANTENNA WT VS FREQUENCY
      DIMENSION YLA(10),YLB(10),YLC(10),YLD(10),YLE(10),YLF(10),
     1 YLG(10),YLH(10),F(10)
      WRITE(6,1)
    1 FORMAT('1',/,'-',10X,'ANTENNA WEIGHT VS FREQ FOR EIGHT ANTENNA WEI
     1GHT FACTORS')
      CALL PLOT (4.0,3.0,-3)
      S=22000*1760*3
      AS=3.1416*(500*1760*3)**2.
      C=(3.*3.281)*10**8
      PRINT10
   10 FORMAT ('-',10X,'F',6X,'YLA',5X,'YLB',5X,'YLC',5X,'YLD',5X,
     1 'YLE',5X,'YLF',5X,'YLG',5X,'YLH')
      READ(5,3000)N1
 3000 FORMAT(I10)
      N2=N1+1
      N3=N1+2
      DO 100 I=1,N1
      F(I)=7.5+FLOAT(I)/2.
      YLA(I)=0.13/AS*((C*S/F(I))**2)*10.**(-18)
      YLB(I)=0.20/AS*((C*S/F(I))**2)*10.**(-18)
      YLC(I)=0.25/AS*((C*S/F(I))**2)*10.**(-18)
      YLD(I)=0.31/AS*((C*S/F(I))**2)*10.**(-18)
      YLE(I)=0.56/AS*((C*S/F(I))**2)*10.**(-18)
      YLF(I)=0.635/AS*((C*S/F(I))**2)*10.**(-18)
      YLG(I)=0.70/AS*((C*S/F(I))**2)*10.**(-18)
      YLH(I)=1.13/AS*((C*S/F(I))**2)*10.**(-18)
  100 WRITE(6,30)F(I),YLA(I),YLB(I),YLC(I),YLD(I),YLE(I),YLF(I),
     1YLG(I),YLH(I)
   30 FORMAT('0',9X,F3.1,8F8.2)
      CALL SCALE (F,5.,N1,1)
      YLA(N2)=0.0
      YLA(N3)=2.0
      YLB(N2)=YLA(N2)
      YLB(N3)=YLA(N3)
      YLC(N2)=YLA(N2)
      YLC(N3)=YLA(N3)
      YLD(N2)=YLA(N2)
      YLD(N3)=YLA(N3)
      YLE(N2)=YLA(N2)
      YLE(N3)=YLA(N3)
      YLF(N2)=YLA(N2)
      YLF(N3)=YLA(N3)
      YLG(N2)=YLA(N2)
      YLG(N3)=YLA(N3)
      YLH(N2)=YLA(N2)
      YLH(N3)=YLA(N3)
      CALL AXIS (0.,0.,'FREQUENCY IN GHZ',-16,5.0,0.,F(N2),F(N3))
      CALL AXIS (0.,0.,'WEIGHT IN LBS',13,5.,90.,YLA(N2),YLA(N3))
      CALL LINE (F,YLA,N1,1,1,0)
      CALL LINE (F,YLB,N1,1,1,1)
      CALL LINE (F,YLC,N1,1,1,2)
      CALL LINE (F,YLD,N1,1,1,3)
      CALL LINE (F,YLE,N1,1,1,4)
      CALL LINE (F,YLF,N1,1,1,5)
      CALL LINE (F,YLG,N1,1,1,6)
      CALL LINE (F,YLH,N1,1,1,7)
      CALL SYMBOL(.1,-1.,.1,23HANTENNA WT VS FREQUENCY,0.0,23)
      CALL SYMBOL(.1,-1.3,.1,28HFOR EIGHT ANTENNA WT FACTORS,0.0,28)
      CALL PLOT (10.0,0.0,999)
      STOP
      END
```

PROGRAM FOR FIGURE 3

```
C       SPACE 3 SOLAR CELL WEIGHT VS POWER
        DIMENSION WA(22),WB(22),WC(22),WD(22),WE(22),P(22)
        CALL PLOT (4.0,3.0,-3)
        WRITE(6,1)
     1  FORMAT('1',/,'-',25X,'SOLAR CELL WEIGHT VS POWER')
        PRINT25
    25  FORMAT('-',18X,'P',6X,'WA',10X,'WB',10X,'WC',10X,'WD',10X,'WE')
        READ(5,2000)N
  2000  FORMAT(I10)
        N1=N+1
        N2=N+2
        DO 30 I=1,N
        P(I)=FLOAT(I)*10./FLOAT(N)
        WA(I)=33.0*(P(I)/0.65+0.23*P(I))
        WB(I)=40.0*(P(I)/0.65+0.23*P(I))
        WC(I)=50.0*(P(I)/0.65+0.23*P(I))
        WD(I)=60.0*(P(I)/0.65+0.23*P(I))
        WE(I)=100.0*(P(I)/0.65+0.23*P(I))
    30  WRITE(6,100)P(I),WA(I),WB(I),WC(I),WD(I),WE(I)
   100  FORMAT('0',15X,F5.1,5F10.4)
        CALL SCALE (P,5.,N,1)
        WA(N1)=0.0
        WA(N2)=400.0
        WB(N1)=WA(N1)
        WB(N2)=WA(N2)
        WC(N1)=WA(N1)
        WC(N2)=WA(N2)
        WD(N1)=WA(N1)
        WD(N2)=WA(N2)
        WE(N1)=WA(N1)
        WE(N2)=WA(N2)
        CALL AXIS (0.,0.,'POWER IN KW',-11,5.,0.,P(N1),P(N2))
        CALL AXIS (0.,0.,'WEIGHT IN LBS',13,5.,90..WA(N1),WA(N2))
        CALL LINE (P,WA,N,1,1,0)
        CALL LINE (P,WB,N,1,1,1)
        CALL LINE (P,WC,N,1,1,2)
        CALL LINE (P,WD,N,1,1,3)
        CALL LINE (P,WE,N,1,1,4)
        CALL SYMBOL (.1,-1.,.1,28HSOLAR CELL WEIGHT VS POWER   ,0.,28)
        CALL SYMBOL (.1,-1.3,.1,12HFREQ=1-4 GHZ,0.,12)
        CALL PLOT(10.,0.0,999)
        STOP
        END
```

PROGRAM FOR FIGURE 4

```
C       SPACE 6 SOLAR CELL WEIGHT VS POWER
        DIMENSION WA(22),WB(22),WC(22),WD(22),WE(22),P(22)
        WRITE(6,1)
      1 FORMAT('1',/,'-',25X,'SOLAR CELL WEIGHT VS POWER')
        CALL PLOT (4.0,3.0,-3)
        PRINT25
     25 FORMAT('-',18X,'P',6X,'WA',10X,'WB',10X,'WC',10X,'WD',10X,'WE
        READ(5,2000)N
   2000 FORMAT(I10)
        N1=N+1
        N2=N+2
        DO 30 I=1,N
        P(I)=FLOAT(I)*10./FLOAT(N)
        WA(I)=33.0*(P(I)/0.58+0.15*P(I))
        WB(I)=40.0*(P(I)/0.58+0.15*P(I))
        WC(I)=50.0*(P(I)/0.58+0.15*P(I))
        WD(I)=60.0*(P(I)/0.58+0.15*P(I))
        WE(I)=100.0*(P(I)/0.58+0.15*P(I))
     30 WRITE(6,100)P(I),WA(I),WB(I),WC(I),WD(I),WE(I)
    100 FORMAT('0',15X,F5.1,5F10.4)
        CALL SCALE (P,5.,N,1)
        WA(N1)=0.0
        WA(N2)=400.0
        WB(N1)=WA(N1)
        WB(N2)=WA(N2)
        WC(N1)=WA(N1)
        WC(N2)=WA(N2)
        WD(N1)=WA(N1)
        WD(N2)=WA(N2)
        WE(N1)=WA(N1)
        WE(N2)=WA(N2)
        CALL AXIS (0.,0.,'POWER IN KW',-11,5.,0.,P(N1),P(N2))
        CALL AXIS (0.,0.,'WEIGHT IN LBS',13,5.,90.,WA(N1),WA(N2))
        CALL LINE (P,WA,N,1,1,0)
        CALL LINE (P,WB,N,1,1,1)
        CALL LINE (P,WC,N,1,1,2)
        CALL LINE (P,WD,N,1,1,3)
        CALL LINE (P,WE,N,1,1,4)
        CALL SYMBOL (.1,-1.,.1,28HSOLAR CELL WEIGHT VS POWER  ,0.,28
        CALL SYMBOL (.1,-1.3,.1,13HFREQ=8-12 GHZ,0.,13)
        CALL PLOT (10.,0.0,999)
        STOP
        END
```

PROGRAM FOR FIGURE 5

```
C      SPACE 2  COMM SYSTEM WT VS POWER
       DIMENSION WTR(22),WPS(22),WTH(22),WT(22),P(22)
       CALL PLOT (4.0,3.0,-3)
       WRITE(6,1)
     1 FORMAT('1',/,'-',25X,'COMM SYSTEM WEIGHT VS POWER')
       PRINT20
    20 FORMAT ('-',17X,'P',7X,'WTR',7X,'WPS',7X,'WTH',7X,'WT')
       READ(5,1000)N1
  1000 FORMAT(I10)
       N2=N1+1
       N3=N1+2
       DO 30 I=1,N1
       P(I)=FLOAT(I)*10./FLOAT(N1)
       WTR(I)=28.+7.5*P(I)
       WPS(I)=62.+16.14*P(I)
       WTH(I)=12.5*P(I)
       WT(I)=WTR(I)+WPS(I)+WTH(I)
    30 WRITE(6,100)P(I),WTR(I),WPS(I),WTH(I),WT(I)
   100 FORMAT('0',15X,F4.1,4F10.4)
       CALL SCALE (P,5.,N1,1)
       WTR(N2)=0.0
       WTR(N3)=100.0
       WPS(N2)=WTR(N2)
       WPS(N3)=WTR(N3)
       WTH(N2)=WTR(N2)
       WTH(N3)=WTR(N3)
       WT(N2)=WTR(N2)
       WT(N3)=WTR(N3)
       CALL AXIS (0.,0.,11HPOWER IN KW,-11,5.,0.,P(N2),P(N3))
       CALL AXIS (0.,0.,'WEIGHT IN LBS',13,5.,90.,WTR(N2),WTR(N3))
       CALL LINE (P,WTR,N1,1,1,0)
       CALL LINE (P,WPS,N1,1,1,1)
       CALL LINE (P,WTH,N1,1,1,2)
       CALL LINE (P,WT,N1,1,1,3)
       CALL SYMBOL (.1,-1.,.1,31HCOMM SYSTEM WEIGHT VS POWER    ,0.,31)
       CALL SYMBOL (.1,-1.3,.1,12HFREQ=1-4 GHZ,0.,12)
       CALL PLOT (10.,0.0,999)
       STOP
       END
```

PROGRAM FOR FIGURE 6

```
C      SPACE 5  COMM SYSTEM WT VS POWER
       DIMENSION WTR(22),WPS(22),WTH(22),WT(22),P(22)
       CALL PLOT (4.0,3.0,-3)
       WRITE(6,1)
     1 FORMAT('1',/,'-',25X,'COMM SYSTEM WEIGHT VS POWER')
       PRINT20
    20 FORMAT ('-',17X,'P',7X,'WTR',7X,'WPS',7X,'WTH',7X,'WT')
       READ(5,1000)N1
  1000 FORMAT(I10)
       N2=N1+1
       N3=N1+2
       DO 30 I=1,N1
       P(I)=FLOAT(I)*10./FLOAT(N1)
       WTR(I)=23.+7.8*P(I)
       WPS(I)=62.+16.14*P(I)
       WTH(I)=10.0*P(I)
       WT(I)=WTR(I)+WPS(I)+WTH(I)
    30 WRITE(6,100)P(I),WTR(I).WPS(I),WTH(I),WT(I)
   100 FORMAT('0',15X,F4.1,4F10.4)
       CALL SCALE (P,5.,N1,1)
       WTR(N2)=0.0
       WTR(N3)=100.0
       WPS(N2)=WTR(N2)
       WPS(N3)=WTR(N3)
       WTH(N2)=WTR(N2)
       WTH(N3)=WTR(N3)
       WT(N2)=WTR(N2)
       WT(N3)=WTR(N3)
       CALL AXIS (0.,0.,11HPOWER IN KW,-11,5.,0.,P(N2),P(N3))
       CALL AXIS (0.,0.,'WEIGHT IN LBS',13,5.,90.,WTR(N2),WTR(N3))
       CALL LINE (P,WTR,N1,1,1,0)
       CALL LINE (P,WPS,N1,1,1,1)
       CALL LINE (P,WTH,N1,1,1,2)
       CALL LINE (P,WT,N1,1,1,3)
       CALL SYMBOL (.1,-1.,.1,31HCOMM SYSTEM WEIGHT VS POWER    ,0.,31
       CALL SYMBOL (.1,-1.3,.1,13HFREQ=8-12 GHZ,0.,13)
       CALL PLOT (10.,0.0,999)
       STOP
       END
```

PROGRAM FOR FIGURE 7

```
C      SPACE7  ATTITUDE, ORBIT CONTROL AND STRUCTURE WEIGHT
      DIMENSION WAC(10),WST(10),WAOST(10),WAST(10)
      CALL PLOT(4.0,3.0,-3)
      WRITE(6,1)
    1 FORMAT('1',/,'-',25X,'ATTITUDE, ORBIT CONTROL AND STRUCTURE WEIGHT'
     *')
      WRITE(6,10)
   10 FORMAT('-',15X,'WAST ',10X,'WAC   ',10X,'WST   ',10X,'WAOST')
      DO 300 I=1,5
      WAST(I)=1000.*FLOAT(I)-1000.
      WAC(I)=0.234*WAST(I)
      WST(I)=28.0+0.272*WAST(I)
      WAOST(I)=28.0+0.506*WAST(I)
  300 WRITE(6,20) WAST(I),WAC(I),WST(I),WAOST(I)
   20 FORMAT('0',5X,4F15.3)
      CALL AXIS(0.,0.,'WAST',-4,5.0,0.,0.,1000.)
      CALL AXIS(0.,0.,'WEIGHT IN LBS',13,5.,90.,0., 500.)
      WAST(6)=0.0
      WAST(7)=1000.0
      WAC(6)=0.0
      WAC(7)= 500.0
      WAOST(6)=0.0
      WAOST(7)= 500.0
      WST(6)=0.0
      WST(7)= 500.0
      CALL LINE(WAST,WAC,5,1,1,1)
      CALL LINE(WAST,WST,5,1,1,2)
      CALL LINE(WAST,WAOST,5,1,1,3)
      CALL SYMBOL(.1,-1.,.1,40HATTITUDE, ORBIT CONTROL AND STRUCTURE WT,
     10.0,40)
      CALL PLOT(10.0,0.0,999)
      STOP
      END
```

PROGRAM FOR FIGURE 8

```
C      SPACE8  ATTITUDE,ORBIT CONTROL AND STRUCTURE WEIGHT
       DIMENSION WAO(10),WST(10),WAOST(10),WAST(10)
       CALL PLOT(4.0,3.0,-3)
       WRITE(6,1)
     1 FORMAT('1',/,'-',25X,'ATTITUDE, ORBIT CONTROL AND STRUCTURE WEIGHT
      *')
       WRITE(6,10)
    10 FORMAT('-',15X,'WAST ',10X,'WAO  ',10X,'WST  ',10X,'WAOST')
       DO 300 I=1,5
       WAST(I)= 500.*FLOAT(I)- 500.
       WAO(I)=0.2  *WAST(I)
       WST(I)=28.0+0.264*WAST(I)
       WAOST(I)=28.0+0.464*WAST(I)
   300 WRITE(6,20) WAST(I),WAO(I),WST(I),WAOST(I)
    20 FORMAT('0',5X,4F15.3)
       CALL AXIS(0.,0.,'WAST',-4,5.0,0.,0., 500.)
       CALL AXIS(0.,0.,'WEIGHT IN LBS',13,5.,90.,0.,250.)
       WAST(6)=0.0
       WAOST(6)=0.0
       WAO(6)=0.0
       WST(6)=0.0
       WAO(7)=250.0
       WAOST(7)=250.0
       WAST(7)=500.0
       WST(7)=250.0
       CALL LINE(WAST,WAO,5,1,1,1)
       CALL LINE(WAST,WST,5,1,1,2)
       CALL LINE(WAST,WAOST,5,1,1,3)
       CALL SYMBOL(.1,-1.,.1,40HATTITUDE, ORBIT CONTROL AND STRUCTURE WT,
      10.0,40)
       CALL PLOT(10.0,0.0,999)
       STOP
       END
```

PROGRAM FOR FIGURE 9

```
C     SPACE9  TOTAL WEIGHT OF SATELLITE
      REAL K1,K2,K3,K4,K5,K6,TWATE(12),POW(12)
      CALL PLOT(4.0,3.0,-3)
      C=(3.0/30.48)*10.**10
      READ(5,1) S,F,DIA,P,K1,K4
    1 FORMAT(6F10.0)
      S1=S
      S=S*5280.
      AS=(DIA*5280./2.0)**2*3.14159
      AS1=AS/(5280.*5280.)
      IF(F-6.) 10,20,20
   10 K2=90.
      K3=36.14
      K5=0.65
      K6=0.506
      GO TO 25
   20 K2=85.
      K3=33.94
      K5=0.58
      K6=0.464
   25 CONTINUE
      WRITE(6,11)
   11 FORMAT('1',/,'-',25X,'TOTAL WEIGHT OF SATELLITE')
      F1=F*10.**9
      W=28.+(1.+K6)*((K1*((C*S/F1)**2)/AS)+K2+P*(K3+K4/K5+0.23*K4))
      WRITE(6,100) S1,F,DIA,AS1,P,K1,K2,K3,K4,K5,K6,W
  100 FORMAT('-','XMIT TO REC ANTENNA IN MILES',14X,'      =',F10.4,/,
     1'0','FREQUENCY IN GHZ                                =',F10.4,/,
     1'0','DIAMETER OF COVERAGE IN MILES                   =',F10.4,/,
     1'0','COVERAGE AREA IN SQ MILES                       =',F10.0,/,
     1'0','POWER IN KW                                     =',F10.4,/,
     1'0','ANTENNA WT FACTOR IN LBS/SQ FT                  =',F10.4,/,
     1'0','ELECTRICAL AND ELECTRONIC EQUIPMENT WT FACTOR   =',F10.4,/,
     1'0','ELECTRICAL AND THERMAL CONTROL WT FACTOR        =',F10.4,/,
     1'0','SOLAR CELL ARRAY WT FACTOR IN LBS/KV            =',F10.4,/,
     1'0','XMITTER EFFICIENCY                              =',F10.4,/,
     1'0','ATTITUDE CONTROL AND STRUCTURE WT FACTOR        =',F10.4,/,
     1'0','TOTAL WEIGHT OF SATELLITE                       =',F10.4)
      WRITE(6,2)
    2 FORMAT('-',25X,'TOTAL WEIGHT VS POWER      ',/,'-')
      DO 30 I=1,10
      POW(I)=FLOAT(I)
      TWATE(I)=28.+(1.+K6)*((K1*((C*S/F1)**2)/AS)+K2+POW(I)*(K3+K4/K5+
     10.23*K4))
   30 WRITE(6,31) POW(I),TWATE(I)
   31 FORMAT('0',5X,'POWER IN KW= ',F10.4,5X,'TOTAL WEIGHT= ',F10.4)
      POW(11)=0.0
      POW(12)=2.
      CALL SCALE(TWATE,5.0,10,1)
      CALL AXIS(0.,0.,'POWER IN KW',-11,5.0,0.0,POW(11),PUW(12))
      CALL AXIS(0.,0.,'WEIGHT IN LBS',13,5.0,90.,TWATE(11),TWATE(12))
      CALL LINE(POW,TWATE,10,1,1,1)
      CALL SYMBOL(.1,-1.,.1,'TOTAL WEIGHT VS POWER',0.0,21)
      CALL PLOT(10.0,0.0,999)
      STOP
      END
```

PROGRAM FOR TABLES 14 - 17

```
      DIMENSION RFA(100,6),SPACO(100,6),NAME(100,7)
      N=0
      DO 100 I=1,100
      READ(5,11)(SPACO(I,J),J=1,6),(NAME(I,J),J=1,7)
      IF(SPACO(I,1).EQ.99.)GO TO 1101
      N=N+1
  100 CONTINUE
 1101 CONTINUE
   11 FORMAT(F5.0,F6.0,F4.0,1X,F4.0,2F5.0,7A4)
      DO 10 I=1,N
      DO 10 J=1,6
      RFA(I,J)=SPACO(I,J)
   10 RFA(I,1)=(SPACO(I,4)-SPACO(I,3))/2.+SPACO(I,3)
      M=100
      CALL SORT(SPACO,NAME,N,M,2)
      WRITE(6.1)
      WRITE(6,2)
      WRITE(6,3)
      WRITE(6,4)
    1 FORMAT('1',/,'-',40X,'TABLE ONE')
    2 FORMAT('0',32X,'RF AMP PARAMETERS VS POWER')
    3 FORMAT('-',17X,'POWER',2X,'FREQ RANGE',3X,'GAIN',2X,'WEIGHT'3X,
     A'COMPANY',3X,'PART NO',3X,'TYPE')
    4 FORMAT(' ',17X,'WATTS',6X,'GHZ',6X,'DB',5X,'LBS',/,'0')
      DO 30 I=1,N
   30 WRITE(6,21)(SPACO(I,J).J=2,6),(NAME(I,J),J=1,7)
   21 FORMAT('0',13X, F8.0,F7.1,'-',F4.1,F7.1,F8.1,7A4)
      CALL SORT(RFA,NAME,N,M,1)
      WRITE(6,101)
      WRITE(6,121)
      WRITE(6,3)
      WRITE(6,4)
  121 FORMAT('0',32X,'RFAMP PARAMETERS VS FREQUENCY')
      DO 60 I=1.N
   60 WRITE(6.21)(RFA(I,J),J=2,6).(NAME(I,J),J=1,7)
      CALL SORT(SPACO,NAME,N,M,5)
      WRITE(6,201)
      WRITE(6.122)
      WRITE(6,3)
      WRITE(6,4)
  122 FORMAT('0',32X,'RFAMP PARAMETERS VS GAIN')
      DO 95 I=1.N
   95 WRITE(6,21)(SPACO(I,J),J=2,6),(NAME(I,J),J=1,7)
      CALL SORT(SPACO,NAME,N,M,6)
      WRITE(6,301)
      WRITE(6,123)
      WRITE(6,3)
      WRITE(6,4)
  123 FORMAT('0',32X,'RFAMP PARAMETERS VS WEIGHT')
      DO 90 I=1.N
   90 WRITE(6.21)(SPACO(I,J),J=2,6),(NAME(I,J),J=1,7)
  101 FORMAT('1',/,'-',40X,'TABLE TWO')
  201 FORMAT('1',/,'-',40X,'TABLE THREE')
  301 FORMAT('1',/,'-',40X,'TABLE FOUR')
      STOP
      END
```

PROGRAM FOR TABLES 14 - 17 (Cont'd)

```
      SUBROUTINE SORT(A,K,N,M,L)
      DIMENSION A(M,6),K(M,7)
      DO 3000 KZ=1,N
      JB=N-KZ
      DO 3000 I=1,JB
      IF(A(I,L).GT.A(I+1,L)) GO TO 1000
      GO TO 3000
 1000 DO 3000 J=1,7
      IF(J.GT.6) GO TO 2000
      BODAK=A(I,J)
      A(I,J)=A(I+1,J)
      A(I+1,J)=BODAK
 2000 KADOB=K(I,J)
      K(I,J)=K(I+1,J)
      K(I+1,J)=KADOB
 3000 CONTINUE
      RETURN
      END
```

COPIES OF SURVEY
QUESTIONNAIRES

Subject: HIGH POWER RF-AMPLIFIERS FOR TRANSMITTERS

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART

FREQUENCY (GHz)	R. F. POWER (KW)	TYPE	OVERALL EFFICIENCY	GAIN (db)	WEIGHT (lbs)	LIFE PREDICTIONS (HRS)	APPROX. COST
(S-BAND) 1.55 - 5.20	3 - 5						
	5 - 7						
	7 - 9						
	9 - 11						
(C-BAND) 5.20 - 8.50	3 - 5						
	5 - 7						
	7 - 9						
	9 - 11						
(Ku-BAND) 10.9 - 14.0	3 - 5						
	5 - 7						
	7 - 9						
	9 - 11						

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART

FREQUENCY (GHz)	R. F. POWER (KW)	TYPE	OVERALL EFFICIENCY	GAIN (db)	WEIGHT (lbs)	LIFE PREDICTIONS (HRS)	APPROX. COST
(Ku-BAND)	3 - 5						
	5 - 7						
	7 - 9						
14.0 - 17.25	9 - 11						
(Ka-BAND)	3 - 5						
	5 - 7						
	7 - 9						
17.25 - 36.0	9 - 11						

COMMENTS:

Subject: GROUND RECEIVERS

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART

FREQUENCY (GHz)	TYPE	NOISE FIGURE (db)	POWER GAIN (db)	WEIGHT (lbs)	LIFE PREDICTIONS (HRS)	APPROX. COST
(S-BAND) 1.55 - 5.20						
(C-BAND) 5.20 - 8.50						
(Ku-BAND) 10.9 - 14.0						
(Ku-BAND) 14.0 - 17.25						
(Ka-BAND) 17.25 - 36.0						

COMMENTS: ____

____

Subject: SOLAR CELLS

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART

TYPE OF CELLS	SIZE	THICKNESS	EFFICIENCY	POWER/CELL	CELL/KW	COST/KW

COMMENTS: ______________________________

____

Subject: SOLAR CELL ARRAYS

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART						
TYPE OF CELLS	WEIGHT (lbs/kw)				POWER TO AREA RATIO (W/Ft^2)	POWER TO WEIGHT RATIO (W/lb)
	CELLS	ELECTRIC MISC.	STRUCTURE	TOTAL		

COMMENTS:

Subject: NICKEL CADMIUM BATTERY SPECIFICATIONS

PRESENT STATE OF THE ART / FUTURE STATE OF THE ART			
LOAD REQUIREMENTS (WATTS)	BATTERY CAPACITY (A-HR)	BATTERY WEIGHT (lbs)	BATTERY VOLUME (IN^3)
0 - 200			
200 - 400			
400 - 600			
600 - 800			
800 - 1000			

COMMENTS: