COLOR TELEVISION SYSTEM FOR A MANNED SPACE BASE

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ABSTRACT

This work is concerned with some of the problems of transmission of live color television information from a ground station, via relay satellite, to an earth orbiting space base (and vice versa). This is an introductory study and will be followed by a more detailed investigation, especially of digital techniques for use in this situation.

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LIST OF SYMBOLS

Symbols	Illustration
A_s	Gain of syncom repeater
B	Transmission bandwidth
C	Carrier power
D	Distance
G	Gain of antenna
G_t	Gain of transmitting antenna
G_r	Gain of receiving antenna
G_{ts}	Gain of syncom transmitting antenna
G_{rs}	Gain of syncom receiving antenna
L	Free space path loss
R	Radius of earth
T	Kelvin temperature
W	Bandwidth of baseband
$\frac{C}{N}$	Carrier-to-noise power ratio
$\frac{S}{N}$	Signal-to-noise power ratio
$(\frac{S}{N})_o$	Signal-to-noise power ratio without de-emphasis
P	Power
P_t	Power transmitted
P_r	Power received
P_{ts}	Power transmitted from syncom
P_{rs}	Power received at syncom
d	Diameter
f	Frequency

Symbols	Illustration
f_u	Up frequency
f_d	Down frequency
$f_{cut-off}$	Cut-off frequency
h	Altitude
h_{SB}	Altitude of space base
h_{SYN}	Altitude of syncom
β	FM modulation index
η	Noise power density
Θ	Vision angle
ρ_{FM}	FM noise improvement factor
ϕ	Central angle
ψ	Elevation angle of ground antenna

CHAPTER I - INTRODUCTION

The artificial satellite has various applications, and among these applications is its use as a communication satellite. It is used to relay messages and live television programs from one continent to another on earth, and to transmit voices and pictures from the moon to the earth. Likewise, it is used to transmit pictures of the surface of Mars to the earth, and pictures of the earth to the earth. All these examples indicate the capabilities of the communication satellite and illustrate the advances made in communication technology in recent years. Hence it is believed that with persistent effort many more valuable uses can be made of the communication satellite.

Presented in this paper is another application of the satellite. This application will constitute the color television system for a manned space base. The system consists of one satellite which is in polar orbit and on which the manned space station is based, three synchronous satellites (syncoms) in stationary equatorial orbit and the ground station. It is the purpose of this paper to describe a possible design for this system. The details are contained in Chapters II, III and IV.

The requirement for the aforesaid television system arises when the polar orbit spacecraft mentioned above is manned with scientists and used as a scientific satellite to study the earth and it is necessary to observe the activities of scientists in spacecraft from the earth, say at Houston, Texas, and meanwhile give them instructions as to what to do in space. In this case, the system transmits television, voice, and telemetry data from a single earth station to the space base by way of the synchronous satellite, and likewise transmit TV, voice, and data from the space base by way of the syncoms to the earth station.

CHAPTER II - INVESTIGATION OF SPACE-BASED TELEVISION SYSTEM

In this chapter we are concerned with the problem of how the space-based television system will work if actually set up. To serve this purpose an analysis is given below:

A. Components of the system

As stated in Chapter I the system is composed of a space-based television station, three syncoms and a ground station. The space station is in a polar orbit. The plane associated with this orbit is perpendicular to the equatorial plane and is in rotation about the polar axis due to the motion of the earth. The three syncoms which are equally spaced in their orbit are at such an altitude that they have a period of 24 hours and appear stationary when observed from the earth. Fig. 1 is a diagram showing these satellites.

B. Communication link

When transmission occurs, a communication link will exist between the space base, one of the syncoms and the ground station. The signals will travel both ways. The possible links are:

1. Space base ⇄ Ground station
2. Space base ⇄ Syncom ⇄ Ground station
3. Space base ⇄ Syncom ⇄ Syncom ⇄ Ground station

The first link exists only when the ground station is being illuminated by the satellite on which the space station is based. However, this type link is not very useful since contact is possible for only a small percentage of the time.

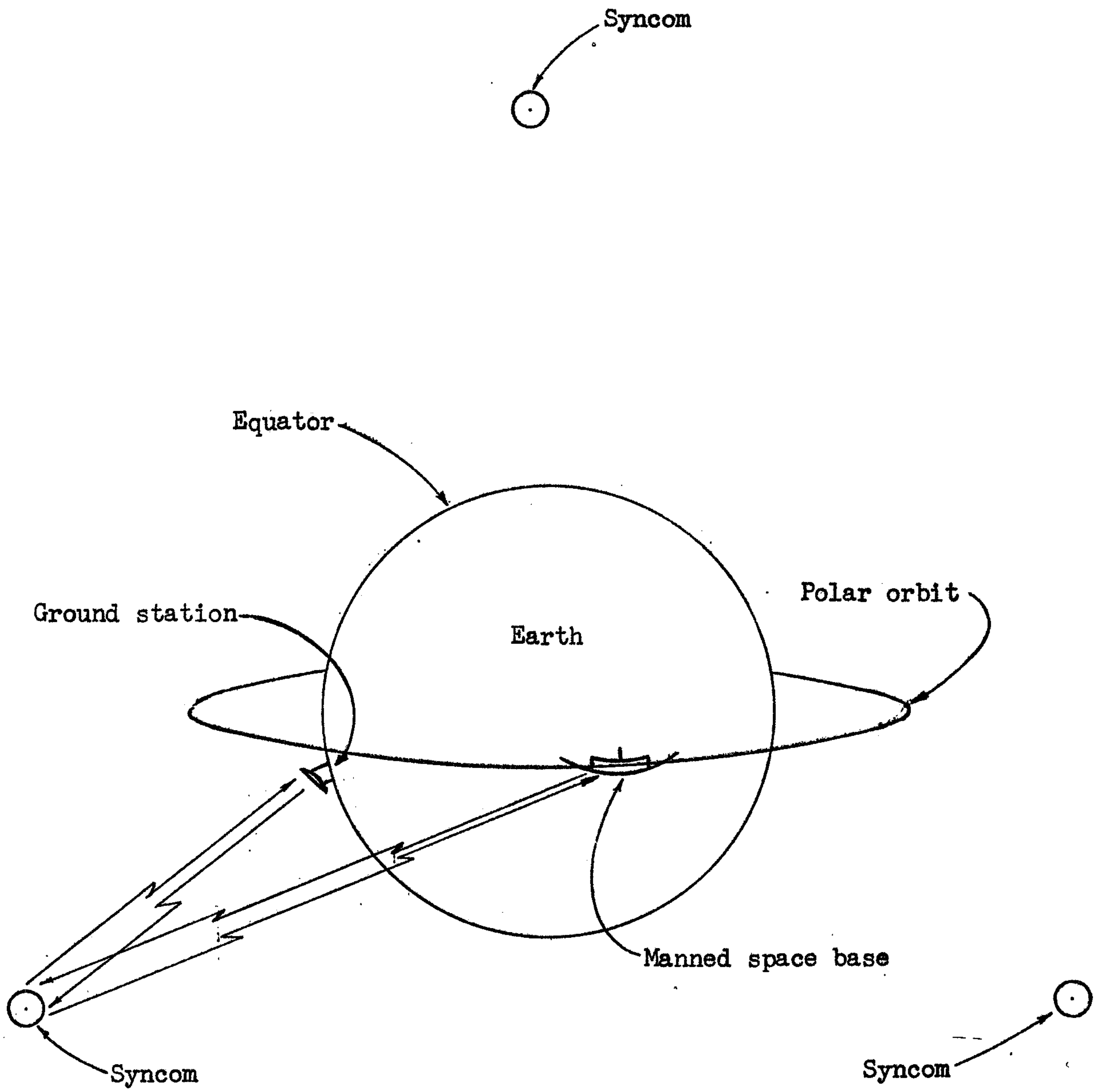


Fig.1 Relay satellite and the manned space base

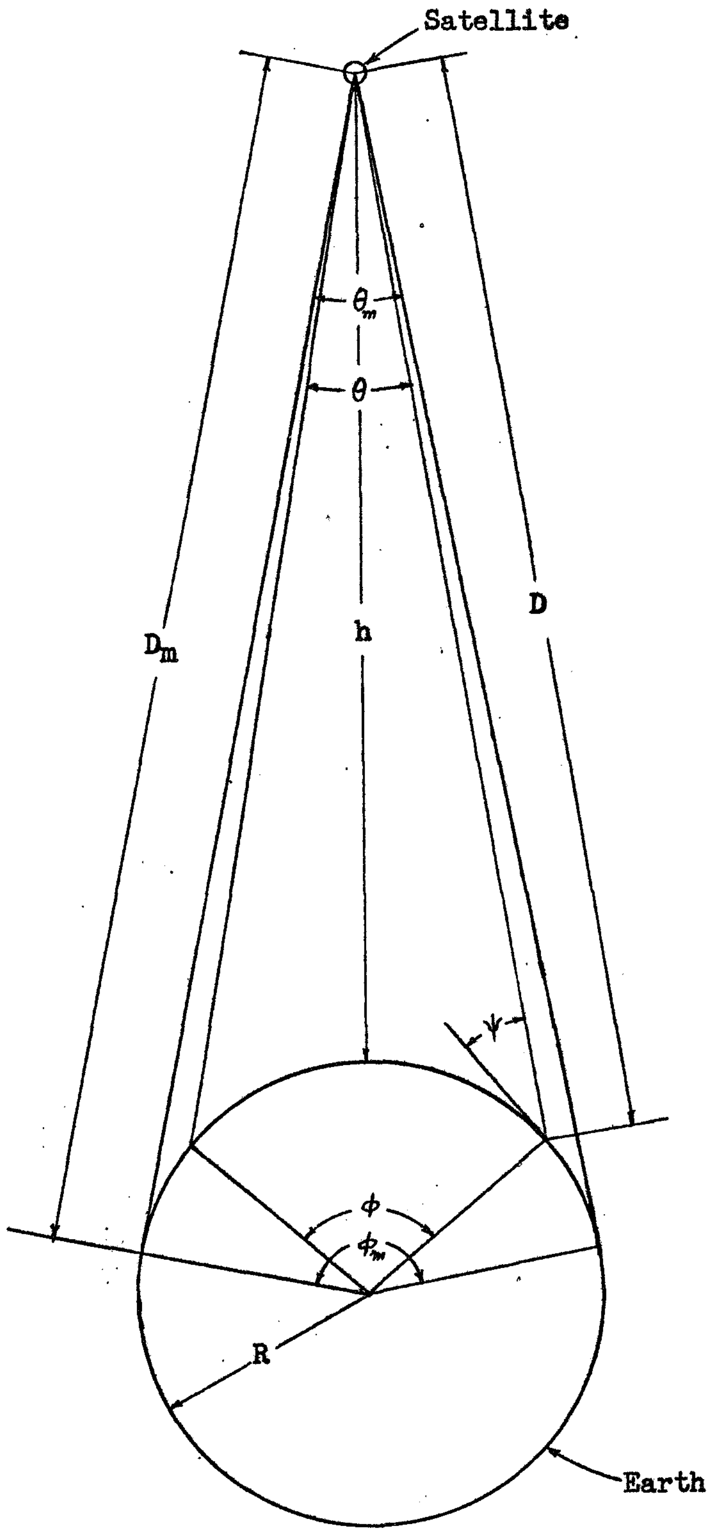


Fig. 2 Orbit geometry

The second type of link exists when the space and the ground stations are being illuminated by the same syncom.

The third type link exists when the space and the ground stations are being illuminated by two different syncoms. In addition to the tracking facilities needed, far more transmitting power will be required for the much longer distance to be covered in this case.

C. Distance of transmission

The distance between a transmitting and a receiving station is very important in the design because of its great effect on the power required for transmission. For any two stations involved in the system the distance between them can be calculated using some knowledge of geometry and trigonometry. Three cases are considered here.

Case 1. Space base $\rightleftarrows$ Syncom

Refer to Fig. 3. It can be shown that the distance is given by

$$D = \sqrt{(R + h_{SB})^2 - 2(R + h_{SB})(R + h_{SYN}) \sin \Theta \cos \phi + (R + h_{SYN})^2}$$

where D = distance, miles

R = radius of earth, miles

= 4,000 miles

h_{SB} = altitude of space base, miles

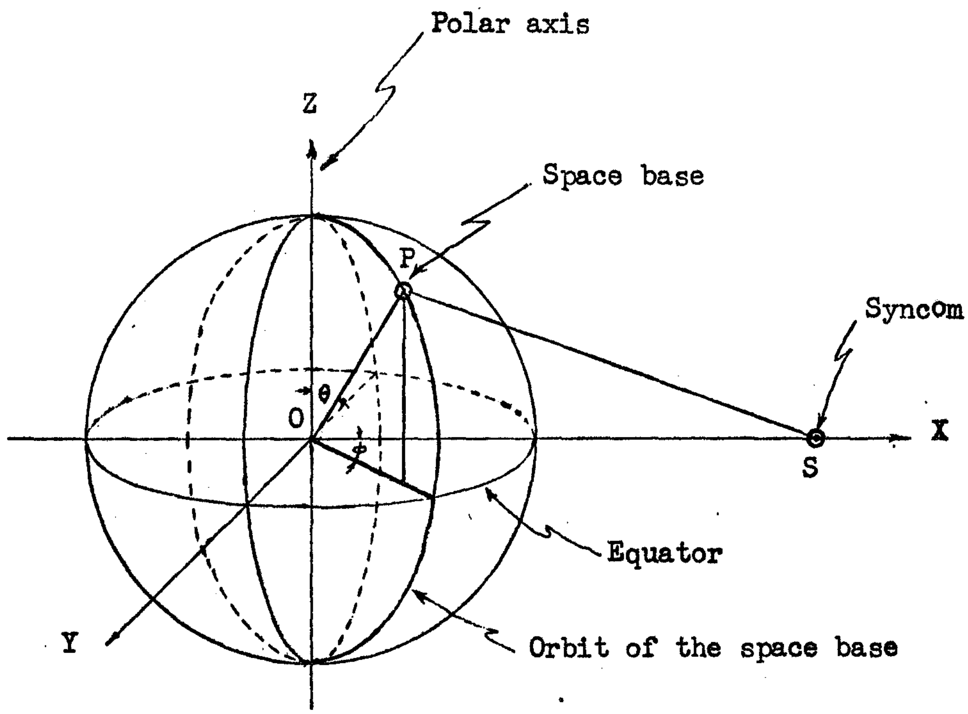
h_{SYN} = altitude of syncom, miles

= 22,300 miles

Θ = angle, degrees

ϕ = angle, degrees

From this equation it can be seen that for given values of R and h_{SYN} the distance is dependent on the altitude of the space base and its orbital



$$-60^\circ \leq \phi \leq 60^\circ$$

$$0 \leq \theta \leq 180^\circ$$

$$OP = R + h_{SB}$$

$$OS = R + h_{SYN}$$

Fig. 3 Determination of distance

position. Further, if the altitude is fixed, the distance will vary with the orbital position only. Three special cases are cited below.

a) When the space base is directly above the Pole, i.e. $\phi = 60°$ and $\Theta = 0$ or $180°$

$$D = D_{max}$$

$$= \sqrt{(R + h_{SB})^2 + (R + h_{SYN})^2}$$

b) When the space base is directly below the syncom, i.e. $\phi = 0$ and $\Theta = 90°$

$$D = D_{min}$$

$$= h_{SYN} - h_{SB}$$

c) When the space base is on the equator and half way between any two syncoms, i.e. $\phi = 60°$ or $-60°$ and $\Theta = 90°$.

$$D = \sqrt{(R + h_{SB})^2 + (R + h_{SYN})^2 - (R + h_{SB})(R + h_{SYN})}$$

Case 2. Ground station $\rightleftarrows$ Syncom

With reference to Fig. 2, this distance is given by

$$D = (R + h)\frac{\sin \phi/2}{\cos \psi}$$

$$= (R + h)\frac{\sin(90° - \psi - \Theta/2)}{\cos \psi}$$

$$= (R + h)\frac{\sin[90° - \psi - \sin^{-1}(\frac{R}{R + h} \cos \psi)]}{\cos \psi}$$

where D = distance, miles

h = altitude of syncom, miles

= 22,300 miles

R = radius of earth, miles

= 4,000 miles

ψ = elevation angle of ground antenna, degrees

Θ = vision angle, degrees

ϕ = central angle, degrees

For given values of R and h, the distance depends on the elevation angle of ground antenna, ψ. When $\psi = 0$, D attains maximum and its value is

$$D_{max} = (R + h)\sin[90° - \psi - \sin^{-1}(\frac{R}{R + h})]$$

$$= 26{,}000 \text{ miles}$$

Case 3. Syncom $\rightleftarrows$ Syncom

Refer to Fig. 4. The distance is given by

$$D = 2(R + h) \cos 30°$$

$$= 45{,}600 \text{ miles}$$

where D = distance, miles

h = altitude of syncom, miles

= 22,300 miles

R = radius of earth

= 4,000 miles

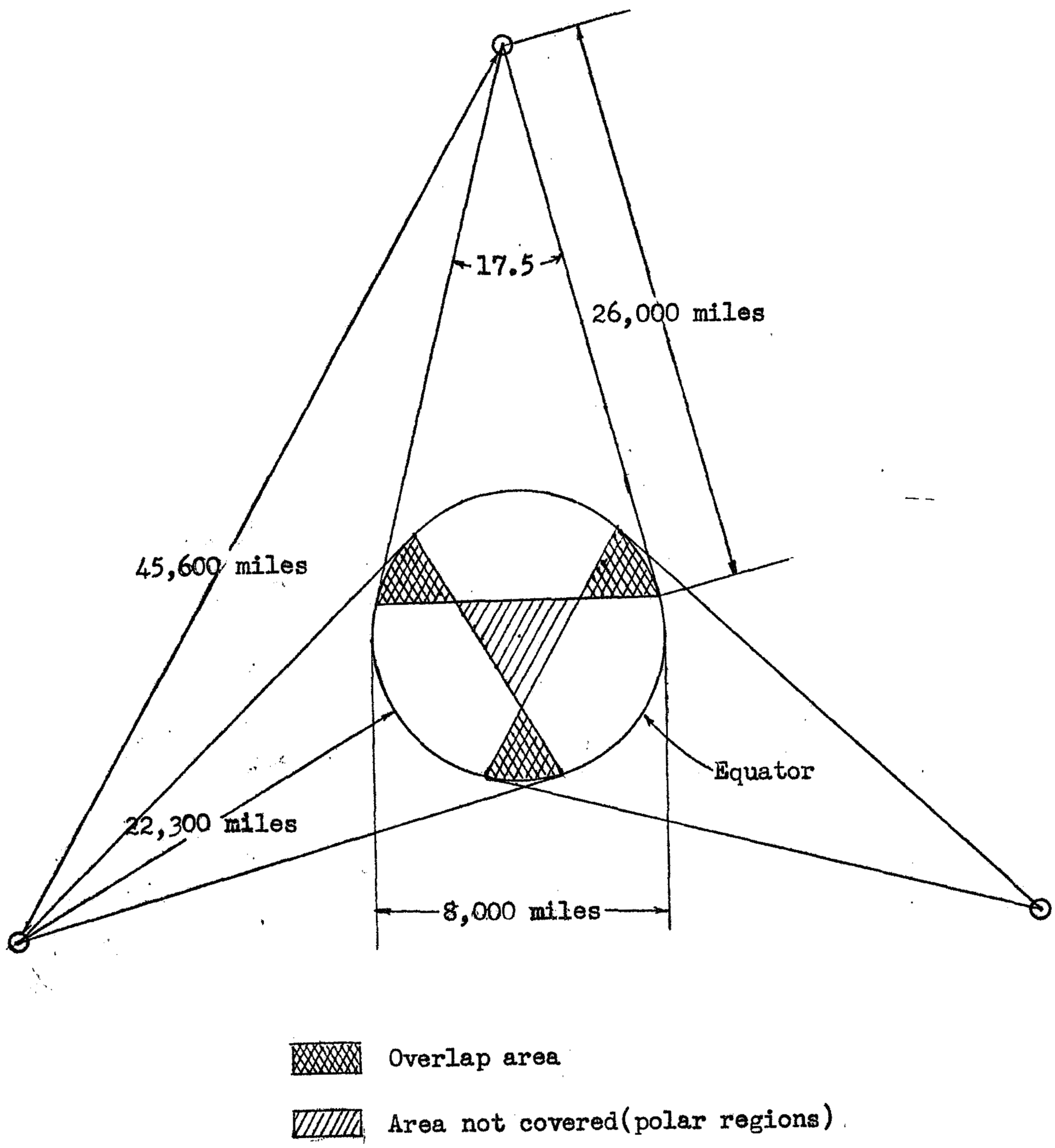


Fig. 4 Geometry of stationary orbit

CHAPTER III - SYSTEM COMMUNICATION REQUIREMENTS

The operation of the space communication system is limited by a number of factors, such as the altitude and inclination of the spacecraft, the number of spacecraft needed, power, range, bandwidth and receiver sensitivity. Based on these constraints requirements for the proposed television system, which must be met by that system, can be set forth as follows:

A.	Number and orbit of communication satellites	3 - Stationary orbit
B.	Altitude of manned space base above mean radius of earth	350 miles
C.	Frequency range	
	Down link	1,550 - 5,200 MHz (S band)
	Up link	5,200 - 10,900 MHz (X band)
D.	Baseband bandwidth	5 MHz
E.	Minimum SNR at terminal receiver	36 dB
F.	Maximum power of transmitter	
	Space base	No limit
	Ground	No limit
	Syncom	100 watts/repeater

Justifications for each listed item are given below.

A. Number and orbit of communication satellites

It is a fact that while a non-synchronous satellite is orbiting, the length of time for a certain ground station to communicate directly with it is limited. If for some reason an unlimited time of communication between such two stations is desired, it is necessary to use synchronous relay communication satellites. In this case the syncom is used to relay voice or picture signal one way or the other. It has been shown that three syncoms will be enough for this purpose. Then the communication link exists at any time no matter what the orbital position of the satellite is.

B. Altitude of space base

The altitude of a space base is primarily determined by the mission to be accomplished. In this paper it has been assumed that the space base carrying scientists is used as a scientific satellite to study the earth. Then it should be low enough to carry out the task assigned. However, if the space base is too low, it will move in the region where there is still an appreciable effect of air resistance and gradually descend toward earth resulting in a short life. The limit is usually on the order of 100 miles, based on past experience. Therefore, 350 miles is chosen for the desired altitude.

C. Frequency range

In communication, frequency always influences radio transmission to a large extent. With the refraction and Faraday effects neglected its selection is mainly determined by the noise of the receiving system and the losses of propagation between the transmitting and receiving antennas. However, frequency band allocations for space communication purposes were already agreed upon during the 1963 International Conference. Besides, NASA has S band (1,550 - 5,200 MHz) equipment developed, and any new equipment will probably be at X band (5,200 - 10,900 MHz). In consideration of these facts the selected frequency ranges are S band for the down link and X band for the up link. This will illustrate the use of both these frequency ranges.

D. Baseband bandwidth

Most useful signals are bandlimited, but their bandwidths vary with the types of the signals involved. For a voice signal the bandwidth is about 3 KHz. The bandwidth of a video signal depends on the resolution and the frame rate used. For analysis in this paper the video signal is assumed to conform to the commercial TV standard, corresponding to a resolution of 525x525 lines and frame rate of 30 frames/sec. So the calculated bandwidth is

$$W = \frac{1}{2} \times 525^2 \times 30 = 4.2 \text{ MHz}$$

Making allowance for the synchronization, the chrominance and the sound components, 5 MHz is taken as the actual bandwidth and will be used throughout this analysis.

E. Signal-to-noise ratio (SNR)

The postdetection signal-to-noise ratio (SNR) is one of the more critical system parameters. While it is a measure of sensitivity of a designed communication system, the required SNR is primarily determined by human factors. Subjective tests have been conducted to evaluate viewers' reaction to television pictures having various signal-to-noise ratios. Fig. 5 defines SNR in terms of TASO* Grades and shows the overall results of numerous subjective tests. It should be noted that the SNR of Fig. 5 is defined as the rms value of sync-tip to rms noise. The SNR's along the ordinate of Fig. 5 should be reduced by 0.8 dB to convert them to black-to-white signal to rms noise. Fig. 6 summarizes the SNR requirements for a 525 line system and shows that either monochrome or color pictures require substantially the same SNR. Hence, from Fig. 6, 36 dB is taken as the required SNR.

*Television Allocations Study Organization

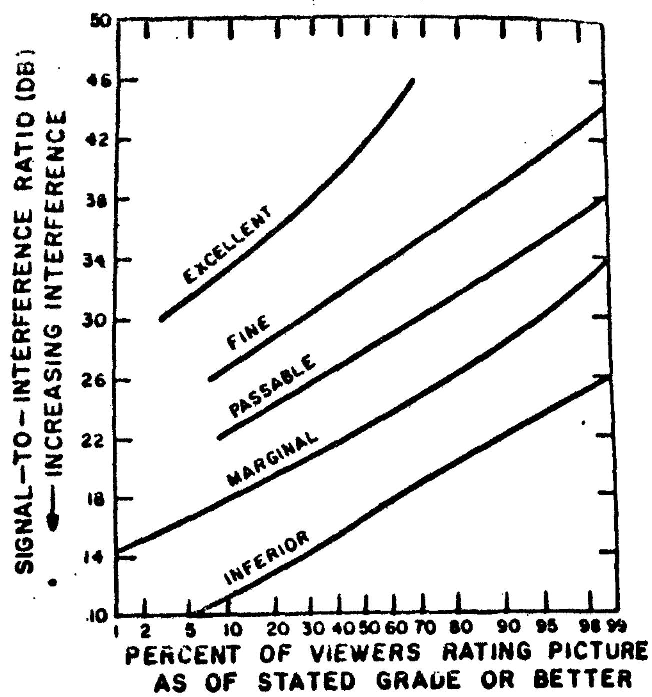


*Fig. 5 Subjective test of television system

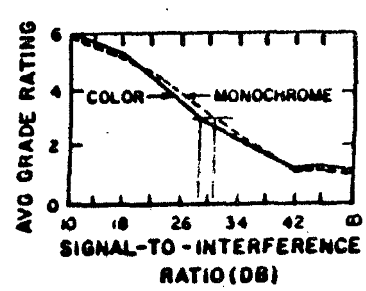


*Fig. 6 SNR requirement

*These two figures are taken from the paper by John D. Kiesling entitled "Spaceborne Transmitter for Direct Color Television Transmission From Satellites".

F. Maximum power output of transmitters

The power output of a transmitter determines the performance of a communication system to a large extent. Of course, it needs a power input. Usually, this power is supplied from solar, nuclear or chemical energy through energy conversion.

To satisfy the power requirement in this paper, the nuclear energy source is assumed for the transmitter of the space base since it is almost unlimited in power. In addition, general advantages of nuclear system include the negligible effect of the space environment and temperature variations on reliability and life, operation independent of spacecraft orientation, extremely high watthours per kilogram, and continuous power, since no storage is required for operation in the shadow.

The repeater is the power source of the syncoms. It has dual functions: to receive and to retransmit a signal at higher or lower frequency. It contains a travelling-wave tube (TWT) and has a high power gain. Its power output, however, is limited by heat dissipation. At present the maximum output of available repeaters is about 100 watts. This value will be used for the design later in this paper.

CHAPTER IV - RECOMMENDED SYSTEM DESIGN

In this chapter a design for the proposed color television system is recommended based on the requirements formulated in Chapter III.

A. Summary of Design

1. System

   a. Frequency of carriers

1) Between ground station and syncom	5,900 MHz(Up) and 3,000 MHz(Down)
2) Between space base and syncom	2,900 MHz(Down) and 6,000 MHz(Up)

   b. Modulation

1) Mode	FM
2) Modulation index	1.0
3) Threshold	10 dB

   c. Transmission bandwidth

1) FM transmission bandwidth	20 MHz
2) Complementary bandwidth including the synchronization, chrominance and sound components	10 MHz
3) Total transmission bandwidth	30 MHz

   d. Signal-to-noise ratio (SNR)

1) At ground station	39.1 dB
2) At space base	36.1 dB

For noise improvement pre-emphasis and de-emphasis filters are included in terminal transmitters and receivers.

e. Tracking

Tracking is accomplished from syncom to space base using radar beacons.

2. Syncom

a. Repeater

1) Number	2
2) Gain	100 dB
3) Power output	
No. 1 (for retransmission to space base)	100 watts
No. 2 (for retransmission to ground station)	6.3 watts

b. Antenna

1) Type	Parabolic, steerable
2) Diameter	1 ft
3) Equivalent noise temperature (ENT)	1,500°K

3. Space base

a. Antenna

1) Type	Parabolic
2) Diameter	24 ft
3) Equivalent noise temperature (ENT) (including feeder and receiver)	800°K

b. Power output of transmitter	2.5 KW
c. Power input of receiver	3.16×10^{-12} watt
d. Power source	Nuclear

4. Ground station

a. Antenna

1) Type — Parabolic

2) Diameter — 60 ft

3) Elevation angle — 5°

4) Equivalent noise temperature (ENT) (including feeder and receiver) — 300°K

b. Power output of transmitter — 8 KW

c. Power input of receiver — 2.5×10^{-12} watt

d. Power source — Conventional

B. Design Equations

Listed below are the equations applied to this design. Their derivation is omitted, but reference is indicated for each of them in the following bracket.

1. FM transmission bandwidth [Ref. 11, P. 171]

$$B(\text{MHz}) = 2(\beta + 1)W(\text{MHz})$$

2. Gain of parabolic antenna [Ref. 17]

$$G = 5.5 \times 10^{-6} f^2(\text{MHz}) \times d^2(\text{ft}) \quad \text{or}$$

$$G(\text{dB}) = 20\log f(\text{MHz}) + 20\log d(\text{ft}) - 52.6$$

3. Beamwidth of parabolic antenna [Ref. 17]

$$\Theta = \frac{70000}{f(\text{MHz}) \times d(\text{ft})} \qquad \Theta \leqq 30°$$

4. Half central angle [Fig. 2]

$$\frac{1}{2}\theta = 90° - \psi° - \frac{1}{2}\Theta°$$

5. Transmission distance between syncom and ground station [Ref. 17]

$$D(\text{Miles}) = (R + h)\frac{\sin(90° - \psi - \Theta/2)}{\cos \psi}$$

6. Transmission distance between space base and syncom [P. 5]

$$D(\text{Miles}) = \sqrt{(R + h_{SB})^2 + (R + h_{SYN})^2}$$

7. Free space path loss [Ref. 7, P. 144]

$$L_p(\text{Miles}) = 4.55\text{x}10^3 f^2(\text{MHz})\text{x}D^2(\text{Miles}) \quad \text{or}$$

$$L_p(\text{dB}) = 36.6 + 20\log f(\text{MHz}) + 20\log D(\text{Miles})$$

8. Power received [Ref. 7, PP. 145, 148]

$$P_r(\text{Watts}) = P_{t(\text{Watts})}\text{x}\frac{G_t G_r}{L} \quad \text{or}$$

$$P_r(\text{dBw}) = P_t(\text{dBw}) + G_t(\text{dB}) + G_r(\text{dB}) - L(\text{dB})$$

9. Noise power density

$$\eta(\text{Watts/MHz}) = 1.38\text{x}10^{-17}\text{x}T°K \quad \text{or}$$

$$\eta(\text{dBw/MHz}) = -168.6 + 10\log T°$$

10. Signal-to-noise ratio without de-emphasis [Ref. 11, P. 180]

$$(\frac{S}{N})0 = 3\beta^2(\beta + 1)(\frac{C}{N}) \quad \frac{C}{N} >> 1 \quad \text{or}$$

$$(\frac{S}{N})0(\text{dB}) = (\frac{C}{N})(\text{dB}) + 20\log\beta + 10\log(\beta + 1) + 4.8$$

11. Noise improvement factor [Ref. 9, P. 447]

$$\rho_{FM} = \frac{1}{3}(\frac{W}{f_{\text{cut-off}}})^2 \quad \text{or}$$

$$\rho_{FM}(\text{dB}) = 20\log(\frac{W}{f_{\text{cut-off}}}) - 4.8$$

C. Calculations

Part I - From space base to syncom to ground station

Up-link

Power output of transmitter at space base	34 dBw
Gain of antenna at space base	51 dB
Beamwidth of antenna at space base	0.5°
Gain of antenna at syncom	24 dB

Beamwidth of antenna at syncom	11.7°
Distance between space base and syncom	26,700 miles
Free space path loss	201 dB
Power received at syncom	-92 dBw
Noise power density	-136.8 dBw/MHz
Noise power	-122 dBw
Carrier-to-noise ratio	30 dB

Down-link

Gain of antenna at syncom	17 dB
Beamwidth of antenna at syncom	23.3°
Gain of antenna at ground station	53 dB
Beamwidth of antenna at ground station	0.39°
Half central angle	73.3°
Distance between ground station and syncom	25,300 miles
Free space path loss	194 dB
Power output of syncom	8 dBw
Power received at ground station	-116 dBw
Noise power density	-143.8 dBw/MHz
Noise power	-129 dBw
Carrier-to-noise ratio	13 dB
SNR without de-emphasis	20.8 dB
Cut-off frequency of de-emphasis filter	0.35 MHz
Noise improvement factor	18.3 dB
Final SNR	39.1 dB

Part II - From ground station to syncom to space base

Up-link

Power output of transmitter at ground station	39 dBw

Gain of antenna at ground station	58 dB
Beamwidth of antenna at ground station	0.2°
Gain of antenna at syncom	23 dB
Beamwidth of antenna at syncom	11.9°
Half-central angle	79°
Distance between ground station and syncom	25,900 miles
Free space path loss	200 dB
Power received at syncom	-80 dBw
Noise power density	-136.8 dBw/MHz
Noise power	-122 dBw
Carrier-to-noise ratio	42 dB
Down-link	
Gain of antenna at syncom	17 dB
Beamwidth of antenna at syncom	24.1°
Gain of antenna at space base	44 dB
Beamwidth of antenna at space base	1°
Distance between space base and syncom	26,700 miles
Free space path loss	195 dB
Power output of syncom	20 dBw
Power received at space base	-115 dBw
Noise power density	-139.6 dBw/MHz
Noise power	-125 dBw
Carrier-to-noise ratio	10 dB
SNR without de-emphasis	17.8 dB
Cut-off frequency of de-emphasis filter	0.35 MHz
Noise improvement factor	18.3 dB
Final SNR	36.1 dB

CHAPTER V - SUMMARY AND CONCLUSION

From the analysis and the recommended design in this paper conclusions can be drawn as follows:

1. The designed system is feasible with a reasonably good quality of TV picture.

2. The recommended design results from compromise of numerous parameters, but it does not represent the only design that is possible.

3. The designed system exhibits different performances when operating one way and the other. It is evident that the system is more efficient for transmission from space base to ground station via syncom than from ground station to space base via syncom.

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VITA

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