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FINAL REPORT

ON

NASA ADAPTIVE MULTIBEAM PHASED ARRAY (AMPA)

AN

APPLICATION STUDY

For Period
15 January 1981 to 30 April 1982

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Department Of Electrical Engineering
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This study was performed under the
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ELECTROMAGNETICS LABORATORY REPORT NO. 82-2

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R.M.
S.W.L.
W.G.

PREFACE

Communication satellites in the last decade played a vital role in modern military defense systems and commercial telecommunication system applications, in particular, where communication systems are sparse and inaccessible in various remote areas of the world.

Furthermore, with the advent of the NASA Space Shuttle proven to be a reliable space transport system, large communication satellite systems and large antenna structures as relay or observatory platforms and experimental space stations, such as the space telescope for deep space exploration, are becoming a physical reality and a continued driving force for advanced communication satellite research and development.

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SUMMARY

An already designed NASA Adaptive Multibeam Phased Array (AMPA) communication system by AIL (Division of Eaton Corporation; Melville, Long Island, New York) was partially tested on 7 December, 1981, at their Long Island test facility. The original intention of such a system was a low cost system for maritime and aeronautical services as a surveillance and geolocation device for search and rescue missions.

This study was initiated in an attempt to conceptualize other viable applications or programs for which AMPA might be deployed or implemented. No attempt will be made to modify the hardware design but simply to use AMPA "as is." Keep in mind, that in any operational scenario, the only critical restriction is that the communication link closure criteria must be satisfied.

An overview of the proposed orbital geometry will be discussed in Section I. Section II will highlight some of the NASA AMPA capabilities and preliminary specifications. In Section III, typical AMPA-User terminal link models and calculations will be presented. The principal AMPA features will be described and its implementation will be demonstrated in Section IV. System trade-offs and requirements will be discussed in Section V, followed by comments and recommendations in Section VI.

ABBREVIATIONS

AIL	Airborne Instrument Laboratories
AMPA	Adaptive Multibeam Phased Array
B/B	baseband
BPSK	biphase shift keying
BW	bandwidth
CEP	circular effective perimeter
C/N	carrier-to-noise density
dBm	power (0 dBm = 1 milliwatt)
dBw	power (0 dBw = 1 watt)
ECM	electronic countermeasure
EIRP	effective isotropic radiated power
EM	electromagnetics
EMI	electromagnetic interference
FAA	Federal Aviation Administration
FCC	Federal Communication Commission
FOV	field-of-view
GPS	global position satellite
GSFC	Goddard Space Flight Center
G/T	receive gain-to-noise temperature
ICBM	intercontinental ballistic missile
IF	intermediate frequency
IR	infrared
LHCP	left hand circular polarization
LNA	low noise amplifier
LO	local oscillator

LOS	line-of-sight
LRC	Lewis Research Center
modem	modulation-demodulation
MRV	multiple reentry vehicles
MSIR	maximize signal-to-noise plus interference ratio
NASA	National Aeronautics and Space Administration
NBFM	narrowband frequency modulation
NF	noise figure
NOAA	National Oceanic & Atmospheric Administration
nm	nautical mile
OTH	over-the-horizon
P/L	path loss
PRN	pseudo-random noise
RCVR	receiver
RPV	remote piloted vehicles
SAR	synthetic aperture radar
SNR	signal-to-noise ratio
SOTA	state-of-the-art
TT&C	telemetry, tracking and control
USCG	U.S. Coast Guard
XMTR	transmitter

I. INTRODUCTION

The NASA AMPA is an advanced communication system slated as a low altitude orbital relay platform, such as the Space Shuttle Spacelab program, by directives given in the Goddard Space Flight Center (GSFC) Specifications S-415, "Performance Specification for Adaptive Multibeam Phased Array (AMPA) Instrument for Spacelab," dated 20 October, 1977. However, the Office of Space and Terrestial Applications, NASA Headquarters, cancelled AMPA as flight hardware for the Space Shuttle Spacelab and redirected AMPA as a laboratory experimental development model to be tested and evaluated at the contractor's facility (AIL, Division of Eaton Corporation; Melville, Long Island, New York). The revisions are described in NASA (GSFC) Specifications S-420(A), dated December, 1979.

AMPA was originally intended to be flown on an earth-viewing low altitude polar orbit in the 200 to 600 kilometer (km) region to provide a low cost system for maritime and aeronautical users as a surveillance device for traffic controlling and the geolocation capability for search and rescue missions. Furthermore, AMPA also possesses a number of advanced antenna technologies giving improved satellite communication performances, particularly in heavy interference environments.

These state-of-the-art (SOTA) antenna techniques are the adaptation and steerable multibeam capabilities. An adaptive antenna produces nulls in the direction of the undesired signals while maintaining the mainbeam onto the signal-of-interest (SOI). Also the steerable (phased array) multibeams provide additional spatial separation and increased power and bandwidth efficiency of the link.

With these AMPA features (ref: section II) in mind, this study is intended primarily to conceptualize other viable applications or programs that AMPA might be deployed or implemented without major modification to the system design or software. No attempts will be made at this point to discuss in detail the signal processing aspect, such as BPSK and PRN, nor what the adaptive algorithm employed is. The main concern in deploying AMPA for the various postulated applications is that the RF link closure be achieved and maintained, i.e., an appropriate signal-to-noise ratio (SNR) be ascertained for any operational scenarios.

Unfortunately, during this writing there are no comprehensive test data to fully evaluate and qualify the overall AMPA system performance. Nevertheless, conceptually low altitude orbital satellites can be advantageous in certain tactical and strategic military and some commercial applications.

II. ORBIITAL GEOMETRY

In this section the basic orbital geometry is discussed briefly in order to determine the slant range between an orbiting satellite and a ground user terminal. A circular orbital path is assumed in the calculation and its geometry is defined and depicted in Figure 1. It is well understood that a geosynchronous satellite appears relatively stationary to an observing earth terminal and that its slant range or line-of-sight (LOS) is nearly constant. However, this is not the case with orbiting satellites. The slant range will be maximum when the nadir angle is approximately 70 degrees or at the horizon and minimum when the satellite is directly overhead or 0 degree nadir. Figure 2 provides an illustrative example for a slant range calculation for a 400 km (216 nm) orbiting satellite. The radius of the earth is assumed to be 3444 nm. Then the maximum LOS is 1238.73 nm when the satellite is at the horizon and 400 km (216 nm) when the satellite appears directly overhead. Once the LOS is determined, the free space path loss (P/L) can be found from the equation:

$$P/L = 10\mathrm{Log}(\lambda/4\ d)^{2}$$

where λ = operating wavelength

d = distance in nm.

Let F = 1.64 GHz, then

$$\lambda = (3\times10^{10})/(2.54\times12\times1.64\times10^{9})$$

$$= 0.60 \text{ ft}$$

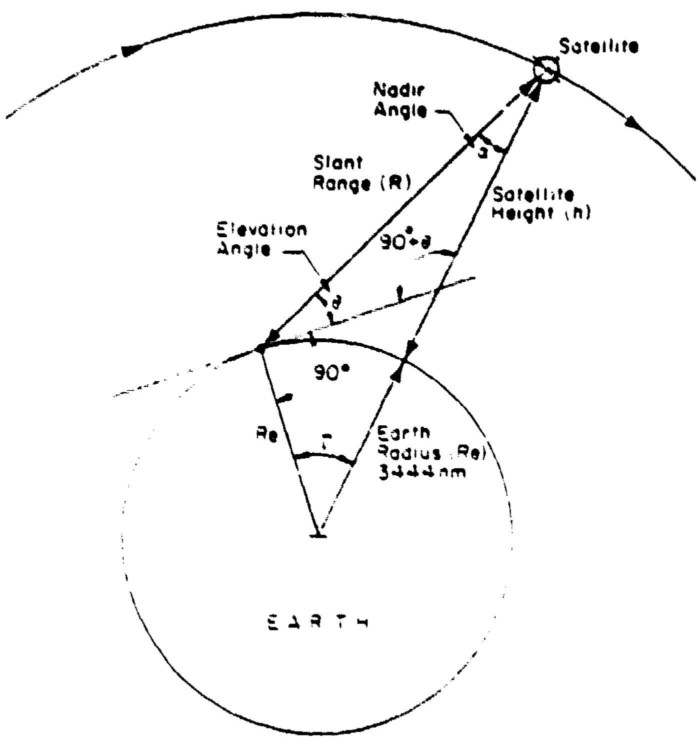

Figure 1: Orbital Geometry Definition

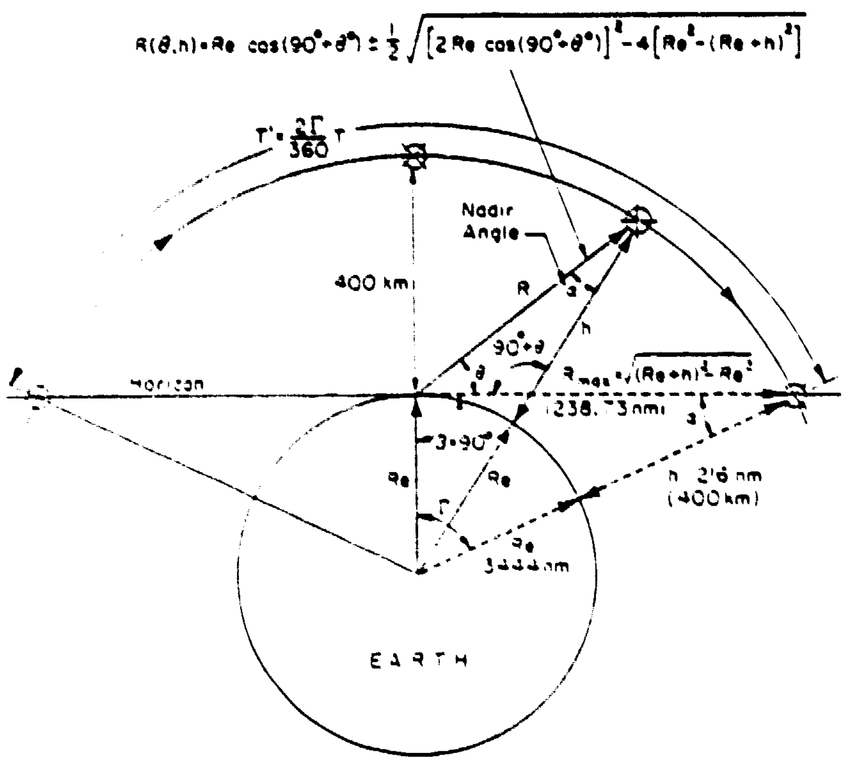

Figure 2: Slant Range Calculation Model

Since 1 nm = 6076.1 ft and max LOS = 1238.73 nm,

the maximum P/L:

$$(P/L)max = 20Log[.6/4\pi(1238.73)(6076.1)]$$
$$= -164\ dB$$

and, when the satellite is directly overhead, the LOS is 400 km (216 nm); then, the minimum P/L:

$$(P/L)min = 20Log[.6/4\pi(216)(6076.1)]$$
$$= -148.8\ dB$$

From Kepler's Law, the period of a satellite in circular orbit around the earth can be expressed by:

$$T = (2\pi a\char`^3/2)/(\mu)\char`^1/2$$

where a = radius of the orbit

μ = 1.4076x10^16 ft^3/sec^2.

is the earth gravitation parameter. Hence, the total orbital period:

$$T = 2\ \pi\{(3660)(6076.1)]\char`^3/2\}$$
$$/(1.4076x10\char`^16)\char`^1/2$$
$$= 5553.92\ sec$$

or,

$$T = 1\ hr\ 32\ min\ 33.9\ sec$$

The velocity of the satellite can be found from the expression:

$$V = 2\pi a/T = 2\pi(3444+216)/5553.92$$
$$= 4.14 \text{ nm/sec.}$$

From Figure 2 the observable period of the satellite at 400 km (216 nm) can be found from the simple relationship:

$$T' = (2\Gamma/360)T = 610.93 \text{ sec}$$

or

$$T' = 10.18 \text{ min}$$

Since, from one horizon to the opposite horizon, the satellite travels an arc of approximately 40 degrees, then it is apparent that nine (9) satellites are required to provide continuous coverage. Each satellite would provide approximately 10 minutes of acquisition time as it passes over an earth terminal.

The doppler frequency shift can be readily found from the expression below:

$$Fd = (1/\lambda)(Re/R)(V)\sin(\alpha)$$

where λ = operating wavelength

Re = radius of the earth

R = line-of-sight (LOS) distance

α = nadir angle (degrees)

V = satellite velocity

For example, suppose that at 400 km (216 nm) the elevation angle $\theta = 30$ degrees, then, the doppler frequency is:

$$Fd = [(1/.6)(3444/399.26)(4.14) \sin(54.58)] = 34.165 \text{ KHz}$$

Tables 1a-1f provide the elevation angles, nadir angles, doppler shift frequency, LOS distances, free space path loss (P/L), orbital time, and velocity as a function of orbital altitude for a nominal frequency of 1.64 GHz. Figures 3a-3b and 4a-4b depict the slant range and path loss as functions of elevation angles for different altitudes, respectively.

Table 1a: Computed Orbital Data (Alt.=100km)

OPERATING FREQUENCY = 1.6400 GHZ

ORBITAL ALTITUDE (H) 100.000 KM (ABOVE SURFACE OF THE EARTH)

TOTAL ORBITAL TIME 5189.2729 SECS (1 HR 26 MINS 29.273 SECS)

ORBITAL VELOCITY 7.84473 KM/SEC

ELEVATION ANGLE(DEG)	NADIR (DEG)	DOPPLER SHIFT(KHZ)	SLANT RANGE(KM)	FREE SPACE PATH LOSS(DB)
0.	79.92	42.2182352	1131.8684	-157.82988022
10.	75.84	41.5748453	477.4730	-150.31760263
20.	67.70	39.6721641	277.0765	-145.59061956
30.	58.50	36.5620642	195.5712	-142.56472546
40.	48.96	32.3410445	153.9033	-140.48358477
50.	39.26	27.1374585	129.8489	-139.00672493
60.	29.49	21.1091176	115.1745	-137.96575353
70.	19.68	14.4394869	106.3092	-137.27004333
80.	9.84	7.3311196	101.5183	-136.86951427
90.	.00	.0000000	100.0000	-136.73862701

Table 1b: Computed Orbital Data (Alt.=200km)

OPERATING FREQUENCY - 1.6400 GHZ

ORBITAL ALTITUDE (H) 200.000 KM (ABOVE SURFACE OF THE EARTH)

TOTAL ORBITAL TIME = 5309.8892 SECS (1 HR 28 MINS 29.889 SECS)

ORBITAL VELOCITY - 7.78406 KM/SEC

ELEVATION ANGLE(DEG)	NADIR (DEG)	DOPPLER SHIFT(KHZ)	SLANT RANGE(KM)	FREE SPACE PATH LOSS(DB)
0.	75.84	41.2592308	1609.7563	-160.07382944
10.	72.72	40.6324104	846.4036	-155.29017701
20.	65.66	38.7709947	529.6352	-151.21816451
30.	57.11	35.7315420	383.2438	-148.40812995
40.	47.97	31.6064045	304.7004	-146.41608741
50.	38.55	26.5209223	258.3449	-144.98262434
60.	29.00	20.6295154	229.7815	-143.96492888
70.	19.37	14.1114880	212.4096	-143.28207092
80.	9.69	7.1645902	202.9894	-142.88009538
90.	.00	.0000000	200.0000	-142.75922692

Table 1c: Computed Orbital Data (Alt.=300km)

OPERATING FREQUENCY = 1.6400 GHZ

ORBITAL ALTITUDE (H) 300.000 KM (ABOVE SURFACE OF THE EARTH)

TOTAL ORBITAL TIME = 5431.4260 SECS: (1 HR 30 MINS 31.426 SECS)

ORBITAL VELOCITY = 7.72558 KM/SEC

ELEVATION ANGLE(DEG)	NADIR (DEG)	DOPPLER SHIFT(KHZ)	SLANT RANGE(KM)	FREE SPACE PATH LOSS(DB)
0.	72.76	40.3359914	1979.1344	-162.66013257
10.	70.15	39.7231971	1160.3950	-158.03074414
20.	63.83	37.9034335	763.9899	-154.40037888
30.	55.80	34.9319932	564.2028	-151.76733186
40.	47.02	30.8991621	452.7000	-149.85483708
50.	37.87	25.9274755	385.6154	-148.46171378
60.	28.52	20.1679957	343.8543	-147.45611652
70.	19.07	13.7957216	318.3007	-146.79560393
80.	9.55	7.0042714	304.4155	-146.40796352
90.	.00	.0000000	300.0000	-146.28105210

Table 1d: Computed Orbital Data (Alt.=400km)

OPERATING FREQUENCY - 1.6400 GHZ

ORBITAL ALTITUDE (H) 400.000 KM (ABOVE SURFACE OF THE EARTH)

TOTAL ORBITAL TIME 5553.8758 SECS (1 HR 32 MINS 33.876 SECS)

ORBITAL VELOCITY - 7.66838 KM/SEC

ELEVATION ANGLE(DEG)	NADIR (DEG)	DOPPLER SHIFT(KHZ)	SLANT RANGE(KM)	FREE SPACE PATH LOSS(DB)
0.	70.22	39.4456771	2294.0424	-163.95065571
10.	67.92	38.8473935	1439.8441	-159.90493622
20.	62.16	37.0677514	984.1858	-156.60016919
30.	54.58	34.1618245	739.3761	-154.11593469
40.	46.12	30.2179078	598.1665	-152.27506893
50.	37.22	25.3558353	511.7378	-150.91957656
60.	28.07	19.7233385	457.4234	-149.94499549
70.	18.77	13.4915582	424.0199	-149.28635275
80.	9.40	6.8490436	405.7987	-148.90484016
90.	.00	.0000000	400.0000	-148.77982684

Table 1e: Computed Orbital Data (Alt.=500km)

OPERATING FREQUENCY = 1.6400 GHZ

ORBITAL ALTITUDE (H) 500.000 KM (ABOVE SURFACE OF THE EARTH)

TOTAL ORBITAL TIME = 5677.2324 SECS: (1 HR 34 MINS 37.232 SECS)

ORBITAL VELOCITY = 7.61243 KM/SEC

ELEVATION ANGLE(DEG)	NADIR (DEG)	DOPPLER SHIFT(KHZ)	SLANT RANGE(KM)	FREE SPACE PATH LOSS(DB)
0.	68.02	38.5895681	2574.5462	-164.95264071
10.	65.95	38.0033058	1695.1023	-161.32254515
20.	60.62	36.2623324	1192.9960	-158.27140665
30.	53.42	33.4195433	909.5055	-155.91473329
40.	45.26	29.5613242	741.3283	-154.13883805
50.	36.59	24.0048962	636.7908	-152.81856194
60.	27.62	19.2947840	570.5171	-151.86400009
70.	18.49	13.1904096	529.5508	-151.21678040
80.	9.27	6.7010082	507.1408	-150.84119863
90.	.00	.0000000	500.0000	-150.71802710

Table 1f: Computed Orbital Data (Alt.=600km)

OPERATING FREQUENCY - 1.6400 GHZ

ORBITAL ALTITUDE (H) 600.000 KM (ABOVE SURFACE OF THE EARTH)

TOTAL ORBITAL TIME - 5801.4889 SECS: (1 HR 36 MINS 41.489 SECS)

ORBITAL VELOCITY - 7.55769 KM/SEC

ELEVATION ANGLE(DEG)	NADIR (DEG)	DOPPLER SHIFT(KHZ)	SLANT RANGE(KM)	FREE SPACE PATH LOSS(DB)
0.	66.07	37.7630547	2030.8913	-165.77709091
10.	64.10	37.1093491	1932.2697	-162.45998207
20.	59.19	35.4856639	1392.4166	-159.61401059
30.	52.33	32.7037647	1075.1948	-157.36836979
40.	44.44	28.9281782	882.3839	-155.65177862
50.	35.98	24.2736237	750.8453	-154.36455477
60.	27.19	18.8815274	683.1612	-153.42909099
70.	18.22	12.9157254	634.9103	-152.79287390
80.	9.13	6.5574856	608.4437	-152.42303560
90.	.00	.0000000	600.0000	-152.30165202

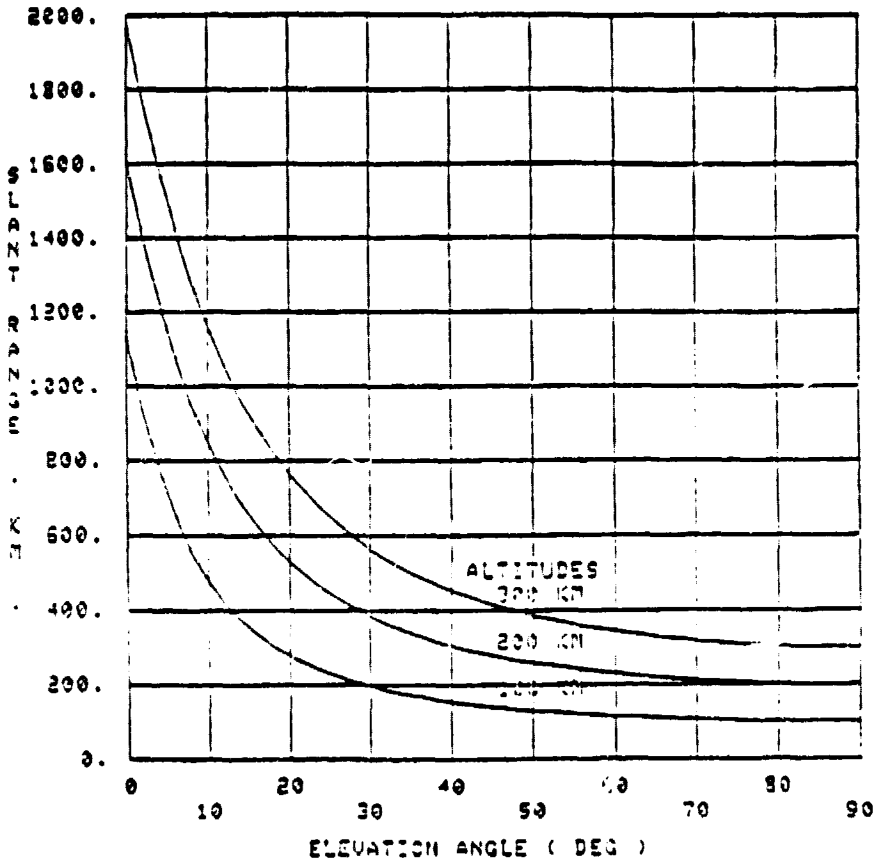

Figure 3a: Slant Range Vs. Elevation Angle (For Altitude = 100, 200 and 300 km)

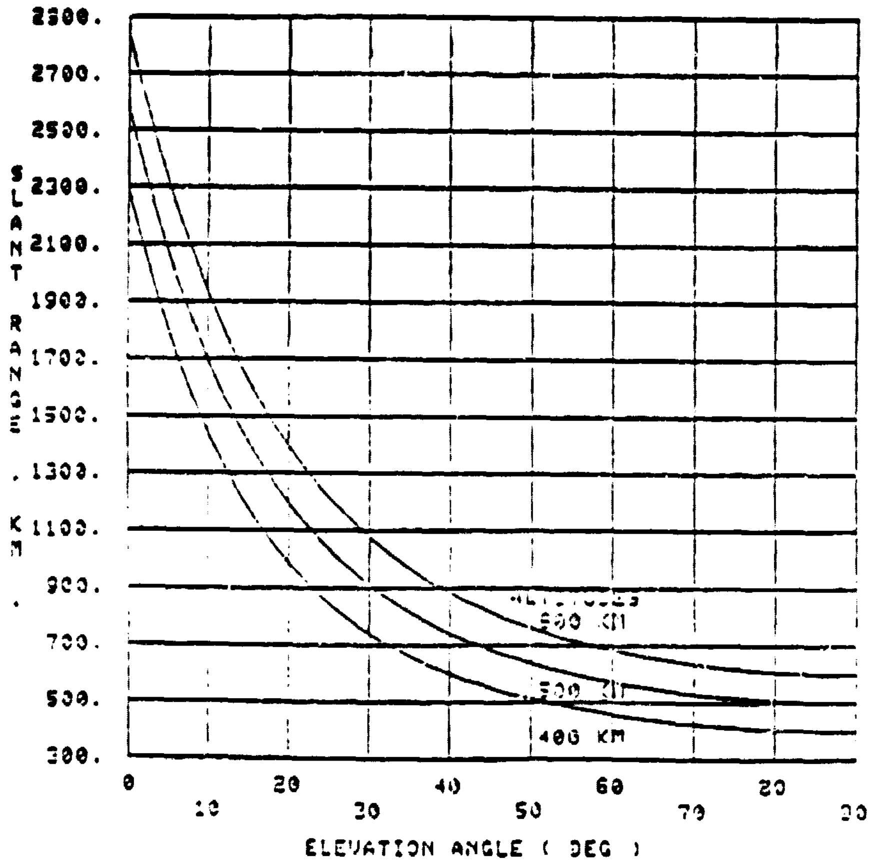

Figure 3b: Slant Range Vs. Elevation Angle (For Altitude = 400, 500 and 600 km)

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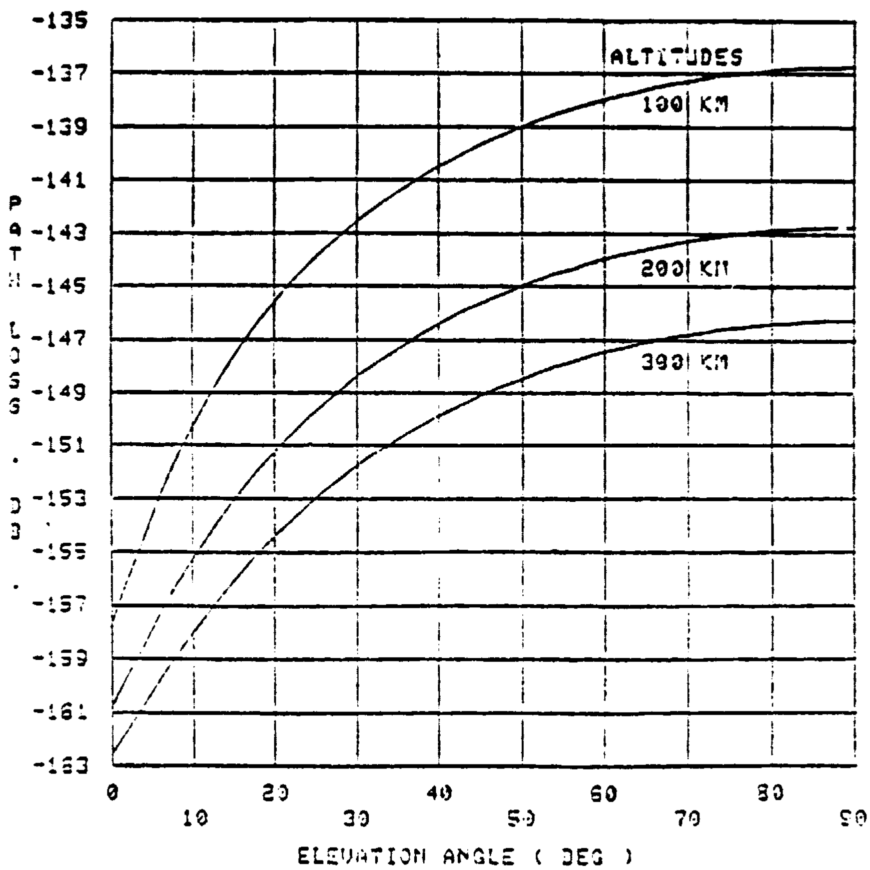

Figure 4a: Path Loss Vs. Elevation Angle (For Altitude = 100, 200 and 300 km)

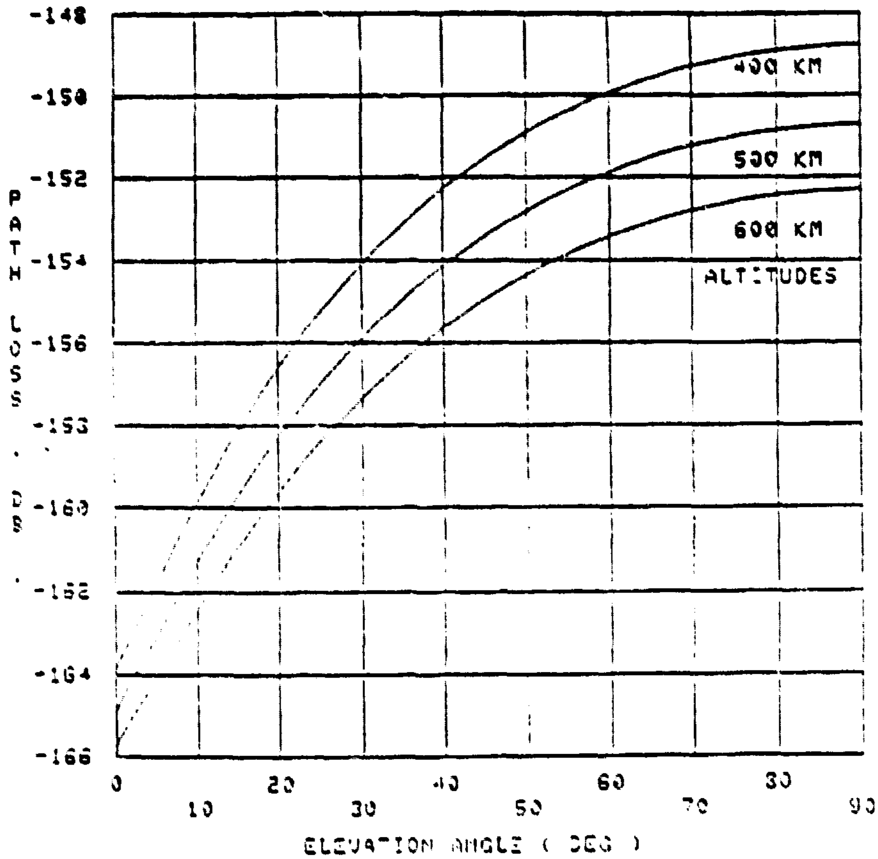

Figure 4b: Path Loss Vs. Elevation Angle (For Altitude = 400, 500 and 600 km)

III. NASA AMPA SYSTEM

In this section, the original AMPA system capability and performance specifications are cited from NASA (GSFC) Specification S-420(A) dated December, 1979, for the purpose of highlighting some of the more pertinent functions of the system. Since no measured data nor actual hardware design information are available, engineering evaluation of the system performance cannot be readily performed. As mentioned earlier, only the proposed AMPA capabilities will be utilized in conceptualizing other applications by assuming that each designed function works accordingly.

The NASA AMPA has incorporated several SOTA antenna concepts into the system design, namely, the multiple beams and adaptive antenna technologies. A multiple beam array directs independent beams to designated geographical locations. Figure 5 depicts a multiple geographical user-terminal coverage. At the same time, each directed beam provides increased power and bandwidth efficiencies, as well as spatial separation to the different telecommunication links. This capability is extremely useful in dense interference or jamming environments. The adaptive antenna concept provides an additional immunity to an interfering signal environment by creating nulls in the direction of the intentional or unintentional signal interference, meanwhile maintaining the peak of the main-beam to the signal-of-interest (SOI). Figure 6 illustrates the

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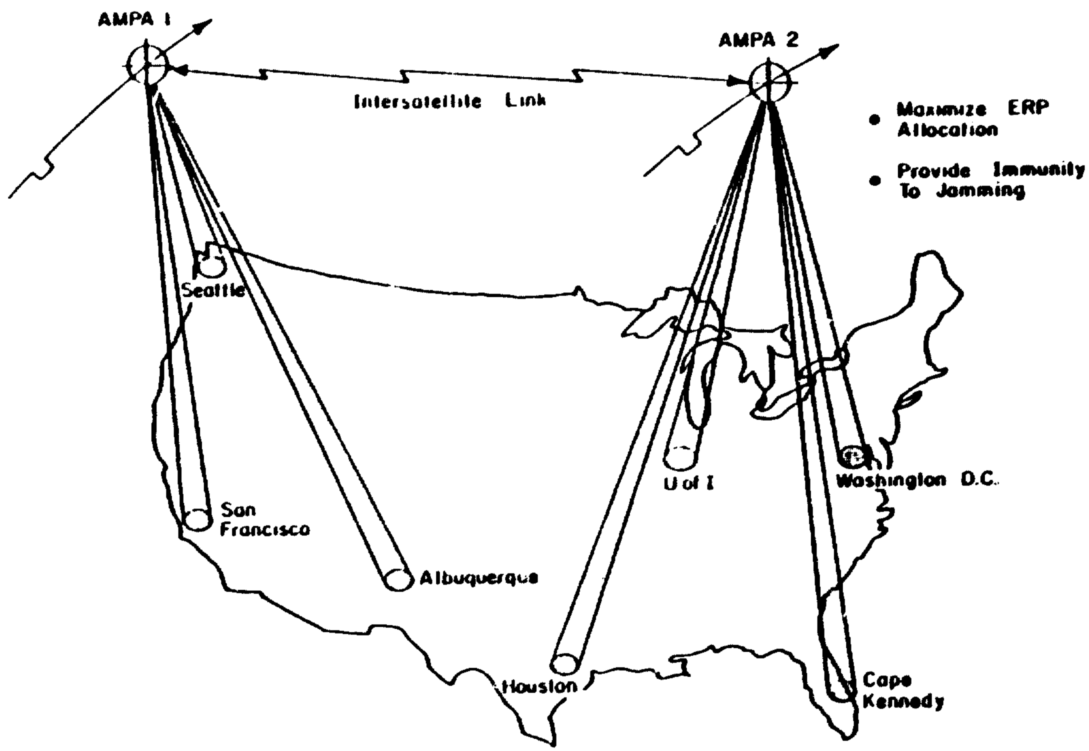


Figure 5: Illustration of a Multiple Beam Antenna Array Directing Independent Beams to Designated Geographical Locations

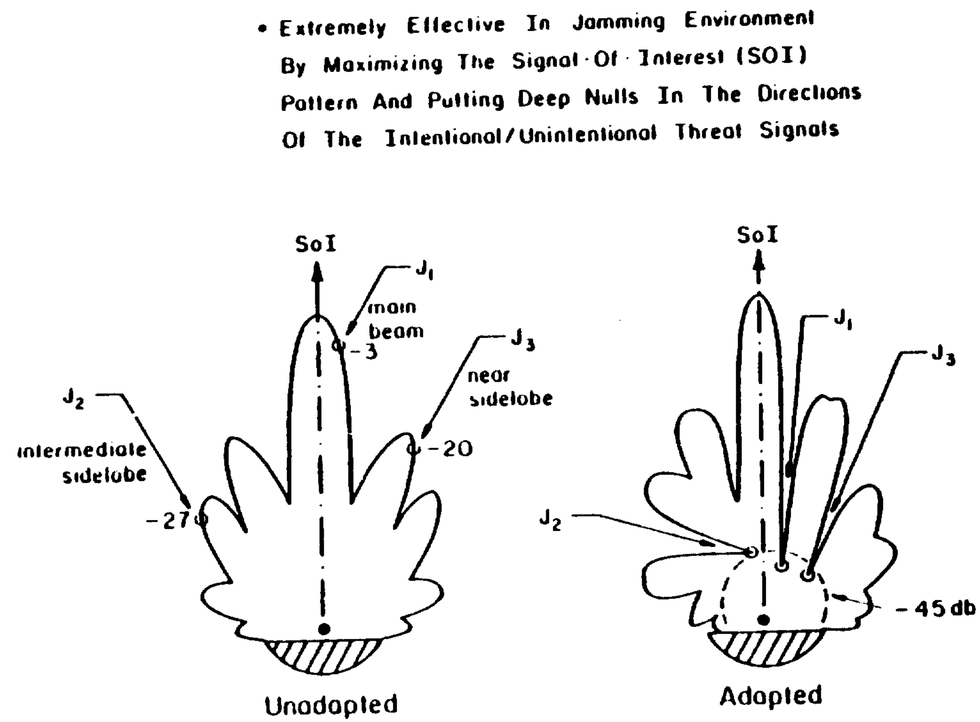


Figure 6: Illustration of an Adaptive Antenna System in an Unadapted and Adapted Mode

action of an adaptive antenna system. The principal AMPA capabilities are listed in Table 2. Another important concept which serves to improve the satellite communication efficiency is the frequency reuse. Frequency reuse is a technique employed for transmitting two separate signals on the same frequency by utilizing two orthogonal polarizations.

In the AMPA communication mode, simplex transmit-receive provides a simultaneous unidirectional link from AMPA to the user-earth terminal and user-earth terminal to AMPA, respectively. Full duplex operation provides a bidirectional link between two user-earth terminals through a modulation/demodulation (modem) process aboard the AMPA, whereas, in the bent-pipe mode, the modem function is omitted. Figures 7, 8 and 9 depict typical simplex, duplex and bent-pipe operations, respectively.

The beam control modes consist of the static programmed pointing, dynamic programmed pointing, adaptive receive and transmit beam pointing, and nulling. The static pointing directs the beam to a fixed direction with respect to the phased array. The dynamic pointing directs the beam to a specific location on the earth. The adaptive receive mode acquires a desired signal and points the beam toward the desired user-earth terminal to maximize the signal-to-noise plus interference ratio (MSIR). In the transmit beam pointing

Table 2 SUMMARY OF AMPA CAPABILITIES

Geolocation

Adaptive Nulling

Frequency Reuse

Beam Controls

- static programmed pointing
- dynamic programmed pointing
- adaptive receive
- transmit beam pointing and nulling

Communications

Modes	Format Available
simplex transmit	narrow-band FM (NBFM)
simplex receive	biphase shift-key (BPSK)
simplex xmt/rcv	pseudo-random noise (PRN)
full duplex	delta-modulation
bent pipe	

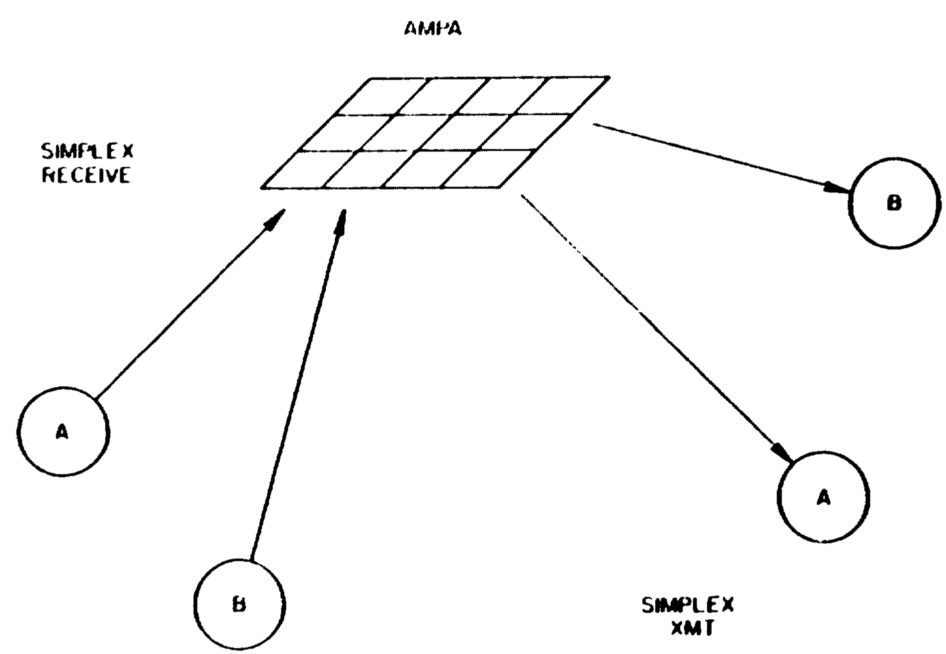


Figure 7: Illustration of a Simplex Transmission in Receive and Transmit

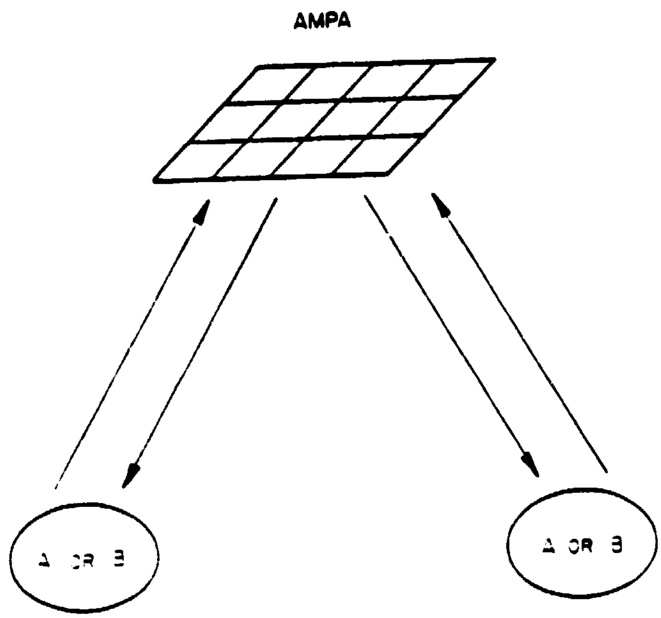


Figure 8: Illustration of a Duplex Transmission with Simultaneous Receive and Transmit

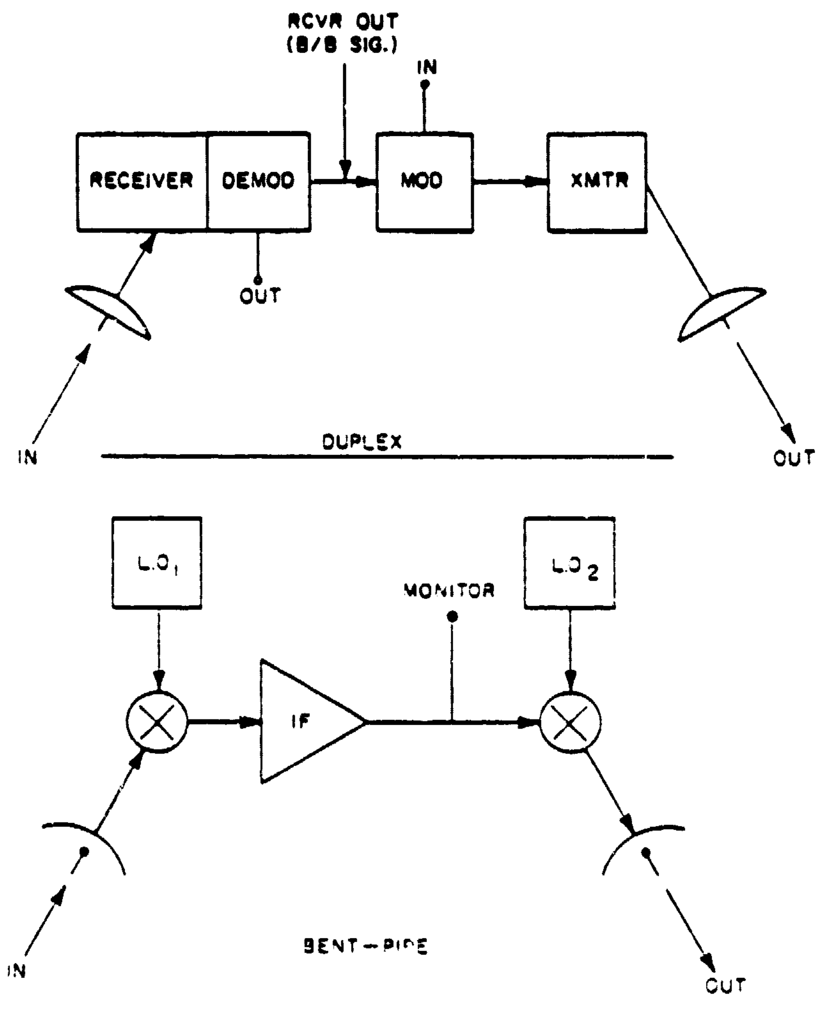


Figure 9: Illustrating the Difference Between the Full Duplex and the Bent-Pipe Transmission Mode

and nulling mode, the transmit beam is peaked to the SOI and nulls in the direction of the undesirable signals. In the geolocation mode, orthogonal elements of the array serve to form a dual baseline interferometer system to determine the angle of arrival of the signal by phase comparison. Tables 3, 4 and 5 list the pertinent AMPA system, antenna and transmitter/receiver characteristics, respectively.

Table 3 AMPA SYSTEM CHARACTERISTICS

Up/Down Link	53 dB-Hz (C/No)
Frequency	
uplink	1646.75+/-1.25 MHz
downlink	1544.75+/-1.25 MHz
Coverage	+/-60 deg. FOV
Number of Beams	
receive	two independent steerable
transmit	two independent steerable
Geolocation	
coarse	+/- 2 deg.
fine	+/- 0.1 deg.

Table 4 AMPA ANTENNA CHARACTERISTICS

Array Size	32 elements
Element Type	Flared Cone Turnstile
Element Gain	7.5 dB
Polarization	LHCP
Array Gain	22 dB
Beamwidth	5 to 10 degrees
G/T	-6 dB/K
EIRP	30.5 dBW/beam

Table 5 AMPA TRANSMITTER/RECEIVER CHARACTERISTICS

Transmitter	
EIRP	0.5 dBW/element
Bandwidth	2.5 MHz
Receiver	
Noise Figure	17 dB
Bandwidth	2.5 MHz
Dynamic Range	55 dB

The User-Terminal characteristics are listed below in Table 6. This represents the equipment required by a typical AMPA subscriber.

Table 6 USER-TERMINAL CHARACTERISTICS

Antenna	
Type	Modified Volute
Coverage	Hemispheric
Polarization	LHCP
Gain	0 dB (overhead)
	+1.9 dB (60 deg.)
	-1.6 dB (horizon)
Receiver	
G/T	-30 dB/K
C/No	53 dB-Hz
Bandwidth	2.5 MHz
Transmitter	
EIRP	10 dBW

IV. LINK CALCULATIONS

The AMPA-User Terminal link model and sample calculation will be presented in this section. Again, the readers are reminded that link closure is absolutely necessary and must be maintained at all times between the AMPA and the user earth terminal for a successful communication link. This criterion applies to any forms of communication and/or data links. Generally speaking, a certain signal-to-noise ratio is required to insure that an adequate amount of signal is available to overcome the various transmission losses, such as free space path losses, atmospheric, polarization, scan losses, and system hardware losses, as well as the inherent system noises in an RF/microwave communication system to provide a useful data output. Figure 10 illustrates a typical multiple AMPA deployment scheme for global coverage.

Satellite communication engineers often tend to use such terminology as carrier-to-noise density (C/No) and gain over temperature in degree Kelvin (G/T) in their link analysis, whereas, the RF/Microwave system engineer (EM type) chooses to use the signal-to-noise ratio (SNR) instead. In this report, the latter is chosen because it is more direct and simpler to visualize in a link calculation. Figure 11 illustrates a communication engineer's version and Figure 12 depicts the RF/Microwave system engineer's approach.

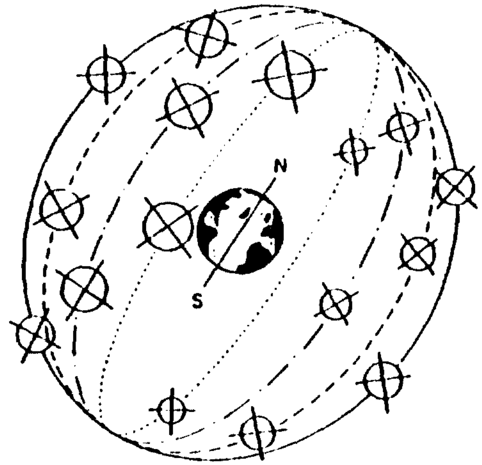
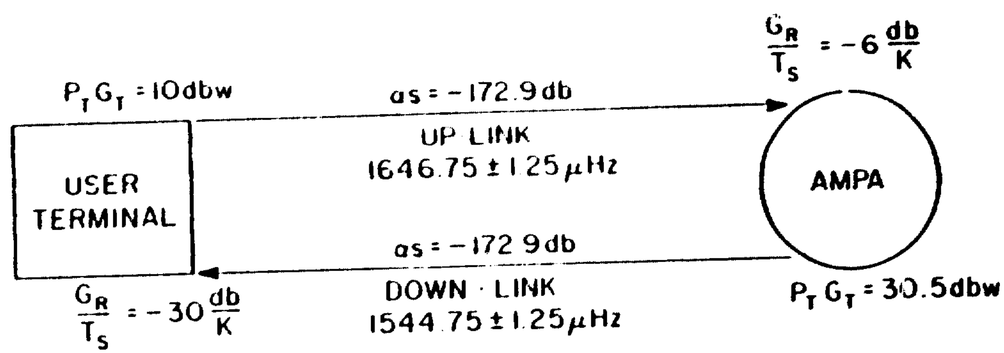


Figure 10: Illustration of a Typical Multiple Satellite Deployment Scheme



from: $\left(\frac{C}{N}\right) = \frac{P_T G_T}{K}\left(\frac{G_R}{T_S}\right) as$, where $K = -228.6$ db/Hz/K

then $\left(\frac{C}{N}\right)_{db\ Hz} = 10 + 228.6 - 6 - 172.9 = 59.7$ db·Hz (up·link)

similarly $\left(\frac{C}{N}\right)_{db\ Hz} = 30.5 + 228.6 - 30 - 172.4 = 56.7$ db·Hz (down·link)

Figure 11: Example of a Link Calculation Using C/No Approach

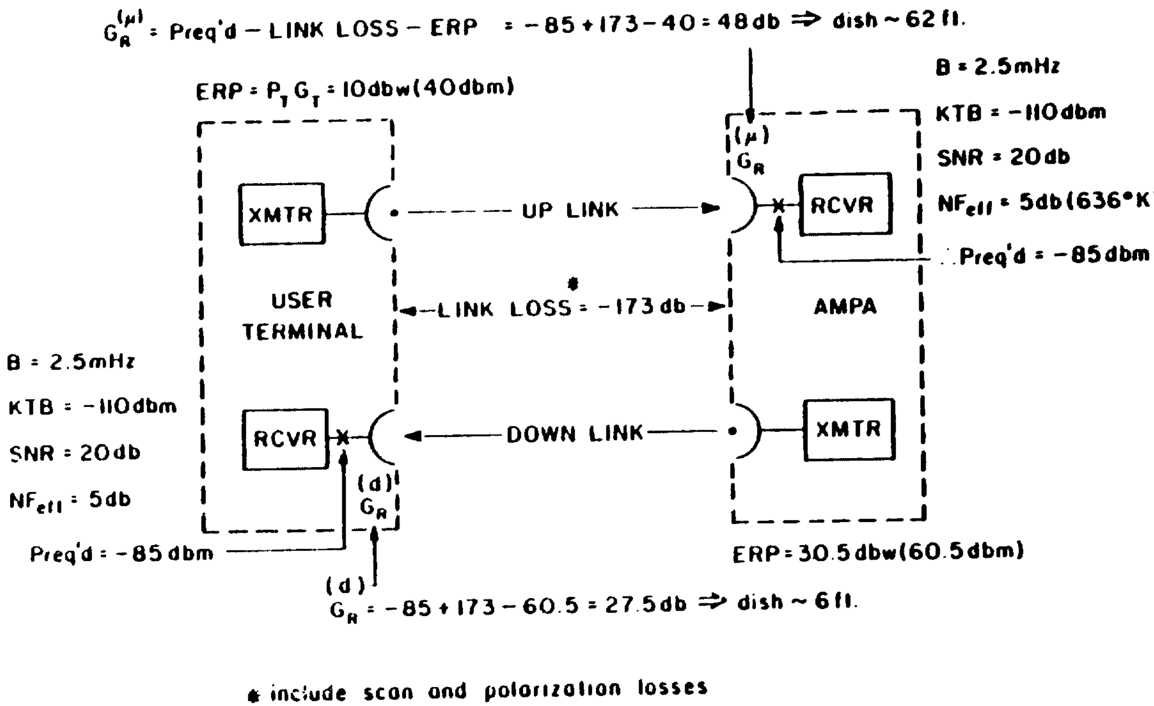


Figure 12: Example of a Link Calculation Using SNR Approach

In Table 7a, an illustrative example of a link calculation for a 400 km (216 nm) orbital altitude is given. In this example, several basic assumptions are made for both the AMPA and user-terminal receiver, that is, the effective noise figure (NFeff) is 5 dB (636 deg. Kelvin), the desired signal-to-noise ratio (SNR) is 20 dB, and the RF bandwidth (BW) is 2.5 MHz. These receiver requirements are well within the SOTA for a system of this kind. Hence, given the effective radiated power (EIRP) of the transmitter, the SNR, the NFeff, and the RF BW of the receiver system, one can readily find the tangential sensitivity and transmission losses to determine the receive antenna gain required to close the communication/data link. A simplified procedure is outlined below:

Step 1. Determine equivalent noise input power (Pn):

$$Pn = 10\mathrm{Log}(kTB)$$

where

k = (1.38x10^-23 joules/K)

T = temperature in degree Kelvin

B = bandwidth in Hz

and if B = 2.5 MHz and T = 290 deg.

Therefore,

$$Pn = 10\mathrm{Log}(1.38\times10^{-23})(290)(2.5\times10^{6})$$

$$= -110 \text{ dBm or } (-140 \text{ dBW})$$

Table 7a LINK CALCULATIONS (Typical)

	User-to-AMPA	AMPA-to-User
EIRP (dBW)	10	30.5
Path Loss (dB)	-163.95	-163.95
Atmos. Loss (dB)	.5	.5
Polar. Loss (dB)	1.0	1.0
Scan Loss (dB)	7.0	7.0
Power Avail. (dBW)	-162.45	-141.95
RF Bandwdth (MHz)	2.5	2.5
Effective NF (dB)	5.0	5.0
Noise Power (dBW)	-140	-140
System Loss (dB)	2.0	2.0
Desired SNR (dB)	20.0	20.0
Rcvr Pwr Req'd (dBW)	-113	-113
Ant. Gain Req'd (dB)	49.45	28.95

Step 2. Determine receiver input power (Pr) required:

$$Pr = Pn - SNR - NFeff - L'$$

where SNR = desired signal-to-noise ratio

NFe = effective noise figure in (dB)

L' = system loss (cables, etc.).

If SNR = 20 dB, NFe = 5 dB and L' = 2 dB

therefore,

$$Pr = -110 + 20 + 5 + 2 = -83 \text{ dBm.}$$

Step 3. Calculate free space path loss (P/L):

$$P/L = 20\text{Log}(\lambda/4\pi R)$$

where λ = c/F (wavelength in m)

R = slant Range in km

c = velocity of light (3x10^8 m/s)

F = Frequency in Hz

and if F = 1640 MHz (nominal), Rmax = 2294.04 km (slant range)

then

$$P/L = 20\text{Log}[3\text{x}10^8/4\pi(1.64\text{x}10^9)(2294.04\text{x}10^3)]$$

$$= -163.95 \text{ dB}$$

Step 4. Determine total transmission loss (Lt):

$$Lt = (P/L) + La + Lp + Ls$$

where P/L = free space path loss (dB)

La = atmospheric loss in (dB)

Lp = polarization loss in (dB)

Ls = scan loss in (dB)

if $La = .5$ dB, $Lp = 1.0$ dB and $Ls = 7.0$ dB

therefore,

$$Lt = -163.95 - (8.5) = -172.45 \text{ dB}$$

Step 5. Find available power (Pa) at the receive antenna:

(a) Given user uplink transmitter EIRP = 40 dBm (10 dBW)

then

$$Pa = EIRP + Lt$$

$$= 40 + (-172.45) \quad = -132.45 \text{ dBm}$$

(b) Given AMPA downlink transmitter EIRP = 60.5 dBm:

then

$$Pa = 60.5 + (-172.45) = -111.95 \text{ dBm}$$

Step 6. Find required receive antenna gain (Gr):

(a) The AMPA receive antenna gain:

$$Gr = Pr - Pa$$

$$= -83 - (-132.45) = 49.45 \text{ dB}$$

and

(b) The user receive antenna gain:

$$Gr = -83 - (-111.95) = 28.95 \text{ dB}$$

It is clear from this illustrative example that, in order to provide link closure, the antenna gain of the AMPA and User-terminal must be 49.45 dB and 28.95 dB, respectively, to have the desired signal-to-noise ratio (SNR). However, with the same scenarios and given equipment specification in section II, the bandwidth must be reduced drastically in order that the link may be closed. Table 7b depicts the required antenna gains if the bandwidth was reduced to 2 KHz. This would place the antenna gains more in the ball park, as given in section II.

Table 7b LINK CALCULATIONS (Reduced Bandwidth)

	User-to-AMPA	AMPA-to-User
Powr Avail. (dBW)	-162.45	-141.95
RF Bandwdth (KHz)	2.0	2.0
Effect NF (dB)	5.0	5.0
Noise Power (dBW)	-171	-171
System Loss (dB)	2.0	2.0
Desired SNR (dB)	20.0	20.0
Rcvr Pwr Req'd (dBW)	-146	-146
Ant. Gain Req'd (dB)	16.45	-4.05

Often terminology can cause confusion, particularly if the parameters are not clearly specified. In brevity, the relationship between the carrier-to-noise density (C/No) and the signal-to-noise ratio (SNR) can be readily shown below.

$$SNR = 10Log(Pr/Pn) = C/N$$

$$= 10Log[PtGtGr(\lambda/4\pi R)\hat{}2/KTB] \text{ dB}$$

and

$$(C/No) = 10Log[PtGt(Gr/T)(\lambda/4\pi R)\hat{}2/K]$$

hence

$$SNR = (C/No) - 10Log(B)$$

where

$$EIRP = 10Log(PtGt)$$

$$P/L = 10Log(\lambda/4\pi d)\hat{}2$$

$$N = 10Log(KT)$$

$$B = \text{bandwidth in MHz}$$

$$Pn = 10Log(KTB)$$

Figure 13 depicts the SNR as a function of the bandwidth for given C/No ratios.

Consider the receiver characteristics from section II Table 6; that is, C/No = 53 dB-Hz amd BW = 2.5 MHz

Then

$$SNR = 53 - 10Log(2.5x10\hat{}6) = -10.98 \text{ dB.}$$

For SNR = 20 dB, this implies that

$$C/No = SNR + 10Log(2.5x10\hat{}6) = 83.38 \text{ dB}$$

and

$$B = (10)\hat{}(53 - 20)/10 = 1995.26 \text{ Hz(2KHz)}$$

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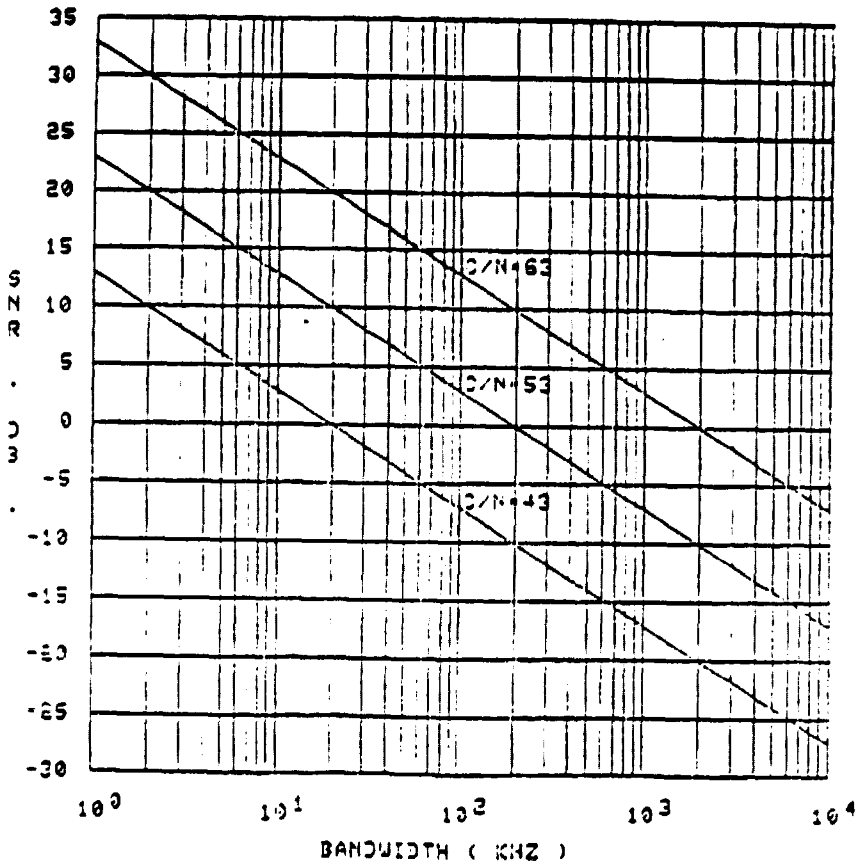

Figure 13: Signal-To-Noise Ratio Vs Bandwidth for Given C/No

Let's take another look at the definition of (C/No). Given EIRP = 10 dBW, P/L = -172.45 dB and if Ts = 636 deg. K, hence let

$$(C/No) = [EIRP + Gr - N + P/L]$$

$$= 10 + Gr -(-200.6)$$

$$+(-172.45) = 53.0$$

Therefore, the expected receive antenna gain

$$Gr = 53 - 38.12 = 14.88 \text{ dB}$$

Similarly, if EIRP = 30.5 dBW, then

$$(C/No) = 30.5 + Gr -(-200.6)$$

$$+(-172.45) = 53$$

Therefore,

$$Gr = 53 - 58.62 = -5.617 \text{ dB}$$

Notice that the bandwidth has not been taken into consideration at this point.

Now let's examine the terminology Receiver Gain-to-Noise Temperature (Gr/Ts). From Section II, Table 4 and Table 6, the AMPA antenna and User-Terminal antenna are specified as -6 dB/k and -30 dB/k, respectively. For the sake of illustration, again assume Ts = 636 deg. K.

Then

$$(Gr/Ts) = 10Log(Gr/Ts) \text{ dB/K}$$

For G/T = -6 dB/K implied the actual antenna gain, therefore,

$$Gr = G/T + 10Log(Ts)$$

$$= -6 + 28.03 = 22.03 \text{ dB}$$

Similarly for G/T = -30 dB/K then

$$Gr = -30 + 28.03 = -1.95 \text{ dB}$$

Extreme care must be exercised when figure-of-merits, such as (C/No) and (G/T), are used in the link calculations. Often times it is not so obvious what the system design engineer has in mind for bandwidths and system noise temperatures. This confusion can lead to an erroneous calculation of the signal margins.

Based on the AMPA and user-terminal specifications given in section II, Table 8 and Table 9 depict the relationship between C/N and SNR at maximum slant range (worst case) at different satellite altitudes for the uplink and downlink, respectively. Figure 14 shows the SNR curves of the uplink and downlink as a function of altitudes. In Table 10 and Table 11 the required antenna gain for a 20 dB SNR is given. Figure 15 gives the corresponding required antenna gain curves for the uplink and downlink.

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Table 8: Uplink C/No and SNR at Max Slant Range

UPLINK

OPERATING FREQUENCY = 1.6400 GHZ

EIRP = 10. DBW

BW = 2.5 MHZ

T = 636. DEG K

G/T = -6. DB/K

K = -228.6 DB/HZ/K

L = 0.5 DB

ALTITUDES (KM)	MAX RANGE(KM)	PATH LOSS(DB)	TOTAL LOSS(DB)	C/N (DB)	SNR (DB)
200.	1609.7563	-160.874	-169.374	63.23	-.75
300.	1979.1344	162.668	-171.168	61.43	-2.55
400.	2294.0424	163.951	172.451	60.15	-3.83
500.	2574.5462	-164.953	173.453	59.15	-4.83
600.	2830.0913	165.777	174.277	58.32	-5.66

Table 9: Downlink C/No and SNR at Max Slant Range

DOWNLINK

OPERATING FREQUENCY = 1.6400 GHZ

EIRP = 30.5 DBW

BW = 2.5 MHZ

T = 636. DEG K

G /T = -30. DB/K

K = -228.6 DB/HZ/K

L = 8.5 DB

ALTITUDES (KM)	MAX RANGE(KM)	PATH LOSS(DB)	TOTAL LOSS(DB)	C/N (DB)	SNR (DB)
200.	1609.7563	-160.874	-169.374	59.73	-4.25
300.	1979.1344	-162.660	-171.160	57.93	-6.05
400.	2294.0424	-163.951	-172.451	56.65	-7.33
500.	2574.5462	-164.953	-173.453	55.65	-8.33
600.	2830.0913	-165.777	-174.277	54.82	-9.16

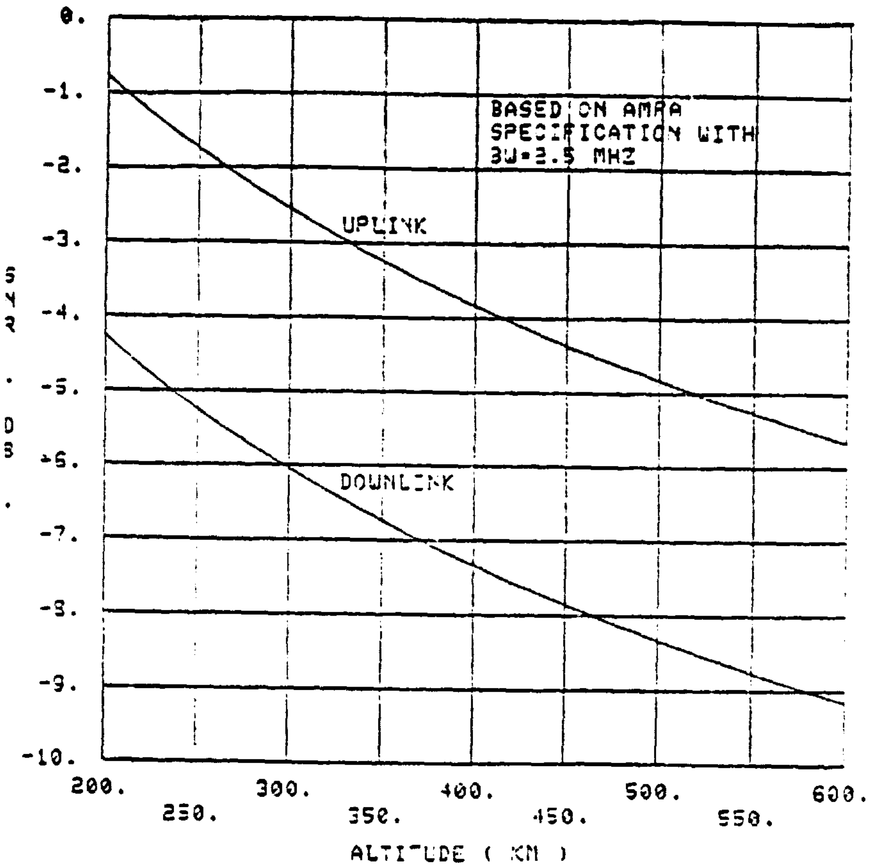

Figure 14: SNR for Uplink and Downlink Vs. Altitude Based on Specification Given in Section II

Table 10: Uplink Required Receive Antenna Gain

UPLINK

OPERATING FREQUENCY - 1.6400 GHZ

EIRP - 10. DBW

BW = 2.5 MHZ

T = 635. DEG K

K - -228.6 DB/HZ/K

L - -8.5 DB

SNR - 20. DB

ALTITUDES (KM)	MAX RANGE(KM)	PATH LOSS(DB)	TOTAL LOSS(DB)	POWER AVAIL(DBW)	RECEIVE POWER REQ D(DBW)	AMPA RECEIVE ANT GAIN(DB)
200.	1609.7563	-160.874	-169.374	-159.374	-116.5872	42.79
300.	1979.1344	-162.668	-171.168	-161.168	-116.5872	44.58
400.	2294.0424	-163.951	-172.451	-162.451	-116.5872	45.86
500.	2574.5462	-164.953	-173.453	-163.453	-116.5872	46.87
600.	2830.8913	-165.777	174.277	-164.277	-116.5872	47.69

Table 11: Downlink Required Receive Antenna Gain

DOWNLINK

OPERATING FREQUENCY - 1.6400 GHZ

EIRP = 30.5 DBW

BW = 2.5 MHZ

T = 636. DEG K

K = -228.6 DB/HZ/K

L = -0.5 DB

SNR = 20. DB

ALTITUDES (KM)	MAX RANGE(KM)	PATH LOSS(DB)	TOTAL LOSS(DB)	POWER AVAIL(DBW)	RECEIVE POWER REQ D(DBW)	USER RECEIVE ANT GAIN(DB)
200.	1609.7563	-160.874	-169.374	-130.874	-116.5872	22.29
300.	1979.1344	-162.668	-171.168	-140.668	-116.5872	24.08
400.	2294.0424	-163.951	-172.451	-141.951	-116.5872	25.36
500.	2574.5462	-164.953	-173.453	-142.953	-116.5872	26.37
600.	2830.8913	-165.777	-174.277	-143.777	-116.5872	27.19

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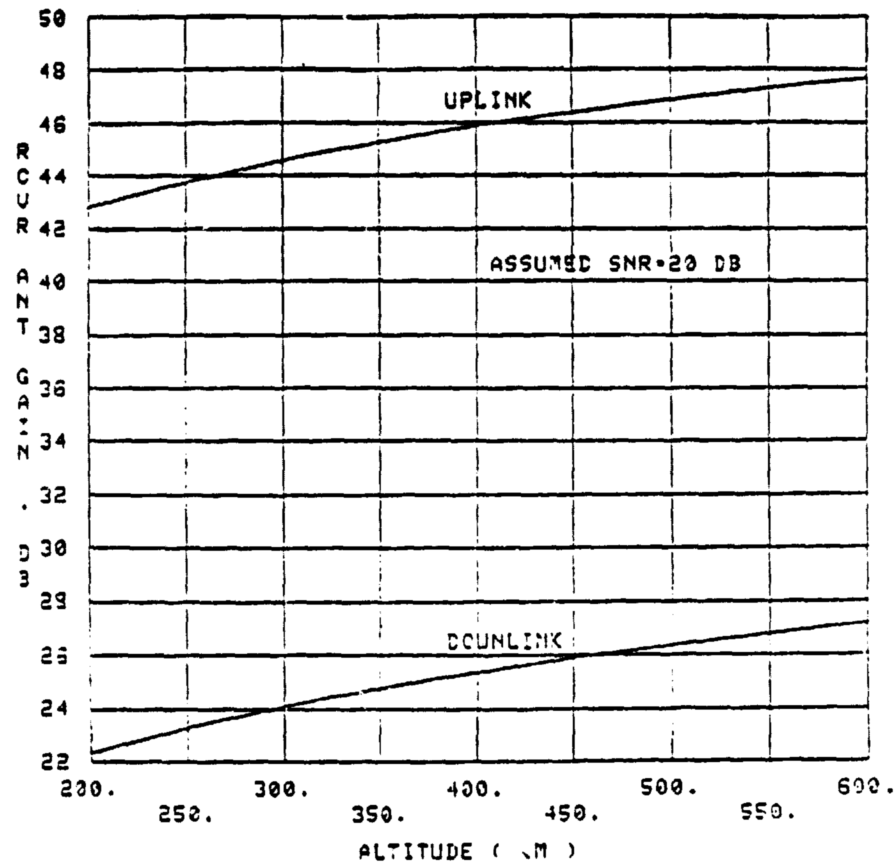

Figure 15: Required Receive Antenna Gain for SNR = 20 dB
Assumed Bandwidth = 2.5 MHz

V. APPLICATIONS

This section will discuss the principal objectives of this study effort, conceptualizing new or improved viable applications by utilizing the basic design features and technology employed in AMPA. To begin with, a low-orbital satellite has its own set of requirements as opposed to geo-synchronous satellites. Namely, geo-synch are virtually stationary and do not have any tracking dynamics with which to contend. Nevertheless, low-orbital satellite concepts are viable candidates for certain commercial telecommunication applications, in particular, tactical and strategic military functions. Of course, the biggest drawback with low-orbital satellites is the need to cluster them in appropriate orbits to obtain the desired coverage and observable period. Recall that typical acquisition time from one horizon to the other is about 10 to 15 minutes. Furthermore, for certain applications, it might be advantageous to be able to observe two or more satellites from any User-Terminal on the ground at any given time. Then the satellites must be deployed in the appropriate orbital geometry to obtain the desired global network. Hence, an orbiting satellite will have tracking and other flight dynamic requirements to be considered.

Table 12 provides a list of the pertinent technological capabilities and potential applications. The two major technological areas are the multi-beam and adaptive antenna systems. These concepts are vital in dense interference environments, particularly where the threats of jamming signals are intentional. Adaptive antenna systems will steer nulls in the directions of the intentional/unintentional threat signals and at the same time maintain or maximize the main-beam onto the direction of the signal-of-interest (SOI). Multi- beam concept provides additional rejection to interferers by directing beams to designated geographical locations. These controlled beam shapes will tend to optimize the power allocation. This will also provide spatial separations between the different geographical locations. Another useful technique is the frequency-reuse. This allows simultaneous use of the same portion of the spectrum by polarization diversity, that is, utilizing the orthogonal linear polarizations.

Much of the conceptual discussions herein will be slanted toward military applications, since military applications are more apt to employ adaptive and multi-beam antenna systems for deployment in severe threat environments. Secure communications and anti-jam constraints are also bases for major military communication systems design and development. Table 13 lists a few of the more commonly used techniques in secure communications. However, secure communication and electronic counter-measures are mentioned only in passing and will not be discussed in this report. It is obvious that the combination of these techniques will play an important part in the design consideration on a tactical and/or strategic system by improving its survivability and vulnerability to electronic counter-measures (ECM).

Table 12 TECHNOLOGY & APPLICATIONS

MAJOR TECHNOLOGICAL CONCEPTS:

- Adaptive Antenna Technology
- Multi-beam Technology
- Polarization Diversity

APPLICATIONS

- Tactical/Strategic Deployment
  - Long Range RPV (Over-the-Horizon)
  - ICBM Terminal Guidance
  - Reconnaissance Platform
- Maritime/Aeronautical Service
- Global Position Satellite Interface
- Meteorological Surveillance
- Remote-Sensing Platform
- International Mail System
- Corporate Business System
- Large-Aperture Antenna Test System

Table 13 SECURE COMMUNICATIONS TECHNIQUES (typical)

Spread Spectrum

Frequency Agility

Multibeams

Pseudo-Random Noise (PRN)

Cryptographic

Polarization Diversity

Adaptive Antenna Techniques

Time Division Multiple Access (TDMA)

During this last decade, much emphasis has been placed on development of unmanned tactical systems, such as remote piloted vehicles (RPV) and cruise missiles. Long range telemetry and guidance are classical problems because of range limitations and inherent tracking problems associated with low altitude vehicles. Figure 16 depicts a typical scenario of a low altitude flying RPV penetrating a low angle radar defense system. The RPV will be in constant view of AMPA and a continuous telemetry and guidance updating can be provided through the terminal phase of the mission. Through this illustrative scenario, AMPA served as the telemetry, tracking and control (TT&C) platform. The instant the RPV(s) are launched TT&C functions can be handed over to AMPA. The entire flight profile of the RPV(s) can be controlled and monitored from the ground or shipboard command post via AMPA.

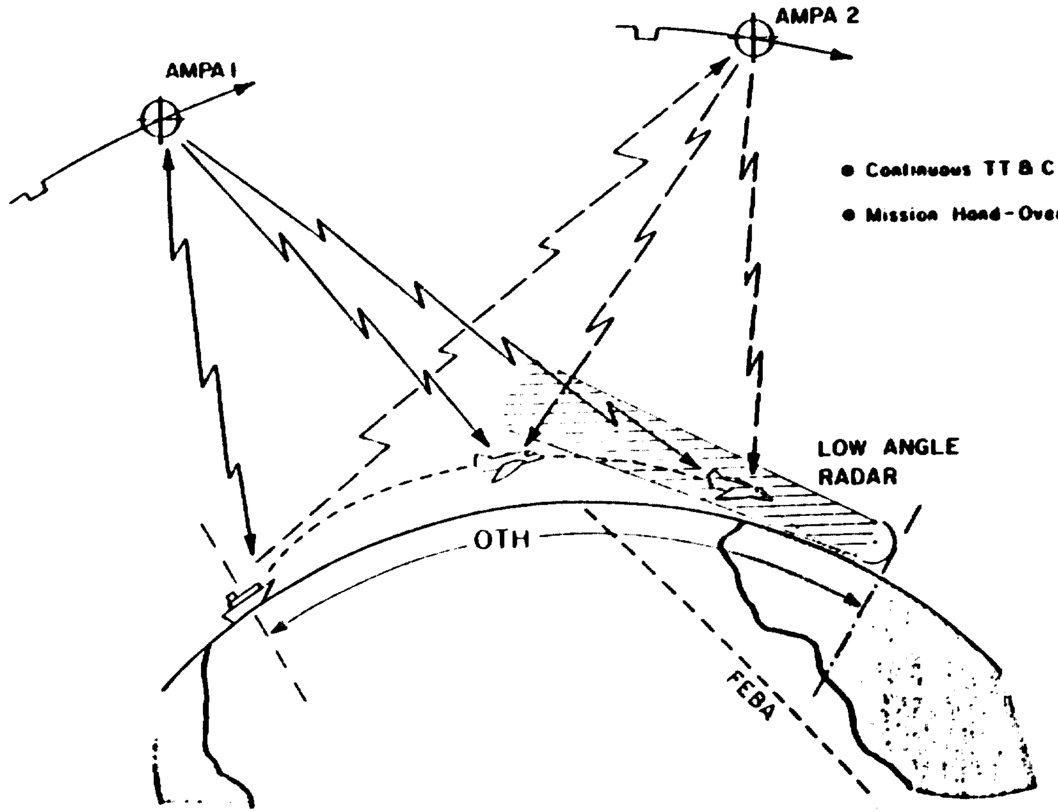

Figure 16: Illustration of a Typical Tactical Mission Deployment for a Long Range RPV - OTH Scenarios

Furthermore, a linkup with NAVSTAR for the GPS will provide precise navigational data for updating the flight profiles of the RPV(s). In the event of a jamming situation, the TT&C functions may be transferred over to other AMPA(s) that are within the FOV of the RPV(s).

Figure 17 illustrates AMPA in an intercontinental ballistic missile(ICBM) strategic scenario. Similarly, AMPA will serve as the TT&C platform but can also serve independently as command post with predetermined flight plans and trajectories transferred via high data burst from the launch vehicle. This, of course, will imply that some form of computer memory is required aboard AMPA to store the command post functions. In conjunction with GPS data from NAVSTAR, continuous trajectory updating for terminal guidance is possible. This capability will improve the target circular-effective-perimeter (CEP) accuracy.

Numerous military applications are possible; however, additional instrumentation will be required. For instance, AMPA can be deployed as a reconnaissance system. Just to mention a few - this could include sensors, such as radiometer, synthetic-aperture radar (SAR) and video or infrared (IR) camera systems. Depending on the specific mission requirement, a combination of these sensors may be incorporated aboard AMPA. The entire reconnaissance mission can be directed and monitored from one or more strategically located earth stations.

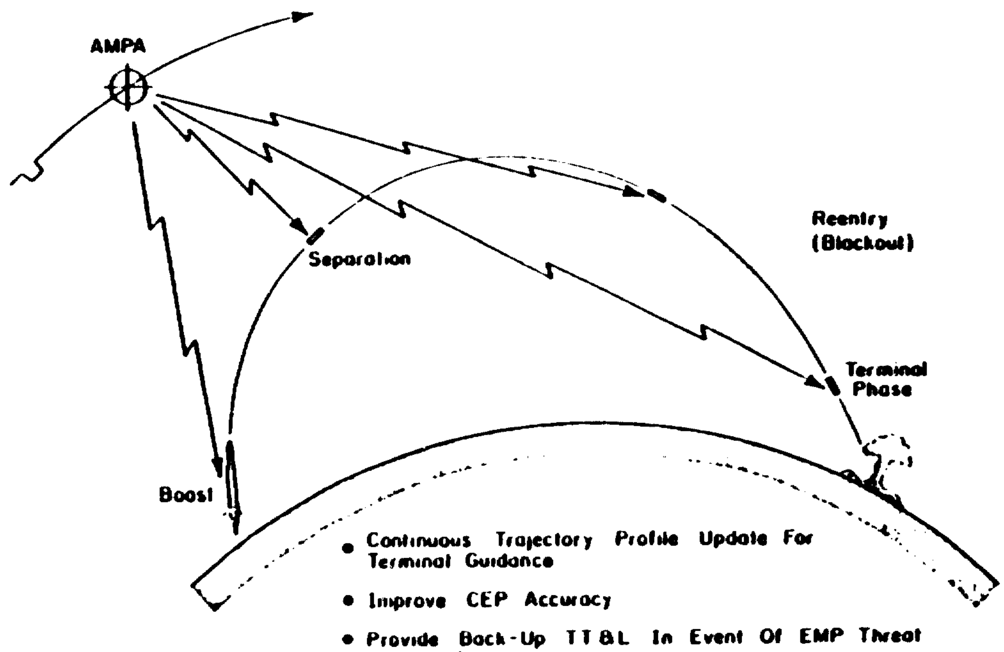

Figure 17: Illustration of a Typical Strategic Deployment for an ICBM/MRV Delivery System

Low altitude polar orbiting AMPA will be able to cover major portions of the world's oceans as it is encircling the earth. It is conceptually feasible that AMPA can be deployed for maritime and aeronautical services. Figure 18 illustrates AMPA(s) deployed in the maritime and aeronautical services. These services can be operated separately or jointly by agencies, such as the U.S. Coast Guard (USCG) and/or Federal Aviation Administration (FAA), or even in a consortium with other nations to provide world-wide coverage. AMPA scans the oceans and air-space for ships and aircrafts and relays its geographical positions and status to their respective agencies for traffic control and coordination. Again, coupling AMPA to NAVSTAR, precise geographical positions for the ships and aircrafts can be obtained. Furthermore, in the event of an emergency, the geo-location system aboard AMPA will provide precise location data of the distress beacon signal to enable rapid search and rescue missions.

Needless to say, a link with NAVSTAR for the GPS capabilities is crucial for precision navigational information. Similarly, numerous other AMPA deployments are possible by incorporating additional instrumentation or sensors for meteorological and earth resource remote sensing services for agencies, such as the National Oceanic & Atmospheric Administration (NOAA).

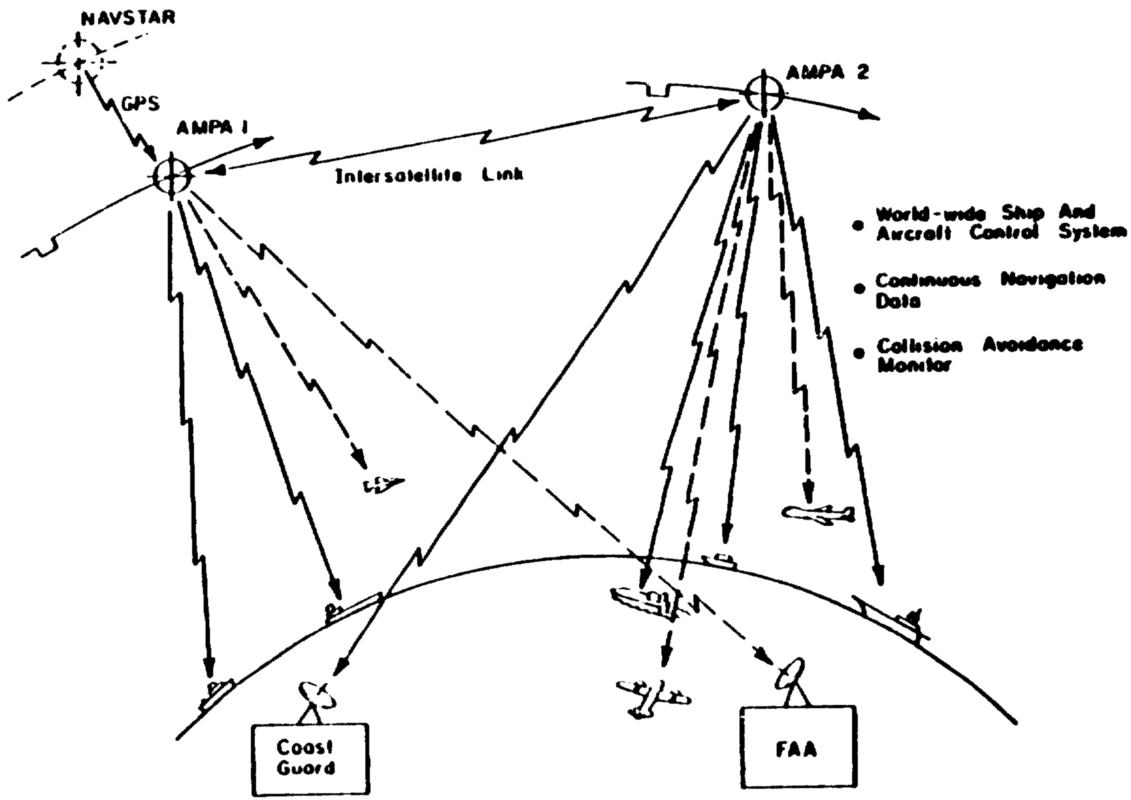

Figure 18: Illustration of a Maritime/Aeronautical Scenario

In the commercial services, AMPA can provide subscribers with a low-cost high-speed data transmission relay link for international mail services, corporate and financial businesses, world-wide medical and health services, educational centers, etc.. Figure 19 demonstrates AMPA as a far field test platform for measuring radiation patterns of extra large aperture antenna systems.

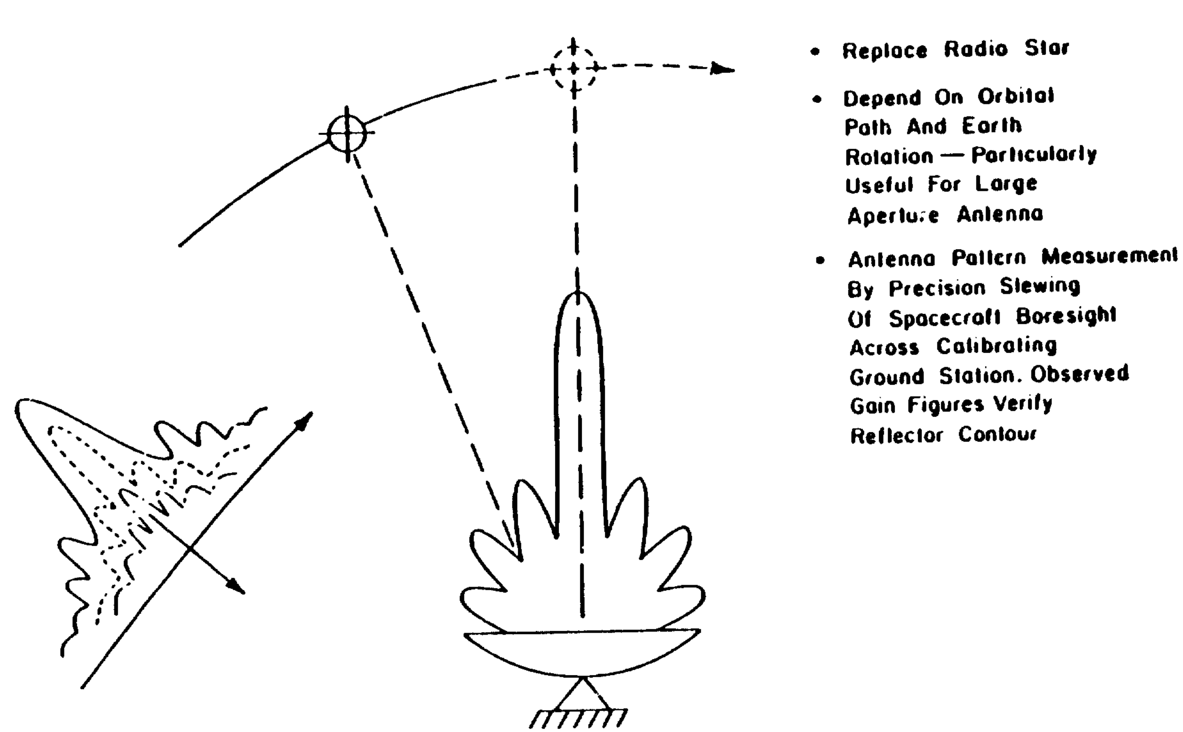

Figure 19: Illustration of a Far Field Test Platform for Extra Large Aperture Antenna System

VI. TRADE-OFF & SYSTEM REQUIREMENTS

As mentioned earlier, no attempts will be made to modify AMPA, but rather, a "use it as it is" format will be used in postulating other applications. However, this ground rule only applies to certain cases in the commercial telecommunication applications. Most of the AMPA features listed in Section II can be used for simple point-to-point digital and narrow-band FM commercial applications. But, a certain amount of hardware and software modifications will be required to meet the peculiar system or operational requirements. The more sophisticated military-type applications will definitely require extensive design modifications before they can qualify as tactical hardware. For example, just to mention a few of the more common military-type system requirements: such subtleties as specific frequency assignments, electromagnetic interference (EMI) shielding, radiation hardening, structural ruggedization, redundancy capabilities, electronic counter-measures (ECM), and communication security will have to be considered and incorporated into the system design. For the special reconnaissance applications, additional instrumentation and software back-up will be required. Specialized sensors, such as radiometer, SAR, video or IR optical system, may be required, depending on the mission deployment.

Serious system trade-off will be required by the potential AMPA user to determine if the basic AMPA features given in Section II are adequate to meet their specific mission or system performance requirements. From the program management point of view, would it be cost-effective to use AMPA, or even worthwhile to make any modifications? What are the reliability factors and growth capabilities of AMPA?

Since AMPA was originally intended for the maritime and aeronautical services, the FCC frequency allocation was in the L band region. For other services, appropriate FCC designated frequency band conformance will be required. This will greatly impact the potential user. New link calculations and system performance analysis must be performed to insure system integrity and hardware design compatibilities.

Figure 20 depicts an AMPA utilization chart. This chart shows how the different AMPA features may be configured for the various applications.

UTILIZATION CHART

	AMPA CAPABILITIES	TACTICAL / STRATEGIC	SECURE COMMUNICATION	MARITIME / AERO	SURVEILLANCE / SEARCH / RECOVERY	POSTAL	METEORLOGICAL / REMOTE SENSING	RELAY / TEST	PLATFORM	
	GEOLOCATION	X		X	X					
	ADAPTIVE NULLING	X	X	X	X					
	FREQUENCY REUSE	X	X	X		X	X			
BEAM CONTROL ●	● STATIC PROGRAM POINTING			X	X	X	X			
	● DYNAMIC PROGRAM POINTING	X	X	X	X	X	X			
	● ADAPTIVE RECEIVE	X	X	X	X	X	X			
	● TRANSMIT BEAM POINTING / NULL	X	X	X	X	X	X	X		
COMMUNICATION MODES Δ	Δ SIMPLEX RECEIVE		X				X	X		
	Δ SIMPLEX XMT		X				X	X		
	Δ SIMPLEX XMT /REV		X	X	X	X				
	Δ FULL DUPLEX	X	X	X	X	X	X	X		
	Δ BENT PIPE	X	X	X	X	X	X	X		
COMMUNICATION FORMATS ▲	▲ NBFM			X	X		X	X		
	▲ BPSK	X	X	X	X	X	X	X		
	▲ PRN	X	X		X	X	X	X		
	▲ Δ - MOD		X							

Figure 20: AMPA User Utilization Chart for System Configuration

VII. COMMENTS & RECOMMENDATIONS

In this section, a candid critique and opinion of the AMPA system with particular emphasis in RF/Antenna system areas will be expressed.

Conceptually, AMPA should have been a cost-effective system, but exorbitant development costs have reduced its attractiveness. In view of the partial testing conducted at AIL on December 7, 1981, and the limited data presented during the final project presentation at NASA - Lewis Research Center on April 4, 1982, the system left much to be desired. There were no real comprehensive test results to demonstrate or signify that AMPA has met all of its design or performance goals.

The antenna patterns presented were confusing and lacking definition. It is not clear which lobe is the main beam nor where the boresight is supposed to be. The antenna measurements conducted on December 7, 1981, were far from laboratory condition. Wind conditions on the roof-top test range were high. Large puddles of water accumulated from the rain or snow and other roof-top obstacles contributed to the multiple scatterings as evident by the jitters and noise on the antenna pattern measurements.

The adaptation performances are below expectation. Under current adaptive antenna technology, one could expect to achieve a jammer noise cancellation in the order of 50 dB for a 400 MHz broadband noise jammer and 70 dB for a narrowband or CW signal. Furthermore, the jammer injected at or near the first null of the antenna radiation pattern is not a fair test for adaptation. A more valid test would be to place the jammer at the half beamwidth of the mainbeam, first and intermediate sidelobes, particularly, the grating lobes. In passing, adaptation at RF rather than at IF can improve the overall adaptive system by avoiding all the accumulated phase dispersions through the mixers and IF(s). Phase and amplitude matchings of the RF hardware are critical.

As mentioned earlier throughout this report, our prime concern was to insure that the communication or data link closes with an acceptable SNR or C/N, as a safety margin. Off hand, judging from the array design, it is not obvious how it can have an antenna gain of 22 dB. Even if it did, the negative gain of the user-terminal antenna would result in a gross gain deficiency in closing the link for a path loss of -173 dB and a 2.5 MHz system bandwidth for the given EIRP and G/T. As a rule, a 10 to 20 dB SNR or C/N would be a conservative safety margin for most types of telecommunication links in the event of severe fading or adverse propagation conditions. These facts were mentioned at the final project meeting. The AIL personnel in attendance chose not to elaborate or attempt to explain why and/or how 53 dB-Hz C/No is sufficient to close the link. Instead, they (AIL) said that this link analysis was done two years ago and that NASA had concurred, and furthermore, that the bandwidth was not 2.5 MHz but instead more like 15 KHz and that they had a signal processing gain. The fact of the matter is, for a predetection system bandwidth of 2.5 Mhz, mother nature (KTB) will provide -110 dBm or -140 dBW of input noise power. Again, unless the system bandwidth and temperature are clearly specified it can certainly cause erroneous and misleading link calculations.

Another puzzling fact that is not so obvious is: Why go through the trouble and expense of having a low noise amplifier (LNA) with a noise figure (NF) of 2.0 dB and then place 15 dB of loss in front of it and come up with an effective noise figure (NFeff) of 17 dB?

It is our opinion that a detailed RF and antenna system test program is necessary to provide a comprehensive engineering evaluation of the overall system design so corrective action may be taken. It is anticipated that AMPA will require some extensive modifications and redesign effort before it can meet all the system performance requirements and design goals.

As it stands, the AMPA system hardware serves no purpose except the computer portion. It is indicative that some more design and development work will be required if this system concept is to be pursued further. The universities are definitely interested in the analytical and theoretical aspect; but, it would be prohibitive from a financial point of view to maintain and operate such a complex system. Also, it would take too long for someone to get fully intimate with the system before any useful work can be done. It was suggested during the final project meeting on April 4, 1982, that perhaps some governmental or military agency with appropriate facility and technical personnel with the expertise in the area of multiple beam and adaptive antenna systems could provide a home for AMPA and the universities could provide the theoretical and analytical support.

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