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REPORT

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ABSTRACT/CONCLUSIONS

This report addresses the utilization of the GPSPAC, which is presently being developed by Magnavox to be used on the Low Altitude Host Vehicle (LAHV), for possible use in the Shuttle Avionics System to evaluate Shuttle/GPS Navigation Performance. Included in this report are analysis and tradeoffs of the Shuttle/GPS link, Shuttle signal interface requirements, Oscillator tradeoffs and GPSPAC mechanical modifications for Shuttle. The report has addressed only the on-orbit utilization of GPSPAC for the Shuttle. Other phases are briefly touched upon. Finally, the report provides recommendations for using the present GPSPAC and the changes required to perform shuttle on-orbit navigation.

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SHUTTLE/GPSPAC EXPERIMENTATION

DEFINITION STUDY

Final Report For

NASA JOHNSON SPACE CENTER
Houston, Texas

AUGUST 15, 1977

Prepared Under Contract NAS 9-15314

By

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1.0 INTRODUCTION

Preliminary studies at Johnson Space Center and other shuttle-related organizations have determined that the NAVSTAR Global Positioning System could significantly improve shuttle navigation performance, particularly during critical mission phases, and would offer autonomy from ground tracking stations.

This report addresses the utilization of the GPSPAC, which is presently being developed by Magnavox to be used on the Low Altitude Host Vehicle (LAHV), for possible use in the Shuttle Avionics System to evaluate Shuttle/GPS Navigation Performance. Included in this report are analysis and tradeoffs of the Shuttle/GPS link, Shuttle signal interface requirements, Oscillator tradeoffs and GPSPAC mechanical modifications for Shuttle. The report has addressed only the on-orbit utilization of GPSPAC for the Shuttle. Other phases are briefly touched upon. Finally, the report provides recommendations for using the present GPSPAC and the changes required to perform shuttle on-orbit navigation.

II. GPSPAC Description

The GPSPAC is the first GPS/NAVSTAR receiver specifically intended for use on orbiting vehicles. This program began in October 1976 and is scheduled to run out to October 1978. Prototype units 1 and 2 are scheduled for system integration and test in May and June of 1978. Flight models 1 and 2 are scheduled for system integration and test in August and September of 1978.

The GPSPAC experiment consists of a receiver/processor (R/PA) being developed by Magnavox which is combined with the Applied Physics Laboratory (APL) supplied interface and support equipment mounted on a single pallet to be flown on the NASA Low Altitude Host Vehicle (LAHV) spacecraft. Fig. 1 shows the R/PA configuration.

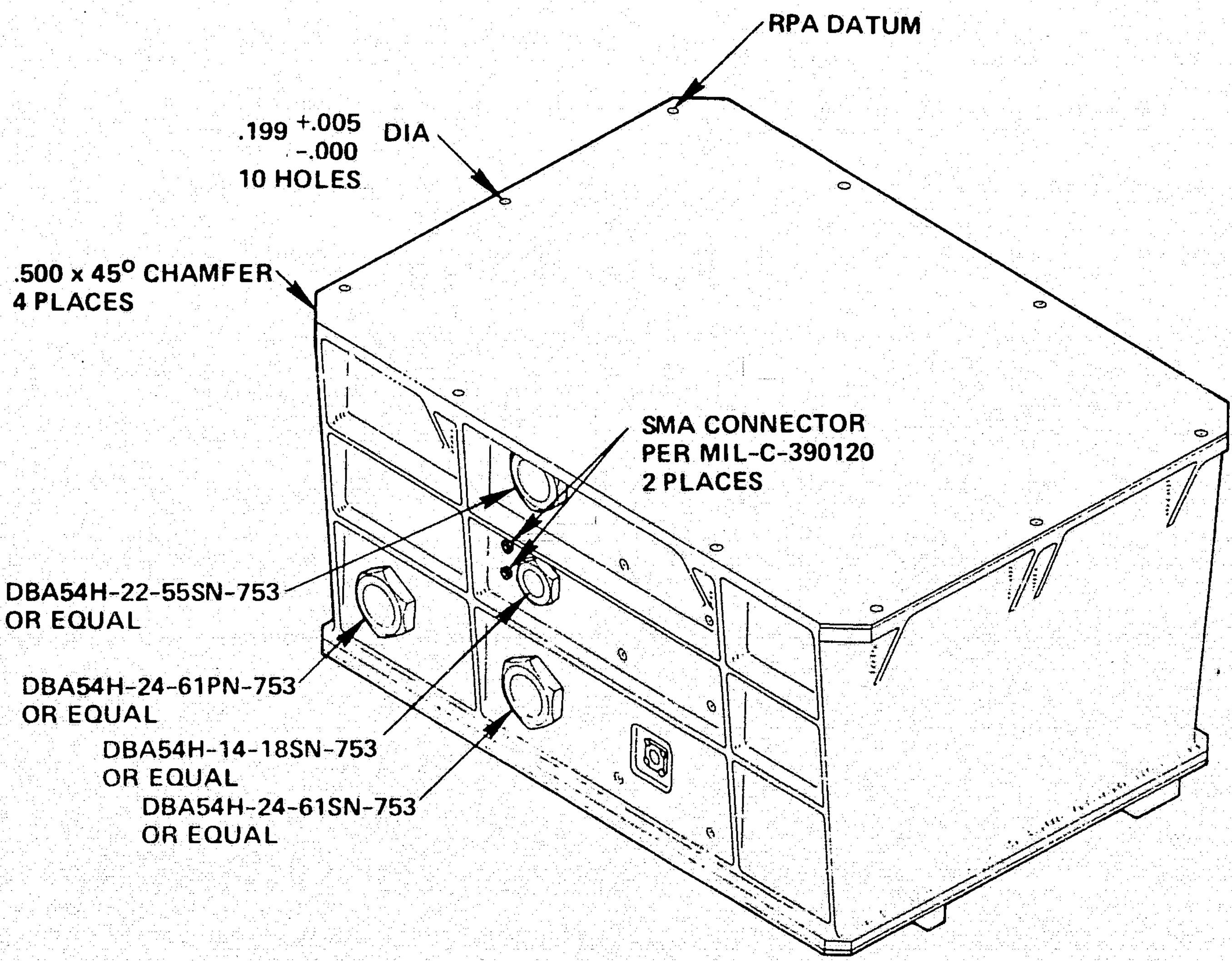

Fig. 1 - R/PA Assembly

The object of GPSPAC is to provide highly accurate on-board, three dimensional position, velocity and time determination of the HV using the signals from the GPS constellation of Navigation Development Satellites (NDS's). The R/PA consists of hardware and software (computer programs) to receive and process GPS navigation signals for accurate positioning and predicting of a satellite host vehicle in real time. In addition, extensive post-processing analysis of raw GPSPAC data will be performed by the experiments.

Fig. 2 shows the basic modules and how they relate to the other GPSPAC components for the LAHV. Fig. 2 also identifies which items comprise the R/PA. The R/PA interfaces with the antenna/preamplifier assembly, HV prime power, precision reference oscillator, and telemetry/command interface (T/CI) for telemetry command/data transfer. The antenna, preamplifier and oscillator are APL supplied items. Figures 3, 4, 5 and 6 provide the functional, operational, environmental and physical requirements of the GPSPAC as it is presently configured for the LAHV.

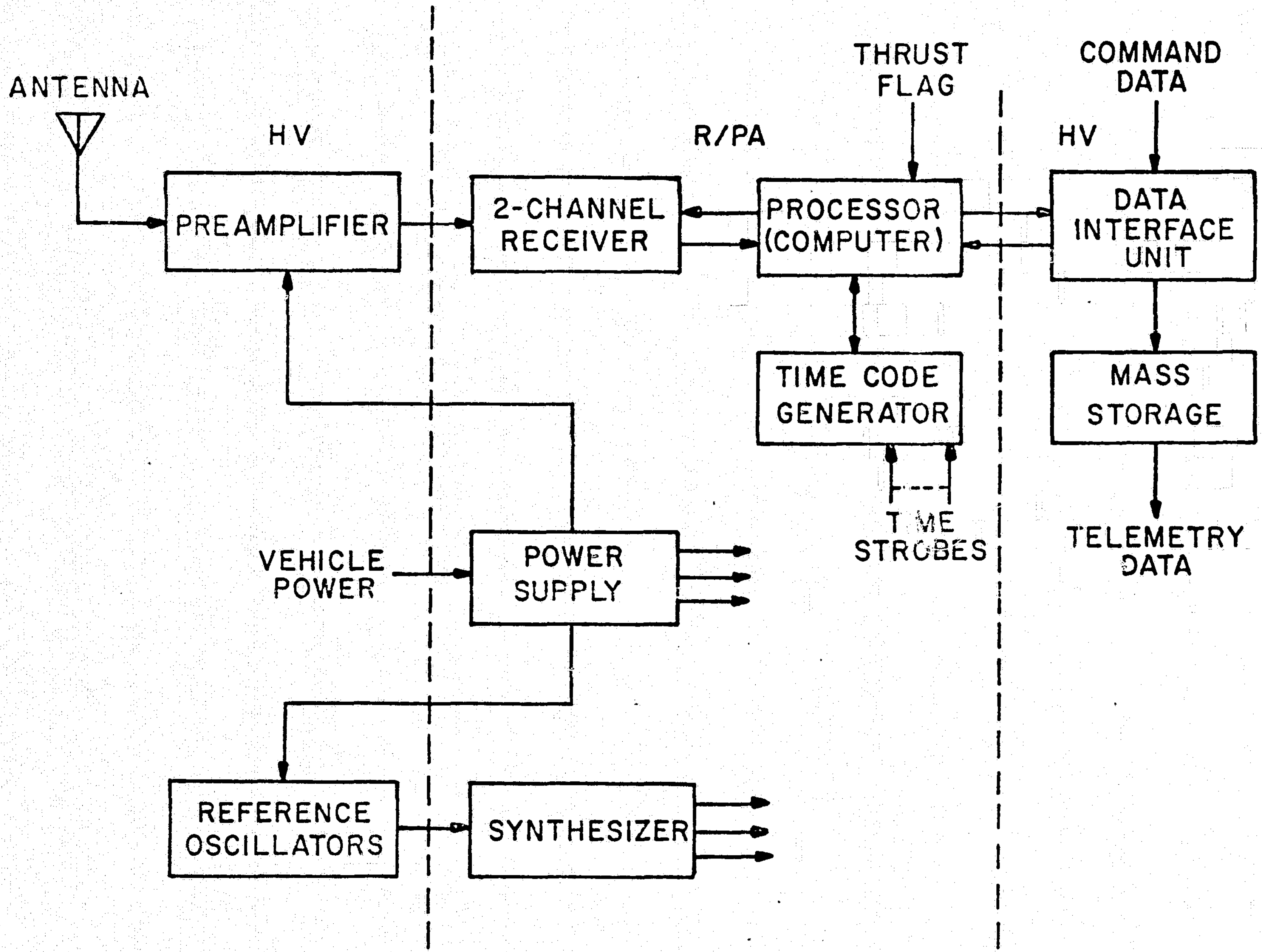

FIG. 2 - GPSPAC FOR LAHV

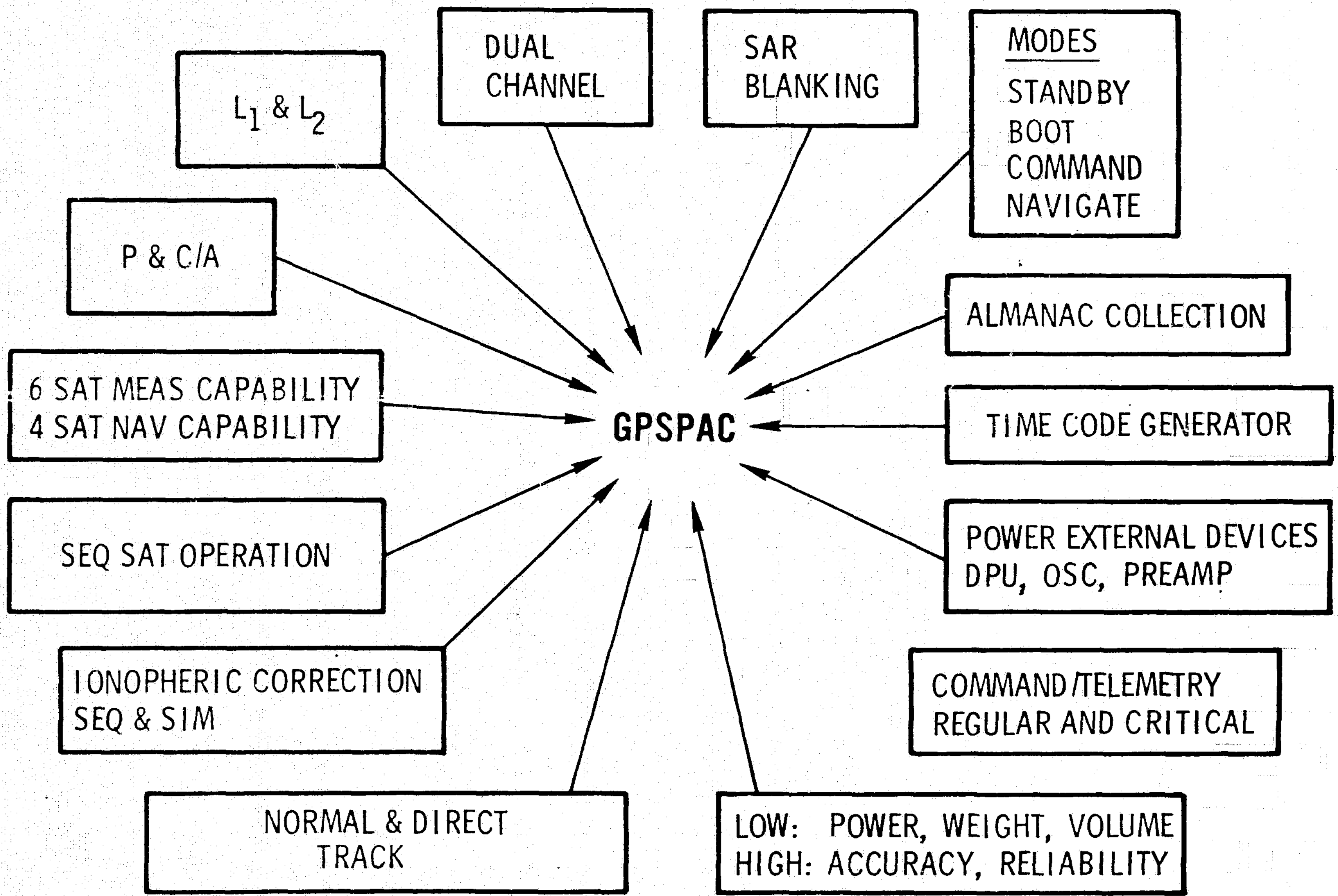

FIG. 3 - GPSPAC FUNCTIONAL CHARACTERISTICS

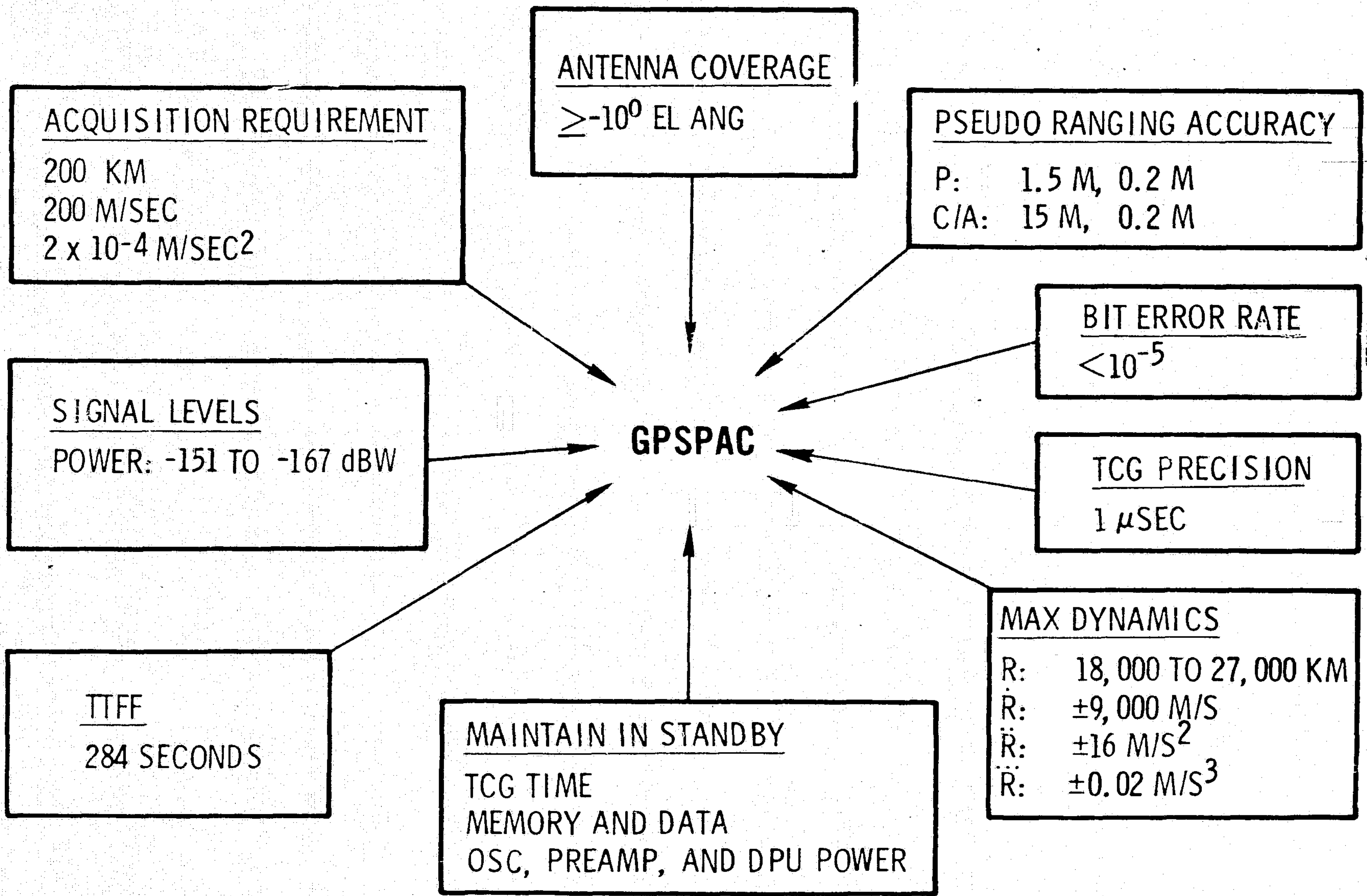

FIG. 4 - GPSPAC OPERATIONAL CHARACTERISTICS

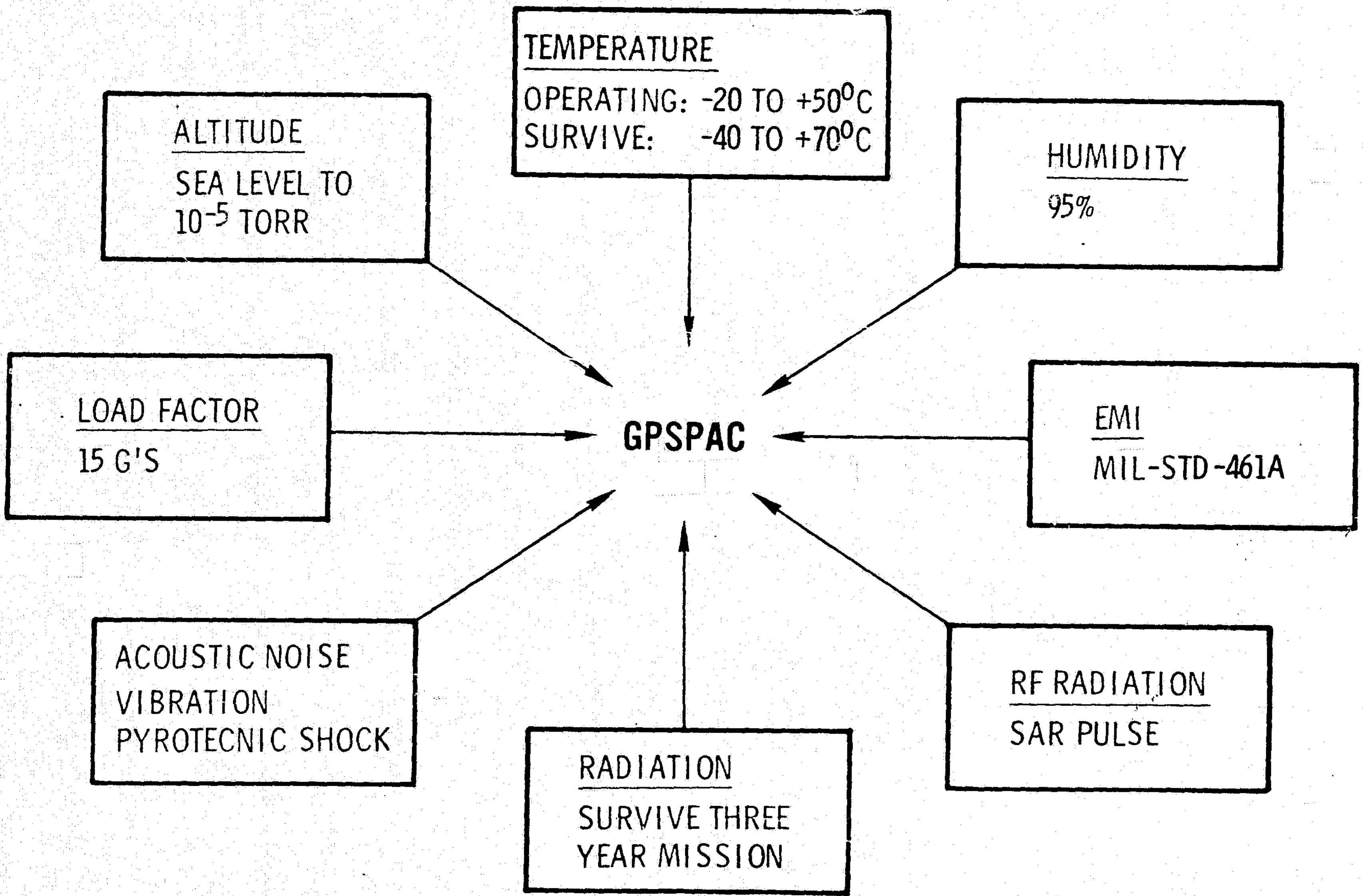

FIG. 5 - GPSPAC ENVIRONMENTAL CHARACTERISTICS

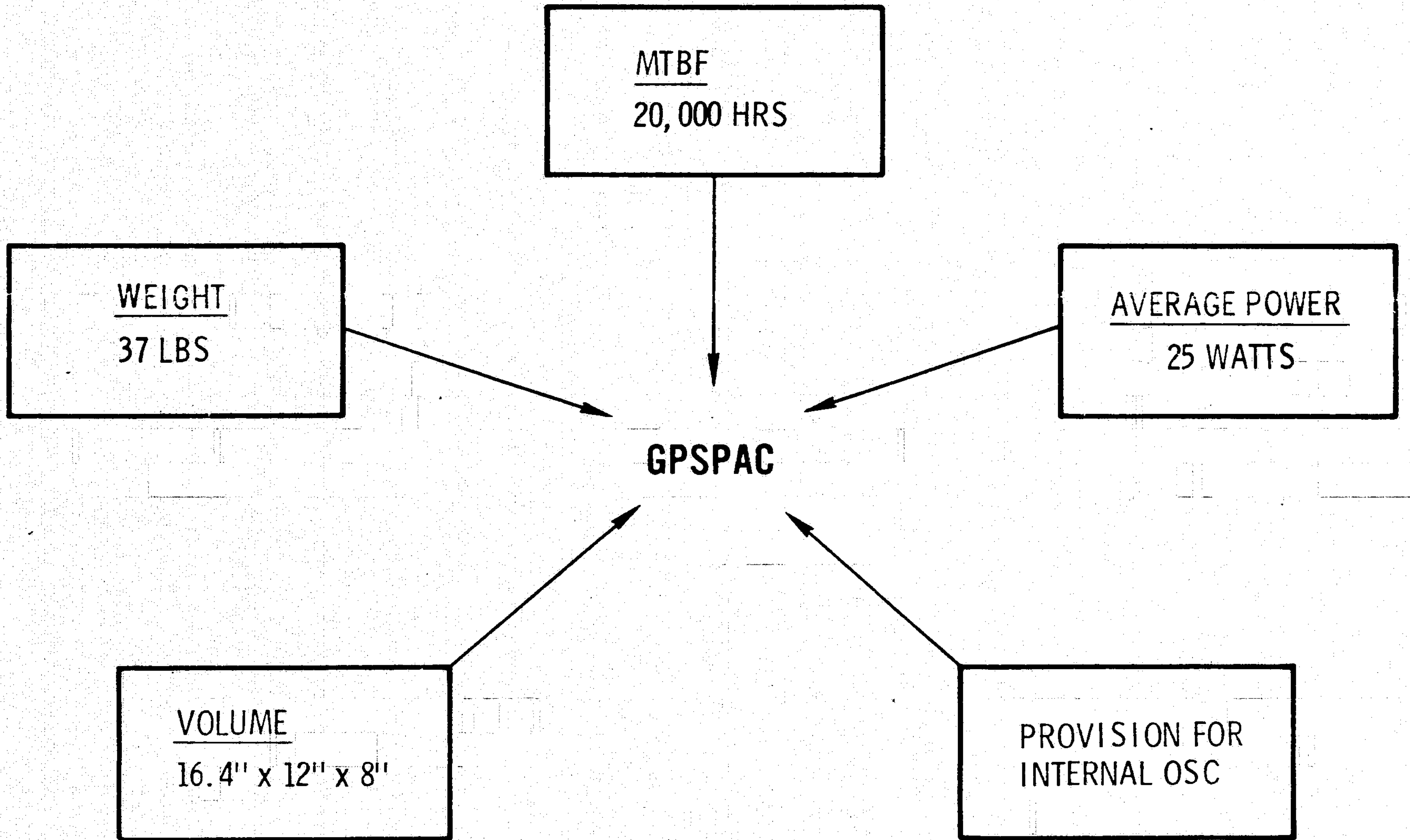

FIG. 6 - GPSPAC PHYSICAL CHARACTERISTICS

IIIA Link Analysis and System Signal Margin

The Shuttle/GPS link was examined for three cases. The baseline, baseline Δ1 and baseline Δ2. The baseline would be the on-orbit configuration. The latter two cases could possible be de-orbit and landing configurations. These three approaches are defined in detail as follows:

- Baseline
  - Ant/Pre-Amp on a Fixed Extension Boom with GPSPAC on the DFI Pallet
- Baseline Δ1
  - Window Dipole Antenna and Pre-Amp located in the Cabin Plus Baseline
- Baseline Δ2
  - Window Dipole Antenna, Pre-Amp and GPSPAC located in the Cabin with Switchable Ant/Pre-Amp Mounted on Deployable Boom located in the Payload Bay

To consider the link budget and the system signal margin for any of the configurations one needs to examine the basic system block diagram. This is shown below in Fig. 7.

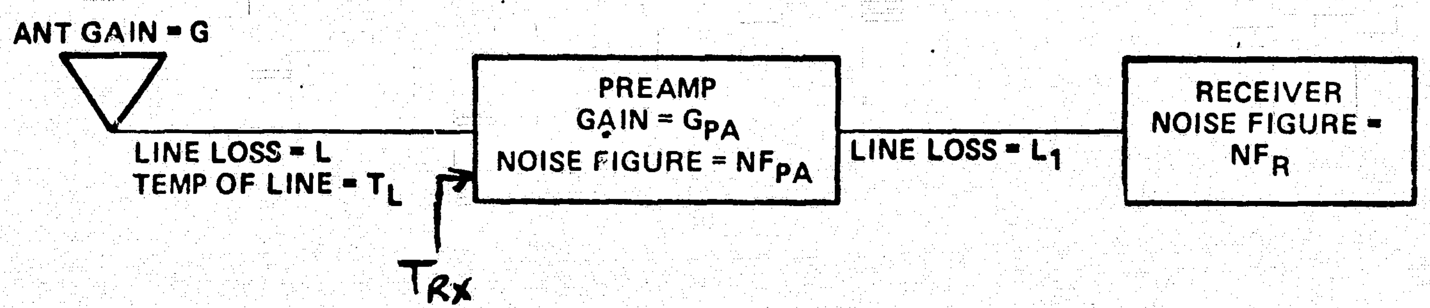

Fig. 7. Basic Link Budget Block Diagram

The defining relationship for the received signal to noise is given by the following:

$$\frac{C}{N_o} = \text{Received Signal} + \frac{G}{T_s} - K - \text{PN Implementation losses}$$

Where, T_s = System Noise Temperature

K = BOLTZMAN's Constant = 1.38×10^{-23}

NF_{PA} = Noise Figure of the Pre-Amp

NF_R = Noise Figure of the Receiver

G_{PA} = Gain of the Pre-Amp

The relationship for systen noise temperature is given by the following:

$$T_S = T_A + (L-1)T_L + L\ T_{RX}$$

Where, T_{RX} = $(NF_{RX}-1)\ 290^{o}K$

$$NF_{RX} = NF_{PA} + \frac{(L_1 + NF_R)-1}{G_{PA}}$$

T_A = Antenna Temperature = $108^{o}K$

T_L = Line Loss Temperature = $323^{o}K$

The Shuttle/GPS baseline is examined for the configuration and conditions shown below in Fig. 8 .

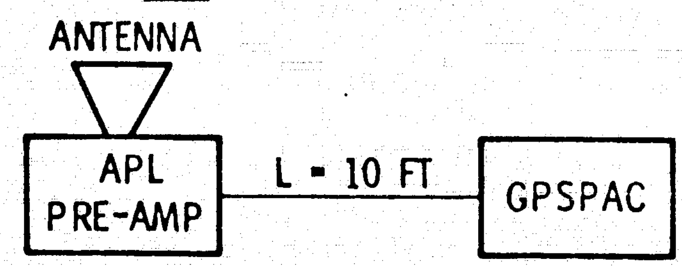

Fig. 8 . Baseline Shuttle/GPS Configuration

CONDITIONS

- APL Antenna Gain -1C0 dB at -10^{o}
- APL Pre-Amp Noise Figure 4 dB Min; Gain 30 dB Min
- GPSPAC Noise Figure 13 dB
- Cable RG/142: Loss 16 dB/100 Ft
- Receiver PN implementation Losses 2.0 dB

The basic GPSPAC has been designed to handle LAHV dynamics. To determine if present loop design is capable of handling the Shuttle On-Orbit Dynamics a comparison is made. Fig. 9 shows the Shuttle/GPSPAC Dynamics comparison:

	GPSPAC	SHUTTLE (ON ORBIT)
$\dot{R}$	$\pm$ 9.0 KM/SEC	$\pm$ 7.07 KM/SEC
$\ddot{R}$	$\pm$ 16 M/SEC^2	$\pm$ 10.2 M/SEC^2
$\ddot{R}$	$\pm$ .02 M/SEC^2	$\pm$ .011 M/SEC^3

Fig. 9 . Shuttle/GPSPAC Dynamics Comparison

It is noted from above that the Shuttle On-Orbit Dynamics are less than the GPSPAC LAHV requirements and therefore no receiver loop redesign is necessary. Based on the above equations and considerations the Shuttle/GPSPAC baseline link budget is shown in Fig. 11 .

The results indicate that there is signal margin in all cases. The ranging L_2 link margin, however, is small. This poses no problem since L_2 is used for ionospheric corrections and the L_1-L_2 difference is averaged over a time interval and can be reduced to whatever accuracy is desired. Total signal margin can vary and these are shown below in Fig. 10 .

Satellite Power Output From Start to End of Life	+6 dB
Satellite Antenna Gain VS User Position	+3 dB
User Antenna Gain	+1 dB
Antenna Axial Ratio Losses and VSWR Mismatch Losses	-2 dB
Atmospheric Losses	+2 dB
Polarization Losses	+2 dB
Range Spreading Loss for Skew Viewing	-2.5 dB
Ionospheric Scintillation Loss for Skew Viewing	-5 dB
TOTAL Variation	+4.5 dB

Fig. 10 . Received Signal Level Variations

PARAMETER / LINK	P-L_1	C/A-L_1	P-L_2	C/A-L_2	COMMENTS
NDS TRANSMITTER POWER (dBw)	10.5	13.1	7.8	7.8	ROCKWELL SPEC MINIMUM
NDS ANTENNA GAIN (dB)	12.0	12.0	10.1	10.1	16^o FROM BORESIGHT
PATH LOSS (dB)	-183.2	-183.2	-181.1	-181.1	MIN ORBIT 90 NM; SLANT-RANGE 5^o = 25,187 Km
ATMOSPHERIC LOSS (dB)	-2.0	-2.0.	-2.0	-2.0	5^o ELEVATION ANGLE
RECEIVED SIGNAL POWER (dBw)	-162.7	-160.1	-165.2	-165.2	
USER ANTENNA GAIN (RHCP)	-1.0	-1.0	-1.0	-1.0	DOES NOT INCLUDE AXIAL RATIO LOSSES OR VSWR LOSSES
SYSTEM NOISE TEMPERATURE T_s (^oK)	580	580	580	580	
C/N_o (dB-Hz) AVAILABLE	35.2	37.8	32.2	32.2	
REQUIRED C/N_o					
• DATA	27.0 db-Hz	27.0	27.0	27.0	10^{-5} BER, ΔPSK
• CARRIER TRACK	31.9(10.8^o)	34.5(8.8^o)	30.1(12.8^o)	30.1(12.8^o)	ACCELERATION 16 M/SEC^2; B_L = 35 Hz
• RANGING	32.9(3.5 FT)	35.5(2.8 FT)	31.1(4.3 FT)	31.1(4.3 FT)	NON-COHERENT τ-DITHER CODE LOOP B_L = 1.6 Hz
C/N_o MARGIN					
• DATA	8.2 dB	10.8 dB	5.7 dB	5.7 dB	
• CARRIER TRACK	3.3 dB	3.3 dB	2.6 dB	2.6 dB	
• RANGING	2.3 dB	2.3 dB	1.6 dB	1.6 dB	

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Fig. 11 . Shuttle/GPS Baseline Link Budget

The Shuttle Baseline Δ1 and Δ2 links are shown in Figs. 12 and 13. From a link standpoint both are essentially the same; that is about 80 ft. of cable between the pre-amp and GPSPAC. No detailed link analysis can be performed in this case because of many unknowns, but some conclusions can be reached. These are:

- Deorbit Dynamics Profile and Antenna Gain Characteristics presently undefined prohibiting detailed link analysis
- This Configuration will incur an additional 2 dB S/N Loss due to Cable Lengths over the Baseline Link Budget
- Inertial Aiding will allow the Carrier Loop Bandwidth to be reduced providing Lower S/N Loop Thresholds
- Certain Links however may have a small S/N margin
- Further analysis required to define the Link Budget for these Alternate Baseline approaches for deorbit and landing

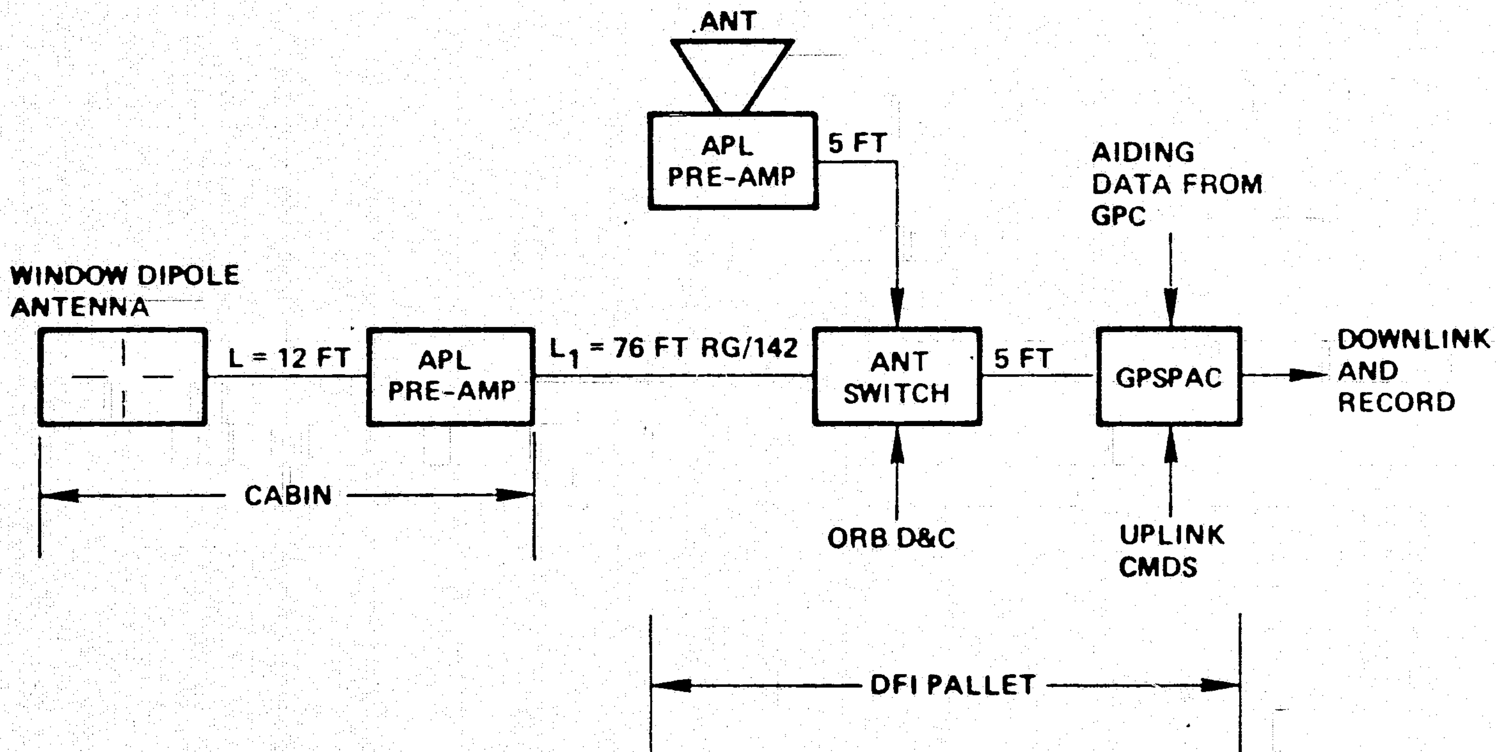


Fig. 12 . Shuttle/GPS Baseline Δl Link

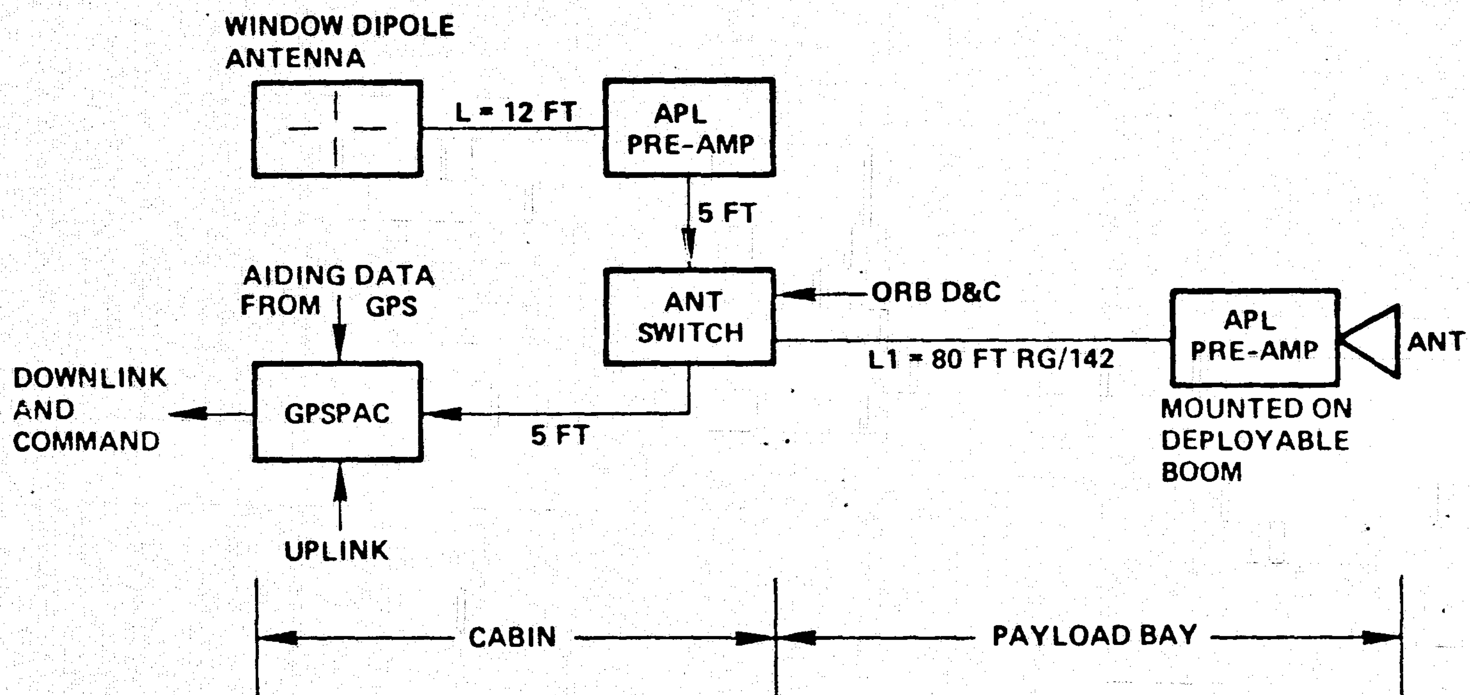


Fig. 13. Shuttle/GPS Baseline Δ2 Link

III-B Shuttle/GPSPAC Oscillator Tradeoffs

There are basically three oscillator options that can be used for the Shuttle application. These are:

1. Use existing APL supplied GPSPAC oscillator.
2. Use the internal shuttle Master Timing Unit (MTU) oscillator.
3. Use a modified type X, Z or Manpack oscillator.

To choose one of these options requires first to identify the Shuttle oscillator requirements. The following characteristics are desired:

Type	Crystal
Redundancy	Single
Frequency	5.115 MHz $\pm$.05 Hz
Sea Level Offset	$\pm$ 1 x 10^8
Warmup Time	$\pm$ 1 pp 10^9 within 4 hrs. (sea level to orbit)
Long Term Drift	$\pm$ 1 x 10^9/day
Short Term Stability	$\pm$ 1 x 10^{11}/sec.
Temperature Range	-20°C to 65°C
Pressure (Alt.) Range	0 to 14.7 psia
Size	Fit into GPSPAC slot 4 3/8" x 3½" x 2 7/16"
Weight	2 lbs.
Power	5 watts

Oscillator comparisons between the APL, Shuttle (MTU) and the present X-Set oscillators are provided in Table 1. The most notable problems with the APL oscillator appear to be the large sea level offset frequency and long warmup time. The problems with the MTU are its output frequency, warmup time pressure range and the fact it is not a self contained unit; that is, it is always tied to the Shuttle system. Detailed tradeoffs and comparisons are provided in Table 2.

The X-Set oscillator appears to meet all the requirements previously specified except that it is not qualified for space. The most cost effective

TABLE 1 - OSCILLATOR COMPARISONS

	GPSPAC (APL)	MTU (SHUTTLE)	X-SET
TYPE	CRYSTAL	CRYSTAL	CRYSTAL
REDUNDANCY	DUAL	DUAL	SINGLE
FREQUENCY	5.115 MHz $\pm$1Hz	4.608 MHz $\pm$0.005Hz	5.115 MHz $\pm$.05 Hz
SEA LEVEL OFFSET	$\pm$20 PP 10^6	$\pm$5 PP 10^9	$\pm$1 PP 10^8
WARMUP TIME	36 TO 48 HRS (SEA LEVEL TO ORBIT)	16 HRS (SEA LEVEL TO ORBIT)	$\pm 2 \times 10^{-9}$ WITHIN 30 MIN SEA LEVEL TO ORBIT
SHORT TERM STABILITY	$\pm 1 \times 10^{-11}$/SEC	$\pm 1 \times 10^{-10}$/SEC	$\pm 2 \times 10^{-12}$/12 SEC
LONG TERM STABILITY	$.05 \times 10^{-9}$/24 HRS	5×10^{-10}/24 HRS	$\pm 1 \times 10^{-9}$/24 HRS
TEMPERATURE RANGE	-20°C TO 50°C	0°C TO 50°C	-20°C TO $+65^{\circ}$C
PRESSURE (ALTITUDE) RANGE	VACUUM ONLY	8 PSIA TO 18 PSIA	0 TO 30,000 FT.
POWER	1.5 WATTS (WARMUP); 6 WATTS STEADY STATE	-	35W (WARMUP 3 MIN) 3.5W (STEADY STATE)
SIZE	57.3 IN^3	-	32 IN^3
WEIGHT	2.2 BBS	-	20 OZ

TABLE 2 - SHUTTLE OSCILLATOR TRADEOFFS/RECOMMENDATIONS

	ADVANTAGES	DISADVANTAGES	RECOMMENDATIONS
GPSPAC	• EXISTING • SPACE QUALIFIED • MEETS PERFORMANCE	• LARGE SEA LEVEL OFFSET FREQUENCY • LONG WARM-UP TIME	POSSIBLE USE AS AN ALTERNATE
SHUTTLE MTU	• EXISTING • SPACE QUALIFIED	• COMPLEX SYNTHESIZER (4.608 MHz TO 5.115 MHz) • LONG WARM-UP TIME • BELOW PERFORMANCE RE-QUIREMENTS • UNIT NOT SELF CONTAINED I.E. ALWAYS TIED TO SHUTTLE	NO
MODIFIED X, Z OR MANPACK	• EXISTING • EXCELLENT PERFORMANCE • SMALL OFFSET FREQUENCY • SHORT WARM-UP TIME	• NOT QUALIFIED FOR SPACE	DEVELOP AS A PRIME CANDI-DATE

approach for the Shuttle/GPSPAC experiment is to use an X-Set oscillator and qualify it for space. We contacted the vendor, Frequency Electronics Inc. and obtained a rough order magnitude (ROM) cost to do this. The costs are broken down in the following manner:

1.	3 X-Set oscillators	$13,500
2.	Acceptance Testing (3)	3,600
3.	Component Screening	14,000
4.	Component Traceability	900
5.	Non-Standard Parts Qualification	6,000
6.	Documentation	22,000
	TOTAL	$60,000

This unit would be hermetically sealed and operate from 0 to 14.7 psia. If not all of the above categories would be required, then the total costs could be reduced substantially. In any event, this is the approach we recommend for the Shuttle/GPSPAC experiment.

III-C GPSPAC Command and Data Interfaces

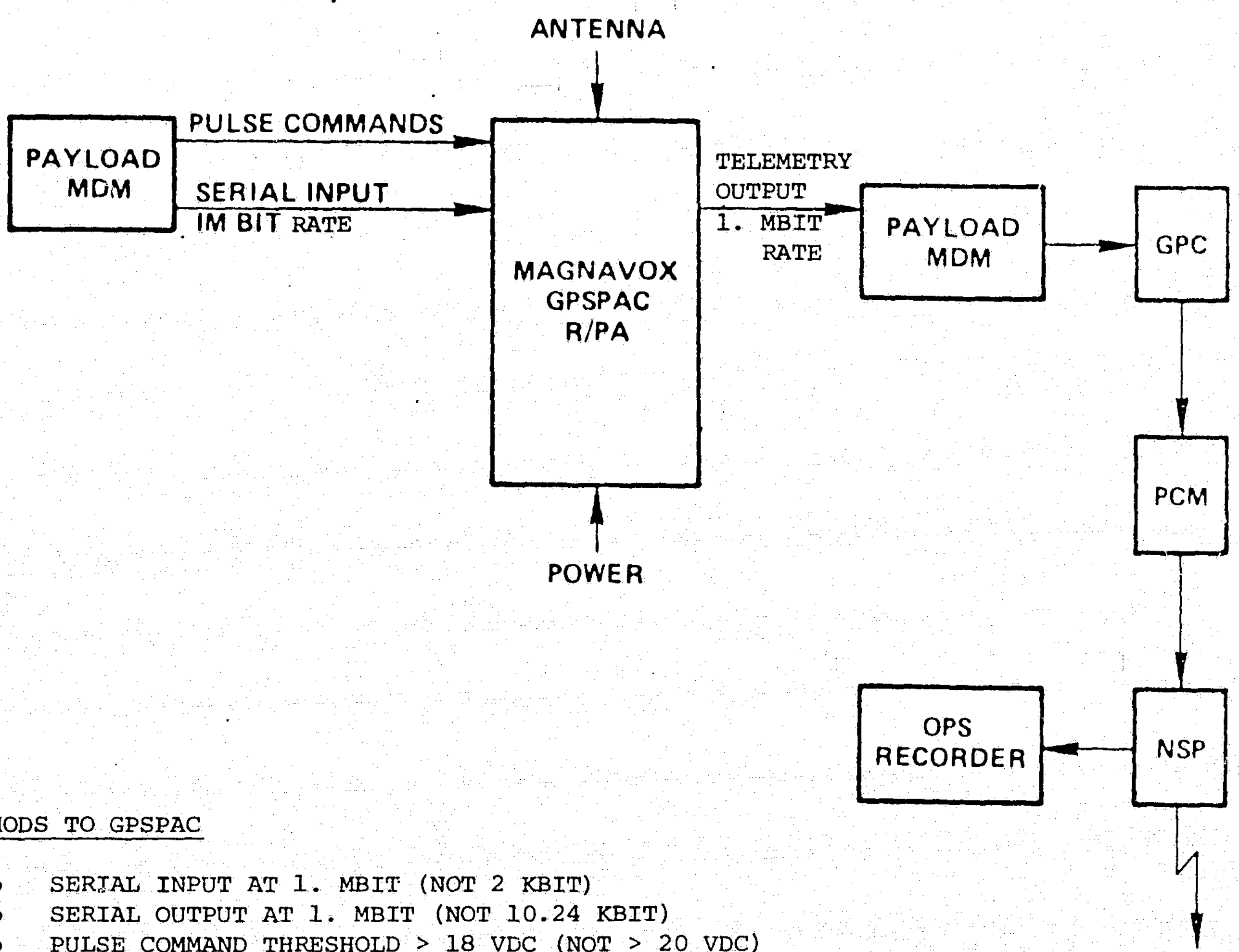
The baseline GPSPAC/Shuttle Interfaces for command and data transfer are pictorially represented by the block diagram of Figure 14 The input interface to the GPSPAC consists of a high voltage pulse interface for discrete commands and a TTL serial data interface for memory loading and transfer of digital commands. The output interface to the GPSPAC consists of a TTL serial data interface for transfer of measurement, navigation and status data to the Shuttle subsystems.

GPSPAC Interface to the Shuttle MDM

Both the input and output interfaces with the GPSPAC described above will be established through the Shuttle MDM and some modification to the existing GPSPAC interfaces as designed for SEASAT A will be required both electrically and in data format to be compatible with the MDM subsystem described in the Rockwell MDM-LRU Interface Control Document dated 3 Jan. 1977. These modifications required in the GPSPAC to be compatible with the MDM interface are characterized by the following:

- Serial input at 1 MBit Rate (not 2 KBit rate)
- Serial output at 1 MBit Rate (not 10.24 KBit rate)
- Input and Output data clock continuous Manchester II
- Pulse command threshold > 18 VDC (not > 20 VDC)
- Reformat data frames into fixed block lengths

The System Partitioning block diagram in Figure 15 identifies the software processing elements and hardware subsystems which comprise the GPSPAC Receiver/Processor assembly. Those processing elements and subsystems which will be modified to provide compatibility with the MDM interface are highlighted in the Figure. They are the Time Code Generator (TCG) Processing, Telemetry (TLM) Processing, Command Processing, and the Command and Telemetry I/O (CMD/TLM) Subsystem. The software modifications consist of changes to the command and telemetry data formats to provide fixed frame block lengths with frame headers as required by the MDM. The specific data formats are to-be-determined upon subsequent analysis but a candidate set of input and output data is described in this section from which the MDM interface bandwidth requirements can be sized. The GPSPAC hardware modifications consist of changes to the CMD/TLM I/O Subsystem in the areas of logic level thresholds, clocking format, and data rate to be



MODS TO GPSPAC

- SERIAL INPUT AT 1. MBIT (NOT 2 KBIT)
- SERIAL OUTPUT AT 1. MBIT (NOT 10.24 KBIT)
- PULSE COMMAND THRESHOLD > 18 VDC (NOT > 20 VDC)
- INPUT & OUTPUT DATA CLOCK CONTINUOUS MANCHESTER II
- REFORMAT DATA BLOCKS INTO FIXED FRAME LENGTHS

FIGURE 14. GPSPAC TO SHUTTLE INTERFACE

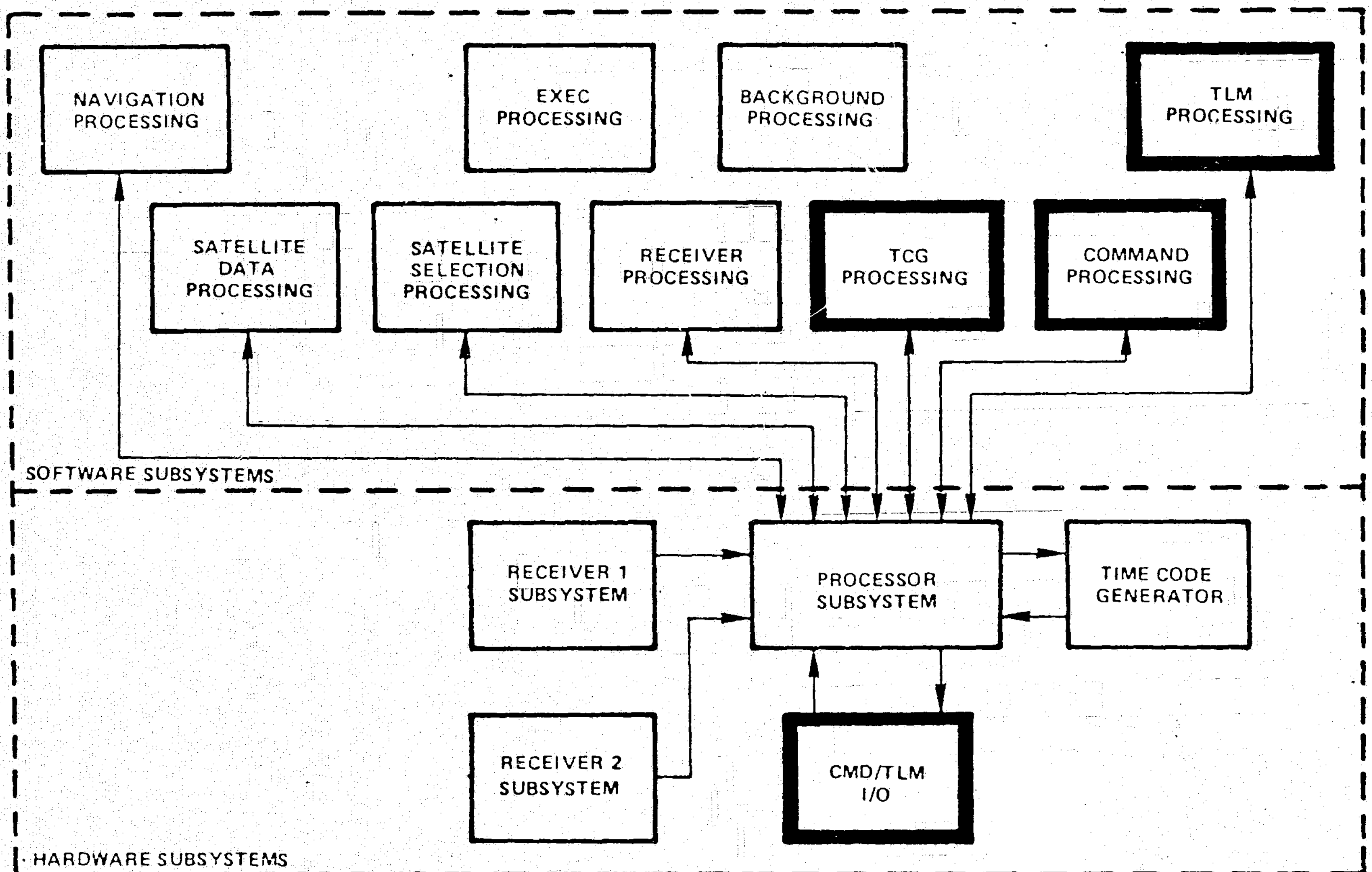


FIGURE 15. HARDWARE/SOFTWARE SYSTEM PARTITIONING

to be compatible with the MDM interface. These changes to the CMD/TLM I/O Board are highlighted in the block diagram of Figure 16. It should be clear from the preceeding discussion that the aggregate of modifications required to the GPSPAC hardware and software to be compatible with the MDM interface, although not trivial, are confined to the areas of data formats, rates, and logic levels, and do not impact the basic functional characteristics of the GPSPAC design or operation.

Shuttle MDM Data Bandwidth Estimate

The existing data block formats which comprise the command inputs and telemetry outputs to/from the GPSPAC assembly, as designed for the SEASAT A mission, are defined in the RPL Interface Control Document for GPSPAC Receive /Processor Assembly dated 7 July 1977 (reference document number 7250-9003). From these data block formats, a select subset can be identified which will provide sufficient data and command capability to meet the mission requirements for Shuttle. This select subset of data blocks will provide all measurement data, status data, and navigation data which is available as output from the GPSPAC without including the redundant or superfluous data which is also available within the existing data block formats. A correlation of the select subset of data blocks with the maximum required data rate for each element of the subset will result in a good estimate of the bandwidth requirements for the interface to the Shuttle MDM.

Selected Subset of Data Available from GPSPAC

Although an analysis of the data bandwidth requirements for the interface between GPSPAC and the MDM includes command input data as well as telemetry output data, there is no operational or functional requirement for rapid data transfer in the command mode and command data is not transferred simultaneously with telemetry output. Therefore, only the telemetry data bandwidth requirements, not the command data, are a constraint on the bandwidth requirements for the interface to the MDM.

An examination of the output telemetry data files specified in the GPSPAC ICD #7250-9003 reveals that, of the twelve (12) different telemetry data formats, only four (4) files are required at a regular rate while in the navigate mode to obtain all status, measurement, and navigation data without including redundant data in the downlist. Table 3 lists all the

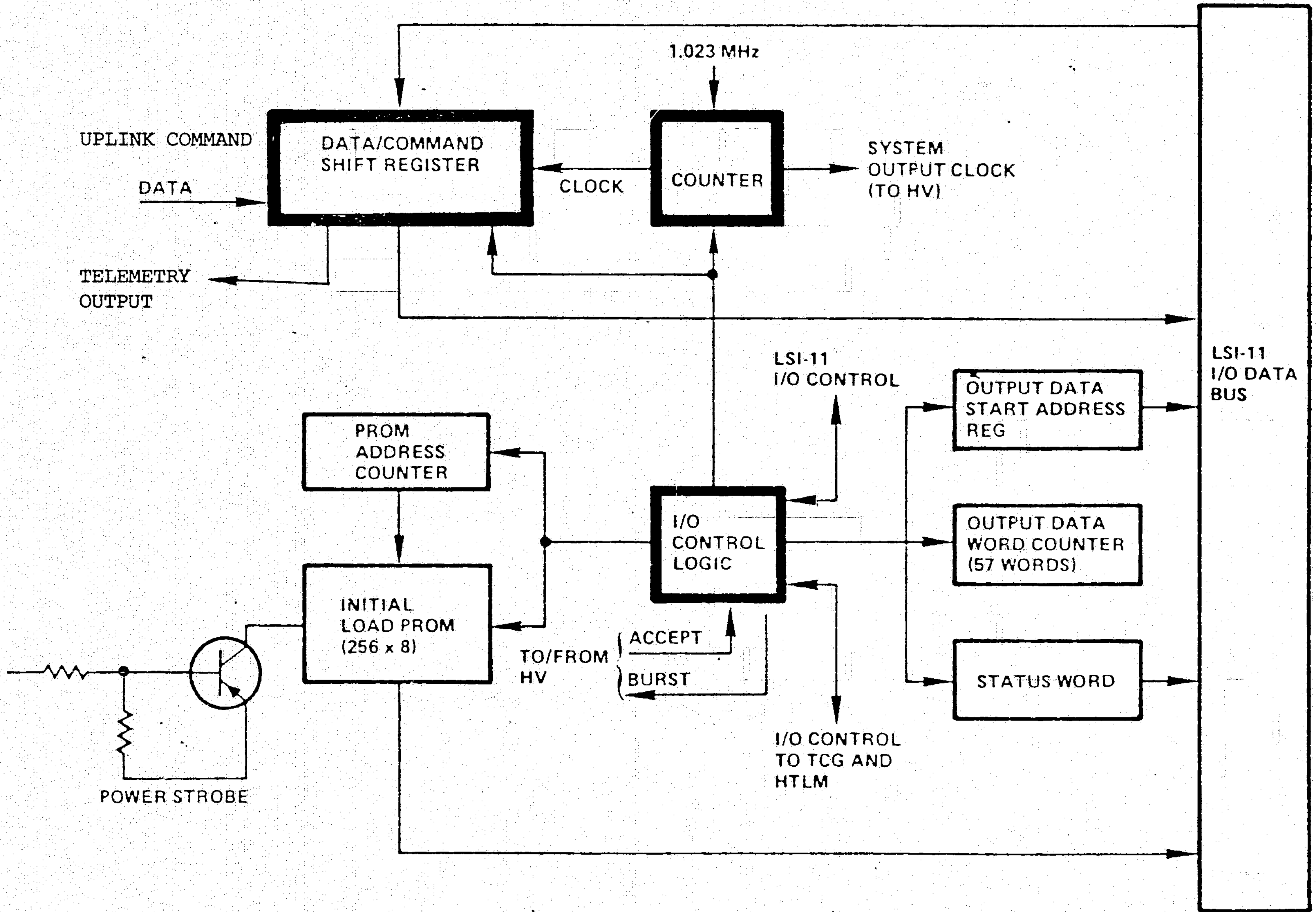


FIGURE 16. DATA AND COMMAND TELEMETRY BOARD

TABLE 3. GPSPAC TELEMETRY DATA BLOCKS

File ID	File Name	Size (Bits)	Shuttle Downlist?
0*	Command Echo Buffer	944	
1**	Memory Load Bit Map	672	
2*	R/PA Memory Contents	944	
3	Current Operating Ephemeris	2832	YES
4	System Status	688	YES
5	NDS Almanacs	4720	
6	Time Marks	912	
7	Navigation Best Estimate	560	YES
8	Kalman Input, Single Channel	432	
9	Kalman Input, Dual Channel	816	YES
10	Measurement Data	320	
11	Compressed Measurement Data	896	

* Output Only when R/PA is in Command Mode

** Output Only when R/PA is in Boot Loader Mode data files available from the GPSPAC telemetry stream and identifies those files which should be included in the bandwidth allocation for the MDM interface. The data rate required for each of these selected files results from the maximum rate at which the data in each file can be expected to change. The update rate for the data in Files four (4), seven (7), and nine (9) is a result of the sequential measurement process which is controlled by the GPSPAC system. The sequential measurement process depicted in Figure 17 indicates that the duration of an individual measurement process (or epoch) is six (6) seconds. Therefore, the maximum rate at which new data can be obtained from these files is every six (6) seconds. Data in files four (4), seven (7), and nine (9) include status data, navigation data, and measurement data, respectively. The update rate for the data in file three (3), current operating Ephemeris, is related to the satellite constellation selection process controlled by the GPSPAC (subject to satellite visibilities) and also related to the upload process controlled by the master control station. For this analysis, an average update rate of once every ten (10) minutes, resulting from the combination of satelitte constellation revision and master station uploading, was used to characterize the repetition rate required for File three (3), current operating Ephemeris. Table 4 summarizes the results of the analysis to define the average and peak data rate requirements for the GPSPAC to Shuttle MDM interface during the nominal (NAVIGATE) operating mode. As indicated in Table the average data rate from the GPSPAC to Shuttle MDM is 348.72 Bits per second. Because of the periodic inclusion of the current operating Ephemeris (File 3) in a fixed frame format along with the other data files being updated at a 6-second rate, the peak data transfer rate is determined to be: 4896 Bits (total) ÷ 6 seconds = 816 Bits per second. This peak data rate is well within the 1M Bit capacity of the MDM interface. For redundant GPSPAC systems operating independantly and concurrently, the required data transfer rates (both average and peak) would be twice the requirement for a single GPSPAC system.

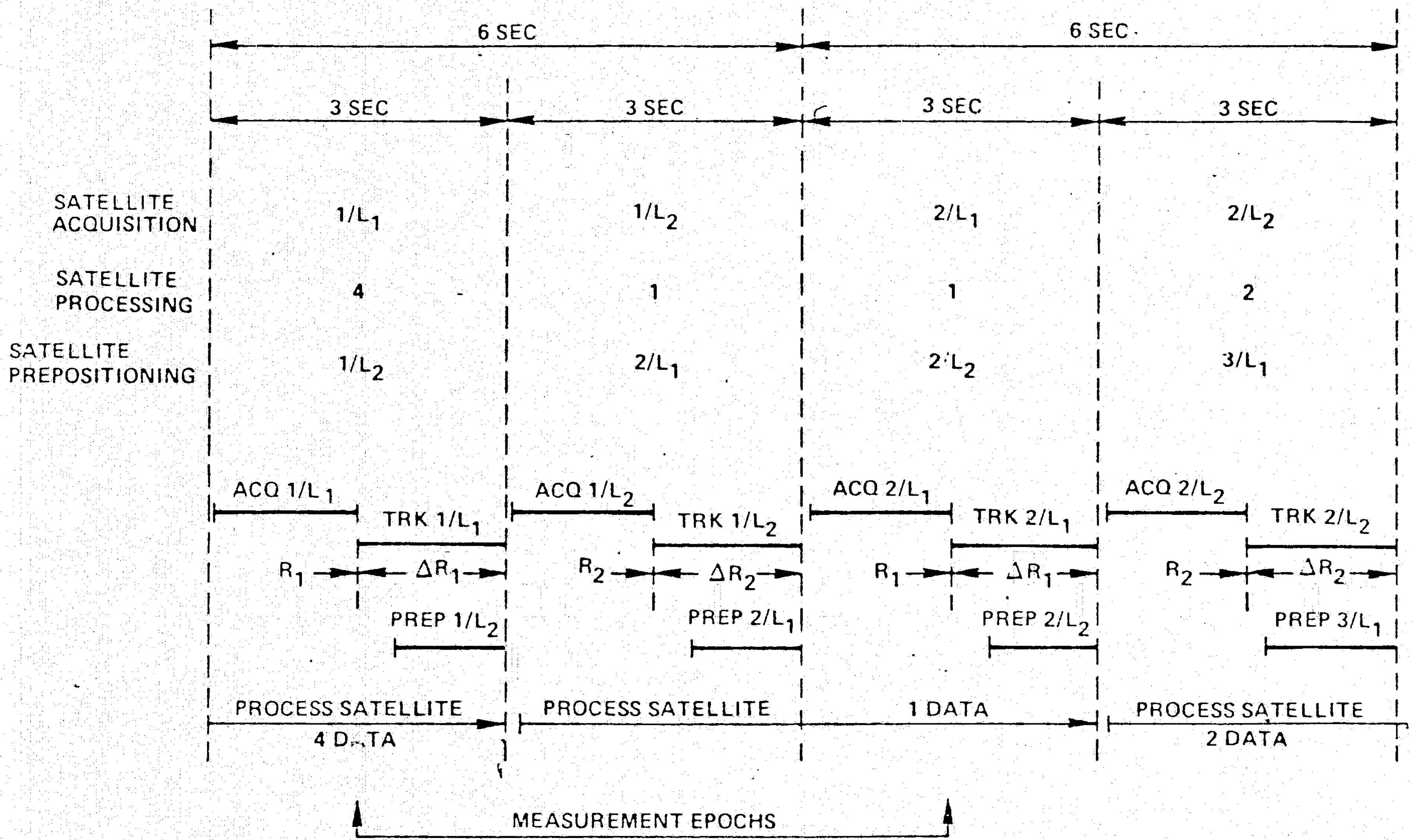


FIGURE 17. SEQUENTIAL MEASUREMENT PROCESSING TIMING

TABLE 4

GPSPAC TO SHUTTLE MDM DATA RATE ESTIMATE

FILE I.D.	FILE NAME	SIZE (Bits)	UPDATE PERIOD	AVERAGE DATA RATE
3	Current Operating Ephemeris	2832	600 sec.	4.72 Bps
4	GPSPAC System Status	688	6 sec.	114.67 Bps
7	Navigation Best Estimate	560	6 sec.	93.33 Bps
9	Kalman Input, Dual Channel	816	6 sec.	136.00 Bps
		4896 Total Bits		348.72 Bps Average Data Rate

III-D. Mechanical and Thermal Modifications of GPSPAC R/PA for Shuttle

Current GPSPAC R/PA Design

The current GPSPAC mechanical design has evolved to meet SEASAT spacecraft interfaces and requirements. These requirements are compatible with other Host Vehicle spacecraft with the following features:

1. The host vehicle thermal control system provides the average temperature limits on the primary heat dissipating surface between -20°C and 50°C when operating, and between -40°C and +70°C when non-operating.

2. The R/PA primary heat dissipating surface is opposite to the mounting surface and has an area of 1.25 square feet.

3. Temperature control louver mounting pads are provided at the heat dissipating surface.

4. All external surfaces are painted black as required by the host vehicle thermal design.

Shuttle Modifications of the R/PA

Various thermal design approaches have been used to solve temperature control problems and several solutions could be implemented for the R/PA. Since shuttle thermal design and heat loads are not known to Magnavox, only preliminary recommendations can be made as potential thermal design solutions.

1. The black surface finish can be readily painted white thus changing the emissivity from 0.8 to 0.2 as the thermal analysis required.

2. The top cover can be easily modified or redesigned. Thermal analysis by Rockwell indicates that a satisfactory R/PA thermal design could be achieved by increasing the top size to 1.75 square feet. This is only 1.25 inches extension of the present cover which would result in 120°F maximum R/PA temperature with 35 watts internal dissipation.

3. From the configuration drawing provided by Rockwell it appears that at least two or three sides of the R/PA would be exposed to radiation, which could eliminate cover modification requirements or further reduce the upper temperature limit.

In summary, "off the shelf" R/PA can be used with very simple modifications; a new cover and a new surface finish at the most. Thermal analysis by Rockwell also indicated that the R/PA does not have cold temperature problems and therefore does not require any heaters. However, analysis indicated that heaters would be required on the APL preamplifier.

IV GROUND SUPPORT EQUIPMENT

The GPSPAC/Shuttle test equipment can take maximum advantage of the existing test equipment and software designs currently being implemented at Magnavox for development testing and "FIELD" support of GPSPAC/LAHV User Equipment. These facilities have the capability of generating simulated satellite L-Band signals as seen by GPS receivers. The complex of test equipment and software can be used to exercise a GPSPAC system under test and to recover and display telemetry data outputs from the GPSPAC system.

It is suggested that the existing four channel GPS Performance Evaluator, which is described in detail in this section, be made available on a noninterference basis at Magnavox to support detailed GPSPAC system performance analysis as required. Monitor modifications would be required for the command and telemetry interface hardware and software to accommodate the changes made to the GPSPAC interface to be compatible with the shuttle MDM interface requirements. With these changes the GPS Performance Evaluator will be capable of dynamically testing a GPSPAC to demonstrate compliance with equipment and system specifications as required for the GPSPAC/Shuttle Program.

It is recommended that a single channel RF Signal Generator (GSU) be employed for GPSPAC System Integration and field testing activities. The single channel GSU is derived from a similar piece of test equipment called an RF Signal Generator which is currently being delivered on the existing GPS Phase I User Equipment Program. The RF Signal Generator design will be modified to interface with the GPSPAC for shuttle and the software would be updated to meet the system telemetry and control requirements. This version of the GSU will provide static solutions over the dynamic performance range of the GPSPAC receiver. Each channel of the GPSPAC will be tested individually under control of the GSU. The single channel GSU is particularly suited to field use where periodic verification of the GPSPAC equipment is required.

The GSU would be housed in a single two-bay rack as shown in Figure 18. EMI gasketing will be used to the extent possible on all subassemblies. The L-Band waveform generator assembly shall be designed to meet MIL-STD-461A to assure that system testing will not be affected.

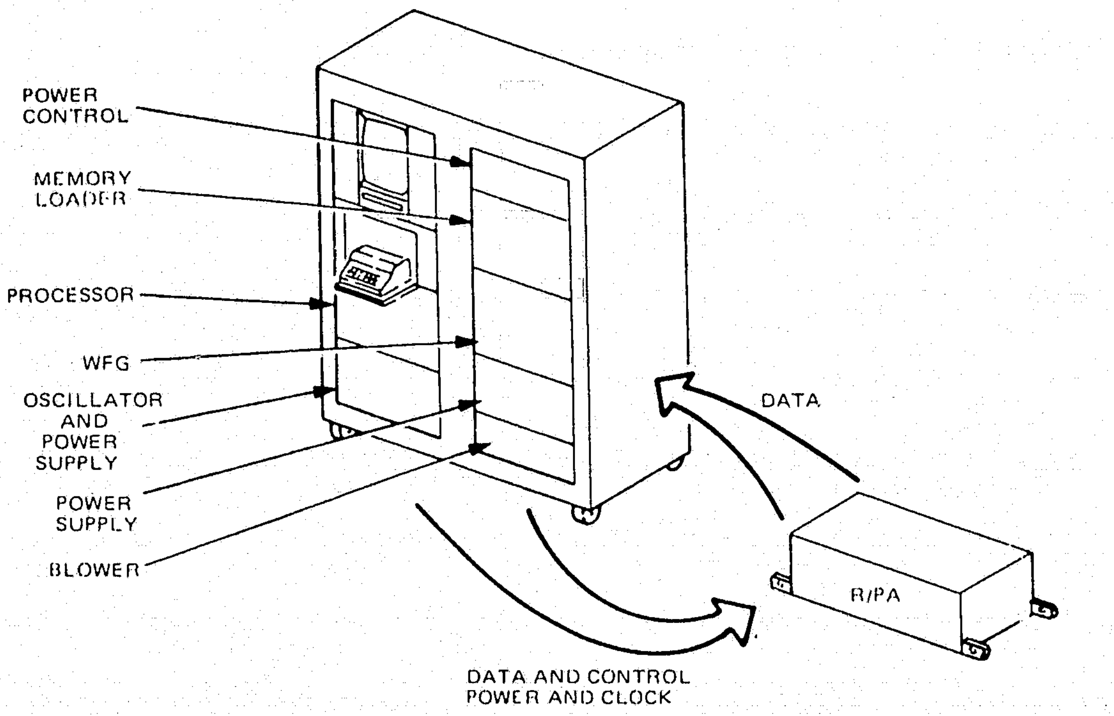


Fig. 18 . RF Signal Generator - GSU

Detailed Description of the RF Signal Generator Assembly

The RF Signal Generator Assembly (GSU) is controlled by digital data and commands from its Data Processor Assembly, accepts signal references from a Frequency Synthesizer Assembly, and outputs a selectable simulated satellite navigation signal in accordance with MH 08-00002-400. This signal will contain all of the phase and frequency information necessary to simulate a satellite navigation signal. The design of RF Signal Generator Assembly will be based on a proven "waveform generator" assembly designed by Magnavox. Six pre-production units of this waveform generator are currently in operation at Magnavox for GPS equipment evaluation.

Each RF Signal Generator (GSU) will generate 37 P, and C/A PN codes in accordance with MH 08-00002-400. The PRN modulated signals are generated for transmission as L_1 and L_2 signals, L_1 containing a composite of the P and C/A signals and L_2 containing only the P signal. Without induced dynamics the L_1 RF carrier frequency will be 1575.42 MHz and L_2 carrier frequency will be 1227.6 MHz. The RF signal from this assembly will be controlled by the data processor through a programmable attenuator such that all signal strengths over a satellite orbit differential range of 27000 km between a -20 deg and 90 deg elevation can be simulated. The power output from the RF Signal Generator Assembly will be continuously variable in 1 dB steps from -30 dBW to -186 dBW. The hardware will have the capability to simulate signal level, dynamic range, satellite/user line-of-sight range changes, velocities, accelerations, jerks and ionospheric delays representative of the GPS signal dynamics received at the R/PA HV. Full capability of the L_1 and L_2 signals is specified in Table ____.

A block diagram of the major components of the proposed RF Signal Generator Assembly (GSU) is shown in Figure 19. The RF Signal Generator will be comprised of an L_1-L_2 Converter Assembly, a Code Generator Assembly, an RF Amplifier Assembly, and Interface Unit, a Data Processor Assembly, and Peripheral Equipment.

Table 5. L_1 and L_2 Specification

Parameter	Specification
Waveshape	Sin X/X, harmonics -40 dB relative to the fundamental
Amplitude	
L_1: P (Variable Power)	-30 dBW to -186 dBW
C/A (Variable Power)	-30 dBW to -183 dBW
L_2: P (Variable Power)	-30 dBW to -186 dBW
Doppler Shift	0 ± 48 kHz in 3.9 Hz continuous steps for L_1 and L_2
Phase Resolution	0.015 of a full cycle for L_1 and L_2
Frequency Accuracy	Phase difference over 1 second is within ±0.01 Hz rms of any selected frequency within the doppler range when tracked with a phase-locked loop of 10 Hz noise bandwidth
Maximum Frequency Rate (Acceleration)	580 Hz/sec (11g acceleration) for L_1 and L_2
Maximum Acceleration Rate (Jerk)	500 Hz/sec^2 (10g/sec jerk) for L_1 and L_2

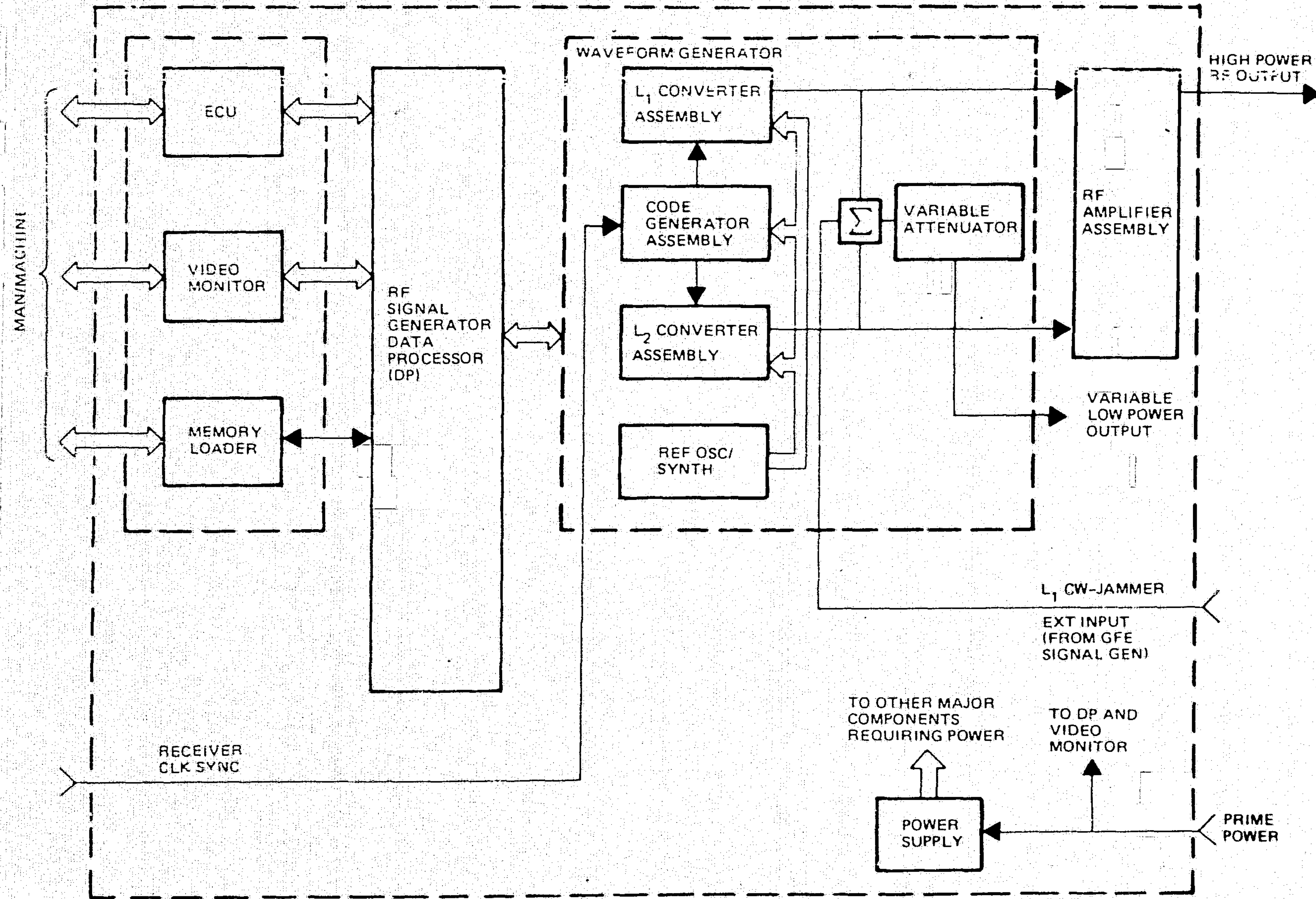


Fig. 19 . RF Signal Generator Block Diagram

GPS PERFORMANCE EVALUATOR

The GPS Performance Evaluator System is an automated laboratory-based simulator capable of exercising and evaluating the GPSPAC equipment in a simulated operational environment. The system is capable of simulataneously simulating the signals from any four GPS satellites that would be received by a GPSPAC onboard a spaceborne vehicle. The system is capable of simulating up to 2-1/2 hours of real-time operations including all motion effects on frequency and power. The system is controlled in real-time by a data processor and provides extensive capability for internal self checking (built in test) and calibration. The system consists of the assemblies listed below. A functional block diagram of the system is shown in Fig. 20 and a detailed block diagram is provided in Fig. 21.

Satellite Signal Generator Assemblies

The four Signal Generator Assemblies will simulate any satellite of the GPS system. Each will generate 50 bps data modulated P and C/A codes. Each will output an L_1 composite signal modulated by the data modulated P and C/A signals and L_2 composite signal modulated by the data modulated P code. All motion effects $(R, \dot{R}, \ddot{R}, \dddot{R})$ will be simulated by the Satellite Signal Generator Assemblies when properly driven by the Data Processor Assembly.

Frequency Synthesizer/Reference Oscillator Assembly

The Frequency Synthesizer/Reference Oscillator Assemblies will generate all of the LO's for the Satellite Signal Generators. Since motion effects are simulated in the signal generators, each Frequency Synthesizer/Reference Oscillator Assembly will provide only fixed frequency output.

GPSPAC Interface Assembly

The GPSPAC Interface Assembly will provide the GPS Performance Evaluator with the capability of acquiring navigational data and status from the GPSPAC. This will allow the system to evaluate GPSPAC System performance. The GPSPAC Interface Assembly will also provide the system with the capability of transferring aiding parameters (for acquisition) and command control data to the GPSPAC equipment.

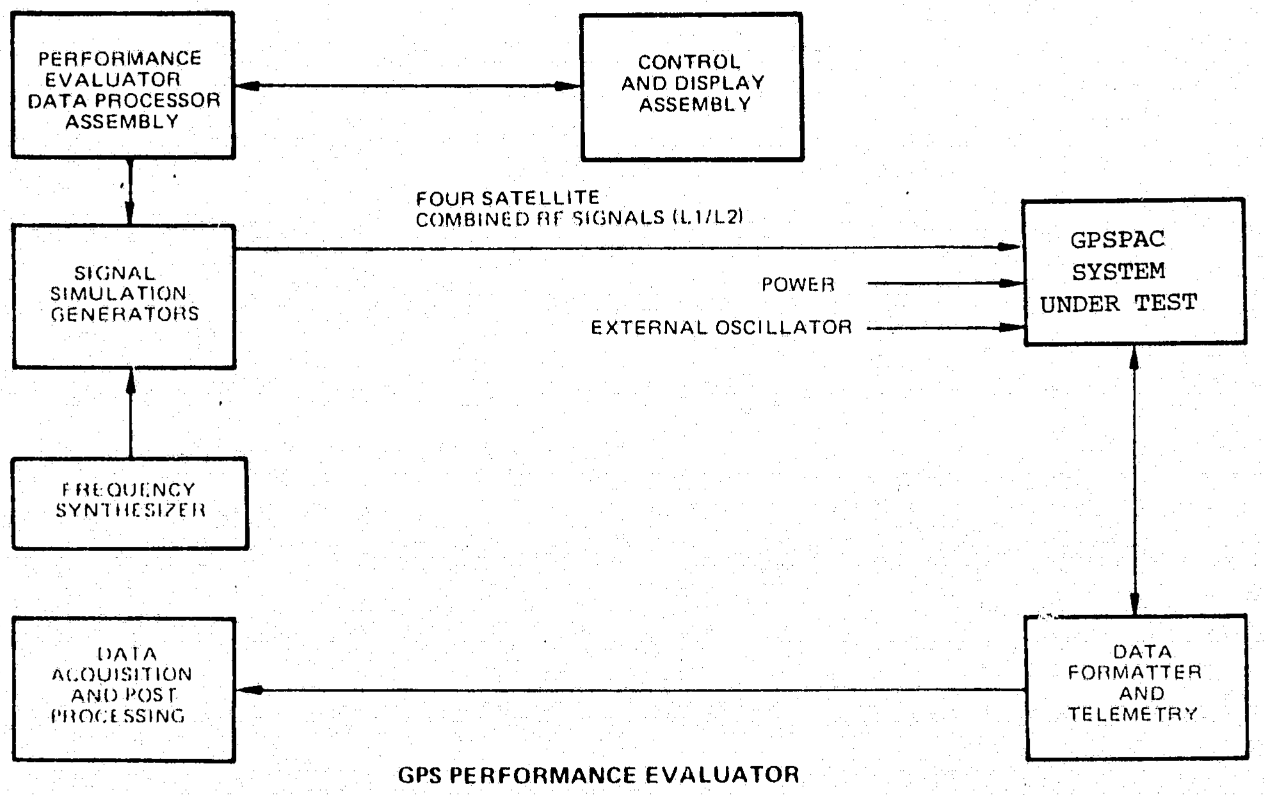


Fig. 20 . GPS Performance Evaluator Functional Block Diagram

Data Processor Assembly

The Data Processor Assembly will accept Space Vehicle orbit scenarios from the Control and Display Assembly, will implement a real-time GPS system simulation based on these scenarios relative to GPS satellite motion, and will gather navigational data and status from the GPSPAC and will log this data on magnetic tape for subsequent non real time performance analysis of the GPSPAC system. The non real time (post flight) performance evaluation is also performed on the GPS Performance Evaluator equipment.

Control and Display Assembly

The Control and Display Assembly provides operator interface with the GPS Evaluator data processor. It will provide the operator with the capability of inputing GPSPAC vehicle orbit parameters and controls, of simulating these mission scenarios in real-time, of receiving and displaying real-time and post flight evaluation of the performance of the GPSPAC, and of running calibration and test of the system hardware.

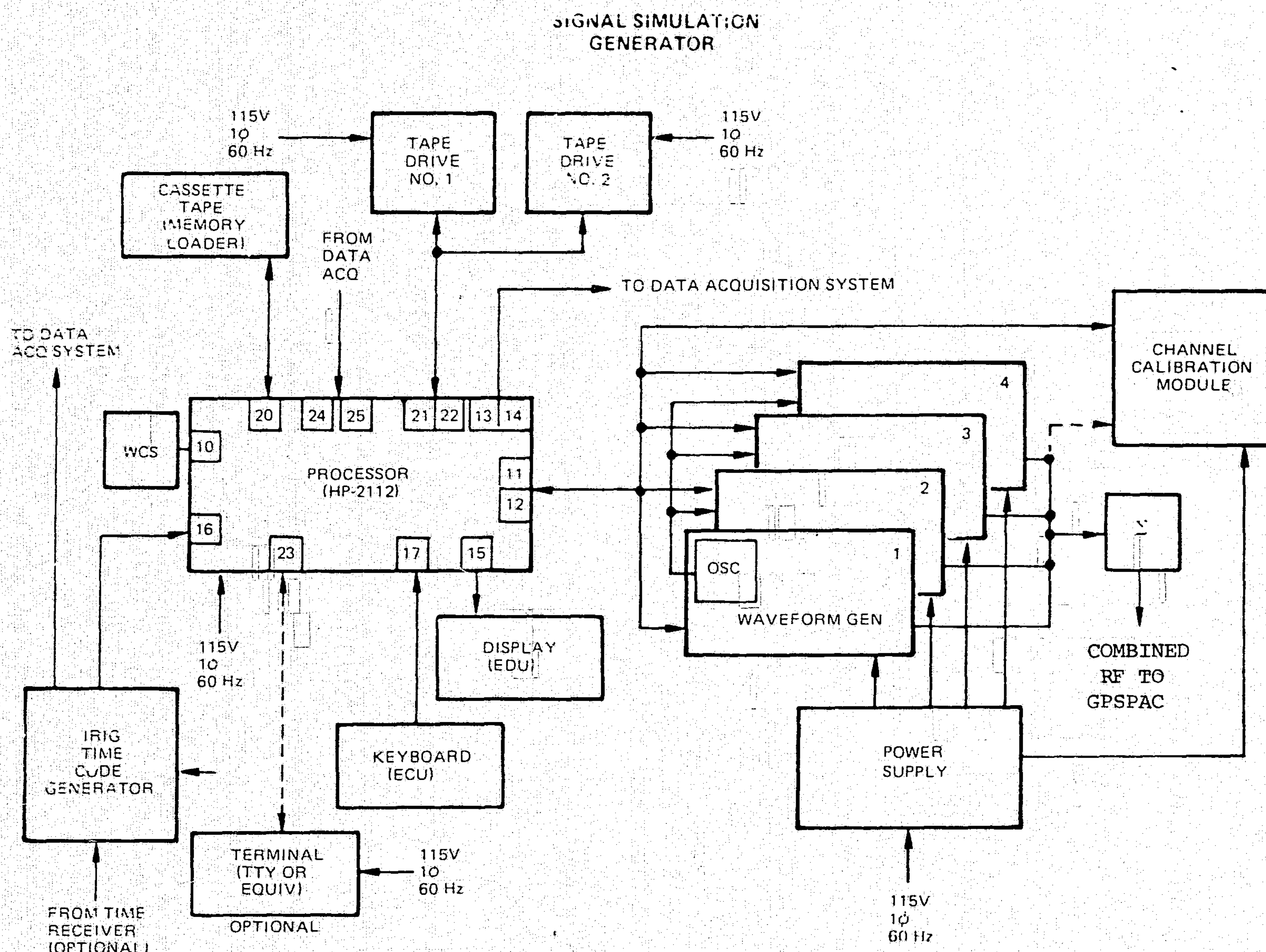


Fig. 21 . GPS Performance Evaluator Detailed Block Diagram

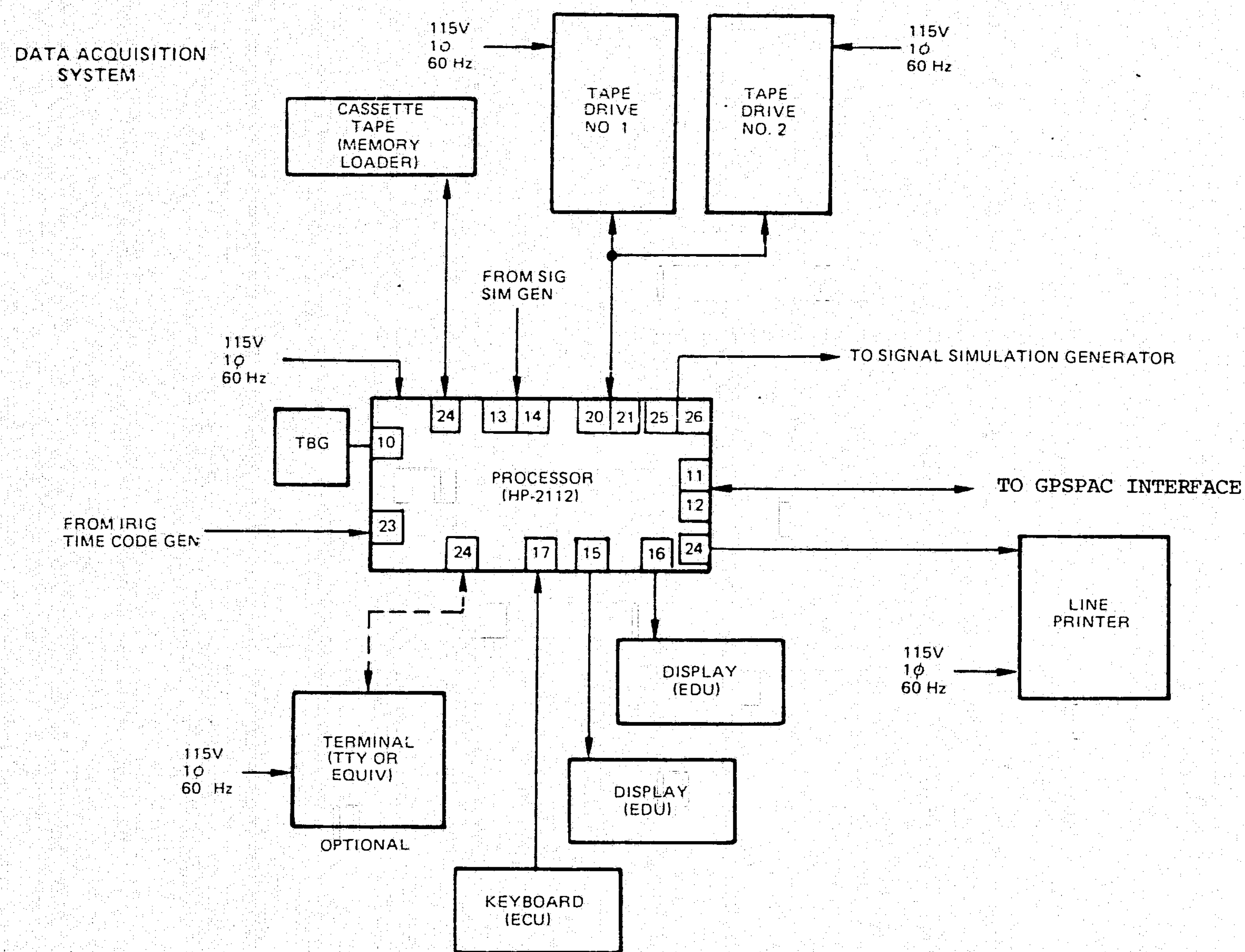


Fig. 21 . GPS Performance Evaluator Detailed Block Diagram (Continued)

Power Supply Assembly

The Power Supply Assembly will provide power to all of the other assemblies, as required, in the GPS Evaluator.

Functional Description of GPS Performance Evaluator Facility Software

The GPS Performance Evaluator (GPS-PE) facility implements the software and hardware necessary to support the testing of the functions and performance of GPS navigation receiver systems such as the GPSPAC.

The GPS-PE is capable of simulating various aircraft flight profiles and/or vehicle motions of GPS receiver systems with respect to GPS satellites and ground transmitters. The GPS-PE system generates and transmits GPS signal waveforms to a GPS navigation receiver, displays selected evaluation parameters and status on video displays, and provides operator control of the simulation process. For an aided receiver configuration, the system also simulates an (IMU) Inertial Measurement Unit and/or an (ADU) Air Data Unit input to the receiver system. The GPS-PE generates up to four GPS signal waveforms simultaneously from the set of 24 possible GPS satellite signals.

The major software subsystems of the GPS-PE facility are:

- An Environmental Simulation Module (ESIM) residing in an IBM 370 computer
- A Real Time Controller Module (RTC) residing in an HP21-M/20 computer
- A User Equipment Field Test Instrument Module (UFTIN) residing in a Data Processor (HP21-MX computer) used to record data from the receiver data processor and the Real Time Controller on digital tape recorders.
- A Post-Flight Evaluator Module (PFE) residing in an HP21-M/20 computer to be used in off-line performance analysis and evaluation.
- A GPS signal waveform generator control module (WFG).

V DISCUSSION OF OTHER POTENTIAL GPS SYSTEMS BEING DEVELOPED THAT MAY BE APPLIED TO SHUTTLE

Candidate Options and Configurations

This section c onsiders the shuttle candidate objectives defined for on-orbit navigation, and ascent/deorbit compared to the candidate GPS configuration currently being developed. The basis for the shuttle objectives is a set of study material derived during the panel sessions by the Analysic Science Corporation (TASC). These objectives have been catagorized in two distinct phases. Table 6 lists the on-orbit objectives developed for shuttle by TASC. Table 7 lists the ascent/deorbit objectives.

Objectives Comparison

Consideration of the on-orbit navigation capabilities of the various candidate systems was the prime objective of the study effort. The candidate systems options which were considered to meet the on-orbit test objectives consist of 12 potential configurations. These 12 candidates comprise the known potential GPS systems currently in development.

Candidate Description

The set of 12 candidates consists of 9 user configurations selected for GPS testing by the Joint Program Office of SAMSO, and 3 additionally developed configurations under separate development. The three additional configurations are: 1) MBRS (Missile Borne Receiver System), 2) M-Set development at Eglin Air Force Base, and 3) the GPSPAC spaceborne equipment defined in previous sections of this report.

Test Configurations

The initial 9 user configurations selected for testing are intended to cover a small yet specific spectrum of the military operations to which GPS could be successfully applied. Final determination and perhaps even consolidation of the equipment classes will result from an iterative evolutionary process of user equipment design synthesis, testing, and operational mission analysis. Promising new military tactics

TABLE 6

EXPERIMENT OBJECTIVES - ON ORBIT PHASE

MAJOR OBJECTIVES

- DEMONSTRATE GPS OPERATION IN THE SHUTTLE MISSION ENVIRONMENT
- VERIFY THAT GPS COULD SERVE AS AN INTERIM NAVIGATION SYSTEM
- ASSESS THE ABILITY OF GPS TO PROVIDE ACCURATE PAYLOAD SUPPORT CAPABILITY
- INVESTIGATE ABILITY TO MEASURE VENTING AND OUTGASSING EFFECTS

OBJECTIVE ELEMENTS

- INVESTIGATE CONDITIONS FOR SATELLITE VISIBILITY
- MEASURE ACQUISITION AND REACQUISITION TIMES BOTH AIDED AND UNAIDED
- ASSESS GPS RECEIVER SIGNAL TRACKING PERFORMANCE
  - VS VEHICLE DYNAMICS
  - VS VEHICLE ATTITUDE AND ANTENNA COVERAGE (S/N)
- DETERMINE MEASUREMENT ACCURACY FOR BOTH C/A AND P CODES
- EXAMINE THE NEED FOR AND ADEQUACY OF ATMOSPHERIC CORRECTIONS
- EVALUATE ALTERNATIVE NAVIGATION FILTERS
- CONSIDER THE ABILITY OF GPS AIDED NAVIGATION TO INITIALIZE THE IUS

TABLE 6 (Cont'd)

EXPERIMENT OBJECTIVES - ON ORBIT PHASE

ADDITIONAL OBJECTIVES

USE OMS BURN TO:

- EXAMINE THE POTENTIAL FOR IMU ALIGNMENT
- DETERMINE THE ACCURACY OF ORBITAL ELEMENT ESTIMATES VERSUS TIME SINCE BURN
- CONSIDER THE POSSIBILITY FOR IMPROVED BURN CONTROL
- ASSESS THE POTENTIAL IMPACT ON RENDEZVOUS SCENARIOS
- EVALUATE THE CAPABILITY FOR STATION KEEPING

USE ORBIT/ATTITUDE DYNAMICS TO:

- FURTHER ASSESS RECEIVER TRACKING PERFORMANCE BOTH AIDED AND UNAIDED

USE GPS GROUND TRANSMITTER TO:

- EXPAND ON ORBIT DYNAMIC RANGES

TABLE 7

EXPERIMENT OBJECTIVES - ASCENT & DEORBIT PHASES

MAJOR OBJECTIVES

- DEMONSTRATE GPS OPERATION IN THE SHUTTLE MISSION ENVIRONMENT
- ASSESS THE ABILITY OF GPS TO AID THE NAVIGATION SYSTEM
- EVALUATE GPS FROM THE POINT OF VIEW OF OFFLOADING OTHER NAV AIDS
- CONSIDER THE USE OF GPS GENERATED EPHEMERIS FOR CALIBRATION OF EXISTING NAV AIDS AND AVIONICS SYSTEM

OBJECTIVE ELEMENTS

- ASSESS RECEIVER TRACKING PERFORMANCE AS A FUNCTION OF
  - VEHICLE DYNAMICS
  - QUALITY OF IMU AIDING (ACCELERATION, ATTITUDE RATES)
  - VEHICLE ATTITUDE AND ANTENNA COVERAGE (S/N)
  - PLASMA EFFECTS (SIGNAL ATTENUATION, MULTIPATH)
- EVALUATE THE ABILITY OF GPS TO MONITOR THE DEORBIT BURN
- DETERMINE THE DURATION OF REENTRY GPS BLACKOUT
- EVALUATE THE EFFECT OF SENSED ACCELERATION ON THE OSCILLATOR

TABLE 7 (Cont'd)

EXPERIMENT OBJECTIVES - ASCENT & DEORBIT PHASES

OBJECTIVE ELEMENTS

- PROVIDE A DATA BASE FOR EVALUATING ALTERNATIVE NAVIGATION FILTERS
- CONSIDER THE ABILITY OF GPS TO SUPPORT RTLS AND AOA
- EXAMINE THE POTENTIAL FOR IMU ALIGNMENT
- CONSIDER THE ABILITY OF GPS AIDED NAVIGATION TO INITIALIZE THE IUS
- EXAMINE THE NECESSITY FOR AND ADEQUACY OF ATMOSPHERIC CORRECTIONS
- ASSESS THE ABILITY OF GPS AIDING TO IMPROVE ESTIMATES OF ANGLE OF ATTACK AND MACH NUMBER
- MONITOR REDUNDANCY MANAGEMENT PERFORMANCE

and innovative applications are expected to evolve as the GPS capabilities are tested, quantified, and eventually realized.

The present Phase I program for the User Segment has as its objective the definition of user equipment costs and the accomplishment of the following:

1. Validation of the basic GPS technical concept and the preferred designs.
2. Quantitative measurement of GPS performance.
3. Substantiation of operational suitability of GPS.
4. Demonstration of military utility of GPS.

All of the indicated developmental user equipments shown in Table 8 will undergo test and evaluation during the Phase I Program. The Yuma Proving Grounds near Yuma, Arizona and the Fleet Operationa Readiness Accuracy Check Site off the California coast will be employed as test ranges for field checkout, quantitative performance evaluation and operational demonstrations.

Several developmental models of user equipment are presently being produced by the Magnavox Advanced Products Division. These user configurations generally consist of an antenna, preamplifier, receiver, navigation data processor, control/display unit, and a power supply. A variety of aiding devices, such as barometric altimeters, inertial navigation systems, or external frequency references can be used to augment the GPS receiver functions. At one extreme of the potential user spectrum will be a "maximum performance" configuration in terms of accuracy, vehicle dynamics, jamming environment and augmentation sensors. This configuration is represented by the X-Set development shown in Figure 23, which is a high dynamic user application intended for operation in a severe hostile jamming environment. Four dedicated satellite channels are employed for rapid signal acquisition and to provide continuous navigation during maneuvers. Designed to operate with two antennas using satellites or test signals from an inverted test range on the ground.

Alternate high-performance user equipment development is being provided by Texas Instruments using five (5) simultaneous channels, and designated as the High Dynamic User Equipment (HDUE). In addition a technology program sponsored by the Air Force Avionics Laboratory to develop a high jamming resistant 5-channel receiver with optimized antennas and

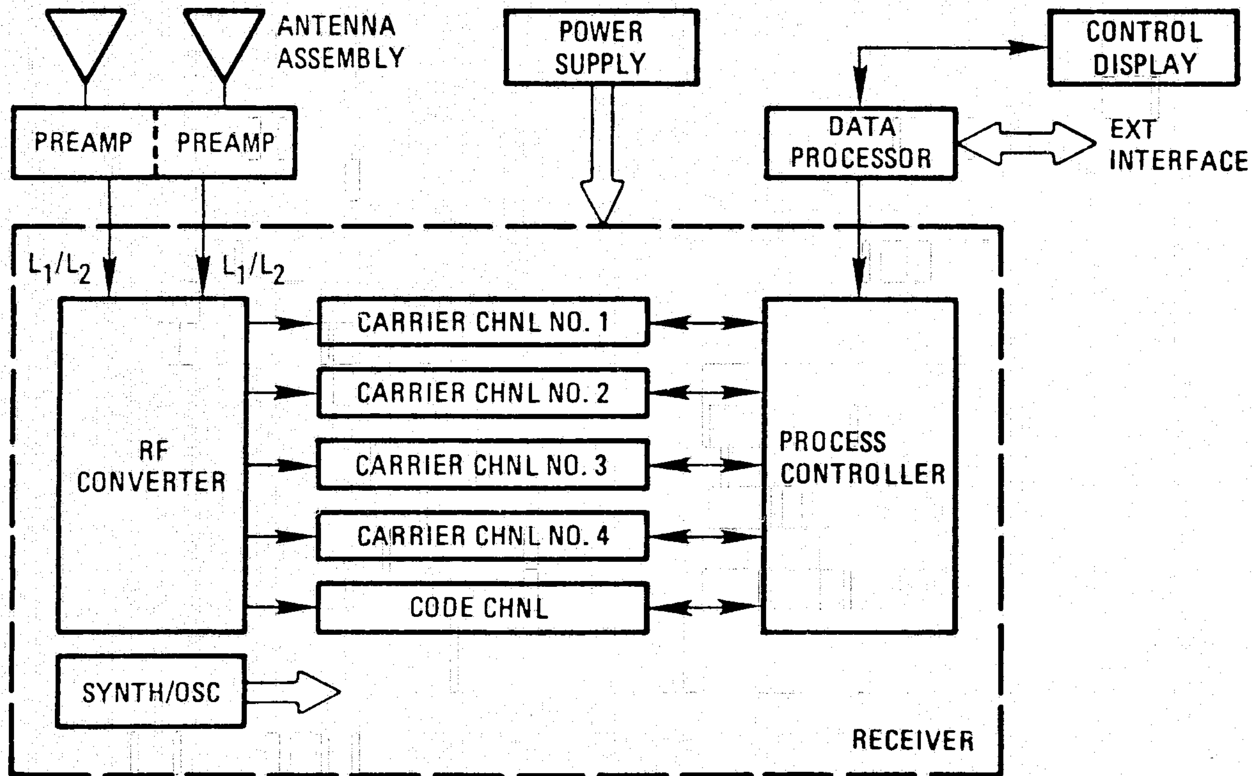
TABLE 8

USER EQUIPMENT TEST ARTICLES

SET	DESCRIPTION	AUXILIARY SENSOR AIDING	OPERATING FREQUENCY L_1 AND L_2	SIGNAL CODE P AND C/A	USER EQUIPMENT CONTRACTOR
XU	4 CHANNEL, HIGH PERFORMANCE		✓	✓	MAGNAVOX APD
YU	1 CHANNEL, MEDIUM PERFORMANCE		✓	✓	MAGNAVOX APD
XA	4 CHANNEL, HIGH PERFORMANCE	✓	✓	✓	MAGNAVOX APD
YA	1 CHANNEL, MEDIUM PERFORMANCE	✓	✓	✓	MAGNAVOX APD
HDUE	5 CHANNEL, HIGH PERFORMANCE	✓	✓	✓	TEXAS INSTRUMENTS
MVUE	1 CHANNEL, MANPACK/ VEHICULAR		✓	✓	TEXAS INSTRUMENTS
AFAL/GDM	5 CHANNEL, HIGH PERFORMANCE	✓	✓	✓	COLLINS RADIO
MP	1 CHANNEL, MANPACK		✓	✓	MAGNAVOX APD
Z	1 CHANNEL, LOW COST				MAGNAVOX APD

FIGURE 23 .

X-SET FUNCTIONAL PARTITION



LSI technology is being undertaken by Collins Radio Division of Rockwell International.

Another significant equipment option in the user spectrum is the single-channel sequenced receiver which offers reduced cost and performance to potential users that don't need or are willing to forego continuous tracking of the GPS satellite. This development configuration is characterized as the Y-Set shown in Figure 49 . The Y-Set is a medium dynamic user application with performance limitations imposed by need for sequencing of a single satellite receiving channel between the selected GPS satellite constellation. This set is capable of being augmented by the same auxiliary sensors as the X-Set.

The development of a user configuration to be employed by mobile ground vehicles and foot soldiers presents a unique challenge to the GPS equipment designer in terms of weight, power, and cost constraints. An Advanced Developmental Model of such user equipment is being provided by Magnavox (termed the Manpack, MP) and by Texas Instruments (termed the Manpack/Vehicular User Equipment, (MVUE). The sets shown in Figure 25 , are intended for low dynamic applications with sequential satellite tracking. They must operate in hostile jamming environment to provide precise positioning, and are configured for small size, weight, and battery power constraints. A unique interface for two-way data connection to an Army Radio is also provided.

A final point being pursued in the user equipment development spectrum for Phase I is the low-cost configuration with performance deliberately compromised to achieve minimum user dollar expense. The low-cost design is the only development geared to a pre-production prototype and hence final design form, fit, and function. The low-cost set characteristics are for a low dynamic application with only coarse signal operation in a non-hostile environment, does not operate with auxiliary sensors but must conform to being a mechanical replacement for existing Department of Defense AN/ARN-118 TACAN sets.

The Z-Set shown in Figure 26 , has a design-to-cost goal of less than $15,000 each for the initial production run of 500 units. The Z-Set is possible configured in 3 designs. The "stand-alone" employment will be comparable to a worldwide three-dimensional TACAN navigator with information displayed the same as a current inertial navigation output.

FIGURE 24.

Y-SET FUNCTIONAL PARTITION

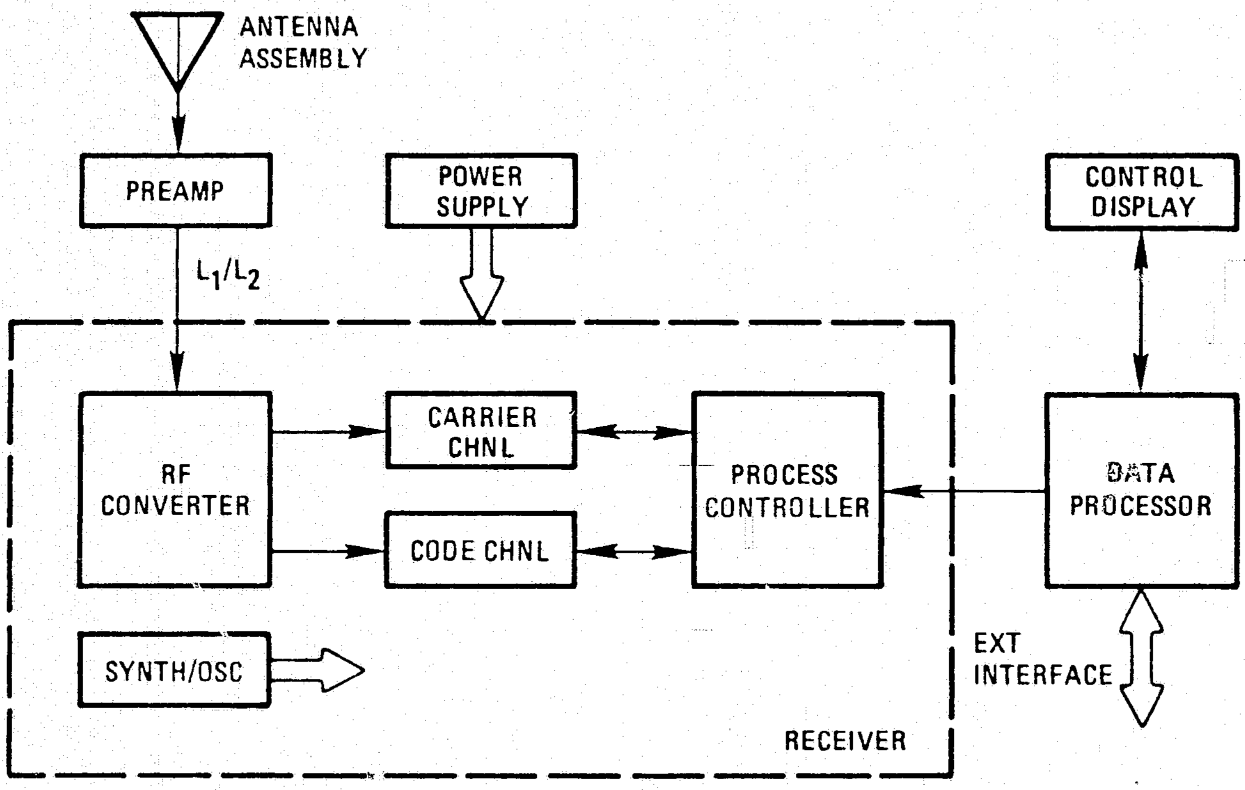


FIGURE 25 .

MANPACK/VEHICLE SET

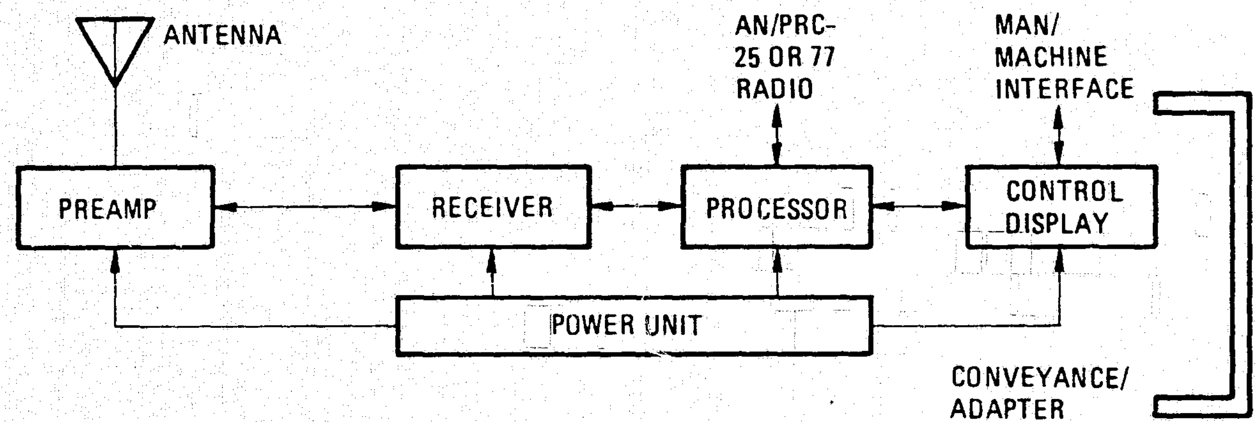
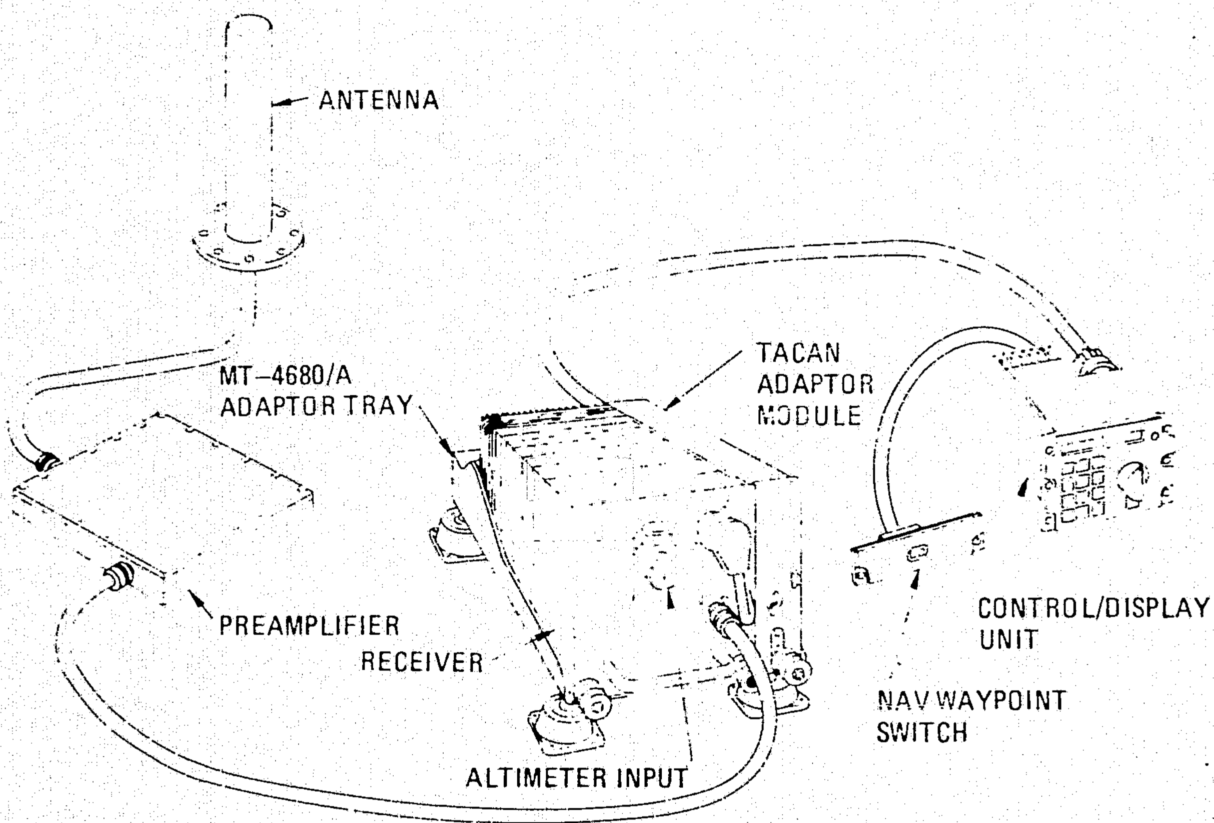


FIGURE 26 .

Z-SET



As a "swap-out" for the TACAN it interfaces directly to a TACAN adapter unit to provide compatible signals to existing cockpit instruments. With additional packaging to satisfy unique environmental conditions, the unit can be a "shipboard" marine navigator.

The MBRS is described in Figure 27, along with the required computer and interface equipments which provide control and data telemetry capability.

The M-Set configuration is briefly summarized in Table 9, which indicates the fact that the M-Set requires as a minimum another GPS receiving and navigation system to provide initialization.

Candidate Evaluation

The major objectives for on-orbit navigation were considered for each of the 12 candidate configurations. Table 10 summarizes these objectives in terms of suitability (a √ mark), no capability (a x mark), or uncertainty (a ? mark). This rather qualitative comparison was considered to be adequate to establish the first gross level of comparison required by this study. The determination of suitability is not meant to imply that the configuration could be immediately implemented to obtain the shuttle objective, but rather that it had the ultimate potential to provide the desired objective with some deliberate modifications. In the same manner the consideration of the specific objective elements was made and is summarized in Table 11.

Conclusions

Consideration of any of these existing candidates for obtaining the ascent/deorbit objectives is precluded at this time due to the need to define specific shuttle dynamics and accuracy requirements. Our recommendation is that a new design is required to provide the fulfillment of the objectives for ascent/deorbit.

For on-orbit objectives a number of suitable candidate configurations exist, among these the GPSPAC. However, if exposure to the space environment is considered as a necessary constraint, the GPSPAC singularly is the only suitable candidate.

FIGURE 27.

MISSILE-BORNE RECEIVER SET MBRS

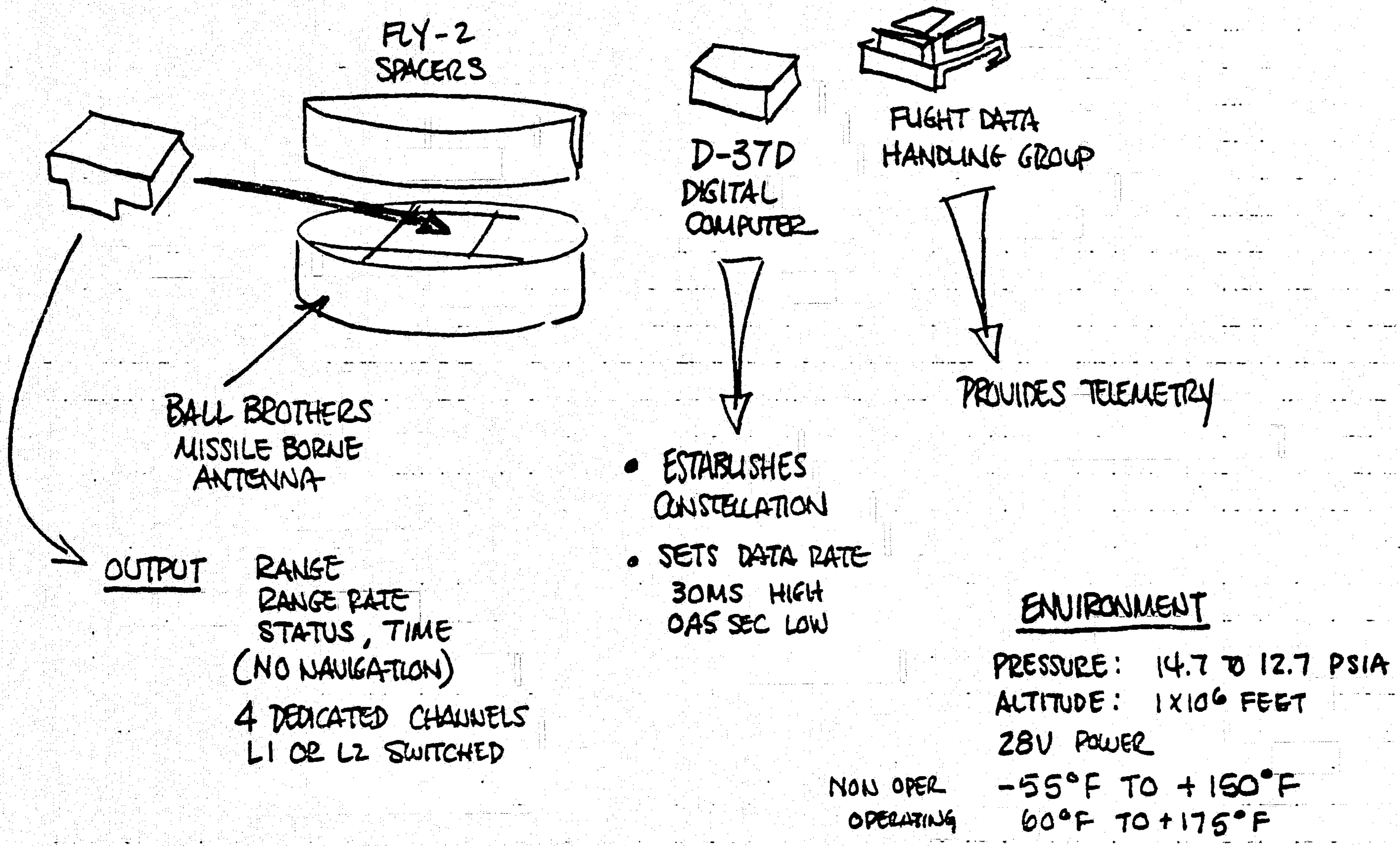


TABLE 9

M-SET CHARACTERISTICS

- Single Channel Sequenced Set
- Operationally Similar to Y-Set

  EXCEPT: No L_2 Freq. for IONO

  No C/A Code Tracking

  No Data Demodulation
- Initialization for P-Code, Time, Ephemeris, and Satellite Switching

  MUST be derived from X-Set.
- Requires aiding interface from IMU

TABLE 10

CANDIDATE SYSTEM OPTIONS

ON-ORBIT OBJECTIVES	X SET	XA SET	Y SET	YA SET	Z	MAN PACK	HI DYNA SET	MAN PACK VEHICLE	MBRS	AFAL GDM	M SET		GPS PAC
MAJOR OBJECTIVES													
• Demonstrate GPS in Shuttle Mission Environment													
– IN PAYLOAD BAY	—	—	—	—	—	—	—	—	?	—	—		✓
– IN MAN-RATED AREA ONLY	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
• Verify GPS as interim Navigation System	✓	✓	✓	✓		✓	✓	✓		✓			✓
– LIMITED NAV PERFORM					x				x		x		
• Assess GPS Accuracy for Payload Support	✓	✓	✓	✓		✓	✓	✓		✓			✓
• Investigate Measurement of Venting and Outgassing	✓	✓					✓		✓	✓			

TABLE 11

CANDIDATE COMPARISON MATRIX

ON-ORBIT OBJECTIVES	X SET	XA SET	Y SET	YA SET	Z	MAN PACK	HI DYNAM SET	MAN PACK / VEHIC.	MBRS	AFAL GDM	M SET		GPS PAC
• Investigate Satellite Visibility	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓
• Measure Acquisition and Re-acquisition Times													
– Unaided	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
– Aided		✓		✓			✓			✓	✓		
• Measure Dynamic Tracking Performance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
• Determine GPS Accuracy													
– P Code	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓
– C/A Code	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
• Measure Iono & Tropo	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓
• Evaluate Alternate Navigation Filters	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
• Investigate GPS Use For IUS INITIALIZATION		✓		✓			✓			✓	✓		

VI. SUMMARY AND CONCLUSIONS

The report has addressed the utilization of the GPSPAC presently being developed by Magnavox to be used on the Low Altitude Host Vehicle (LAHV) for use in the Shuttle Avionics System to evaluate the on-orbit navigation performance of the Space Shuttle. It is concluded that minor modifications to the presently configured GPSPAC are required to perform shuttle on-orbit navigation. We conclude the following:

- For on-orbit objectives a number of suitable candidate user configurations exist, among these the GPSPAC. However, if exposure to space environment is considered as a necessary constraint, the GPSPAC singularly is the only suitable candidate.

- Consideration of any of many existing user candidates for obtaining the ascent/deorbit objectives is precluded at this time due to the need to define specific shuttle dynamics and accuracy requirements. Our recommendation is that a new design is required to provide the fulfillment of the objectives for ascent/deorbit.

- The Baseline Shuttle/GPS link has adequate signal margin to meet the GPS receiver performance requirements when using the APL antenna specified at $\geq$ -1 dblC.

- The Shuttle on orbit dynamics are less than the LAHV requirements and no receiver redesign is required.

- No detailed link analysis can be performed at the present time for ascent and deorbit phases.

- A space qualified X-Set oscillator is recommended as the most cost effective approach for the Shuttle/GPSPAC experiment.

- The following modifications are required in the GPSPAC to be compatible with the Shuttle MDM interface:

- Serial input at 1 MBit Rate (not 2 KBit rate)
- Serial output at 1 MBit Rate (not 10.24 KBit rate)
- Input and Output data clock continuous Manchester II
- Pulse command threshold > 18 VDC (not > 20 VDC)
- Reformat data frames into fixed block lengths

- The following hardware/software modification will be required to provide compatibility with the MDM interface:
  - o Time Code Generator (TCG) Processing
  - o Telemetry (TLM) Processing
  - o Command Processing
  - o Telemetry I/O (CMD/TLM) Subsystem

- Only 4 of the 12 data files are required at a regular rate while in the navigate mode to obtain all status, measurement, and navigation data without including redundant data in the downlist.

- The average data rate from the GPSPAC to Shuttle MDM is 348 BPS; the peak data rate is 816 BPS.

- The black surface finish on the GPSPAC must be changed to white reducing the emissivity from 0.8 to 0.2.

- The top size surface area of the R/PA must be increased to 1.75 square feet to meet heat dissipation requirements.

- Minor modifications to the existing Single Channel RF Signal Generator (GSU) would be required for system integration and field testing.

- It is recommended that the existing four channel GPS performance evaluator be made available on a noninterference basis at

Magnavox to support detailed GPSPAC system performance analysis as required.

APPENDIX I

RESULTS OF ACTION ITEMS RESULTING FROM PANEL WORKING MEETINGS

ACTION ITEM 1.8

COMPARISON: SHUTTLE PALLET ENVIRONMENT

⇕

GPSPAC ENVIRONMENT

PROVIDED TO ROCKWELL

- MECHANICAL DRAWINGS AND OUTLINES AND MOUNTING PATTERN
- ACOUSTIC NOISE SPEC.
- SINUSOIDAL VIBRATION SPEC.
- RANDOM VIBRATION SPEC.
- PYROTECHNIC SHOCK
- LOAD FACTORS

RECEIVED FROM ROCKWELL

- MDM INTERFACES
- MTU SPEC.
- SL-E-0002 VOLTAGE CHARACTERISTICS

ACTION ITEM 1.8 RESULTS

△ NO CONFLICT EXCEPT FOR		SUSPENSE DATE
o EMI	(NEED FOR FURTHER STUDY)	MAY 15
o 28 VOLT RIPPLE AND TRANSIENTS	(NEED FOR FURTHER STUDY)	MAY 15

△ REQUIREMENT GUIDANCE NEEDED ON

- o TEMPERATURE
- o ALTITUDE
- o SAFETY AND OUTGASSING

△ EXTERNAL OSCILLATOR FROM APL IMPLIES OPERATING CONSTRAINTS

ACTION ITEM 2.20

MATRIX OF CANDIDATE OPTIONS AND CONFIGURATIONS

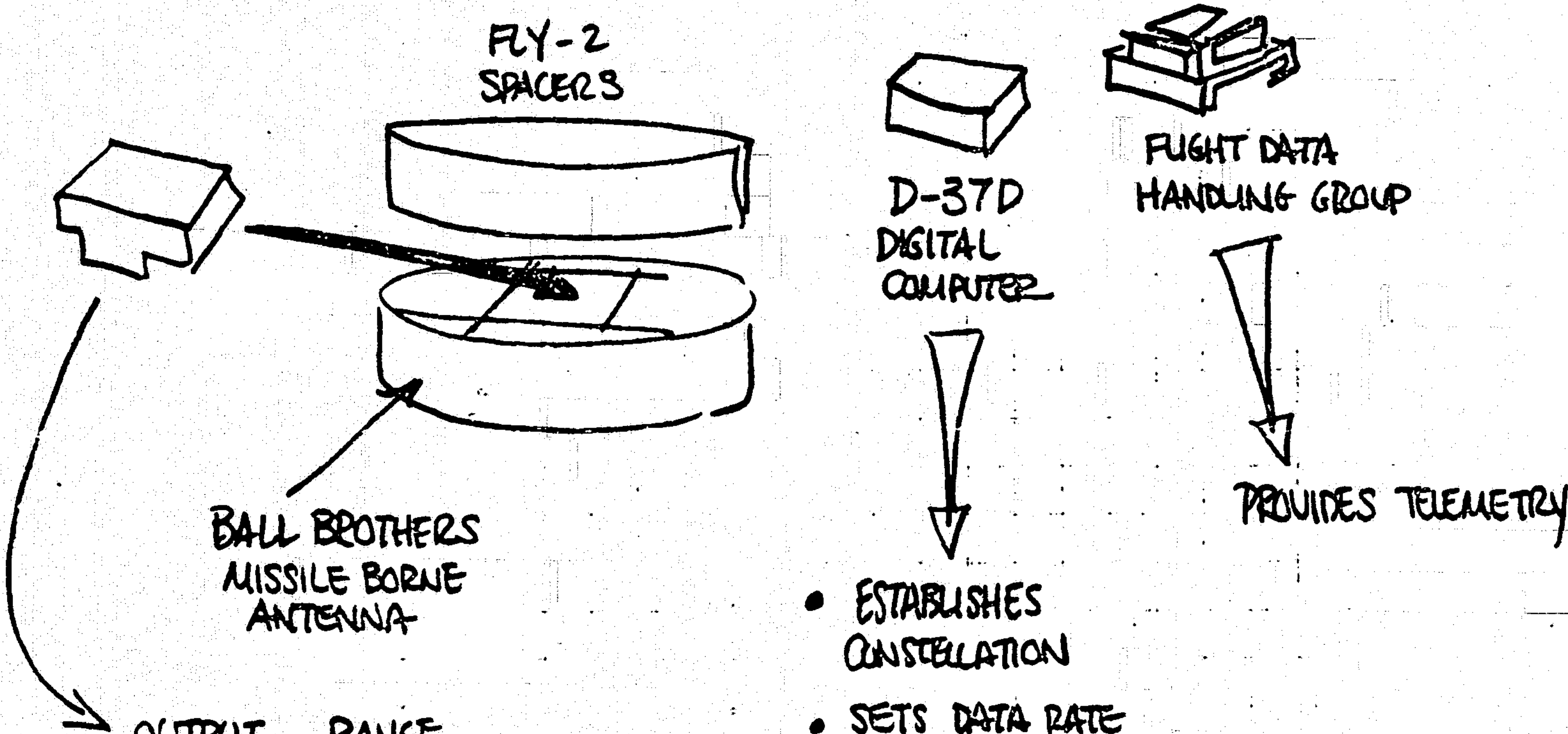
CANDIDATE SYSTEM OPTIONS

ON-ORBIT OBJECTIVES	X SET	XA SET	Y SET	YA SET	Z	MAN PACK	HI DYNA SET	MAN PACK VEHICLE	MBRS	AFAL GDM	M SET		GPS PAC
MAJOR OBJECTIVES													
• Demonstrate GPS in Shuttle Mission Environment													
– IN PAYLOAD BAY	—	—	—	—	—	—	—	—	?	—	—		✓
– IN MAN-RATED AREA ONLY	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
• Verify GPS as interim Navigation System	✓	✓	✓	✓		✓	✓	✓		✓			✓
– LIMITED NAV PERFORM					x				x		x		
• Assess GPS Accuracy for Payload Support	✓	✓	✓	✓		✓	✓	✓		✓			✓
• Investigate Measurement of Venting and Outgassing	✓	✓					✓		✓	✓			

CANDIDATE COMPARISON MATRIX

ON-ORBIT OBJECTIVES	X SET	XA SET	Y SET	YA SET	Z	MAN PACK	HI DYNAM SET	MAN PACK VEHIC.	MBRS	AFAL GDM	M SET		GPS PAC
• Investigate Satellite Visibility	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓
• Measure Acquisition and Re-acquisition Times													
– Unaided	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
– Aided		✓		✓			✓			✓	✓		
• Measure Dynamic Tracking Performance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
• Determine GPS Accuracy													
– P Code	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓
– C/A Code	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
• Measure Iono & Tropo	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓
• Evaluate Alternate Navigation Filters	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
• Investigate GPS Use For IUS INITIALIZATION		✓		✓			✓			✓	✓		

MISSILE-BORNE RECEIVER SET
MBRS



- ESTABLISHES CONSTELLATION
- SETS DATA RATE
  30MS HIGH
  0.45 SEC LOW

OUTPUT
RANGE
RANGE RATE
STATUS, TIME
(NO NAVIGATION)
4 DEDICATED CHANNELS
L1 OR L2 SWITCHED

ENVIRONMENT

PRESSURE: 14.7 TO 12.7 PSIA
ALTITUDE: 1X10⁶ FEET
28V POWER

NON OPER	-55°F TO +150°F
OPERATING	60°F TO +175°F

ACTION ITEM 2.19

DETERMINE ROM $ FOR GPSPAC X-SETS, OR M-SETS

GPSPAC: OPTION TO BUY 3 ADDITIONAL R/PA FLIGHT MODELS

---85K EACH

X-SET: ROM FOR ALL EQUIPMENTS

- 2 PREAMPLIFIERS
- RECEIVER
- DATA PROCESSOR
- POWER SUPPLY
- BATTERY BACK-UP
- CONTROL/DISPLAY
- PILOT INDICATOR
- CABLES

} $200 - 250K

M-SET: COMPETITIVE PROCUREMENT

NO DELIVERIES TILL OCTOBER 1978

MUST BE INITIALIZED BY X-SET

M-SET CHARACTERISTICS

- SINGLE CHANNEL SEQUENCED SET

- OPERATIONALLY SIMILAR TO Y-SET

  EXCEPT: NO L_2 FREQ FOR IONO

  NO C/A CODE TRACKING

  NO DATA DEMODULATION

- INITIALIZATION FOR P-CODE, TIME, EPHEMERIS, AND SATELLITE SWITCHING

  MUST BE DERIVED FROM X-SET

- REQUIRES AIDING INTERFACE FROM IMU

Magnavox apd

ACTION ITEM 2.10

- ITEM - TO RESOLVE PRESSURE SPECIFICATION DIFFERENCE BETWEEN ORBITER AND GPSPAC
  - GPSPAC REQUIREMENT - SEA LEVEL TO 10^{-5} TORR
  - ORBITER REQUIREMENT - SEA LEVEL TO 10^{-8} TORR
- RESULTS -
  - THE 10^{-8} TORR SPEC REQUIRES A MUCH MORE SOPHISTICATED VACUUM CHAMBER THAN FOR THE 10^{-5} TORR REQUIREMENT
  - MUCH LONGER STABILIZATION TIME REQUIRED
    - 10^{-8} TORR REQUIRES 48 HOURS OR MORE
    - 10^{-5} TORR REQUIRES 8 HOURS
  - THE 10^{-8} TORR REQUIREMENT HAS A DEFINITE COST IMPACT IN TESTING GPSPAC FOR THE SHUTTLE
- CONCLUSION
  - DESIGN AND TEST GPSPAC FOR SHUTTLE TO 10^{-5} TORR

677-3773

ACTION ITEM 2.21

- ITEM - SHUTTLE 28 VOLT RIPPLE AND TRANSIENTS AND IT'S IMPACT ON GPSPAC

- RESULTS
  - RIPPLE - SHUTTLE REQUIREMENT 0.9 V P-P
    GPSPAC REQUIREMENT 1.8 V P-P
  - TRANSIENTS - SHUTTLE REQUIREMENT 300×10^{-6} V-S
    GPSPAC REQUIREMENT 3.75×10^{-3} V-S

- CONCLUSION - GPSPAC OPERATES WITHIN SPEC OF THE 28V RIPPLE AND TRANSIENT REQUIREMENT SPECIFIED IN SL-E-0002

677-3774

ACTION ITEM 2.21

- ITEM - IMPACT OF SHUTTLE EMI ENVIRONMENT ON GPSPAC AS SPECIFIED IN SL-E-0002

- RESULTS
  - RADIATED ELECTRIC AND MAGNETIC FIELDS ARE NOT SEVERE AND WILL PRODUCE NO ADVERSE EFFECTS ON POWER SUPPLY INTERNAL PARTS
  - EMI EMISSIONS ARE NO WORSE THAN GPSPAC REQUIREMENT OF MIL-STD-461A

- CONCLUSION
  - SL-E-0002 RELAXES THE REQUIREMENT OF MIL-STD-461A; THEREFORE SL-E-0002 POSES NO PROBLEM

677-3775

Magnavox
GOVERNMENT & INDUSTRIAL ELECTRONICS COMPANY • ADVANCED PRODUCTS DIVISION
2829 maricopa street • torrance, california 90503 • telephone (213) 328-0770 • telex 674-373 • twx 910-3496657

File Reference: BR7025

In Reply Refer To:
AP-6:6:77:JM-1

6 June 1977

Rockwell International
Dept. 382, FC49
12214 Lakewood Blvd.
Downey, California 90241

Attention: Mr. Andrew Van Leeuwen

Subject: Response to Voltage Ripple and EMI Requirements of GPSPAC as applied to Shuttle Action Item 2.21, May 10, 1977, Space Shuttle GPS Panel Meeting

References: Space Shuttle Program Specification EMI Characteristics, Requirements for Equipment: SL-E-0002, Revision A, September 16, 1974

Dear Andy:

This letter is addressing your specific questions addressed to Magnavox regarding the Voltage Ripple and EMI Requirements of GPSPAC as applied to the Shuttle. Detailed answers are given to the following specific questions you requested Magnavox to address:

1. Can GPSPAC operate within spec with the 28V Ripple requirements and air frame loop voltages of Vol. XIV, Paragraph 4.2.2.8.1.a, b, c, and e?

2. What is the impact of the radiated EMI environment per Paragraph 4.2.2.8.2.a through d?

3. Can GPSPAC meet requirements for EMI emissions as specified in Paragraph 4.2.2.8.3.a through e?

4. What is the impact of the EMI requirements specified in SL-E-0002 (Delta to MIL-STD-461A requirements)?

Each specific requirement is addressed in detail. In summary, the power supply characteristics as specified in SL-E-0002 have been reviewed and compared to the anticipated GPSPAC system performance. SL-E-0002 relaxes the requirements of MIL-STD-461A.

The GPSPAC power supply is presently designed to comply with MIL-STD-461A. Therefore, SL-E-0002 should be no problem.

Very truly yours,

MAGNAVOX GOVERNMENT AND
INDUSTRIAL ELECTRONICS COMPANY
ADVANCED PRODUCTS DIVISION

Jack Moses

Jack Moses
Advanced Programs Department

JM/vl

Enclosure as stated

cc: J.C. MacLeod/JSC
P. Nilsen/AXIOMATICS
E. Martin/MAGNAVOX

QUESTION: Can GPSPAC operate within spec with the 28V ripple requirements and airframe loop voltages of Vol. XIV, Paragraph 4.2.2.8.1.a, b, c, and e.

ANSWER: Para. 4.2.2.8 SHUTTLE EMI ENVIRONMENT.

4.2.2.8.1 CONDUCTED NOISE ENVIRONMENT.

A. 1. .9V P-P is less than that shown in Figure 17A (.64V rms). Satisfying the requirements of Item 14, will comply with this line item.

2. Same as Item A, above.

3. Same as Item A, above.

4. Same as Item A, above.

B. Transients. The 300 x 10^{-6} V-S envelope is less than presently spec ified for the system. The system presently must absorb 3.75 x 10^{-3} V-S for the sum of positive and negative transients.

At present the peak amplitude is limited to ±10V. Whereas in SL-E-0002 it is limited to ±50V. Since the main concern is with the V-S product; the shuttle requirement is less.

C. C-M Voltage. The converter transformer will reject any C-M noise within the dynamic regulation range. .3V P-P is well within this range. This item seems to discuss two things at the same time. Transients of 50V amplitude have to be single-ended.

D. AC Power. N/A

E. DC Ground Power.

1. Same as 4.2.2.8.1 A.

2. Same as 1. above.

3. Same as 1. above.

QUESTION: What is the impact of the radiated EMI Environment per Paragraph 4.2.2.8.2 a through d.

ANSWER: Para. 4.2.2.8.2 (RAD. H-Fields).

A. MAGNETIC FIELD.

1. DC: 170 db above 1 picotesla.

2. DC Field Strength: (In Gauss)

$B = (\text{Antilog}_{10}\ 170/20 \times pt) = 3.16$ Gauss, where:

TESLA = Weber/SQ. Meter

Weber/Sq. Meter = 1×10^{4} Gauss

Picotesla (pt) = 1×10^{-8} Gauss

The main concern with magnetic fields is that high permeability magnetic devices might saturate in the presence of such fields. However, a DC Field of 3.16 Gauss, which presents the worst-case, will produce no adverse effects on power supply internal parts.

B. ELECTRIC FIELDS.

NOTE: Electric Field strength is referenced to Figures 4-25 and 4-25 which are not included. However, since a similar general expression relates the E-Field (Electric) and H-Field (Magnetic) vectors: it may be assumed that the characteristic impedance defines the Field Strength ratio, at any point in time. Thus: Z = E/H, and E = ZH. Furthermore, since Z is fairly constant it may be further assumed that the E-Field is also constant and equal to the H-Field for free space values. From these assumptions it may be concluded that the E-Field is as weak as that specified for the H-Field.

The problem of preventing radiated E-Field injection into the system is much simpler to handle than that posed by the H-Field. This is because system enclosure being aluminum is opaque to the E-Field, while remaining transparent to the H-Field.

Deployment of GPSPAC in a free space satellite application requires a thick enclosure to shield against proton radiation. This same enclosure, properly terminated to shielded cables will protect the GPSPAC Power Supply by circulating the E-Field energy in the enclosure (R-F Ground).

C. LIGHTNING PRODUCED FIELDS.

The bolt wavefront specified describes a peak current of 170 KA. This energy will be confined to the system enclosure, providing proper grounding and bonding procedures are employed. Thus, the problem involves air vehicle design more than payload per se, however, in event of internal damage, the GPSPAC Power Supply is designed to prevent second failure propagation. Therefore, any damage due to lightning strikes should remain within the affected subsystem.

D. ELECTROSTATIC DISCHARGE.

N/A

QUESTION: Can GPSPAC meet requirements for EMI Emissions as specified in Paragraph 4.2.2.8.2 a through e.

ANSWER: Para. 4.2.2.8.3 (SL-E-0002, Page 4-14)

NOTE: Here again, reference is made to Figures, 4-26 and 4-27, not provided.

A. It is assumed the specified levels are no worse than those specified in MIL-STD-461. This assumption is based on information supplied for Items 12 through 21. This being the case, the design will comply with the requirement.

B. Magnetic Field Strength emission should not present a problem, since magnetic devices are either toroidal or cup cores with negligible stray fields..

C. Power Supply design, due to large energy storage and wide-band filtering elements, will not support signals in the range of 1770 to 2300 MHz. However, it is possible for parasitic parameters to support and/or generate signals in this frequency range. Since it is virtually impossible to predict this situation the only alternative is to test for compliance.

D. <u>ELECTROSTATIC DISCHARGE</u>.

N/A

E. <u>PAYLOAD GENERATED TRANSIENTS</u>.

(See Item 4.2.2.8.1 B)

QUESTION: What is the impact of EMI requirements specified in SL-E-0002 (Delta to MIL-STD-461A requirements).

ANSWER: <u>SL-E-0002 MIDIFICATION OF MIL-STD-461</u>.

A. 1. (Para 2.1) Require copy of Handbook AFSC DH1-4 for proper evaluation.

2. (Para. 4.1.1) No impact.

3. (Para. 4.1.3.1) No impact.

4. (Para. 4.1.3.3) No impact.

5. (Para. 4.1.4) No impact.

6. (Para. 4.1.6) No impact.

7. (Table II Notes thereto.) Impact discussed in Items 12 [illegible] 21.

8. (Para. 4.5 new addition) Same as Item 1, above.

9. (Para 5.2) No impact - so long as proper correlation exists between antenna type to result in similar readings.

10. (Para 5.2.2 (b)) No impact, since this deals with test definition more than allowable field strength.

11. Para 5.8.2) This item degrades the accuracy of the measuring equipment by comparison to the accuracy of the impulse generator?

12. (Para. 6.1) This requirement dictates a power supply switching frequency sufficiently high to preclude generation of synthesized narrow-band harmonics within the limits of Fig. 13A. SL-E-0002 Figure-13A is less stringent than the original specification in Figure 13 of MIL-STD-461.

13. (Para. 6.2) This requirement relaxes the attenuation requirement of Figure 15 in MIL-STD-461. Normal filtering to satisfy MIL-STD-461 will be adequate.

14. (Para. 6.1) CSOI has always been a tough requirement for switching power supplies due to gain band-width constraints imposed by the integrating L-C filter. Fortunately, SL-E-0002 relaxes the amplitude for injected disturbances. While the frequency for maximum injection is increased from 1.5 KHz, per MIL-STD-461 Figure 17, to 7 KHz; it does not pose a problem since the critical frequency occurs near the L-C filter quarter wave time contant which is typically 1.5 to 2.5 KHz.

15. (Para. 6.5) Switching power supplies normally do not propagate signals above the integrating filter's frequency attenuation curve. In the frequency range from 50 KHz to 400 MHz, the L-C filter acting in combination with the EMI filtering can be made to provide sufficient rejection. In addition SL-E-0002 reduces the amplitude of the injected signal from the 1.0 (one) volt specified in MIL-STD-461 to .22 volts.

16. (Para. 6.11) No impact.

17. (Para. 6.12.1) Figure 21A of SL-E-0002, allows a +10 db relaxation over the entire frequency band over the requirements of MIL-STD-461.

18. (Para 6.12.2) Figure 22A is also a reduction from that specified by MIL-STD-461. While broad-band emissions are integrated by the spectral bandwidth, they present the most serious noise problem since at lower frequencies the energy content can be appreciable. The proper combination of L-C filtering, power supply dynamic response and late developments in wide band monolithic EMI filters can serve to provide attenuation of offensive EMI signals compatible with MIL-STD-461.

19. (Para. 6.13) No impact. This requirement is strictly a measurement convenience.

20. (Para. 6.17) No impact. CSOI presents the real limitation.

21. (Para. 6.20 NEW ADDITION).

NOTE: Figure "B" mentioned in the text of 21 is not supplied.

Test TT01, deals with transient reflected on the power line by load changes and/ or sudden interruption of electrical power to utilization equipment. This requirement does not apply to the GPSPAC system since the primary interface is via the power supply input termination.

One of the fundamental requirements is for a complete de-coupling of power supply elliptical load line reflections beyond the input interface, to comply with general isolation requirements of MIL-STD-461. Since the input interface is a balanced network with negative image reflections it protects the prime power source from supply transients in a manner similar to protecting the supply from incoming transients.

22. (Delete Fig. 12) No impact.

23. (Subs. Fig. 13 with Fig. 13A) See Item 12.

24. (Delete Fig. 14) No impact. This requirement is not thoroughly understood since GPSPAC utilizes switching power supplies as the primary mode of line power conditioning; and switching supplies are notorious for generating noise signals rich in broad-band harmonics.

25. (Subs. Fig. 15 with Fig. 15A) See Item 13.

26. (Delete Fig. 20) No impact. See Item 20.

27. (Subs. Fig. 21 with Fig. 21A.) See Item 17.

28. (Subs. Fig. 22 with Fig. 22A.) See Item 18.

NOTE: MIL-STD-461 Fig. 17 is substituted with SL-E-0002 Fig. 17A. (See Item 14) This should be re-capped in Item 26. Item 26 becomes 27, etc. for 29 Line Items.

MAGNAVOX

SL-E-0002
REVISION A
SEPTEMBER 16, 1974

SUPERSEDING
SL-E-0002
JUNE 4, 1973

SPACE SHUTTLE PROGRAM

SPECIFICATION

ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS, REQUIREMENTS FOR EQUIPMENT

National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER
Houston, Texas

REVISIONS AND CHANGES

REV LTR	CHANGE NO.	DESCRIPTION	DATE
		BASELINE ISSUE (REFERENCE PRCBD S00125)	6/4/73
A		PRCBD S00734	9/16/74

SPACE SHUTTLE PROGRAM

SPECIFICATION

ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS, REQUIREMENTS FOR EQUIPMENT

SEPTEMBER 16, 1974

FOREWORD

This document has been prepared specifically to tailor the requirements of MIL-STD-461A to Space Shuttle equipment level procurements. Changes to MIL-STD-461A required by the issuance of notices 1, 2, and 3 have been included directly in this document if they were appropriate to equipment level procurements for the Space Shuttle. MIL-STD-461A, dated August 1, 1968, as modified by this document shall be applicable to Space Shuttle flight equipment level procurements. These requirements are not applicable to ground equipment procurements unless specifically required by the procuring activity in order to comply with paragraph 3.2.4.1 of MIL-E-6051D as amended by Space Shuttle Amendment "A" dated June 4, 1973.

Robert F. Thompson
Manager, Space Shuttle Program

SPACE SHUTTLE PROGRAM

SPECIFICATION

ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS,

REQUIREMENTS FOR EQUIPMENT

This document is applicable to all NASA Space Shuttle System procurements and should be filed in front of MIL-STD-461A, dated August 1, 1968, and supersedes that document in those areas detailed herein.

TO ALL HOLDERS OF MIL-STD-461A:

Make the following changes:

1. Paragraph 2.1 Add the following document:

   Handbook
   AFSC DH1-4 Electromagnetic Compatibility

2. Paragraph 4.1.1 Delete and Substitute:

   Subsystems - Units or equipments within a single procurement subcontract shall be tested as a subsystem. Tests on individual units of the subsystem are not required unless directed by the procuring activity. (For this purpose, a subsystem would not normally be considered to be a spacecraft, launch vehicle, or ground C-e shelter.) Table I, Table II and thereto shall be used as guides for test selection. For each procurement the procuring activity shall specify the applicable tests from Table II.

3. Paragraph 4.1.3.1 Delete the words "required by this standard" from the first sentence.

4. Paragraph 4.1.3.3 Delete without replacement

5. Paragraph 4.1.4 Delete without replacement.

6. Paragraph 4.1.6 Delete second sentence.

7. **Table II and notes thereto.**

Tests CE02 and CE04

Class IC   Delete "Y" and substitute "N"
Class ID   Delete "Y" and substitute "N"
Class IIA   Delete "Y" and substitute "N"

Delete Test CE05 without replacement
Delete Test RE01 without replacement
Delete Test RS01 without replacement

Note 4 Delete without replacement

Note 5 Delete (RE01), (RS01)

Add the following to Table II:

	EQUIPMENT CLASS											
	IA	IB	IC	ID	IIA	IIB	IIC	IIIA	IIIB	IIIC	IIID	IV
TT01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

NOTE: This test described in detail in item 21 of this amendment.

8. Paragraph 4.5 Add new paragraph.

4.5 <u>Design Criteria and Guidance</u>. - AFSC DH 1-4 supplements this standard and shall be used as a guide for design information and criteria.

9. Paragraph 5.2 Delete and substitute.

Antennas other than those specified can be used if described in the test plan and approved by the procuring activity. Antenna factors used shall be those published by the antenna manufacturer, measured in accordance with SAE ARP 958 or other approved procedure.

10. Paragraph 5.2.2 (b) Delete and substitute.

The 41 inch rod antenna need not be used for susceptibility testing. Antennas such as parallel plates, long wires, etc., are preferred. The antenna used and general procedures shall be described in the test plan.

11. Paragraph 5.8.2 Delete ± 2 dB, substitute ± 4 dB.

12. Paragraph 6.1 Delete and substitute.

6.1 Limits for CE01 and CE02. - Electromagnetic emissions in the frequency range of 30 Hz to 20 kHz shall not appear on power leads, control leads, signal leads and interconnecting cables between parts, sources and loads of an equipment in excess of the values shown on Figure 13A. The broadband test is not required. Only leads going external to the subsystem/equipment shall be measured. Intentional transmissions by conduction on signal leads are exempt.

13. Paragraph 6.2 Delete and substitute.

6.2 Limits for CE03 and CE04. - Electromagnetic emissions in the frequency range of 20 kHz to 50 MHz shall not appear on power leads, control leads, signal leads and interconnecting cables between parts, sources and loads of an equipment, in excess of the values shown on Figure 15A. The broadband test is not required. Only leads going external to the subsystem/equipment shall be measured. Intentional transmissions by conduction on signal leads are exempt.

14. Paragraph 6.4 Delete and substitute.

6.4 Limit for CS01. - The performance characteristics of the subsystem/equipment shall not be degraded beyond the tolerances given in the individual equipment specification or approved test plan, in the frequency range of 30 Hz to 50 kHz, when subjected to electromagnetic energy injected on its power leads equal to or less than the values shown on Figure 17. The reduced limits of Figure 17A shall apply to equipment powered from Orbiter +28VDC.

15. Paragraph 6.5 In first line, delete "Class I equipment" and substitute "the subsystem/equipment." Also, Add the following sentence: "The test limit shall be .22 volts for equipment powered from Orbiter +28VDC."

16. Paragraph 6.11 Delete without replacement.

17. Paragraph 6.12.1 Delete Figure 21 and substitute Figure 21A.

18. Paragraph 6.12.2 Delete and substitute.

6.12.2 Continuous or repetitive broadband E-field emissions shall not be generated and radiated in excess of the values shown in Figure 22A. Broadband E-field emissions resulting from equipment turn on/off and switching transients are exempt from this requirement. Switching transient requirements are covered by the time domain transient and ripple test described in item 21 of this amendment.

19. Paragraph 6.13 Add the following note:

This test should be performed only when CE06 cannot be accomplished and when authorized by the procuring activity.

20. Paragraph 6.17 Delete without replacement.

21. Add new paragraph.

6.20 Time Domain Transient and Ripple Test (TT01). - Any load on the 28 VDC power bus system shall not generate a transient in excess of ± 30 VDC (+ 58 or -2 volts maximum peak) when measured at the power input terminals of the test sample, as described in Figure A, and when using the test NETWORK as described in Figures B and C. This requirement applies to turn ON and turn OFF and switching through all operational modes. Oscilloscope photographs shall be made of the real-time transients and submitted to the procuring agency as proof of compliance. The oscilloscope for measuring real-time transients shall have a minimum bandwidth of 50 MHz. All oscilloscope photographs submitted to meet these requirements shall have sweep speed and vertical deflection sensitivity identified. In addition, representative oscilloscope photographs of characteristic steady-state ripple of the load, as measured across the power input terminals to the load, terminal pair "A", and terminal pair "B", shall be submitted to the procuring agency for evaluation in determining Space Shuttle subsystem ripple allocation. Sweep speed and vertical deflection sensitivity shall also be identified for these photographs.

22. Figure 12 Delete without replacement.

23. Figure 13 Delete and substitute attached Figure 13A.

24. Figure 14 Delete without replacement.

25. Figure 15 Delete and substitute attached Figure 15A.

26. Figure 20 Delete without replacement.

27. Figure 21 Delete and substitute attached Figure 21A.

28. Figure 22 Delete and substitute attached Figure 22A.

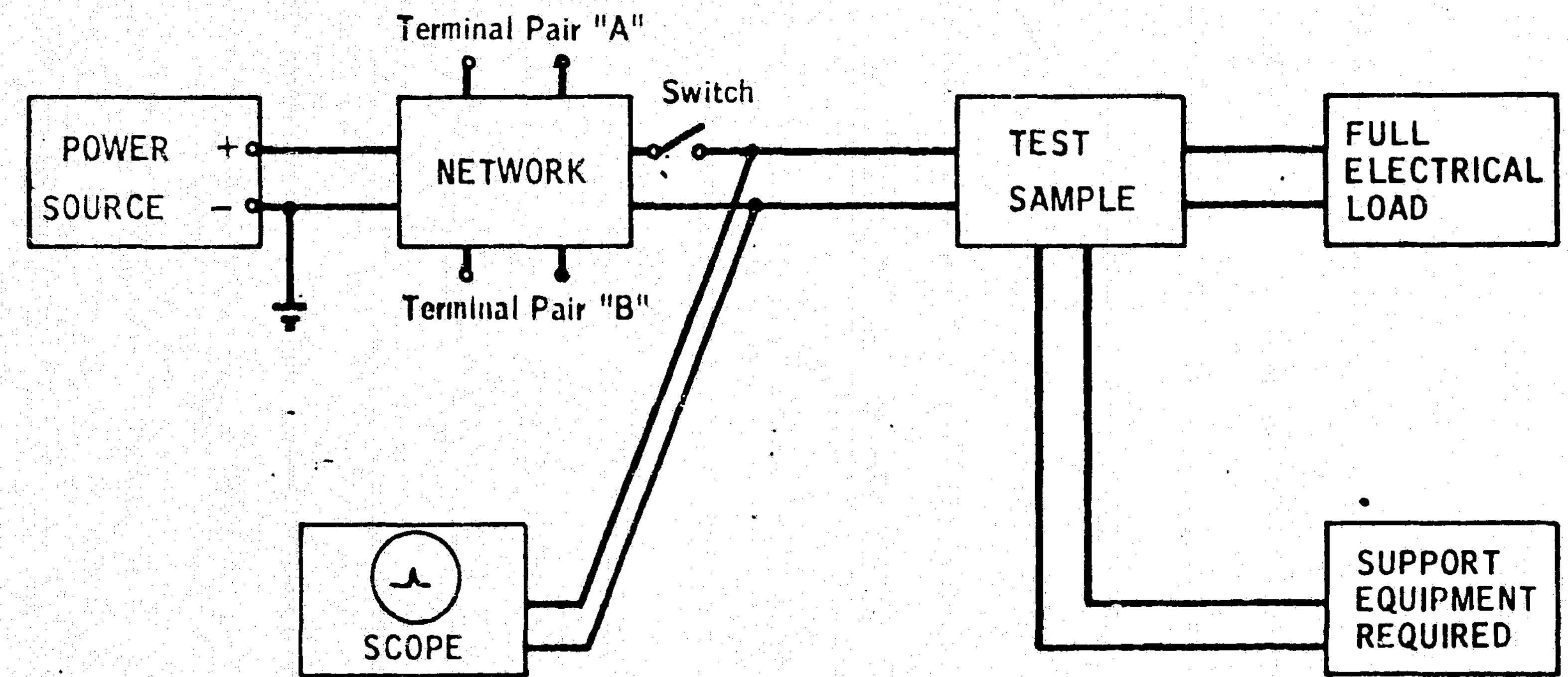


Figure A. Transient and Ripple Generation Test Set Up.

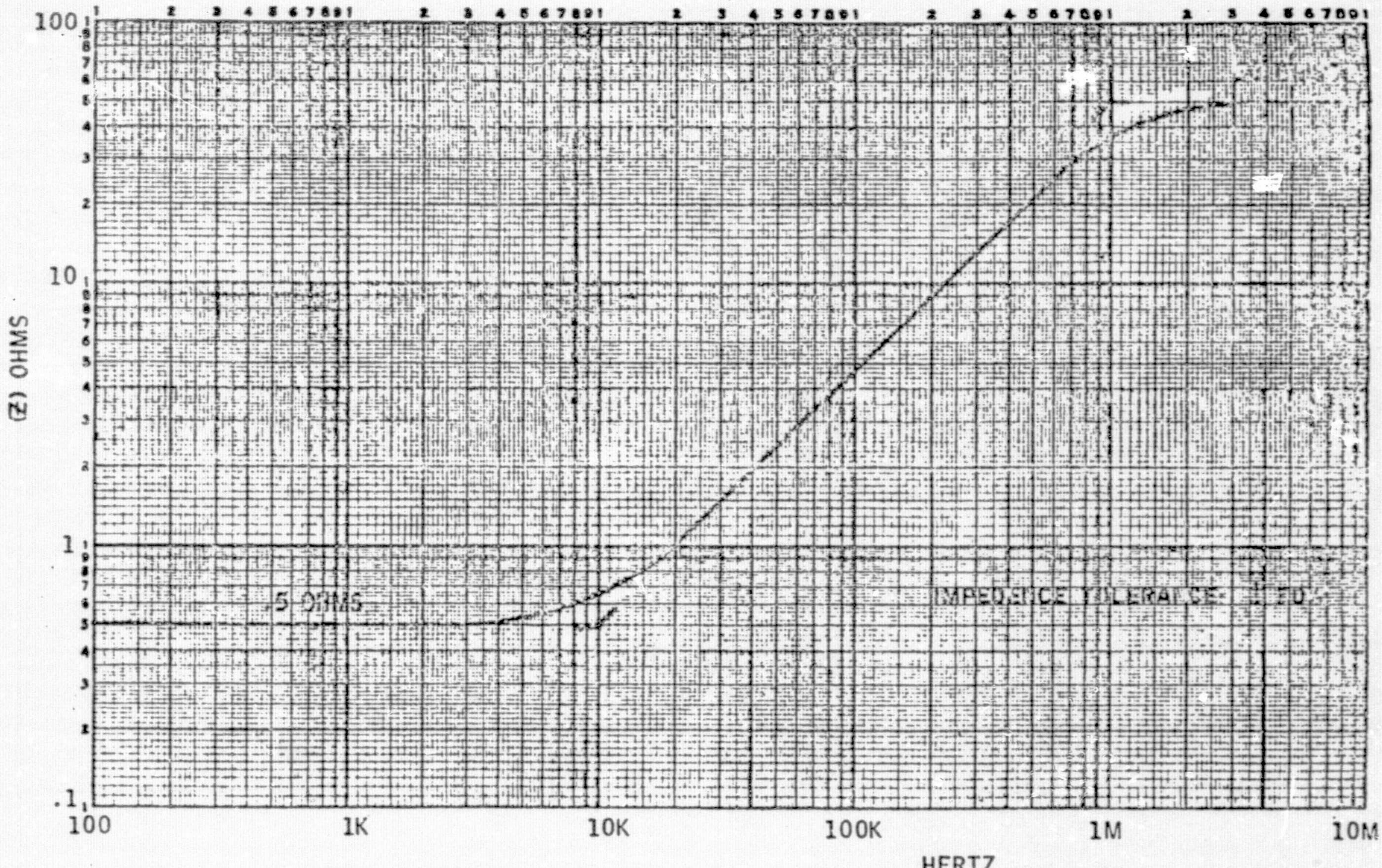


Figure C Network Input Impedence

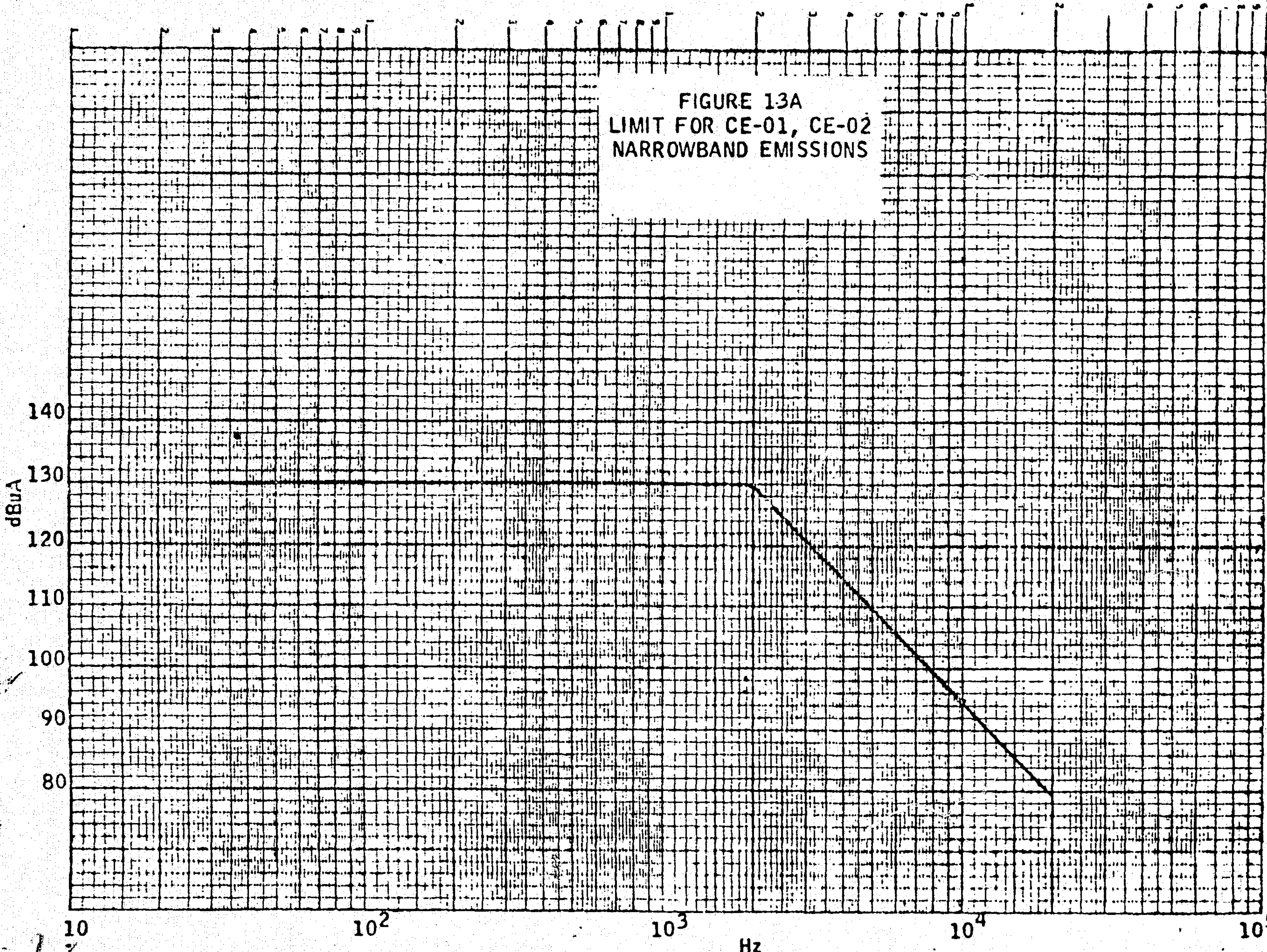


FIGURE 13A
LIMIT FOR CE-01, CE-02
NARROWBAND EMISSIONS

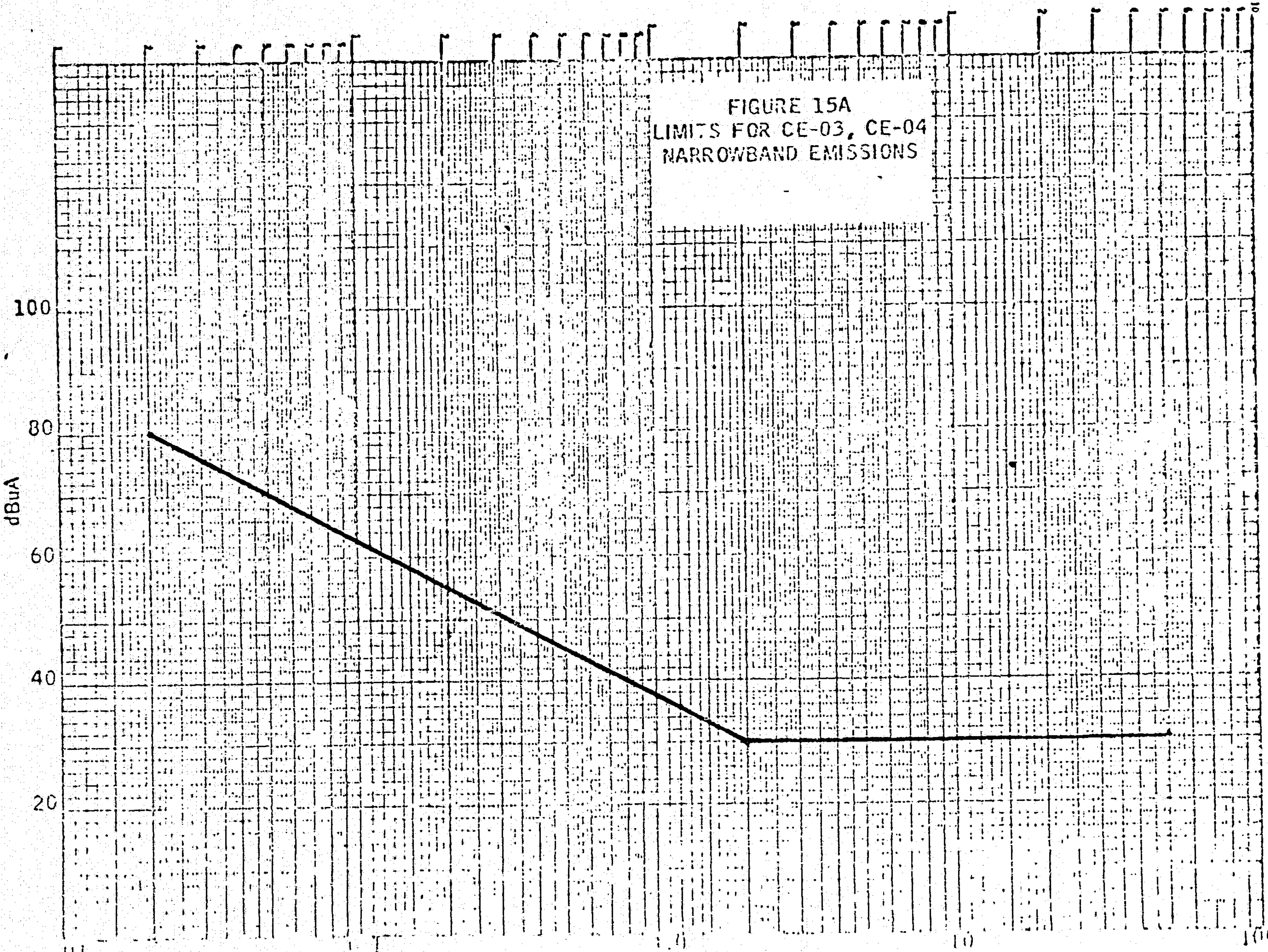
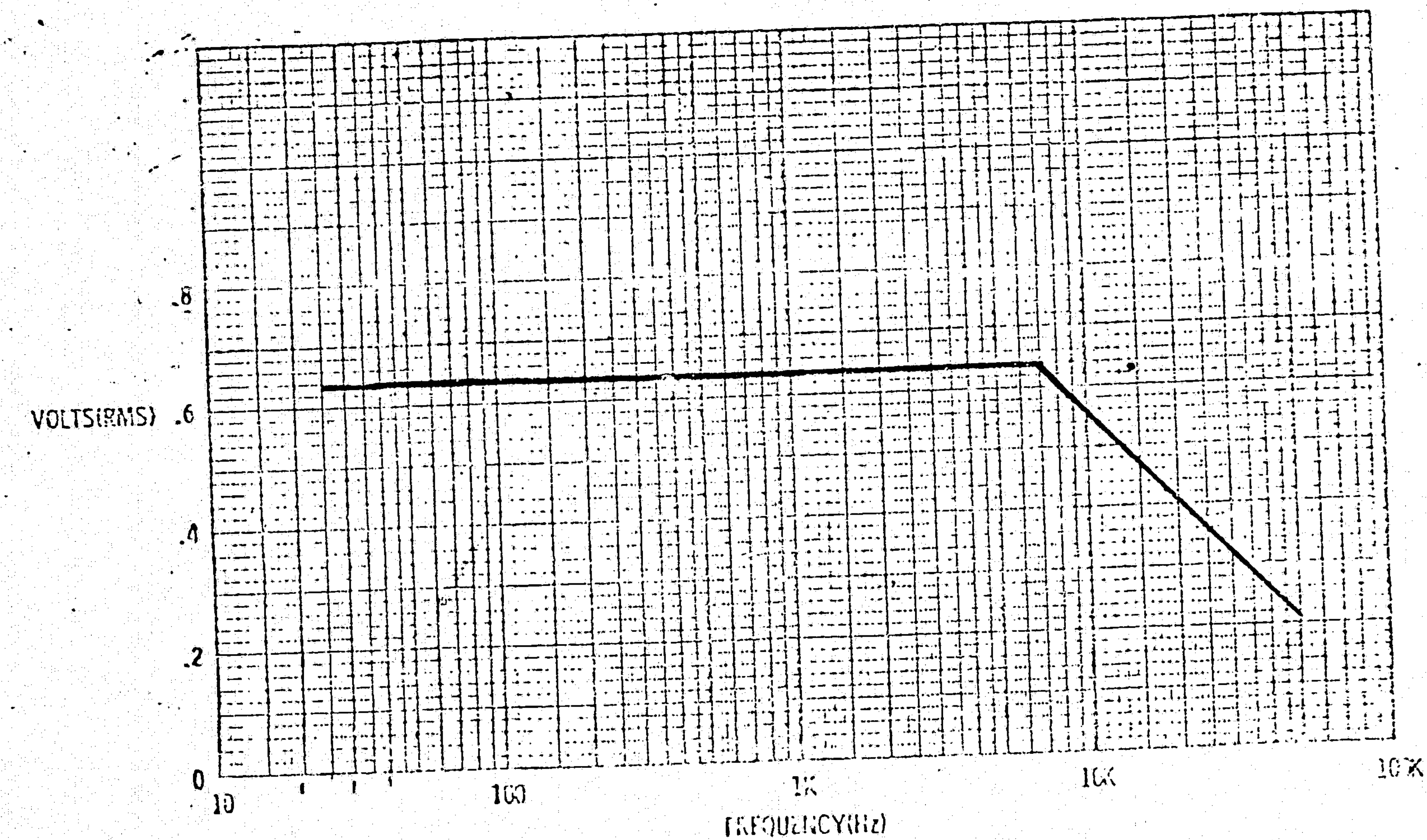


FIGURE 15A
LIMITS FOR CE-03, CE-04
NARROWBAND EMISSIONS

FIGURE 17A LIMITS FOR CS01 28 VDC POWER



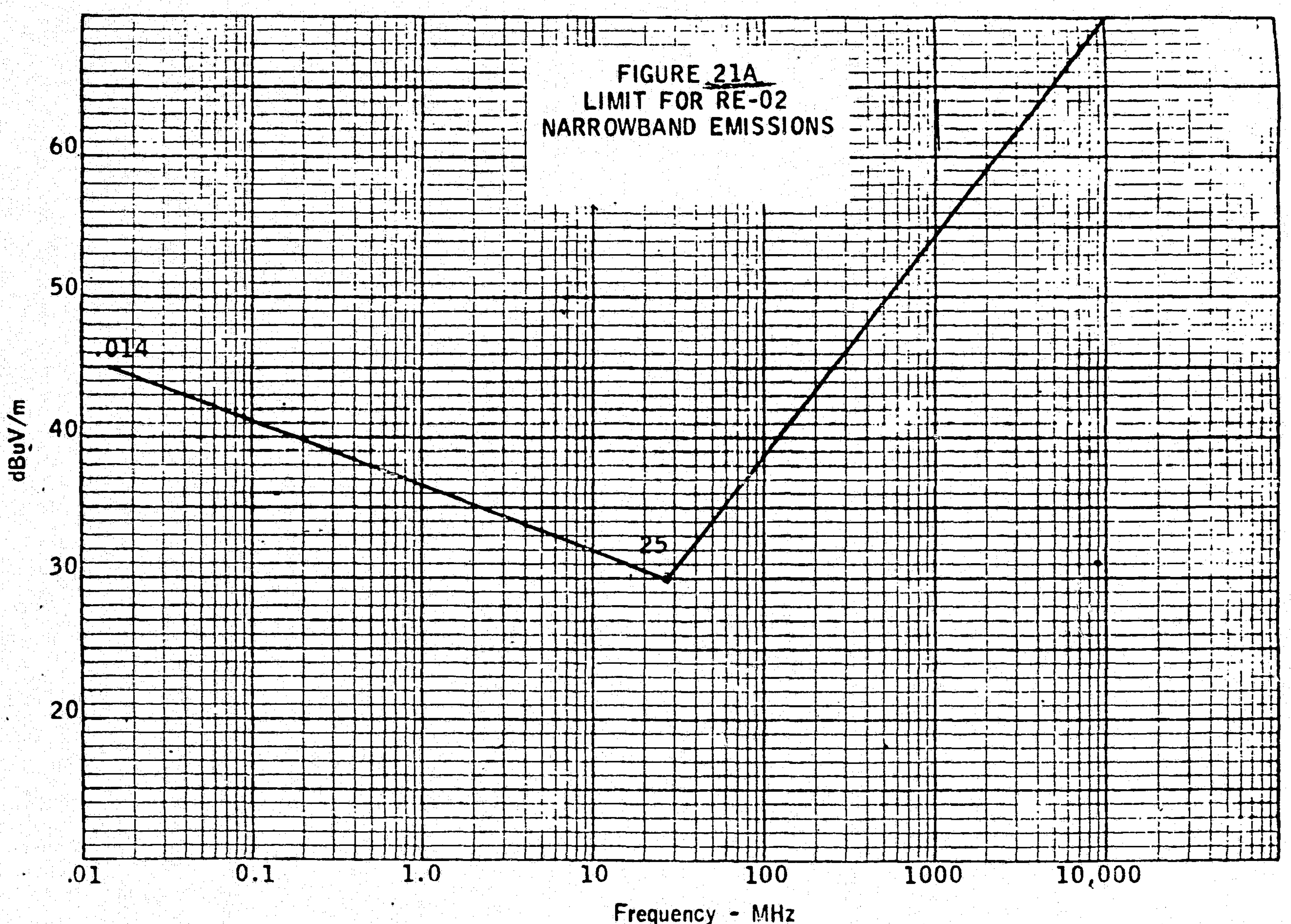


FIGURE 21A
LIMIT FOR RE-02
NARROWBAND EMISSIONS
60
50
40
30
20
dBuV/m
.014
25
.01
0.1
1.0
10
100
1000
10,000
Frequency - MHz

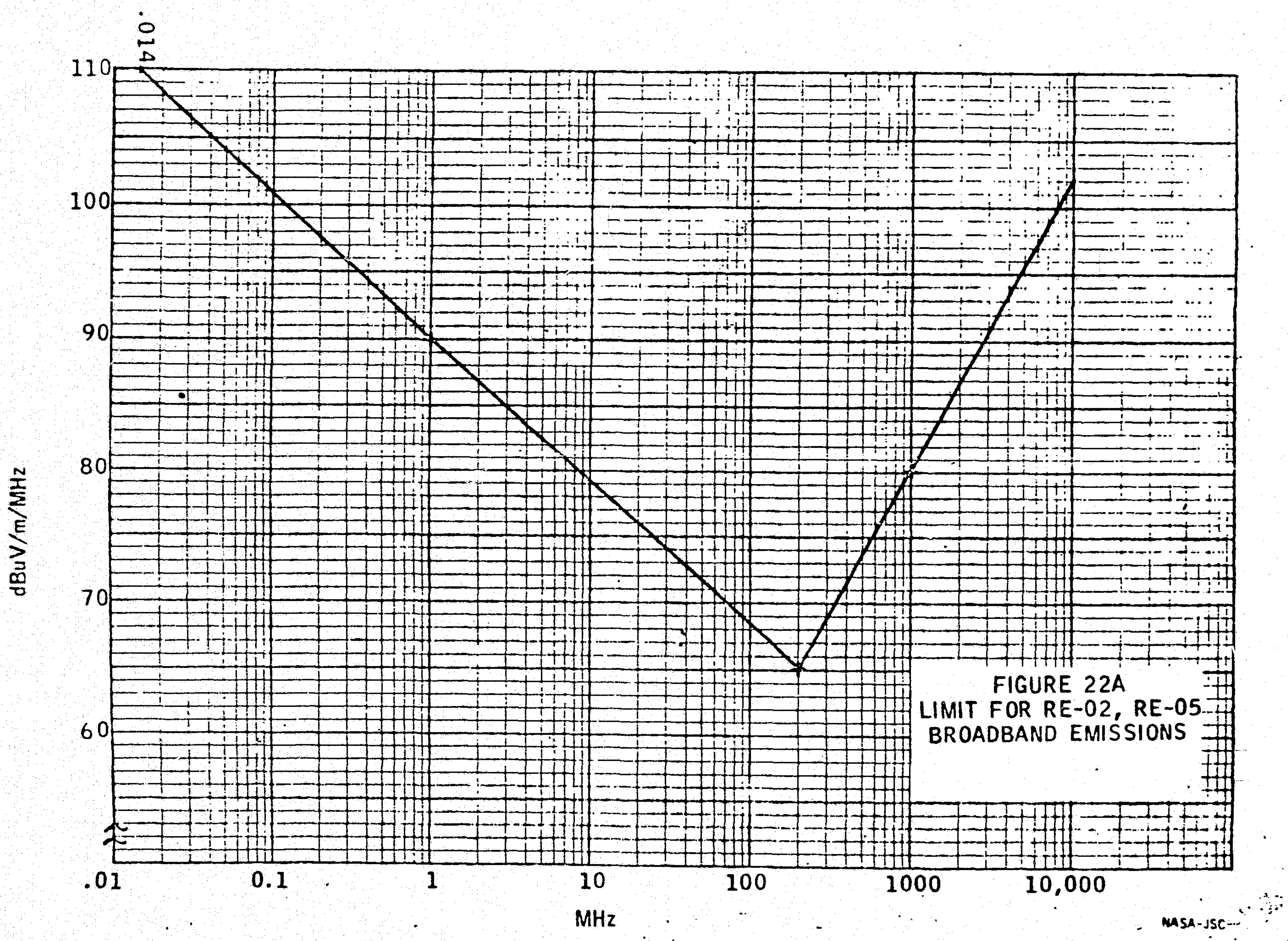


FIGURE 22A
LIMIT FOR RE-02, RE-05
BROADBAND EMISSIONS

4.2.2.7.4 Post-Landing Thermal Condition. For normal thermal condition at touchdown + 30 minutes, the GSE purge for interstitial cooling would be provided so that the temperatures given in Figure 4-13 represent the maximum predicted values and would gradually decrease to ambient conditions as indicated in Figure 4-20 for the boundary cases on no heat transfer to or from payload (adiabatic) and constant temperature (infinite heat sink). The effect of continuing heat soak to the payload bay beyond touchdown + 30 minutes is also given in Figure 4-20.

4.2.2.8 Space Shuttle Electromagnetic Environment. The Space Shuttle System is designed and tested in accordance with the requirements of SL-E-0001. The Space Shuttle electromagnetic environment will be limited to the values indicated in 4.2.2.8.1 through 4.2.2.8.2, provided payload generated conducted and radiated emmissions do not exceed the values indicated in paragraph 4.2.2.8.3.

4.2.2.8.1 Shuttle-Produced Conducted Noise Environment. The conducted interference produced by the Shuttle will be limited as follows:

a. In-flight DC power bus ripple at the interface will not exceed:

   1. 0.9 Volts peak-to-peak narrowband (30 Hz to 7 KHz) falling 10 dB per decade to 0.28 volts peak-to-peak to 70 KHz, thereafter remaining constant to 400 MHz.

   2. 1.6 Volts peak-to-peak broadband from 30 Hz to 50 MHz.

   3. Under the conditions of a passive payload (resistive simulation of load), the ripple on the power supplied will not be greater than 0.8 volts peak-to-peak broadband (DC to 50 MHz); no discrete frequency will exceed 0.4 volts peak-to-peak. This condition applies at the midbody power interface only.

   4. For the dedicated fuel cell operation, the Shuttle-generated ripple at the interface will not exceed 100 millivolts peak-to-peak (30 Hz to 10 MHz).

b. In-flight DC power bus transients will not exceed the impulse equivalent of 300 X 10^{-6} volt seconds above or below normal line voltage. Peak trasients will be limited to ± 50 volts from nominal bus voltage and rise and fall times shall not be less than 1 microsecond.

CHANGE NO. 1

c. The common-mode voltage between any two payload attach-points, and between any payload attach-point and the forward avionics ground reference point, will not exceed 0.3 volts peak-to-peak, when measured in the time domain with an instrument bandwidth of a least 50 MHz. This is inclusive of the DC component which may exist in the vehicle structural members. Discrete frequencies will not exceed 0.15 volts peak-to-peak. Transient excursions will be limited to ± 50 X 10^{-6} voltseconds with rise and fall times not less than 1 microsecond; the peak voltage will not exceed ± 9 volts.

d. A. C. Power Ripple and Transients

1. A. C. power bus ripple will be limited to 1.5 volts RMS from 30 Hz to 1.5 KHz falling to 0.6 volts RMS at 50 KHz thereafter remaining constant to 400 MHz, except that the ripple will not exceed 4% of the A.C. line voltage at inverter harmonic frequencies.

2. A.C. power bus transients spikes will not exceed the levels specified in AS1212, paragraph 5.1.4.

e. Ground D. C. Power

1. The narrowband ripple voltage at the interface will not exceed 1.2 volts peak-to-peak (30 Hz to 7 KHz) falling log-linear to 0.28 volts peak-to-peak at 70 KHz, thereafter remaining constant to 400 MHz.

2. The broadband ripple voltage at the interface will not exceed 2.0 volts peak-to-peak (30 Hz to 50 MHz).

3. Transients will not exceed the impulse equivalent of 300 X 10^{-6} volt seconds above or below normal line voltage. Peak transients will be limited to ± 50 volts from nominal bus voltage and rise and fall times shall not be less than 1 microsecond.

4.2.2.8.2 Shuttle-Produced Radiated Fields. The Shuttle-produced radiated fields environment will be limited as follows:

a. Magnetic fields will be limited to less than 140 dB above 1 picotesla (30 Hz to 2 KHz), falling 40 dB per decade to 50 KHz. The D.C. field will be less than 170 dB above 1 picotesla.

at inverter harmonic frequencies.

2. A.C. power bus transients spikes will not exceed the levels specified in AS1212, paragraph 5.1.4.

e. Ground D. C. Power

1. The narrowband ripple voltage at the interface will not exceed 1.2 volts peak-to-peak (30 Hz to 7 KHz) falling log-linear to 0.28 volts peak-to-peak at 70 KHz, thereafter remaining constant to 400 MHz.

2. The broadband ripple voltage at the interface will not exceed 2.0 volts peak-to-peak (30 Hz to 50 MHz).

3. Transients will not exceed the impulse equivalent of 300 X 10^{-6} volt seconds above or below normal line voltage. Peak transients will be limited to ± 50 volts from nominal bus voltage and rise and fall times shall not be less than 1 microsecond.

4.2.2.8.2 Shuttle-Produced Radiated Fields. The Shuttle-produced radiated fields environment will be limited as follows:

a. Magnetic fields will be limited to less than 140 dB above 1 picotesla (30 Hz to 2 KHz), falling 40 dB per decade to 50 KHz. The D.C. field will be less than 170 dB above 1 picotesla.

b. Electric fields will be limited to the levels shown in Figures 4-24 and 4-25 except at frequencies of installed transmitters as identified in Table 4.3. Installed transmitter field strengths apply only with payload bay doors open.

c. Lightning produced fields will be limited to a peak level of 280 amperes/meter. The pulse will rise to peak in 2 microseconds and fall to zero in 100 microseconds. This environment is produced when a direct lightning strike attaches to the vehicle which is a remote possibility. If this should happen, the payload should be designed such that a failure would not propogate catastrophically to the Space Shuttle.

d. The design of the cargo bay and cargo bay doors should preclude any electrostatic discharges.

4.2.2.8.3 Payload-Produced Electromagnetic Envirionment Limits. The electromagnetic environments defined in paragraphs 4.2.2.8.1 and 4.2.2.8.2 apply, provided the payload generated conducted and radiated emissions are limited to the levels indicated below: .

a. The power line conducted emissions shall be limited to the levels indicated in Figures 4-26 and 4-27. These levels may be exceeded when operating from a dedicated fuel cell; however, the power bus ripple voltages of paragraph 4.2.2.8.1 will not be applicable.

b. The magnetic fields generated shall not exceed 130 dB above 1 picotesla (30 Hz to 2 KHz) falling 40 dB per decade to 50 KHz. The d.c. field shall not exceed 160 dB above 1 picotesla.

c. The radiated electric fields shall not exceed the levels indicated in Figures 4-28 and 4-29 except the broadband emissions for payload equipment in the cargo bay shall be limited to 70 dB above 1 microvolt/meter/MHz in frequency range of 1770 MHz to 2300 MHz. Narrowband emissions shall be limited to 25 dB above 1 microvolt/meter from 1770 MHz to 2300 MHz excluding the payload intentional transmitters.

d. Electrostatic discharges are not permitted within the cargo bay other than those contained and shielded by the payload.

e. Payload generated power bus transients produced by single event switching or operations occurring less than once per second shall not generate transients in excess of 300 X 10^{-6} volt seconds above or below normal line voltage when feed from a source impedance shown in Figure 4-30. Peaks shall be limited to ± 50 volts and rise and fall times shall not be less than 1 microsecond.

4.2.2.9 Hazardous Gas Detection. The Hazardous Gas Detection System monitors GH2 and GO2 concentrations on the pad by continuously drawing samples of payload bay constituents through vacuum sample lines located at the Xo 1307 bulkhead check valves as shown in Figure 4-1. The sample lines are connected to a GSE mass spectrometer which analyzes and displays sample concentrations up to time of lift-off. Hypergolic gas concentrations emanating from the payload bay via the Xo 1307 check valves are monitored by a ground based sensor system with external probes located at the aft fuselage vent ports. The probes are withdrawn when the pad payload service room is removed.

CHANGE NO. 29

APPENDIX II

COPIES OF ALL PRESENTATION MATERIAL USED DURING THE THREE PROGRAM REVIEWS AT JOHNSON SPACE CENTER, HOUSTON, TEXAS

NASA STUDY FOR GPSPAC
ON BOARD THE SPACE SHUTTLE ORBITER
FIRST SPACE SHUTTLE GPS PANEL MEETING

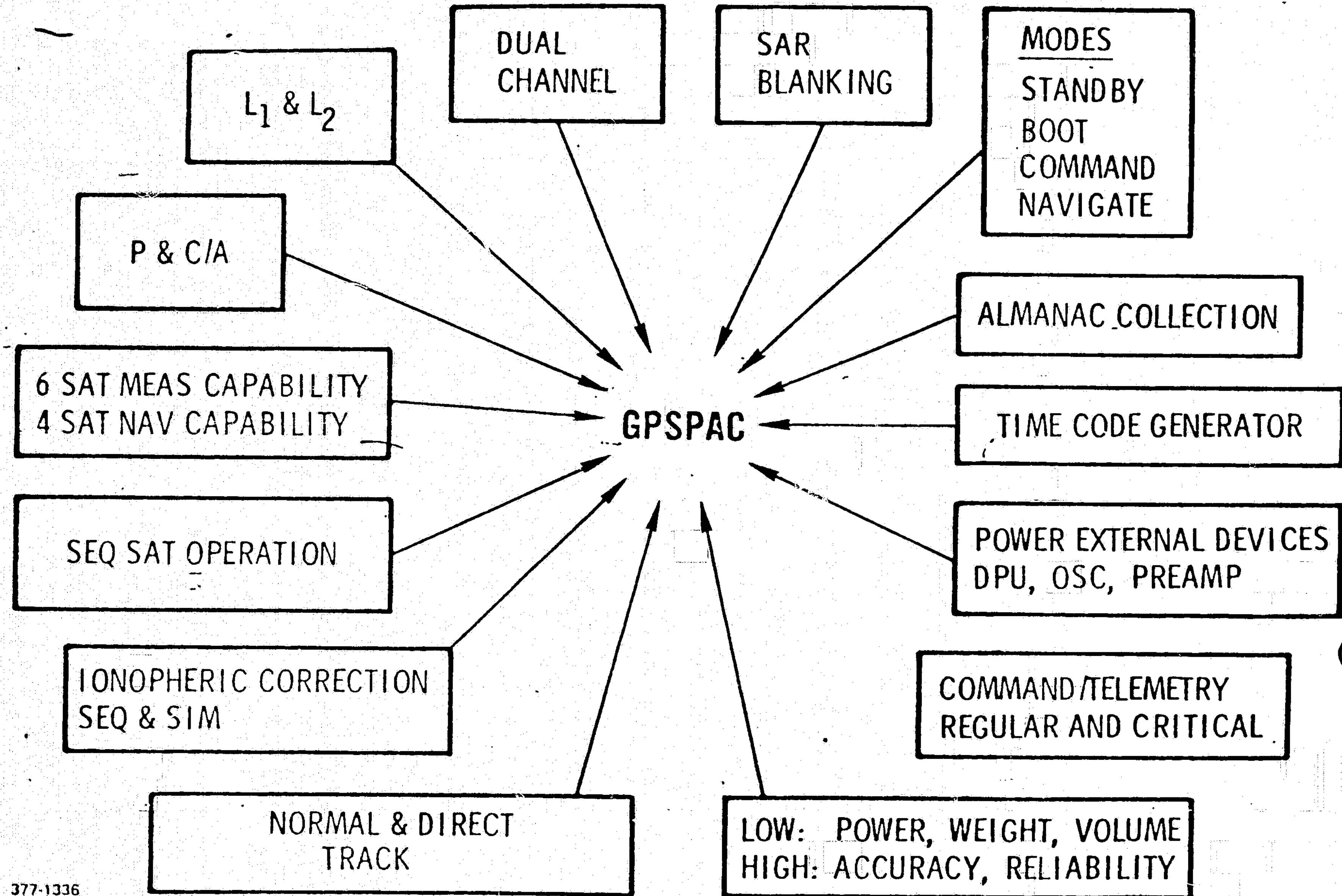
AT

SAMSO
APRIL 5,6, 1977

ED MARTIN
MAGNAVOX

GPSPAC PERFORMANCE REQUIREMENTS

FUNCTIONAL



377-1336

GPSPAC PERFORMANCE REQUIREMENTS

OPERATIONAL

ANTENNA COVERAGE

$\geq -10^0$ EL ANG

ACQUISITION REQUIREMENT

200 KM
200 M/SEC
2×10^{-4} M/SEC^2

PSEUDO RANGING ACCURACY

P: 1.5 M, 0.2 M
C/A: 15 M, 0.2 M

BIT ERROR RATE

$<10^{-5}$

SIGNAL LEVELS

POWER: -151 TO -167 dBW

GPSPAC

TCG PRECISION

1 μSEC

TTFF

284 SECONDS

MAINTAIN IN STANDBY

TCG TIME
MEMORY AND DATA
OSC, PREAMP, AND DPU POWER

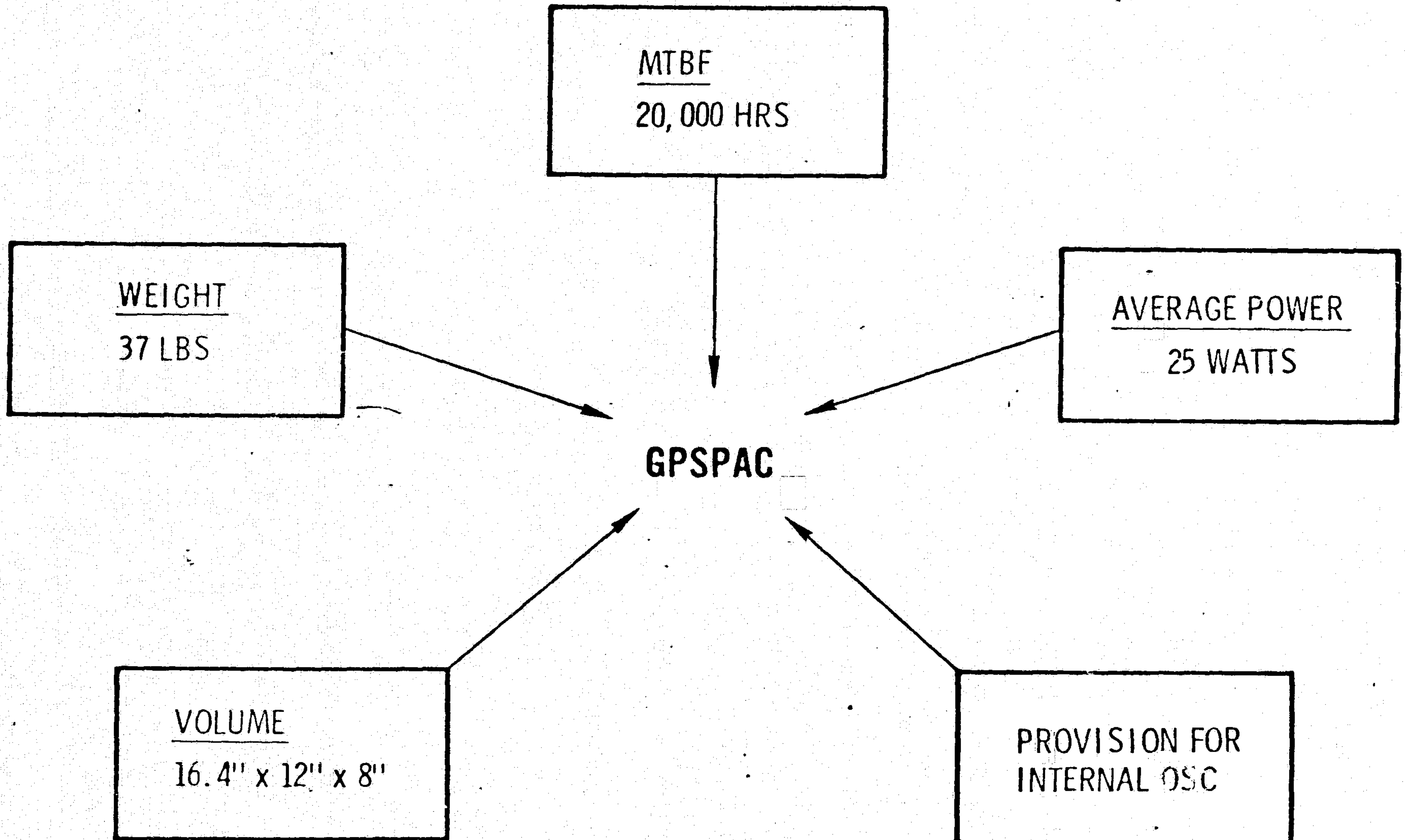
MAX DYNAMICS

R: 18,000 TO 27,000 KM
$\dot{R}$: ±9,000 M/S
$\ddot{R}$: ±16 M/S^2
$\dddot{R}$: ±0.02 M/S^3

377-1337

GPSPAC PERFORMANCE REQUIREMENTS

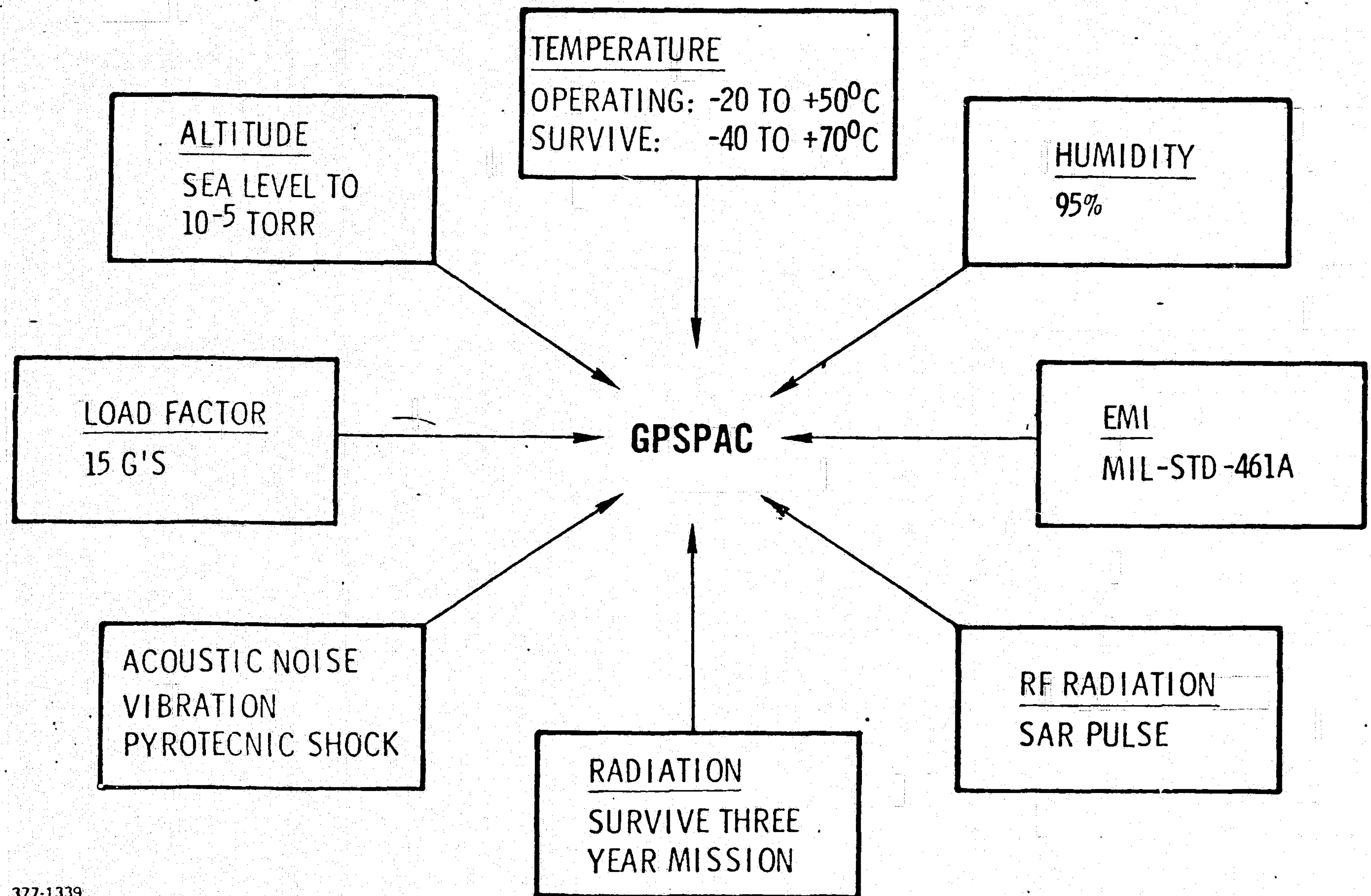
PHYSICAL



377-1338

GPSPAC PERFORMANCE REQUIREMENTS

ENVIROMENTAL



377-1339

GPSPAC PERFORMANCE REQUIREMENTS

DESIGN & CONSTRUCTION

• MATERIALS, PARTS, AND PROCESSES	—	MIL-M-38510C, MIL-STD-883A
• BONDING	—	MIL-B-5087
• ELECTROMAGNETIC RADIATION AND SUSCEPTABILITY	—	MIL-STD-461A
• DISSIMILAR METALS	—	MIL-STD-889
• WORKMANSHIP	—	MIL-STD-454D, REQ 9
• RELIABILITY AND QUALITY ASSURANCE	—	MIL-Q-9858A, MIL-HDBK-217B MIL-STD-785A, MIL-STD-109B
• SAFETY	—	MIL-B-5087

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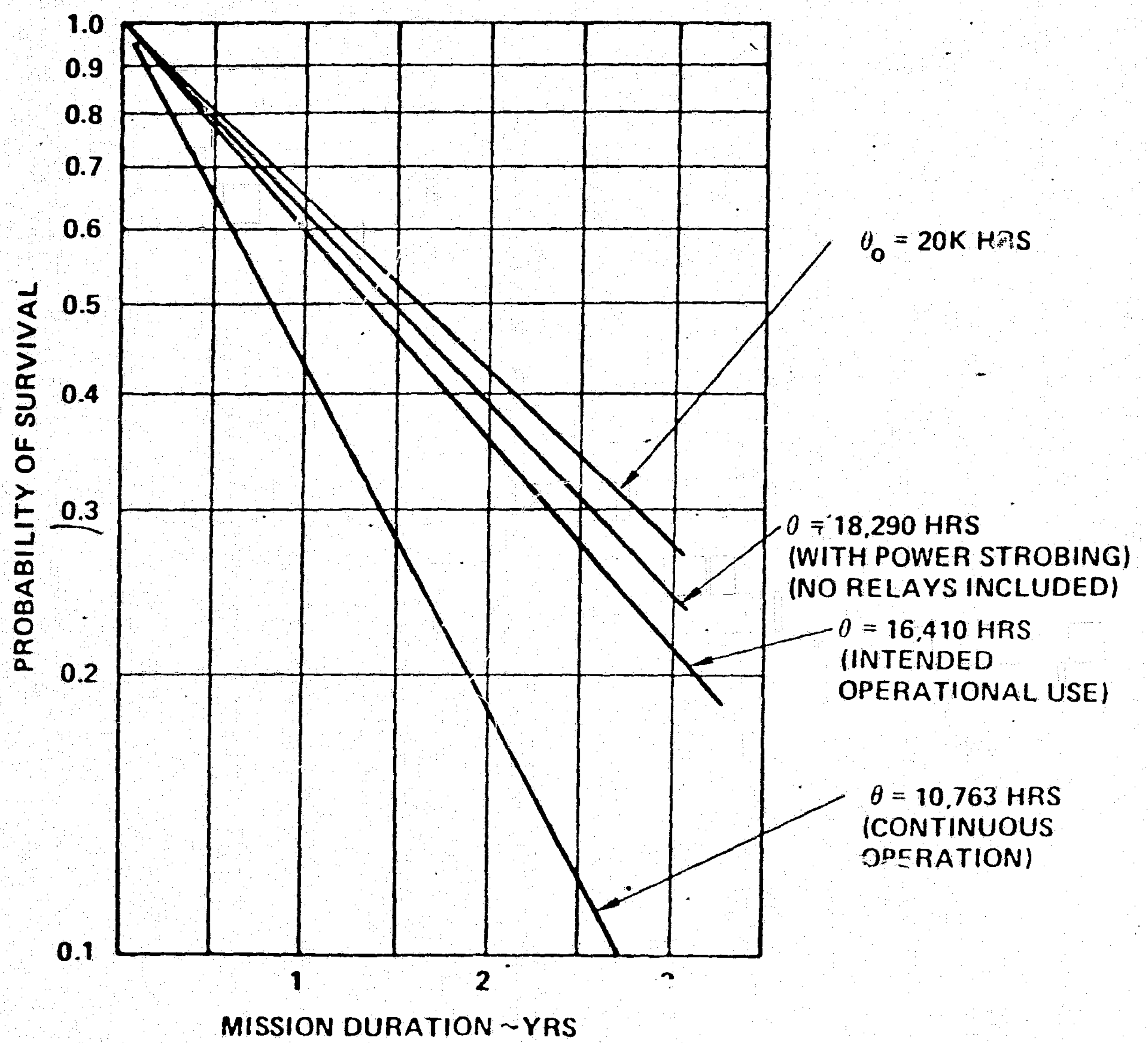
377-1340

GPS PAC PS vs MISSION DURATION



377-1738

GPSPAC RELIABILITY PREDICTION

MODULE		FAIL RATE ($FX10^{-6}$ HR)
RF/IF	Rx NO. 1	1.343
SYNTH	Rx NO. 1	3.052
BASEBAND	Rx NO. 1	1.678
UTC	Rx NO. 1	2.371
C/A CODER	Rx NO. 1	1.753
P CODER	Rx NO. 1	1.978
RF/IF	Rx NO. 2	.196
SYNTH	Rx NO. 2	.413
BASEBAND	Rx NO. 2	.244
UTC	Rx NO. 2	.257
C/A CODER	Rx NO. 2	.256
P CODER	Rx NO. 2	.288
Rx I/O		.690
TCG		.938
CPU		4.000
MEMORY		26.615
TLM I/O (INC BLANKING)		1.022
POWER SUPPLY		5.494
CHASSIS		2.089
	TOTAL	54.677

MTBF = 18,289 HR

377-1663

GPSPAC HARDWARE DELIVERABLES

- MECHANICAL HOLE PATTERN TOOL

PDR

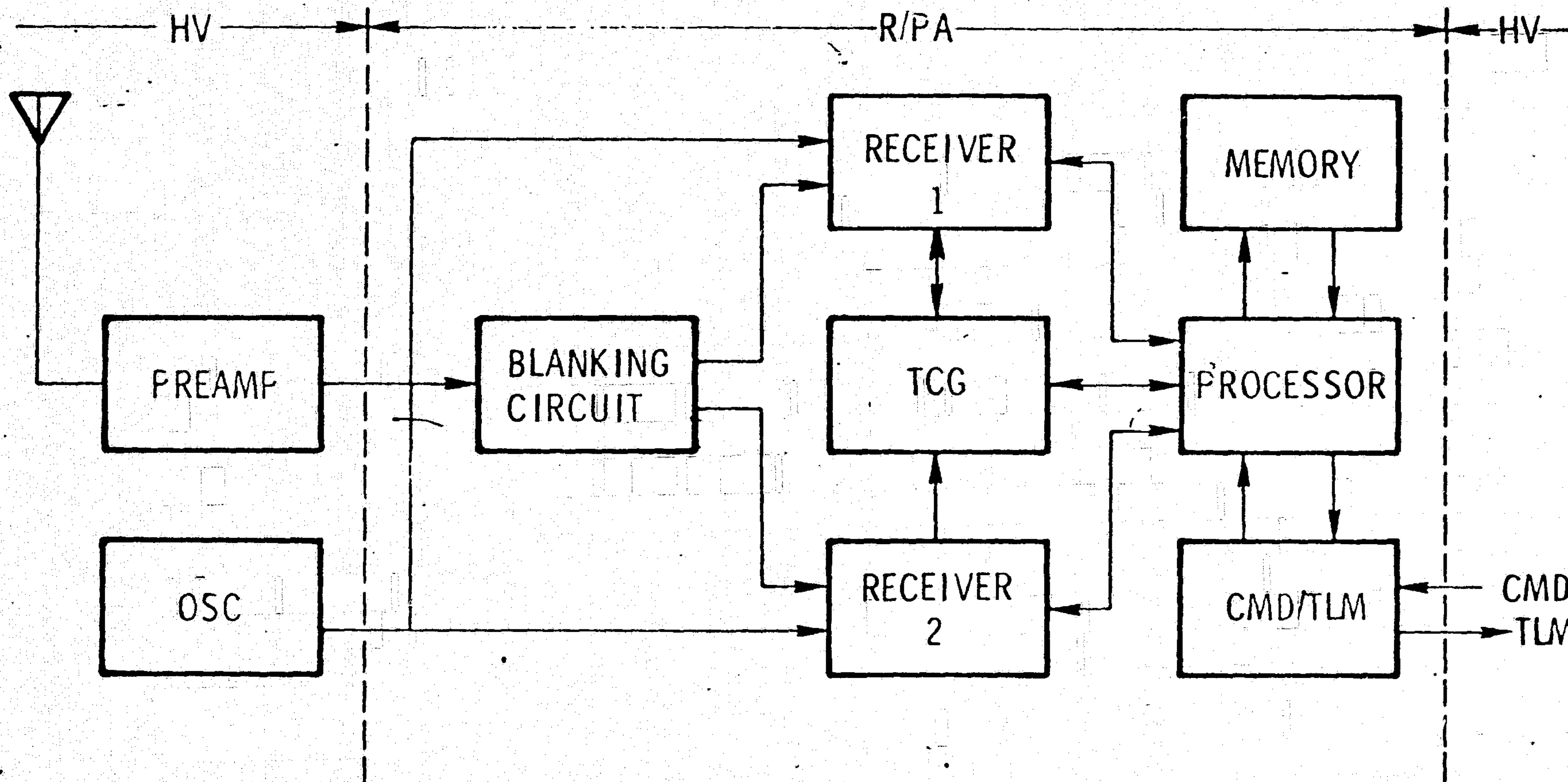
- R/PA MASS PROPERTIES MODEL
- R/PA MATING CONNECTORS
- R/PA ENGINEERING MODEL
- GSU NO. 1
- R/PA PROTOTYPE NO. 1
- GSU NO. 2
- R/PA PROTOTYPE NO. 2

CDR

- R/PA FLIGHT MODEL NO. 1
- R/PA MATING CONNECTORS
- R/PA FLIGHT MODEL NO. 2

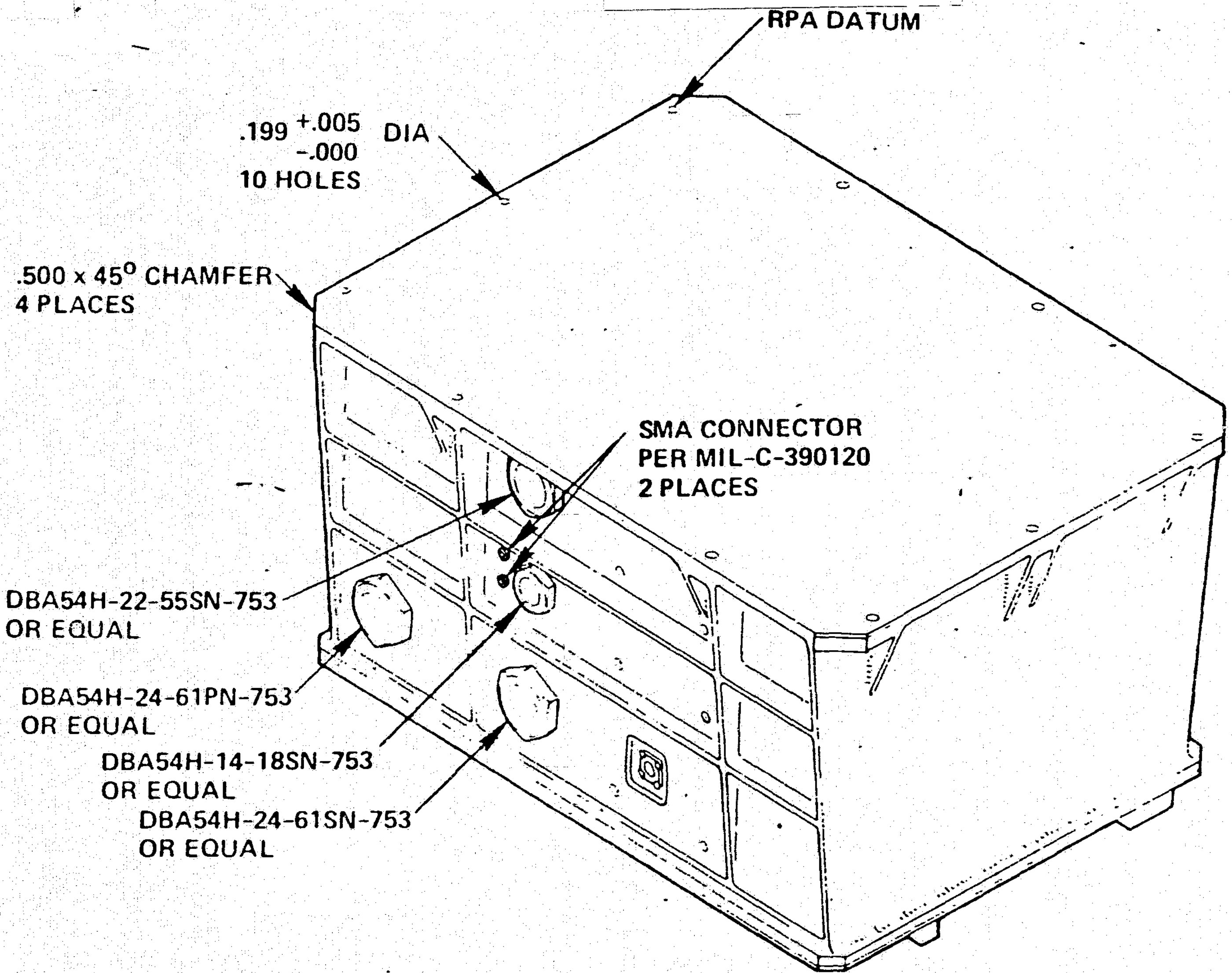
377-13..

GPSPAC BLOCK DIAGRAM

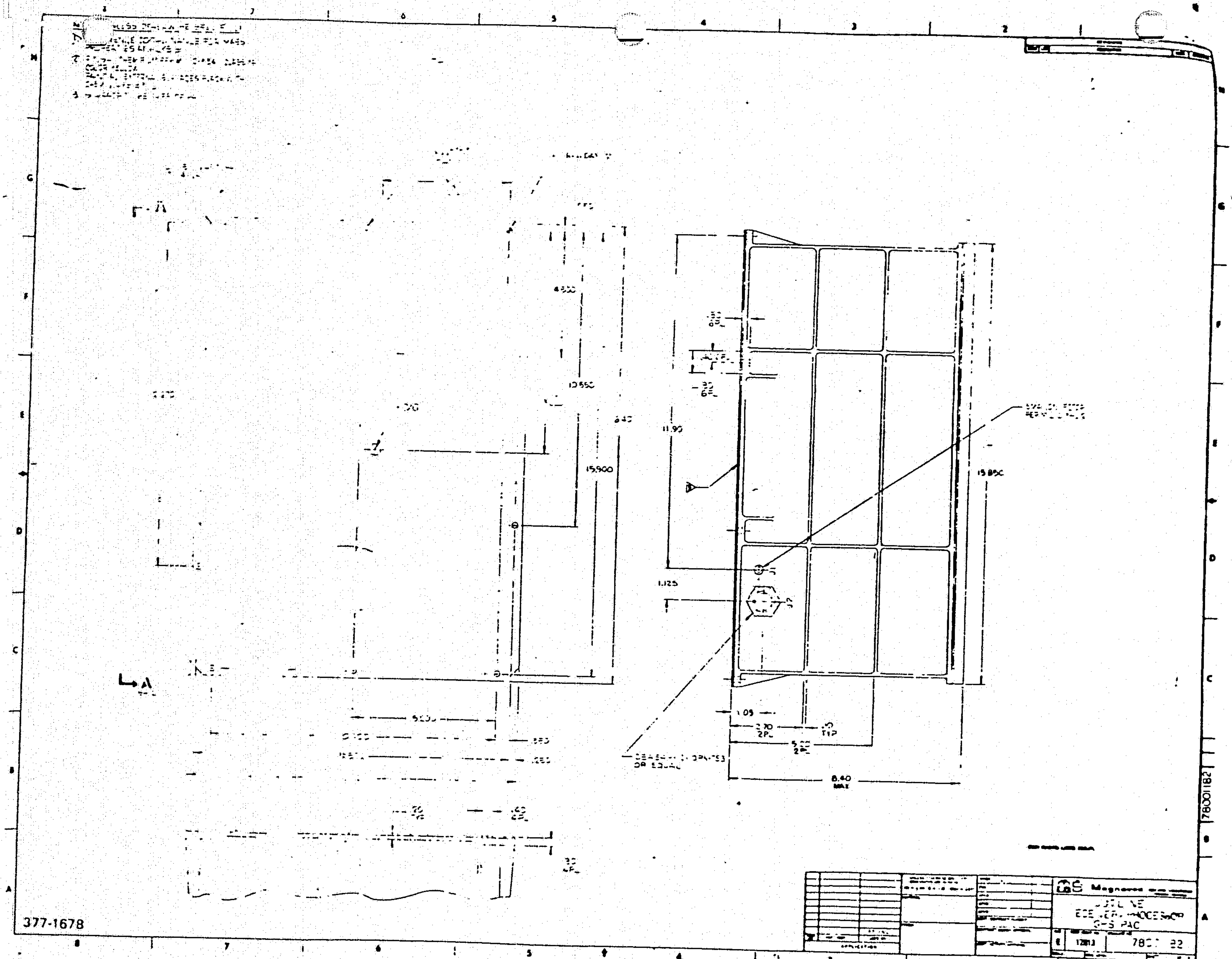


377-1500

ADD OF COMPLETE ASSY



377-1678



377-1678
Magnavox
12813
78001182
8.40 MAX
15.900
15.850
11.90
1.125
1.05

113

377-1679

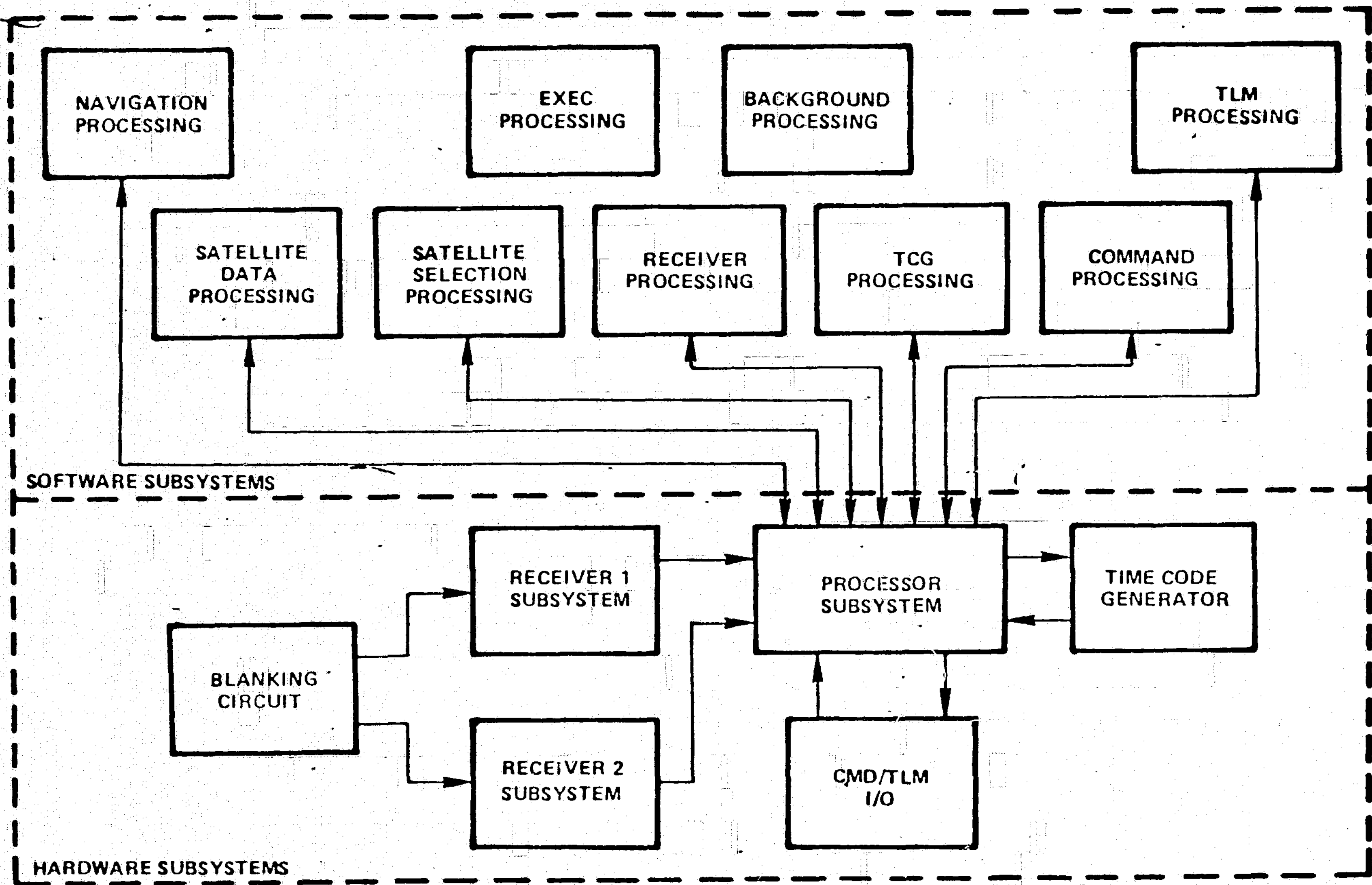
GPS PAC TRACKING RECEIVER PERFORMANCE

SPEC/DERIVED REQUIREMENTS		$P\text{-}L_1$	$C/A\text{-}L_1$	$P/C/A\text{-}L_2$
P_S		-165.1 dBW	-162.5 dBW	-166.9 dBW
ACCELERATION	16 METERS/SEC^2			
(1) $(C/n_o)_e$		32.9 dB-Hz	35.5 dB-Hz	31.1 dB-Hz
DATA THRESHOLD	26 dB-Hz	(2) 31.9 (+5.9 dB)	34.5 (+8.5 dB)	30.1 (+4.1 dB)
COSTAS THRESHOLD (B_L = 35 Hz)	15^o RMS	(2) 10.8^o (+2.9 dB)	8.8^o (+4.6 dB)	12.8^o (+1.4 dB)
				(3) 9.5^o (+4 dB)
RANGE MEASUREMENT (B_L = 1.6 Hz)	.05 CHIPS	0.35 (+3.0 dB)	0.028 (+5.2 dB)	0.043 (+1.2 dB)
DELTA RANGE MEASUREMENT	.2 METERS	0.016 METERS	0.015 METERS	0.016 METERS

(1) NF = 4 dB, IMPLEMENTATION LOSS = 2 dB
(2) OFF-PEAK CORRELATION LOSS = 1 dB
(3) RATE AIDING, RESIDUAL ACCEL = 2 M/SEC^2, B_L = 20 Hz, B_F = 3 Hz

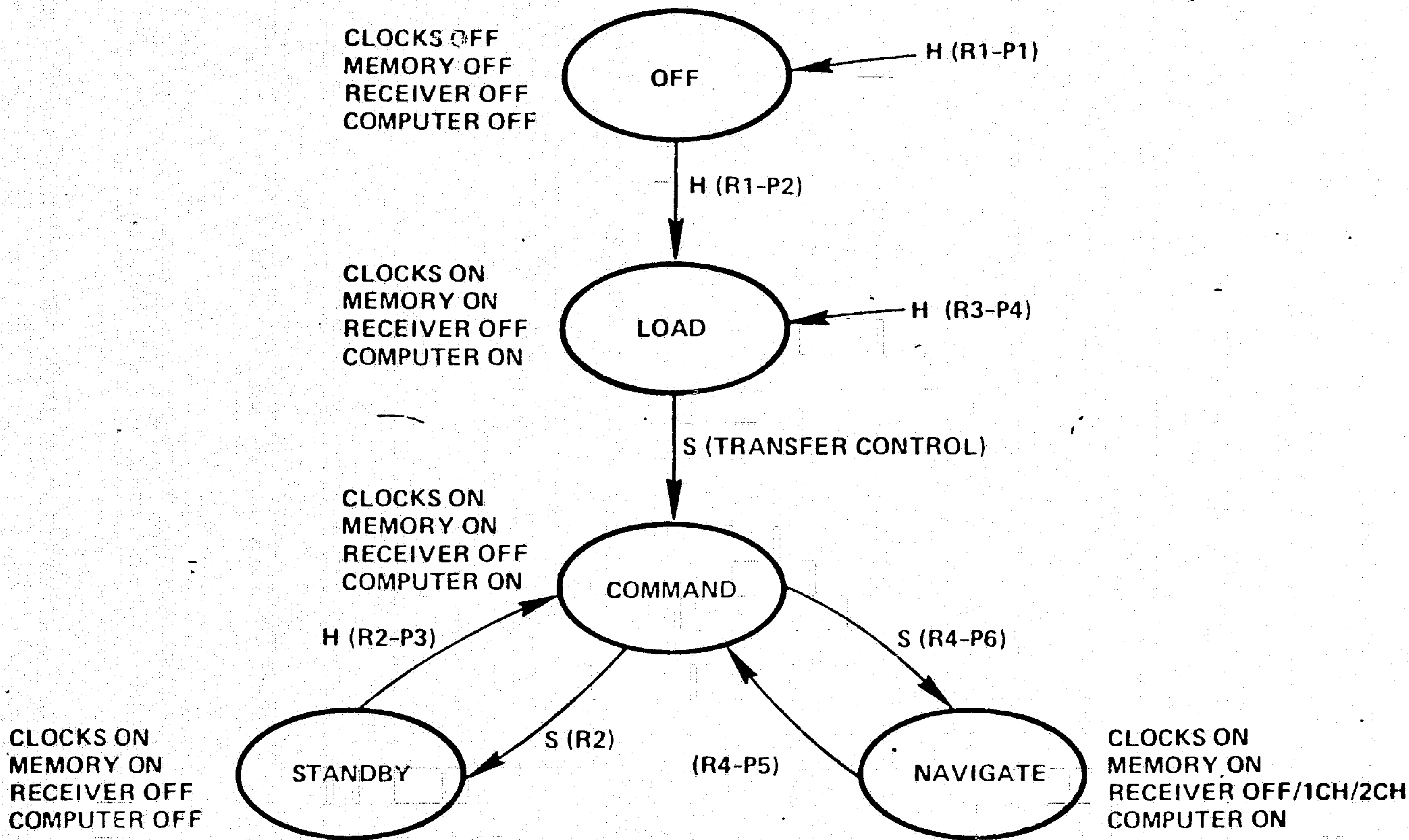
377-1610

SYSTEM PARTITIONING



377-1623

GPSPAC SYSTEM OPERATIONAL STATES



377-1728

GPS SATELITE VISIBILITY

- LAHV TRAJECTORY
- PHASE I GPS CONSTELLATION
- VISIBILITY CRITERION: $\geq -10^0$

SATELLITES VISIBLE	PERCENT OF TIME
0	17
1	15
2	14
3	17
4	13
5	13
6	11

377-1505

SATELLITE EPHEMERIDES COMPUTATIONS

- HIGH SPEED - LOW MEMORY REQUIREMENTS ALGORITHM
  - ALL POLYNOMIAL EVALUATIONS - ADDS AND MULTIPLIES
  - NO SINES AND COSINES COMPUTED
  - NO SQUARE ROOTS

- ACCURATE - LESS THAN ONE METER POSITION ERROR OVER 1 HOUR PERIOD

- COMPUTES SATELLITE POSITION AND VELOCITY RELATIVE TO ECEF COORDINATES

NAVIGATION PROCESSING

CHARACTERISTICS:

- TIME DIVISION MULTIPLEXED PROCESSING OF THE RECEIVER PSEUDORANGE (CODE) AND DELTA PSEUDORANGE (INTEGRATED DOPPLER) MEASUREMENTS. THE SEQUENTIAL MEASUREMENT PROCESSING DWELL CYCLE IS NOMINALLY 6 SECONDS PER SATELLITE WITH 3 SECONDS OF DWELL ON L_1 AND 3 SECONDS ON L_2

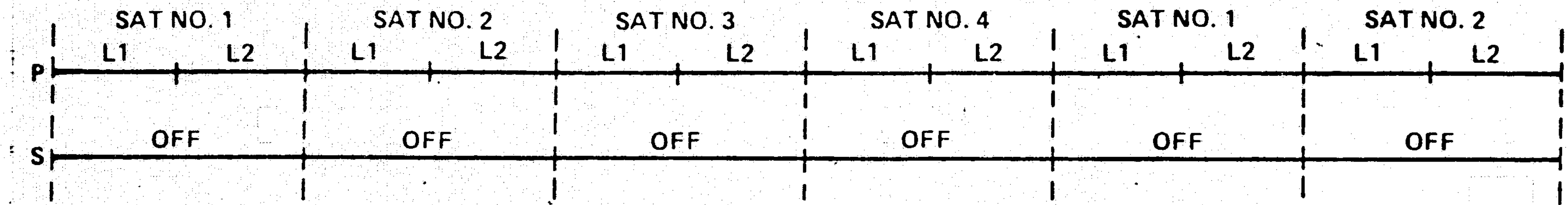
- ESTIMATION OF NAVIGATION SET POSITION, VELOCITY, CLOCK BIAS, CLOCK BIAS RATE, AND ATMOSPHERIC DRAG FROM THE SEQUENTIAL RECEIVER MEASUREMENTS. THE STATE ESTIMATION PROCESS IS CONTROLLED BY A 9-STATE EXTENDED KALMAN FILTER. THE STATE PROPAGATION PROCESS UTILIZES AN EULER INTEGRATOR AND A LOW ORDER GRAVITY MODEL

- RECEIVER PREPOSITIONING FOR SIGNAL ACQUISITION AIDING AT THE NEXT SEQUENTIAL DWELL CYCLE. THE ESTIMATED PSEUDORANGE AND ITS FIRST TWO DERIVATIVES ARE COMPUTED FROM THE NAVIGATION STATE VECTOR AND PROVIDED TO THE RECEIVER FOR CODE AND FREQUENCY PREPOSITIONING FOR THE NEXT SEQUENTIAL DWELL CYCLE

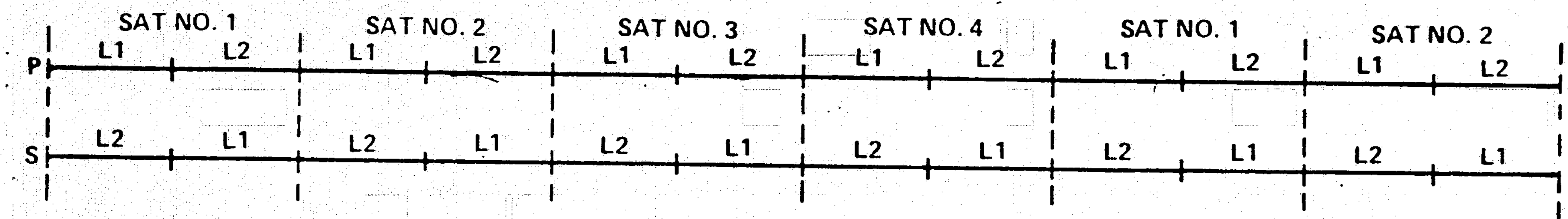
377-1525

SEQUENTIAL TRACKING MODES

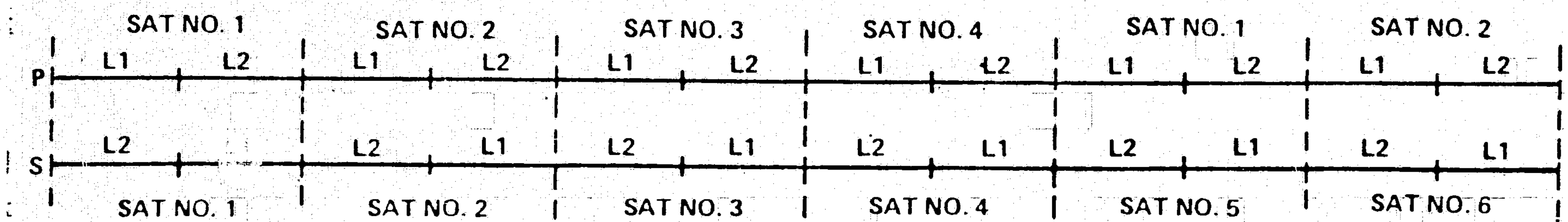
SINGLE CHANNEL SEQUENTIAL 4



DUAL CHANNEL SEQUENTIAL 4

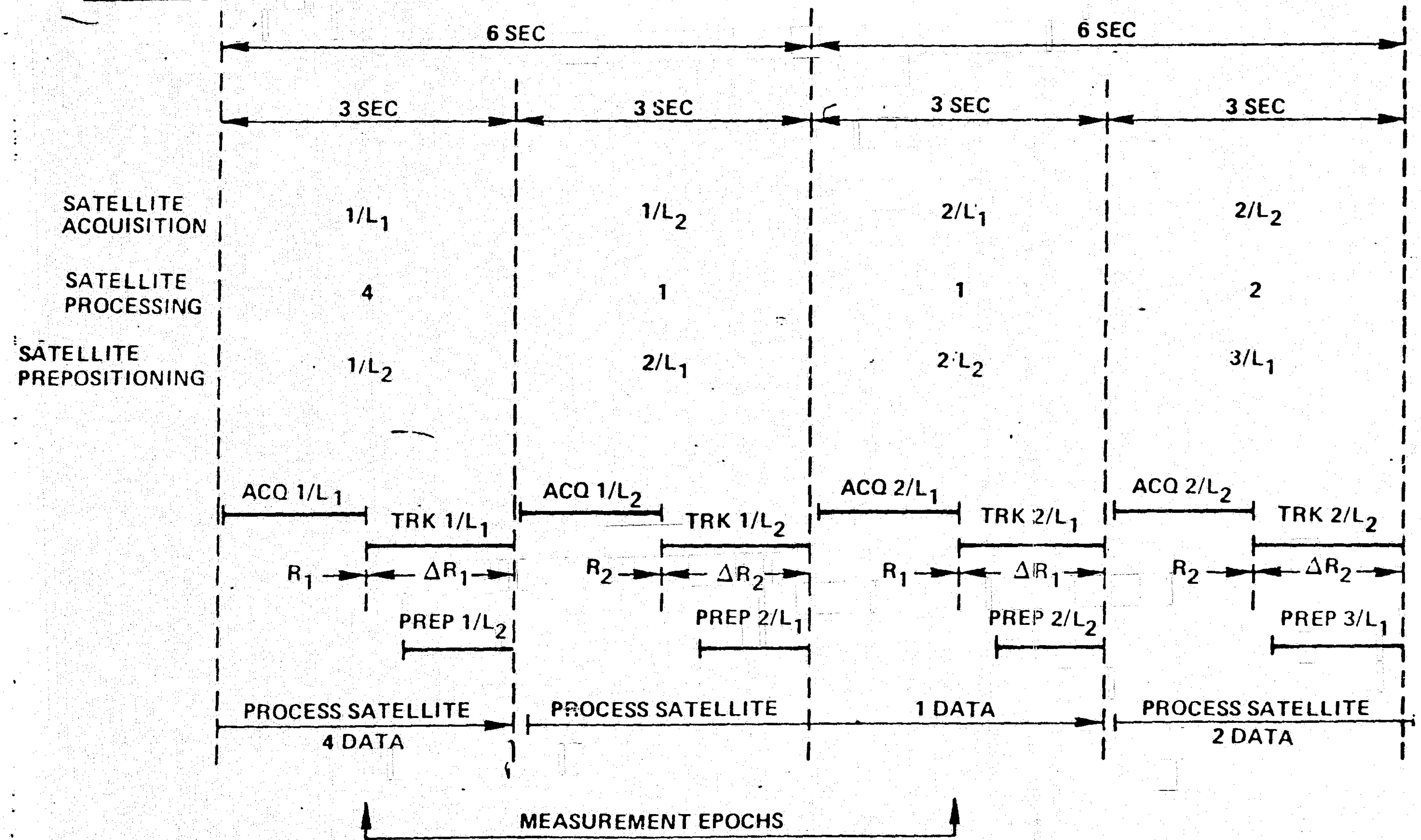


PRIMARY SEQUENTIAL 4 - - SECONDARY SEQUENTIAL 6



377-1527

THE SEQUENTIAL MEASUREMENT PROCESSING SEQUENCE



377-1528

ESTIMATION OF THE NAVIGATION STATE VECTOR

- IMPLEMENTED AS A 9-STATE "EXTENDED KALMAN FILTER"

$$\underline{\delta s} = \left| \delta x \quad \delta y \quad \delta z \quad \delta b \quad \delta \dot{x} \quad \delta \dot{y} \quad \delta \dot{z} \quad \delta \dot{b} \quad \delta d \right|^{\dagger}$$

$(\delta x, \delta y, \delta z)$: ECEF POSITION ERROR (METERS)

$(\delta \dot{x}, \delta \dot{y}, \delta \dot{z})$: ECEF VELOCITY ERROR (METERS/SECOND)

$(\delta b, \delta \dot{b})$: RECEIVER CLOCK BIAS AND BIAS RATE ERROR (METERS AND METERS/SECOND)

(δd): DRAG ACCELERATION COEFFICIENT ERROR (METER^2/KILOGRAM)

- FILTER IMPLEMENTATION TECHNIQUE: U-D COVARIANCE FACTORIZATION

  COVARIANCE TIME UPDATE: MODIFIED CHOLESKY ALGORITHM

  COVARIANCE MEASUREMENT UPDATE: MODIFIED BIERMAN U-D UPDATE ALGORITHM

  DIVERGENCE CONTROL: FADING MEMORY DRIVEN BY MEAN MEASUREMENT RESIDUALS

GPSPAC MEMORY RESOURCE ESTIMATE

NAVIGATION FILTER/CONTROL	4,100	
NAVIGATION STATE PROPAGATION	3,000	
GPS SATELLITE SELECTION	1,795	
GPS SATELLITE POSITION	1,030	
BUILT-IN-TEST	530	
LIBRARY (NAVIGATION)	210	
LIBRARY (OTS)	5,402	
EXECUTIVE	361	
SATELLITE DATA (GPS)	1,088	
SYSTEM MONITOR	2,300	
RECEIVER PROCESSING	6,000	
COMMAND/TLM PROCESSING	1,300	
DATA BASE	4,000	
TOTAL	31,116	16-BIT WORDS

377-1753

GPSPAC THROUGHPUT RESOURCE ESTIMATE

	TIME (MS)	% OF 3 SEC CYCLE
NAVIGATION CONTROL	60	2
U-D FILTER MEASUREMENT UPDATE (2)	192	6.4
U-D FILTER TIME UPDATE	230	7.7
NAVIGATION STATE PROPAGATION	340	11.3
GPS EPHEMERIS EVALUATION (3)	150	5.0
RECEIVER PREPOSITION AIDING	150	5.0
	1122 MS	37.4%
GPS SATELLITE SELECTION	3000 MS	5.0% OF 60 SEC CYCLE
EXECUTIVE/SYSTEM MONITOR		* 3.0%
RECEIVER PROCESSING		*25.0%
COMM[illegible]AL PROCESSING		*10.0%
	TOTAL	80.4%

*ESTIMATE

377-17..

SINGLE CHANNEL IONOSPHERIC DELAY ERRORS

- ERRORS CAUSED BY NON SIMULTANEOUS PSEUDORANGE MEASUREMENTS ON L1/L2
- PSEUDORANGE ERROR (METERS) AS A FUNCTION OF ELEVATION ANGLE AND L1-L2 MEASUREMENT TIME SEPARATION

	SPHERICAL MODEL h_v = 150 KM		SPHERICAL MODEL h_v = 800 KM	
	ΔT = 3 SEC	ΔT = 6 SEC	ΔT = 3 SEC	ΔT = 6 SEC
90	5×10^{-4}	2.4×10^{-3}	4×10^{-6}	1.5×10^{-5}
0	0.14	0.29	1.4×10^{-3}	3.1×10^{-3}
30	0.52	1.04	6.5×10^{-3}	1.3×10^{-2}
10	1.16	2.32	3.5×10^{-2}	7×10^{-2}
0	NA	NA	0.15	0.31
−10	NA	NA	1.58	3.26

NA = NOT APPLICABLE DUE TO MODEL LIMITATIONS

DYNAMIC SIMULATION STATUS AND FEATURES

- STATUS
  - BASIC HOST VEHICLE SIMULATION RUNNING
- FEATURES
  - GRAVITY MODEL

    — FOUR PARAMETER FORMULATION WITH WGS-72 HARMONICS
  - DRAG MODEL

    ONE DIMENSIONAL (NO LIFT) WITH DYNAMIC ATMOSPHERE
  - INTEGRATION METHOD

    FOURTH ORDER RUNGE-KUTTA IN ROTATING ECEF FRAME

377-1546
NASA-JSC

NASA STUDY FOR GPSPAC

ON BOARD THE SPACE SHUTTLE ORBITER

SECOND SPACE SHUTTLE PANEL MEETING

AT

JOHNSON SPACE CENTER, HOUSTON, TEXAS

MAY 10, 11, 1977

ED MARTIN

MAGNAVOX

GPS EXPERIMENT DEFINITION

MAGNAVOX INVOLVEMENT

A. PROVIDE DATA ON EXISTING EQUIPMENT CONFIGURATIONS

- △ SCHEDULES
- △ FORM FACTORS
- △ INTERFACES
- △ PERFORMANCE

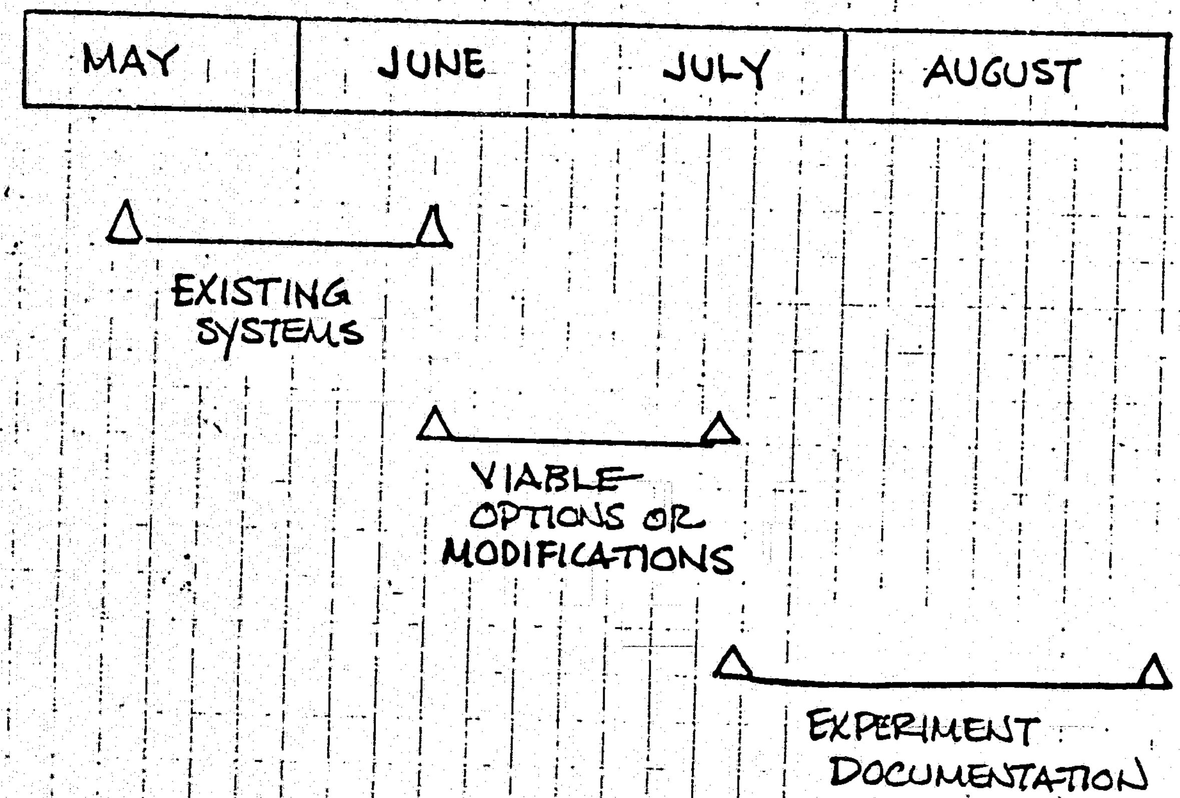
B. DEFINE VIABLE CONFIGURATION OPTIONS FOR EXPERIMENT

- △ PERFORMANCE REQUIREMENT MODIFICATIONS
- △ PHYSICAL ENVIRONMENT MODIFICATIONS
- △ SHUTTLE OPERATOR IMPACTS
- △ COST/SCHEDULE FOR COMPLYING MODIFICATIONS

C. ESTABLISH PRELIMINARY REGRETS DOCUMENTATION

- △ SIGNAL INTERFACES
- △ OPERATING PROCEDURES
- △ ELECTRICAL MODIFICATIONS
- △ TESTING PROCEDURES

SCHEDULE - GPS EXPERIMENT



SIGNAL LEVELS*			MINIMUM S/No
L_1-P CODE	1575 MHz	-163 dBw	36 dB.Hz
L_1-C/A CODE	1575 MHz	-160 dBw	39 dB.Hz
L_2-P CODE	1227 MHz	-166 dBw	33 dB.Hz

*MINIMUM SIGNAL LEVEL AT THE RECEIVER LOCATED AT SURFACE OF THE EARTH

N_o = KT_s (NOISE FIGURE)

= -199 dBw/Hz

WHERE T_s = EARTH NOISE TEMPERATURE OF 290^oK

NOISE FIGURE = 5 dB

SIGNAL LEVEL VARIATIONS

SATELLITE ANTENNA GAIN VS. USER POSITION	+ 3 DB
SATELLITE POWER OUTPUT FROM START TO END OF LIFE	+ 6 DB
USER ANTENNA GAINS	(±)
ATMOSPHERIC LOSSES	+ 2 DB
POLARIZATION LOSSES	+ 2 DB
RANGE SPREADING LOSS FOR SKEW VIEWING	(-)
IONOSPHERIC SCINTILLATION LOSS FOR SKEW VIEWING	(-)
TOTAL VARIATION	

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NASA STUDY FOR GPSPAC
ON BOARD THE SPACE SHUTTLE ORBITER
THIRD SPACE SHUTTLE GPS PANEL MEETING
AT
ROCKWELL INTERNATIONAL, DOWNEY, CA.
JUNE 21, 22 1977

JACK MOSES
MAGNAVOX

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OSCILLATOR OPTIONS FOR SHUTTLE

- USE EXISTING APL SUPPLIED GPSPAC OSCILLATOR
- USE THE INTERNAL SHUTTLE MTU OSCILLATOR
- USE A MODIFIED TYPE X, Z, MANPACK OSCILLATOR

SHUTTLE OSCILLATOR REQUIREMENTS

~~x~~-set – 2.6 x 5¾ x 2.15
= 32 in³

TYPE	CRYSTAL
REDUNDANCY	[redacted] single.
FREQUENCY	5.115 MHz ±.05 Hz
SEA~~L~~ LEVEL OFFSET	±1 PP 10^8
WARMUP TIME	±1 PP 10^9 WITHIN ~~1~~ 4 HR (SEA LEVEL TO ORBIT)
LONG TERM DRIFT	$\pm 1 \times 10^{-9}$/DAY
SHORT TERM STABILITY	$\pm 1 \times 10^{-11}$/SEC
TEMP RANGE	-20°C TO 65°C
PRESSUSRE (ALT) RANGE	~~VACUUM~~ 0–14.7 psia
SIZE	IF POSSIBLE FIT INTO GPSPAC SLOT OF ~~33~~ 48 IN^3 2½ x 3½ x 5½
WEIGHT	< 2 LBS
POWER	< 5 WATTS

677-3777

OSCILLATOR COMPARISONS

	GPSPAC (APL)	MTU (SHUTTLE)	X SET
TYPE	CRYSTAL	CRYSTAL	CRYSTAL
REDUNDANCY	DUAL	DUAL	SINGLE
FREQUENCY	5.000 MHz ±1 Hz	4.608 MHz ±0.005 Hz	5.115 MHz ± .05 Hz
SEA LEVEL OFFSET	±20 PP 10^6	±5 PP 10^9	±1 PP 10^8
WARMUP TIME	36 TO 48 HRS (SEA LEVEL TO ORBIT)	16 HRS (SEA LEVEL TO ORBIT)	$\pm 2 \times 10^{-9}$ WITHIN 30 MIN SEA LEVEL
SHORT TERM STABILITY	$\pm 1 \times 10^{-11}$/SEC	$\pm 1 \times 10^{-10}$/SEC	$\pm 2 \times 10^{-12}$/SEC
LONG TERM STABILITY	0.5×10^{-9}/24 HRS	5×10^{-10}/24 HRS	$\pm 1 \times 10^{-9}$/24 HRS
TEMPERATURE RANGE	-20°C TO 50°C	0°C TO 50°C	-20°C TO +65°C
PRESSURE (ALTITUDE) RANGE	VACUUM ONLY	8 PSIA TO 18 PSIA	0 TO 30,000 FT
POWER	1.5 WATTS (WARMUP); 6 WATTS STEADY STATE	-	35W (WARMUP 3 MIN) 3.5W (STEADY STATE)
SIZE	57.3 IN^3	-	32 IN^3
WEIGHT	2.2 BBS	-	20 OZ

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SHUTTLE OSCILLATOR TRADEOFFS/RECOMMENDATION

	ADVANTAGES	DISADVANTAGES	RECOMMENDATIONS
GPSPAC	• EXISTING • SPACE QUALIFIED • MEETS PERFORMANCE	• NOT BUILT TO 5.115 MHz YET • LARGE SEA LEVEL OFFSET FREQUENCY • LONG WARM-UP TIME	POSSIBLE USE AS AN ALTERNATE
SHUTTLE MTU	• EXISTING • SPACE QUALIFIED	• COMPLEX SYNTHIZER (4.608 MHz TO 5.115 MHz) • LONG WARM-UP TIME • BELOW PERFORMANCE REQUIREMENTS • UNIT NOT SELF CONTAINED I.E. ALWAYS TIED TO SHUTTLE	NO
MODIFIED X, Z OR MANPACK	• EXISTING • EXCELLENT PERFORMANCE • SMALL OFFSET FREQUENCY • SHORT WARM-UP TIME	• NOT QUALIFIED FOR SPACE • NOT A REDUNDANT UNIT	DEVELOP AS A PRIME CANDIDATE

677-3779

SHUTTLE/GPS LINK EXAMINED FOR THREE CASES

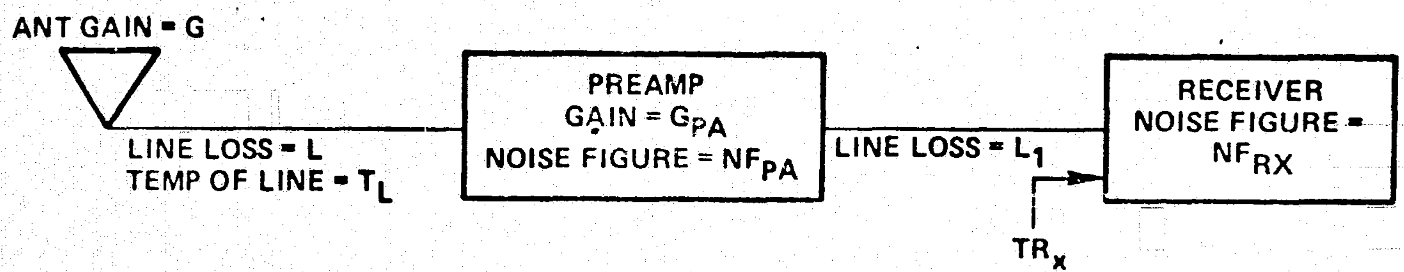
- BASELINE
  - ANT/PRE-AMP ON A FIXED EXTENSION BOOM WITH GPSPAC ON THE DFI PALLET

- BASELINE Δ1
  - WINDOW DIPOLE ANTENNA AND PRE-AMP LOCATED IN THE CABIN PLUS BASELINE

- BASELINE Δ2
  - WINDOW DIPOLE ANTENNA, PRE-AMP AND GPSPAC LOCATED IN THE CABIN WITH SWITCHABLE ANT/PRE-AMP MOUNTED ON DEPLOYABLE BOOM LOCATED IN THE PAYLOAD BAY

SHUTTLE/GPS LINK BUDGET EQUATIONS

BASIC BLOCK DIAGRAM



$$\frac{C}{N_o} = \text{RECEIVED SIGNAL} + \frac{G}{T_S} + K - \text{PN IMPLEMENTATION LOSSES}$$

T_S = SYSTEM NOISE TEMPERATURE

K = BOLTZMAN'S CONSTANT = 1.38×10^{-23}

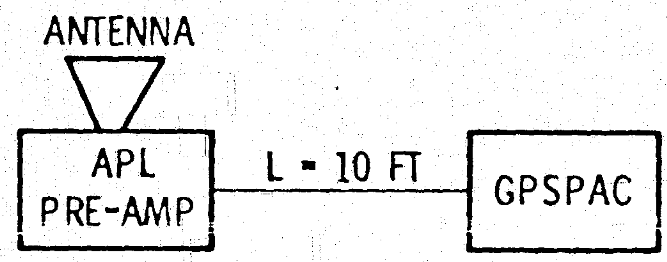
$$T_S = T_A + (L-1)\,T_L + L\,T_{RX}$$

$$T_{RX} = (NF_{SYS}-1)\ 290^{o}K$$

$$NF_{SYS} = NF_{PA} + \frac{(L_1 + NF_{RX})-1}{G_{PA}}$$

677-3781

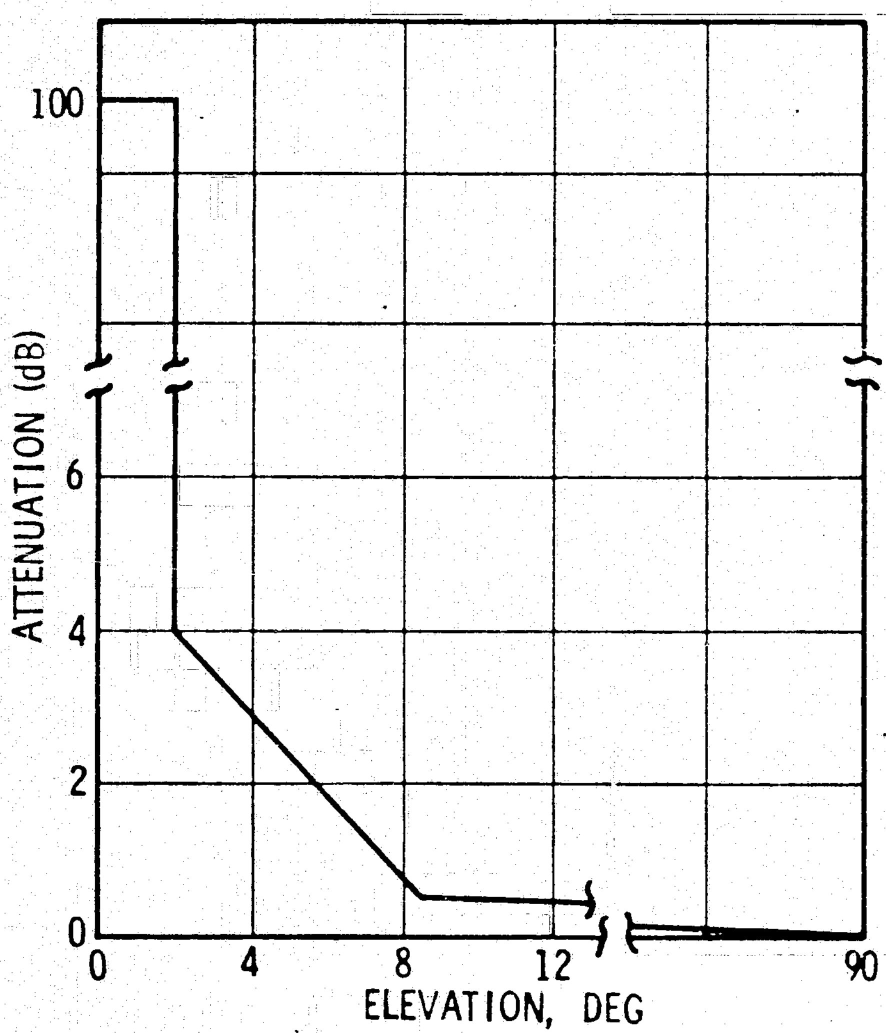
SHUTTLE/GPS BASELINE LINK



CONDITIONS

- APL ANTENNA GAIN -1.0 dB AT -10^0
- APL PRE-AMP NOISE FIGURE 4 dB MIN; GAIN 30 dB MIN
- GPSPAC NOISE FIGURE 13 dB
- CABLE RG/142: LOSS 16 dB/100 FT
- RECEIVER PN IMPLEMENTATION LOSSES 2.0 dB

ATMOSPHERE ABSORPTION AT 1575 MHZ



SOURCE: AEROSPACE REPORT NO.
TR-0172 (2521-01)-1

SHUTTLE/GPSPAC DYNAMICS COMPARISON

	GPSPAC	SHUTTLE (ON ORBIT)
$\dot{R}$	$\pm$ 9.0 KM/SEC	$\pm$ 7.07 KM/SEC
$\ddot{R}$	$\pm$ 16 M/SEC^2	$\pm$ 10.2 M/SEC^2
$\ddot{R}$	$\pm$ .02 M/SEC^2	$\pm$ .011 M/SEC^3

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SHUTTLE/GPS BASELINE LINK BUDGET

PARAMETER / LINK	$P-L_1$	$C/A-L_1$	$P-L_2$	$C/A-L_2$	COMMENTS
NDS TRANSMITTER POWER (dBw)	10.5	13.1	7.8	7.8	ROCKWELL SPEC MINIMUM
NDS ANTENNA GAIN (dB)	12.0	12.0	10.1	10.1	16° FROM BORESIGHT
PATH LOSS (dB)	-183.2	-183.2	-181.1	-181.1	MIN ORBIT 90 NM; SLANT-RANGE 5° = 25,187 Km
ATMOSPHERIC LOSS (dB)	-2.0	-2.0.	-2.0	-2.0	5° ELEVATION ANGLE
RECEIVED SIGNAL POWER (dBw)	-162.7	-160.1	-165.2	-165.2	
USER ANTENNA GAIN (RHCP)	-1.0	-1.0	-1.0	-1.0	DOES NOT INCLUDE AXIAL RATIO LOSSES OR VSWR LOSSES
SYSTEM NOISE TEMPERATURE T_s (°K)	580	580	580	580	
C/N_o (dB-Hz) AVAILABLE	35.2	37.8	32.2	32.2	
REQUIRED C/N_o					
• DATA	27.0 db-Hz	27.0	27.0	27.0	10^{-5} BER, ΔPSK
• CARRIER TRACK	31.9(10.8°)	34.5(8.8°)	30.1(12.8°)	30.1(12.8°)	ACCELERATION 16 M/SEC^2; B_L = 35 Hz
• RANGING	32.9(3.5 FT)	35.5(2.8 FT)	31.1(4.3 FT)	31.1(4.3 FT)	NON-COHERENT τ-DITHER CODE LOOP B_L = 1.6 Hz
C/N_o MARGIN					
• DATA	8.2 dB	10.8 dB	5.7 dB	5.7 dB	
• CARRIER TRACK	3.3 dB	3.3 dB	2.6 dB	2.6 dB	
• RANGING	2.3 dB	2.3 dB	1.6 dB	1.6 dB	

677-3785

RECEIVED SIGNAL LEVEL VARIATIONS

SATELLITE POWER OUTPUT FROM START TO END OF LIFE	+6 dB
SATELLITE ANTENNA GAIN VS USER POSITION	+3 dB
USER ANTENNA GAIN	+1 dB
ANTENNA AXIAL RATIO LOSSES AND VSWR MISMATCH LOSSES	-2 dB
ATMOSPHERIC LOSSES	+2 dB
POLARIZATION LOSSES	+2 dB
RANGE SPREADING LOSS FOR SKEW VIEWING	-2.5 dB
IONOSPHERIC SCINTILLATION LOSS FOR SKEW VIEWING	-5 dB
TOTAL VARIATION	+4.5 dB

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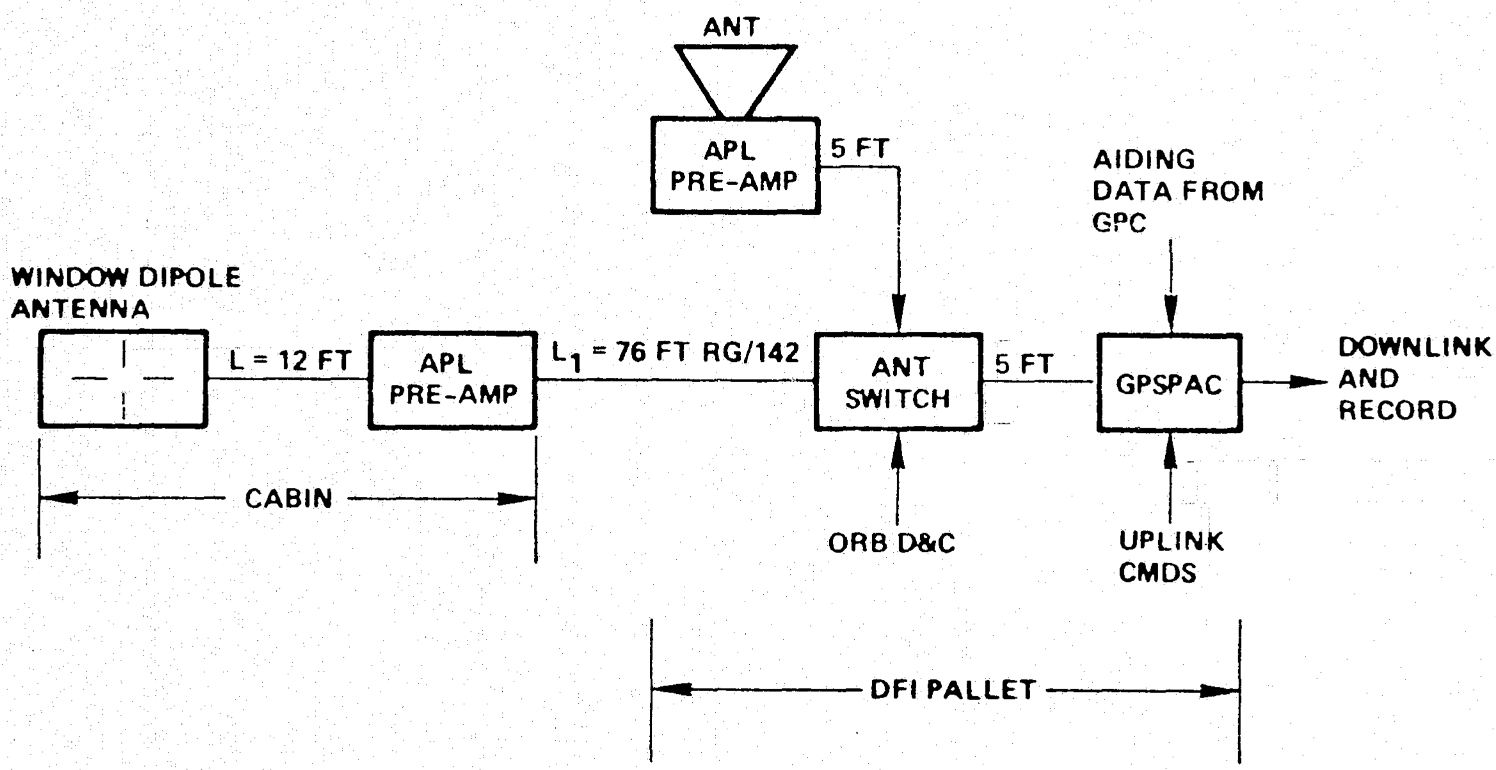
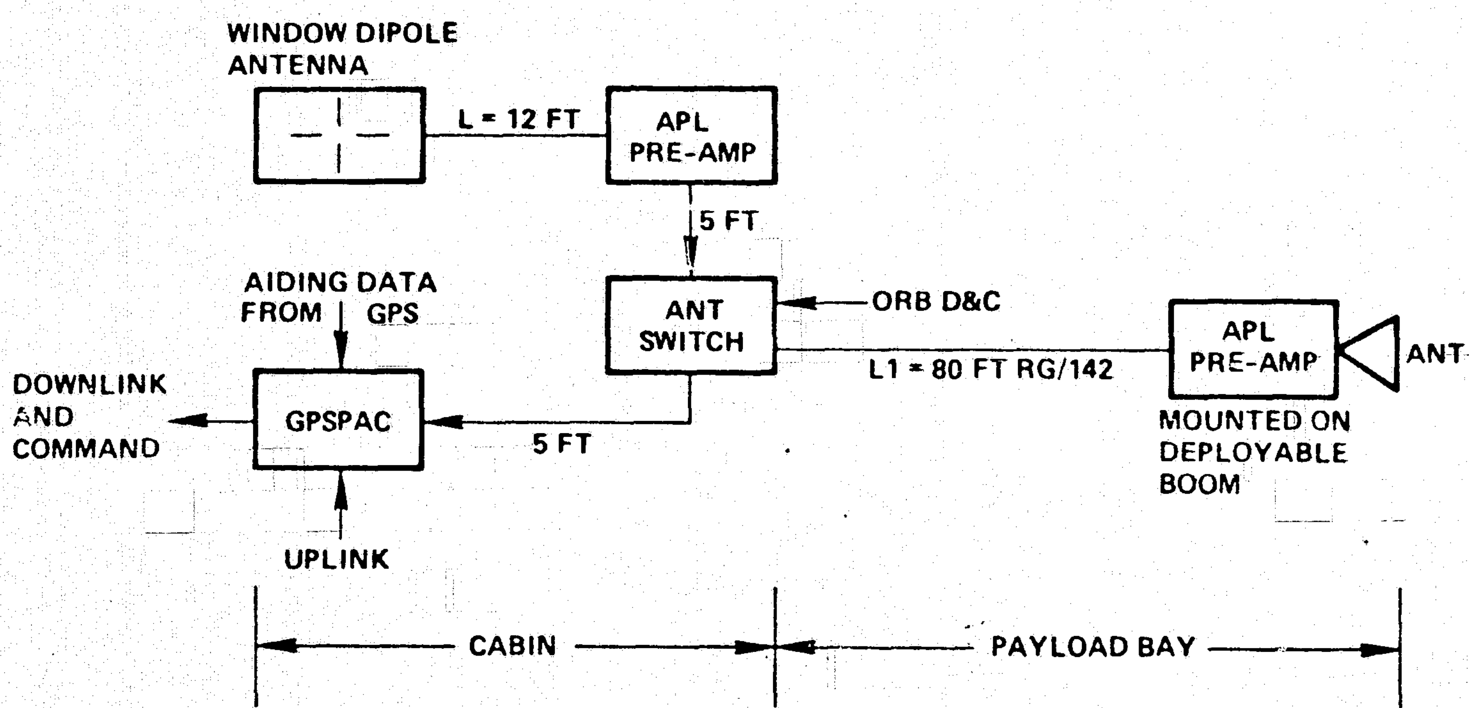
SHUTTLE/GPS BASELINE△1 LINK



SHUTTLE/GPS BASELINE Δ2 LINK



BASELINE Δ1 AND Δ2 LINK SUMMARY

- DEORBIT DYNAMICS PROFILE AND ANTENNA GAIN CHARACTERISTICS PRESENTLY UNDEFINED
- THIS CONFIGURATION WILL INCUR AN ADDITIONAL 2 dB S/N LOSS DUE TO CABLE LENGTHS OVER THE BASELINE LINK BUDGET
- INERTIAL AIDING WILL ALLOW THE CARRIER LOOP BANDWIDTH TO BE REDUCED PROVIDING LOWER S/N LOOP THRESHOLDS
- CERTAIN LINKS HOWEVER MAY HAVE A NEGATIVE S/N MARGIN
- FURTHER ANALYSIS REQUIRED TO DEFINE THE LINK BUDGET FOR THESE ALTERNATE BASELINE APPROACHES

NASA STUDY FOR GPSPAC
ON BOARD THE SPACE SHUTTLE ORBITER
THIRD SPACE SHUTTLE GPS PANEL MEETING

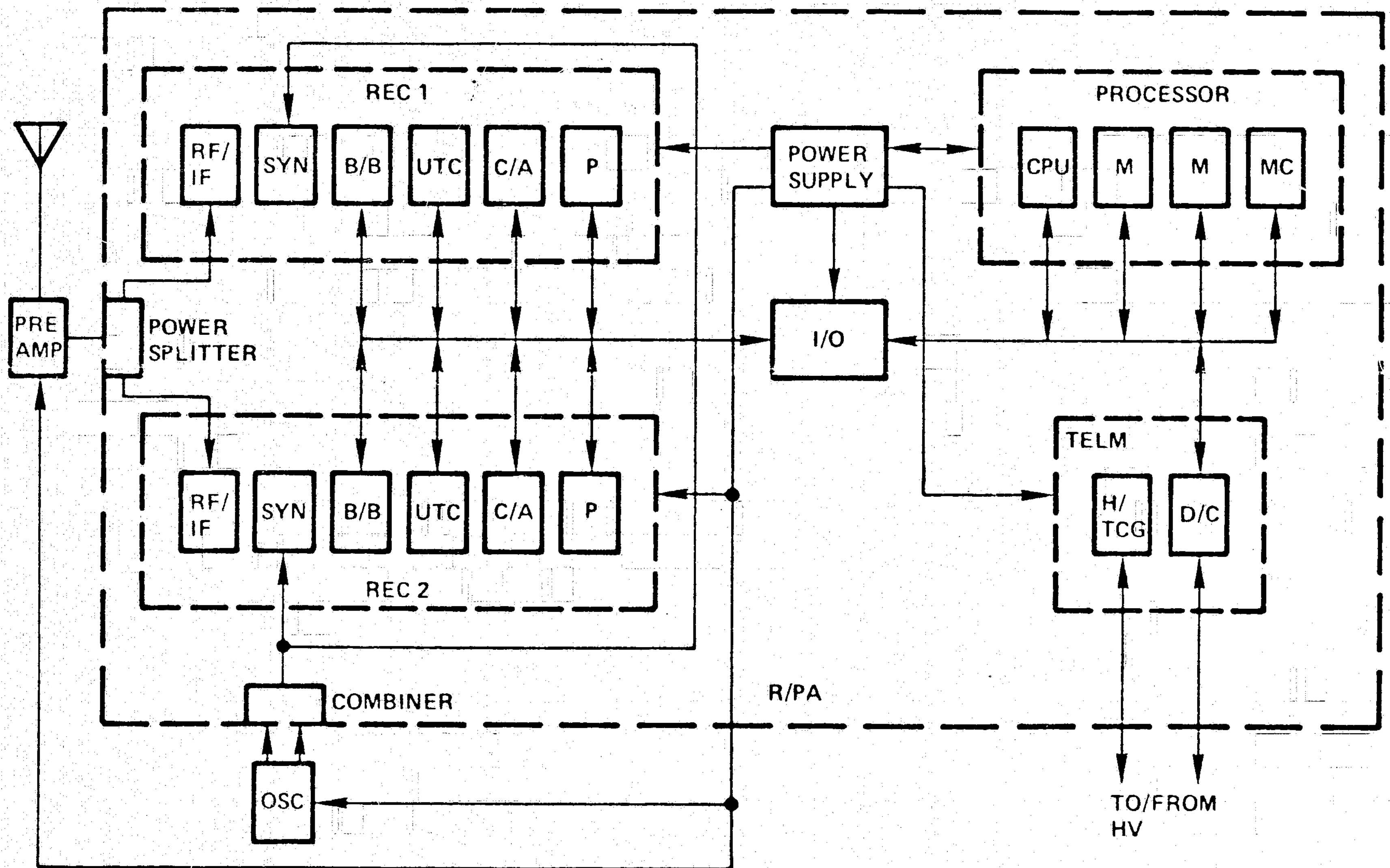
AT

ROCKWELL INTERNATIONAL, DOWNEY, CALIFORNIA

JUNE 21, 22, 1977

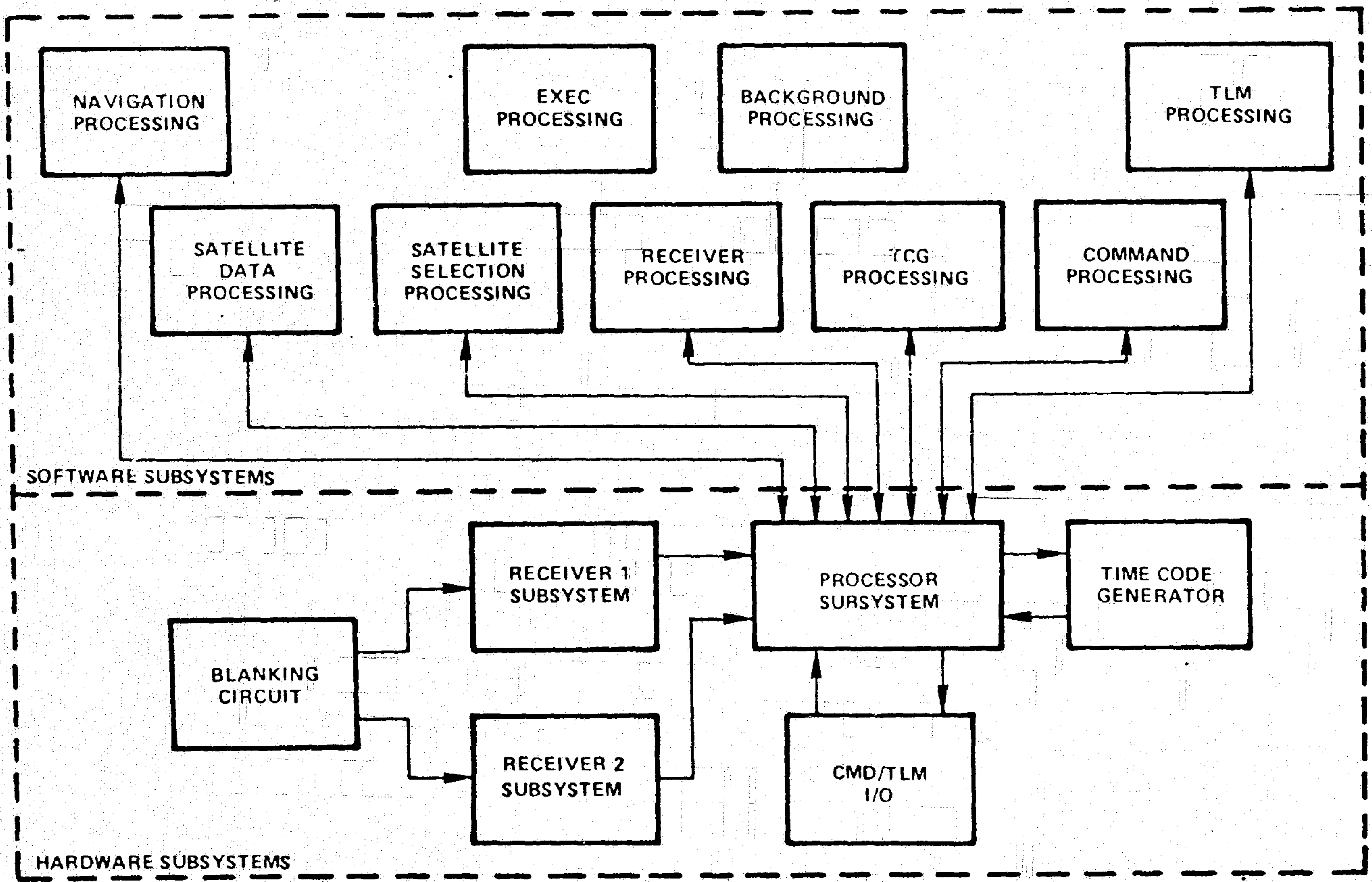
JIM FLACK
MAGNAVOX

R/PA BLOCK DIAGRAM



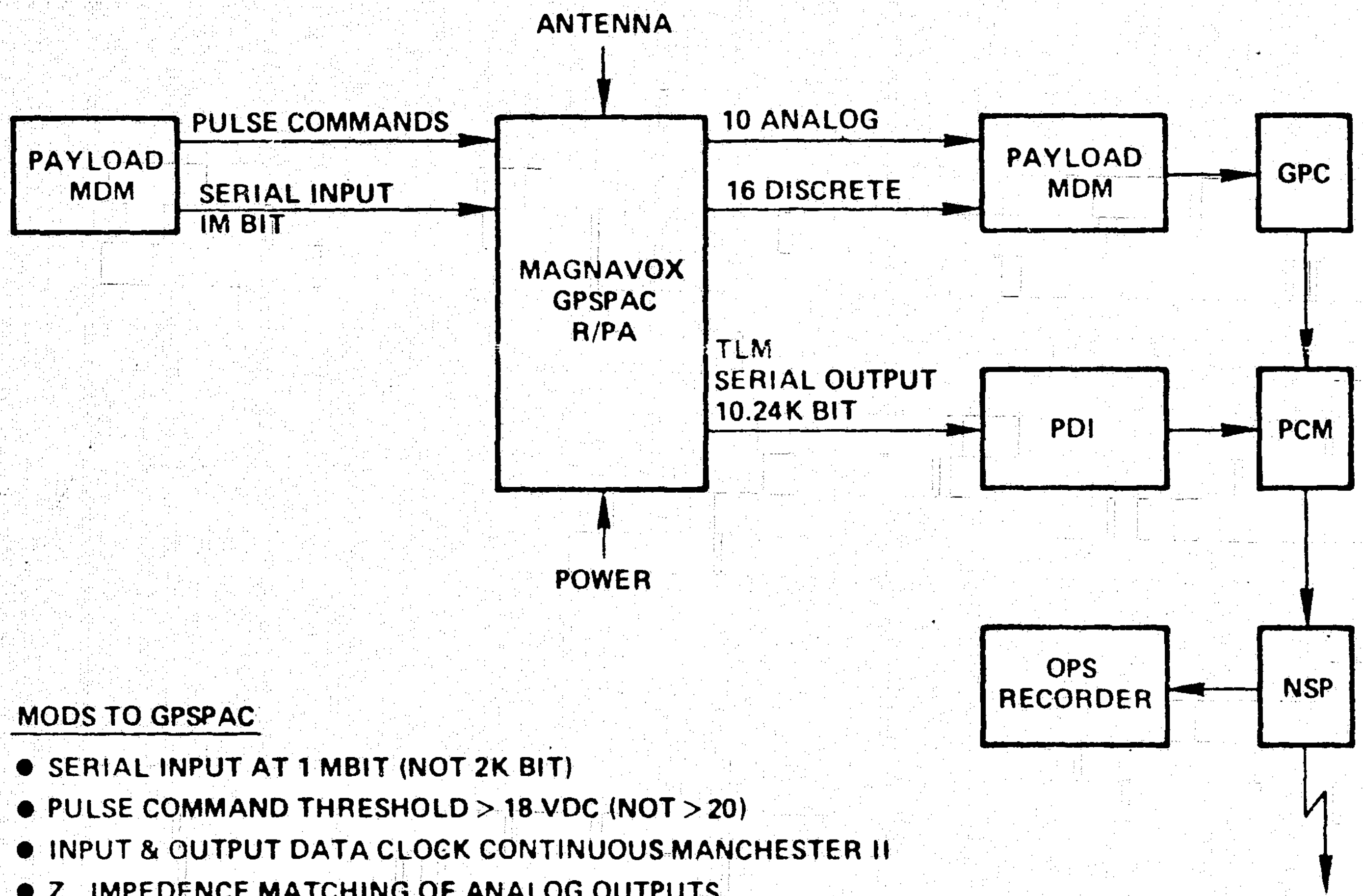
377-1205

SYSTEM PARTITIONING



377-1623

MINIMUM BASELINE GPSPAC/SHUTTLE INTERFACE

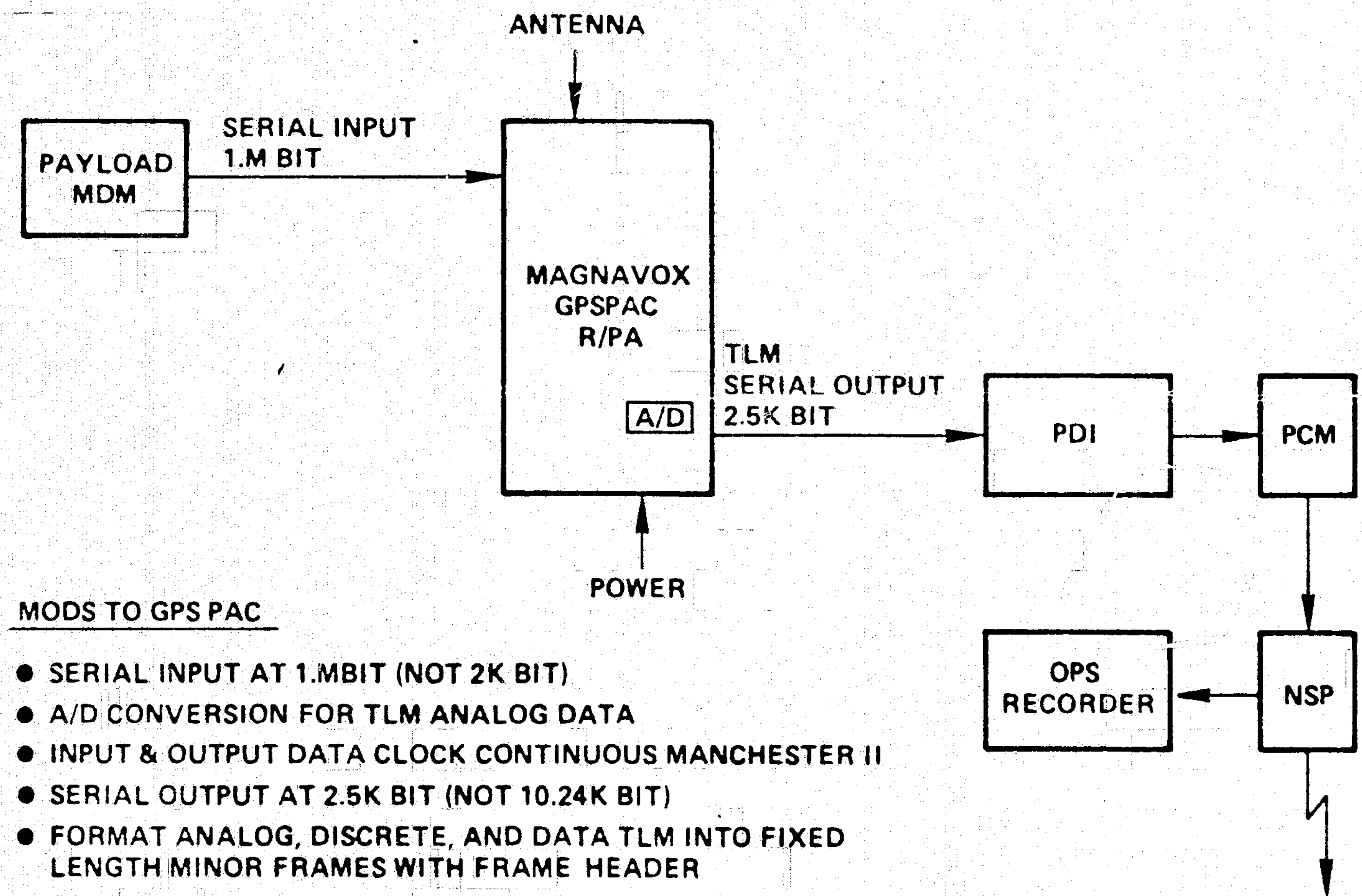


MODS TO GPSPAC

- SERIAL INPUT AT 1 MBIT (NOT 2K BIT)
- PULSE COMMAND THRESHOLD > 18 VDC (NOT > 20)
- INPUT & OUTPUT DATA CLOCK CONTINUOUS MANCHESTER II
- Z_o IMPEDENCE MATCHING OF ANALOG OUTPUTS

677-3833

PREFERRED BASELINE GPSPAC/SHUTTLE INTERFACE

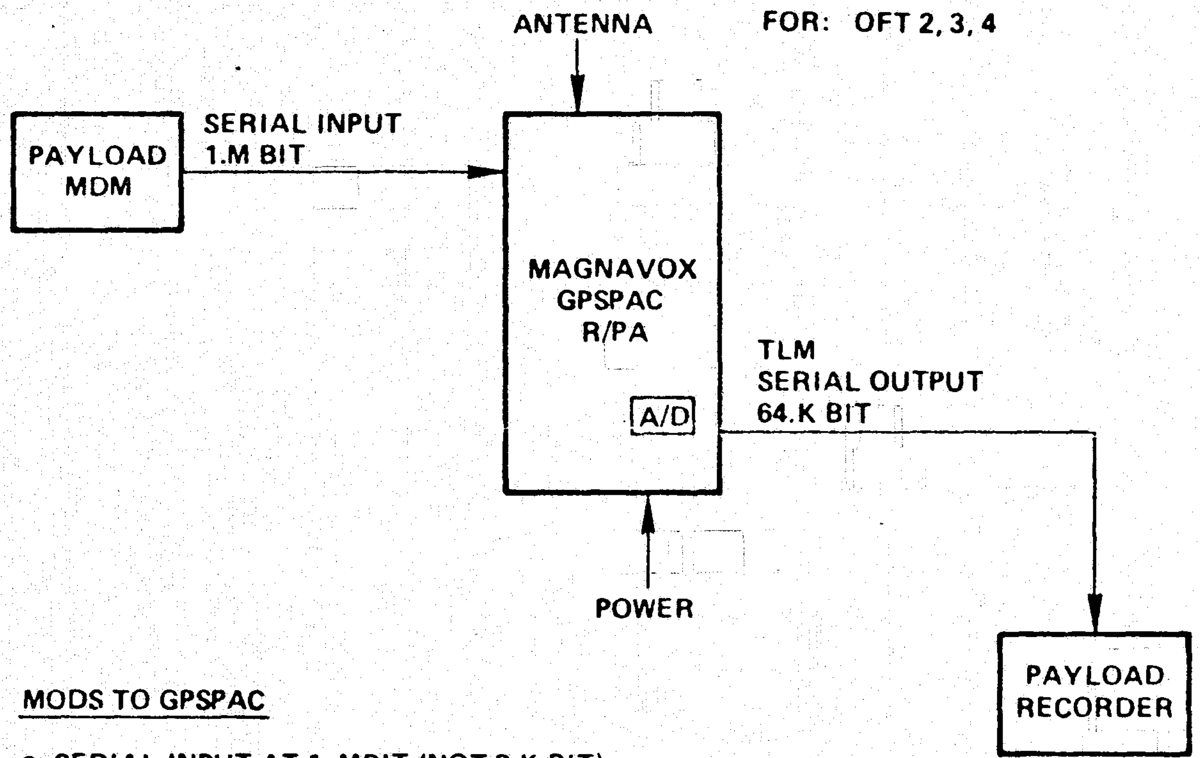


MODS TO GPS PAC

- SERIAL INPUT AT 1.MBIT (NOT 2K BIT)
- A/D CONVERSION FOR TLM ANALOG DATA
- INPUT & OUTPUT DATA CLOCK CONTINUOUS MANCHESTER II
- SERIAL OUTPUT AT 2.5K BIT (NOT 10.24K BIT)
- FORMAT ANALOG, DISCRETE, AND DATA TLM INTO FIXED LENGTH MINOR FRAMES WITH FRAME HEADER
- FORMAT "PULSE COMMANDS" INTO DIGITAL MODE COMMANDS

677-3834

BASELINE DELTA 1 GPSPAC/SHUTTLE INTERFACE



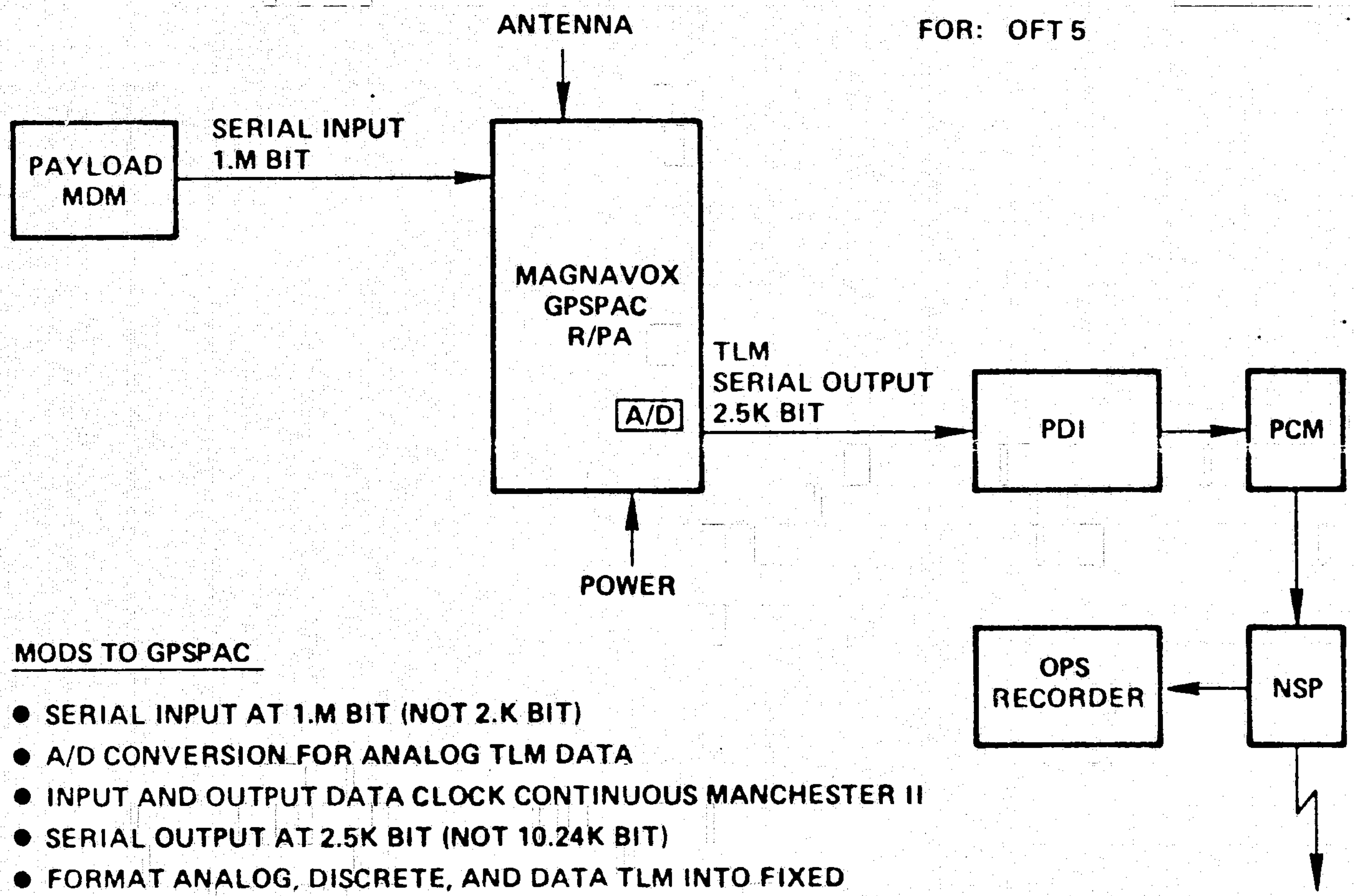
MODS TO GPSPAC

- SERIAL INPUT AT 1. MBIT (NOT 2.K BIT)
- A/D CONVERSION FOR TLM ANALOG DATA
- INPUT AND OUTPUT DATA CLOCK CONTINUOUS MANCHESTER II
- SERIAL OUTPUT AT 64.K BIT (NOT 10.24K BIT)
- FORMAT ANALOG, DISCRETE, AND DATA TLM INTO FIXED LENGTH MINOR FRAMES WITH FRAME HEADER
- FORMAT "PULSE COMMANDS" INTO DIGITAL MODE COMMANDS
- INPUT IMU AIDING DATA THROUGH MDM INTERFACE

677-3835

BASELINE DELTA 1 GPSPAC/SHUTTLE INTERFACE

FOR: OFT 5

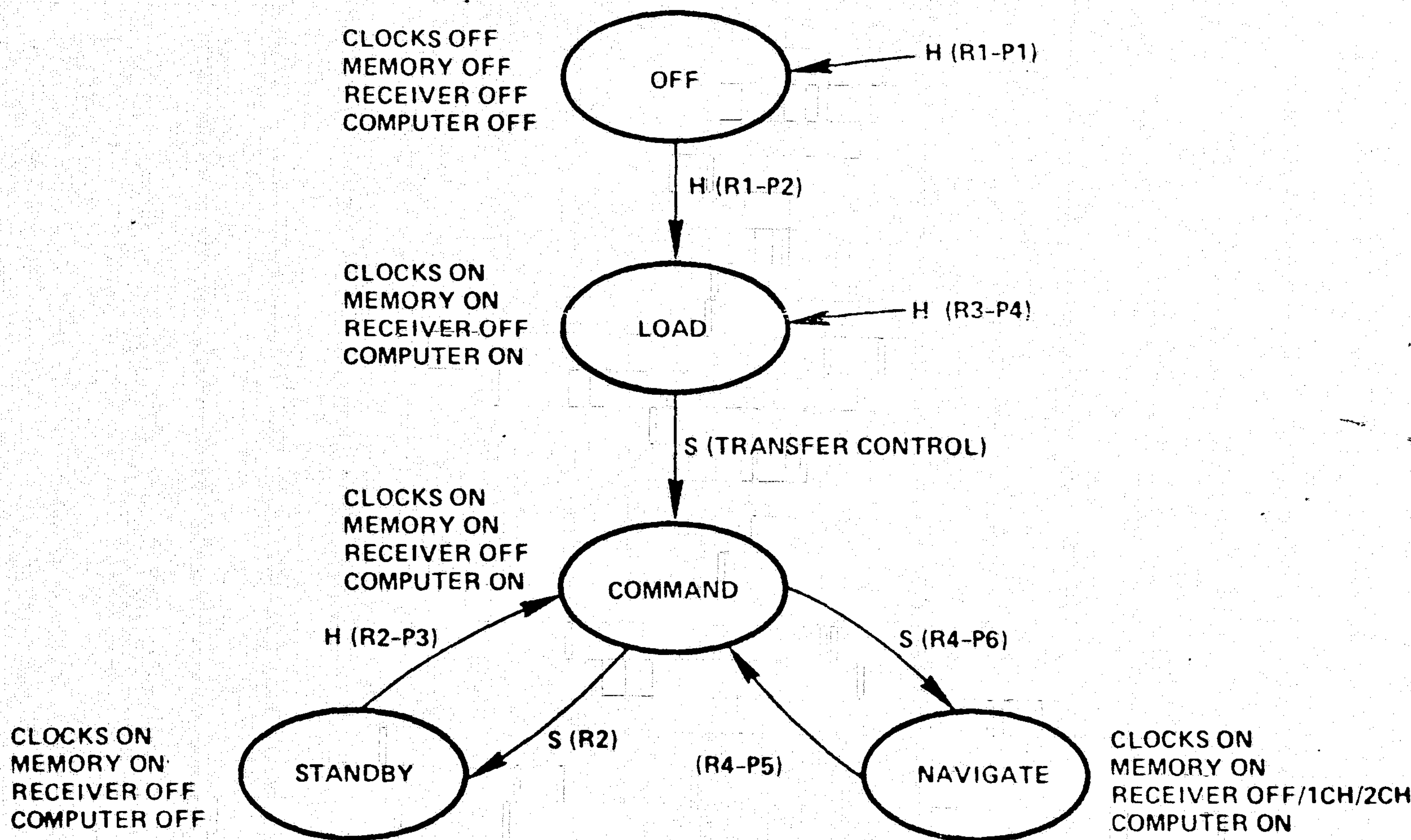


MODS TO GPSPAC

- SERIAL INPUT AT 1.M BIT (NOT 2.K BIT)
- A/D CONVERSION FOR ANALOG TLM DATA
- INPUT AND OUTPUT DATA CLOCK CONTINUOUS MANCHESTER II
- SERIAL OUTPUT AT 2.5K BIT (NOT 10.24K BIT)
- FORMAT ANALOG, DISCRETE, AND DATA TLM INTO FIXED LENGTH MINOR FRAMES WITH FRAME HEADER
- FORMAT "PULSE COMMANDS" INTO DIGITAL MODE COMMANDS
- INPUT IMU AIDING DATA THROUGH MDM INTERFACE

677-3836

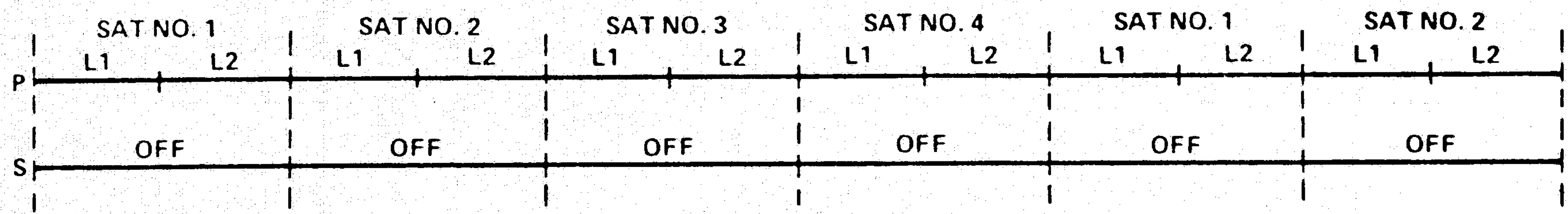
GPSPAC SYSTEM OPERATIONAL STATES



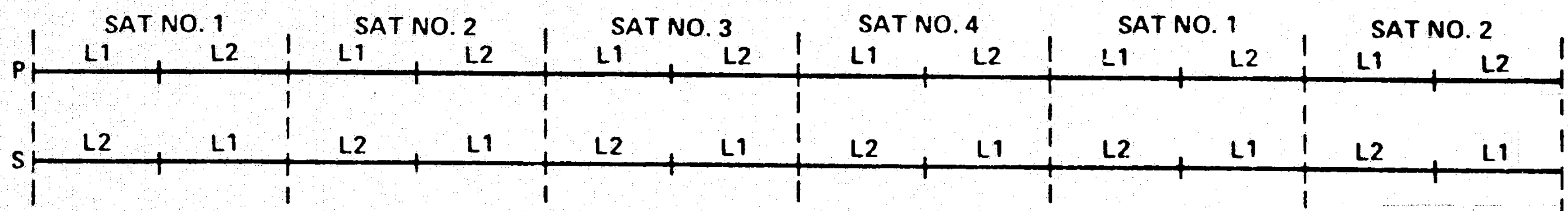
377-1728

SEQUENTIAL TRACKING MODES

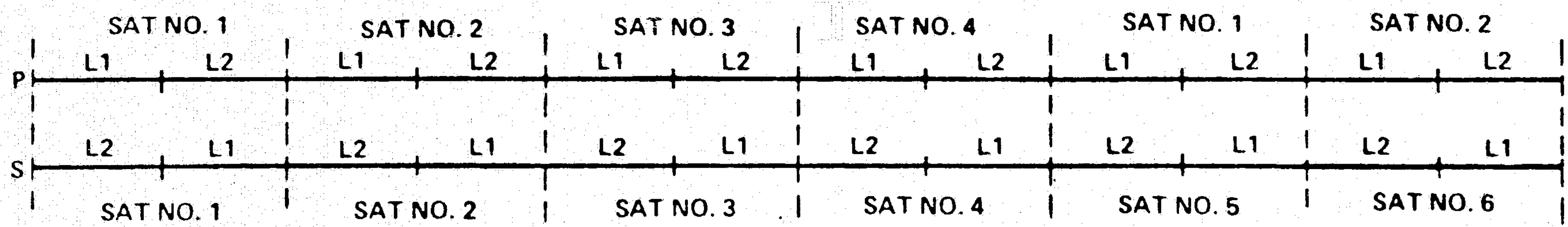
SINGLE CHANNEL SEQUENTIAL 4



DUAL CHANNEL SEQUENTIAL 4

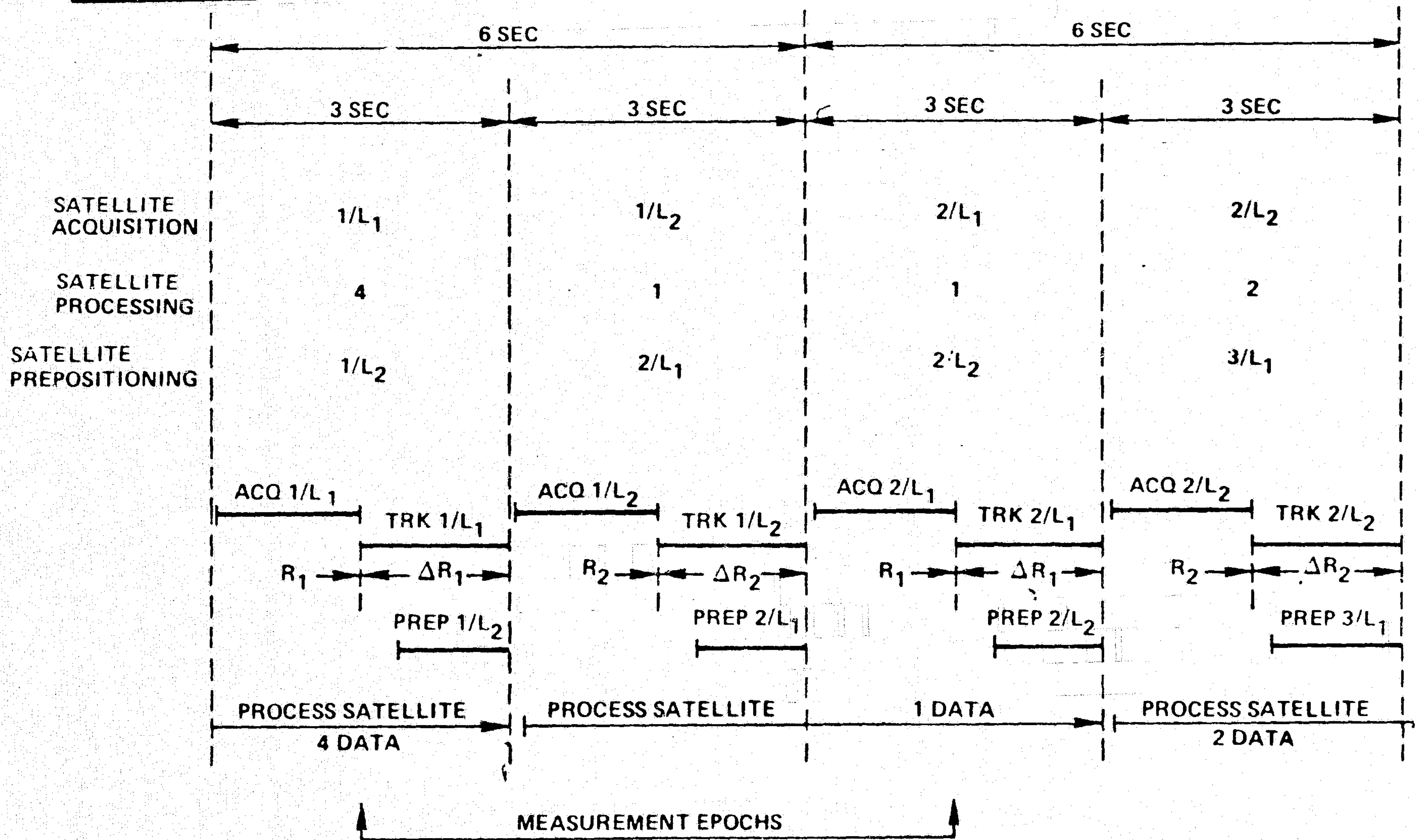


PRIMARY SEQUENTIAL 4 - - SECONDARY SEQUENTIAL 6



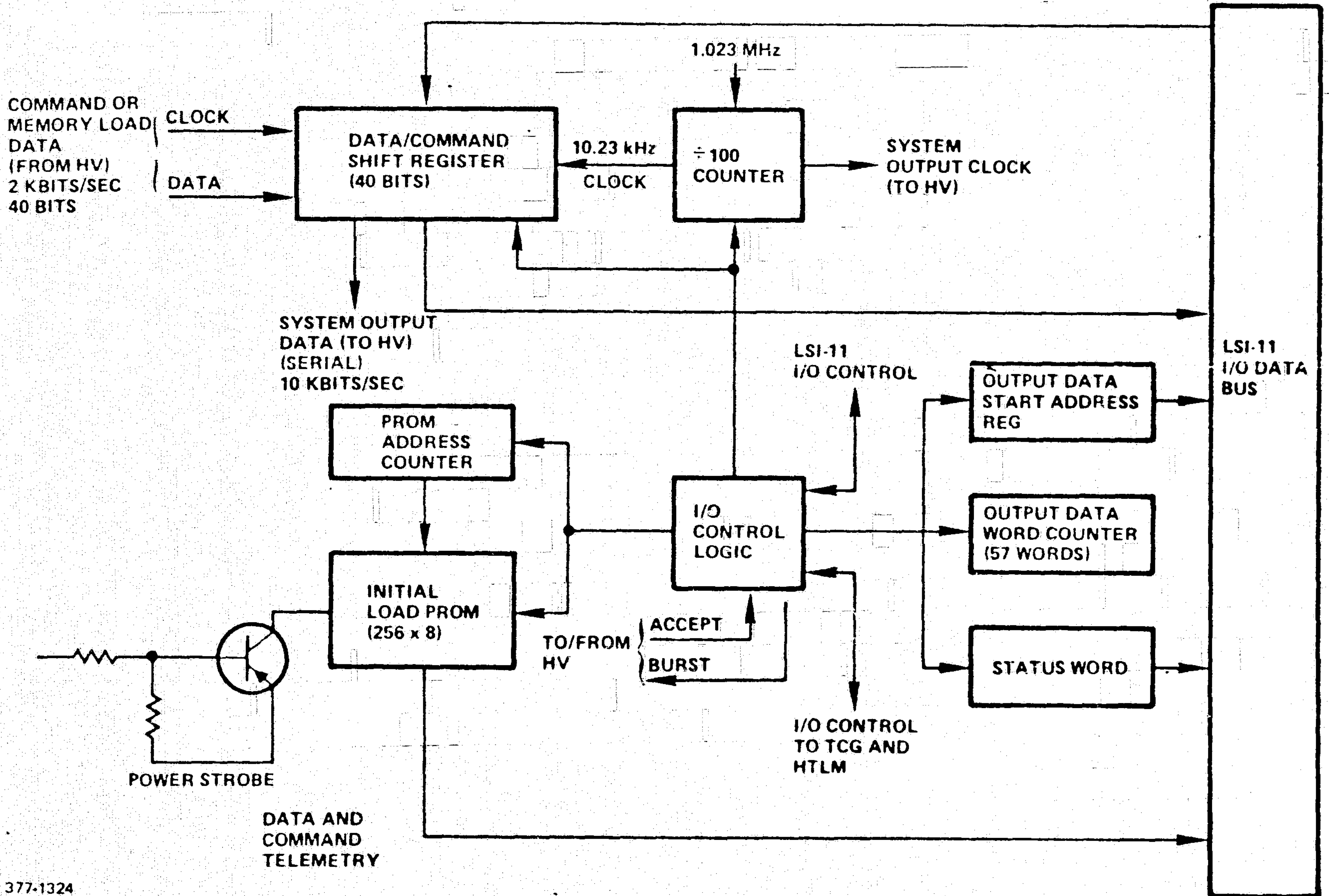
377-1527

THE SEQUENTIAL MEASUREMENT PROCESSING SEQUENCE



377-1528

DATA AND COMMAND TELEMETRY BOARD - BLOCK DIAGRAM



377-1324

COMMAND AND TELEMETRY DATA

377-1622

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DATA COMMAND BLOCKS

COMMAND TYPE	COMMANDS
1	SET RECEIVER CHANNELS
2	SET MODE
3	SET DATA FILE
4	SET TCG
5	SET TCG TO GPS TIME
6	"NDS ALMANAC UPLOAD"
7	MEMORY DUMP
10_8	HV ALMANAC UPLOAD

DATA COMMAND BLOCK FORMAT

GPSPAC COMMANDS CONSIST OF A SEQUENCE OF N 40-BIT BLOCKS PARTITIONED INTO FIVE 8-BIT BYTES:

BYTE 1			BYTE 2	BYTE3	BYTE 4	BYTE 5
BLOCK TYPE	E	COMMAND TYPE				

E → ECHO BIT: 0 = NO ECHO, 1 = ECHO

BLOCK TYPE:

0 = DATA BLOCK
1 = SIMPLE COMMAND
2 = COMPLEX COMMAND
3 = COMMAND TRAILER
4 = LOADER COMMAND

COMMAND TYPE:

LOADER COMMAND TYPES

1 = MEMORY LOAD
2 = BIT MAP OUTPUT
3 = START
4 = RELOAD

SIMPLE/COMPLEX GENERAL COMMAND TYPES

1 = SET RECEIVER CHANNELS
2 = SET MODE
3 = SET DATA FILE
4 = SET TCG
5 = SET TCG TO GPS TIME
6 = NDS ALMANAC UPLOAD
7 = MEMORY DUMP
10_8 = HV ALMANAC UPLOAD

377-1626

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TELEMETRY DATA FILES

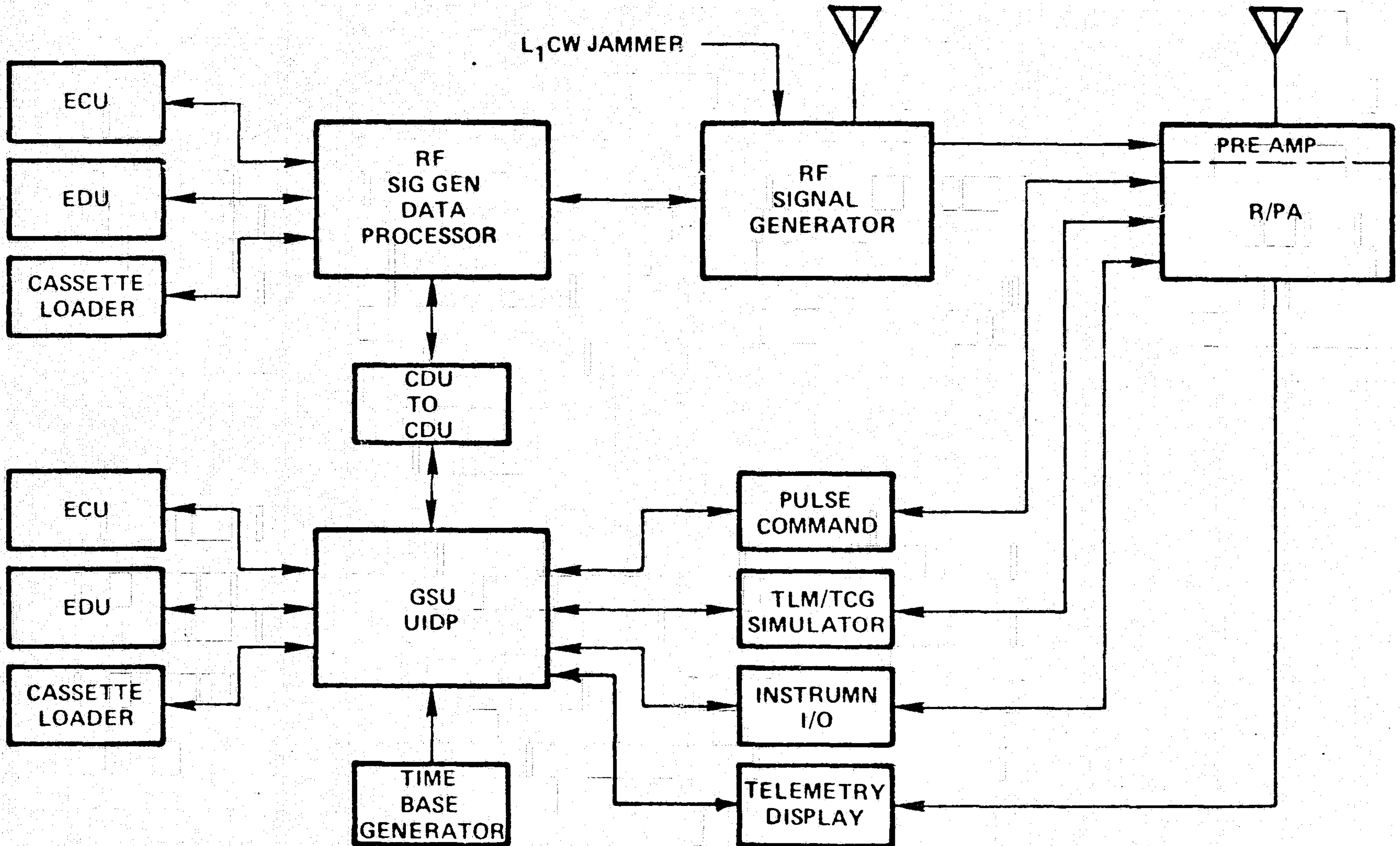
FILE ID	CONTENTS		SIZE (BITS)	TLM THRU-PUT DEMAND
o*	COMMAND ECHO BUFFER	$1 \le N \le 7$	40 (N+1)	1 SECOND
1**	BIT MAP OUTPUT		672	1 SECOND
2	EPHEMERIS DUMP		2376	3 SECONDS
3	MEMORY DUMP	$1 \le N \le 55$	56 + 16N	1 SECONDS
4	SYSTEM STATUS		688	1 SECOND
5	NDS ALMANAC DUMP	$1 \le N \le 24$	40 + 184N	1-5 SECONDS
6	TIME MARK	$1 \le N \le 18$	40 + 48N	1 SECOND
7	NAVIGATION BEST ESTIMATE		488	1 SECOND
10_8	KALMAN INPUT DATA	SINGLE CHANNEL DUAL CHANNEL	(448) 432 (856) 824	1 SECOND
11_8	MEASUREMENT DATA	SINGLE CHANNEL DUAL CHANNEL	304 568	1 SECOND

* ECHO COMMAND DURING COMMAND MODE ONLY

** BIT MAP OUTPUT DURING LOADER MODE ONLY

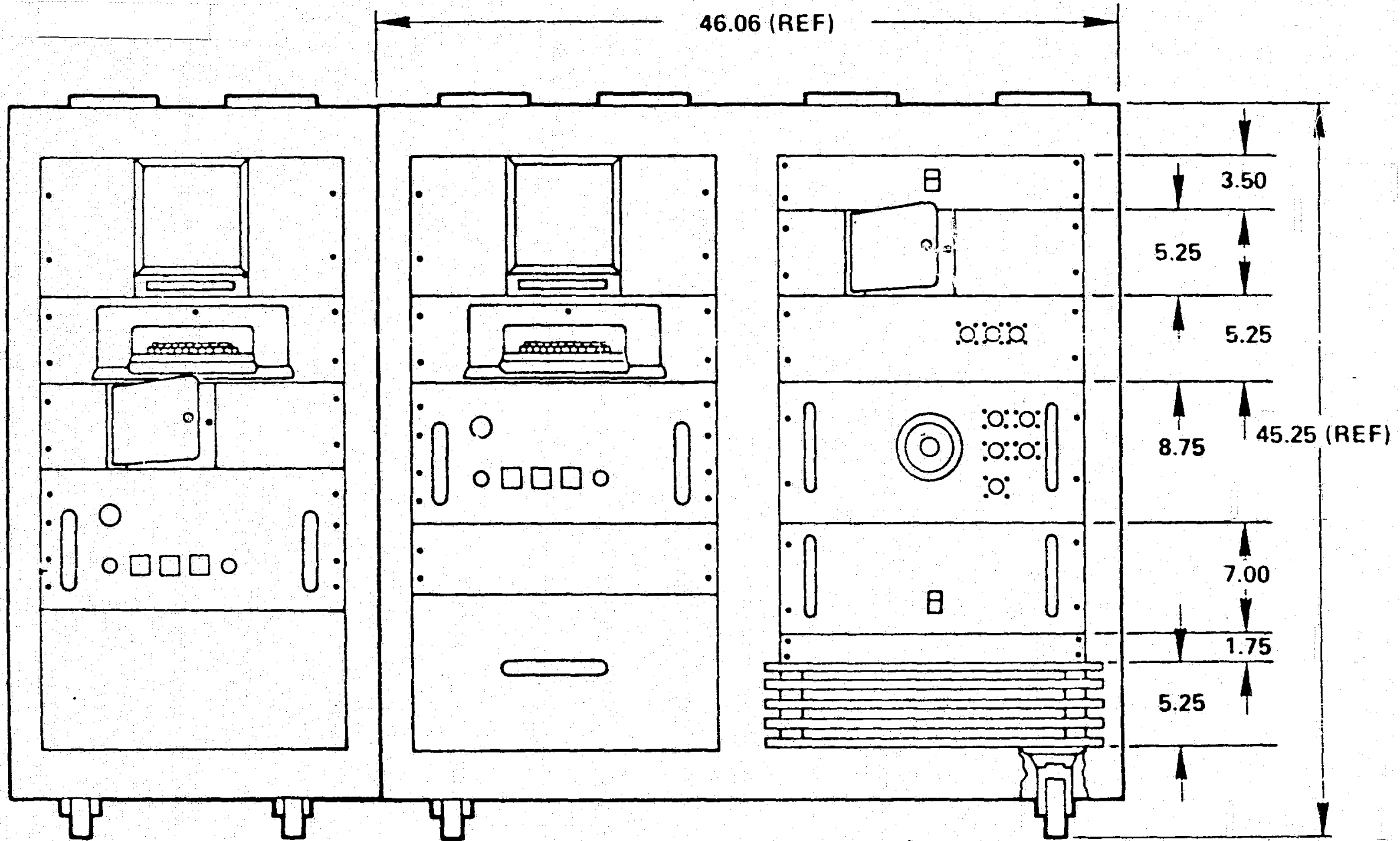
377-1637

GPSPAC GSU HARDWARE CONFIGURATION



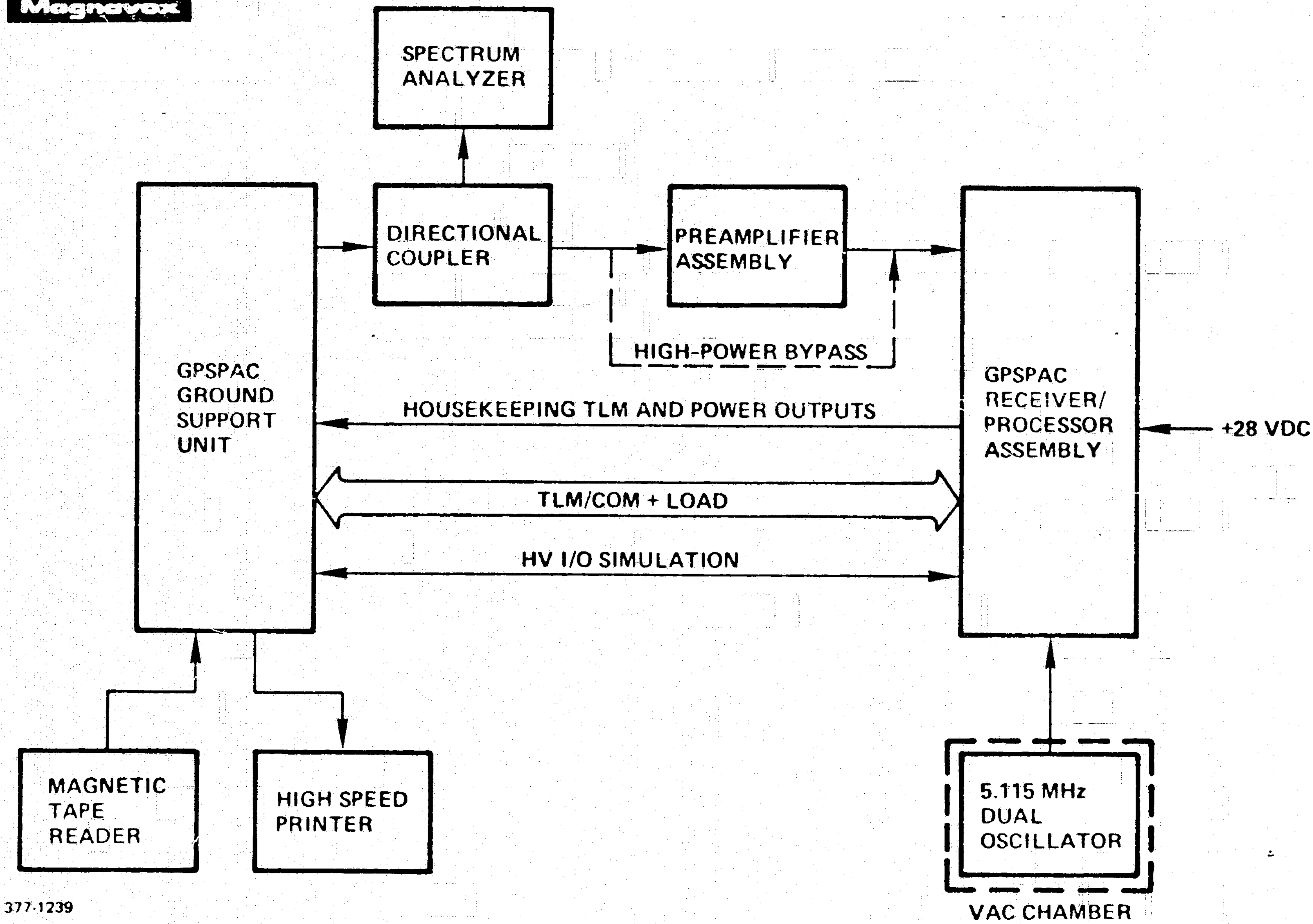
377-1374

GPSPAC GSU - FRONT VIEW



377-1223

GPSPAC GSU - R/PA LABORATORY TEST CONFIGURATION



377-1239