MULTIFUNCTION RECEIVER SYSTEM FOR INTEGRATED TRACKING, TELEMETRY AND RANGING DATA ACQUISITION[1]

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Summary The state-of-the-art for Tracking, Telemetry and Ranging data acquisition has reached a point where simultaneous performance of each of these functions is possible with one receiving system. In addition to simultaneous reception of data with one receiver, this Multifunction Receiver System was developed to be compatible with the other DOD and NASA Tracking and Data Acquisition systems besides the specific system for which it was designed, the Goddard Range and Range Rate System. NASA/Goddard Space Flight Center initiated development of this integrated receiver system in September 1967 and will have the first system operational in December 1968 at Rosma4, North Carolina. Three more systems will be installed: one each at NASA STADAN stations in Alaska, Tananarive, and Carnarvon, Australia. The receiver system was designed to cover all the currently known NASA and DOD frequency bands from VHF to 10 GHz. The data handling capability of the system is optimized for both narrowband and wideband data. AM, FM and PM data is accommodated in varying bandwidths from 10 kHz to 10 MHz. The primary objectives for developing such a system were to achieve improved mission effectiveness of NASA STADAN operations and reduce life-cycle costs in carrying out NASA Tracking and Data Acquisition responsibilities.

Introduction This paper has been prepared in two parts. The first part presents the rationale, concepts, background requirements and technical justifications leading to the

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decision by NASA/Goddard Space Flight Center to develop the Multifunction Receiver System. The second part of this paper addresses the specific design approach used by General Dynamics Electronics Division, Rochester, New York, to satisfy the requirements of this program.

Tracking and Data Acquisition functions generally include automatic antenna steering, telemetry data demodulation and ranging to a satellite. Traditionally these functions have been performed individually with separate receiving systems. The first attempt to integrate these functions by NASA was the APOLLO Unified S-Band System in 1962. The state-of-the-art is technology plus the schedule requirements of the APOLLO program did not permit the development of a fully integrated system that would simultaneously perform tracking, telemetry data acquisition and ranging to a satellite with the same receiver. Since that time, NASA has sponsored developments which provided the technology base which ultimately led to the present Multifunction Receiver development as part of the Goddard Range and Range Rate System up-date program. Some of these developments included the Diversity Telemetry Receiver which was a dual channel data receiver with polarization diversity capability; the Polarization Diversity Autotrack Receiver System (APDAR) which was a six-channel monopulse autotrack system and, of course, the GRR-1; GRR-2; and most recently, the ATS Range and Range Rate System. Technology from all of these systems has been integrated into the new Multifunction Receiver System.

Beyond the immediate application of the Multifunction Receiver to GRARR, it is planned to use this Receiver System in all the primary STADAN stations for autotrack and telemetry data acquisition. The advanced state-of-the-art capabilities of the Multifunction Receiver such as: frequency capability from VHF to 10 GHz; polarization diversity with predetection combining, computer control interface and wideband data handling permit a flexible instrumentation concept that will provide more mission effectiveness and lower life-cycle costs for Tracking and Data Acquisition.

Part I In reviewing the international and domestic frequency allocations assigned for spacecraft and the currently available receiving systems it was found that receiving systems (excluding antennas) varied from simple $5,000 to $10,000 receivers to systems costing close to $500,000. Due to changing requirements of the “Space Program”, small changes within the receiving system are costly and, on occasion, the system may have to be operated with slightly degraded performance. Therefore, GSFC set out to design a new receiving system that would have an operational life of 10 to 15 years and could become a standard receiver for various network organizations.

The receiving systems utilized by the Unified S-Band System (USBS) for APOLLO the Deep Space Network (DSN) for the Jet Propulsion Laboratory, the Space Ground Link System (SGLS) for the U. S. Air Force and the Space Tracking and Data Acquisition

Network (STADAN) for the Goddard Space Flight Center were designed to meet specific requirements. The USBS, DSN and SGLS receiving systems are somewhat similar in design with the exception that the SGLS will operate over the 100 MHz frequency band from 2200 MHz to 2300 MHz while the USBS covers frequencies from 2270 MHz to 2290 MHz and the DSN systems between 2290 MHz to 2300 MHz. The USBS, DSN and SGLS receiving systems are phase locked systems and are used for receiving telemetry, range and range rate data, as well as antenna automatic tracking (auto-track) from a single carrier. Generally, each of these functions are performed using separate receiving systems.

The USBS, DSN and SGLS were designed to operate with specified mission requirements in the 2200 MHz and 2300 MHz frequency band. The STADAN, however, is a multimission network which presently operates in the frequency bands of 136 MHz to 138 MHz, 400 MHz to 401 MHz, 1700 MHz to 1710 MHz and in the 4 GHz spacecraft-to-ground band. Due to new mission requirements, the STADAN will begin operating in 2200 MHz to 2300 MHz in 1968 and the 7 GHz band in the early 1970's. To satisfy these diverse requirements, a new receiver system was needed that would provide multi-mission support, multi-purpose functions, and have sufficient performance capability to satisfy the most sophisticated technical requirements for data acquisition.

The STADAN has utilized three separate receiving systems. One system is for monopulse antenna auto-track with single auto-track receivers for each frequency band. Monopulse antenna systems have been selected for use by NASA because of their inherent accuracy and reliability for acquisition of telemetry data. The "turnaround" time between passes for data acquisition from different spacecraft is currently a maximum of 15 minutes and as low as five minutes. The short "turnaround" time presents the possibility of requirement for re-phasing and/or gain realignments. Also this short "turn-around" presents requirements for semi-automated remote control of the receiving system for such functions as mode selection, receiver tuning, bandwidth selection and frequency band selection.

The second receiving system used is for acquisition of telemetry data. This system features post-detection polarization diversity utilizing the maximal-ratio squared combining technique. Post-detection combining was acceptable since narrow band data (3MHz) was being received. The telemetry receivers are installed with the antennas but may be switched to any antenna.

The third receiving system within the STADAN is the Goddard Range and Range Rate System (GRARR). This system performs the functions of acquiring range and range rate data and auto-track at the VHF and S-Band frequencies. The new frequency allocation which dictated the use of 1750 MHz to 1850 MHz for ground-to-spacecraft and 2200

MHz to 2300 MHz for spacecraft-to-ground presented the opportunity to design a new receiving system, known as the Multifunction Receiver (MFR).

Analysis of the past, present and possible future requirements for the Tracking and Data Systems Directorate of Goddard Space Flight Center indicates the need for multiple network operation, improved mission effectiveness and better cost effectiveness.

MULTIPLE NETWORK OPERATION The multiple network operation requirement is defined as having the capability to acquire and receive data in the frequency band used by any ground based data acquisition network by changing the down converter. The receiver first intermediate frequency was specified such that the system will operate up to 10 GHz, but specifically within the frequency bands of 130 MHz to 140 MHz, 400 MHz to 401 MHz, 1435 MHz to 1540 MHz, 1700 MHz to 1710 MHz, 2200 MHz to 2300 MHz, 4000 MHz to 4100 MHz, 7000 MHz to 7200 MHz. The data bandwidths are selectable from 1.5 kHz to 10 MHz using pre-detection combining. The wider data bandwidths were determined necessary because of requirements for higher resolution data for earth resources investigations and for operation with the future Orbiting Data Relay Network with high resolution television requirements. The most difficult requirement was maintaining the frequency coherence for the two way Doppler measurement.

The receiver system was to be designed to be capable of operation with both types of spacecraft transponders in use by the various networks, SGLS, USBS, DSN and GRARR. The first is a multiple access, fixed frequently (fixed crystal oscillator) transponder. The second is a single channel phase locked loop transponder which is phase locked to the ground transmitted frequency and mathematically related by the spacecraft transponder translation ratio. The receiving system has the capability of extracting Doppler measurements for the USBS, DSN, SGLS and STADAN.

MISSION EFFECTIVENESS Mission effectiveness is defined as the technical performance of the receiving system other than the usual noise figure, threshold, gain distribution, etc.

The first requirement is that the receiver system be capable of operation with amplitude, frequency and phase modulated signals and auto-track in open or closed loop modes.

The second is the need for maximal ratio predetection diversity combining techniques for data acquisition and auto-track. For spinning or tumbling spacecraft, diversity combining serves as an electronic switch for receiving different polarizations and, thereby, preventing possible loss of data.

The existing telemetry systems within the STADAN utilize maximal ratio postdetection diversity combining. Polarization diversity is required for specific space projects where spacecraft are spin stabilized or must be reoriented so that a different polarization is transmitted to the ground receiving system. Pre-detection combining was specified for the Multifunction Receiver because of the requirement to handle wideband data. To accomplish this, it will be seen that it was necessary to combine 20 MC RF bandwidth signals.

The third and probably the most difficult requirement is the operation of the receiver system over a 100 MHz band. The design of a receiving system which is tunable over a 100 MHz band places restrictions on the choice of intermediate frequencies as opposed to the normal 10 MHz to 20 MHz bandwidth receivers that presently exist for 2200 MHz to 2300 MHz.

COST EFFECTIVENESS Cost effectiveness must be analyzed based on criteria of cost savings plus improvement in performance to produce satisfactory data.

Experience indicates that there are less adjustments and maintenance problems with solid state integrated circuit systems. We have estimated there will be a 50% savings in maintenance. Also, this receiver concept has shown that an improved MTBF is achieved. This has been calculated to be 877 hours which is an improvement of 300% over previous systems in the NASA STADAN inventory.

Reduced costs in training are expected because separate operators are not required for different receivers. The building block concept allows flexibility in implementing the receiver system. Additional RF channels can be added without duplicating the whole receiver system.

Automatic polarization switching in the MFR has eliminated risks in loss of data and loss of time previously required to manually switch polarizations.

Another contributor to cost effectiveness is the reduction of logistics support. An experience factor for the cost of logistics for receivers has been six percent per year of the cost of the receiver. It is anticipated that a logistics cost of 2 to 3 percent will be achieved for an MTBF of 877 hours for the complete MFR system. An annual cost savings of $300,000 to $400,000 is logistics could possibly be saved when the STADAN is totally equipped with these receivers.

It is important to point out that long lead times of three to four months are often encountered to receive some spare parts. In such cases the receiver is not used until the components are received or the receiver is used to receive data from a spacecraft where the spacecraft is required to transmit enough power to offset the receiver degradation.

The fifth and most significant savings is the centralized control concept for combined operations of auto-track and data demodulation.

As mentioned earlier, the STADAN uses separate receiver systems for data, auto-track and ranging and, therefore, the centralized control concept for the MFR will allow one operator to perform the functions presently requiring two operators. This savings in STADAN 85-foot antenna installations has been calculated to be $224,000 per year. When the 40-foot parabolic antenna systems are equipped with the MFR, an additional savings of $280,000 per year is anticipated.

The cost effectiveness studies have indicated that the new receiving systems will pay for themselves within a time interval of five to six years for the parabolic antennas. The cost to implement the new receiving system with antennas other than parabolic reflectors is offset by improvement of performance and quality of data.

Part II The Multifunction Receiver (MFR) is being developed in response to the requirements outlined in the first part of this paper and shown in Figure 1.

This Receiving System is a multipurpose receiver designed to meet the current and projected requirements of the NASA STADAN (Space Tracking and Data Acquisition Network), APOLLO Unified S-Band and Deep Space Instrumentation Facility (DSIF) Stations, plus the DOD National Ranges. To achieve this compatibility, the MFR was designed to be capable of both narrow bandwidth and wide bandwidth data acquisition plus satisfy the IRIG 106-66 Telemetry Receiver Standards.

The MFR achieves its multifunction capability by performing simultaneous functions of monopulse antenna auto-track, telemetry data acquisition, and ranging to a satellite, aircraft or missile suitably equipped to operate with the MFR. Also this multifunction capability is a result of its ability to operate in all the existing NASA and DOD frequency bands from VHF to X-Band. The data handling ability includes AM, FM and PM demodulation and the ranging capability can handle side tone or pseudo random noise (PRN) ranging codes.

The auto-track capability is designed to operate with antennas equipped with monopulse feed systems. The receiver will operate with either circular or linear polarized signals and provides predetection combining using optimal ratio squared combining techniques.

The telemetry data demodulation function provides capability for demodulation of coherent and non-coherent signals. Coherent AM and PM, and non-coherent AM, FM and PM, signals can be demodulated. Data bandwidths from 1.5 kHz to 10 MHz can be handled with the demodulators.

The MFR provides range and range rate data output using either side tone or pseudo random noise (PRN) codes. Range information is provided by the subcarrier demodulator and range rate data is provided in the Doppler extractor unit. Typical accuracies using the MFR in the NASA GRARR System are 0.1 meters/sec. (RMS) in range rate and 15 meters (RMS) in range.

Figure 2 is a pictorial layout of the MFR System concept showing the interrelated functions and information flow within the MFR.

Figure 3 is a system block diagram showing the operation of the MFR.

It can be seen that the MFR is a triple conversion, superheterodyne receiver system. The preamp converters are located on the antenna and it is necessary to select the proper preamp for the desired frequency band to be covered. All converters provide an output at 400-500 MHz. It can be seen in this diagram that all tuning is done in the second mixer. Digital tuning is accomplished by frequency synthesis techniques. Tuning is in 10 kHz steps across the entire frequency range with fine tuning capability of ±300 kHz about the receiver center frequency. The receiver tuning signals are provided using the HP 5105A Synthesizer and HP 5110B Driver. The second IF is 110 MHz and the third IF is 10 MHz. It can be seen that wideband combining is done at 110 MHz to preserve wideband data demodulation capability and narrowband combining is done at 10 MHz.

A summary of the unique systems features is shown in Figure 4.

Figures 5 and 6 show respectively the electrical performance characteristics and the applicable MIL spec and NASA standards for the MFR.

Figure 7 shows the layout of the MFR rack mounted equipment and the remote control console. All of the solid state switching is located in the receiver rack and merely the control panels have been mounted in the console. All switching and control functions are performed using standard switching levels of 0 and +6 volts. The receiver can be controlled locally at the rack or remotely from the console.

One of the primary features pointed out in the first part of this paper is the modular building block concept of the MFR. Figure 8 shows the layout of a typical drawer. The basic building block in the system is the throw-away, thick film microelectronic integrated circuit shown in Figure 8. This is a hybrid microelectronic integrated circuit cince only the passive elements are deposited on the substrate, whereas, the active elements are applied as discrete components. This type of circuit was selected because of its economy, power handling capability, and reliability. A typical throw-away submodule costs approximately $40. Furthermore, this overall economy of design is reflected in the price of the MFR. The complete receiver system plus console sells for approximately $200 K.

One of the requirements stressed by NASA for this system is commonality of submodule building blocks. Approximately 600 submodules are required in the MFR. A family of 20 different RF and IF circuit submodules have been developed for use in the MFR. These submodules are repeated several times for the different functions thereby achieving a multipurpose submodule performance. This will provide an indication of the level of multifunction circuitry used in the MFR system. Figure 9 shows the different submodules used in the MFR.

Figure 10 illustrates the electrical characteristics of a typical, standardized general purpose amplifier used in the MFR.

Using the circuit techniques described above and the mechanical construction features described elsewhere in this paper, the MFR has a calculated MTBF of 877 hours or approximately 5 weeks.

Flexibility in the mechanical and electrical design of the MFR permit its application to a wide spectrum of tracking, telemetry and ranging requirements. For instance, the system is partitioned in such a manner that it is possible to configure the following single function receivers from individual building blocks:

A. AUTOTRACK:
   - Three (3) Channel Monopulse Receiver
   - Six (6) Channel Monopulse Receiver

B. TELEMETRY DATA
   - Single Channel Data Receiver
   - Dual Channel Data Receiver with Predetection Combining

In a typical system application where more than one RF carrier is transmitting from a single satellite or missile, additional sum channel receivers and demodulators can be added to receive data from the same receiving antenna by using multicouplers operating at the first IF frequency.

Some of the anticipated applications for the MFR concept include the AFWTR and AFETR up-date programs that address automated telemetry data acquisition.

In conclusion, the MFR, as conceived by NASA, offers advantages of technical performance previously unavailable in a single system . Usually this functional capability was obtained by collecting an assortment of special purpose receivers or using general purpose receivers with an assortment of plug-in modules depending on the mission requirement. The MFR has incorporated design features which allow for optimized performance in both narrowband and wideband operations: thereby, providing a true multipurpose, multifunction receiver system.

Thank you.

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INCREASE TELEMETRY LINK UTILIZATION
IMPROVE TDA LINK PERFORMANCE
REDUCE OPERATING & MAINTENANCE COST
IMPROVE EQUIPMENT RELIABILITY
PROVIDE FLEXIBLE INSTRUMENTATION CONCEPT TO ALLOW STATION RECONFIGURATION AND MISSION SUPPORT GROWTH
PROVIDE COMPATIBLE UNIVERSAL RECEIVER SYSTEM TO INTERFACE WITH STATION AUTOMATION CONCEPTS

Fig.1 NASA Objectives for MFR

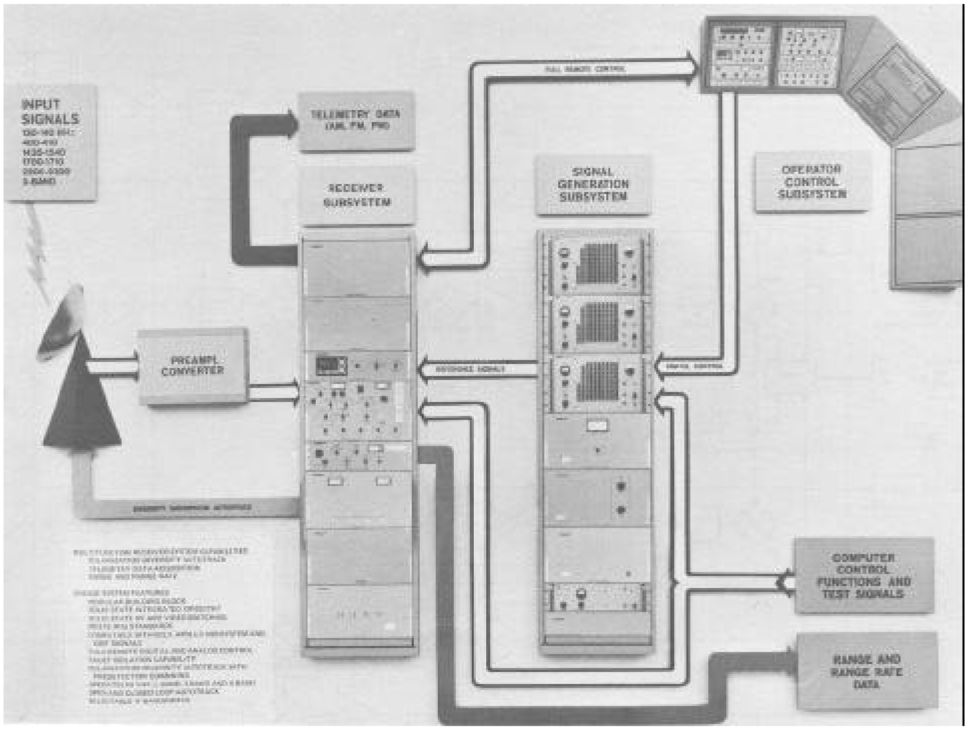

Fig. 2 Multifunction Receiver System Concept

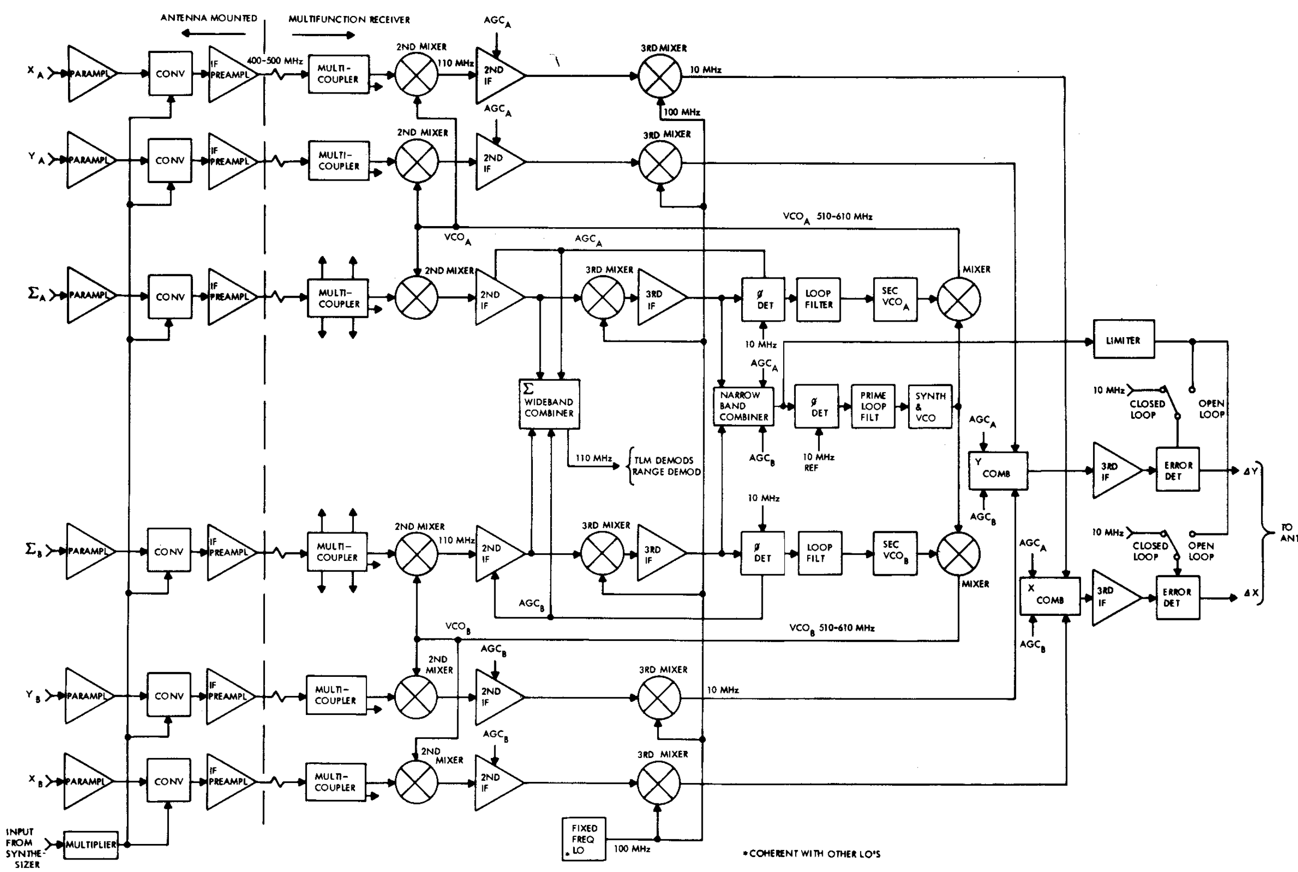

Fig. 3 Multifunction Receiver System Block Diagram

MODULATOR BUILDING BLOCKS
POLARIZATION DIVERSITY WITH PREDETECTION COMBINING
MEETS IRIG RECEIVER STANDARDS
SIGNAL COMPATIBILITY WITH USB, DSIF & SGLS
COMPATIBLE WITH STATION AUTOMATION
REMOTE DIGITAL CONTROL
SOLID STATE RF AND VIDEO SWITCHING
FAULT ISOLATION CAPABILITY
SAME RF CHANNEL USED FOR AUTOTRACK, DATA, AND
RANGING FUNCTIONS

Fig. 4 Summary of Unique Systems Features

FREQUENCY TUNING IN 10 kHz STEPS

130 - 140 MHz	1700 - 1710 MHz
400 - 410 MHz	2200 - 2300 MHz
1435 - 1540 MHz	4000 - 4100 MHz

TUNING ACCURACY 3 PARTS IN 10^8
PHASE-LOCK OPERATION
  MANUAL OR AUTOMATIC ACQUISITION
  ANTISIDEBAND LOCK
  SEARCH MEMORY
NON PHASE-LOCK OPERATION
  MANUAL TUNING $\pm$ 300 kHz
  AFC
  CROSS-CORRELATION
RECEIVER NOISE FIGURE 6 dB @ 2300 MHz
DYNAMIC RANGE 110 dB (PHASE-LOCK)
  84 dB (NON PHASE-LOCK)
DIFFERENTIAL GAIN BETWEEN CHANNELS 2 dB
DIFFERENTIAL PHASE SHIFT BETWEEN CHANNELS 5 DEGREES
TRACKING BANDWIDTHS 10 TO 3 kHz
PHASE-LOCK LOOP CHARACTERISTICS
  PRIMARY LOOP IS 3RD ORDER
  SECONDARY LOOP IS 2ND ORDER
PREDETECTION COMBINERS
  WIDEBAND COMBINER 20 MHz bw @ 110 MHz
  NARROWBAND COMBINER 1 MHz bw @ 10 MHz
SPURIOUS RESPONSE 70 dB
CROSS COUPLING
  50 dB ISOLATION BETWEEN SUM AND ERROR CHANNEL
  100 dB ISOLATION BETWEEN SEPARATE POLARIZATIONS
RECEIVER SENSITIVITY
  PHASE-LOCK OPERATION

PRIMARY LOOP

Bw/10	ACQUISITION THRESHOLD	TRACKING THRESHOLD
	-151 dBm	-159 dBm

SECONDARY LOOP

Bw/3	ACQUISITION THRESHOLD	TRACKING THRESHOLD
	-157 dBm	-161 dBm

NON PHASE-LOCK OPERATION

Bw/10 kHz	THRESHOLD
	-134 dBm

Fig. 5 Summary of Electrical Performance Characteristics

MIL-STD-202, "TEST METHODS FOR ELECTRONIC AND ELECTRICAL COMPONENTS PARTS".
MIL-HDBK-127, "RELIABILITY STRESS AND FAILURE RATE DATA FOR ELECTRONIC EQUIPMENT".
MIL-STD-756(Wep), "RELIABILITY OF WEAPONS SYSTEM, PROCEDURES FOR PREDICTION AND REPORTING PREDICTION OF".
MIL-STD-826, "ELECTROMAGNETIC INTERFERENCE TEST REQUIREMENTS AND TEST AND TEST METHODS".
NASA QUALITY PUBLICATION NPC-200-3 AND 4, "QUALITY PROGRAM PROVISIONS FOR SPACE SYSTEM CONTRACTORS".
NASA QUALITY PUBLICATION NPC-250-1, "RELIABILITY PROGRAM PROVISIONS FOR SPACE SYSTEM CONTRACTORS".

Fig. 6 Summary of Applicable Specifications and Standards

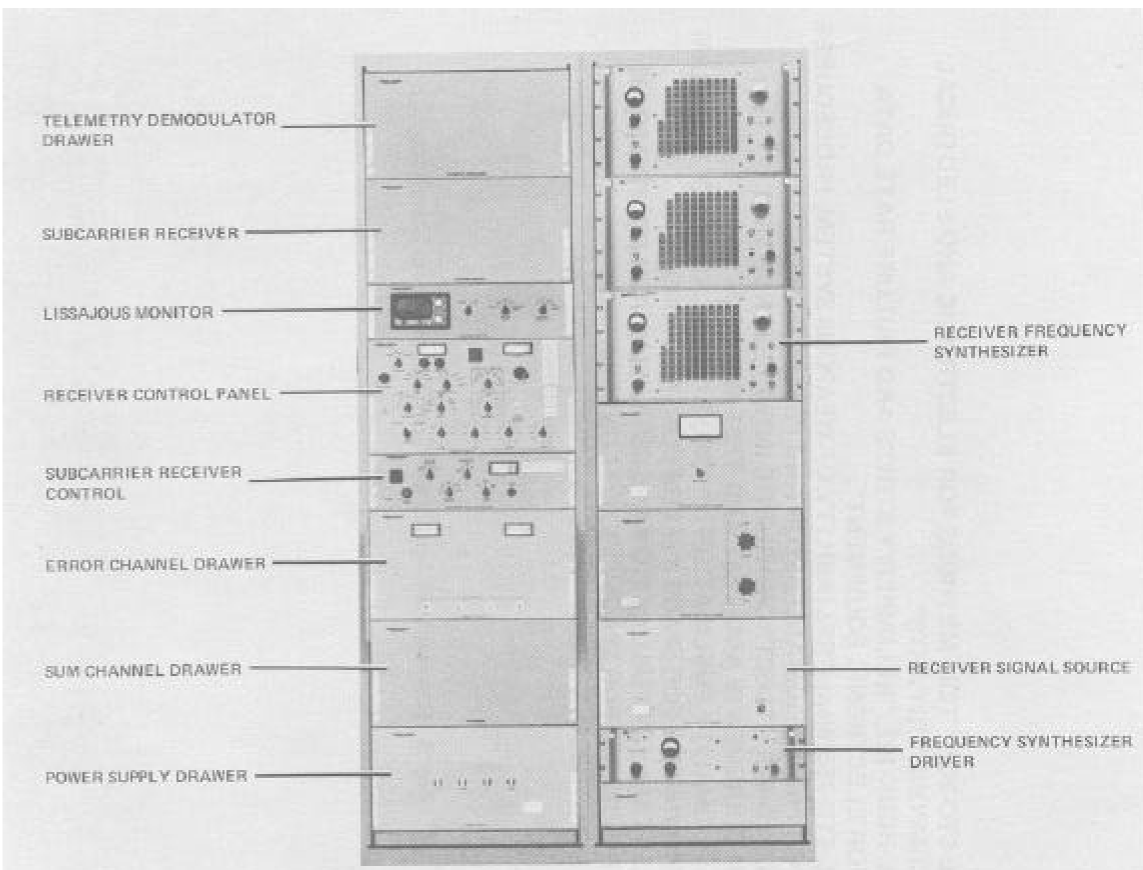

Fig. 7 Multifunction Receiver System Rack Layour

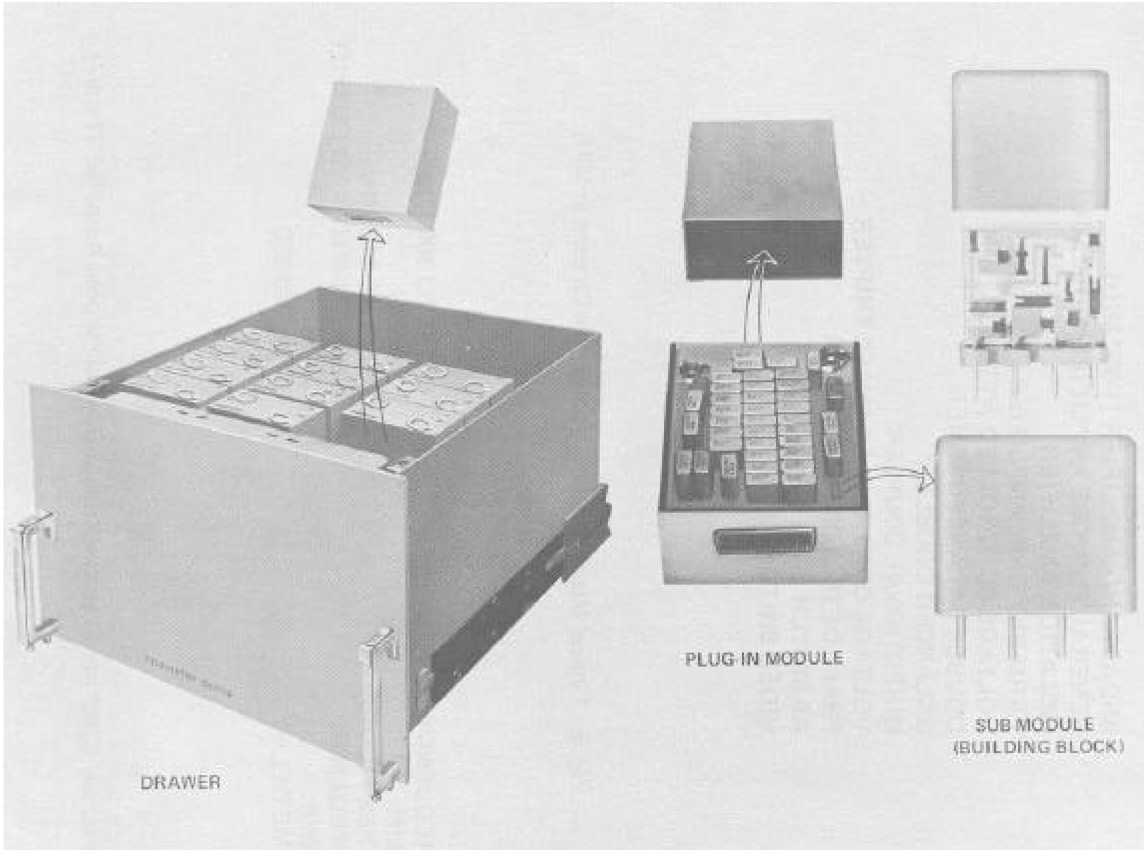

Fig. 8 Receiver Modular Concept

BROADBAND AMPLIFIER (1-300 MHz)
GENERAL PURPOSE AMPLIFIER (1-100 MHz)
ISOLATION AMPLIFIER
VARIABLE GAIN AMPLIFIER
VOLTAGE-CONTROLLED ATTENUATION
DOUBLE BALANCED MIXER
BALANCED DOUBLER
DIRECTIONAL COUPLER
VOLTAGE-CONTROLLED PHASE SHIFTER
PHASE DETECTOR AND DRIVER
RF SWITCH
VIDEO SWITCH

Fig. 9 Typical Microelectronic Submodule Circuits in MFR

FREQUENCY COVERAGE:	1 MHz TO 300 MHz
GAIN:	+14.5 dB
NOISE FIGURE:	6.5 dB AT 110 MHz
IMPEDANCE:	50 OHM INPUT AND OUTPUT
VSWR:	1.4 TO 1
TIME DELAY:	1.7 NANOSEC

Fig. 10 Electrical Characteristics of General Purpose Amplifier (Type 1)