THE LEASAT COMMUNICATIONS SATELLITE

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ABSTRACT

Beginning in 1982 communication services will be provided to the U.S. Navy by a series of UHF communications satellites known as LEASAT. The communications payload will be carried on a new spacecraft bus developed as an optimum bus for space shuttle launches; the program is the first of its kind to take advantage of the full 15 foot shuttle payload bay diameter. Several new spacecraft design concepts are employed in this optimized bus.

The communications payload incorporates transponders in the UHF and SHF regimes. Four distinct types of transponders are employed: wideband, narrowband, relay, and fleet broadcast. The functional characteristics of each type is described in detail. The frequency plan leads to a significant potential for passive generation of intermodulation products, and intermodulation considerations are an integral part of the spacecraft design.

INTRODUCTION

The LEASAT Communication System will provide wordwide communication services for the United States Navy beginning in 1982. The Navy awarded the LEASAT contract in 1978 to the Hughes Communication Services, Inc. (HCSI), which is in turn procuring the satellite system from the Hughes Aircraft Company. The LEASAT system will be the follow-on for the existing GAPFILLER (MARISAT) and FLTSATCOM systems, which have projected end of life dates in the early 1980's.

System elements provided by HCSI include four geosynchronous orbit satellites and associated telemetry, tracking and command facilities. The four satellites will be located nominally over the continental United States and the Atlantic, Pacific, and Indian Oceans, as shown in Figure 1. Four fixed ground stations, or primary satellite control sites (SCS), will be located at Hawaii, Norfolk, Guam, and Stockton, California. Centralized satellite control facilities will be located at the HCSI operational control center in Los Angeles. A direct interface exists between the HCSI control center and the Navy Telecommunications Command Operations Center in Washington D. C. , and between the control center and the SCS.

SPACECRAFT CONFIGURATION

The LEASAT bus is an outgrowth of the Hughes Syncom IV program, and is optimized specifically for Space Transportation System (STS) launch. This optimization has resulted in an arrangement distinctly different from transitional designs (expendable launch vehicle compatible). The most notable feature of the STS-optimized LEASAT bus is the relatively short axial length when the bus is installed in the STS. This is made possible by the 14 foot diameter spacecraft body which permits installation of the perigee propulsion stage centrally within the spacecraft enclosure, as shown in Figure 2. This compact axial length results in a payload length fraction of the STS capability closely matched to the mass fraction of the STS capability. Since STS launch fees are based on the greater of these fractions, the matched LEASAT system efficiently uses the STS resources and benefits from the resulting launch cost economies.

This full-diameter LEASAT layout also yields very ample payload installation areas, mass properties distributions yielding passively spin stable inertia ratios, ample thermal enclosure surface area (permitting passive thermal balance while accommodating large payload dissipations), and sufficient enclosure surface area for a simple body-mounted solar array.

As seen in Figure 2, the spacecraft is built around the 8000 pound solid perigee motor centrally located within the spacecraft. The 4000 pound bipropellant fuel tanks are mounted symmetrically around this motor, and are attached to the solid motor support structure. Loads from these elements are transferred to a graphite composite tubular truss structure to pickup points at the spacecraft periphery where they are carried through a cradle to the STS attachment points.

An annular shelf is provided at the outside diameter of the spun truss structure for mounting bus subsystem hardware, including batteries, power regulation electronics, attitude control units, spun telemetry and command (T&C) units, and driver units for pyrotechnic and propulsion valve operation. A solar cell array installed on a composite sandwich substrate forms the outer spacecraft enclosure.

Two 100 pound liquid bipropellant axial thrusters are located at the aft end of the spacecraft. These thrusters provide the apogee impulse which circularizes the orbit at synchronous altitude, and also serve to augment the perigee motor burn. A total of six

5 pound thrusters are also used about the spacecraft. These hydrazine thrusters provide both axial and lateral thrust for stationkeeping throughout the life of the mission. The lateral thrusters, when fired in opposing pairs, also provide spinup and spindown control.

The weight and power summaries for the spacecraft are given in Tables I to III. Table I highlights the propulsion requirements for taking the spacecraft from the STS parking orbit to synchronous orbit, and shows how the 2700 pound spacecraft weight grows to over 15,000 pounds in the STS. The allocation of the 2700 pound dry weight to the various space craft subsystems is given in Table II. The overall spacecraft power budget is summarized in Table III. The power subsystem generates over 1 kW of dc power at the end of the spacecraft lifetime, over 75 percent of which is devoted to the communications subsystem.

All communications equipment is carried on a shelf forward of the truss spaceframe. During launch, the shelf is structurally locked to the truss. On-orbit following lock release, the shelf is despun and earth pointed by means of the bearing and power transfer assembly (BAPTA) and despin control subsystem. Power and some spacecraft T&C signals are carried across the BAPTA on slip rings. All RF connections from the shelf to the various antennas are carried via waveguide or coaxial cable.

Both the large 14 foot UHF helices and the 7 foot mast for the omnidirectional T&C antennas are stowed during launch to minimize the axial length occupied in the STS. To provide T&C capability during the transfer orbit, the omni antenna is deployed immediately after the spacecraft is ejected from the STS. After the spacecraft is on-station and the communications platform despun, the UHF antennas will be deployed using a passive spring damper system. The deployed antenna configuration is shown in Figure 3. The helices are deployed far above and forward of the spacecraft body to minimize potential for passive intermodulation (IM) generation on the structure.

COMMUNICATIONS SUBSYSTEM OVERVIEW

Users of the LEASAT system will consist of designated mobile (air, surface, and subsurface) units and fixed stations. These users are largely DOD, including users from the Navy, Army, Air Force, and Marine Corps. Readers who are interested in the various ground segment terminal characteristics should refer to Reference 1.

The communication subsystem consists of five equipment groups: the fleet broadcast, the 500 kHz channel (wide band), the 25 kHz channel (relay), the 5 kHz channel (narrow band), and the common channel group. A functional diagram of the communication subsystem is shown in Figure 4. A summary of the operating characteristics and quantities of the various types of channels in the LEASAT communications subsystem is shown in Table IV.

TABLE I. SPACECRAFT STAGED WEIGHT SUMMARY

Stage	Weight, lbs
Spacecraft in STS	15,170
Solid motor plus ejectable case	8,077
Liquid motor bipropellant fuel	4,030
Hydrazine fuel used in ascent	215
Spacecraft on-station	2,848
Stationkeeping fuel	137
Spacecraft dry weight	2,711

TABLE II. SPACECRAFT SUBSYSTEM WEIGHT SUMMARY

Subsystem	Weight , lbs
Communications	440
T&C	162
Attitude control	49
Reaction control (dry)	36
Liquid axial motor (dry)	282
Power and harness	651
Thermal control	141
Structure	835
Dry hardware	2596
Minimum margin	115
Allowable spacecraft dry weight	2711

TABLE III. POWER SUMMARY, WATTS

Subsystem	Weight, lbs
Communications	763
T&C	63
Attitude control	18
Thermal control	25/115*
Power and distribution	101
Margin	70
Total	1040/1130*

* Eclipse season heaters.

TABLE IV. LEASAT CHANNEL CHARACTERISTICS

Channel Type	No.	Bandwidth (kHz)	EIRP * (dBw)	G/T* (dB/K)
Relay	6	25	26	-18
Wideband	1	500	28	-18
Narrowband	5	5	16.5	-18
Fleet broadcast	1	Onboard processing	26	-20

* These are specified minimum values over coverage areas

500 kHz WIDEBAND CHANNEL

The wideband channel subassembly consists of four main units: the preamplifier, the receiver, the transmitter, and the output multiplexer. The preamplifier assembly is common to all the channels being received at UHF, which include the narrowband and relay channels in addition to the wideband channel. Uplink UHF signals are received through a separate receiving helical antenna, filtered in a bandpass filter to reduce transmitter leakage signals that couple from the transmitting antenna, and amplified in one of two redundant low noise UHF preamplifters. The redundant outputs of the preamplifters are cross-strapped through a hybrid network and split to separate receivers for the various types of channel groups.

The wideband receiver is shown in Figure 5. The signal from the preamplifter is downconverted to a fixed IF at a center frequency of 25 MHz. The downconversion local oscillator (LO) signal is generated in a reference generator which may be tuned to one of four frequencies by command to accommodate the four frequency plans, W, X, Y, and Z. Functionally, the same design is used to accomplish the selectable frequency plans and is shown in Figure 6.

The channel crystal filter establishes the channel passband characteristics with a 1 dB bandwidth greater than 480 kHz and a 60 dB bandwidth less than 2 MHz. The filter output signal is fed to a limiter to normalize the signal level for receiver input signal levels over a 46 dB dynamic range. The gain of the limiter is set to provide limiting on front end noise within the crystal filter bandwidth.

The limiter output signal is upconverted to the transmit frequency with a second LO signal from the reference generator. Both downconverter and upconverter LOs are stepped in frequency by the same amount to maintain a constant translation frequency when tuning to one of the WXYZ frequency plans.

The receiver unit is completely redundant, with cross-strapping at the input and output of the signal path. The output from the receiver unit drives redundant UHF transistor power amplifiers. An amplifier consists of a two stage low level module, a single stage hybrid coupled driver, and a paralleled pair of hybrid coupled output stages. The redundant amplifier outputs are selected by a coaxial relay switch. The power level at the switch output is greater than 17.2 dBw.

The output from the switch is coupled to the UHF transmitting helical antenna through the UHF multiplexer. The multiplexer consists of a series of high Q bandpass filters, each tuned to a particular channel frequency and interconnected to a common coaxial transmission line. The spacing of the filters along the transmission line is designed to achieve isolation between the filters. A six section filter with 3.6 MHz bandwidth is provided for the wideband channel. The filter has more than 100 dB rejection over the UHF receiver band to prevent transmitter noise and spurs at the receive frequency from degrading receiver sensitivity.

25 kHz RELAY CHANNEL

The layout and functioning of the 25 kHz channels are similar to that of the wideband channel. The preamplifier assembly is common to all channels being received at UHF, including the narrowband and wideband channels in addition to the relay channel. Cross strapped outputs of the redundant preamplifier are fed to the relay receiver for processing of the relay channels.

The relay receiver is shown in Figure 7. The six relay channels are downconverted as a group to an IF ranging from 15 to 28 MHz. The downconversion LO is generated in a reference generator that is locked to the system master oscillator in a manner similar to that previously described for the wideband channel. A nearly octave bandwidth IF amplifier follows the mixer in the downconverter to provide gain prior to a large loss incurred in splitting the channels.

The IF amplifier output in the downconverter is split in a six-way power divider and distributed to the individual relay channels. A crystal filter at the input of each IF channel establishes channel passband characteristics with a 1dB an width greater than 24 kHz and a 60 dB bandwidth less than 110 kHz. The crystal filters for the six channels are identical except for the center frequency.

In each of the channels, the filter output signal is fed to a limiter whose gain is set to provide limiting on front-end noise within the crystal filter bandwidth in the absence of an input signal in the channel. Each limiter output signal is individually upconverted to the transmit frequency with a second LO signal from the reference generator. The entire group of relay channels operates on the same frequency plan, but independently of the other groups of UHF channels.

The receiver unit is completely redundant, except for cross-strapping passive hybrid and power dividing networks. The redundant downconverters are cross-strapped at the input and output, allowing either downconverter to drive all 12 filter/limiter upconverter channels (six redundant pairs). The 19 filter/limiter upconverter channels are connected in two banks of six each, such that a given channel may be selected from either bank independent of the other channels. Each individual upconverter output is hybrid coupled with its corresponding redundant upconverter to provide cross-strapping at the receiver output. The two redundant LO reference generators also are cross-strapped so that either generator may supply the downconverter LO to all of the channels.

The receiver unit outputs drive redundant UHF transistor power amplifiers which are very similar to the wideband units. The power level at the switch output is greater than 15.2 dBw. The switch output in each channel is coupled to the UHF transmitting helical antenna through the UHF multiplexer. In the multiplexer, a three section filter with 0.7 MHz bandwidth is provided for each of the relay channels, 3 through 8. The filter has more than 100 dB rejection over the UHF receiver band to prevent transmitter noise and spurs at the receive frequency from degrading receiver sensitivity.

5 kHz NARROWBAND CHANNEL

The basic design of the narrowband channels is similar to that of the relay channel except that there is a common power amplifier for the five channels.

The narrowband receiver is shown in Figure 8. The five narrowband channels are downconverted as a group to an IF of 8 MHz. The downconversion LO is generated in a reference generator in manner similar to that previously described for the wideband and relay channels. The reference generator is phase locked to the 5 MHz reference signal from the system master oscillator to achieve high frequency accuracy. An IF amplifier follows the mixer in the downconverter to provide gain prior to a large loss incurred in splitting the channels.

The output from the IF amplifier in the downconverter is split in a five-way power divider and distributed to the individual narrowband channels. A 4 kHz crystal filter at the input of each IF channel establishes the channel passband characteristics with a 1 dB bandwidth greater than 4 kHz and a 60 dB bandwidth less than 20 kHz.

In each of the channels the filter output signal is fed to a limiter whose gain is set to provide limiting on front end noise within the crystal filter bandwidth in the absence of an input signal in the channel.

The LO signals from each channel are passed through a second crystal filter and recombined in an IF summer. The crystal filter prevents degradation of the noise floor of adjacent channels due to spectral spreading caused by the limiter. The combined group is then upconverted in the receiver unit to the transmit frequency with a second LO signal from the reference generator.

The receiver unit is completely redundant except for cross-strapping passive hybrid and power dividing networks. The redundant IF chains are cross-strapped at the input and output, allowing either downconverter to drive all ten filter/limiter channels (five redundant pairs).

The upconverted UHF output from the receiver unit drives a redundant UHF power amplifier. Due to the stringent intermodulation requirements, a pair of amplifiers is operated in parallel with reduced output power in each amplifier. The switch output level is greater than 5.1 dBw per channel.

The output from the switch is coupled to the UHF transmitting helical antenna through the UHF multiplexer. A three- section filter with 3.2 MHz bandwidth is provided for the narrowband transmitter. The filter has more than 74 dB rejection over the UHF receiver band to prevent transmitter noise and spurs at the receive frequency from degrading receiver sensitivity.

FLEET BROADCAST GROUP

The fleet broadcast group is shown in Figure 9. The signal is received on the earth coverage receive super high frequency horn antenna, and downconverted in the SHF receiver to the IF required by the fleet broadcast processor. After processing, the resulting signal is routed to the bypass electronics where it is filtered, limited, and upconverted to UHF for transmission through the channel one 35 watt transmitter. In the bypass mode, the processor is bypassed and the output of the SHF receiver is routed directly to the bypass electonics. The SHF beacon transmitter is included to transmit processor status information through the earth coverage transmit SHF horn antenna.

PASSIVE INTERMODULATION PRODUCTS

Historically, one of the most severe problems encountered in UHF communication satellites has been with passive intermodulation products. Weak nonlinearities in the common transmit path will generate signals in the spacecraft receive band.

The severity of the IM problem is determined by both the system definition (number of carriers and frequency plan) and the spacecraft design. LEASAT has 13 downlink channels, and the resulting order of the lowest IM which will fall in a receive channel is fifth order as shown in Figure 10.

Spacecraft design to minimize IMs involves eliminating poor metal-to-metal contacts and ferromagnetic materials in the common transmit path, minimizing UHF currents flowing on the external spacecraft surface, and maximizing the transmit to receive antenna isolation. The separate receive and transmit helices have been located as high above and forward of the spacecraft structure and as far apart from each other as other system design constraints would allow.

REFERENCE

1. Braverman, D. J. and Waylan, C. J., “LEASAT Communication Services,” Proceedings ICC ’79, June 1979.

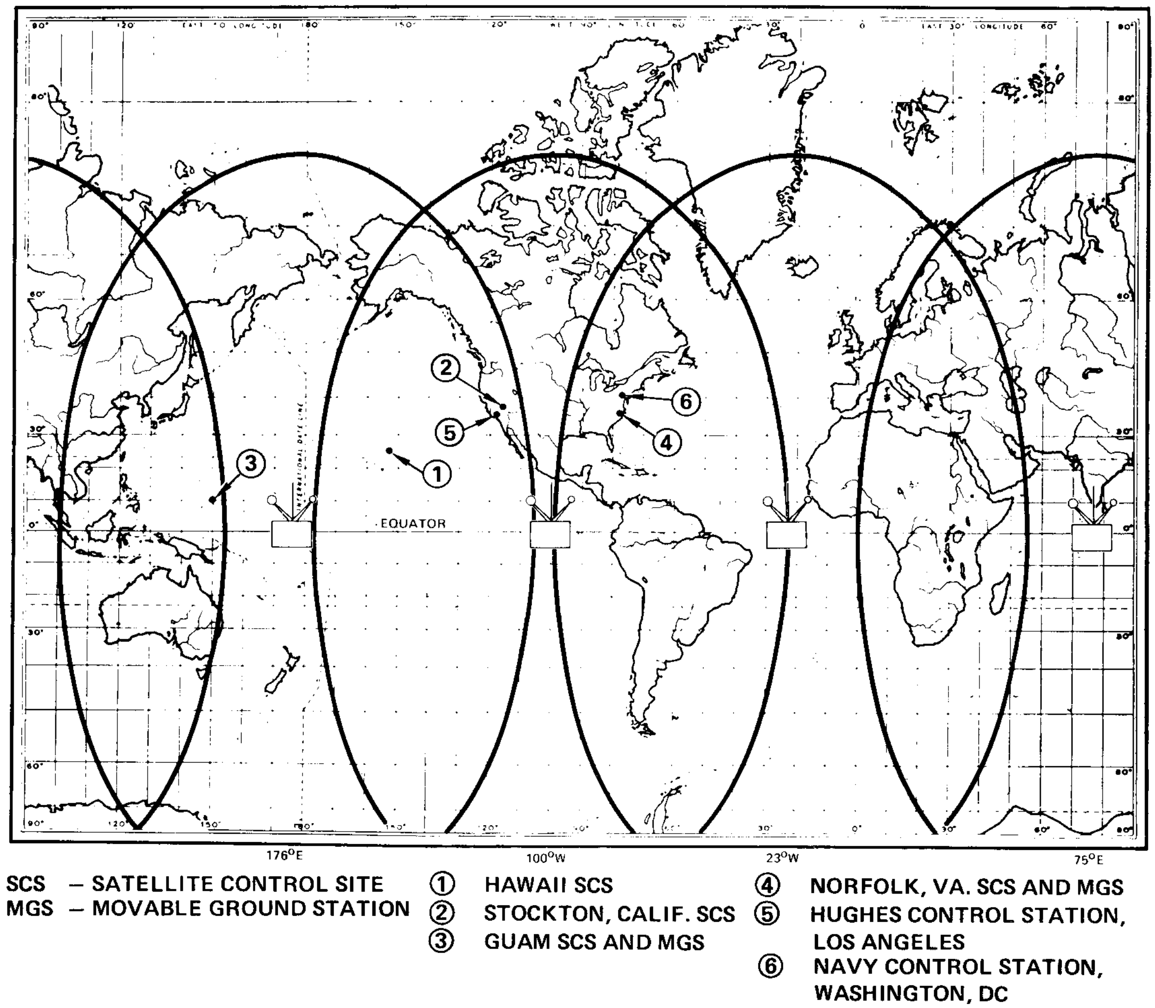

Figure 1. Worldwide LEASAT System

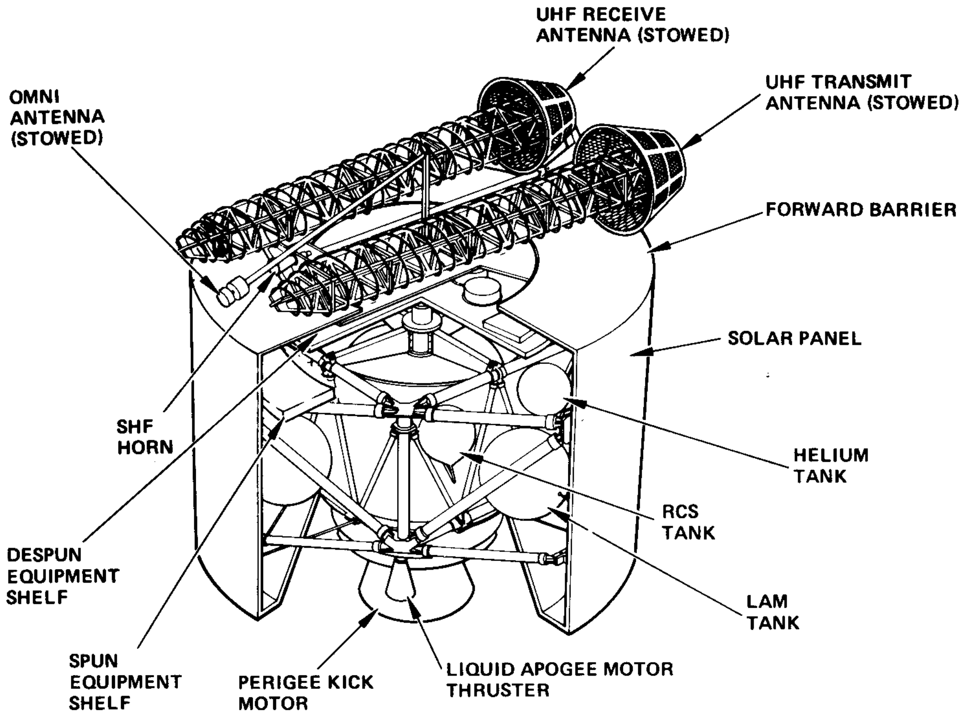

Figure 2. LEASAT Launch Configuration

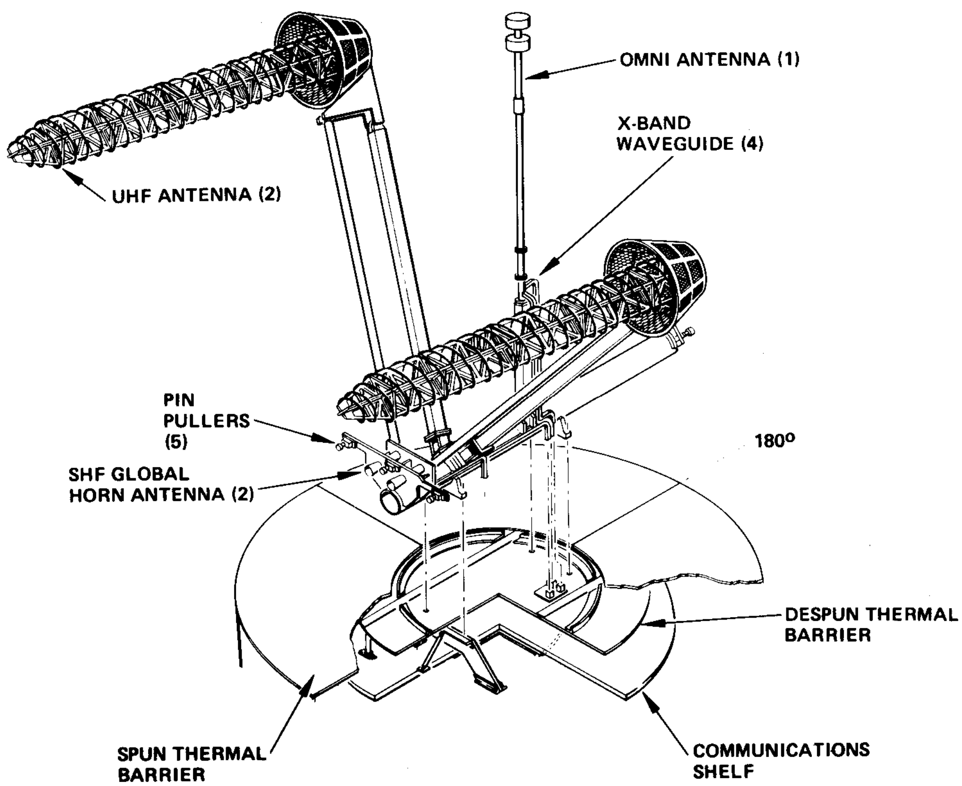

Figure. 3. LEASAT Deployed Antenna Configuration

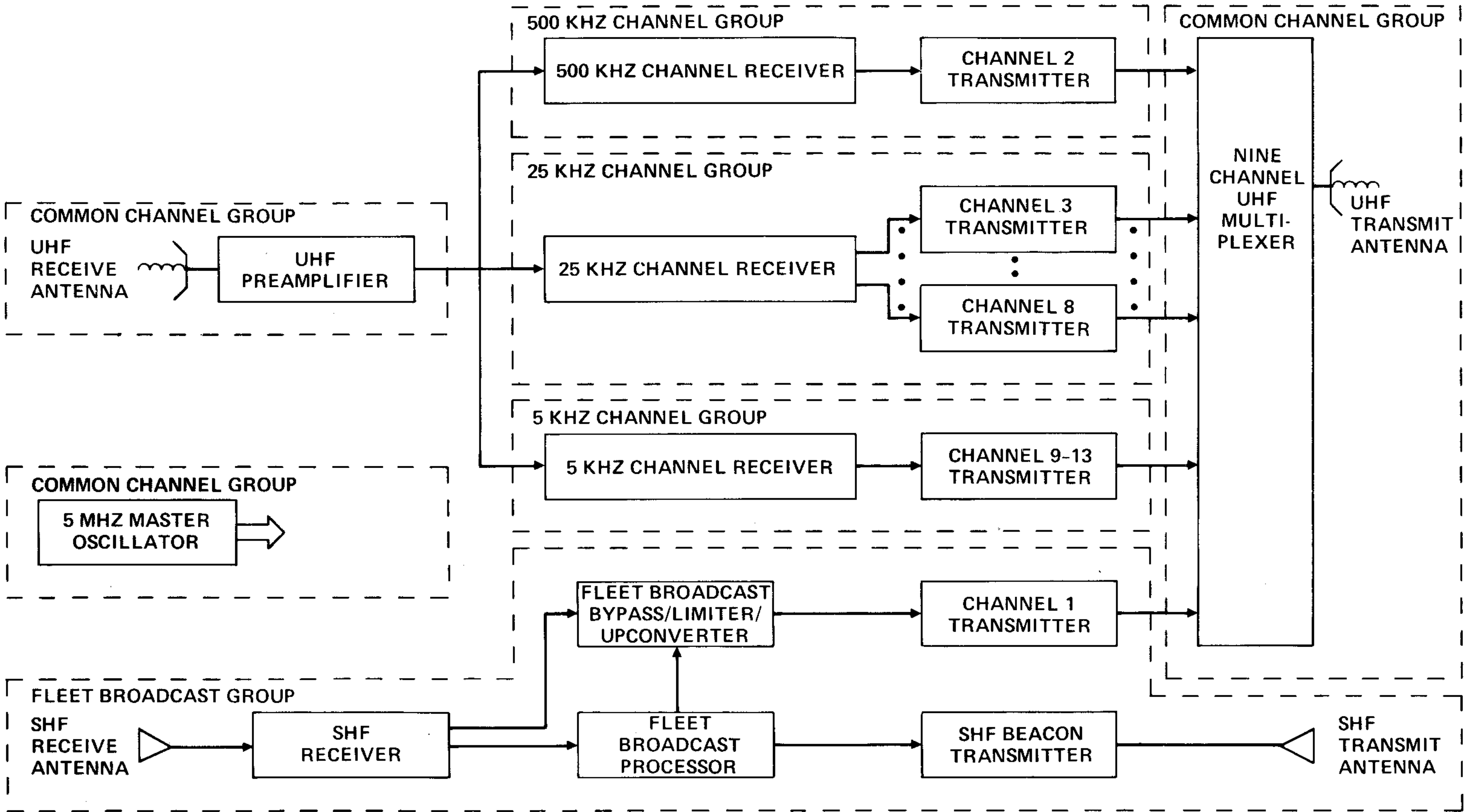

Figure 4. Communication Subsystem Functional Groups

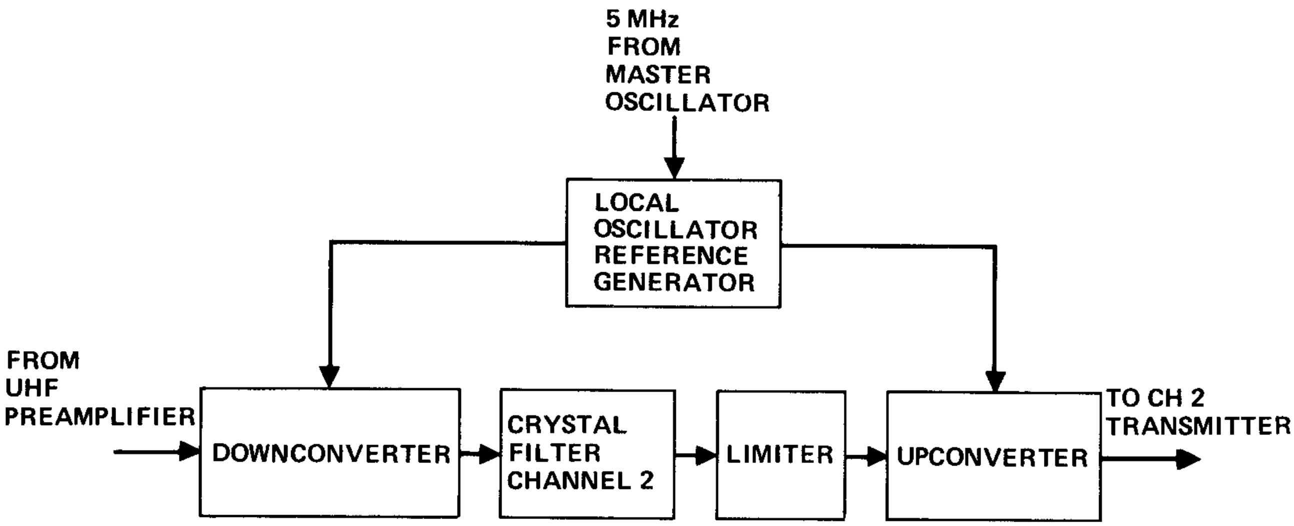

Figure 5. 500 kHz Receiver Block Diagram

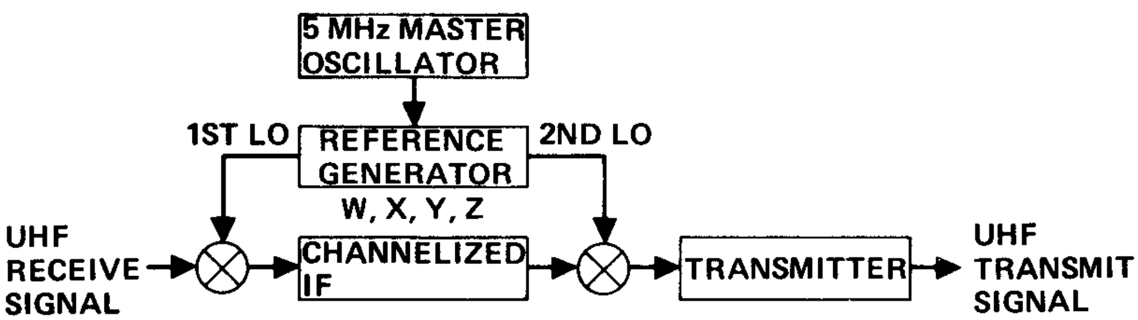

Figure 6. UHF Channel Group Typical Signal Flow

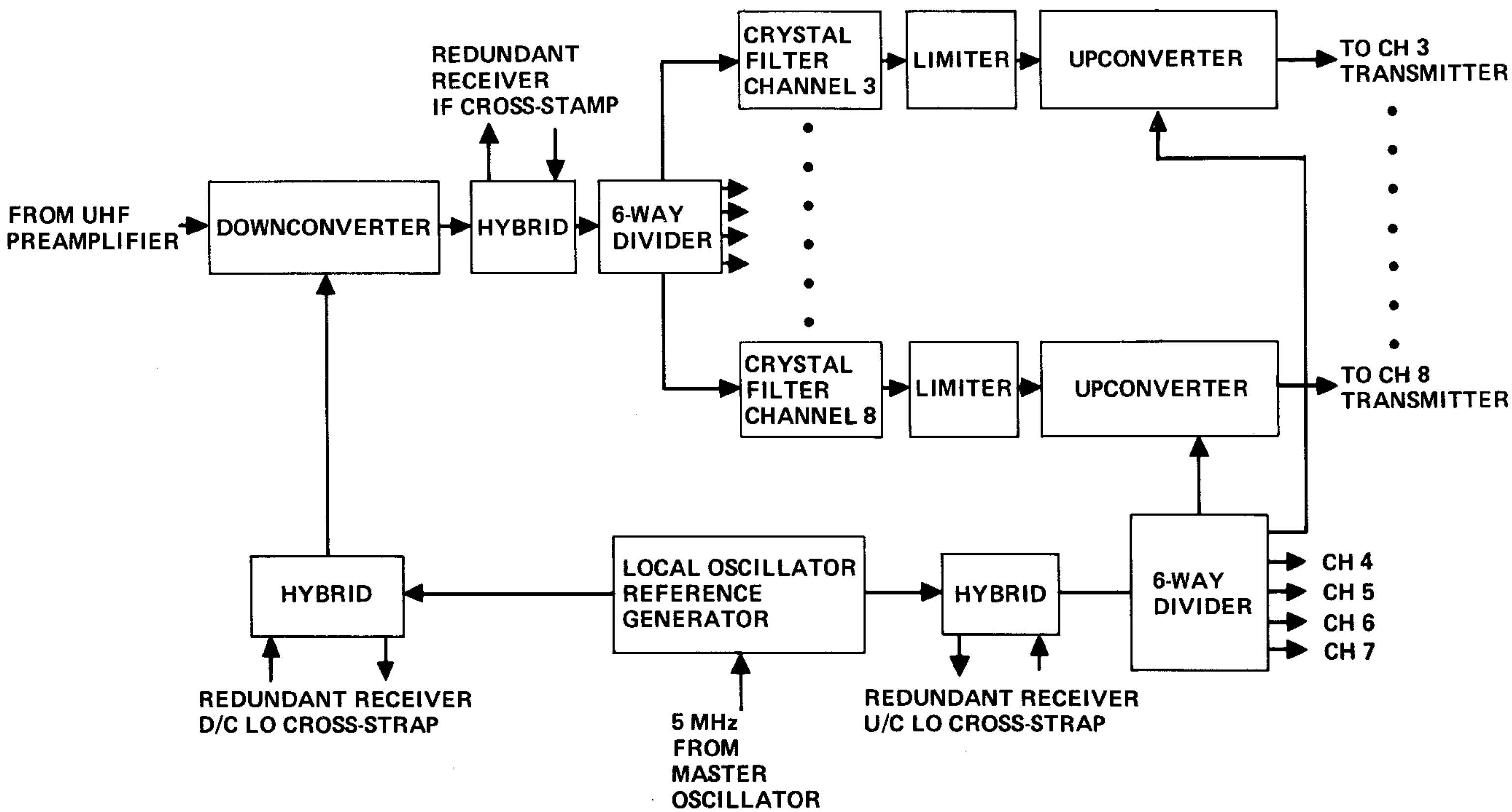

Figure 7. 25 kHz Channel Receiver

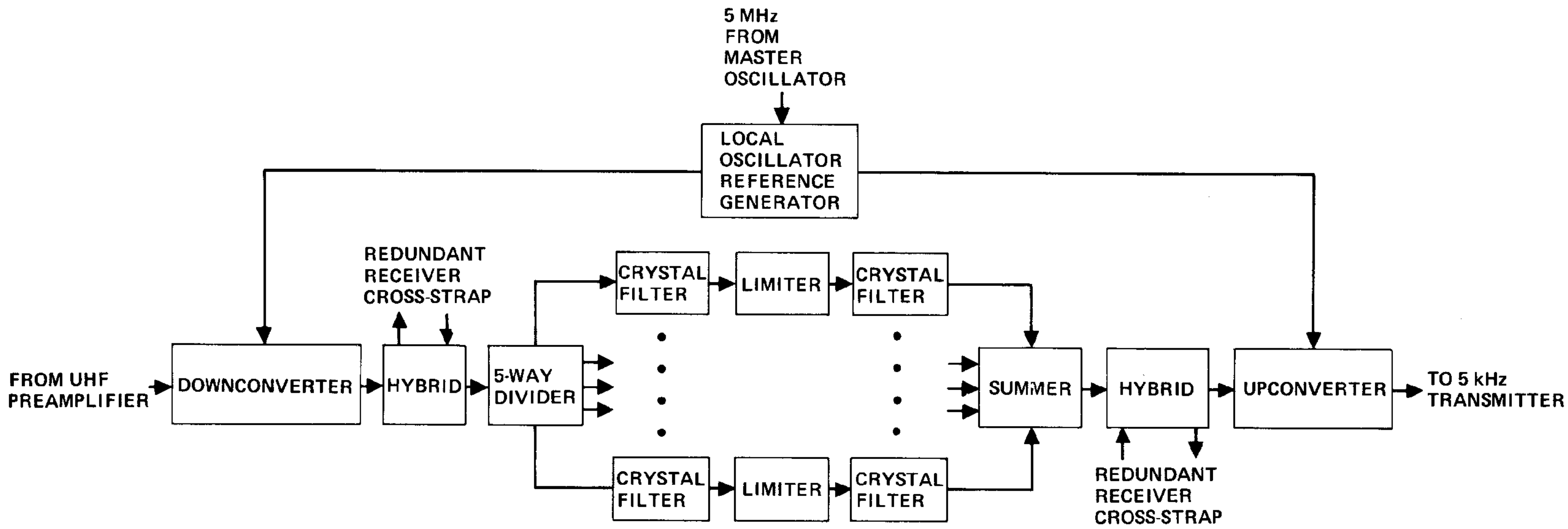

Figure 8. 5 kHz Receiver Block Diagram

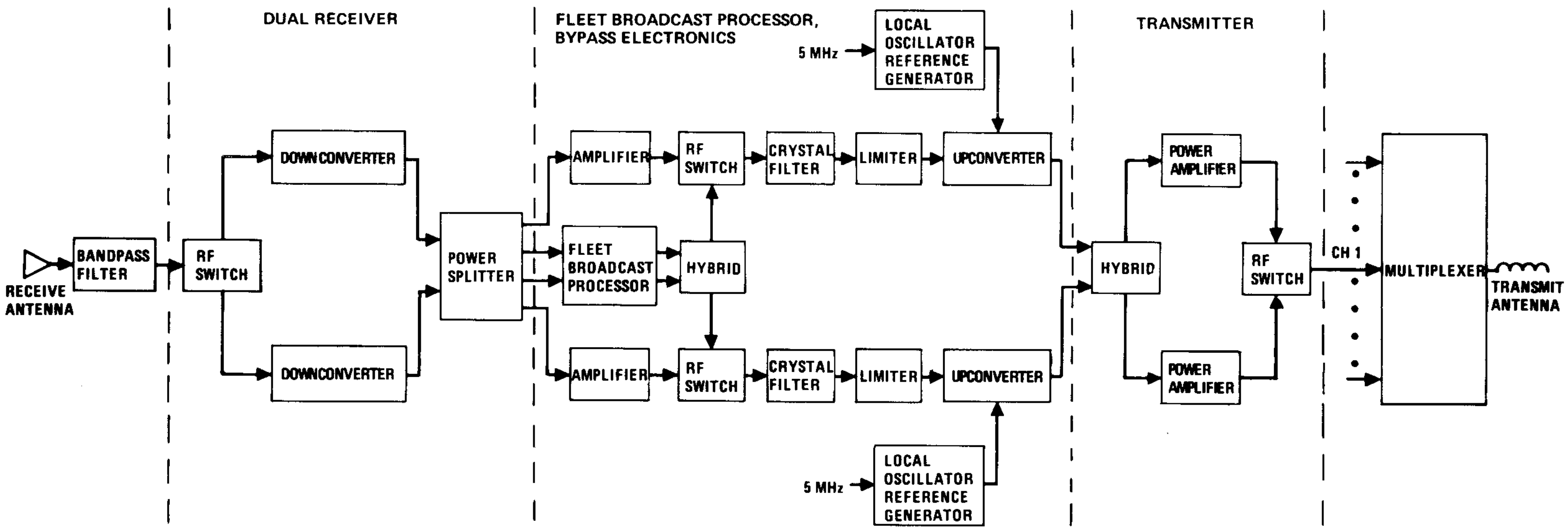

Figure 9. Fleet Broadcast Block Diagram

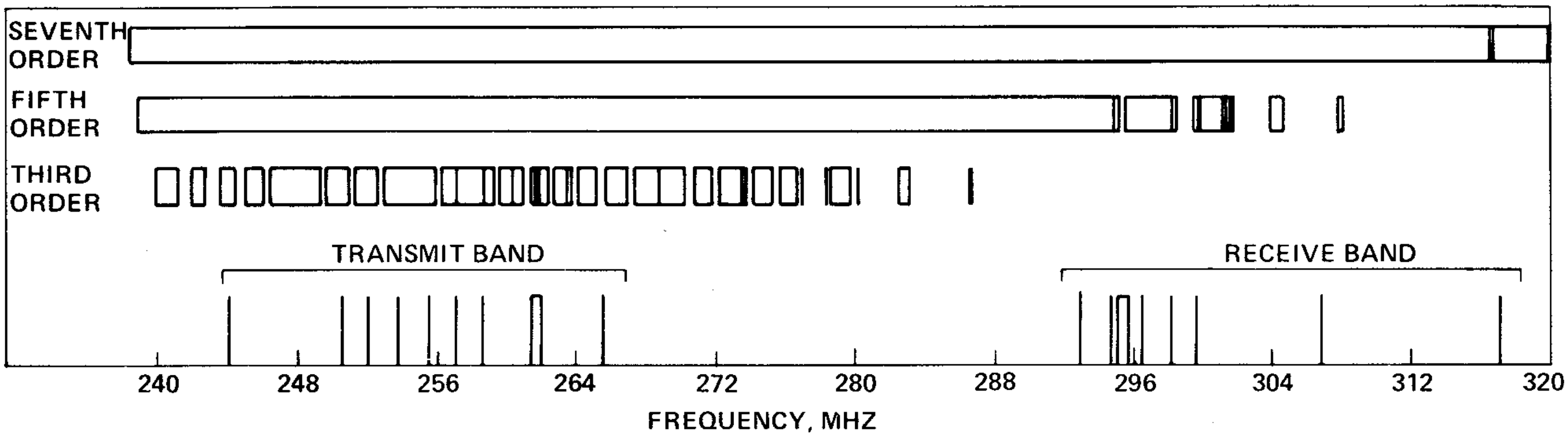

Figure 10. LEASAT Frequency Plan Passive IM Products