A WIDEBAND UHF TRANSMITTER FOR SPACE APPLICATIONS

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Summary This paper describes the design and performance of a frequency-modulated 10watt S-band transmitter. Analogue frequency response is in excess of 7 Mc and digital signals at rates up to 10 megabits per second are transmitted satisfactorily. This extra wideband transmitter, ruggedized for space applications, utilizes a solid state exciter for signal generation, a traveling wave tube amplifier for power amplification, and a solid state traveling wave tube power supply that will withstand critical atmospheric pressures. A detailed analysis of rf bandwidth requirements and the state of the semiconductor art at the time of transmitter design resulted in the exciter taking the form of a 70 Mc voltage controlled oscillator whose output is amplified and converted to the S-band output frequency by means of broadband varactor harmonic generators. Production versions of this transmitter have consistently demonstrated satisfactory orbital operation. Laboratory data has indicated a minimum rf power output of 10 watts at base-plate temperatures ranging from -35° to +75° Centigrade. Baseband response is from 10 cycles to more than 7 Mc at ±6 Mc frequency deviation.

Introduction This paper describes the design and performance of a wideband UHF transmitter. The transmitter (Type VIII Transmitter) is one of a series of UHF telemetry and data transmitters designed, developed, and manufactured by Lockheed Missiles and Space Company. The Type VIII Transmitter is a versatile unit used for applications requiring extra wide bandwidth capabilities and can be frequency modulated by analog baseband information up to 7 Mc or by digital signals with information rates up to ten million bits per second.

The equipment provides an output power of 10 watts in the S-band frequency range. The operating potentials for its TWT (traveling wave tube) power amplifier are provided by a self-contained DC-DC converter.

This unit has been fully qualified for space applications and has proven its reliability by repeated successful orbital operations.

Design Considerations In developing the concept and functional design of the Type VIII Transmitter, careful consideration was given to the various facets comprising a good transmitter design. This included investigations on life, reliability, design margins, and a detailed analysis of the bandwidth requirements. The results of this study were combined with a survey of the state of the semiconductor art to arrive at the basic scheme for the transmitter design. As a result, it was decided that the transmitter would take the form of solid-state exciter driving a TWT power amplifier. The DC power for the TWT would be provided by a solid state DC-DC converter.

As is shown in detail under Appendix A, Spectral Analysis and Bandwidth Requirements, the required rf bandwidth at S-band is approximately 30 Mc, while the bandwidth required at one-fourth of the output frequency is only 20 Mc. At lower rf frequencies where the modulation index is much less than one, the required rf bandwidth does not decrease appreciably from the 20 Mc figure. This is a result of the fact that the circuits must pass at least the first and usually the second pair of modulation sidebands to maintain good fidelity of the frequency modulated signal. As a compromise between percentage bandwidth required and basic oscillator stability, an oscillator center frequency of approximately 70 Mc (1/ 32 of the output frequency) was chosen. Within limits in these frequency ranges, the lower the center frequency of the voltage controlled oscillator (VCO), the greater the inherent stability, because higher capacitance to inductance ratios can be used to make the circuit less sensitive to variations in semiconductor capacitance. With the choice of 70 Mc as the center frequency of the VCO, the required stability of ±. 03% for this system could be achieved while requiring only a 25% to 30% bandwidth of the power amplifiers and input stages of the frequency multipliers.

The operation of the Type VIII Transmitter is best understood by referring to figure 1. The heart of the transmitter is the rf oscillator operating at 70 Mc. This unit is an oscillator of the Hartley configuration which is frequency modulated by a voltage variable capacitance (varactor diode) in the resonant tank circuit. The oscillator is operated at a relatively low power level to enhance frequency stability. Temperature compensation is used in the resonant tank circuit since the high modulation rates precluded the use of a quartz crystal for frequency stabilization. Modulation is applied to the varactor diode via the modulation amplifier and premodulation filter. The premodulation filter is a linear phase three section design with a 3 db cutoff frequency of approximately 7.5 Mc.

The rf signal from the oscillator-buffer combination is amplified to a level slightly in excess of 1 watt by the rf power amplifiers. These units are non-tuned broadband amplifiers utilizing wideband toroidal transformers for the inter-stage coupling networks, and have a 3 db bandwidth in excess of 20 Mc. Circuits designed using this type of interstage coupling network have demonstrated bandwidths restricted only by the transistor parameters and decoupling resonances. Once designed, these circuits have excellent reproducibility characteristics and tuning requirements are essentially nil.

Multiplication of the power amplifier output signal to the UHF output frequency is accomplished by two varactor multiplier sections. The first of these is synthesized in lumped constant circuitry and consists of three doubler circuits operated in cascade. As the percentage bandwidth required in the two lower frequency doublers is quite high, symmetrical multiplier circuits are used in this application. This design, employing two varactors in a 11PUSh7PUsh11 configuration, provides inherent rejection of odd harmonics, thus relaxing filtering requirements and allowing the use of wideband circuitry.

The second multiplier section is a quadruplet operating at an input frequency of approximately 560 Mc. In this design, a “pill” varactor diode is imbedded in a distributed element circuit. A coaxial filter structure resonant at the input frequency provides frequency selectivity at the input as well as providing return paths for the intermediate frequency components generated in the x4 process. The output signal is selected by a multisection S-band cavity which also provides return paths for the idler currents. Matching of the varactor to input and output circuits is provided by stripline circuitry.

The performance characteristics of the TWT amplifier require that the excitation power be maintained within relatively narrow limits to ensure saturated operation of the TWT. This was accomplished by incorporating an automatic gain control (AGC) loop around the lumped circuit section of the exciter. The AGC circuit uses a detector diode to sample the rf level at the input to the x4 multiplier section. The x4 multiplier was found to be sufficiently insensitive to its environment and was therefore excluded from the control loop. This enabled the design to be simplified by utilizing the rf power at the input to the last x4 multiplier instead of at the lower exciter output power. Any rf power level deviations are detected by the detector diode and the resultant error signal is amplified and applied to the power amplifier section as a correction signal. This correction signal changes the gain of the rf amplifier so that the output power of the exciter is maintained at a relatively constant level under various environmental conditions.

The exciter output is amplified to the 10 watt level by a ruggedized TWT. It then passes to the antenna through a ferrite isolator, provided for protection of the TWT, and a lowpass filter which suppresses harmonic outputs of the tube.

The relatively high operating voltages required by the TWT (approximately 1500 volts) were provided by an all solid-state power supply. This design, employing a magamp boost regulator developed at LMSC, furnishes the necessary output potentials regulated to within 1%. A 200 second high-voltage delay was incorporated to permit TWT heater warm-up.

High voltage corona was a matter of particular concern in the power supply design since expected ambient pressures ranged from atmospheric pressure at sea level to 10^{-6} mm of mercury. Complete pressure sealing of the equipment was undesirable from a logistics interchangeability viewpoint and because of the difficulty of attaining a sufficiently low leak rate for long-term missions. As a result, all the high voltage circuits were packaged compactly into one area of the equipment and this module completely encapsulated. Thus, the convenience of encapsulation was provided without incurring the excessive weight of a totally encapsulated unit.

Performance Results The performance of the Type VIII Transmitter has been evaluated by careful laboratory testing and by observation of operational characteristics during orbital missions. The transmitter has consistently demonstrated its ability to maintain a pow r output of at least 10 watts and a frequency stability of better than 6 parts in 10^4 over a temperature range of -35° to +75° Centigrade. Production transmitters are capable of surviving satellite launch environment and will operate at any altitude. The transmitter frequency response is shown in figure 2(a); and the oscillograph of figure 2(b) shows the transmitter response to a 10 megabit pseudo-random digital sequence. A 525 line television signal as processed by this equipment is presented in 2(c). Finally, a photograph of the unit is shown in figure 3.

Appendix - Spectral Analysis and Bandwidth Requirements The transmitter design was guided by an analysis of the FM spectra resulting from the anticipated modulation formats. The two basic formats shown in figure Al were selected as representative of the expected types of modulation.

The 1010 format of the 10 megabit PCM signal was considered the most difficult digital sequence to process, while the 500 ns. non-recurrent pulse was included as a possible modulation type in connection with the primary application of the transmitter.

a. 1010 PCM Format The video spectrum of the 1010 format (5 Mc square wave) is obtained by Fourier Analysis and consists of odd harmonics of the fundamental square wave frequency. The digital information is processed through a linear-phase premodulation filter which introduces 20 db of attenuation at 25 Mc; thus only the 5 Mc and the 15 Mc components of the square wave are considered.

An FM spectral distribution equation for 2 tone modulation has been developed by Corrington.

$$V(t) = A_o \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} J_m(\beta_1) J_n(\beta_2) \sin(\omega + 2\pi m\mu_1 + 2\pi n\mu_3)t$$

In this expression β_1 is the modulation index associated with tone 1 and β_2 the index associated with tone 2. Similarly, μ_1 and μ_2, are the frequencies of tones 1 and 2. When the first 2 components of the 5 Arc square wave are introduced into eqn (1) and all components less than 1% of the unmodulated carrier are neglected, the FM spectra of figure A2 are produced.

b. 500 ns Nonrecurrent Pulse   This waveform can be expressed mathematically as

$$f(t) = V_o \quad \text{for} \quad -\frac{\tau}{2} < t < \frac{\tau}{2} \qquad (2)$$

$$f(t) = 0 \qquad \text{elsewhere.}$$

Introducing this time function into the FM equation gives

$$V(t) = A_o \cos[\omega_c t + \Phi(t)] \qquad (3)$$

$$\text{where} \quad \Phi(t) = D_o \int f(t)\, dt$$

The frequency domain relationship is obtained by application of the Fourier Integral.

$$V(\omega) = \int_o^\infty A_o \cos[\omega_c t + \Phi(t)] \cos \omega t\, dt \qquad (4)$$

and since $\Phi(t) = D_o V_o t$ for $|t| < \frac{\tau}{2}$

$= 0$ elsewhere

$$V(\omega) = 2A_o \int_o^{\tau/2} [\cos(\omega_c + \omega + D_o V_o)t + \cos(\omega_c - \omega + D_o V_o)t]\, dt$$

$$+ 2A_o \int_{\tau/2}^{\infty} [\cos(\omega_c + \omega)t + \cos(\omega_c - \omega)t]\, dt \qquad (5)$$

Performing the indicated integration results in the spectral distribution of eqn (6). The spectral plot of figure A3 indicates that a bandwidth of 20 Mc at the transmitter output should be adequate for transmission of the pulse.

$$V(\omega) = 2A_o \left[\frac{\sin(\omega_c - \omega + D_o V_o)\frac{\tau}{2}}{\omega_c - \omega + D_o V_o} - \frac{\sin(\omega_c - \omega)\frac{\tau}{2}}{\omega_c - \omega} + \frac{1}{\omega_c - \omega} \right] \qquad (6)$$

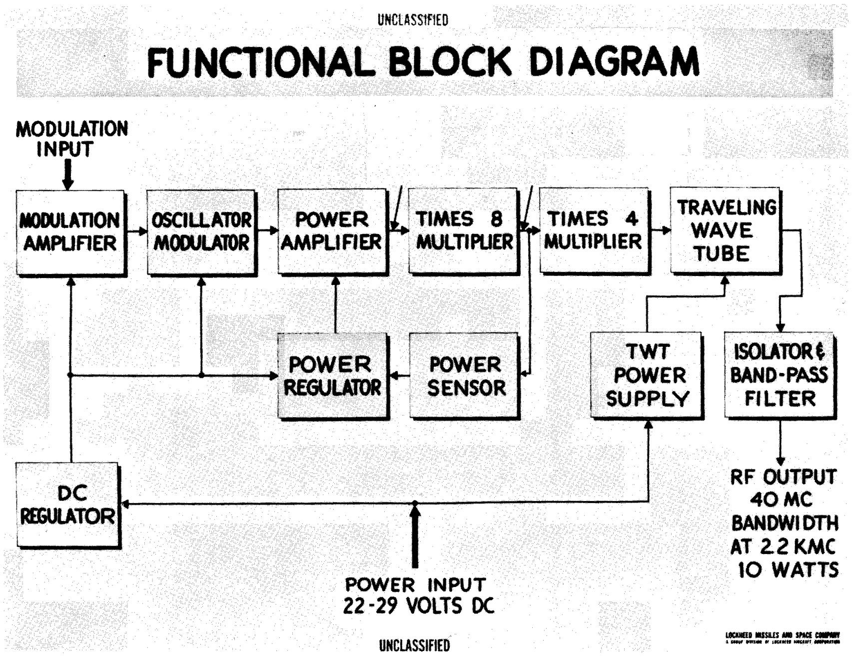

Figure 1. Transmitter Block Diagram

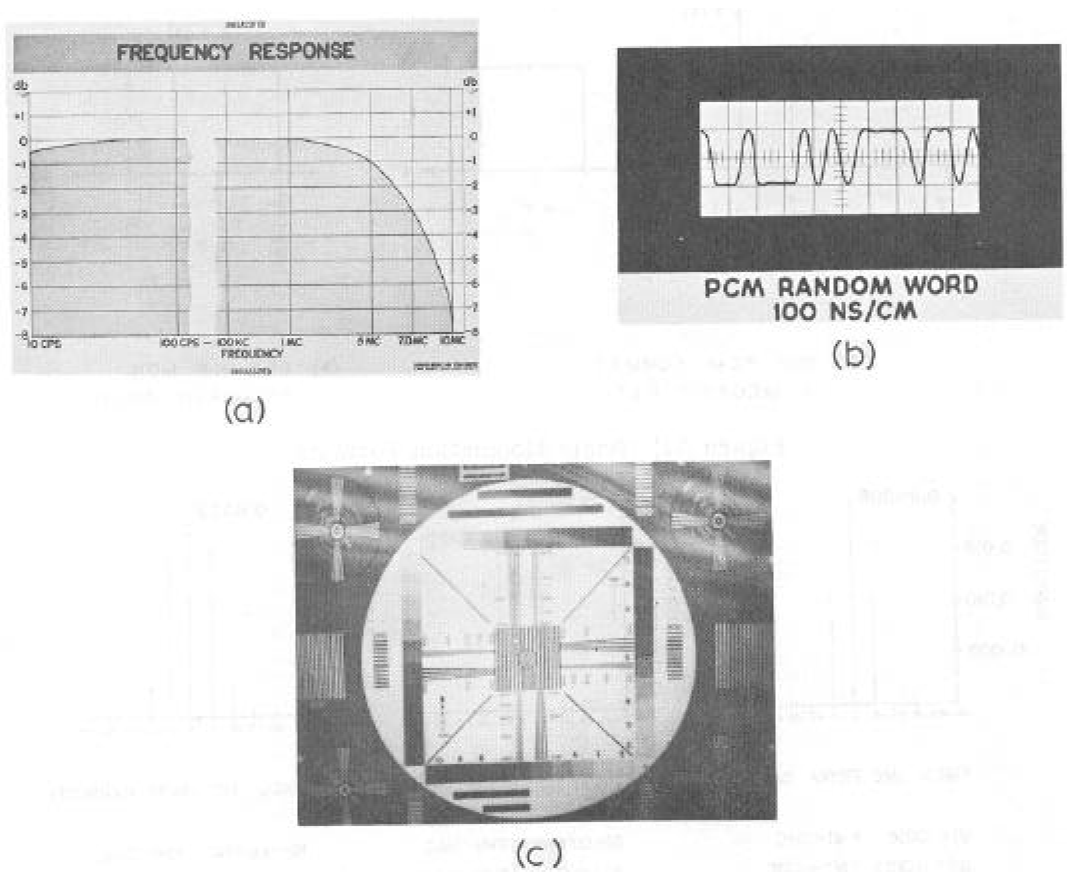

Figure 2. Transmitter Performance (a) Frequency Response, (b) Megabit Digital Signal, (c) 525 Line Television Signal

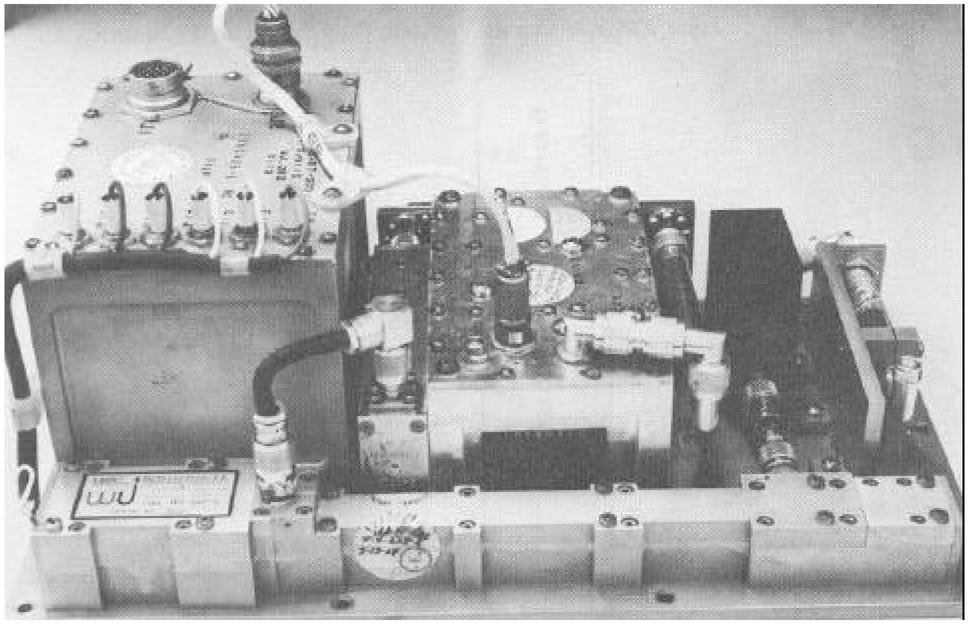

Figure 3. UHF Transmitter Type VIII

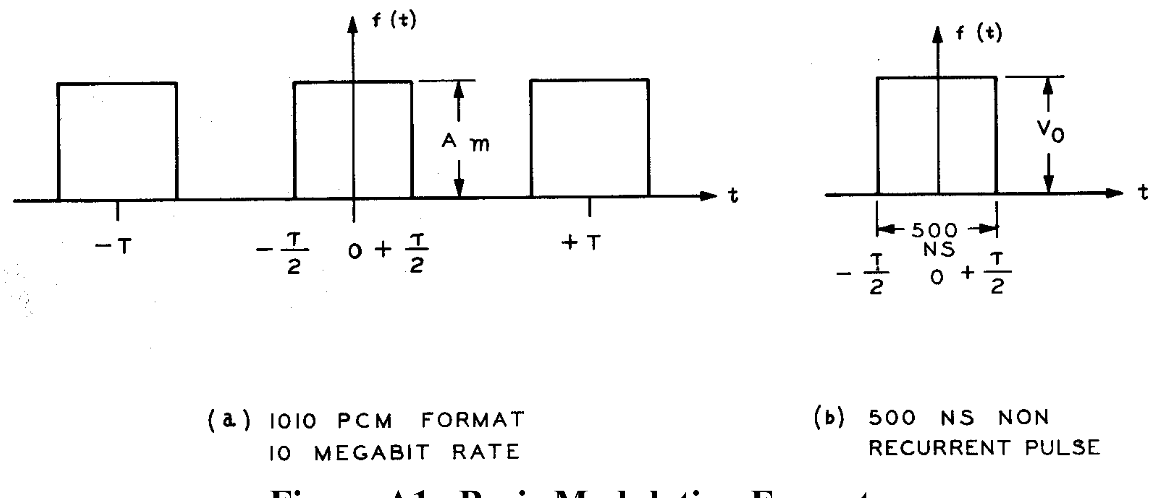

Figure A1. Basic Modulation Formats

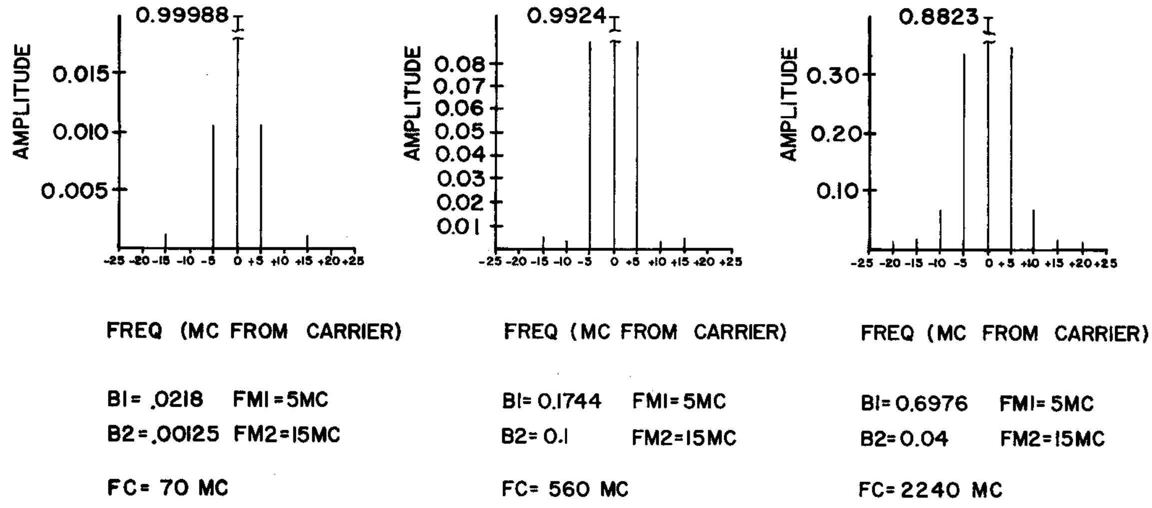

Figure A2. Two-Tone FM Spectra at Various Stages of the Transmitter

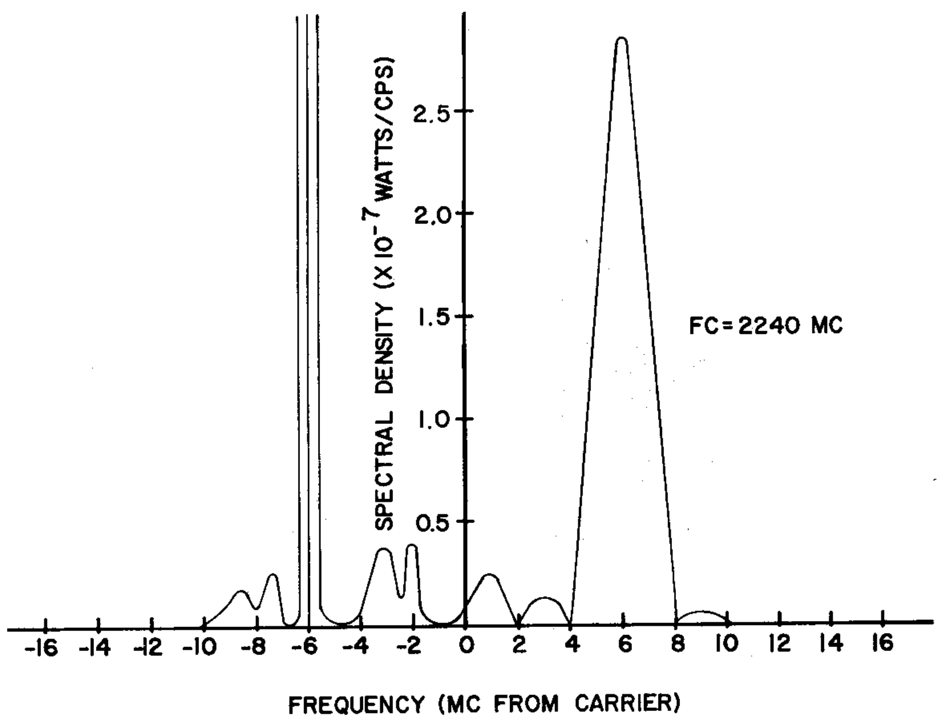

Figure A3. FM Spectrum of 500 ns. Non-Recurrent Pulse