PRELIMINARY REPORT ON THE DEVELOPMENT OF A CRYSTAL-CONTROLLED L-BAND ARTILLERY TELEMETRY TRANSMITTER

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Summary Harry Diamond Laboratories (HDL) has a need for gun-rugged UHF telemetry transmitters for use in research and fuze testing programs. An in-house design program was started because of the specialized performance requirements for artillery electronics. This is the first status report on the effort.

UHF transmitters are extremely sensitive to physical deformation because small dimensional changes produce reactance changes that can cause an appreciable change in frequency. Since ruggedized crystal-controlled oscillators limit the frequency shift to low levels and therefore permit early acquisition of artillery telemetry signals; a prototype transmitter was constructed to determine the degree of efficiency and compactness that could be obtained at L band. A compact 1510-MHz transmitter having an efficiency of 6 percent at an output power level of 160 mW is described. Physical dimensions are such that the transmitter can be readily potted in any artillery telemetry housing currently in use. Temperature compensation and gun ruggedization tests are currently in progress.

Introduction Implementing the Department of The Army mandate to convert telemetry equipment from VHF to UHF required considerable in-house and contractual efforts to develop ruggedized components for application in the 1435 to 1535-MHz telemetry band. As a result of these efforts a high shock crystal was developed at HDL and a gun-rugged step recovery diode (SRD) capable of high-order harmonic generation was developed under HEIL contract by Hewlett-Packard Associates (HPA). Both of these components have survived tests at shock levels up to 70,000-g, a level judged sufficient for current artillery applications.

The need remained for compact, efficient UHF circuitry that could be potted in artillery telemetry housings with the accessory hardware currently employed at VHF. The development of a prototype L-band transmitter was undertaken to fulfill this need.

System Configuration A block diagram of the prototype is shown in figure 1. The transmitter contains four interconnected 1-1/2-in diameter modules. Components for the modulator, crystal oscillator, and 75-MHz power amplifier were mounted on a single 1-1/2-in diameter printed circuit board. The multiplier, filter, and 1.5-GHz amplifier sections were assembled on three separate boards. Stripline circuitry was employed to confine the electric field to the region between ground planes and thereby reduce the detuning effects caused by subsequent encapsulation. Input and output impedances were kept at 50 ohms to facilitate electrical testing of the individual modules and to allow the transmitter to be assembled with minimum redesign.

Modulator, 75-NHz Crystal Oscillator, and Power Amplifier In the schematic diagram shown in figure 2, transistors Q_1, Q_2 , and Q_3 are the modulator,, crystal oscillator, and power amplifier stages, respectively. These components are mounted on a 1-1/2-in diameter circuit board as shown in figure 3. The quartz crystal shown in the center of the board was developed by HDL to withstand gun-launched accelerations up to 70,000-g.[1]

The crystal oscillator is a modified Colpitts type utilizing a 2N3553 transistor in a common base configuration. Temperature tests over a -40° to 90°C range indicate that a frequency stability of 0.002 percent can be obtained with oscillators of this type.

In telemetry applications, the transmitter is modulated by a subcarrier oscillator (SCO) whose frequency is modulated by the desired data. The SCO output is applied to transistor Q_1, and appears across capacitor C_3 , which also serves as an RF ground for the base of the crystal oscillator. Measurements of the resulting spectrum at 1.5 GHz yielded a phase modulation sensitivity of 13.1 radians/volt (fig. 4).

In phase modulation, the frequency deviation is directly proportional to the modulating frequency, so higher SCO output voltages are required at lower subcarrier frequencies. With a 70-kHZ subcarrier, a r.m.s. output voltage of 136 mV is required to obtain a deviation of ± 125 kHZ. Using a 165-kHZ subcarrier, the same deviation can be obtained with a 58-mV output.

When Q_1 is driven by the mixed outputs of several SCOs, the output voltages must be adjusted in the ratio of the three halves power of their frequencies to maintain the same signal-to-noise ratio in each channel at the receiving station. For standard I.R.I.G. frequencies of 22, 40, and 70 kHZ, the output voltages required to obtain a total deviation of 125 kHZ are 50, 65, and 85 mV.

Step-Recovery Diode Multiplier Since it was desirable to minimize the number of tuned circuits and tuning adjustments in order to facilitate the encapsulation procedure, a

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[1] F. T. Liss and J. F. Richardson, “Ruggedized Quartz Oscillator Crystals for Gun-Launched Vehicles,” TM-68-23, Harry Diamond Laboratories, July, 1968.

single step-recovery diode (SRD) was employed to provide a frequency multiplication factor of twenty. A detailed analysis of the input impedance of a SRD multiplier was performed by Hewlett Packard Associates (HPA) under an HDL contract. This analysis showed that the input impedance of a network consisting of the drive inductance L and an SRD can be represented by a parallel equivalent impedance containing an inductive reactance in parallel with a resistance. In the multiplier schematic shown in figure 5 capacitor C_T resonates with the equivalent inductive component of the input impedance at the input frequency and provides a low impedance path for most of the spectral components of the diode-generated pulse. The equivalent resistive component is then matched to the 50-ohm source impedance by means of the L_M-C_M matching network. Choke L_{CH} provides RF isolation for the self-bias resistor R_1 , and coupling capacitor C_b provides d-c isolation from the source. Component values were initially taken from HPA[2] and experimentally adjusted.

Unlike a conventional diode, the conduction angle of an SRD is very large since charge stored in the diode during the forward current portion of the cycle maintains the diode in the conducting state over a major portion of the reverse current cycle. Near the end of the reverse current cycle, the stored charge is depleted and at this instant, the diode becomes an uncharged capacitor. Energy stored in the field of the drive inductance L is then transferred to the capacitor, and the exchange of energy that follows would produce the typical ringing waveform of an RLC circuit if the diode remained in its off state. Since the second half cycle of the transient drives the diode into conduction, the resonant action is destroyed, and a single pulse having a width approximately equal to one-half the period of the output frequency is produced once each input cycle.

The diode generated pulse enters the output line where it undergoes multiple reflections from the output and diode ends of the line. Reflections at the output end occur without phase reversal, while those at the diode or shorted end occur with phase reversal. Since the pulse traverses a distance of one-half wavelength between output reflections and returns each time with its phase reversed, a damped waveform appears at the output.

Output capacitor C was experimentally adjusted, and the line length, appropriately foreshortened, until the maximum amplitude in the damped output spectrum appeared at the 20th harmonic of the input frequency. In this state the damped waveform could be filtered to obtain a CW output with little loss due to rejected sideband energy.

A photograph of the metalization pattern and a completely assembled multiplier is shown in figure 6. The resonant line has a characteristic impedance of 50 ohms, since lower impedance lines loaded the diode and reduced the multiplier efficiency. The multiplier was assembled by soldering the lumped components to the metalization pattern placed

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[2] Hewlett-Packard Application Note 920, “Harmonic Generation Using Step-Recovery Diodes.”

on a 1-1/2-in diameter Teflon fiberglass disk and then eyeleting this assembly to a second disk. The unit so sealed is almost completely shielded electrically by the outer ground planes thereby minimizing the detuning effect of the encapsulant.

Interdigital Filter Undesired harmonics of the 75-MHz fundamental are attenuated at the multiplier output by a five-element interdigital filter having a center frequency of 1.5 GHz, a fractional bandwidth of 5 percent, and a temperature coefficient of 185 kHZ/°C. With this, the amplitude of the closest 75-MHz harmonic was 45 dB below the 1.5-GHz carrier. A photograph of the filter and its metalization pattern is shown in figure 7. Resonator widths and spacings were computed from equations given by Mathaei[3] et al.

The measured filter insertion loss was 5 dB as predicted from L band measurements of the dissipation factor of the dielectric employed in the stripline. A similar estimate from manufacturers data indicated that the insertion loss can be reduced to 2 dB by employing 50-mil alumina substrates.

L-Band Amplifier The 1.5-GHz output from the filter is amplified to a level of 160 mW in a one-stage amplifier employing a 2N5715 transistor. A photograph of the amplifier is shown in figure 8, and its schematic representation is shown in figure 9, Values for the components of the input and output matching networks were experimentally determined. The collector is connected to the d-c supply through the center conductor of eyelet feedthrough capacitor C_4 which also provides an a-c ground for inductor L1. Input bias is supplied through a quarter wavelength line terminated by feedthrough capacitor C_3.

Future Plans A photograph of the prototype transmitter is shown in figure 10 and its characteristics are tabulated in table 1. Future plans call for a continuation of the development effort in the areas of temperature compensation and g-hardening.

The crystal oscillator -provides adequate frequency stability over the -40 to +60°C temperature range but additional compensation in the multiplier and power amplifier circuits will be required to maintain the transmitter power output level constant. As shown by Hamilton and Hall[4], the value of the multiplier bias resistance R_1 is directly proportional to the diode lifetime. Since the lifetime increases almost linearly with temperature at a rate of +0.5 to 0.7 percent/°C, the multiplier output can be maintained

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[3] Mathaei, Young and Jones, "Microwave Filters, Impedance Matching Networks and Coupling Structures," Section 10.06, McGraw-Hill, 1964.

[4] S. Hamilton and R. Hall, "Shunt-Mode Harmonic Generation Using Step-Recovery Diodes," The Microwave Journal, April, 1967.

constant by replacing R_1 with a silicon resistor. In a similiar manner, it should be possible to stabilize the amplifier stages by replacing the fixed bias resistors with appropriate temperature compensating resistors. The filter has adequate bandwidth and needs no compensation.

With the exception of the low loss capacitors and the 2N5715 transistor, all circuit components have been qualified for an artillery environment. Prototype printed circuit boards have not been qualified, since it is intended to fabricate the final version on ceramic substrates. The entire unit will be tested at shock levels up to 40,000-g, following current shock tests on the capacitors and the 2N5715 transistor.

Table 1

Frequency	-	1510-MHz
RF Power Output	-	160-mw into 50 Ω
Efficiency	-	6 percent with 13-V d-c supply
Spurious Outputs	-	40-dB below carrier
Modulation	-	P.M. (see figure 4)
Size	-	Fits in a 1-1/2-in diameter by 1-1/2-in long cylinder
Output	-	Semirigid coaxial cable with Sealectro connector
Shock and Spin	-	Presently under test
Temperature	-	Not tested

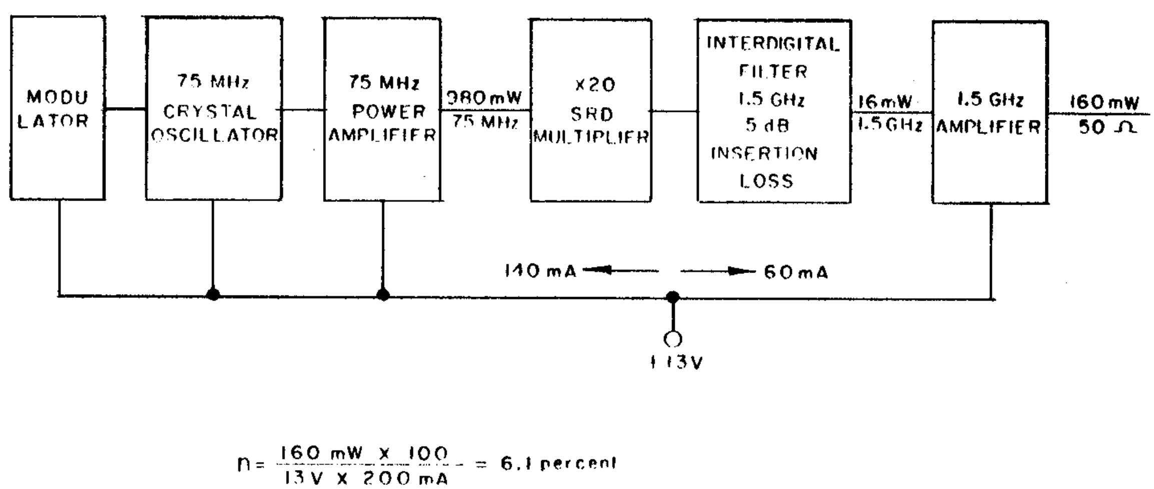


Fig. 1 - L-Band Transmitter Block Diagram

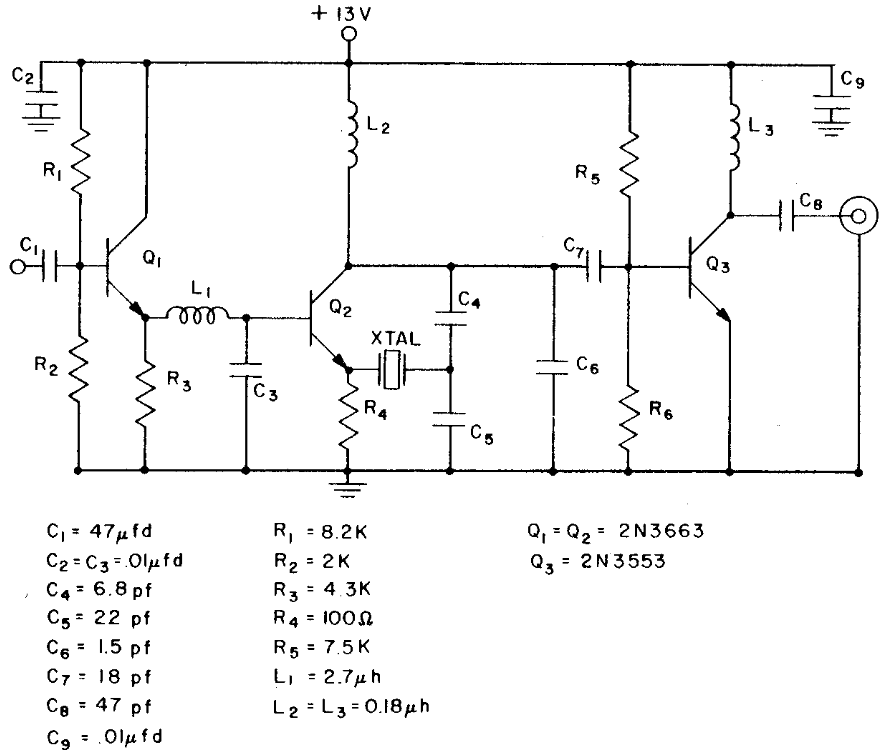


Fig. 2 - Modulator, 75-MHz Crystal Oscillator, and Power Amplifier

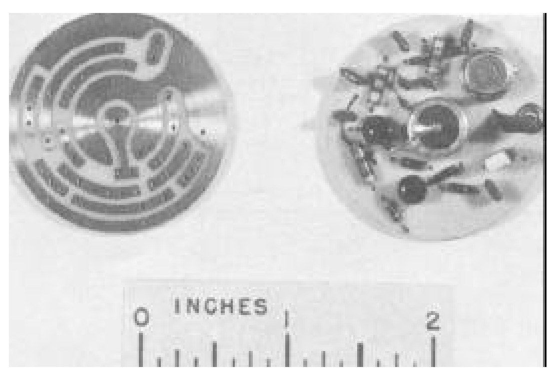


Fig. 3 - Modulator, 75-MHz Crystal oscillator, and Power Amplifier

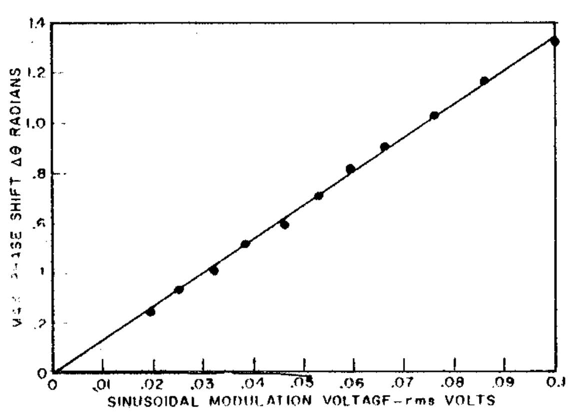
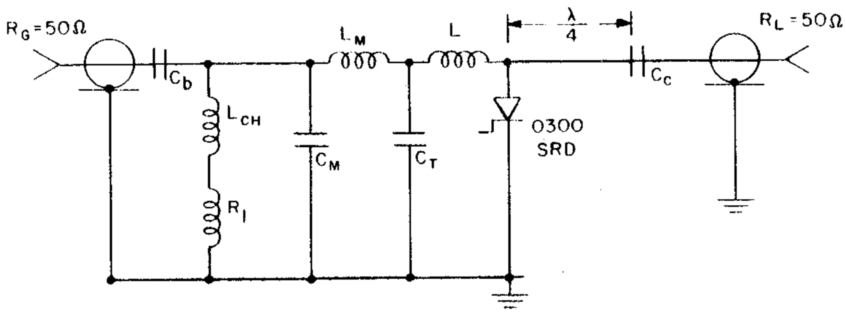


Fig. 4 - Modulation Sensitivity



C_b = 62 pf R_1 = 18 ohms L_{CH} = 1.5 μh MOLDED CHOKE

C_T = 430 pf ATC -100 STRIPLINE CAPACITOR OR EQUIVALENT

C_M = 130 pf

C_c = 0.3 pf ATC - 100 STRIPLINE CAPACITOR OR EQUIVALENT

L_M = 2.2 INCH LENGTH OF STRIPLINE .027 INCHES WIDE

L = 0.3 INCH LENGTH OF STRIPLINE .091 INCHES WIDE

$\frac{\lambda}{4}$ LINE = 0.91 INCH LENGTH OF STRIPLINE .091 INCHES WIDE

Fig. 5 - X20 S.R.D. Multiplier Schematic

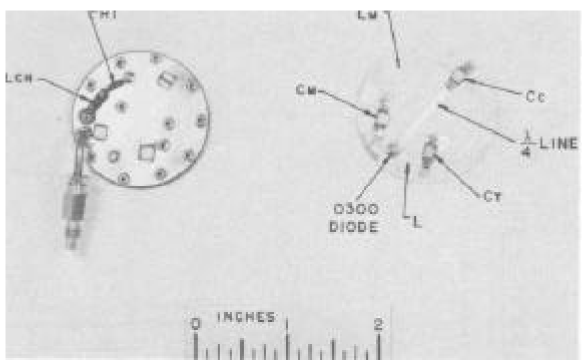


Fig. 6 - X20 S.R.D. Multiplier

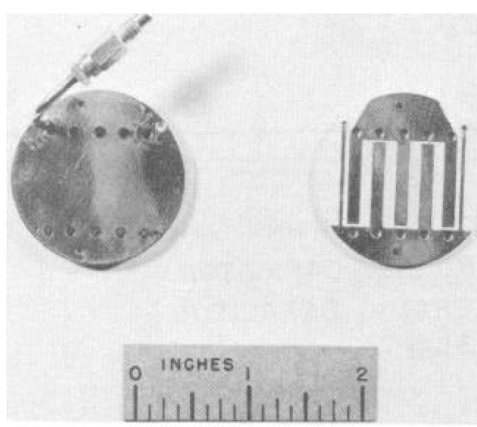


Fig. 7 - 1.5 GHz Interdigital Filter

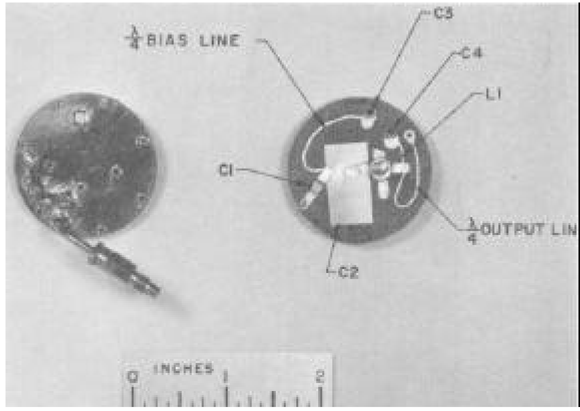


Fig. 8 - 1.5 Ghz Amplifier

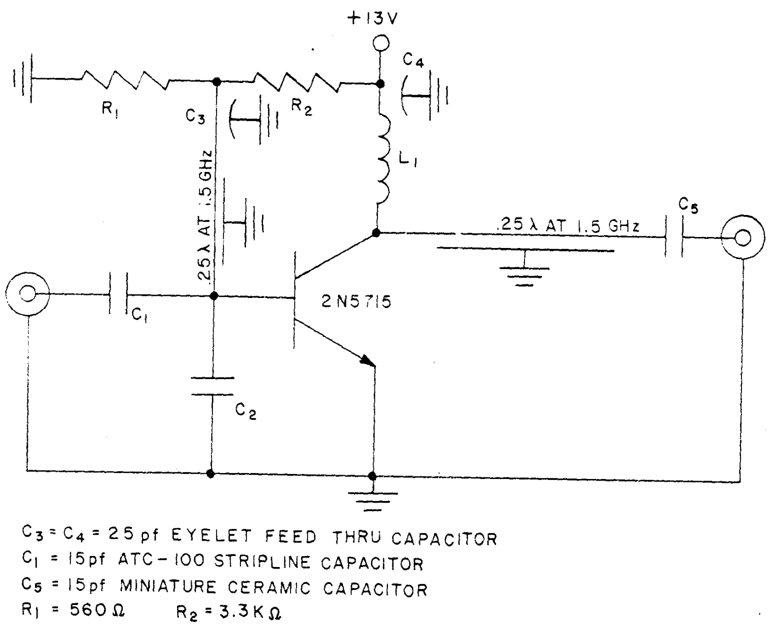


Fig. 9 - 1.5-Ghz Amplifier Schematic

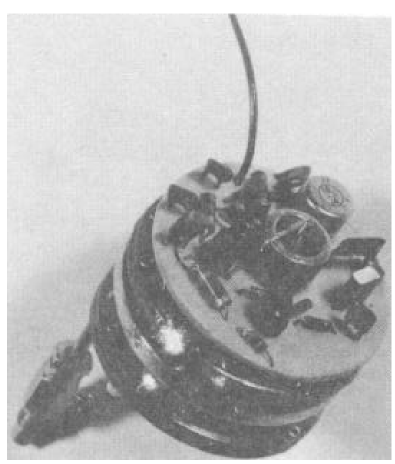


Fig. 10 - L-Band Transmitter