A NONCOHERENT W-BAND TRANSCEIVER

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ABSTRACT:
This paper discusses the design, configuration, and performance of a W-band transceiver with a volume of 1 in ^{3}. The transceiver employs a noncoherent chirped waveform for a pulse compression radar application. Other topics include a design procedure for the local oscillator, which employs a theoretical circuit model of the oscillator geometry, and the use of preheat bias control as a means to temperature compensate the chirp spectrum of pulsed IMPATT diode transmitters.

INTRODUCTION:

The next generation of short range, precision-guided systems will employ millimeter-wave seekers. These systems must provide sufficient performance to acquire and designate targets at significant ranges and yet satisfy temperature, volume and weight constraints so as to be mounted directly on a gimbaled antenna. Since the W-band transceiver occupies only one cubic inch (1 in ^{3}), it is a good choice for this application.

Previous work in transmitter [1] [2] and transceiver development [3] [4] has employed an injection locked transmitter design. This transceiver is significantly different in that it takes advantage of the noncoherent, chirped frequency response of the IMPATT diode transmitter. As a result of this approach, the radar employs fewer oscillator stages compared to an injection locked system. The chirp response is matched to a SAW filter and the radar return pulse is compressed. A necessary feature of this technique is spectral waveform control.

The key features discussed in this paper are: 1) The design and performance of the W-band transceiver, 2) a new circuit design technique for millimeter- wave sources, which employs a top-hat resonator [5] in rectangular waveguide, and 3) the application of controlled bias preheating [6] to maintain the chirp bandwidth of a W-band IMPATT diode transmitter over a 0 - 50^{o}C temperature range.

TRANSCEIVER DESCRIPTION:

The transceiver occupies a volume of one (1 in^3) cubic inch and is composed of five elements: 1) a PIN diode, bulk window, receiver protection switch, 2) a cross-bar, single balanced mixer with integrated preamplifier; 3) a ferrite circulator, 4) an indium phosphide (InP) Gunn diode local oscillator, and 5) a pulsed, silicon on diamond, IMPATT diode transmitter. A function block diagram and an illustrated photograph are shown in Figures 1(a) and 1(b), respectively.

The PIN diode, bulk window, switch, which was designed and built by Millitech, provides mixer protection during the transmit period of the radar. The bulk window concept, first developed by M/A-COM [7], provides the advantage of low insertion loss with high off state isolation. The switch's insertion loss and high isolation states were measured to be less than 0.75 dB and greater than 35 dB, respectively from 94 to 97 GHz.

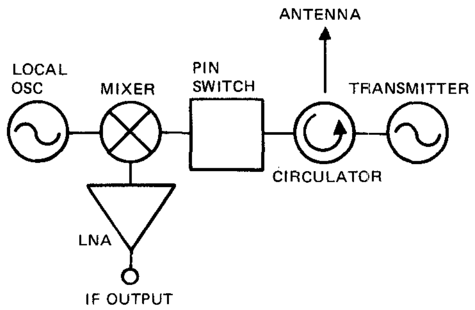

FIGURE 1a. W-BAND TRANSCEIVER FUNCTIONAL BLOCK DIAGRAM

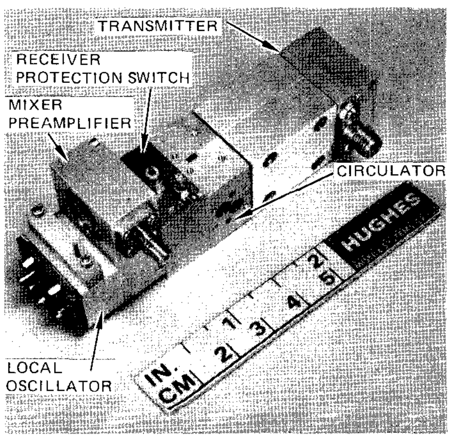

FIGURE 1b. W-BAND RECEIVER ASSEMBLY

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The mixer preamp assembly was built by the Hughes Microwave Products Division. The local oscillator (L.O.) and transmitter (T.O.) frequencies are separated by the IF frequency of 1 GHz. This IF is the center frequency of the mixer preamplifier passband. Conversion gain, measured at the preamp output, ranged from +3 to +4 dB over a RF frequency range of 4 GHz for L.O. and T.O. input power levels of +10 dBm and -10 dBm, respectively. A plot of conversion gain versus L.O. drive power set the minimum L.O. power requirement of +9 dBm.

The double Y-junction ferrite circulator module routes the transmitter power to the antenna and the radar returns to the mixer preamp assembly. From 92.1 GHz to 95.8 GHz, typical insertion loss was 1.5 dB and the isolation was greater than 28 dB.

The local oscillator is a CW, bias-tuned oscillator. A tunable L.O. is necessary to account for system performance variations with temperature. The active device is a Varian, InP, Gunn diode. The oscillator was fabricated using the WR-10 waveguide cross-section dimensions. The diode was mounted in the gap between a top-hat/disc resonator and the bottom surface of the waveguide. The disc resonator provides the appropriate impedance transformation necessary to match the diode impedance to the waveguide impedance and thereby generate a sustained diode oscillation. The frequency and power are determined by the impedance presented to the diode terminals. Two different bias configurations were employed for two different Gunn diodes during the local oscillator development. Circuit #1 uses a two step, low pass, coaxial filter in the bias port to provide a RF short circuit at the top of the waveguide. Circuit #2 employs a coaxial entry/cavity in the top wall of the waveguide.

The configuration of Circuit #1 has been analyzed theoretically by Bialkowski [5]. His analysis rendered an equation for the circuit admittance presented at the gap beneath the disc resonator, i.e., the admittance seen at the diode terminals. This analysis handled the case when both waveguide arms are matched and also the practical case when one waveguide arm is terminated in a short. It should also be stated that evanescent mode coupling between the short and the disc was also accounted for in his model.

An X-band waveguide fixture was designed to include a disc resonator. Beneath the disc resonator a coaxial probe was inserted and measurements were performed to determine the gap impedance/admittance experimentally. Agreement between the Bialkowski theoretical predictions and the computer simulation verified that we had correctly implemented his model. A W-band test fixture was then designed and built for the oscillator development. An Eisenhart [8] style waveguide short was employed as the waveguide arm tuning element. This type of short is preferable to other designs due to the repeatability in oscillator tuning and the well established short circuit reference plane. An accurate description of the circuit geometry for the model requires the exact location of the short circuit relative to the disc resonator.

The model was then used to predict circuit impedance as a function of geometry and frequency for Circuit #1. These impedance computations when used in conjunction with oscillator performance data, provided us with active diode impedance information. Furthermore, based on model predictions of gap impedance, the dimensions of the disc and short position were altered to control the diodes output power and frequency.

The model, although not an accurate representation of Circuit #2 because of the coaxial entry, was nevertheless an effective tool in predicting circuit impedance trends and again facilitated the control of oscillator performance. The final L.O. design was performed in Circuit #2 with a Gunn diode whose RF power rating was greater than that used in the Circuit #1. With this design almost 800 MHz of bias tuned bandwidth was achieved at W-band with a corresponding power variation of +9 to 16 dBm.

Three transmitters were developed and tested on this project, two 10 watt peak units and a five watt peak unit. Each transmitter is a pulsed, silicon on diamond, double drift IMPATT diode oscillator. The RF pulse width is 100 nanoseconds, and the RF output spectrum shown is a noncoherent chirped frequency waveform with a bandwidth of 300 MHz. The chirped frequency is a result of a thermal shift in the diode impedance as the diode heats up during the bias current pulse. Since this chirp bandwidth is matched to a SAW filter to achieve pulse compression, the chirp performance must not degrade over temperature. A controlled preheat bias pulse, which is below the RF generation threshold of the IMPATT diode, is injected prior to the main current pulse (see Figure 3). The amount of prebias "on time" is adjusted to maintain the desired chirp bandwidth as the environment's ambient temperature changes.

Each transmitter was placed in a thermal chamber and operated over a 0 - 50^{o}C temperature range, with temperature measured on the oscillator housing. Tests were performed with and without an adjustment of the preheat "on-time". The amount of preheat and the degree of compensation required is diode dependent. Figure 2 shows a plot of chirp bandwidth for a ten watt transmitter as a function of temperature with a constant preheat bias. This chirp bandwidth variation was eliminated and the 300 MHz of chirp bandwidth maintained over temperature by appropriate adjustment of the preheat pulse. A more dramatic improvement in spectrum was realized for the five watt transmitter. Figure 3 shows a comparison of bias pulse, detected RF pulse, and downconverted spectrum, for a transmitter which was tuned at room temperature, with and without preheat compensation for a housing temperature of 0^{o}C. Additionally, some compensation of the transmitter center frequency with temperature was also demonstrated. Consequently, the technique can also be employed to minimize the center frequency shift of the transmitter [6]. The latter objective is of particular importance in an injection locked system application where maintaining a fixed operating band with temperature is important.

Finally, the downconverted output spectrum of a W-band, IMPATT diode transmitter, whose slope matches that of a surface acoustic wave (SAW) compression filter is shown in Figure 4(a). Figure 4(b) shows the unweighted 5ns compressed pulse output of the SAW filter in response to the downconverted transmitter signal. Adjacent 1st time sidelobes are -10 and -14 dB respectively below the main lobe. Transmitter preheat bias is used to match the transmitter's chirp slope to the dispersion value of the SAW filter. A "high side" LO frequency provides the necessary spectral inversion.

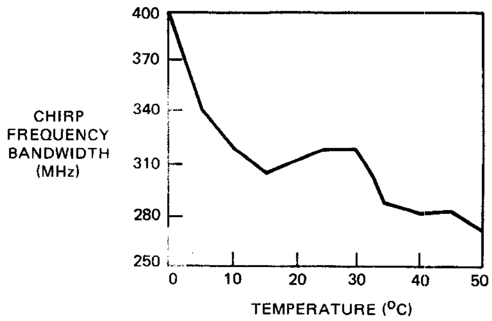


Figure 2. Chirp Frequency Bandwidth vs Housing Temperature for Constant Preheat

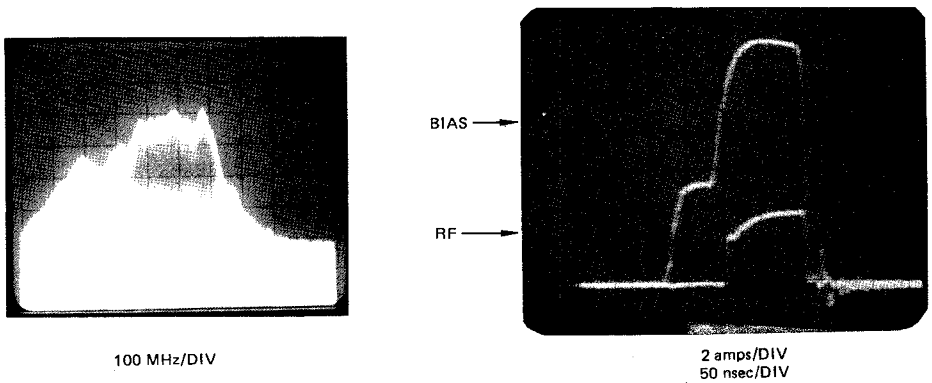


Figure 3a. The Degraded RF Spectrum with Bias and Detected RF Waveform at 0°C

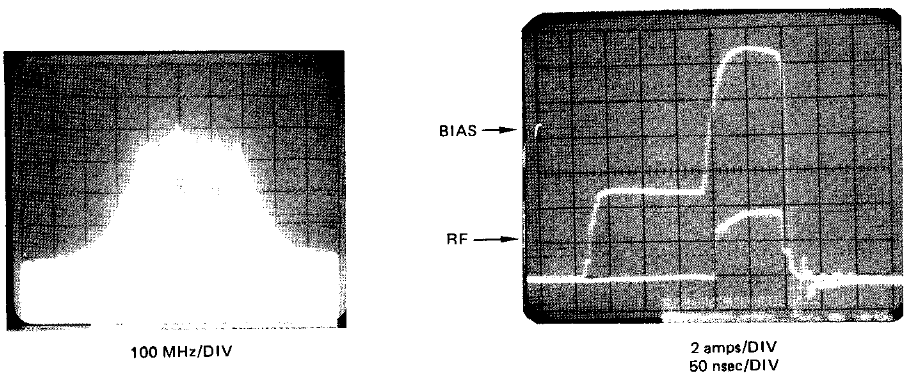
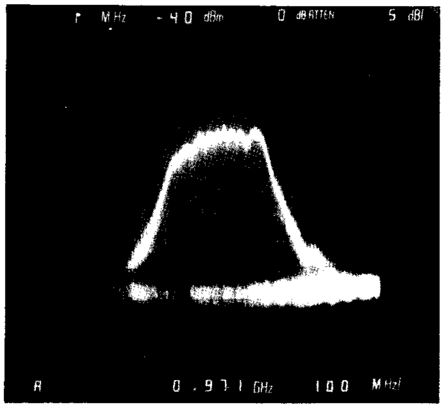
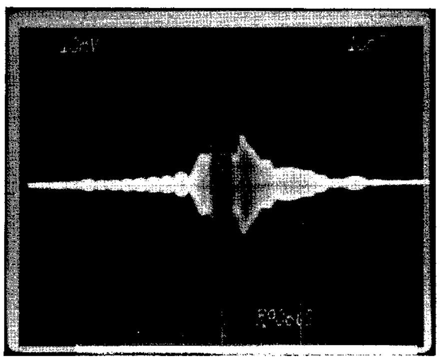


Figure 3b. The Prebias Compensated RF Spectrum with Bias and Detected RF at 0°C. The Lengthened Preheat Pulse Accounts for the Sharp, Clear Spectrum



HORIZONTAL: 100 MHz/DIV
VERTICAL: 5 dB/DIV

Figure 4 (a). The Down converted Chirp Spectrum of the Transmitter: Bandwidth ≈ 300 MHz



HORIZONTAL: 10 nsec/DIV

Figure 4 (b). The Corresponding 5 Nanosecond Compressed Pulse Waveform

CONCLUSION:

This paper discussed the design and performance of a noncoherent, pulsed, W-band transceiver, for use in a pulse compression radar application. A design technique was discussed for the local oscillator of the radar, and the successful demonstration of a Gunn diode L.O. validated the design procedure. The technique of preheat bias control was demonstrated as a method to compensate the chirp response of IMPATT diode transmitters for ambient temperature variations. Finally, noncoherent pulse compression was demonstrated. The use of noncoherent pulse compression and the achievements demonstrated during this project may lead to the development of a low cost, high range resolution radar system for future radar seekers.

ACKNOWLEDGEMENTS:

The authors would like to thank William Hoult for performing the measurements on the mixer, Reynold Johnson for his fabrication efforts on the circulator, and Roy Monzello and Dr. Robert Eisenhart for making available their work in W-band transmitter development. The authors also wish to express their appreciation to Dr. Bialkowski for providing us with a manuscript of his research. Also, thanks to Julie Jerbic and Jim Crowley for their informative discussions on circuit and device operation. Finally, thanks to Linda Lott for typing our manuscript.

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