A W-BAND, COHERENT, PULSE-COMPRESSION RADAR TRANSCEIVER USING LINEAR FREQUENCY MODULATION

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ABSTRACT

A W-Band, solid state, coherent pulse-compression radar transceiver is described that has demonstrated 0.6m range resolution and 25 Hz doppler resolution. Passive pulse expansion and compression was implemented using two nearly identical microwave SAW filters with 0.47 GHz dispersive bandwidth and a time-bandwidth product of 220. Range (time) sidelobes of -18 dB were obtained in preliminary tests by taking advantage of the natural frequency-time slope inherent in the 94 GHz IMPATT oscillator with peak output power of +25 dBm.

Introduction

A number of advanced anti-armor missile radar seekers and battlefield fire control radar systems operating at millimeter wavelengths are presently in development. Millimeter band operation offers improved angular resolution (for fixed aperture size) over microwave frequencies, while retaining adverse weather and battlefield smoke/dust penetration not offered by higher resolution electro-optical systems. These developing radar systems encompass a variety of coherent, non-coherent, pulse, pulse doppler, FM-CW, and pulse compression design techniques. Achieving higher range resolution concurrent with a pulse doppler capability has been the driving force behind the MMW transceiver development described in this paper. Recent advances in solid state MMW sources and Surface Acoustic Wave (SAW) dispersive delay lines[1,2] have provided a basis for the development of the transceiver.

The transceiver uses a linear frequency modulation (LFM) "chirp" waveform. Both digital and analog pulse compression techniques were considered in initial design studies. The LFM waveform was selected, having the best compatibility with the RF thermally-induced chirp characteristics of the pulsed W-band IMPATT diode.

The transceiver, currently in test at the Hughes Aircraft Company in Canoga Park, has demonstrated 0.6m range resolution and 25 Hz doppler recovery.

Transceiver Description

The basic elements of the transceiver, shown in Figure 1, are: the frequency reference, the L-band exciter, the W-band upconverter, the injection-locked pulsed IMPATT transmitter, and the matched filter receiver. All RF signals are derived via phase lock to a master quartz oscillator. The LFM waveform is generated passively at 1.3 GHz,[3] upconverted to W-band and used to injection lock an IMPATT oscillator. The MMW signal is coupled to an antenna via a Y junction duplexing circulator. The received signal is down converted to 1.3 GHz and compressed in a matched SAW filter.

Frequency Reference

The frequency reference is comprised of a master quartz crystal-controlled oscillator (f_r = 108.33 MHz), a 1.3 GHz phase-locked oscillator, and two W-band Gunn diode phase-locked oscillators (PLOs). One W-band PLO injection locks a CW IMPATT oscillator driving the upconverter at 91.1 GHz while the second serves as the receiver local oscillator at 93.7 GHz.

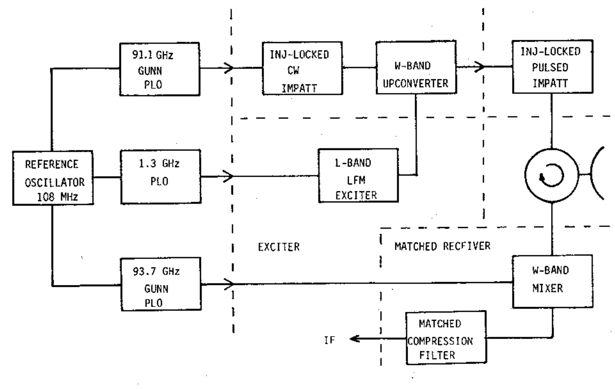
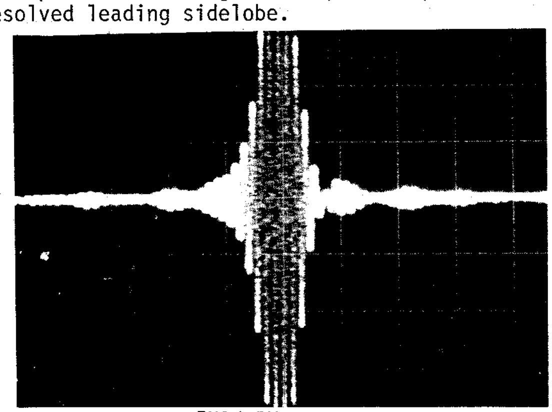


FIGURE 1 TRANSCEIVER BLOCK DIAGRAM

Exciter

The exciter filter consists of a balanced Schottky diode RF switch, a SAW dispersive filter (DF) and associated IF amplifiers, and timing circuitry. The linear frequency modulated (LFM) exciter output signal is produced at the output of the SAW DF when it is excited by a 2 ns duration RF burst centered at 1.3 GHz. The exciter output has a bandwidth of 470 MHz and 470 nsec. duration. The RF switch used to gate the 1.3 GHz signal has 0.75 nsec rise and fall times and, a 50 dB on-off ratio.

The waveform quality was initially determined by recompressing the LFM signal in a matched SAW filter. Figure 2 shows the recompressed pulse having a lagging first sidelobe level of -22 dB. Figure 5a shows the computed response with corresponding features such as the deep null following the compressed pulse and an unresolved leading sidelobe.



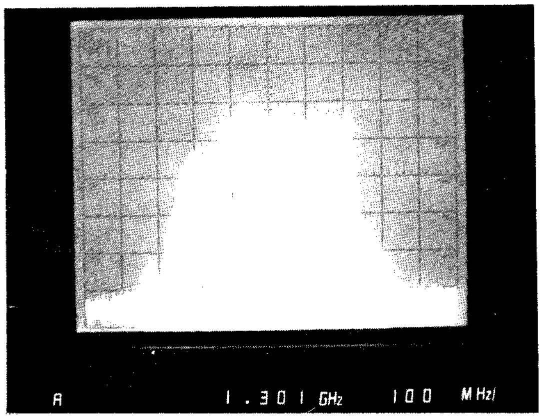
5NS/DIV

FIGURE 2: PULSE RESULTING FROM RECOMPRESSING THE LFM EXCITER OUTPUT -4 dB PULSEWIDTH = 3.75 nsec. SSL = -22 dB

Injection Locked Transmitter

The transmitter is a single-stage pulsed IMPATT double drift diode with a breakdown voltage of about 14 volts and typical peak operating current of 1.2 amperes. The PRF is 52 KHz. The output power is 0.3 watts.

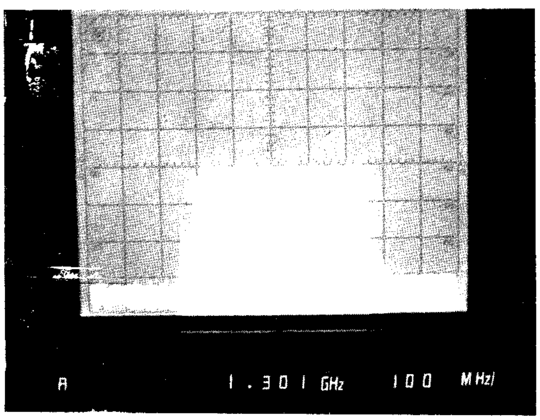
Figure 3 shows the pulse IMPATT transmitter spectra before and after injection locking. Pre-lock adjustment of the bias pulse and cavity tuning are used to bring the free-running IMPATT frequency and chirp slope into close alignment with the lock signal. Consequently, a locking gain of ~24 dB was sufficient to minimize the ILO LFM phase error. This is a key factor to the operation of the IMPATT for minimum waveform distortion.



5 dB/DIV

100 MHz/DIV

FIGURE 3a: PULSED IMPATT "FREE-RUNNING" SPECTRUM WITH BIAS SHAPING.

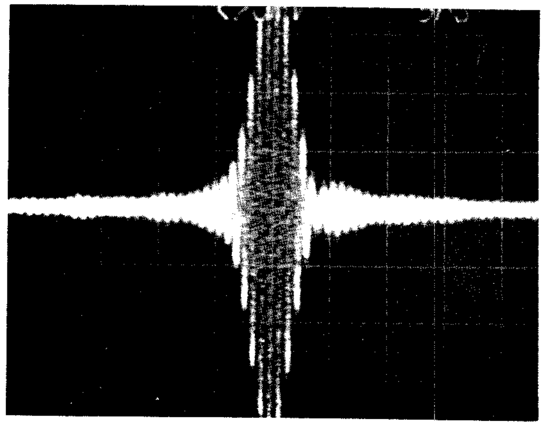


5 dB/DIV

100 MHz/DIV

FIGURE 3b: PULSED IMPATT SPECTRUM AFTER INJECTION LOCKING WITH LFM SIGNAL.

The compressed pulse after upconversion, injection-locking, and down conversion (shown in Figure 4) has -18 dB sidelobes. The best sidelobe level obtainable based on the "matched" SAW DF characteristics is about -23 dB. Performance estimates based on paired-echo theory[4] indicate that the pulsed IMPATT introduces ±2 degrees phase distortion; an additional ±6 degrees being contributed mainly by W band circulators and isolators.



5NS/DIV

FIGURE 4: PULSE RESULTING FROM RECOMPRESSING THE INJECTION-LOCKED IMPATT TRANSMITTER SIGNAL -4 dB PULSEWIDTH ≈3.75 NS, SSL ≈-18 dB

Matched Receiver

The matched receiver consists of a W-band balanced mixer and the SAW DF. The mixer uses highside LO injection to invert the LFM waveform. A transversal filter (approximating HAMMING weighting) following the SAW DF is used to reduce the compressed signal time sidelobes.[5] The filter broadens the pulsewidth by a factor of 1.5. Other system mismatch factors combine to reduce the overall transceiver pulse compression ratio to about 125.

The SAW filters exhibit 470 MHz bandwidth and a time bandwidth of 220. The delay slope mismatch of the filters used in this test was less than 0.4 percent. Potential improvements in SAW filter and system performance may be directly related to achievable reduction in these phase errors. A comparison of matched SAW filter performance can be readily made by inverse Fourier transformation of the product of the measured SAW filter complex frequency responses. Figure 5 shows an example of such computed response of the two SAW filters (one with weighting) used in this preliminary evaluation. A comparison of Figures 5a and b indicates that the elimination of phase errors in these two filters reduces the range (time) sidelobes from -22 dB to -31 dB. By implication, the additional errors, responsible for the 4 dB degradation (from 22 to 18 dB) are incurred in the system itself and most likely in the injection locking process of the otherwise free-running IMPATT source.

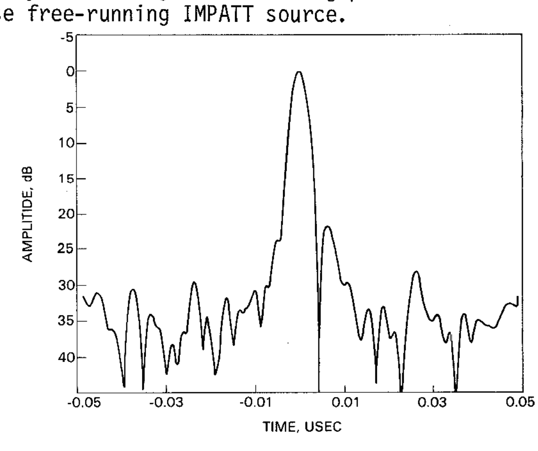


FIGURE 5a: PASSIVE PULSE EXPANSION AND COMPRESSION USING TWO DEVELOPMENTAL SAW DISPERSIVE FILTERS, ±10° PHASE ERRORS EACH FILTER, DELAY MISMATCH ≈0.34 PERCENT.

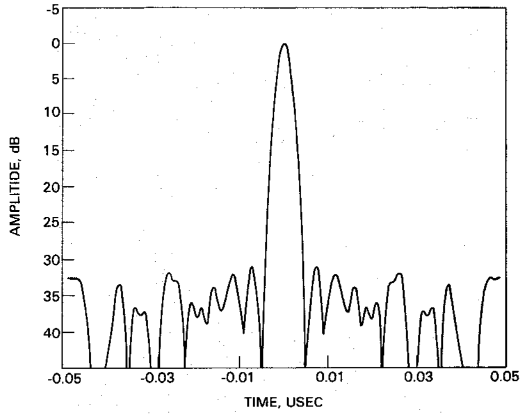


FIGURE 5b: ZERO PHASE ERRORS AND DELAY MISMATCH

Summary

A solid-state, W-band radar transceiver has been developed with the following features; full coherent operation established by system master oscillator, LFM waveform effective time-bandwidth product of 125, SAW filter LFM generation and compression, and chirped, injection-locked, pulsed IMPATT transmitter.

Furthermore, in preliminary field testing, the system has demonstrated; 0.6 meter range resolution, and 25 Hz target doppler recovery.

To the author's knowledge, coherent radar systems described elsewhere[6-9] do not exhibit the above combination of system features and measured performance. This development has demonstrated that high resolution coherent pulse compression (LFM) radar technique can be extended to solid state W-band systems.

Acknowledgement

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