PERFORMANCE OF 94 GHz COHERENT PULSED IMPATT TRANSMITTERS

M. D. Simonutti, D. L. English, and F. J. Bernues
Hughes Aircraft Company
Electron Dynamics Division
3100 West Lomita Boulevard
Torrance, California 90509

Abstract

Millimeter-wave injection-locked pulsed oscillators using double drift silicon IMPATT diodes have been developed for coherent radar applications at 94 GHz. Measurements of the intra-pulse phase ripple, the additive phase noise, and the locking bandwidth of these devices, as determined by means of a phase bridge, are described.

Introduction

The development in recent years of solid state transmitter and receiver components for frequencies around 94 GHz has made possible the development of coherent solid state millimeter-wave radar systems. A key component in these systems is the high power pulsed silicon IMPATT oscillator used in the output stage of the transmitter. This paper describes the performance of short-pulse, low duty-cycle, coherent, injection-locked IMPATT oscillators which have been developed for pulsed doppler radar applications. The results of measurements of the intra-pulse phase ripple, additive phase noise, and injection locking bandwidth of a two-stage injection-locked pulsed IMPATT transmitter are presented. These parameters are critical ones in determining the suitability of the device for pulsed coherent radars. Effects which result from the transient conditions associated with the short-pulse operation of the IMPATT and which directly affect these parameters are described.

Characteristics of Pulsed IMPATT Oscillators

Short-pulse (<100 nsec), low duty cycle (<2%) IMPATT oscillators have been developed which produce up to 17 watts peak power output at 94 GHz using a single IMPATT diode. Operated in this mode these devices are biased at power levels exceeding 200 watts peak. Far more power is dissipated in the silicon junction during the short pulse than the 5 to 10 watts which can be dissipated safely on a cw basis. A junction temperature increase of about 200°C takes place during the 100 nsec bias pulse. For the case of a rectangular bias current pulse, this thermal transient causes a variation of the device impedance and of the noise level during the pulse. This causes frequency chirp or, in the case of an injection locked oscillator, causes intra-pulse phase ripple. To some extent the frequency chirp or phase ripple can be reduced by shaping the bias current pulse. However, experience indicates that the higher power pulsed IMPATTs are more difficult to control in this respect and the range of compensation is more limited.

Another significant characteristic peculiar to pulsed oscillators concerns the finite rise and fall time of the bias current pulse. During the leading and trailing edge portions of the pulse of a free running oscillator the noise level is high and there are large transients in the output frequency. In the case of an injection locked oscillator the noise level is high, there are large phase shifts, and the edges of the pulse are unlocked. With bias current rise and fall times of 10 to 20 nsec, typical values for the modulators used with these devices, the leading and trailing edges of the 50 to 100 nsec output pulse which cannot be made coherent constitute a significant portion of the total output pulse. For certain systems applications this is not acceptable. In this case p-i-n switches may be used following the output stage of the transmitter to blank the noncoherent edges of the pulse. There is a tradeoff of insertion loss of the p-i-n switches and the reduction of noise at the pulse edges which must be considered for each individual system.

Measurement Technique

Injection locked IMPATT oscillators generally have an AM noise level which is relatively low compared with their phase noise level. The AM noise level will, therefore, be neglected for the devices to be described. A millimeter-wave phase bridge employing a balanced phase detector was used for the measurement of the intra-pulse phase ripple, additive phase noise, and injection locking bandwidth of these oscillators.

A block diagram of the measurement system is shown in Figure 1. The power output from a low-noise driver oscillator is split and directed into the reference and amplifier arms of the phase bridge. Approximately equal length arms of the phase bridge result in a large degree of cancellation at the phase detector of the phase noise of the driver source. The effect of additive phase noise from the IMPATT injection-locked oscillator can be observed as noise on the waveform of the phase detector output when the phase shifter is adjusted to the position at which the balanced mixer phase detector is most phase sensitive. This is the position at which the video output of the phase detector is nulled.

The intra-pulse phase ripple can be determined directly from the waveshape of the output of the phase detector. The signal-to-additive phase noise ratio is determined as follows: With the phase detector adjusted to the null position the frequency spectrum of the output of the phase detector is measured at typically 1 KHz bandwidth from zero frequency up through several times the pulse repetition frequency. The noise floor of the spectrum between the PRF lines is noted. Next the phase shifter setting is changed by 90° to operate the balanced mixer in its amplitude sensitive mode. The frequency spectrum of the video output of the phase detector is again recorded, and the amplitude of the peak of the PRF lines is noted. The signal to additive phase noise ratio at the specified bandwidth is the difference in dB between the amplitude of the peak of the PRF lines from the amplitude sensitive mode, and the amplitude of the noise floor for the phase sensitive mode.

Measurement Results

The injection locked amplifier system studied consists of two circulator-coupled, 94.6 GHz, pulsed IMPATT oscillator stages followed by a pair of p-i-n switches to blank the high noise edges of the pulse. The system is operated at a pulse repetition frequency of 100 KHz and an output pulsewidth of 60 nsec. The first IMPATT stage has an output power of +24 dBm peak at a pulsewidth of 125 nsec. The final IMPATT stage has an output power of +41 dBm and a 75 nsec pulsewidth. Two stages are used to improve the gain-bandwidth product of the amplifier. The system is operated with a nominal cw input power of 4 dBm.

Figure 2 shows the waveform of the phase detector output for three different settings of the phase shifter: for the null position in which the phase noise is indicated, and plus and minus 90° from the null position

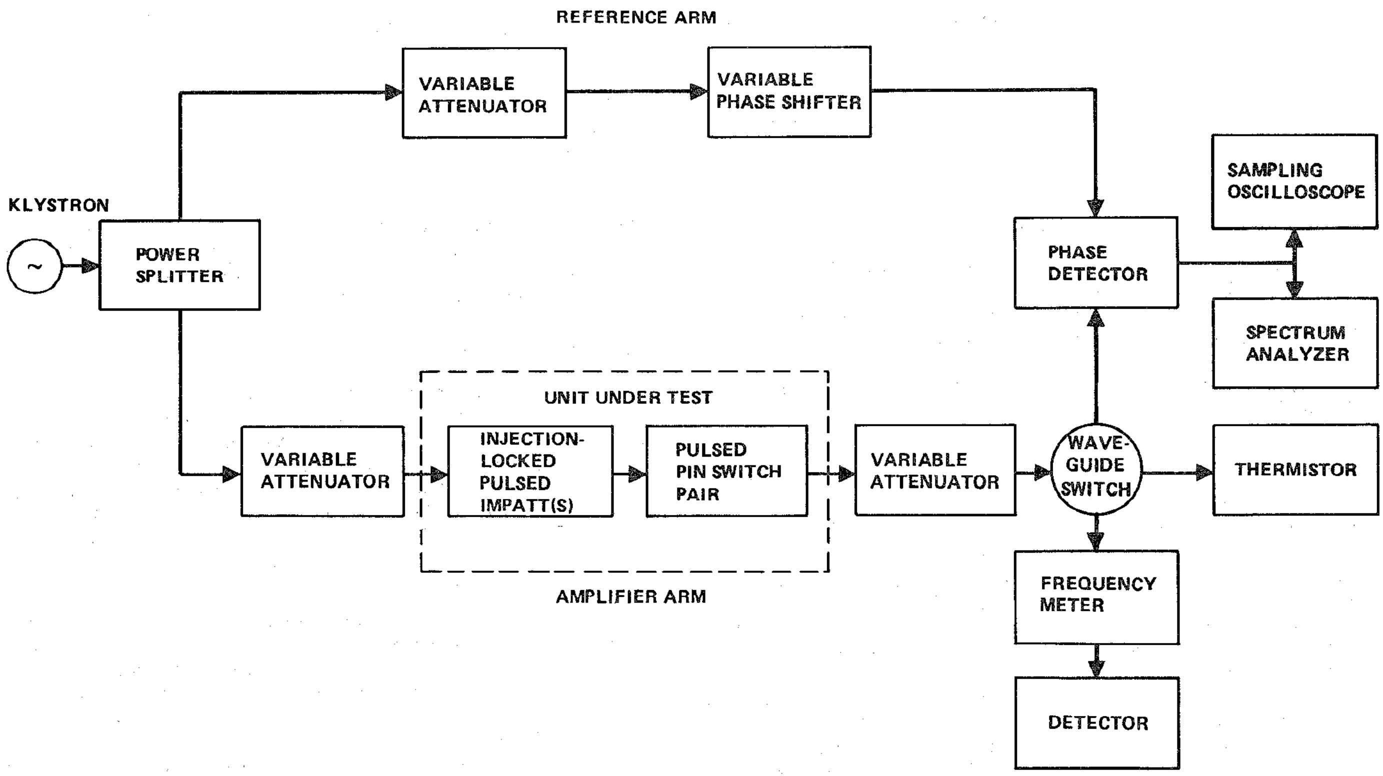

Figure 1 Block diagram of 94 GHz phase bridge for phase-noise testing of pulsed IMPATT transmitters.

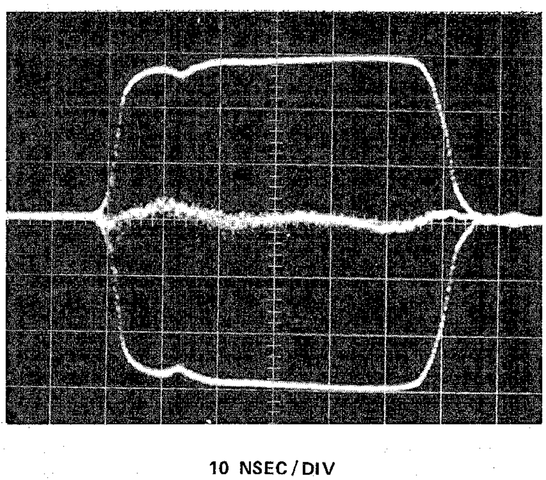

Figure 2 Balanced phase detector output for three positions of the phase shifter spaced by 90 degree increments. Top and bottom traces are for the amplitude sensitive setting, center trace for the phase sensitive setting.

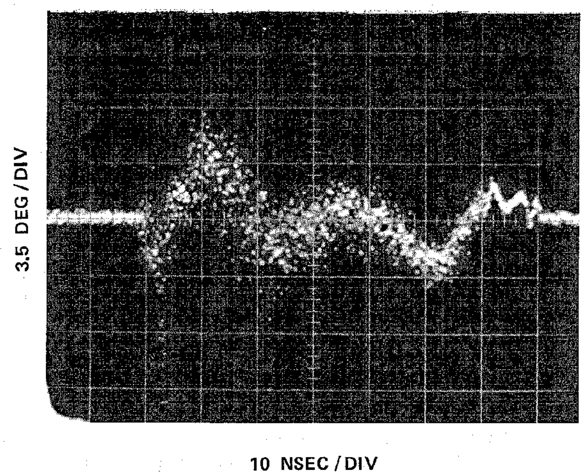

Figure 3 Balanced phase detector output with the phase shifter set for the phase sensitive position of the detector. Vertical scale is expanded over Figure 2.

indicating the amplitude reference. Figure 3 shows the waveform of the phase sensitive trace expanded vertically by a factor of five. The indicated phase noise is approximately 4 degrees and peak-to-peak phase ripple is about 8 degrees. The pulse current waveshape to the IMPATTs was adjusted to minimize this phase ripple. The frequency spectra of the two phase detector output waveforms are shown in Figure 4. Note that the noise floor for the phase sensitive trace is greater than for the amplitude sensitive trace. The peak-to-valley ratio for this system is 64 dB. This measurement technique was used to determine the injection locking bandwidth of the unit which was >300 MHz for a minimum peak-to-valley ratio of 60 dB over this band.

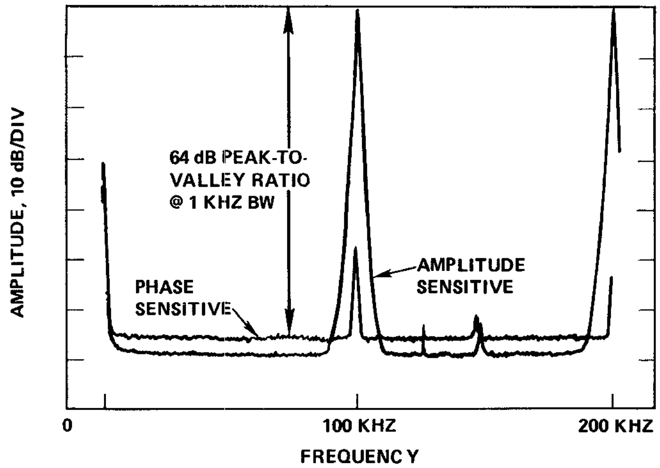

Figure 4 Frequency spectra of the phase detector output for both the amplitude and phase sensitive positions.

Conclusion

Low noise, high-power, pulsed millimeter wave IMPATT transmitters have been developed for 94 GHz operation. These devices are presently being employed in prototype systems used for evaluating the performance of 94 GHz pulsed coherent radar systems for various applications.

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