A 63 W W-BAND INJECTION-LOCKED PULSED SOLID STATE TRANSMITTER*

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ABSTRACT

A high power three-stage W-band injection-locked pulsed solid state transmitter using four hybrid-coupled two-diode IMPATT power combiners as the final stage has been developed. Coherent peak output power of 63 W at 92.6 GHz has been achieved. The transmitter was operated at 100 ns pulsewidth and 0.5 percent duty cycle.

INTRODUCTION

The rapidly increasing demand in millimeter-wave radar systems has created an urgent need for a high power W-band solid state transmitter. In this paper, we will present the development of high power three-stage injection-locked pulsed transmitter using four hybrid-coupled two-diode IMPATT power combiners as the final power stage. Coherent peak power output of 63 W at 92.6 GHz has been achieved. The transmitter was operated at 100 ns pulsewidth and 0.5 percent duty cycle.

The silicon IMPATT diodes used in this work have been reported earlier.[1-3] Typical peak output power is more than 13 W with 8 percent DC-to-RF conversion efficiency. Compatible high power diodes were first selected to form two-diode combiners, which constituted the basic building blocks for the transmitter. Four of these two-diode combiners were then hybrid combined through the 3-dB hybrid couplers to further increase the peak output power. A stable CW source was used to injection lock this hybrid combiner to achieve coherent peak output power of 63 W with more than 70 percent combining efficiency.

TWO-DIODE COMBINER MODULES

The circuit used for the two-diode combiner was modified from that proposed by Kurokawa.[4] The design and performance of such a combiner has been reported previously[3] and will not be repeated here. Typically, peak output power of 20 to 23 W can be achieved with 80 to 90 percent combining efficiency. Because of the narrow injection locking bandwidth, minimum frequency chirp is required for the two-diode combiners before injection locking. This can be achieved by providing an upward ramp on the bias current pulses. Using this method, frequency chirp of two-diode combiners was minimized to 300 MHz or less. The two-diode modules form the basis for the combiners.

TRANSMITTER USING TWO HYBRID-COUPLED MODULES

A three-stage transmitter using two hybrid-coupled modules (four diodes) as the final power stage has been constructed. The block diagram of this transmitter is shown in Figure 1 and a photograph of the hybrid-coupled output stage is shown in Figure 2. The first stage is a low power CW IMPATT source of about 100 mW output power. Since this power level was insufficient to injection lock the final output, an intermediate stage was added that uses a single-diode IMPATT source with 10 W peak output power. This single-diode source was injection locked by the CW source to produce a coherent pulse output with less than 100 MHz chirp over 100 ns pulsewidth, which in turn injection locked the final high power stage.

The last stage consists of two two-diode combiners, hybrid-coupled through a 3-dB short-slot hybrid coupler. Each combiner produced 23 W output at 92.6 GHz and was dechirped to less than 200 MHz. Before injection power was applied, the combiners were biased to a free running oscillation state. Due to a random phase relationship between these two combiner outputs, substantial power was reflected back to the input port. As the injection power was increased, the oscillations were gradually synchronized, resulting in a coherent peak output power of 40 W with about 250 MHz overall frequency chirp. The combining efficiency was 85 percent and the loss in the hybrid combining circuit was 0.7 dB.

The locking bandwidth and injection power gain were also studied. According to theory, the fractional locking bandwidth $(2\Delta f/f_0)$ is approximately proportional to $(P_O/P_L)^{-1/2}$, where Δf is the one-sided bandwidth, f_o is the free running frequency, and P_O and P_L are the output and injection power respectively. The proportional constant is equal to twice the inverse of the external quality factor Q of the oscillator circuit. The experimental results which are summarized in Figure 3, generally agreed well with theoretical predictions. The deviation for small frequency offset is believed to be due mostly to lack of frequency resolution with our setup. The external Q inferred from these data is about 50, which gives roughly a total locking range of 900 MHz at a locking gain of 13 dB.

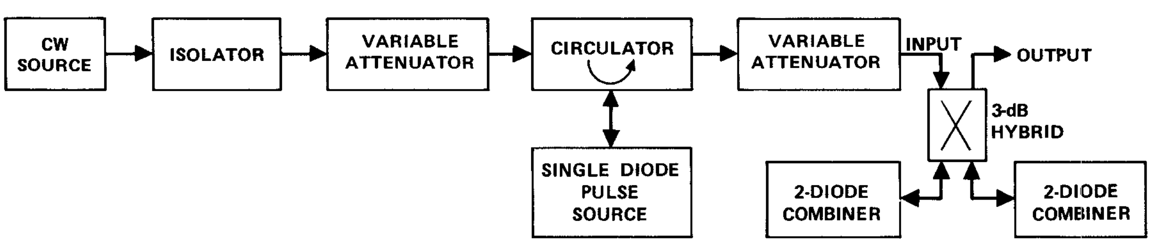

FIGURE 1: BLOCK DIAGRAM FOR A THREE-STAGE INJECTION-LOCKED TRANSMITTER USING A FOUR-DIODE COMBINER AS THE FINAL STAGE.

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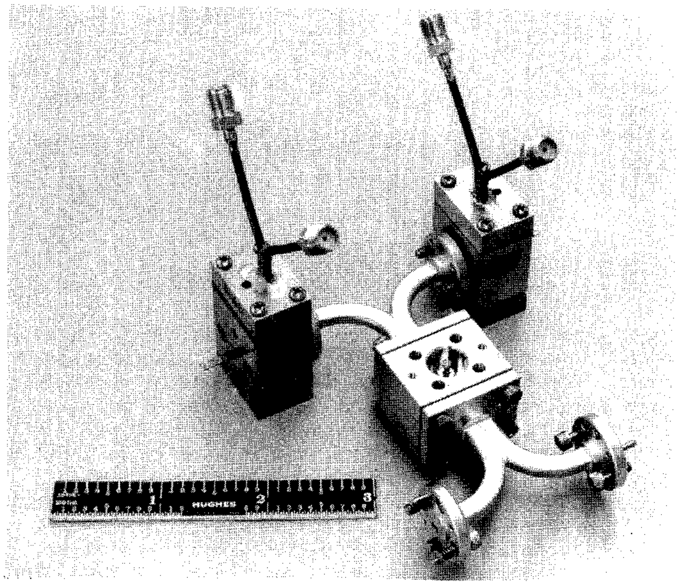


FIGURE 2: HYBRID-COUPLED FOUR-DIODE COMBINER.

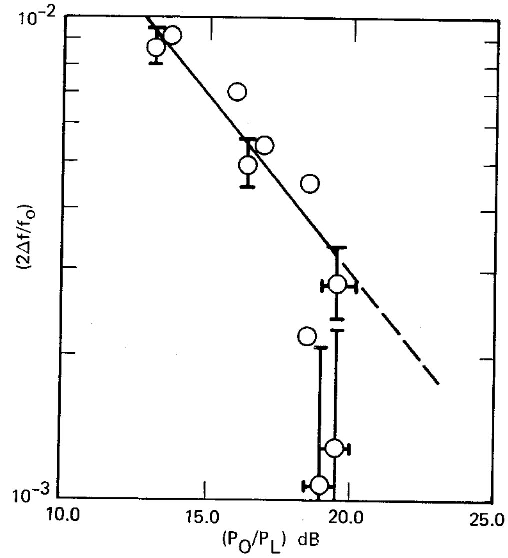


FIGURE 3: FRACTIONAL INJECTION LOCKING BANDWIDTH ($2\Delta f/f_O$) AS A FUNCTION OF POWER GAIN (P_O/P_L).

TRANSMITTER USING FOUR HYBRID-COUPLED MODULES

In order to further increase the output power, a three-stage transmitter using four hybrid-coupled modules (eight diodes) as the final stage was built. Four 3-dB hybrid couplers were connected to a four-way adaptor as shown in Figure 4. Two of the four two-diode combiners, each of 23 W peak output power, and the other two combiners of 18 W were used. All four combiners were tuned to oscillate within 50 MHz of a center frequency of 92.6 GHz and dechirped to less than 300 MHz over substantial portion of the pulse duration. The transmitter was optimized for maximum power output and high degree of coherency by varying the current bias and relative bias delay for each diode, as well as the injection power level. Peak output power of 63 W at 92.6 GHz has been achieved with good coherency. The combining efficiency is about 76 percent, indicating 1.2 dB loss in the combining circuit. A photograph of this transmitter is shown in Figure 5.

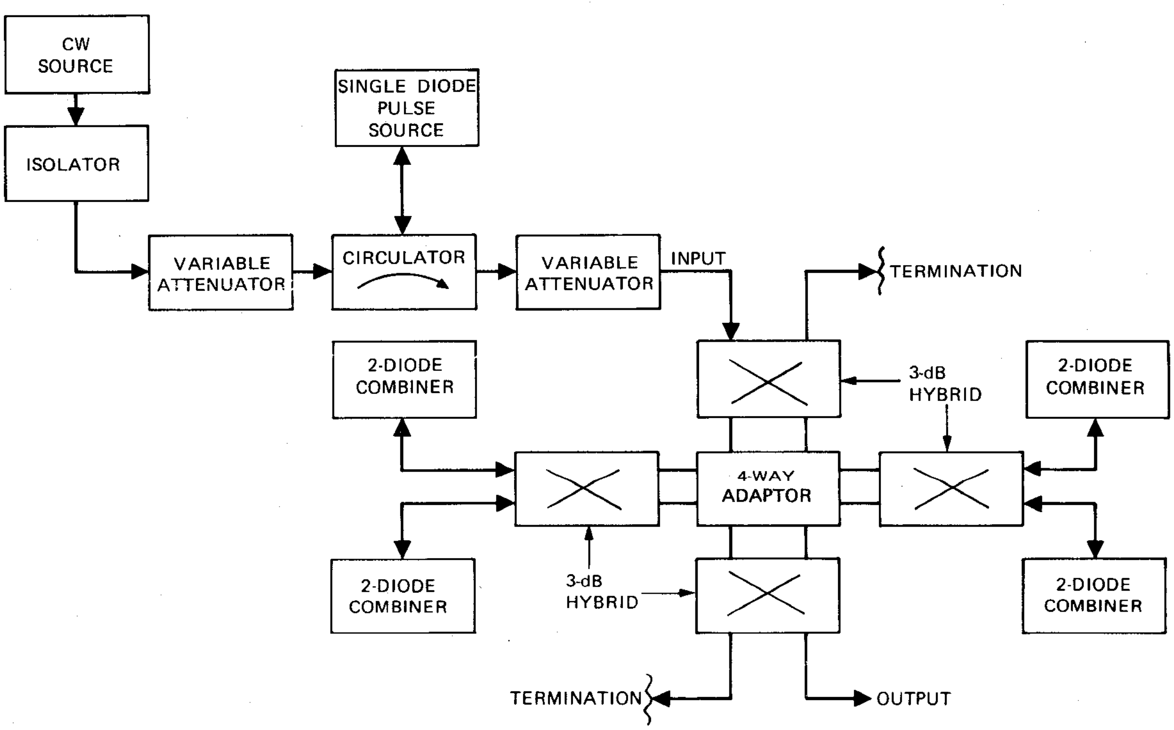
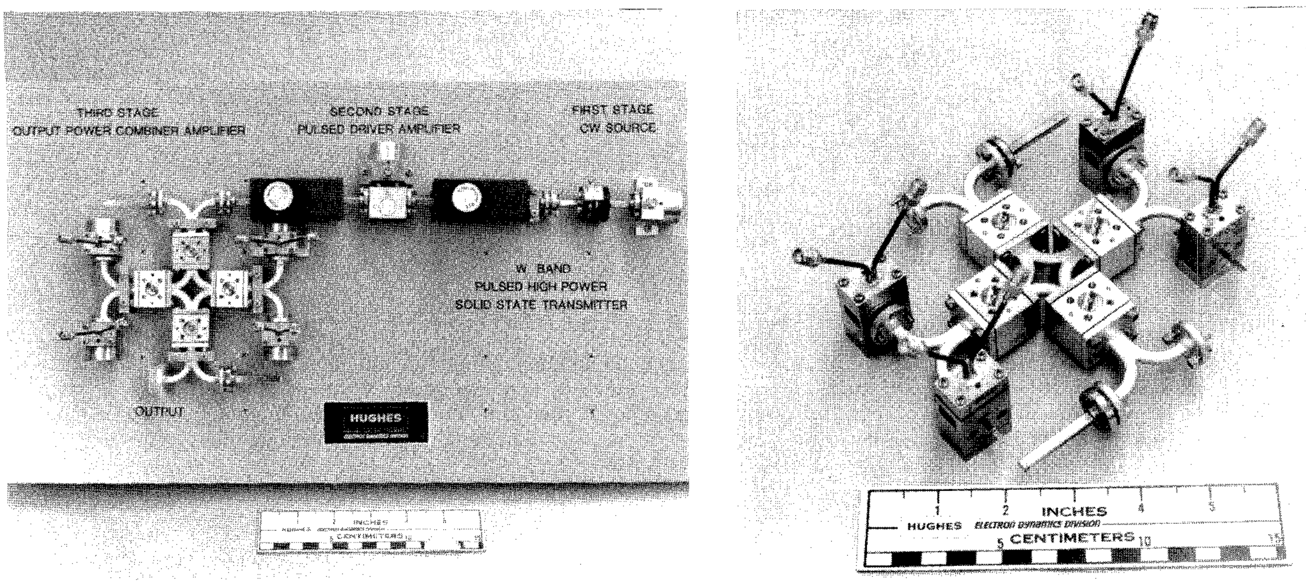


FIGURE 4: BLOCK DIAGRAM FOR A THREE-STAGE INJECTION-LOCKED TRANSMITTER USING AN EIGHT-DIODE COMBINER AS THE FINAL STAGE.



(a) (b)

FIGURE 5: HARDWARE OF 63 W TRANSMITTER. (a) THREE-STAGE INJECTION-LOCKED TRANSMITTER. (b) EXPLODED VIEW OF THE FINAL STAGE OF HYBRID-COUPLED FOUR TWO-DIODE COMBINER MODULES (EIGHT DIODES).

CONCLUSIONS

A high power three-stage injection-locked pulsed transmitter using four hybrid-coupled two-diode combiners as the final stage has been developed. Coherent peak output power of 63 W at 92.6 GHz has been achieved. This achievement has firmly established the feasibility of high power coherent solid state transmitters for radar applications.

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