E-3 A HIGH POWER W-BAND (90-99 GHz) SOLID STATE TRANSMITTER FOR HIGH DUTY CYCLES AND WIDE BANDWIDTH

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ABSTRACT

A high average power W-Band solid state transmitter using a 2-diode and a 4-diode IMPATT power combiner has achieved over 1.89 W and exceedingly versatile performance over a broad range of pulsewidths and duty cycles with a tunable bandwidth from 90 GHz to 99 GHz.

INTRODUCTION

A new generation of millimeter wave systems will demand high-power solid state W-Band transmitters.[1] Millimeter wave technology tracking radars and active seekers for precision guided munitions need small, lightweight, reliable solid state transmitters capable of operating over a broad range of pulsewidths, duty cycles, and bandwidth. A transmitter has been developed that delivers such state-of-the-art power levels over such broad ranges of these parameters so that signal processing techniques that use a variety of pulse codes (digital sequence and chirps) can be readily employed.

Previous implementations of W-Band transmitters have been limited to pulsewidths less than 300 ns (typically 100 ns) and duty cycles less than 2 percent (typically 0.5 percent).[2,3] Higher average power levels in combination with signal processing are needed for longer detection range and target classification.

In this development effort commercially available silicon IMPATT diodes were combined in a unique modification of a Kurokawa waveguide combiner designed for versatile operation at W-Band. A key element in achieving such a versatile transmitter was the ability to adjust precisely the circuit impedance that is seen by each IMPATT in the power combiner. This paper will present this power combiner design and the performance of this new solid-state W-Band transmitter.

IMPATT POWER COMBINERS

Both 2-diode and 4-diode IMPATT power combiners were developed for this transmitter. Typical performance of each combiner is summarized in Table 1. The combiner design is a modification of the Kurokawa waveguide combiner.[4] Identical coaxial tuning structures are used in both the 2-diode and 4-diode combiners so that all internal parts are interchangeable thereby minimizing the design complexity and development cost.

TABLE 1

MILLIMETER WAVE IMPATT POWER COMBINER PERFORMANCE

ITEM	PERFORMANCE ACHIEVEMENTS	
	2-Diode Combiner	4-Diode Combiner
Frequency*	92 - 104 GHz	90 - 99 GHZ
Power	300+ mW free-running 400+ mW locked	1.89 W
Pulsewidths	100 ns to 4 μs (CW-like operation)	100 ns to 4 μs (CW-like operation)
Duty Cycles	1 - 35 percent	5 - 35 percent

*mechanically tuned bandwidth

Several of these combiners are shown in Figure 1. The 4-diode combiner of this report is a 6-diode combiner with the two coaxial lines near the sliding short blocked. The unique coaxial tuning modules which house the Eccosorb terminations can also be seen. The heat sinks and the internal waveguide configuration are shown in the dissassembled parts display.

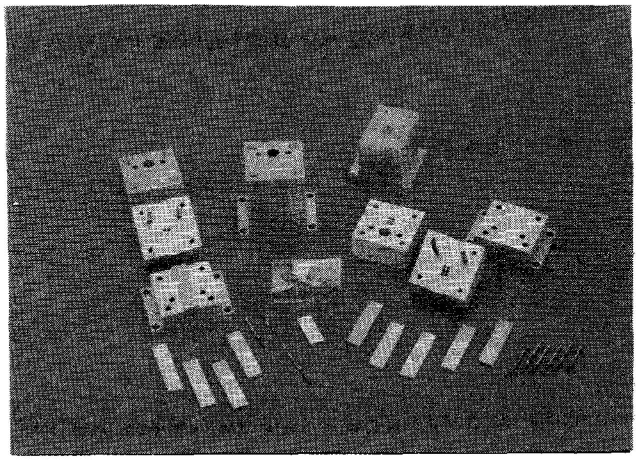


Figure 1 - Power Combiners with Internal Structure and Parts Displayed

The ability to adjust precisely the impedance seen by each IMPATT led to very high combining efficiencies. The IMPATTs performed more efficiently in the combiners than their individual operating data would predict. Combiner circuit losses are difficult to determine at these frequencies but are probably less than 1 dB based on the observed performance. No iris coupling or screw tuning was used to match the reduced height waveguide of the power combiner to the full height waveguide of the measurement network. A simple tapered transition built as part of the combiner circuit was used for this interface.

PRECISION TUNING

A unique Eccosorb load tuning assembly (as shown in Figure 2) was used in both power combiner designs. The position of the Eccosorb is continuously variable within the coaxial line that is located above the waveguide. This tuning is precise, reversible, reproducible and capable of matching each IMPATT over a broad range of frequencies. Additional tuning is provided by a sliding short within the reduced height waveguide. No ramping or variation in the biasing current pulse amplitude was necessary since both the undesirable frequency jumps and any power amplitude variation across the RF pulse could be eliminated by proper tuning.

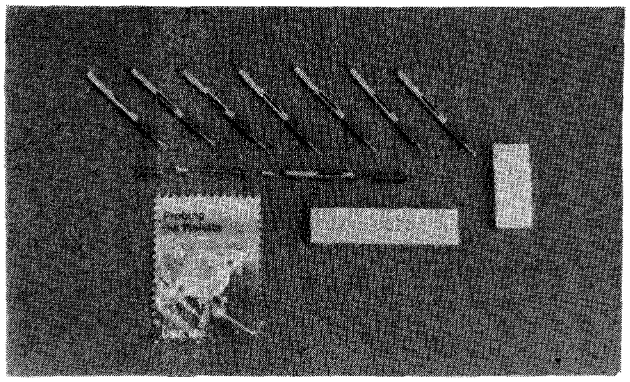


Figure 2 - Precision Tuning Assembly

THE IMPATTS

The IMPATTs used are Hughes silicon diodes mounted on type IIA diamond and specified at 200 mW per device with thermal coefficients of Θ_T = 30°C/W. The CW silicon IMPATTs selected for power combining were first tested individually to determine their performance characteristics. Diodes that exhibited similar characteristics were then soldered in heat sink slabs for use in the 2-diode and 4-diode combiners. The diodes were then biased and the position of the Eccosorb loads adjusted for maximum output power. A comparison of the individual diode operating characteristics with the 4-diode combiner performance is shown in Table 2. This comparison points out the higher efficiency and improved performance achieved in the precision tuned 4-diode combiner as compared to a single diode, "fixed-tuned" circuit.

TABLE 2

COMPARISON OF IMPATT PERFORMANCE BETWEEN THE FIXED-TUNED SINGLE DIODE CIRCUIT AND THE 4-DIODE POWER COMBINER

Device	Data	V_{BK} V	C_O pF	V_{OP} Ave. V	V_{OP} Peak V	I_{OP} mA	P_{IN} W	RF CW mW	P_{OUT} Pulsed mW	f_o GHz	* N %	Θ_t °C/W	T_j °C
241	Single Diode	15.1	.93	18.3	---	268	4.90	240	---	93.2	4.89	30.0	169
	∝ 4-Diode Combiner	N/A	N/A	16.7	17.5	440	7.35	---	420*	90.0	5.72	30.0	<253
242	Single Diode	15.1	.97	18.7	---	289	5.40	250	---	93.6	4.63	30.0	184
	∝ 4-Diode Combiner	N/A	N/A	16.5	17.5	310	5.11	---	296*	90.0	579	30.0	<184
243	Single Diode	15.0	.95	18.6	---	272	5.06	250	---	93.6	4.94	30.0	174
	∝ 4-Diode Combiner	N/A	N/A	16.7	17.5	500	8.35	---	477*	90.0	5.71	30.0	<285
244	Single Diode	15.1	.97	18.4	---	280	5.15	250	---	93.3	4.85	30.0	176
	∝ 4-Diode Combiner	N/A	N/A	16.7	17.5	480	8.02	---	457*	90.0	5.70	30.0	<274

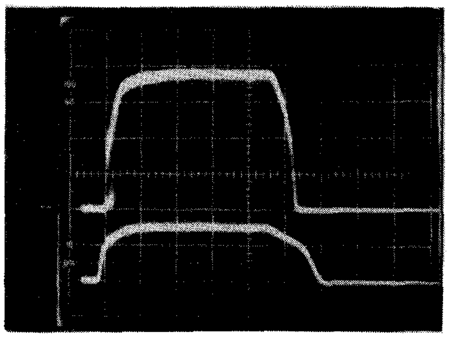
∝ 0.1 to 4.0 µsec pulsewidth
* estimated in proportion to current (I_{OP})

2-Diode Combiner

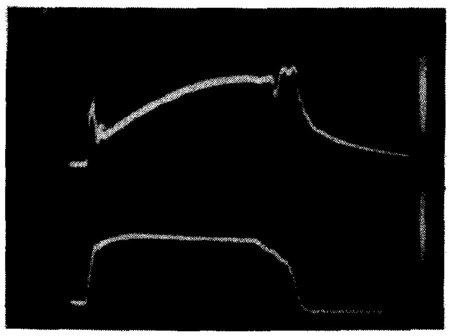
The 2-diode combiner achieved more than 300 mW as a freerunning oscillator. More than 400 mW was achieved when this unit was injection locked at gains between 7 and 15 dB. More than 300 mW was achieved for duty cycles between 1 and 35 percent and pulsewidths ranging from 100 ns to more than 4 µs. No tuning of the combiner was needed to accommodate these broad variations. By slightly adjusting the tuning mechanisms this performance was obtainable over a frequency range from 92 GHz to 104 GHz. At 10 dB locking gain about one percent instantaneous bandwidth was achieved. No effort was made to optimize this instantaneous bandwidth beyond 1 GHz. Duty cycles in excess of 35 percent were not tested due to a decrease in the current amplitude supplied by the breadboard modulator circuits. It is expected that such performance will be maintained at duty cycles well in excess of 50 percent but such duty cycles are not generally used in pulse transmitter applications.

4-Diode Combiner

The 4-diode power combiner final stage achieved a state-of-the-art power in excess of 1.89 W of peak output power at 90 GHz with duty cycles between 10 and 25 percent and pulsewidths from 0.1 to 4 µs. For duty cycles from 5 to 35 percent this unit generated over 1.3 W of peak power over the mechanical tuning range of 90 to 99 GHz. Mechanical tuning of 35 MHz/mil could easily be obtained with the sliding short between 89.5 and 90.5 GHz with less than 0.9 dB variation in output power. Frequencies lower than 89.5 GHz were not tested since no locking source was available. The non-optimized injection locked bandwidths were about one percent. Typical waveforms for the freerunning 4-diode output stage are shown in Figure 3. Slight instabilities can be seen in the first 40 ns of the RF envelope due to the initial heating of the IMPATT. The duration of these instabilities is decreased to less than 20 ns with injection locking. The overall RF envelope is "clean" and displays the performance of the combiner.



A) RF ENVELOPE
TIME SCALE = 200 nsec/DIV
TYPICAL CURRENT PULSE
VERTICAL SCALE = 200 mA/DIV



B) VOLTAGE PULSE
DC OFFSET = 15 VOLTS
VERTICAL SCALE = 1 V/DIV
CURRENT PULSE
VERTICAL SCALE = 200 mA/DIV

Figure 3 - Typical 4-Diode Combiner Performance

MEASUREMENT NETWORK

The waveguide measurement network is shown in Figure 4. The insertion loss in each component of the network was calibrated from 90 to 104 GHz. The insertion loss of assembled network was correlated with the sum of the losses in the components. A precision variable attenuator was adjusted to set the network loss at 30 dB for each measurement. The final three stage transmitter will generate a locked, stable output between 90 GHz and 99 GHz. The estimated gain per stage is indicated in the block diagram Figure 5.

CONCLUSIONS

State-of-the-art IMPATT Power Combiners have been developed for use in a 3-stage W-Band solid state transmitter. Extremely versatile performance has been achieved with operation spanning pulsewidths from 0.1 to 4 μs and duty cycles from 5 to 35 percent with a mechanimally tuned bandwidth from 90 GHz to 99 GHz. A variety of pulse coded millimeter wave radar applications can now be addressed where digital or chirp coding and high average power is required for long detection ranges and target classification.

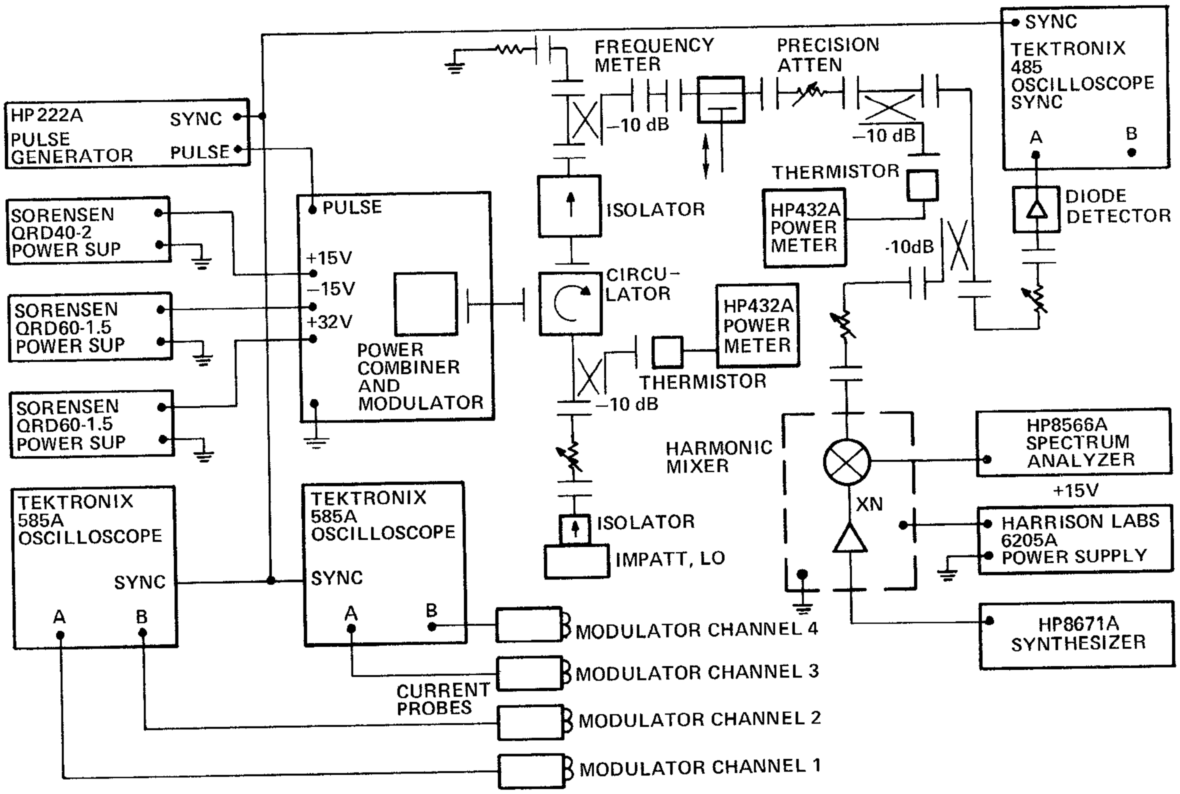


Figure 4 - Waveguide Measurement Network

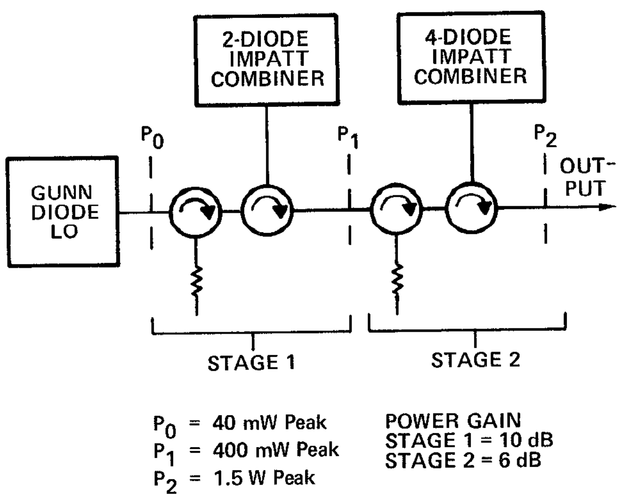


Figure 5 - Block Diagram of Transmitter With Stage Gain Indicated

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