CW InP GUNN DIODE POWER COMBINING AT 90 GHz

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Abstract

CW power combining of two, three, or four InP Gunn devices has been achieved at 90 GHz. Diodes were first characterized in individual radial line circuit modules. Modules with similar operating characteristics were stacked in-line to form power combining units. Greater than 1/4 watt was obtained from four InP diodes.

Introduction

With the advent of millimeter wave systems has come an increased demand for a low noise, high power source. In the past, GaAs Gunn devices have been used to provide low noise sources. The output power of these devices is limited by the low dc to rf conversion efficiency of GaAs at these frequencies.

InP is a superior material for millimeter wave Gunn oscillators. Studies show the peak-to-valley ratio of the velocity field characteristic of InP is significantly higher than that of GaAs. The transferred electron cutoff frequency of InP is predicted to be a factor of two greater than that of GaAs. Indications are that GaAs can operate in a fundamental mode up to 60 GHz, while InP can operate in a fundamental mode up to 110 GHz.[1] These factors suggest that InP should be a more efficient source of millimeter waves, increasing output powers obtainable from single devices. However, the performance of a single device may not be good enough to satisfy millimeter wave systems requirements. A viable choice is that of combining more than one InP Gunn device to increase output power.

This paper describes a simple approach to the CW power combining of two, three, and four InP Gunn diodes at 90 GHz. Single diode performance is presented first. The diode construction and radial line circuit configuration is then discussed. This is followed by a description of the multiple-diode, multiple-radial line, power-combining unit. The important features of diode characterization and selection will then be presented. The best results achieved with two, three, and four InP Gunn diodes are summarized. Greater than 1/4 watt was obtained from four InP Gunn diodes at 90 GHz.

Single Diode Results

The material used to fabricate diodes was grown by vapor-phase epitaxy. Three different device structures have been produced for operation at 90 GHz: (a) a two-layer structure; (b) a three-layer structure; and (c) a two-zone cathode. To date, the two-layer structure has produced the highest powers and efficiencies. Results reported in this paper were obtained using this device structure. It consists of an n+ buffer layer followed by an active layer doped in the $6\text{-}8\times10^{15}$ cm^{-3} range. Active layer thicknesses vary from 1.5-2.5 µm.

The material is processed into devices using an integral heat sink (IHS) technique. The finished devices consist of 75 µm diameter InP mesa on a gold or silver plated heat sink. The standard IHS process produces devices with an overall thickness down to 20 µm. A more advanced technique produces devices with thicknesses down to 10 µm.

Results in the 90-100 GHz range were obtained, using a radial line circuit configurationn like the one shown in Figure 1. The disk resonator is formed by the diode package flange on the bottom and a thin disk on the top. The disk rests on the cap of the diode package and is connected to the bias choke by a small diameter post. The sliding short behind the resonator is used to adjust the coupling of the resonator to full height WR10 waveguide.

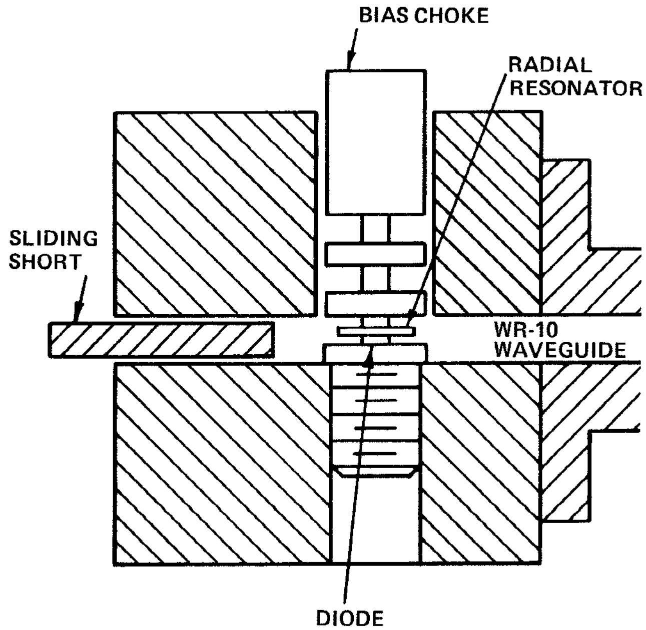

FIGURE 1. 90 GHz RADIAL RESONATOR CIRCUIT

The frequency of oscillation for this structure is strongly dependent on the diameter of the disk. For operation in the 90-100 GHz range, diameters from 1.90 mm to 2.16 mm were used.

CW results for single InP diodes operating in the 90-100 GHz range are shown in Table I. The best results exceed 100 mW at 90 GHz. DC to rf conversion efficiencies as high as 4.7% have been obtained.

Power Combining Approach

The approach chosen for combining multiple InP Gunn diodes was to stack radial line circuit modules in series. This approach has been attempted previously, using GaAs Gunn devices.[2] Figure 2 shows a circuit module with diode and choke next to a combining unit of four modules in line. The four modules are bolted to a mounting flange adapter for WR10 waveguide. Behind the modules is bolted a block containing the sliding short used for tuning the oscillators.

The modules were designed to have a spacing of multiple half wavelengths between the diodes. The guide wavelength at these frequencies is around 4 mm. Since the diode flange is 3 mm in diameter, a spacing of $\lambda g/2$ is not possible without modifying the diode package. Therefore, a wavelength spacing of $3\lambda g/2$ was attempted.

To allow for the range of frequencies to be encountered, thin waveguide spacers are used between each module to vary this spacing, insuring the correct distance between devices.

TABLE I
Performance of Single Diode InP Gunn Oscillators

DEVICE	F (GHz)	P_O (mW)	n (%)
EE211-1	89.5	125	3.27
EE198-380	89.6	107	3.48
EE198-395	90.1	100	2.80
EE198-380	93.1	91	2.96
EE198-384	93.15	79	2.81
EE198-382	94.48	71	2.48
EE198-390	94.8	68	2.5
EE198-392	94.9	63	2.4
EE198-390	100.5	44	1.52
EE196	89.7	35	4.7
EE271B-24	90.4	80	1.6
EE271B-26	90.5	72	1.9
EE271B-8	90.5	71	2.0

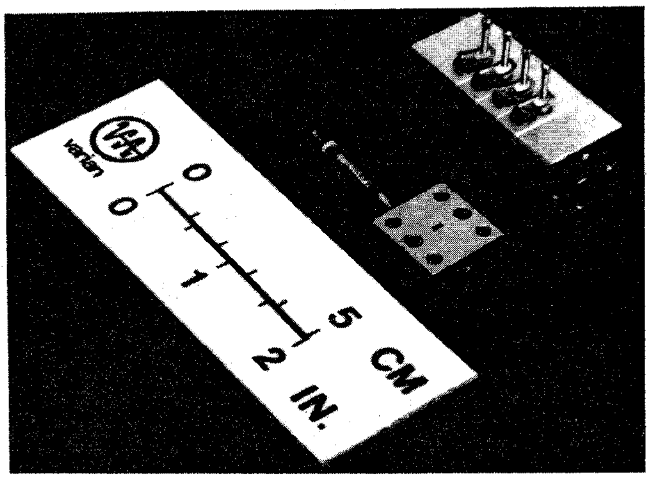

FIGURE 2. ASSEMBLY VIEW OF SINGLE DIODE MODULE AND FOUR MODULES STACKED IN-LINE

Diode Selection

A reasonably straightforward process was used to select devices for combining. Each device was tested separately in a radial line circuit module. Output power and frequency versus bias voltage were plotted for each oscillator. With these data, similar oscillators could be selected for power combining.

Figure 3 shows an example of these data. There are several important factors to note from these plots. Consider the frequency versus bias voltage curves. Each of the oscillators must operate within a common frequency range in order to combine. There is little chance of combining a module which operates near 90 GHz with one that operates near 100 GHz. Therefore, each module can only be operated within a limited range of bias voltages. Once this is established, consideration is given to the slope of the curve (i.e., voltage pushing factor). Consider a steep slope. This would give a large number of frequencies over a small interval of bias voltages and therefore make it easier to select other oscillators that may have a common frequency range. However, these types of modules are very sensitive to voltage. This makes it hard to set the operating voltage of the oscillators and keeps them in

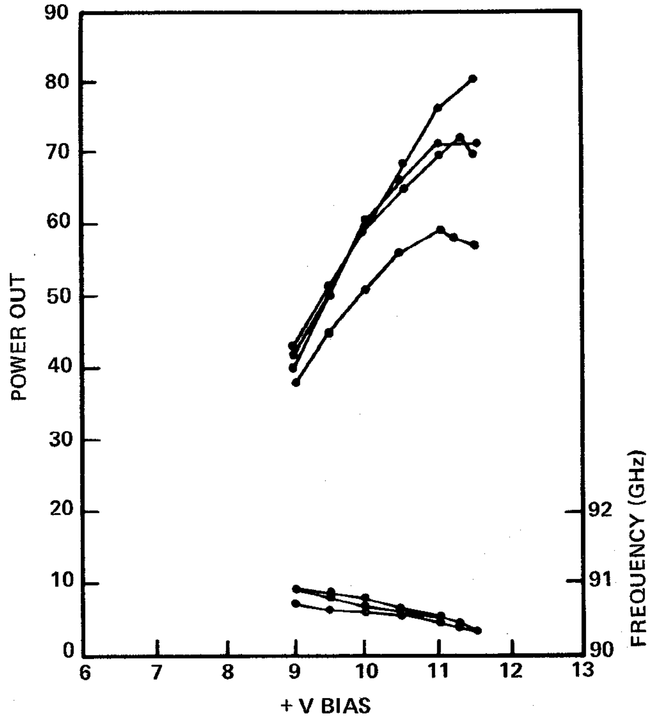

FIGURE 3. OUTPUT POWER AND FREQUENCY vs BIAS OF FOUR DIODES USED IN POWER COMBINER

lock. To overcome this problem, one may choose an oscillator whose frequency curve shows zero slope. However, finding another oscillator with a common frequency range becomes a near impossible task. Thus, the optimum frequency versus bias voltage curve is one that falls between these extremes. In the present work, oscillators with frequency versus bias voltage curves, having slopes between 200 MHz and 250 MHz, combined with high combining efficiency. Combining efficiency is determined by the ratio of output power achieved from a combining unit to the sum of individual peak powers of the oscillators when operated separately.

Another factor to note is the shape of the power versus bias voltage curves. A broad power peak is desirable as it indicates a greater range of bias voltages can be used and still obtain close-to-maximum output power. The peaks of these curves should occur in the range of common frequencies. This insures a greater probability of high combining efficiencies. The oscillators, whose characteristics are shown in Figure 3, combined for 260 mW at 90.5 GHz, with a combining efficiency of 93%.

An alternative way of looking at the diode selection process is to observe the power versus frequency variation of the individual oscillators. Figures 4 and 5 exhibit two sets of data like this. Figure 4 shows individual oscillator curves for a two-diode combiner. Both sets of data show a common range of frequencies which the oscillators operate within. The plots for the two-diode combiner show a large power variation over a narrow range of frequencies. This is indicative of a small voltage pushing factor (~ 150 MHz/V) and a sharp power versus bias voltage peak. The four diode combiner plots in Figure 5 show little power variation with frequency. This is indicative of their broad power versus bias voltage characteristics and larger voltage pushing factor (~ 230 MHz/V). As mentioned previously, this insures the least amount of difficulty when combining individual modules. This can be seen by the fact that the two-diode combiner of Figure 4 has an 85% combining efficiency, whereas the four-diode combiner of Figure 5 has a combining efficiency >100%.

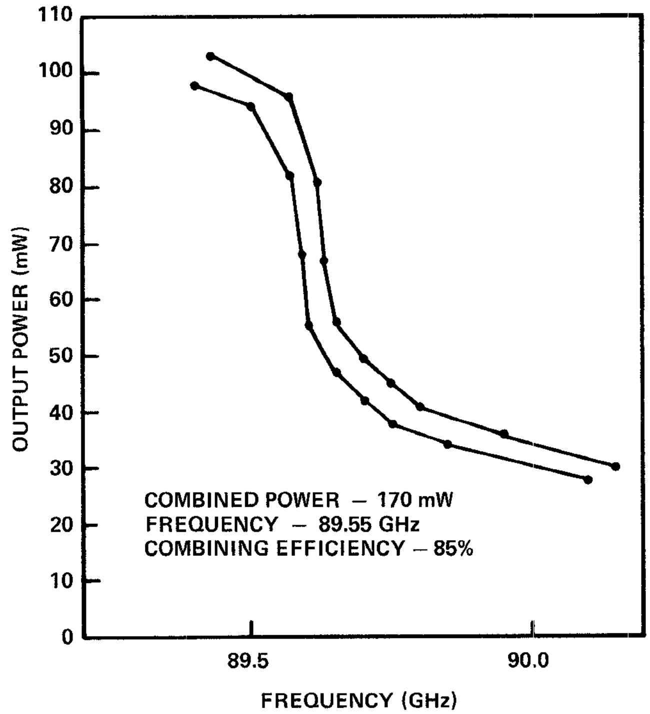

FIGURE 4. INDIVIDUAL OSCILLATOR POWER vs FREQUENCY CHARACTERISTICS FOR TWO-DIODE COMBINER

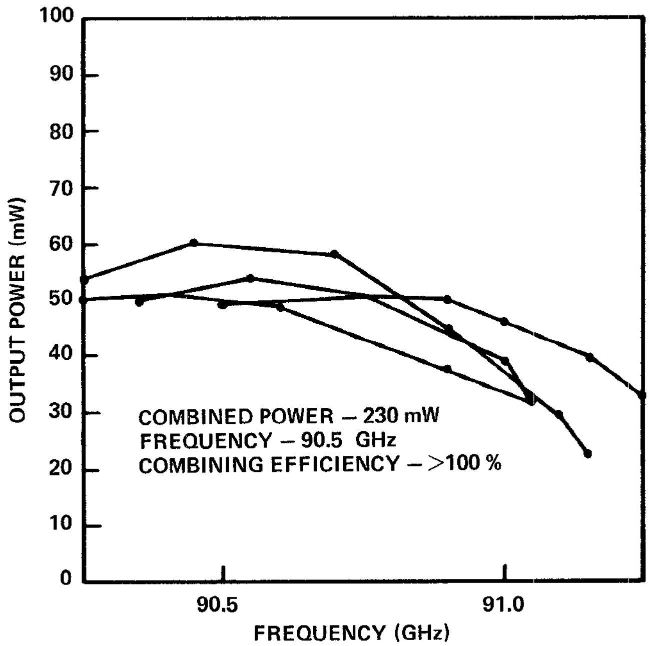

FIGURE 5. INDIVIDUAL OSCILLATOR POWER vs FREQUENCY CHARACTERISTICS FOR FOUR-DIODE COMBINER

The testing of diodes in individual cavities adds to the convenience of the combining process. With the above data taken, the device and circuit moduel are set aside while other devices and circuit modules are characterized. Once the selection of similar oscillators has been completed, the circuit modules can be stacked in line and bolted together. In this way, any error introduced by testing the devices in one circuit, then using another for the combining purposes, can be kept to a minimum.

Power Combining Results

Power combining of two, three and four diodes has been accomplished using this approach. Table II lists the best power-combining results achieved with two, three, and four diodes. With four diodes, a combining power of 260 mW was measured at 90.5 GHz, with a 93% combining efficiency. A three diode combining unit achieved 163 mW at 90.45 GHz with a combining efficiency of 96%. Using two diodes, a combined power of 170 mW was obtained at approximately 90 GHz, with a combining efficiency of 85%. Combining efficiencies greater than 100% have been obtained with both two and four diodes, as shown in Table II.

TABLE II
Power Combining Results

INDIVIDUAL PEAK PERFORMANCE				COMBINED PEAK PERFORMANCE			
Device	Frequency (GHz)	Output Power (mW)	DC to RF Efficiency (%)	Frequency (GHz)	Output Power (mW)	DC to RF Efficiency (%)	Combining Efficiency (%)
EE271B-8	90.50	71	2.02	–	–	–	–
EE271B-26	90.45	72	1.95	–	–	–	–
EE271B-31	90.53	59	1.00	90.50	260	1.60	93
EE271B-24	90.35	80	1.60	–	–	–	–
EE268-6	90.40	52	1.16	–	–	–	–
EE268-26	90.55	54	1.34	–	–	–	–
EE268-15	90.50	60	1.49	90.75	230	1.4	>100
EE268-22	90.75	51	1.20	–	–	–	–
EE271B-8	90.50	71	2.02	–	–	–	–
EE271B-12	90.60	44	1.12	90.45	163	1.41	96
EE271B-9	90.05	53	1.30	–	–	–	–
EE198-397	89.53	105	3.29	–	–	–	–
EE198-401	89.50	96	3.01	89.55	170	2.7	85
EE268-32	90.25	36	1.03	–	–	–	–
EE268-35	90.25	38	.86	90.6	84	1.1	>100

Conclusion

In conclusion, we see that a simple approach to power combining has been successful. Testing of devices in individual modules contributes to the convenience of the diode selection process which, in turn, simplifies the power-combining approach. Greater than 1/4 watt at 90 GHz can be obtained from four InP Gunn devices. It is conceivable that more than four devices can be combined in order to boost the output power even more.

Acknowledgements

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