120-GUNN DIODE POWER COMBINING AT 23 GHz

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by

Shizuo Mizushina and Mohammad Madihian

The Research Institute of Electronics
Shizuoka University

3-5-1 Johoku, Hamamatsu 432, Japan

Summary

Powers from a total of up to 120 Gunn diodes were combined at 23 GHz by combining three or five or seven 12- or 24-device Kurokawa oscillators through short-slot couplers in conjunction with high-level injection locking. Overall power combining efficiencies were 76-91 percent.

Introduction

It has been shown possible to combine, say, up to 30-40 devices at X-band freqencies[1,2] by the single-cavity multiple-device techniques of Kurokawa-Magalhaes[3] and of Harp-Stover.[4] Powers from several units of these multiple-device oscillators can be combined further by appropriate methods to increase the total number of devices combined.[5,6,7] This paper presents results of an experiment on combining powers from up to 120 K-band Gunn diodes by combining three or five or seven 12- or 24-device Kurokawa oscillators through 3-dB short-slot couplers in conjunction with high-level injection locking.

Principles of Operation

Fig.1 illustrates the combiner network that combines 2N+1 oscillators with N short-slot couplers to deliver a combined power, P_c, to a matched waveguide load at a frequency, f_c, where the couplers are indicated by the heavy lines. All the oscillators are designed and built to generate their maximum powers at f_c when operated into the matched waveguide load individually.

The combiner can be adjusted to operate at a desired frequency, f_c, as follows: First, operate the oscillator 1 alone at $f_1=f_c+\Delta f_1$ with $\Delta f_1=+5\sim+10$ MHz. Second, operate the oscillators 1 through 3 and tune the oscillators 2 and 3 to make the power at the output port of the combiner maximum while keeping frequency-locked conditions maintained. When the tuning is made properly as described in Ref.5, the oscillator 2(3) reflects almost all of the injected power, $P_1/2$, and generates its maximum power, $P_2(P_3)$, simultaneously. The sum of $(P_1/2 + P_2)$ and $(P_1/2 + P_3)$ is obtained at the output port of the first stage coupler. A small unbalanced power is injected back into the oscillator 1, and hence, Δf_1 is small. Subsequently, the oscillators 4 and 5 are brought into operation and are adjusted similarly, and so on. This technique has been successfully applied to multiple-device oscillators to increase the total number of devices combined.

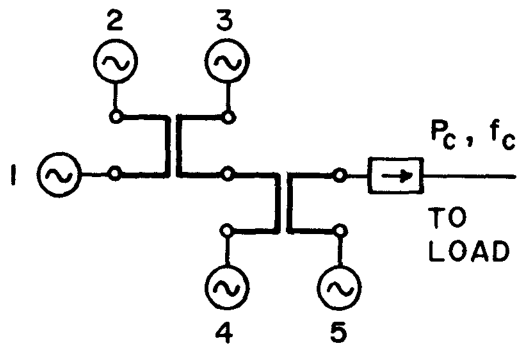

Fig.1. The (2N+1)-oscillator combining network with N=2.

Experiments

Ten 12-device Kurokawa oscillators were built using K-band GaAs Gunn diodes(New Japan Radio Co.) and used in our experiments. The diodes were tested in a post-mount waveguide (10.7 mm×4.3 mm) cavity and grouped into three groupes according to their optimum dc-bias voltages: 4.5, 5.0, 5.5 volts. The maximum output power from a single diode was 4 to 6 mW with an average at about 5 mW. From each group, diodes were taken in dozens and mounted in Kurokawa waveguide(10.7 mm×4.3 mm) cavity combiners. Positions of diodes and non-tapered stabilizing absorbers with respect to the waveguide cavity were adjusted and then proper output windows were selected for the maximum power, 48-72 mW, at 23.30 GHz. Power combining efficiencies at this combining stage, defined by the ratio of combined power and sum of individual diode maximum powers, were 90-93 percent. 24-device oscillators were also constructed by simply stacking pairs of the pre-adjusted 12-device oscillator modules and selecting proper output windows. The oscillation frequency was tunable over a 300-MHz range by means of a tuning screw in the waveguide cavity.

Three or five or seven(2N+1) of these multiple(M)-device oscillators were combined through N short-slot couplers as shown in Fig.1. Results are summarized in Table 1 and in Fig.2, where M×(2N+1)=36, 60, 72, 84, 120 diodes were combined at about 23 GHz. As described earlier, P_c approaches the sum of maximum powers from individual oscillators when tuned properly.

Table 1. Results of power combining experiments at 23 GHz using 12- and 24-Gunn-diode Kurokawa oscillators.

Exp. No.	Total No. of Diodes Combined	M×(2N+1)	f_c GHz	P_c mW	η %
1	36	12×3	23.46*	160	89
2	36	12×3	23.30	193	107**
3	60	12×5	23.31	242	81
4	72	24×3	23.32	323	90
5	84	12×7	23.30	382	91
6	84	12×7	23.30	362	86
7	120	24×5	23.47*	451	76
8	120	24×5	23.32	486	81

* Oscillators were adjusted for the mximum power at 23.45 GHz.
** Larger power oscillators were used.

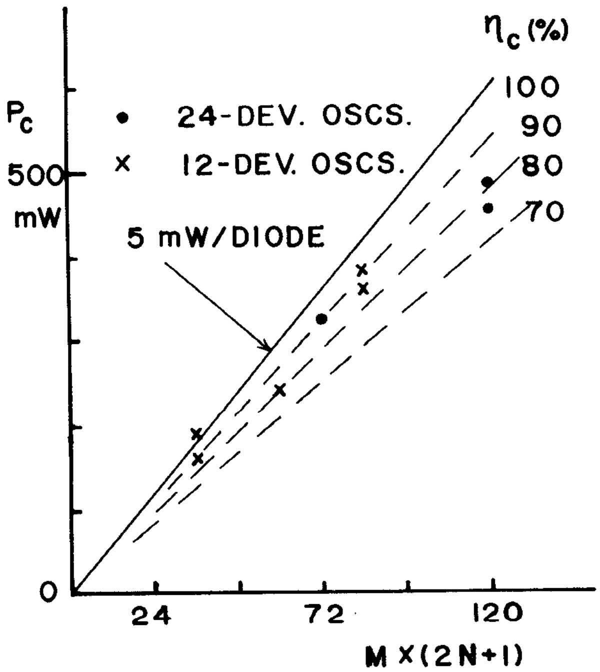

Fig.2. Combined power versus total number of diodes combined at about 23 GHz. Output power from individual diodes was about 5 mW on average.

The solid-line in Fig.2 corresponds to 5-mW per diode and can be interpreted as a 100-percent overall power combining efficiency line, roughly speaking. The 120-diode combiner, where all the diodes were biased by a common power supply, produced 486 mW at 23.32 GHz with an 81-percent overall combining efficiency. We have not tried to combine the diodes above 120 so far, but it appeared quite possible to extend the number to a 150-200 range.

Tuning characteristics of the 36-device combiner of Exp.1 in Table 1 were measured and results are presented in Fig.3. In this measurement, the combiner was first adjusted for the maximum power, P_{co}=160 mW, at f_{co}= 23.46 GHz, and then the oscillator 1 alone was tuned to tune f_c. The combined power, P_c, is given as a function of the frequency difference, $\Delta f_c = f_c - f_{co}$, in Fig.3.

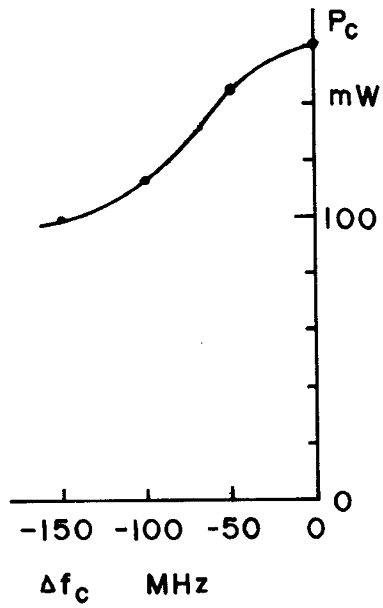

Fig.3. Tuning characteristics of the 36-device combiner of Exp.1 in Table 1.

Dependence of combiner operation on the dc-bias voltage was also measured on the same combiner. Results are represented by the P_c and f_c versus bias-voltage curves in Fig.4. Operation of all the combiners was found stable over a certain range of bias voltage when circuit adjustments were made properly.

Pulsed operation of the combiners was also found possible. An RF spectrum obtained from another 12×3=36-diode combiner operating under pulsed and primed conditions is shown in Fig.5. Conditions of the operation were: bias-voltage pulse height=6.5 volts, pulse width=2 μs, duty ratio=10 percent, frequency= 23.29 GHz, peak output power=325 mW, CW priming power=1.3 mW.

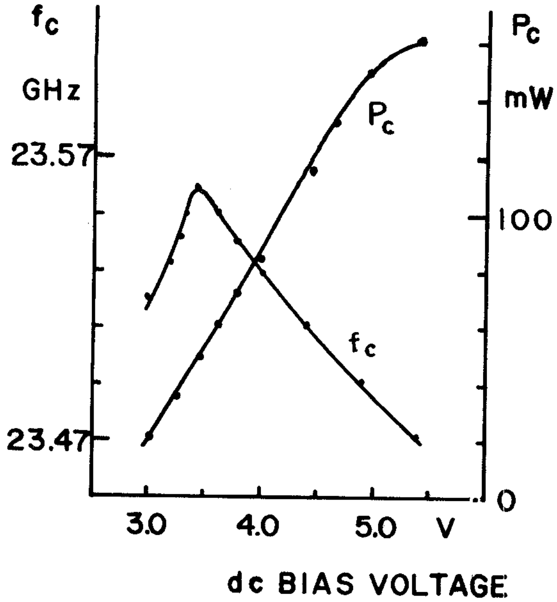

Fig.4. Combined power, P_c, and frequency, f_c, versus dc-bias voltage for the 36-device combiner of Exp.1 in Table1.

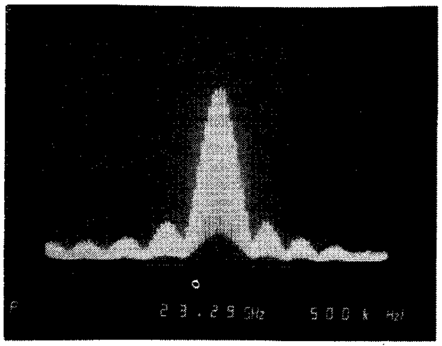

Fig.5. An RF spectrum of a 12×3=36-device combiner.
Pulse width: 2 μs. Duty ratio: 10 %. Peak output power: 325 mW.
CW priming power: 1.3 mW.
Frequency: 23.29 GHz.
Bias voltage pulse height: 6.5 V.

Conclusions

The (2N+1)-oscillator combining technique has been successfully applied to combine powers from several units of the single-cavity multiple-Gunn-diode oscillator of Kurokawa type to increase the total number of devices combined up to 120 at about 23 GHz. It appears quite possible to extend the number to a 150-200 range. The present technique will be readily applicable to other devices such as IMPATT as well as to other types of oscillators such as of Harp-Stover. Of particular interest for future works is application of the present method to millimeter waves.

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