MULTIPLE ELEMENT OSCILLATORS UTILIZING A NEW POWER COMBINING TECHNIQUE

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ABSTRACT

A new method to generate high microwave and millimeter wave power by combining the output of many two or three terminal devices is presented. This method forms a single resonant structure from many active devices, and therefore the combiner is stable and does not suffer from simultaneous multimode difficulties. This technique produces compact structures and is readily adaptable to monolithic integration. Experimental results from several power combiners utilizing Gunn diodes are presented.

INTRODUCTION

At millimeter and sub-millimeter wave frequencies individual solid state devices have a limited ability to produce microwave power [1]. In order to obtain higher power, it is very desirable to be able to combine the power generated from many separate devices [2]. The typical method employed to combine microwave power from active devices employs some manner of locally resonating the individual active elements. These "tuned" units are then ganged together in some one or two dimensional structure capable of adding their powers. Typical configurations place the devices on hybrids [2], at half-wavelength spacings [3], form ring structures with a common load at the center [4], or employ quasi optical techniques [5,6].

In this paper we present a new combining technique which achieves resonance from the incorporation of the reactive or susceptive elements of the individual gain elements (diodes or transistors) into a filter like structure. The advantage of this technique is that the oscillation is very stable and no simultaneous multimodes are excited. Also due to the fact that the complete structure acts as a single resonator, wide-band frequency tuning of such an oscillator is possible.

To demonstrate the idea, a two, three and four device combiner utilizing Gunn diodes was designed and fabricated. Also a four diode structure was constructed using Rucker's combining technique [4] used as a second level combining circuit. Experimental results for these circuits are presented.

THEORY

The power combining technique proposed herein is similar to the construction of direct coupled waveguide cavity filters. This technique can be illustrated by considering a two device structure. Fig. 1 displays two negative resistance devices, presumed essentially identical, spaced a distance l apart on a transmission line. The distance l determines the resonant frequency of the structure for given device susceptances and is chosen such that the susceptive components of the devices cancel. Incorporation of the microwave equivalent circuit for a negative resistance device into the structure of Fig. 1 yields that shown in Fig. 2 where it is assumed that the values of $-G_{1n}$ and jB_{1n} are those appropriate at the desired oscillation frequency normalized to the line's characteristic impedance. The length of the transmission line "l", is chosen such that $-G_{1n} + jB_{1n}$ i.e. the admittance of the first device is transformed to $-G_{1n} - jB_{1n}$ at the operation frequency. By placing another device having the same admittance at the other end of the line, the total admittance of the structure becomes $-2G_n$. The terminating load admittance G_L is chosen for the maximum power transfer. The similarity of Fig. 2 to that for a single cavity microwave filter suggests that analogues to multiple cavity filters might also be considered as extended resonant

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structures utilizing multiple devices. For example, Fig. 3 shows a three device combiner as an extension to the above discussion. The susceptance of the middle device, jB_{2n} should be twice the susceptance of the first and the last device ($jB_{2n} = 2jB_{1n}$). This extra susceptance can be provided by connecting a stub to the port of the middle device. In design of MMIC circuits, the middle device can be fabricated to have twice the area of first and the last device, therefore the need for the stub can be eliminated. The case of a N device combiner is exactly similar to that of three device combiner (the susceptance of all the devices should be twice the susceptance of the first and the last device).

As the number of devices in the combiner increases, the negative resistance of the structure drops. In general this can set a limit to the number of devices that are power combined in a single structure. This is due to the physical dimension of the matching transformer required and circuit loses involved. A method to avoid this limitation is shown in Fig. 4. Assuming the conductance of each device normalized to the line impedance is $-G_n$, the total negative conductance of a branch consisting of N devices is $-NG_n$ (i.e. negative resistance of the branch is 1/N of the negative resistance of a single device). A quarter wave line can then be connected to each branch to transform its conductance to $-1/(NG_n)$. The negative resistance of a single device can be recovered by connecting N branches to each other (i.e. $N(-1/NG_n) = -1/G_n$) using Rucker's method [4] as a second level combiner. This structure (containing N^2 devices) then in turn can be used as a building block to construct a larger combiner. Using this method one can combine the power generated from many devices and simultaneously maintain the output impedance at a desirable level so that the choice of the resistive load for satisfying the oscillation condition will not be a limiting factor.

EXPERIMENTAL RESULTS

Several planar power combining structures were fabricated on Duroid™ substrate with a dielectric constant of 2.3 and thickness of 31 mils. The active elements are X-band low power (10 mW) Gunn devices with dc to rf conversion efficiency of 2% and a typical bias voltage of 10 volts. Results from a two, a three and a four device power combiner are presented. To illustrate the structures, Figs. 5a and b show a two and a three Gunn diode combiner. Biasing is accomplished through a bias tee connected to the output of these structures. This is possible due to the lack of sensitivity to individual device admittances. The model for the Gunn diode is shown in Fig. 6. The table below shows the output power and frequency of operation of the two, three and four diode combiners.

# of devices	Frequency (GHz)	Power (dBm)
Two-diode	9.2	16.9
Three-diode	9.5	19.1
Four-diode	9.1	20.2

It should be mentioned that no adjustment was performed to optimize the circuits' performance and the active devices were not matched. The variation of the output power and oscillation frequency for these power combiners are shown in Figs. 7a, b and c. Due to the fact that the complete power combining circuit forms a single resonant structure, the circuits are very stable and are not sensitive to bias voltage variation. These structures appear very attractive for the design of high power, frequency tunable sources. The maximum frequency tuning bandwidth for the two, three and four diode combiners are 920, 816 and 572 MHz. Frequency spectrum of the three diode combiner is shown in Fig. 7. Phase lock was maintained with bias variations as high as 50% and no discontinuities were observed in frequency or power. These results are supported by the large signal simulation of the combiner using Spice. In order to maintain the power level while varying the frequency, these structures could be loaded with varactor diodes at each device port. Based on the small signal analysis a 50% variation in device capacitance results in more than 600 MHz frequency variation.

A Rucker type power combiner [4] for second level power combining was fabricated. It utilizes a four-diode structure containing of two, two-diode resonator branches as shown in Fig. 8. An output power of 18.8 dBm at 9.9 GHz was obtained. This result is important since it demonstrates that the technique presented here can handle very large number of devices by using a Rucker type combiner as second level combining circuit.

CONCLUSION

Based on a new power combining technique which forms a single resonant structure out of many negative resistance devices, several planar power combiners are designed and fabricated. These structures are stable, they do not suffer from simultaneous multimodes and are not sensitive to bias and device parameter variations.

ACKNOWLDGEMENTS

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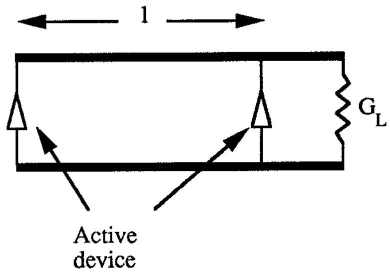


Fig.1 A two device power combining structure

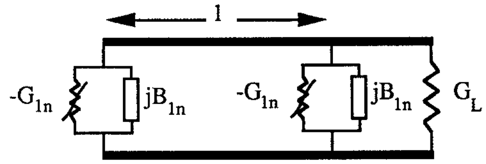


Fig. 2 A two device combiner

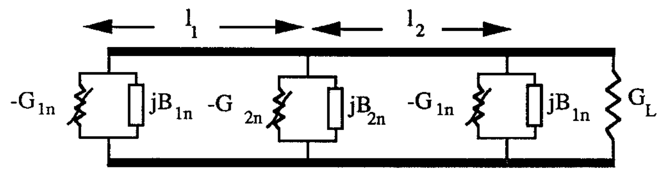


Fig. 3 Equivalent Circuit for the three device Combiner

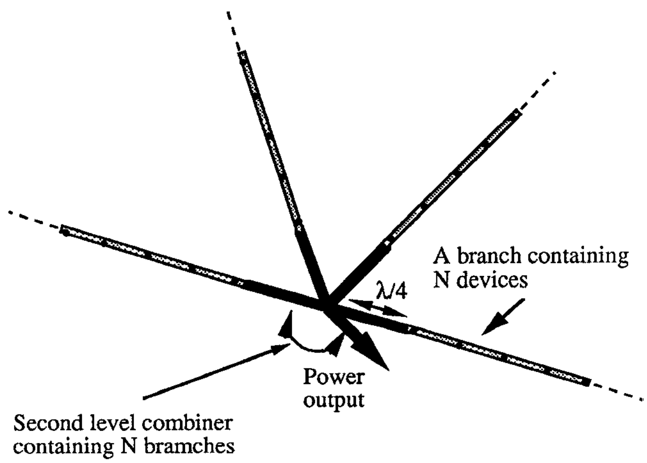


Fig. 4 A method to combine power from many devices and to maintain the output impedance at a desirable level.

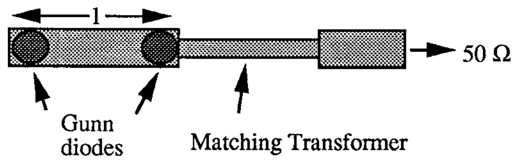


Fig. 5a A two diode planar power combiner

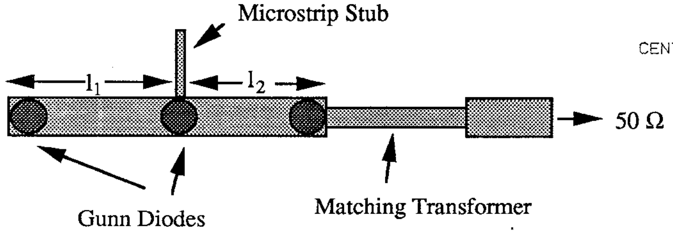
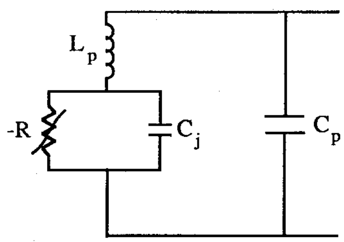


Fig. 5b A three diode planar power combiner



-R=370 Ω, Cj=0.1 pF, Lp=0.5 nH, Cp=0.18 pF

Fig. 6 Small signal equivalent circuit for the Gunn diode

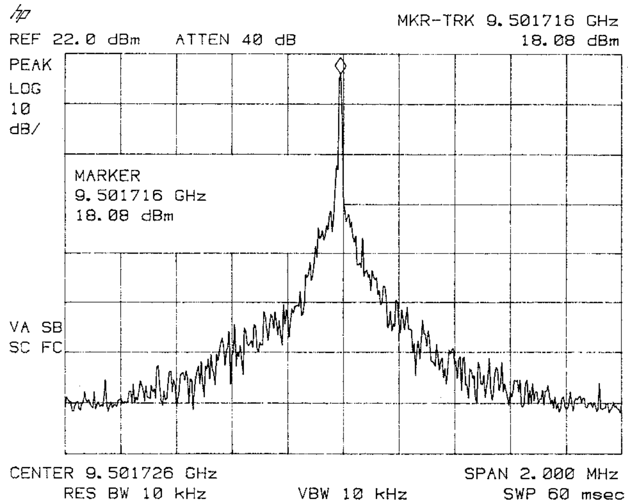


Fig. 7 Frequency spectrum of the three device combiner

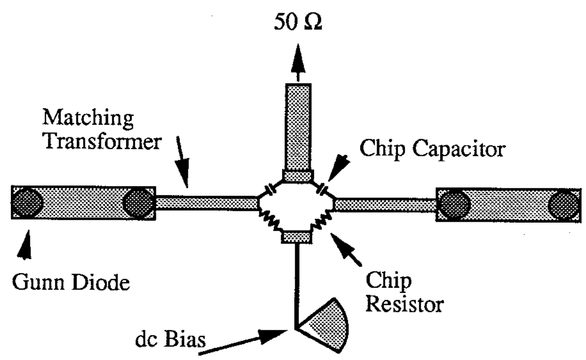


Fig.8 A four diode planar power combiner using Rucker's combiner as a second level combiner.