ACTIVE MICROWAVE POWER COMBINER/DIVIDER USING A DUAL-GATE MESFET

J. J. Pan
Harris Corporation
P. O. Box 37
Melbourne, Florida 32901
Telephone: (305) 727-4074
727-4451

ABSTRACT

An active power combiner/divider using a gallium arsenide (GaAs) dual-gate metal semiconductor field-effect transistor (MESFET) is presented herein. This new component is feasible for monolithic microwave integrated circuit (MMIC) fabrication, and provides the advantages of amplification gain, both amplitude and phase adjustability, and reverse isolation.

Introduction

The phased-array and multibeam antennas for communications and radar systems require a variable power combiner/divider for phase shifters, complex weights, and switching applications. To minimize the cost as well as the size of the large array, these combiners/dividers should be fabricated in the configuration of an MMIC, using GaAs, indium phosphide (InP) or other III - V semiconductor compounds. The conventional passive power combiner/dividers, including the Wilkinson slitter, interdigital coupler, rat-race hybrid, edge coupler, and branch-line coupler, are large in size, and are not feasible for MMIC fabrication. Passive microstrip components have additional disadvantages: no gain, insertion and dividing losses, lack of reverse isolation, and absence of adjustability.

On the other hand, an active power combiner/divider using the GaAs dual-gate MESFET provides a forward amplification gain and a reverse isolation. The new component also offers both magnitude and phase tunability among ports by simply adjusting the device bias. Many other microwave components, such as balanced mixers, balanced amplifiers, phase shifters, demodulators, channelized filters, frequency discriminators, and switches, can be directly derived and fabricated from the active combiner/divider, with a resultant insertion gain.

Operation Principle and Circuit Design

The basic configuration of a power combiner using a dual-gate MESFET is illustrated in Figure 1. Gate 1 and gate 2 are two input ports, and the drain serves as the output. For power divider application, gate 1 splits the input signal into gate 2 and the drain.

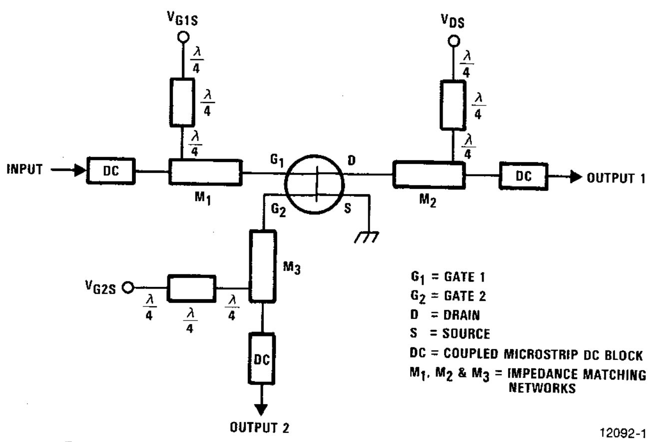

Figure 1. Block Diagram of the Active Power Combiner Using a Dual-Gate MESFET

It is feasible to consider the dual-gate MESFET, similar to a vacuum tetrode, as two single-gate devices. The single-gate MESFET has been used successfully in the low-noise, wideband amplifier design. Figure 2 depicts the equivalent circuit of the dual-gate FET. The characteristics of the amplification modes strongly depend upon the bias conditions of FET_1 and FET_2. The transconductance, $g_m k$, and the drain conductance, g_d, of the device at the first gate input vary with V_{G1S}, which is a function of V_{G2S}. The feedback of a dual-gate FET is smaller than the single-gate, and will result in a higher gain and a better stability. The reverse transmittance dual-gate FET is:[1,2]

$$(y_{12})_{dual} = -j\omega C_{gd1} \frac{g_{d2}}{g_{m2}} - j\omega C_{th} \qquad (1)$$

which is reduced by a factor g_{d2}/g_{m2}, when compared to the single-gate FET. The maximum stable gain (MSG), maximum available gain (MAG), and the stability factor, k, can be computed from the three-port S-parameter or by the circuit elements. Analytically stated,[1,2]

$$(MSG) = (MSG)_1 \cdot (MSG)_2$$
$$\frac{g_{m1}}{\omega C_{gd1}} \cdot \frac{g_{m2}}{g_{d2}} \qquad (2)$$

and

$$k_{dual} \simeq k_1 + 2 \frac{\omega C_{gs2}}{g_{m2}} \qquad (3)$$

Equations (2) and (3) indicate that the gain stability of dual-gate FET's are outperforming the single-gate device over a wide frequency range.

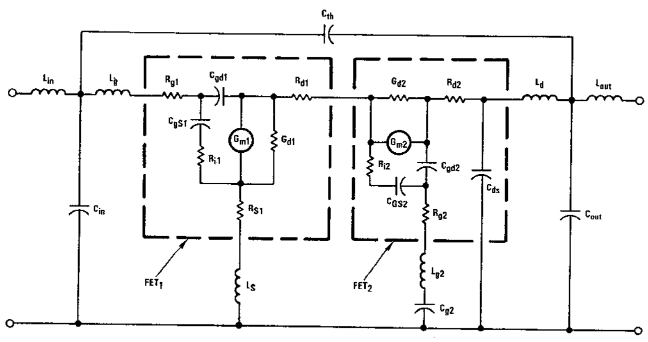

Figure 2. Equivalent Circuit of Microwave Dual-Gate MESFET Which Represents Two Single-Gate FET's

The dual-gate MESFET can be considered as two single-gate MESFET's with different stable gain factors at different G1 and G2 bias conditions. Therefore it is conceivable that a power combiner/divider can be constructed by properly arranging the input/output port. With the bias adjustability both amplitude and phase among the input/output ports are tunable and can be optimized according to the system requirement.

The gain, phase, and stability factors of the active combiner or divider can be calculated and optimized using the device's 3-port S-parameter. The measurement and computation formulas of the 3-port S-parameter may be found elsewhere.

Commercially available Plessey Dugat 10/000 and NEC NE463 packaged dual-gate devices were used in the investigation at X-band. These devices have an f_{max} of 50 GHz. The active combiners/dividers are fabricated on an alumina substrate which is 25 mils thick. The direct current blocks with flat response and 0.2 dB insertion loss are built with symmetrically coupled microstrip lines. Three individual biases are applied to G1, G2, and D through $\frac{\lambda_g}{4}$ high-low-high impedance lines. The impedances are conjugately matched and optimized using an S-parameter. One of the active combiners/dividers is illustrated in Figure 3.

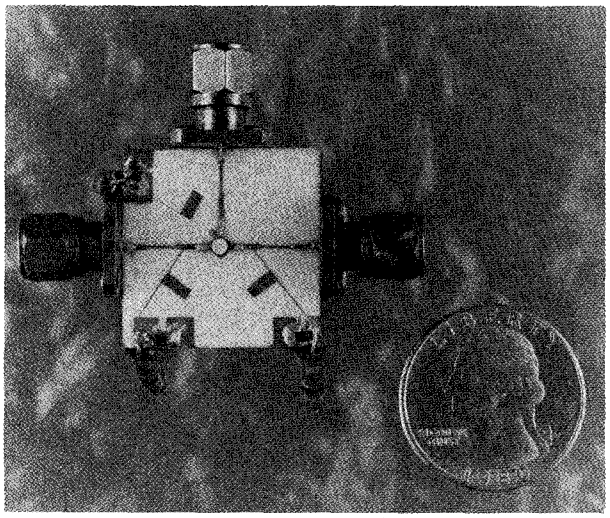

Figure 3. X-Band Dual-Gate MESFET Active Power Combiner/Divider

Experimental Results

The active combiners/dividers were characterized by the HP automatic network analyzer at different bias conditions over a frequency of 7.25-7.75 GHz. The data indicates that the amplitude and phase are adjustable by varying the bias condition. The power divider, using the Plessey Dugat 10/000, biased at V_{DS} = +3.0 V, V_{G1S} = -1.45 V and V_{G2S} = +3.5 V, provided an almost equal power split at G2 and D, with a peak gain of 4.5 dB and a reverse isolation greater than 18 dB. These results are presented in Figure 4. When the bias changes to V_{DS} = +3.0 V, V_{G1S} = -1.25 V, and V_{G2S} = +0.5 V, the peak gains become 8.3 dB at G2 and 6.5 dB at the drain.

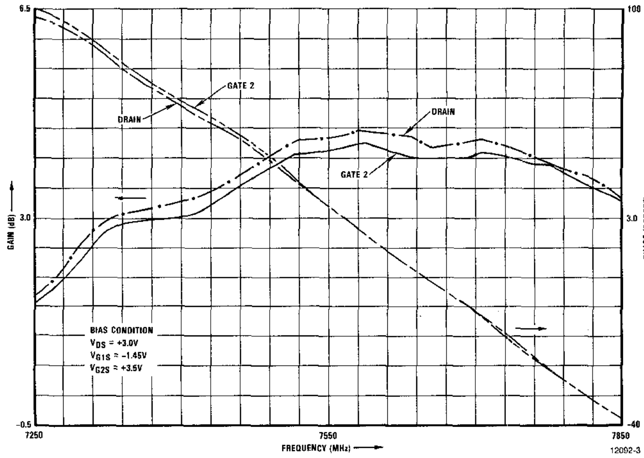

Figure 4. Active Power Divider Using Plessey Dugat 10/000 Dual-Gate MESFET

When two equal power signals are simultaneously applied to G1 and G2, a peak gain combining power gain of 7.9 dB emerges at the output of the drain. The bias condition was V_{DS} = +4.0 V, V_{G1S} = -2.6 V and V_{G2S} = -1.6 V.
The active combiner/divider also has been tested as a single-pole, double-throw switch in X-band. The device provides a 10 dB power gain at "on" mode and a -19 to -24 dB loss at "off" mode, at a bias of V_{DS} = +4.0 V, V_{G1S} = -2.0 V and V_{G2S} = -0.7 V.

Conclusion

An active power combiner/divider using a GaAs dual-gate MESFET has been designed, fabricated, and demonstrated. Demonstrations revealed several advantages of active encounters over passive encounters. Some extremely attractive characteristics of the active power combiner/divider exist in the areas of amplification gain, reverse isolation, and phase and amplitude adjustability. For MMIC fabrication, impedance matching and bias stabilization can be achieved by using active devices which will not be a burden to the cost of the MMIC. Consequently, the miniature phase shifters and complex weights for low-cost phased arrays result. Cascading multiple dual-gate FET's, an active N-port divider, a combiner, or a multichannel channelized power divider becomes realizable.

Acknowledgement

The author would like to express his gratitude to M. G. Kunz for his fabrication and measurement efforts.

References

1. S. Asai, F. Mural and H. Kodera, "GaAs Dual-Gate Schottky-Barrier FET's for Microwave Frequencies," IEEE Trans. on MTT, Oct. 1975, pp. 897-904.

2. J. J. Pan, "Variable Gain Dual-Gate MESFET Amplifier for Adaptive Phased-Array Application," Internal R&D Report, Harris Corporation, July 1978.