BALANCED DUAL GATE GaAs FET FREQUENCY DOUBLERS

by

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Abstract

A new technique for broadband microwave power generation is presented: The balanced dual gate MESFET frequency doubler. Design and results for 18-26.5 GHz and 4-23 GHz doublers are presented.

Introduction

Power generation above 18 GHz is very costly and tedious, and results in either low power with poor frequency stability (Gunns, Impatts), medium power with low reliability (BWOs), or high power with poor bandwidth capability (other tubes). A new medium power technique which can take advantage of the better frequency stability of microwave bipolar oscillators at higher frequencies by frequency multiplication is the balanced dual gate MESFET frequency doubler. I will present design considerations and results for two circuits.

Device Characterization

The first step in any active design is to characterize the devices one wishes to use. With the method reported earlier,[1] I performed a harmonic load-pull characterization on an in-house 1 x 400 micron GaAs dual gate MESFET. The results are shown in Figure 1 for all possible passive loads presented to the drain of the FET at 6 GHz as a function of power extracted through 50 Ω at 12 GHz.

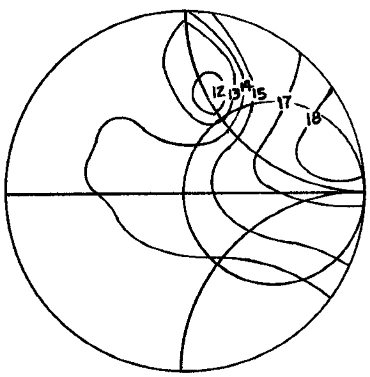

Figure 1: dual gate GaAs FET 2fo power vs. fo load Vds=5V, Vgs=0V, Vg_2=2.8V, Pin= 15dBm @ 6GHz Z(2fo)=50Ω

The optimum load at fo is an open circuit shifted by the conjugate of the FET's output capacitance. If we look at the I-V characteristic of the FET (Figure 2) we can get a good feeling for the mechanism of doubling. With an open circuit loadline, a very small input voltage swing results in a very large distorted output swing. The FET is acting as an active half-wave rectifier. The optimum load at 2 fo is, conveniently, 50Ω.

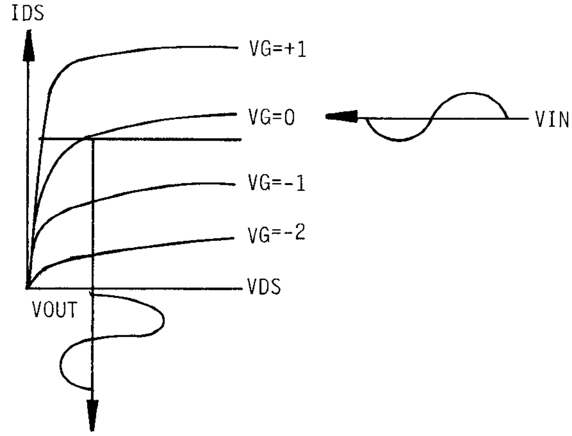

Figure 2: I-V characteristics and open circuit load line for GaAs FET

Balanced Operation

If we hook up two devices as shown in Figure 3, we can achieve significant performance and circuit realization advantages over a single-device multiplier.[3] With the input signals 180° out-of-phase, the outputs at fo and all odd harmonics will also be 180° out-of-phase. Hence, any combining point will be a virtual ground which will (ideally) null these signals out. Only even harmonics can pass such a point.

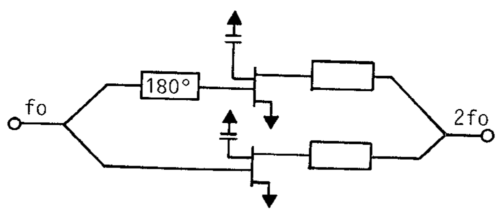

Figure 3: Balanced doubler circuit

Also, a virtual ground represents an excellent RF ground, so we can have independent matching conditions for odd and even harmonics. We rotate the virtual ground through a length of transmission line to achieve any pure reactive phase we desire; in the doubler case, this is the "conjugate open". Since the combining point is common-mode for 2 fo, we can achieve whatever impedance we want here by matching after this point. The only difficult design problem for this circuit is the 180° phase shifter.

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Baluns

Two Balun structures were investigated for this application; the 3-wire phase splitter, and the Wilkenson/4-wire phase shifter combination. These are shown in Figure 4.

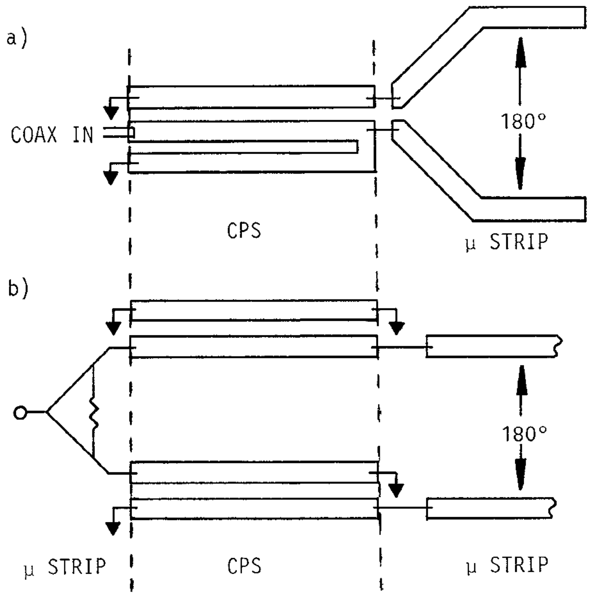

Figure 4: Baluns - a) 3 wire b) 4 wire

The 3-wire device works by inducing a 180° out-of-phase current in the coupled arm, which also serves as part of the ground shield for this coplanar waveguide. Note ground and center-conductor currents are 180° out-of-phase in such a system. The amplitude splitting is adjusted by spacing and is optimum when the system is matched. In the four wire case, amplitude splitting is achieved with a Wilkenson power divider and the phase splitting in a coplanar strip section, where "center-conductor" and ground are swapped on one side but not on the other. The three wire system is the most compact but limited to 2.5:1 bandwidths, where the four wire system is capable of decade operation, but it is large and, hence, more lossy.

Doubler Circuit (18-26.5 GHz)

The 18-26.5 GHz doubler is shown schematically in Figure 5.

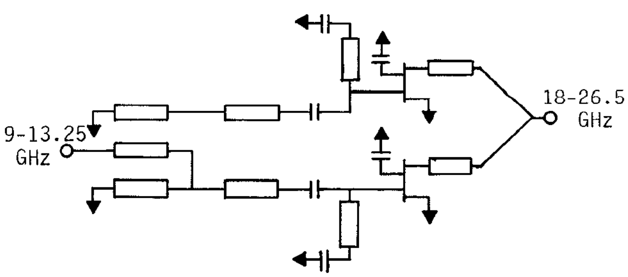

Figure 5: 18-26.5 GHz doubler circuit

The 3-wire balun was chosen for its compact and low-loss qualities. Matching into the devices is like matching to an amplifier; we want to deliver maximum fo power to each device. The impedance presented to the input at 2 fo is irrelevant.[1] The output match is achieved as mentioned above. The performance of this circuit is shown in Figure 6 for three different input powers.

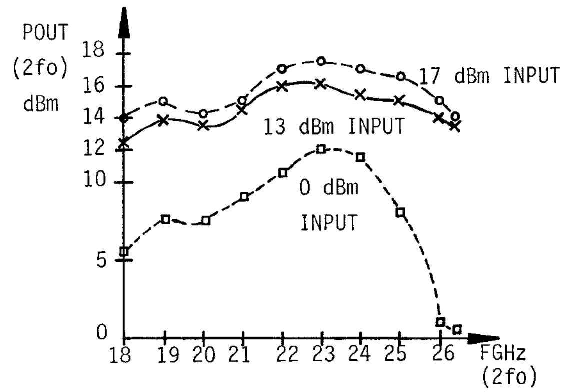

Figure 6: 18-26.5 GHz doubler results for various input powers

At 0 dBm in, we have greater than unity gain conversion over the full band with 12 dB gain at midband. As we increase the input to 13 dBm, we still have unity or greater conversion, with significant compression. At 17 dBm in, we have full compression but 14 dBm minimum output. The signal at 3 fo is -35 dBc due to the balance. The signal at fo is -15 to -25 dBc, but is not a problem since the doubler operates into a waveguide which cuts off this component. All higher order harmonics are easily removed by filtering. Note that both devices draw about 80 ma at 5 volts, so the peak power-added efficiency is around 7%.

Doubler Circuit (4-23 GHz)

In order to remove balun limitations and move toward a monolithically integrated structure, an active phase splitter was developed. This is shown along with a broadband doubler circuit in Figure 7.

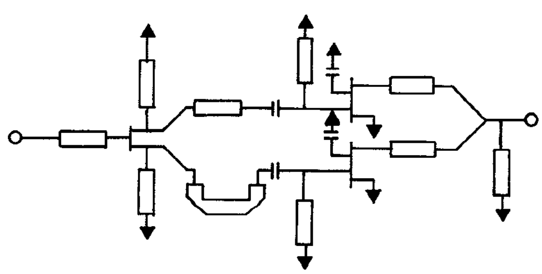

Figure 7: Active phase-splitter/doubler circuit

The phase splitter is derived from a conventional audio phase-splitter. The only difference is that some differential phase shift must be added at microwave frequencies to compensate for Cgs not being equal to Cgd. This phase splitter has 3dB gain and 180±5°

phase shift from 2-12 GHz. I used a .5 x 350 micron GaAs FET for this application. The performance of the total circuit is shown in Figure 8 for +10 dBm input.

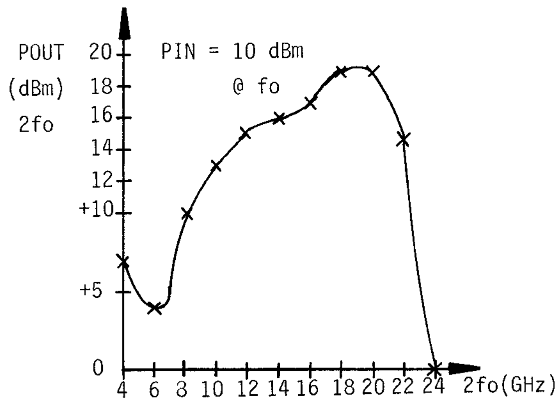

Figure 8: Active doubler results

The input and output circuits were optimized for the 10-20 GHz output range, hence the shape of the output characteristic. Even so, there is greater than unity conversion gain from 8-23 GHz with a peak near 20 dBm output at 20 GHz. This circuit suffers from a lack of isolation from source to gate in the phase-splitter; this causes a phase ripple which hurts the odd-order harmonic rejection. This could be helped by placing the phase splitter very close to the doubler devices to eliminate standing waves, something easily done monolithically.

Conclusion

In conclusion, I have shown a new technique for power generation; the balanced GaAs dual gate MESFET frequency doubler. This circuit shows promise for applications above 18 GHz in that a lower frequency highly-stable bipolar oscillator could be multiplied upwards in frequency with a resulting phase noise benefit over fundamental oscillators at these frequencies. Also, the output power of this device compares favorably with any other broadband device available. The potential for monolithic integration shown could be of benefit in the push to still higher frequency ranges.

Acknowledgements

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