ULTRA LOW CHIRP GaAs DUAL GATE FET MICROWAVE OSCILLATORS

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ABSTRACT

Pulsed RF oscillators using dual gate gallium arsenide FETs have been realised in X and J band frequencies. These oscillators have excellent chirp characteristics. The dual gate MESFET properties which provides such chirp performance are discussed together with experimental results. Further work which needs to be undertaken to improve the performance of these oscillators for practical applications is outlined.

INTRODUCTION

During the last several years solid state microwave devices have achieved considerable technical importance. They have made possible many novel applications in radar techniques for measurement of range and velocity and have enabled utilisation of these systems for many commercial non-military applications.

The problem to resolve when a microwave power source is used is the unambiguous determination of the range and/or velocity of the target remote from the sensor. The properties which may be used to characterise target behaviour are frequency, phase and time delay. These parameters are compared between the transmitted and received signals to obtain range and velocity information about the target.

Doppler frequency shift provides an accurate technique for the measurement of target velocity for many applications. In CW Doppler radar systems the Doppler shift is proportional to the axial component of the velocity and is therefore related to the difference between the transmit and receive frequency. Pulsed RF systems are capable of providing both the target velocity and range information. The transmitted and received signals when mixed generate the IF signal with the appropriate Doppler modulation impressed upon it. One transient effect which can cause problems in pulsed RF systems is the frequency change during the RF pulse due to changes within the microwave device. This phenomenon is commonly known as chirp, and has to be minimised if it is a significant fraction of or much larger than the receiver bandwidth. Extremely elaborate and expensive techniques have to be employed to minimise the chirp.

For security applications microwave devices are used as intrusion alarms with a selection of antenna beam widths enabling a range of areas or perimeters to be protected. For perimeter protection a "microwave fence" can be used, which usually consists of a low power pulsed Gunn oscillator connected to a narrow beam width antenna pointing along the perimeter to be protected. A detector and tuned amplifier act as receiver. Any interruption of the beam causes the alarm circuits to trigger. It is however, not possible to obtain very good chirp performance with Gunn oscillators because of temperature changes within the device. An alternative technique which has been implemented uses a PIN diode switch connected between the oscillator and the antenna. By appropriately switching the PIN diode desired pulsed r.f. output can be obtained. This method circumvents the problem of frequency variation during the pulse but at the expense of increased component count and current drain from the d.c. power source. The latter can be a very significant drawback for portable systems working on batteries.

In this paper a novel approach for obtaining low power pulsed r.f. oscillators with very low frequency variation within the pulse is demonstrated. This approach uses the dual gate GaAs field effect transistor and indicates yet another application avenue for this extremely versatile microwave solid state device. This paper outlines the design philosophy for the dual gate pulsed FET oscillator, discusses circuit design techniques and performance of the oscillator. Possible applications of such a source are pointed out and future work for making further improvements to these oscillators is indicated.

DESIGN PHILOSOPHY

The GaAs FET device in recent years has proved to be quite attractive for oscillator applications. A number of publications have appeared in the recent years demonstrating their high efficiency, electronic tunability and ease of operation (1-3). A conventional single gate GaAs FET oscillator can also be easily pulse modulated through the gate or drain terminal. The pulse amplitude levels have to be such as to quench the oscillations. For negative pulses to the gate, the pulse amplitude need not be up to pinch-off level because in most cases the inherent gain of the device falls to such a low value that steady state oscillations can not be sustained. A conventional single gate GaAs FET oscillator when pulse modulated by drain or gate terminals, however, indicates large frequency variation within the pulse and thus renders such oscillators unsuitable for practical applications. The cause of this will be apparent later.

The GaAs dual gate FETs however have an inherent property which make them extremely suitable for low chirp pulsed r.f. oscillator applications. This property can be best illustrated by considering a simple physical model of the dual gate FET. Fig. 1 shows the cascode equivalent of a dual gate FET. If the first FET containing gate 1 is used as an active element for obtaining steady state oscillations; the second FET containing gate 2 can be operated as a high speed switch to obtain pulsed r.f. output. This can be easily done by applying a negative pulse to the second gate.

Plessey dual gate GaAs MESFET DUGAT 10000 devices in chip form were used in the work reported here. These devices have two 1 x 300μm gates obtained by conventional photolithography technique and etched channel processing. For a grounded source configuration the device gain as a function of second gate voltage is shown in Fig. 2. The maximum gain is obtained at a drain current of approximately 15 to 20 mA which is achieved by controlling the first gate bias level. As the second gate voltage is increased the gain of the device decreases rapidly (Fig. 2) due to reduction in the internal gain of the device. Alternatively, one can visualise that the second FET (Fig. 1) is acting as an attenuator as its gate bias is increased.

Table 1 indicates the magnitude and phase of the gate 1-to-source and gate 1-to-drain scattering parameters S_{11} and S_{31} for different gate 2 bias levels. It can be seen that as the second gate voltage is increased from 0 to -0.9V the phase of the input reflection coefficient remains virtually unchanged while the forward gain of the device decreases by as much as 6 dB. This minimal phase change in S_{11} maintains the operating frequency. However, the phase of S_{11} changes very rapidly beyond this level as V_{G2} is biased towards pinch-off. But this phase change does not give rise to any change in oscillation frequency because the gain of the device has fallen significantly to be not able to sustain oscillations. Thus these two factors; minimal phase change in S_{11} and reduction of gain $|S_{31}|$ act in unison to result in minimal frequency change during the pulse.

On the basis of the above discussion low chirp GaAs dual gate FET pulsed r.f. oscillators can be realised by incorporating feedback and matching elements between gate 1 and source. The drain source port is coupled to the load while modulation is applied to gate 2. An important factor to note here is that drain current is virtually zero when the device is off. This results in less heat dissipation in the device and thus improves device reliability because of low operating junction temperature.

CIRCUIT REALISATION AND RESULTS

Fig. 3 shows a schematic diagram of the dual gate GaAs FET pulsed oscillator. Series feedback element is introduced at the gate 1 terminal while the source terminal is capacitively terminated by appropriate 50 ohm short-circuited line length. The design procedure for this oscillator was along the lines indicated in the previous work (3).

Two circuits at X and J band frequencies were fabricated. Both of these circuits use dual-gate GaAs FETs in unencapsulated form. The circuits were made on .025" thick alumina substrates, the X band circuit was on a 1" x ½" size, while the J band circuit was on a ½" x ½" size substrate. Drain and gate bias arrangements were integrally provided. The gate bias networks have sufficiently high cut-off frequency enabling application of fast pulse modulation to the gates. In both cases the output was connected to a 50 ohm load through matching networks. Fig. 4 shows the complete X and J band oscillator assembly.

Fig. 5 shows the spectra of the RF output for the X and J band pulsed FET oscillators. The X band source had a peak output power of 15 mW at a CW d.c. to r.f. conversion efficiency of 20%. In the pulsed r.f. mode the drain current was less than 4 mA at 25% duty cycle. The J band source had a peak power of 5 mW at 5% efficiency at 20% duty cycle.

As can be evaluated from the side lobes of the output spectra of Fig. 5 the frequency variation for the duration of the pulse is approximately 0.3 MHz. The output spectrum is virtually symmetrical in both cases indicating linear frequency variation during the pulse duration. The chirp characteristics of the oscillators were also verified by using a cavity wavemeter in conjunction with an r.f. detector.

With the present oscillators the pulse width has been varied from 20 nS to 1μS and 1 to 25% duty cycle. The minimum pulse width is mainly dictated by acceptable pulse rise and fall times obtainable from commercial pulse generators. Successful pulse modulation at gigabit rate has also been achieved.

The X band oscillator was also pulse modulated through the first gate. As expected excessive frequency variation within the pulse was observed. Similarly pulse modulation of the drain also resulted in poor chirp characteristics. The phase angle of S_{11} changes quite rapidly as the first gate and drain bias levels are varied. Similar results were obtained with conventional (single gate) FET oscillators.

CONCLUSIONS

This paper has described the use of dual gate GaAs FETs to produce pulsed RF oscillators at X and J band frequencies. The particular device characteristics which result in extremely small frequency variation within the pulse are identified. The peak output power of the oscillators is limited to the maximum output power under CW conditions. The device operation is limited by breakdown voltage rather than by thermal considerations. It is considered that unlike other solid state sources causes for the low oscillator chirp are electrical rather than thermal in nature. The peak output power of these oscillators can be increased by using larger gate width devices.

It is believed that these oscillators will be attractive in "microwave fence" type applications where low current drain is an essential requirement. Further work, however, needs to be done to bring these oscillators from laboratory stage to real life applications.

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TABLE 1

Input reflection coefficient S_{11} and forward gain S_{31} (between drain and gate 1) for the dual gate GaAs FET as a function of V_{G2}. V_{G1} = -1.03V.

V_{G2}, Volts	S_{11}		S_{31}	
0	.56	-42.0	1.15	-58.5
-0.4	.58	-42.6	0.93	104.8
-0.9	0.61	-46.4	0.57	116.7
-3.2	0.62	-95.3	0.03	171-0

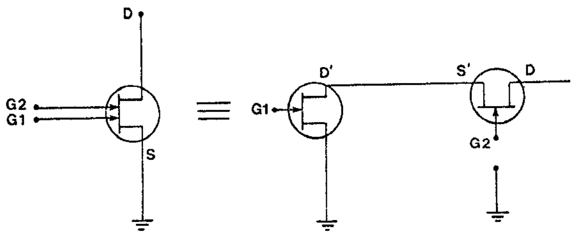

FIG.1. DUAL GATE GaAs FET AND ITS CASCODE EQUIVALENT

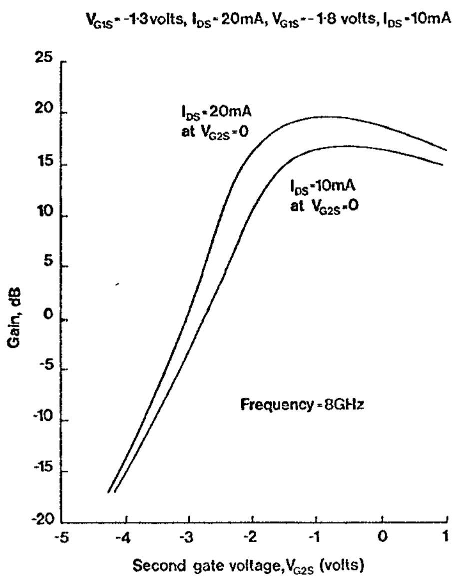

Figure 2

Example of gain versus V_{G2S} voltage

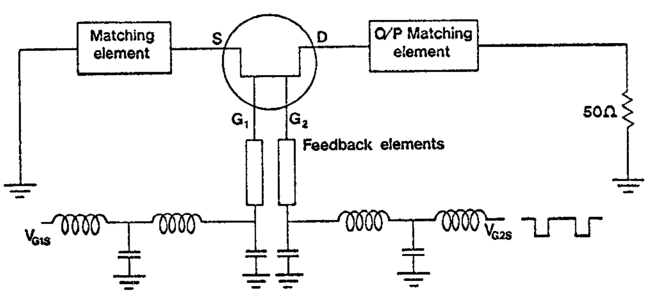

Figure 3

Fig. 4. X and J Band Pulsed FET Oscillators

Fig. 5. Output Spectra of Pulsed r.f. Oscillators
(a) X band, (b) J band