A MILLIMETRE-WAVE SELF-OSCILLATING MIXER USING A GaAs FET HARMONIC-MODE OSCILLATOR

David H. Evans

Philips Research Laboratories, Redhill, Surrey RH1 5HA, England

ABSTRACT

A 34 GHz self-oscillating mixer is described. The harmonic-mode oscillator which is constructed in microstrip produces 4 mW and as a mixer has minimum detectable signal sensitivity of -121.6dBm/Hz at a Doppler frequency of 4 kHz. It is potentially a low cost sensor for motion and proximity detection.

Introduction

There has been some interest in recent years in self-oscillating mixers (SOMs)(1,2),their most obvious uses being simple hetrodyne receivers and Doppler radar sensors. The most common type of active device that is used in these applications are the BARITT and the Gunn. However, the former is limited to operation below 20 GHz, the latter is inefficient and they are both difficult to integrate. The GaAs FET offers some benefits over these devices such as millimetre-wave operation and monolithic integration. This indicates the possibility of low cost sensors for motion and proximity detection. Though FET SOMs have been reported (3),neither millimetre-wave operation or low frequency IF performance (Doppler) were considered. This paper will present some results obtained from observations on a GaAs FET SOM operating in Ka-band. Also, a serrodyne frequency translator is described. This was used to generate the low frequency Doppler signal and provided an easy method of assessing the SOM's performance.

Oscillator Design

The basis for this SOM is a harmonic-mode FET oscillator. This oscillator consists of a device embedded in a feedback/tuning network which is lossless at a fundamental frequency of 17 GHz. Since all the fundamental output power from the device is available for feedback, the device can be made to operate well into saturation and hence its non-linear regions and this enhances harmonic generation and mixing. The embedding network components are chosen to further enhance the harmonic generation within the device. Figure 1 shows the general topology of such an oscillator with the filter which is used to extract the second harmonic.

Time domain modelling has been performed on the oscillator and a large signal FET model and this has suggested that the second harmonic, P_{o2}, produced by such a circuit is 10 dB lower than the circulating fundamental, P_c. Figure 2 shows a comparison of these powers as a function of frequency with the output power, P_{osc}, obtainable from a fundamental oscillator (4). Note that for a circulating power at a frequency of 0.6 f_{max}, the second harmonic output would be at 1.2 f_{max} indicating the potential of this type of oscillator for extending the usable frequency range of FETs.

The lumped element design was translated to a distributed form and constructed on microstrip with the output being taken via a transition into waveguide as shown in Figure 3. An output power of 4.0 mW at 34 GHz has been obtained from an NEC 673 device. The associated d.c. to RF conversion efficiency, η, was 4.5% when operating from a 3v supply. The oscillator's phase noise is -70 dBc/Hz at 100 kHz carrier offset and is typically 10 dB worse than a comparable fundamental oscillator (4).

SOM Measurement Technique

Previous techniques (2) for assessing the Doppler performance of SOMs have relied on returning the output of the mixer back into itself after it has been amplitude modulated with a PIN switch. Although this produces a spectrum component with the required frequency shift, a large component is still present at the source frequency which could give rise to erroneous results through mixer saturation. This can be improved upon by using phase modulation which can cause all the signal power to be converted in sidebands. Further, one specific form of modulation whereby the phase of a signal is increased continuously produces a true frequency shift, i.e. all the power at one frequency is shifted to another frequency. This technique, known as serrodyne frequency translation, has been used in this work to produce Doppler type frequency shifts for assessment of the SOM's performance.

It has been shown (5) that the required phase shift for frequency translation can be incremented digitally and that the minimum number of phase shift steps that are required to produce a satisfactory shift is three. The use of digital rather than continuous phase shifting results in a spectrum of frequency shifted components rather than a single component. These steps are 0° and ±120° with preferably no amplitude differences

0149-645X/86/0000-0601$01.00 © 1986 IEEE

between them. This phase shift has been achieved by using a Mullard 770CL1 E-plane SPDT PIN switch. The switch's outputs are terminated in variable shorts and the third phase state is generated when both sets of PIN diodes are biased on (producing a short at the switch's junction). The resultant spectrum, seen at the SOM's IF output for a 15 kHz Doppler shift (Δf), is shown in figure 4. The two variable shorts were adjusted to produce minima for the components at $3\Delta f$ and $6\Delta f$ since both are ideally zero. Slight amplitude imbalances between the three phase states have caused the relative amplitudes of the spectrum components to degrade slightly to -5.5 dB, -11.6 dB and -13.2 dB from ideal values of -6 dB, -12 dB and -14 dB for the spectra at 2, 4 and $5\Delta f$ respectively. This however does not affect the assessment of the SOM.

The complete measuring system is shown in Figure 5. The return loss of the coupler, rotary vane attenuator (RVA) and PIN switch combination was measured prior to SOM assessment and added to RVA's attenuation. This is used to provide target range attenuation.

MESFET SOM Performance

The SOM's IF output can be taken from two different connections into the FET oscillator's circuitry. These give significantly different mixer performance. The first is across the device's gate to source self-bias resistor. The large power levels that are circulating in the oscillator give rise to rectification at the device's gate. This results in a negative gate to source voltage when a resistor is placed across a convenient IF connection point. The second possible output is from the device's drain. This is accomplished by placing a 56 ohm resistor in series with the drain supply. In both cases the device's drain to source voltage and the gate bias resistor were adjusted to give the best mixer conversion gain. These settings and the resultant conversion gains, G_C are tiven in Table 1. In both cases the IF load impedance is 50 ohms.

	Gate output	Drain output
V_{DS}	2.0 v	1.6 v
I_{DS}	12.5 mA	18 mA
R_{GS}	650 Ω	193 Ω
V_{GS}	-0.65 v	-0.54 v
P_{out}	1.3 mW	1.1 mW
G_C	-18 dB	3 dB
η	5%	2.3%

Table 1: Comparison of the SOM's optimum bias conditions for both IF outputs. The efficiency figure for the drain output includes the voltage dropped across the 56 ohm IF output resistor.

As can be seen, the necessary reduction in drain voltage results in a reduction of the oscillator's output power although the associated efficiencies are still better than Gunn devices. Note that the maximum output power of 4 mW was obtained with R_{GS} = 22 ohms and V_{GS} = - 0.4 v. The poor conversion gain from the gate output can possibly be explained by noting that the mixing products have to pass through the device in a reverse manner, i.e. from drain to gate synonymous with the device parameter S_{12} which typically has a magnitude of -20 dB. The conversion gain from the drain output is considerably better at 3 dB although it is suspected that instability may be occurring since the SOM's bias settings were found to be critical in obtaining this figure. Conversion gains of greater than unity have been reported previously (3) although at a somewhat lower operating frequency and it was not clear as to what device terminals were used for mixer input and IF output.

The most important measure of a SOM's performance is its minimum detectable signal sensitivity or MDS. This is defined as the point when (signal + noise)/noise = 3 dB. This was measured with an IF amplifier having a bandwidth of 10 Hz to 100 kHz and then normalized to a 1 Hz bandwidth. The measured response of both IF outputs is shown in Figure 6. Clearly, the gate output despite its poor conversion gain is better, displaying a sensitivity of -121.6 dBm/Hz at 4 kHz. The poorer performance of the drain output might be explained by the previously suggested instability. Comparing the FET SOM's performance with an X-band Gunn SOM (2) indicates that the former's MDS sensitivity is typically 15 dB better although if the Gunn's greater output power is taken into account they become similar. If the same comparison is applied to the BARITT device (2) then the FET SOM is only 10 dB worse. Obviously the FET SOM is considerably less sensitive than a diode balanced mixer where an MDS figure of better than -160 dBm/Hz might be expected at 1 kHz Doppler frequency.

Figure 7 shows the output compression characteristic of the SOM. The near constant difference between the two curves is in keeping with the difference in conversion gains and suggests that a common saturation effect applies to both IF outputs. This is possibly connected with the drain characteristics of the device, g_m and g_d, since they are known to be the principle non-linear contributors to harmonic generation in the FET and hence also mixing in the SOM.

Conclusion

The millimetre-wave operation of a FET self-oscillating mixer has been demonstrated. The MESFET oscillator, which operates in a harmonic-mode, has potential performance well into the millimetre-wave region. A serrodyne frequency translator has been utilized to simulate Doppler frequency shifts and provides an easy means of assessing the SOM's performance. The FET SOM has demonstrated comparable sensitivity to existing devices for Doppler radar applications. This SOM has demonstrated an MDS figure of -121.6 dBm/Hz at 4 kHz. It has the benefits of low power consumption and the potential for monolithic integration. A typical application might be a single chip short range proximity or motion sensor which could also include a planar antenna on the same GaAs substrate.

References

(1) M.V. Lazarus and F.R. Pantoja, "Ultra-wideband millimetre-wave self-oscillating mixer", IEE Proceedings, vol. 130, Pt. H, August 1983, pp340-342.

(2) J.R. East et al., "Design, Fabrication and Evaluation of BARITT Devices for Doppler Systems Applications", IEEE Trans. MTT-24, December 1976, pp943-948.

(3) I.D. Higgins, "Performance of Self-Oscillating GaAs MESFET Mixers at X-band", Electronics Letters, vol. 12, 11th November 1976, pp605-606.

(4) D.H. Evans, "High-Efficiency Ka and Ku-band MESFET Oscillators", Electronics Letters, vol. 21, 14th March 1985, pp254-255.

(5) J.S. Jaffe and R.C. Mackey, "Microwave Frequency Translator", IEEE Trans. MTT-13, May 1965, pp371-378.

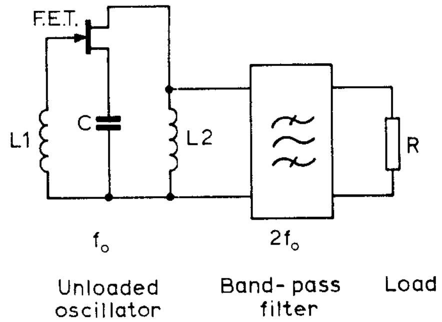

Figure 1: Topology of the harmonic-mode FET oscillator

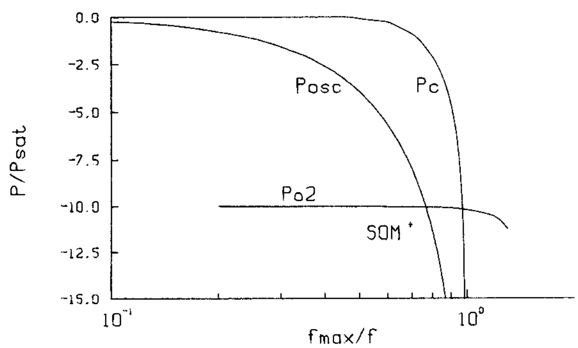

Figure 2: Oscillator output powers versus frequency

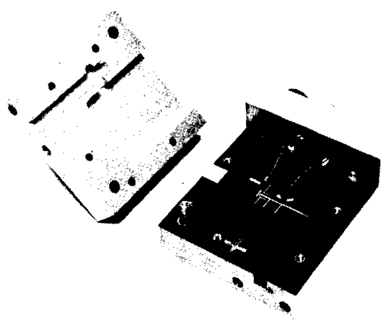

Figure 3: Harmonic-mode MESFET oscillator

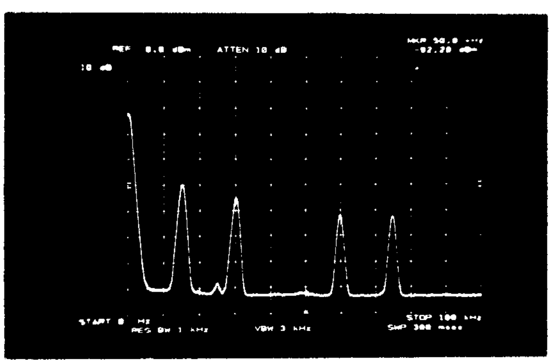

Figure 4: frequency spectrum produced by translator

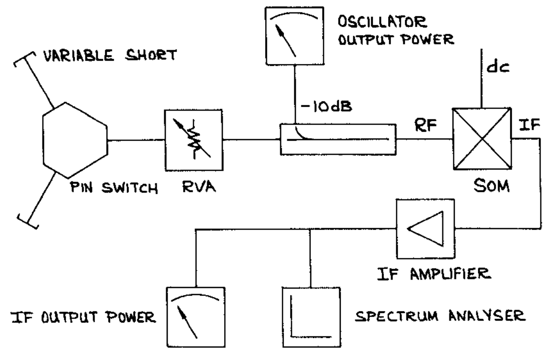

Figure 5: Measuring setup used to assess the SOM

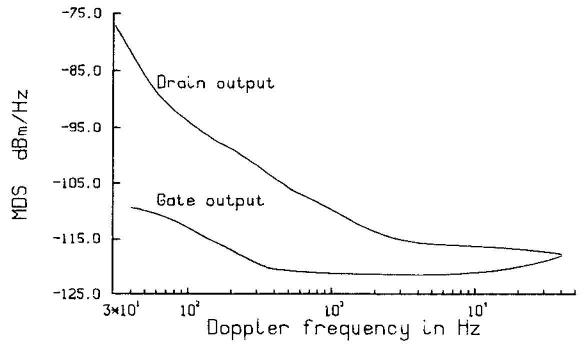

Figure 6: FET SOM MDS sensitivity versus Doppler frequency

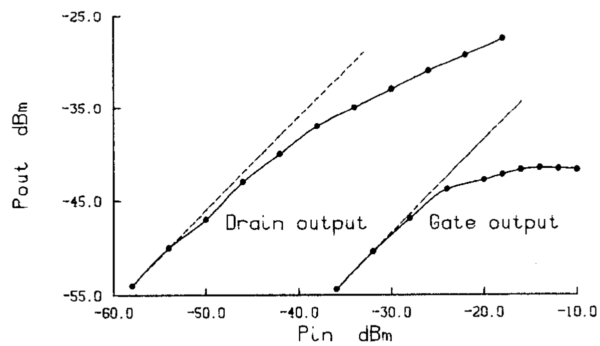

Figure 7: FET SOM output saturation characteristics