A DUAL-GATE Ga As F.E.T ANALOG FREQUENCY DIVIDER

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ABSTRACT

Theoretical and experimental performances of a dual-gate Ga As F.E.T. analog frequency divider are presented. The preliminary results show the feasibility of such a divider, obtaining a half-frequency conversion gain of 4 dB within an operating bandwidth of 20 % with less than 10 mWatts input power level.

Introduction

By applying the principle of regenerative modulation [1], [2], submultiple of fractional frequency ratio may be obtained. The basic circuit, represented in figure 1 a), consists of a mixer, an amplifier, a filter and a feedback loop.

If some F/2 signal appears in the loop, it mixes with the F input signal in the mixer to generate again a F/2 signal. The phase condition can adjust itself within the loop over a wide frequency band since the phase lag between the F/2 and F signals entering the mixer is not imposed.

The frequency band of the divider is mainly limited by the condition that the loop gain be greater than unity.

Ga As F.E.T's are now widely used as amplifiers, oscillators or non-linear active elements such as mixers. So, they can also by used to implement a frequency divider and since both linear and non-linear characteristics are needed for the divider, a dual-gate Ga As F.E.T. can advantageously be used leading to a very simple circuit. This general basic circuit is shown in fig. 1 b). The pump, applied on one gate, modulates the gain so that the dual-gate becomes a parametric subharmonic oscillator.

Theoretical considerations

The simplest hypothesis is to suppose that both gates are independent so that the resulting gain may be expressed as a product of individual gains, each one depending only on the applied voltage on that gate. If the signal at frequency F/2 is small compared to the pump at frequency F, the Fourier expansion of the gain can then be written as :

$$G = 2 \sum_{l=o}^{\infty} b_l \cos (lwt)$$

Let θ_1 be the lag angle between the input signal at F/2 and the pump and $\alpha_1-\theta_1$ be the angle between the output signal at F/2 and the input signal at the same frequency.

It can be shown that, in terms of the scattering parameters, S_{21} may be considered as the sum of two vectors:

S^o_{21} which is the gain when the pump level is zero

and S^1_{21} which is a function of the pump level and phase θ_1.

The phase between S^1_{21} and S^o_{21} is found to be $2\theta_1$, therefore :

$$\left|S_{21}\right|^2 = \left|S^o_{21}\right|^2 + \left|S^1_{21}\right|^2 + 2 \left|S^o_{21}\right| \times \left|S^1_{21}\right| \times \cos 2\theta_1$$

$$\alpha_1-\theta_1 = \underline{/S_{21}} = \underline{/S^o_{21}} + \text{ATN} \frac{\left|S^1_{21}\right| \times \sin 2\theta_1}{\left|S^o_{21}\right| + \left|S^1_{21}\right| \times \cos 2\theta_1} + k\pi$$

The modulus and phase of the power gain at F/2 are then a function of the pump level and of the phase between the signal at F/2 and the pump.

Stability criterion

Without the pump, the system must be stable and in the presence of sufficient pump level, the system must oscillate at F/2.

A necessary, but not sufficient condition is that in case of a feedback loop, $|S_{21}|$ be greater than 1 with the pump and less than 1 without the pump, which leads to the choice of $|S^o_{21}| < 1$ by proper choice of bias conditions.

In that case, the frequency band of the divider will be limited by the phase loop condition since the gain, which is a function of the phase lag between the F/2 and F signals entering the dual gate, must be greater than unity to oscillate.

Measurements

The new "dynamic" measurement system is shown in figure 2. S parameter measurements between one of the gates and drain are made under computer control while the phase between the pump and input signal and the pump level are changed.

Typical results concerning S_{21} in the complex plane, for various pump levels at 9.5 GHz, are shown in fig. 3. The pump is applied on gate 2 biased at -2.2 v so that the channel is pinched-off without the pump. As can be seen in this figure, S_{21} lies on a circle as predicted but all the circles are not concentric due to the fact that as the pump power is increased, a greater and greater detected voltage is applied on gate 2 resulting in increased S^o_{21}. The S_{11} and S_{22} are very slightly changed as the pump level is increased and the maximum S_{21} obtained with this method turns out to be very near the maximum S_{21} obtained when applying the optimum values for the bias conditions.

Experimental results

The dual gate was measured as a three port (G1 - G2-D) biased either in common source or in common drain (reverse channel) to increase the instability.

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*Common drain configuration

AT 3.5 GHz, the instability region corresponds to a high series inductance of about 10 nH in gate 1. Then, a first device has been realized with such an inductance in gate 1. The transistor used is the THOMSON's 0.5 µ dual-gate 29 GMDF.

The pump is applied on gate 2 and the different output signals are examined on a spectrum analyzer.

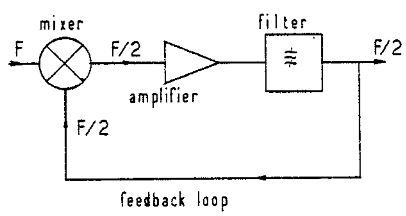
In figure 4, the output power spectrum of the different signals is represented as a function of the pump level. For a 2.5 dBm input power, there appears an abrupt transition corresponding to the limit at which the gain is large enough to sustain parametric oscillation. For a pump level between 2.5 dBm and 9 dBm, the signal at F/2 is greater than the input signal at frequency F of about 4 dB (Fig. 5).

This conversion gain has been observed over 8-10 % bandwidth around 9 GHz with this common drain configuration.

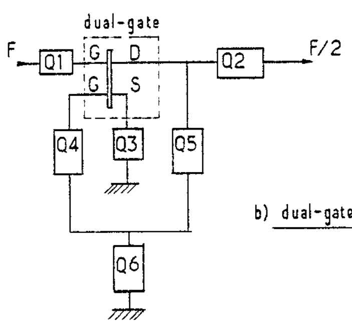
*Common source configuration

Common source configurations with parallele passive feedback has been computed to increase the bandwidth. The schematic of a typical circuit is shown on figure 6. The output power spectrum for the different signals vs input signal level is represented on figure 7 at 7 GHz.

A 4 dB conversion gain is observed with a 10 mWatts input power level. About 17 - 20 % bandwidth has been obtained with this circuit (see figure 7) and a broader bandwidth (about 40 % around 7.5 GHz) have been reached but with negative conversion gain. As far as bandwidth is concerned and with equal conversion gain values, common source circuit gives therefore better results than common drain and with lower inductance values (≤ 2 nH).



a) principle of regenerative modulation



b) dual-gate divider

FIG.1 PRINCIPLE OF THE DIVIDER

CONCLUSION

Experimental results confirm the interest of the dual-gate Ga As F.E.T. analog frequency dividers.

It has been shown that with a small input signal power at frequency F (<10 mW) the F/2 division can be obtained with a positive conversion gain (≤ +4 dB) within an operating bandwidth of more than 20 %, which makes it a good candidate to implement a phase locked oscillator.

Octave bandwidth can be reached with appropriate feedback but it has not yet been proven that the conversion gain could still be positive over such a large bandwidth.

The circuit is simple and seems to be appropriate for monolithic integration, at frequencies where other solutions cannot be used.

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[1] R.L. MILLER "Fractional-frequency generators utilizing regenerative modulation" Proc. IRE, Vol 27, pp 446 - 456, July 1939.

[2] S.V. AHAMED, J.C. IRVIN, H. SEIDEL "Study and fabrication of a frequency divider-multiplier scheme for high efficiency microwave power" IEEE, Trans. Commun. Tech. Vol COM. 24, pp 243 - 249, Feb. 1976.

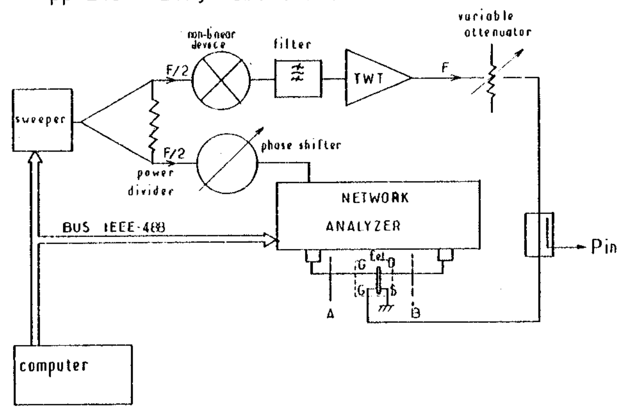


FIG:2 "DYNAMIC" MEASUREMENT SYSTEM

FIG:3 COMMON SOURCE PUMP ON GATE 2 F=9.5GHZ

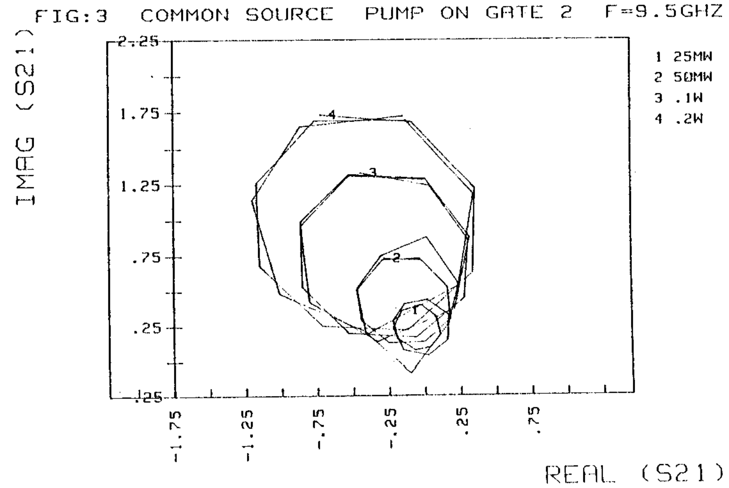


FIG:4 output spectrum power of the divider F=6.65 GHz

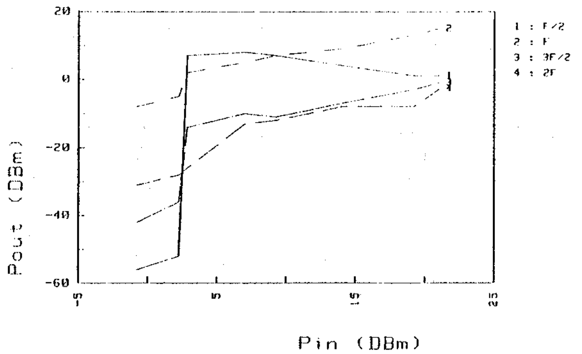
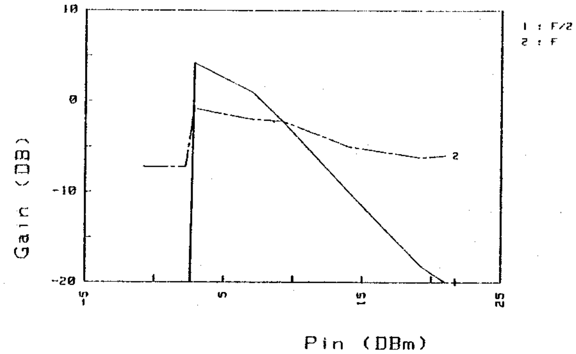


FIG:5 Output signals gain (F=6.65GHz)



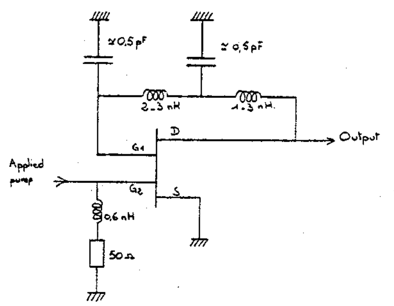


FIG.6 SCHEMATIC OF A DIVIDER

FIG:7 Output power spectrum (F=7GHZ)

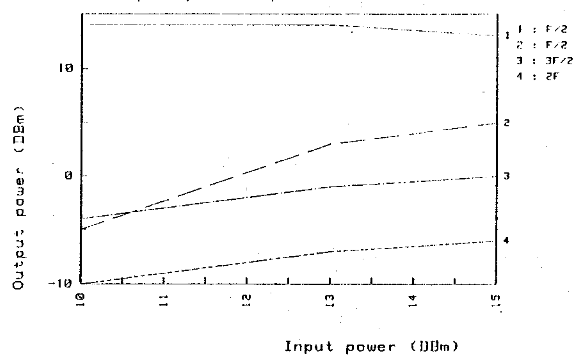


FIG:8 Division bandwidth VS input power level