GaAs MONOLITHIC CIRCUIT FOR FMCW RADARS+

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ABSTRACT

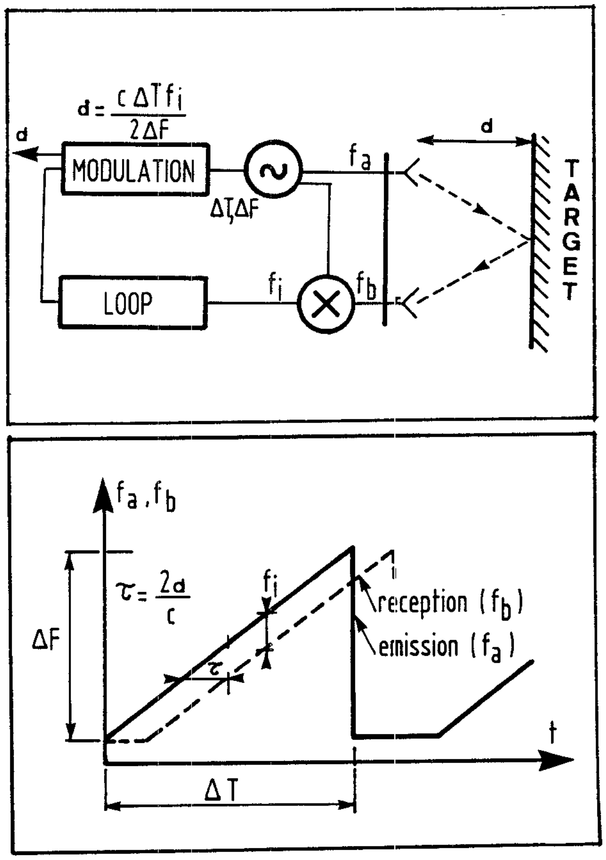
A GaAs monolithic transmitter-receiver to be used in a radar system has been fabricated. It operates between 4 and 6 GHz with a 200 to 400 MHz tuning range. The excellent Voltage Controlled Oscillator tuning linearity, the very high external quality factor, the low 1/F noise at the 5 kHz to 10 MHz output port, combined with a reduced size show that the GaAs monolithic ICs are suitable for this type of Radar systems.

INTRODUCTION

FMCW Radars measure the distance between moving vehicules and obstacles. Basically, the distance d could be measured by the time τ = 2d/c elapsed between the emission and the reception of a microwave signal reflected by the target. Using a linear frequency modulation of the transmitter and mixing the emission and reception signals, this small time difference (some tens of nanoseconds) is replaced by a frequency difference fi (some tens of KHz). The distance is deduced from :

$$d = \frac{c\,\Delta T\, f_i}{2\,\Delta F} \quad \text{(figure 1) (1)}$$

+This project has been carried out in collaboration with T.R.T.-OMERA.



Notations :
d = distance, c = light velocity
ΔF = frequency modulation amplitude
$\Delta F / \Delta T$ = slew rate
fi = frequency difference between emission and reception

Figure 1 : FMCW Radar principle

IEEE 1988 Microwave and Millimeter-Wave Monolithic Circuits Symposium

CIRCUIT SPECIFICATIONS AND DESIGN

A monolithic chip, including varactor tuned oscillator, buffer amplifier and double balanced mixer with active phase splitters has been designed (figure 2).

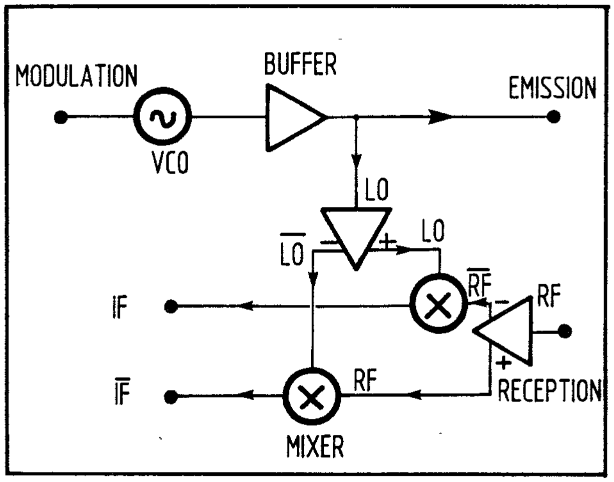


Figure 2 :
Complete circuit diagram of the monolithic chip

Voltage controlled oscillator :
The accuracy of the distance measurement is greatly dependent on the frequency modulation linearity n of the Voltage Controlled Oscillator given by :

$$n = \frac{\left(\frac{dF}{dV_{m\ max}}\right) - \left(\frac{dF}{dV_{m\ min}}\right)}{\left(\frac{dF}{dV_{m\ mean}}\right)}$$

where F is the output frequency and V_m the modulation voltage. n must be less than 20 % in the tuning range. This imposes that the maximum deviation of the frequency from the best fit straight line must be less than about 3 MHz. Time domain simulations using very accurate non linear models have shown that this could be obtained by a convenient combination of the FET and Schottky diode non linearities (2).

Buffer amplifier :
The VCO output signal must be made insensitive to load variations (external quality factor $Q_{ext} > 1000$).
As this Q_{ext} is much higher than that normally achieved with varactor tuned oscillators, a buffer amplifier has been added : it improves the Q_{ext} by a factor roughly equal to $1/|S_{12} * S_{21}|$. A small gain (4 dB) and very high isolation (- 50 dB) have thus been our design targets.
By increasing the gate to drain distance (a specifically MMIC approach to reduce the FET parallel feedback) and using via-holes through the substrate (series feedback reduction), along with a specific interstage network, the required isolation has only necessitated two stages, although wide FETs (high Cgd) had to be used to produce the required output power level.

Double balanced mixer :
The very low intermediate frequency (down to 5 kHz) required by this system is a challenging problem for a Gallium Arsenide mixer : the 1/f noise of GaAs devices happens to be some 20 dB higher than that of silicon bipolar devices at such low frequencies. We have got round this limitation by using a mixer stage with no DC current : the RF signal is applied to the unbiased drain of the mixing FET, and the LO signal to the gate, biased near the pinch-off voltage.
A double balanced configuration has been chosen to cancel RF and LO parasitics and to produce balanced outputs convenient for the low frequency part of the system. The 180° out of phase RF and LO signals are generated by wideband active phase splitters which are also integrated on chip (3).

FABRICATION AND MEASUREMENT

The circuits have been fabricated with an in-house 0.7 µm MESFET process, including implanted resistors, MIM capacitors and via holes through the substrate. The chip area is 2.3 mm^2, including the VCO tuning network and the complete biasing circuitry (figure 3).
The center frequency can be set between 4.1 GHz with a 200 MHz tuning range and 5.8 GHz with a 400 MHz tuning range. A frequency modulation linearity better than 10 % has been measured ; the maximum frequency deviation from the ideal straight line is 1 MHz. The output power is 15 dBm (± 0.3) at 4 GHz and 7 dBm (± 0.9) at 6 GHz. The phase noise of the oscillator is - 80 dBc at 100 kHz from the carrier.

The Q_{ext} measured at the emission port is better than 4000 (5000 at 4 GHz), so that the frequency pulling is about 1 MHz (VSWR 2:1).

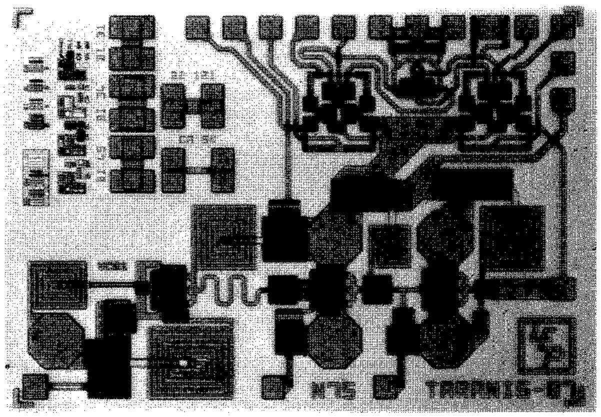


Figure 3 : Microphotograph of the circuit

No measurable 1/f noise has been detected at the low frequency output port. The parasitic coupling between RF and LO ports, mostly due to direct air-coupling, is - 50 dB and could be improved by better packaging. The total power consumption is 1.2 W.

The complete circuit has been tested in an actual radar configuration, with emission and reception ports connected through a delay line to simulate a reflection. Figures 4b and 4c show the IF response of the mixer. The measured sensitivity of this circuit is - 105 dB below the emission power.

CONCLUSION

This circuit, including a transmitter (modulated RF source and buffer amplifier) and a receiver (local oscillator and double balanced mixer) on a single chip, has demonstrated the ability of GaAs MMICs to fulfill the specific and sharp specifications of FMCW radar systems : especially small size and weight, tuning linearity, high pulling factor and low 1/f noise at the low frequency output.

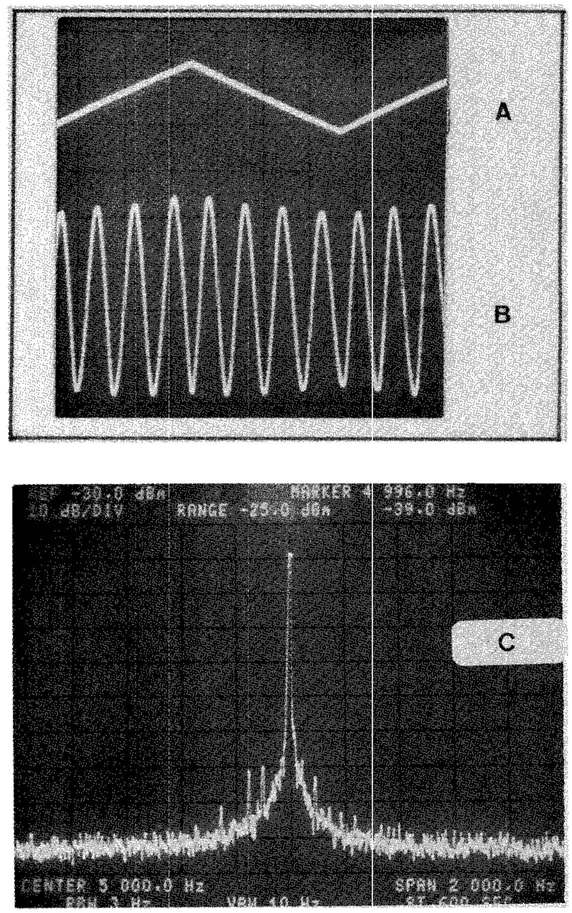


Figure 4
a) : VCO modulation
(b and c) : IF signal of the system

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