MONOLITHIC COMPONENTS FOR 77 GHz AUTOMOTIVE COLLISION AVOIDANCE RADARS

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ABSTRACT

This paper will examine design methodology and test results of monolithic components specifically designed for a 77 GHz collision avoidance radar. In addition cost-trade-offs between a fundamental 0.15 micron pseudomorphic HEMT based approach and a multiplied 0.25 micron power MESFET based solution will be discussed.

INTRODUCTION

Automotive Collision Avoidance Systems include a Sensor capable of detecting the presence of obstacles in front of the vehicle, a signal processor to identify those obstacles that pose a real threat to the driver and a display to present the data to the driver.

The optimum sensor for automotive applications should satisfy high antenna directivity and small volume requirements; in addition the system should be fully operational during adverse weather conditions such as dense fog or rain. The sensor needs also to offer high reliability and low unit production cost.

Millimeter-wave radars provide significant advantages as compared to alternative technologies (such as laser-based systems) and successfully meet most of the requirements with cost being the only challenge. These systems have been mainly developed for low volume military applications based on waveguide and/or hybrid components. These technologies being labor intensive, do not lend themselves to low production cost. In addition at Millimeter-wave frequencies, integrated circuit bond wires, particularly in areas subject to high VSWR will hinder performance and repeatability.

In order to reduce production cost, automotive radars need to rely on GaAs Monolithic Components. Alpha Industries has been developing Monolithic Technology at Millimeter-wave frequencies for the last ten years, mainly for defense contracts such as SADARM, Longbow, SDI, and MIMIC.

The technology already developed find a unique opportunity to be inserted in collision avoidance production programs with projected costs, as already demonstrated for military customers at similar frequencies, fully compliant with automotive radar program requirements.

MONOLITHIC TRANSCEIVER

In Europe the allocated frequency band for Collision Avoidance Radars is 76 to 77 GHz. The system architecture has different options available: the source could use either a fundamental or a multiplied approach, the modulation technique could take advantage of either FMCW or pulsed techniques; we could also use two separate receiving and transmitting antennas or combine the two functions in one.

In order to cover most system requirements, Alpha Industries is developing the following Monolithic Chips:

* VCO (38 GHz or fundamental)
* Driver Amplifier
* Doubler
* Down Converter
* 77 GHz Pin Switch

38 GHz VCO Chip

The 38 GHz VCO MMIC Chip is shown in Fig.1. The design uses a 0.25 x 400 micron power MESFET in common source configuration and two double mesa integrated varactors (1), one for frequency tuning and one for temperature compensation. The drain of the power MESFET is connected to the output through a coupler that transforms the impedance and decouples the oscillator. The double mesa varactor technology was specifically designed to reduce the diode series resistance and improve the Q of the resonator, therefore resulting in lower VCO phase noise as compared to a planar varactor process. Typical performance is as follows:

* Frequency	38-38.5 GHz
* Pout	+10 dBm
* Tuning BW	600 MHz
* Temp. Stability	Less than 1 MHz/°C
* Phase Noise	-100 dBc/Hz @ 1 MHz offset

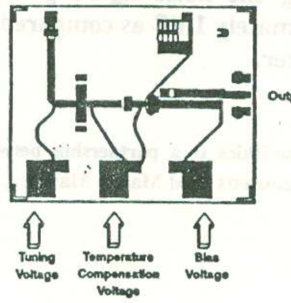

Fig. 1
38.5 GHz VCO Chip

DRIVER AMPLIFIER CHIP

GAMMA[1] Monolithics has already developed and tested power amplifiers in Ka-band based on our standard 0.25 micron power MESFET process. Output power exceeding 3 watts has been achieved using basic cells which combine four standard 400 micron power MESFET devices. Test data for one of these cells is reported in Fig. 2. By using an amplified source in Ka-Band multiplied up to 77 GHz, we can very easily achieve the power levels (10-20 dBm) required for a collision avoidance system.

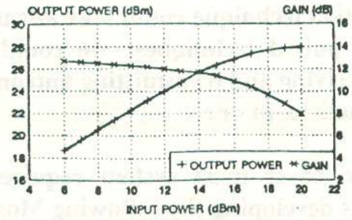

Fig. 2
Gain and Power Output of a 400 mW Power Amplifier

38.5 to 77 GHz DOUBLER

Multipliers in W-Band could utilize either FET or Varactor Monolithic Technology(2). A Varactor-based doubler is preferred because of better conversion efficiency and superior bias and temperature stability. In addition, our VCO design integrates two high Q double mesa varactors with power MESFET material; therefore further monolithic integration of the varactor function with either the VCO or the power amplifier is an available option. A simulation of the monolithic doubler yielded better than 8 dB conversion loss at 77 GHz.

DOWNCONVERTER

A 60 GHz subharmonic mixer has been already fabricated and tested for a space communication program.

The use of a 30 GHz LO signal reduces the power required at the fundamental frequency without compromising the noise figure performance by more than approximately 1 dB as compared to a fundamental down-converter.

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[1] GAMMA Monolithics is a partnership between Alpha Industries, Woburn, Massachusetts, and Martin Marietta, Baltimore, Maryland.

The mixer chip used two anti-parallel Schottky diodes to produce a virtual Lo signal at 60 GHz. The diode exhibits a series resistance of 6 ohms and a capacitance of 0.035 pF, allowing efficient frequency conversion at 60 GHz. Conversion loss is typically 6-7 dB across a 10% bandwidth. It is felt that this conversion loss can be improved by 1-2 dB by optimizing the diode structure to produce lower series resistance and capacitance. The mixer, due to the self-biased nature of the subharmonic configuration, requires as little as +6 dBm LO drive.

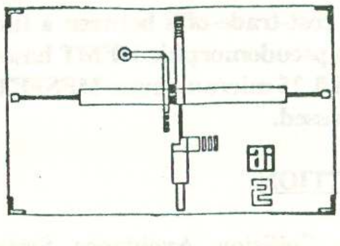
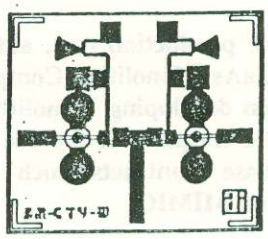


Fig. 3
77 GHz Subharmonic Mixer Chip

A simulation of a 77 GHz mixer, presently in fabrication at Alpha was performed using the same diode utilized in the V-band mixer described earlier. The simulation gave us a noise figure of 6.5 dB DSB when inserted into a balanced rat-race mixer configuration, (see Fig. 3) and 7.5 dB in a subharmonic-type down converter.

77 GHz PIN SWITCH

At 77 GHz monolithic pin-based switches are definitely offering superior performance as compared to their FET-based counterparts. Considering that in the Transceiver the power amplifier function is the major cost driver, we opted for the PIN-based solution as compared to a more integratable FET-based approach. The lay-out of a 77 GHz SPDT is represented in Fig. 4. The design yielded 25 dB of isolation and 1 dB loss at 77 GHz.



Measured Performance @ 77 GHz:
Insertion Loss: 1.0 dB
Isolation: 24 dB

Figure 4
77 GHz SPDT Pin Switch

MULTIPLIED VERSUS FUNDAMENTAL APPROACH

The source at 77 GHz could take advantage of either a fundamental or a multiplied approach. Let's assume an output power requirement of 100 mW and a times two multiplier conversion loss of 8 dB. (See Table 1)

The positive feature of a signal multiplied from an amplified source at 38.5 GHz is that it relies on 0.25 micron GaAs power MESFET technology that is already in production in Alpha Industries. On the other hand, assuming a monolithic varactor multiplier conversion loss of 8 dB, to generate 20 dBm at 77 GHz, would require 28 dBm of power at 38.5 GHz, which makes the driver amplifier at least twice as large and its Fet output periphery a minimum of three times as wide as compared to the buffer in W band.

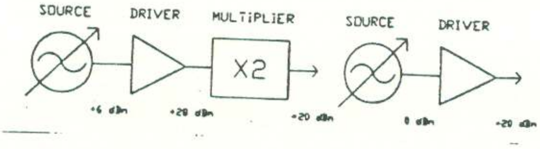
At 77 GHz the device required is based on a 0.15 micron Pseudomorphic HEMT. This technology, although demonstrated, is not as mature from a manufacturing point of view.

On the positive side, it will deliver a monolithic chip with half the size or less. In terms of yields, at 77 GHz the shorter gate length and the more complex material structure could be balanced off by the reduced gate periphery.

Assuming 4" wafers and 30% chip sort yields, a 1995 cost projection derives a chip cost of $45 for the multiplied source. At 77 GHz, with the same overall yield, the chip cost is down to $22.50.

MULTIPLIED
(38.5 GHz x 2)

FUNDAMENTAL
(77 GHz)



6 dBm 28 dBm 20 dBm 0 dBm 20 dBm

TABLE 1

FET REQUIRED		
TYPE	POWER MESFET	PSEUDOMORPHIC
GATE LENGTH	0.25 MICRON	0.15 MICRON
GAIN	8 dB (AT 38.5 GHz)	7 dB AT (77 GHz)
TECHNOLOGY STATUS	MATURE	UNDER DEVELOPMENT
DRIVER AMPLIFIER		
NUMBER STAGES	3	3
FET OUTPUT PERIPHERY	2.1 mm	0.666 mm
SOURCE FET PERIPHERY	400 MICRON	200 MICRON
REAL ESTATE		
VCO	4 mm²	2 mm²
MULTIPLIER	1 mm²	N/A
OVERALL SIZE	18 mm²	9 mm²
WAFER COST/mm (ASSUMING 4" WAFER)	$2.50 (30% YIELD)	*$2.50 (30% YIELD) **$5 (15% YIELD)
OVERALL COST (1995 PROJECTION)	$45	* $22.50 **$45

CONCLUSIONS

It is true that 30% yields in W band have yet to be proven, but it is also true that 30 % yields in Ka-Band is today, based on recent experience, a conservative projection for the foreseable future. The GaAs technology is progressing very fast when we consider that only a few years ago the 1 micron MESFET was the only process in production. The automotive sensor business is offering GaAs monolithic circuits an unprecented opportunity to be inserted in large volume programs. To be successful in this market the engineers have to focus on how to bring the required processes, from wafer fabrication to assembly and test, in a real low cost manufacturing environment.

References

1. McDermott, M.G. et al, "Integration of High-Q GaAs Varactor Diodes and .25 μm GaAs MESFET's for Multifunction Millimeter-Wave Monolithic Circuit Applications", IEEE Trans. on MTT, vol. 38, no. 9, Sept. 1990, pp. 1183-1190.

2. Lamberto Raffaelli and Earle Stewart "Millimeter-wave Monolithic Components for Automotive Applications", Microwave Journal, Vol. 35, no. 2, February 1992.