A MMIC RADAR CHIP FOR USE IN AIR-TO-AIR MISSILE FUZING APPLICATIONS

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ABSTRACT

The next generation of air-to-air missiles will require Target Detecting Devices (TDD) that must utilize directional target sensing to optimize weapon effectiveness. Conventionally, a centralized radar proximity sensor is switched sequentially between fixed directional antennas elements to provide the required directionality. This implementation involves expensive and bulky RF cabling and switching circuits to connect the TDD to each antenna element. By utilizing Microwave Monolithic Integrated Circuit (MMIC) technology, a single radar chip has been developed which allows for the simultaneous operation of ultra-miniature, low-cost fuze sensors which are mounted onto the backside of each antenna element, obviating the need for RF switches and cabling. The MMIC described includes all the RF circuitry required to operate each radar sensor synchronously (phased-locked) to a common low frequency clock signal. This allows all directional fuze sensors to be operated simultaneously without mutual interference, and results in an attractive, low-cost, miniaturized TDD electronic package.

INTRODUCTION

To optimize the effectiveness of the new generation of air-to-air missiles, the on-board proximity fuze sensor or target detecting device (TDD) must have the ability to determine the relative spatial orientation of the target with respect to the incoming missile. The knowledge of the relative physical orientation (as well as closing velocity) between the warhead and the target can be utilize to adjust the trigger point to achieve maximum weapon effectiveness. One method to achieve directional target sensing utilizing RF radar techniques is to utilize fixed, selectable directional antennas connected to a centralized fuze proximity sensor. Figure 1 shows the composite radiation pattern of a four quadrant antenna array configured to provide target discrimination among four equally spaced quadrants, each tilted forward of the missile boresight. Traditional microwave hybrid design techniques for the proximity sensor's RF circuitry result in a rather bulky and expensive TDD electronics package which is usually mounted in some centralized portion of the missile body and is connected to the antenna elements via RF cabling. A RF switch matrix must also be provided to sequentially switch the TDD among the four antenna elements.

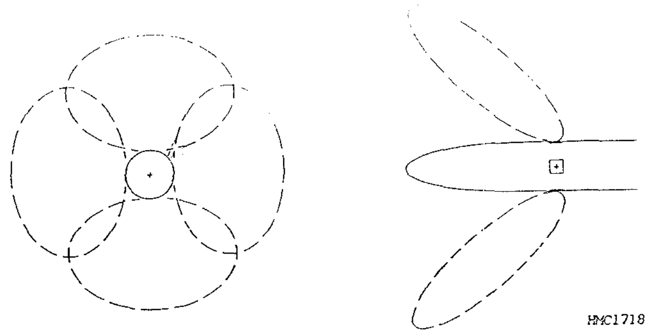

Figure 1. TDD Composite Antenna Radiation Pattern

This paper describes an alternative approach to directional target detecting for air-to-air missile fuzing. By utilizing Monolithic Microwave Integrated Circuit (MMIC) technology, the entire RF circuitry of the TDD has been reduced to a single chip of minute dimensions. The small size of the MMIC fuze sensor, along with the attendant low production costs, provide for a wide range of flexibility in the configuration of the missile TDD architecture. An attractive example of such flexibility is the option to utilize multiple, self-contained RF fuze sensors, each individually exciting a directional antenna. Due to the ultra-small size of the MMIC fuze sensor electronics, the fuze sensors may be located on the backside of each antenna element. In this way, expensive and bulky RF distribution circuitry is eliminated, which would be required for a centralized fuze processor design. Figure 2 illustrates the multiple, autonomous, four-quadrant MMIC TDD concept that was selected for development. It consists of four individual, miniaturized fuze sensors mounted on the backside of each antenna element, with the composite radiation pattern covering a 360 degree detection zone. Since each quadrant proximity sensor operates autonomously, each fuze sensor provides target detection functionality independent of the operation of the other sensors. Each quadrant sensor consists of a conformal, microstrip patch array, and a single circuit board which contains all of the RF and low-frequency signal processing circuitry for that quadrant. Since it has been previously demonstrated that psuedo-random (PN), bi-phase modulated (BPSK) radar techniques offer several performance advantages for RF proximity sensors, this architecture was chosen for adaptation to the MMIC-based fuze sensor described above. A description of the theory of operation for the overall fuze sensor system can be found in [1].

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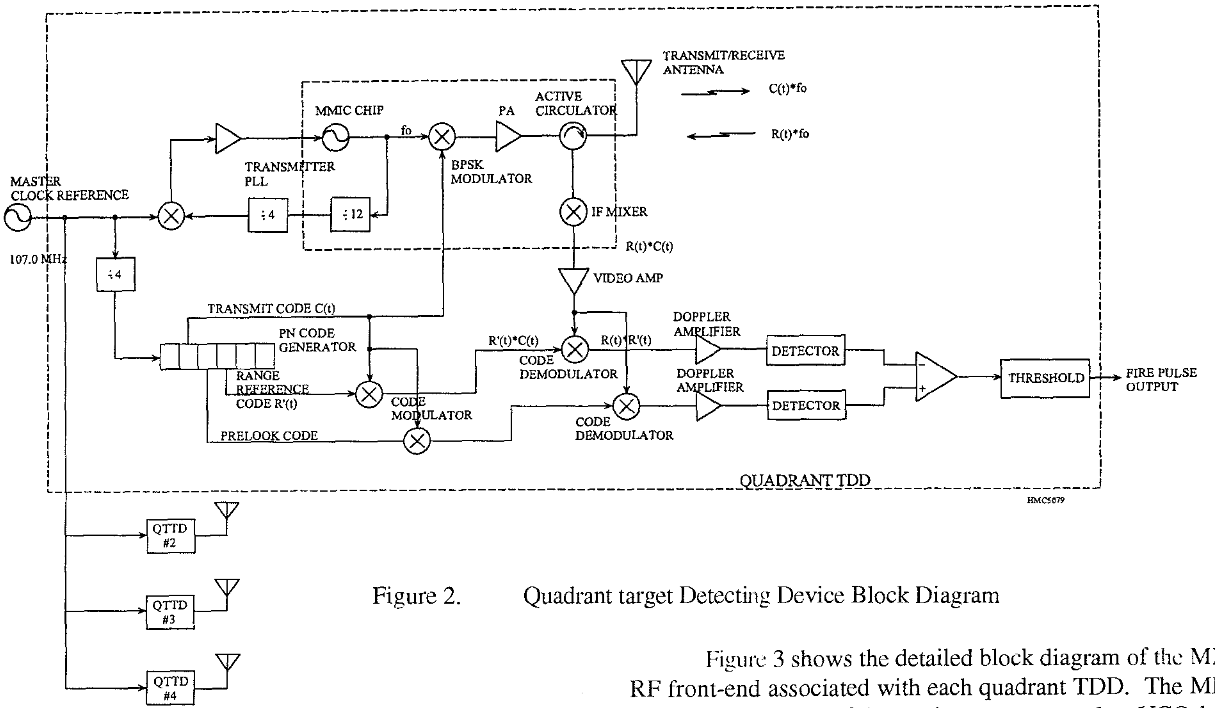


Figure 2. Quadrant target Detecting Device Block Diagram

MMIC DESIGN

Figure 2 shows that the entire RF circuitry associated with each quadrant TDD is implemented with a single MMIC design. A single antenna is utilized for both transmit and receive, with transmit\receive diplexing accomplished with an on-chip electronic circulator. Each quadrant sensor has an umbilical to a central target processor, over which the central unit sends DC power and a synchronization signal, and over which the sensors send target detection signals. Since there are no critical high frequency signals required, the umbilical can be realized with a small ribbon cable. The key to allow all quadrant sensors to operate simultaneously and autonomously without mutual interference, is to phased-lock all MMIC transmitters to a common, low-frequency reference oscillator. In this way, since all quadrant transmitters have precisely the same RF phase, coupled with the fact the radar receiver responds only to phase transitions, only the residual AM sideband noise power of the phase-locked transmitter oscillators contribute to mutual interference.

Figure 3 shows the detailed block diagram of the MMIC RF front-end associated with each quadrant TDD. The MMIC chip consists of a VCO, a microwave prescaler, VCO buffer amplifier stages, bi-phase modulator, output power amplifier stages, an electronic circulator, and a receive mixer. A photograph of the MMIC is shown in Figure 4. The MMIC performance parameters are listed in Table 1. The MMIC chip was designed utilizing standard 0.5 micron gate-length, GaAs MESFET process technology, available at a variety of commercial GaAs MMIC foundries.

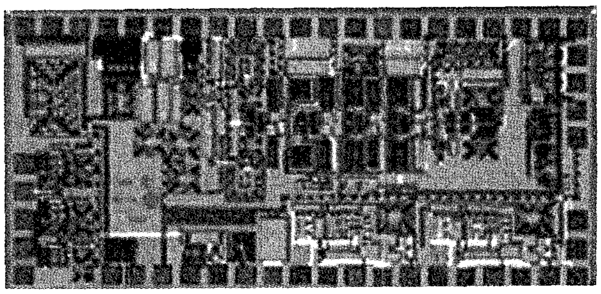


Figure 4. Photograph of the Single-Chip Radar MMIC

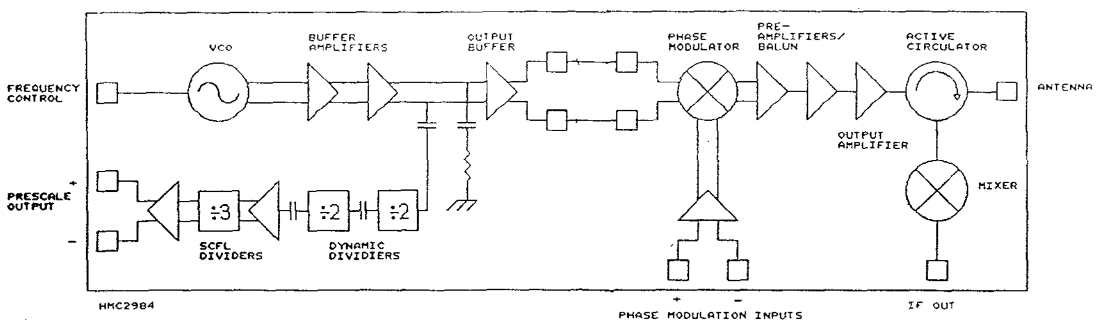


Figure 3. Single-Chip Radar MMIC Block Diagram

Parameter	Value
Transmitter:	
Operating Frequency	5.136 Ghz
Prescaler Output Frequency	428 Mhz
AM Noise	-150 dBm/Hz at 225 Khz offset
VCO Tuning Range	4.8 to 5.4 Ghz
FM modulation bandwidth	50 Mhz
Output Power	+17 dBm
Phase Modulation:	BPSK
Phase Accuracy	+/- 2°
Amplitude Balance	+/- 0.5 dB
Modulation Rate	50 Mhz
Switching Speed	3 nsec
Receiver:	
3 dB bandwidth	50 Mhz
Voltage Conversion Gain	0 dB, nominal
Noise Figure	30 dB, max.
Power Supply:	+5.0 VDC, 400 mA
Temperature Range:	-55°C to +75°C

Table 1. MMIC Chip Performance Parameters

In order to operate all quadrant sensors simultaneously without mutual interference, all transmitters are phased locked to a common, low-frequency reference oscillator. The phased-locked loop (PLL) transmitter consists of a VCO, a microwave prescaler, a phase-frequency detector, loop amplifier, and the reference crystal oscillator. To minimize cost and size, the VCO and high frequency portions of the prescaler are integrated onto the MMIC chip. The VCO utilizes a cascode FET configuration with the gate bias levels chosen to provide an oscillation amplitude level which is primarily determined by the voltage drop across the diode chain (see Figure 5). This diode bias network reduces the effects of voltage fluctuations on the Vdd supply by more than a factor of ten. The divide-by-twelve prescaler consists of a cascade configuration of two high-speed dynamic GaAs dividers, followed by a static divide-by-three. The lower frequency portion of the prescaler, along with the phase-frequency detector and loop amplifier were realized utilizing external common commericial components. Figure 6 shows the output spectral response of the phase-locked transmitter, indicating greater than -100dBc/Hz residual sideband noise power at a 10 kHz offset frequency. Only the residual sideband (uncorrelated) noise power contributes to mutual interference, as opposed to the total transmit power in the case of non-synchronous transmitters.

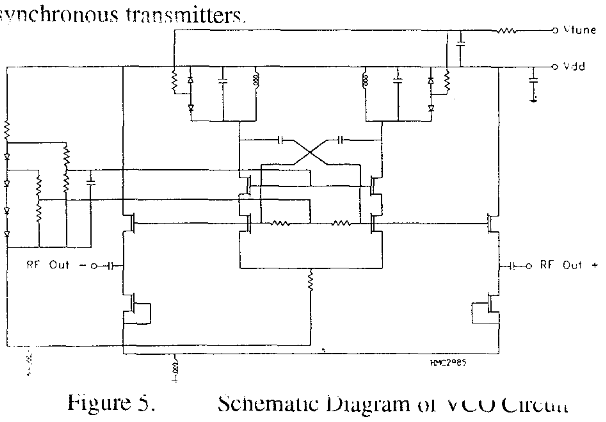


Figure 5. Schematic Diagram of VCO Circuit

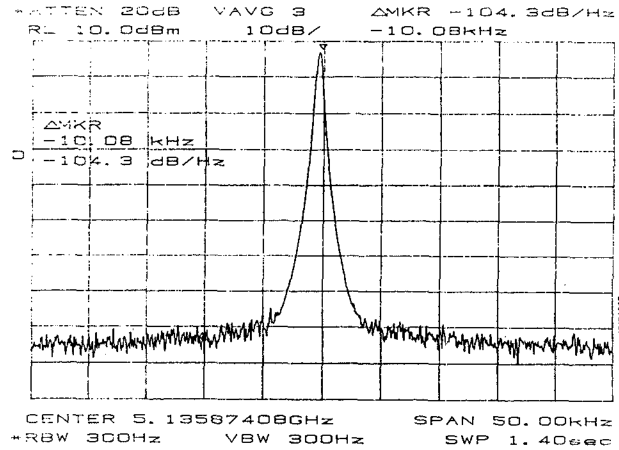


Figure 6. Transmitter Residual Sideband Noise Levels

The MMIC VCO, buffer amplifiers, phase modulator, and output preamplifier stages all are balanced circuit designs which minimize RF power-supply decoupling requirements and total DC power dissipation. The BPSK modulator circuit design complexity is much reduced when embedded in a balanced configuration. It consists of a differential amplifier arrangement in which the modulating signal simply forces the circuit to switch either the 0 or 180 degree input to the output port. The on-chip modulation driver circuit has balanced inputs to allow for high-frequency differential input modulation signals, and to provide for maximum flexibility for single-ended logic voltage levels such as TTL or CMOS. A planar MMIC-compatible transformer balun is used to drive the single-ended output power amplifier stages.

Figure 7 shows the schematic diagram of the MMIC output power amplifier circuit. The first stage is similar in design to the balanced cascode buffer amplifier stages used between the VCO and the BPSK modulator. A planar, spiral transformer is used to provide a single-ended drive signal to the output stages. The small signal voltage gain is approximately 17 dB; however, the output amplifier is driven hard into compression with a large signal gain of -4 dB, providing 21 dB of gain compression. This mode of operation dramatically reduces AM noise, which is the main source of self-generated sensor noise for each of the quadrant sensors. The receiver mixer schematic diagram is shown in Figure 8. It is a single-ended, voltage-doubler topology designed to provide relatively constant conversion gain and input\output impedances over a wide range of LO power variations. External bias can be provided for increased voltage conversion efficiency.

The MMIC described above was packaged in a standard metal- based, 10-pin flatpack suitable for surface mounting. The low-frequency portion of the sensor which includes the external PLL components, the PN code generator, the code demodulators, doppler amplifiers, and target detection decision circuitry was realized with standard commericial CMOS and silicon bipolar technologies. The entire prototype sensor electronics for a given quadrant, including the MMIC chip, was integrated onto a standard printed-circuit board approximately three by four inches in size. A photograph of the quadrant sensor electronics is shown in Figure 9.

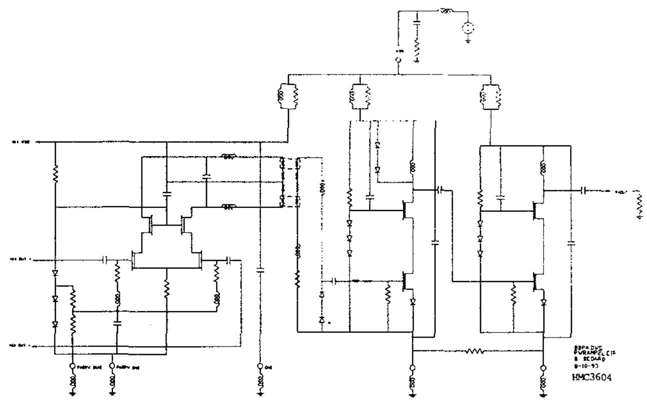


Figure 7. Schematic of Output Amplifier Circuit

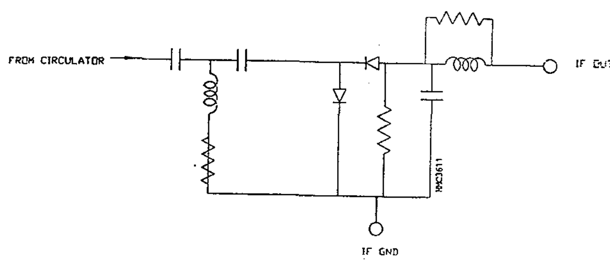
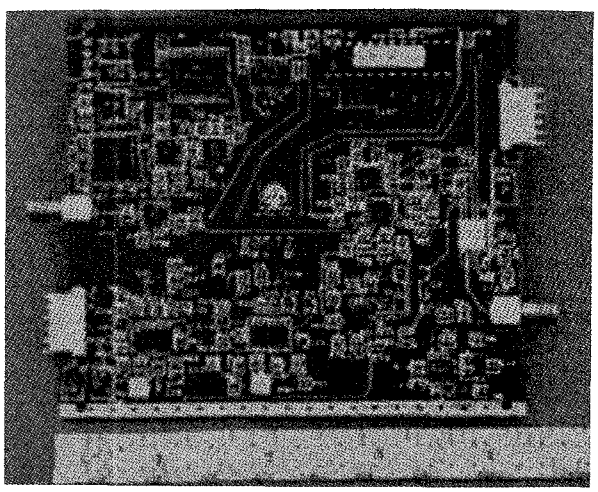


Figure 8. MMIC Rec[illegible]ve Mixer Schematic Diagram



[illegible]e 9. Phot[illegible] of the Qu[illegible] [illegible]nsor Assembly

MEASURED RESULTS

The MMIC-based quadrant sensor described above was fabricated and assembled into a seven-inch missile mockup which was tested in an anechoic chamber. A photograph of the final assembly is shown in Figure 10. Anechoic chamber testing consisted of target detection sensitivity measurements utilizing an artificial target generator located downrange of the missile mockup. Table 2 shows the measured results for target detection sensitivity for both the anechoic chamber test as well as laboratory bench testing. The internal sensor decision threshold was adjusted to give a positive target indication at a nominal 15 dB signal to noise ratio. The first column indicates the fuze sensor target detection sensitivity with only a single quadrant operational. The second column shows the same measurement with all quadrants simultaneously transmitting, while the last column shows the result for a single quadrant sensor tested in the laboratory (no anechoic chamber). Note that there is no desensitization of any given quadrant sensor when all quadrant sensors are operating simultaneously, validating the original concept of autonomous operation of nearby fuze sensors mounted in close proximity on a single weapon platform.

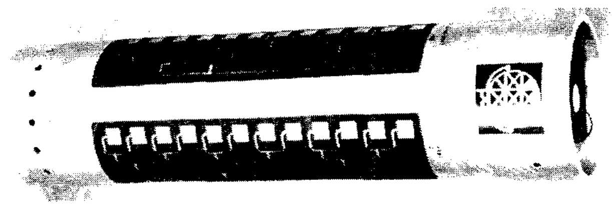


Figure 10. Photograph of prototype missile TTD assembly

Range Bin	Bench Test	Anechoic Chamber Test	
		Single Quadrant	Four Quadrant
20 meters	92 dB	89 dB	90 dB
25 meters	92 dB	90 dB	91 dB
30 meters	92 dB	91 dB	92 dB

Table 2. Measured Sensor Target Detection Sensitivity

SUMMARY

This paper has described a miniaturized, directional air-target fuze sensor which utilizes four low-cost autonomous sensors configured as target detecting array. The use of MMIC technology was key in reducing the individual sensor size and cost to the point where it became more economical to use separate directional sensors operating simultaneously, rather than a centralized fuze processor design. In order to operate in close proximity without mutual interference on the same weapon platform, all sensors were synchrounized (phase-locked) to a common, low-frequency reference oscillator. Anechoic chamber performance evaluation of an integrated four-quadrant missile fuze prototype validated the concept of autonomous, directional target detection.

ACKNOWLEDGMENT

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REFERENCE

(1) S.E. Craig, W. Fishbein and O.E. Rittenbach (1962). Continuous-Wave Radar with High Range Resolution and Unambigous Velocity Determiniation. IRE Transactions on Military Electionics, Vol. MIL-6, No. 2.