MMIC Transmitter for a Commercial Search and Rescue Radar Transponder

J. B. Vincent and D. G. van der Merwe

Abstract—**This paper reports the design and use of MMIC's in the transmitter of a commercial Search and Rescue Transponder (SART). The SART is a maritime unit operating in the frequency band 9.2–9.5 GHz. The microwave unit is integrated on a single thick film hybrid, using an optimum combination of MMIC's and discrete components. This has resulted in a highly reliable, cost-effective product. There are two MMIC's, namely the VCO and the power amplifier. The VCO MMIC has a typical linearity of better than 5-MHz deviation over a 300-MHz sweep. The power amplifier MMIC has a minimum power output of 27-dBm over the band.**

I. Introduction

As part of the Global Maritime Distress and Safety System (GMDSS), the International Maritime Organization (IMO) requires that by February 1995 all ships of between 300 and 500 tonne carry at least one SART and one Electronic Position Indicating Radio Beacon (EPIRB) and that ships of over 500 tonne carry at least two SART's and two EPIRB's. The EPIRB provides the initial distress notification as well as approximate position information. CAT I and II EPIRB's operate at 406 MHz and also have a 121.5-MHz homing signal. The 406-MHz EPIRB's use the COSPAS/SARSAT polar orbiting satellites and a Doppler technique for position information, which can be inaccurate by up to three miles [1].

There is also a delay in determining position and relaying it to the ground station. EPIRB's have a VHF homing signal, but accuracy is limited, and range information is only available with two or more search craft.

The SART is used for the final search, once the approximate position is known. It can be detected by airborne radars at a distance of at least 30 nmi and by ship borne radars with a 15 m elevation at a distance of at least 5 nmi. It provides real time range and bearing information on a radar display. The SART is invaluable for quick survivor location, especially in rough seas or poor visibility. The worldwide market for SART's is estimated to be in the 100 000's.

The SART (Fig. 1) is a portable, active radar transponder used to increase the radar cross section of vessels in distress at sea. Its operational and performance requirements are given in international specification IEC-1097-1.

II. System Requirements

As shown in Fig. 2, the electronics of the SART comprises the Microwave Unit and the Control Logic.

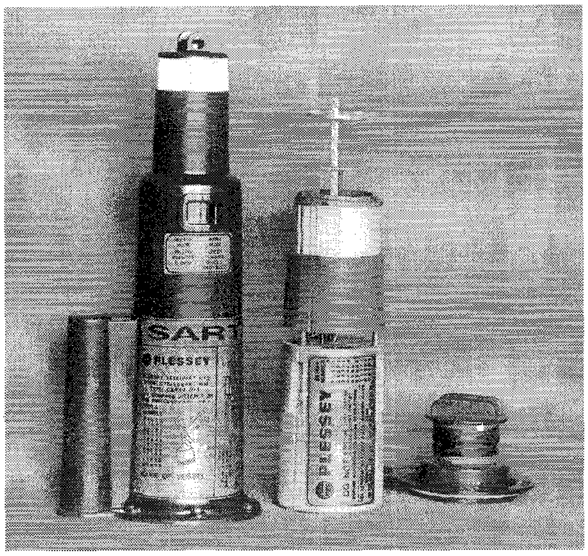

Fig. 1. SART showing microwave unit.

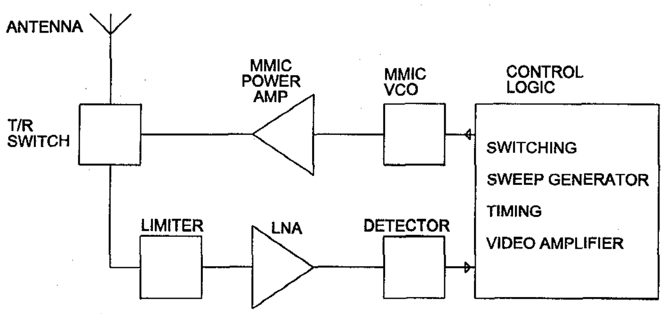

Fig. 2. SART block diagram.

Once activated, the SART detects the radar signal of a search craft and responds with a series of 12 pulses, the closest pulse indicating the position of the Transponder. These appear as equally spaced arcs on the search craft's radar display. The transmitter is normally off to conserve the batteries. When a pulse is detected, the control logic turns the transmitter on, sweeps the VCO frequency 12 times across the band, and turns the transmitter off.

The transponder must respond within 500 ns of receiving a radar pulse. Thus, the video amplifier and control logic need to switch the transmitter stage very fast. In addition, the VCO must settle to the correct frequency in the time allowed.

III. Design

As SART is a commercial product one of the prime considerations in the design was keeping production costs as low

Manuscript received May 15, 1994; revised January 30, 1995.
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IEEE Log Number 9412086.

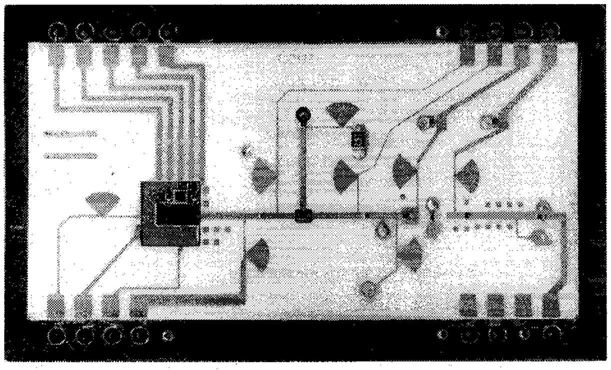

Fig. 3. Photograph of microwave hybrid (25 mm × 50 mm).

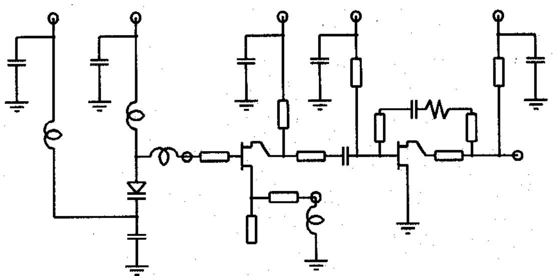

Fig. 4. Schematic diagram of the VCO MMIC and off-chip varactor.

as possible. As thin film substrates are expensive, a thick film process incorporating an additional etching step for fine line geometries down to 40 μm was developed for the design of the microwave unit or hybrid.

The hybrid (Fig. 3) uses hermetically sealed cans with integral glass seals. A waveguide antenna is used and is fed directly via a pin from the thick film module.

A cost comparison between using discrete components and MMIC's was carried out on each module forming the microwave unit shown in Fig. 2. Assembly time, ease of manufacture and tuning were also taken into account. As a result of this costing exercise it was decided to use MMIC's for the VCO and power amplifier. Low power MESFET's are relatively low cost. Therefore the receiver, consisting of a limiter, low noise amplifier, and detector, was designed using discrete devices. This approach resulted in a cost reduction of almost 50% compared to a unit using discrete components only.

The nonrecurring engineering cost per iteration in developing MMIC's is relatively high. The "time-to-market" for this product was also very important, therefore it was critical to get the design right on the first iteration. This was achieved by designing wide band circuits, using an off-chip varactor for the VCO and off-chip output matching for the power amplifier. Extensive use was made of feedback in the amplifier circuits to improve the yield while accommodating a wide spread in process parameters.

Where possible, circuits were designed to cover the range 8–12 GHz. Layouts were optimized for maximum yield.

Several GaAs foundries were investigated. Texas Instruments was chosen, as they had a process with a proven power capability and good yields.

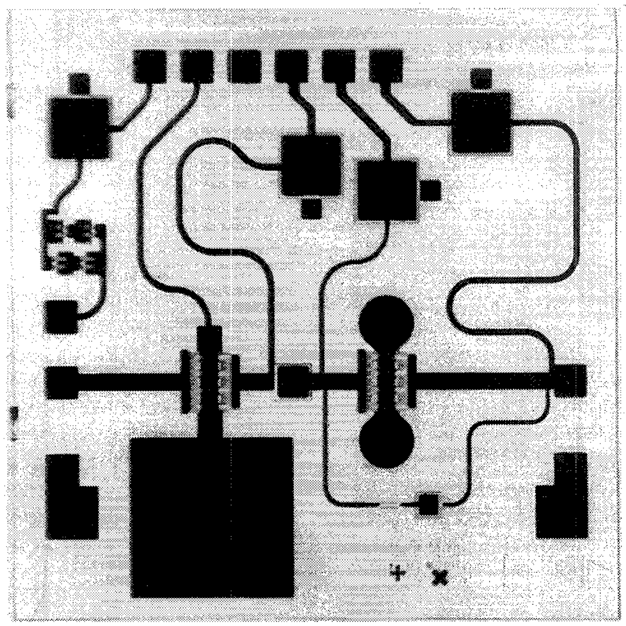

Fig. 5. Photograph of the VCO MMIC (2 mm × 2 mm).

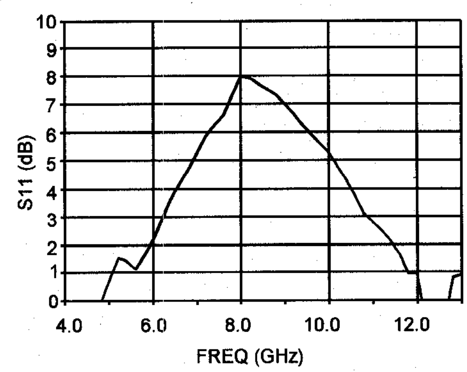

Fig. 6. Measured S_{11} of VCO MMIC.

IV. Voltage Controlled Oscillator

The VCO MMIC uses two 600-μm MESFET's. The first forms the oscillator and the second a buffer amplifier. The oscillator is a series feedback type.

The negative input resistance is achieved by optimizing the distributed source capacitance. Fig. 6 shows the measured S11 indicating a negative resistance from 5–12 GHz. The resonant circuit is off-chip using a hyperabrupt varactor diode, and the bond-wire, as an inductor. This type of oscillator is normally fairly sensitive to frequency pulling and any load variation over the tuning range will effect the linearity of the oscillator. Therefore, a buffer amplifier follows the oscillator. The buffer amplifier uses feedback to realize a very flat, well-matched load over the operating frequency range.

V. Power Amplifier

The power amplifier MMIC uses two MESFET's. The first stage uses a 600-μm FET in a feedback configuration, to achieve a good match over a wide band. The matching circuits were synthesized using the program Multimatch [2]. The load was calculated using the Cripps method [3]. To

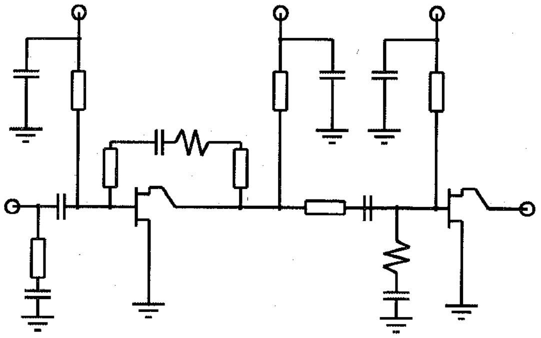

Fig. 7. Schematic diagram of power amplifier MMIC.

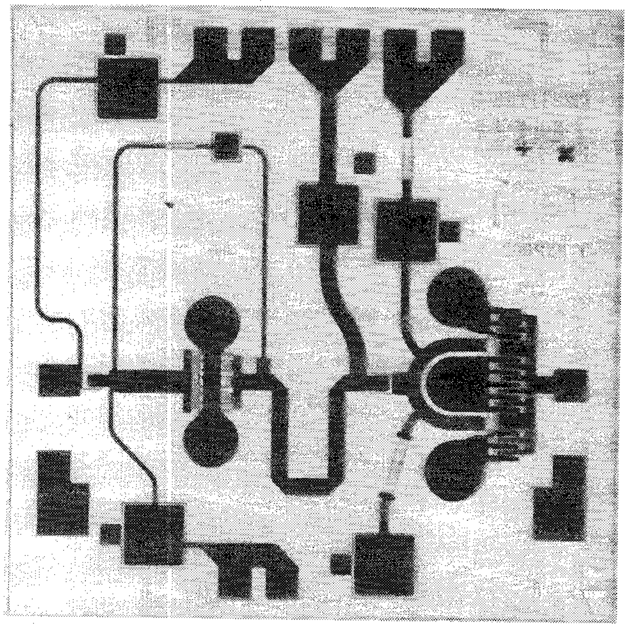

Fig. 8. Photograph of amplifier MMIC (2 mm × 2 mm).

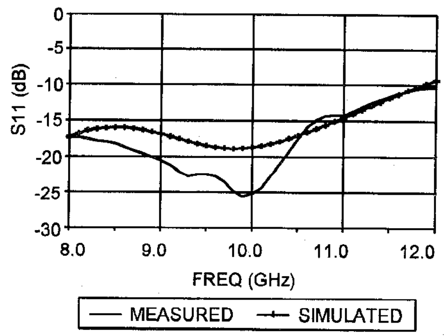

Fig. 9. Measured versus simulated input match of amplifier MMIC.

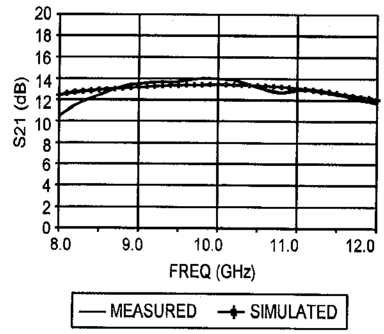

Fig. 10. Measured versus simulated gain of amplifier MMIC.

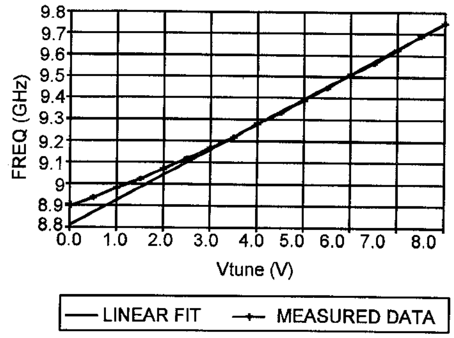

Fig. 11. VCO linearity compared to a straight line fit.

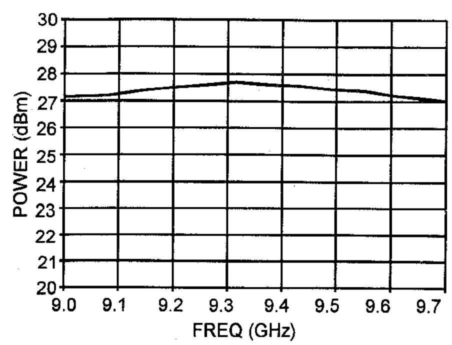

Fig. 12. Amplifier power output into a 50-ohm load.

optimize the load of the feedback amplifier in the circuit the S-parameter probe method [4] was used. Using this method allows optimization of the circuit to achieve the correct load impedance while simultaneously obtaining the necessary gain sloping and stability. This stage has a gain of 8 dB and a power output of more than 23 dBm.

The second stage uses a 1200-μm FET with the input matched over the band 8–12 GHz. The output is matched off-chip to minimize the MMIC area. Again the Cripps method was used to determine the load. The gain of this stage is 6 dB with output power of more than 27 dBm.

VI. Results

All FET's were biased at .5 IDSS. Figs. 9 and 10 show the modeled versus measured results for the MMIC power amplifier.

Fig. 11 shows the measured frequency versus tuning voltage for the VCO compared to a straight line fit. The linearity is better than 3 MHz from 9.2–9.5 GHz. Fig. 12 shows the measured output power of the amplifier into a 50-Ohm load.

The two MMIC's met or exceeded both the design goals set and all the requirements for the SART. To date 30 wafers have been processed. In-house wafer probing during this time has shown an RF yield of better than 80%.

A histogram of gain for a typical wafer is shown in Fig. 13. Note that all wafer measurements are performed at reduced bias levels to prevent overheating of the FET's. This results in the circuit having approximately 1.5 dB less gain than at full power.

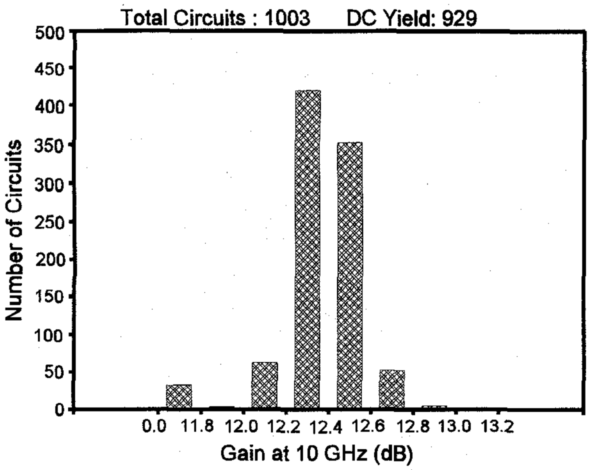

Fig. 13. Histogram of gain for a typical wafer.

The SART is GMDSS approved and has passed stringent type approval tests according to international specification IEC-1097-1.

VII. Conclusion

This design has shown that a judicious combination of MMIC technology and discrete components integrated with low cost thick film technology can produce a cost-effective product within a relatively short development time, requiring only a single iteration for the MMIC designs. The use of feedback in the MMIC's allowed the design of wide band circuits that were relatively insensitive to process variations. Using feedback with the S-Parameter Probe, it was possible to design an amplifier with a power match over a very wide band. In addition, the use of MMIC's greatly reduced the assembly and test time.

In short, this is a very favorable method for high volume, low cost, high reliability commercial products, which will become even more so as the "wafer costs" for GaAs decrease.

References

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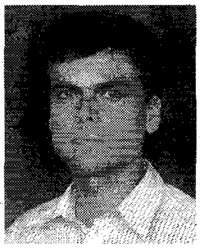

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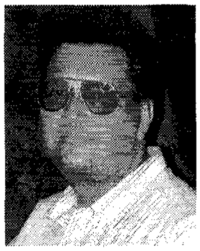

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He joined the Department of Electronic Engineering, University of Pretoria, in 1980 as a senior lecturer specializing in the design of active and passive microwave circuits. In 1985, he joined the Carl and Emily Fuchs Institute for Microelectronics at Pretoria University as professor, where he worked on the development of an MMIC fabrication process using ion implanted material and direct write electron beam lithography. In June 1990, he joined Plessey Tellumat Ltd. SA, where he is in charge of the Microelectronic group responsible for the development of GaAs MMIC's and MIC modules.