MMIC RADAR TRANSCEIVERS FOR INDUSTRIAL SENSORS

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ABSTRACT

Active microwave sensors perform radar functions to detect presence of objects and measure position and speed of those objects. With the benefit of MMIC technology, advanced radar techniques may be applied to expand sensor functions without increasing the cost of the microwave front-end significantly. One example of low-cost MMIC radar sensors is Hittite's FM-CW transceiver for proximity fuze integrated into a 1 mm^2 chip. Hittite has also demonstrated low-cost techniques for packaging and automated functional testing. These low-cost design and manufacturing techniques are applicable to a wide variety of industrial sensors. As an example of industrial applications, a radar sensor designed for liquid level measurements will be described.

LOW-COST FM-CW RADAR

To realize the full promise of MMIC advantages, it is necessary to develop MMIC techniques for the full complement of microwave circuit functions. To integrate a complete transceiver front-end with a full duplex capability in a single chip, for example, Hittite developed a novel active circulator [1,2]. Figure 1 shows block diagram of Hittite's FM-CW radar transceiver and its chip photograph. For low-cost production, the chip design is optimized for minimum size, no via-hole, minimum I/O, and single-voltage operation. This radar transceiver was originally developed for proximity fuze applications for munitions for range measurement of 1 to 100 meters with an accuracy of +/- 5% [3,4].

Once the chip design is optimized for low-cost production, the cost of packaging and testing becomes the major contributor to the over-all cost of the transceiver. The plastic encapsulation technique, used widely for silicon ICs, provides a solution to the packaging problem. To adopt this well-established commercial practice to MMIC chips operating at microwave frequencies, a series of experiments was performed to assess: (1) the dielectric loading effect, (2) RF and thermal properties of the lead frame, and (3) mechanical stress on the chip induced by the packaging material [5]. Figure 2 shows an example of test results showing the frequency shift of the oscillator caused by plastic encapsulation. The SEM photos in Figure 3 shows that the structural integrity of the chip, which contains many air-bridged inductors, is unaffected by the encapsulation material or process.

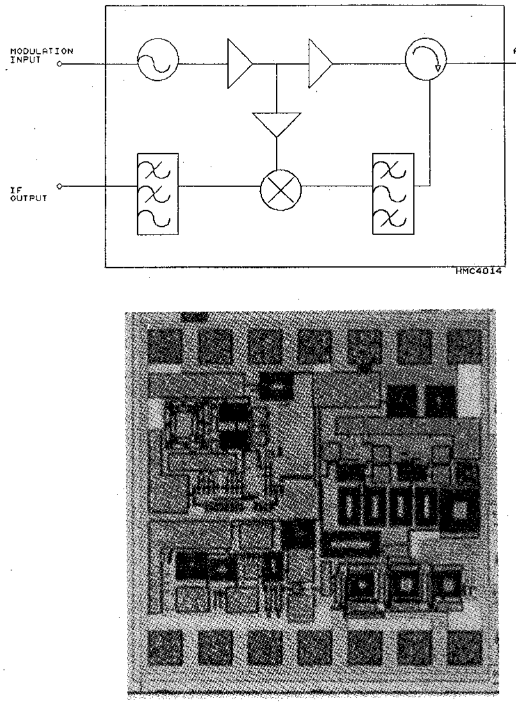

Figure 1. Block diagram and chip photo of single-chip FM-CW radar sensor. Chip dimensions: 1mm x 1 mm.

The performance criterion for the chip is its ability to measure the range. For low-cost production testing, the transceiver is tested in its normal intended mode of operation, using a range simulator programmed for the range and range steps, doppler shift and path loss. The transceiver generates its own test signal, and the return signal from the range simulator is decoded by the signal processor, and compared to the prescribed accept/reject criteria. The test procedure is designed to allow correlation of the "self-test" results to 16 specification parameters. The testing time is less than 10 seconds/unit.

The low-cost design and manufacturing techniques described above for the FM-CW radar sensors for fuzes are also applicable to microwave sensor products for commercial applications.

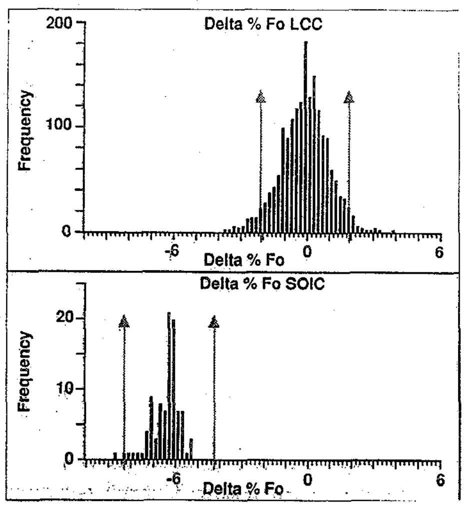

Figure 2. Distribution of output frequencies of FM-CW radar in cavity type package (LCC) and plastic package (SOIC).

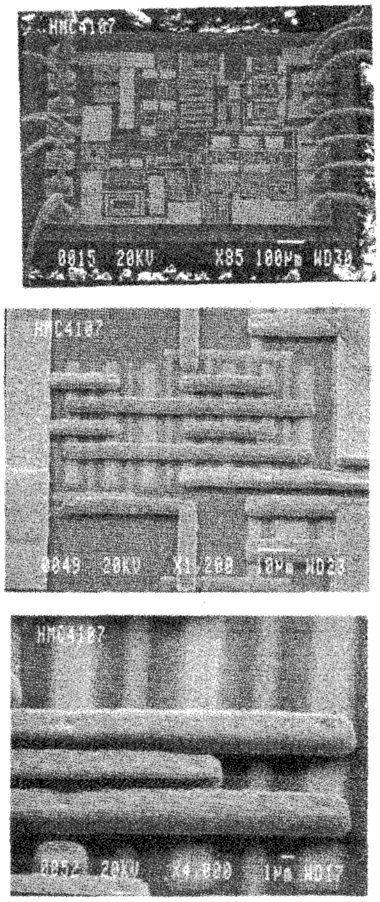

Figure 3. SEM photos of plastic encapsulated MMIC with encapsulation material removed after temperature cycle per MIL-STD-883 method 1010C.100 cycles -65°C to +150°C.

LIQUID-LEVEL SENSOR

Microwave range sensors are used widely for monitoring and controlling the volume of chemicals, fuel, molten metal, as well as food products in enclosed containers. Design approach for the microwave transceiver are dictated by the operational requirements for range, range resolution, accuracy, measurement up-date rate, multi-path rejection, etc. For low-cost equipment, the microwave portion of the sensor should be designed to operate with a signal processor of modest complexity.

Of various design options available for RF parameters, Hittite has selected a pseudo-random phase coded CW radar operating in the ISM band of 5.7 - 5.825 GHz for this application. Figures 4 and 5 show block diagrams and chip photos of two commercial versions of the RF transceiver and Figure 6 shows block diagram of a sensor assembly. This sensor system is based on the "delay discriminator" architecture. Ranging is accomplished by observing and processing the autocorrelation function of the transmit waveform and the received (delayed) radar echo from the liquid level surface. The waveform chosen is a pseudo-random code because of its very desirable autocorrelation function which exhibits a very sharp peak when the codes are aligned and drops off very rapidly and uniformly when the codes are misaligned. The PN code biphase modulates an RF carrier. The return echo is compared with a variable delay PN code in which the delay is adjusted to locate the peak of the autocorrelation function. The delay between the codes is then measured to give an indication of the target delay. The autocorrelation peak width is related to the transmitted bandwidth defined by the chip rate. Thus the higher the chip rate, the narrower the peak and hence the finer the range resolution. To achieve sub inch range resolution, however, the transmitted bandwidth must be several GHz, which is impractical or would require expensive millimeter wave RF circuitry. However, the midpoint between the autocorrelation peaks of two codes separated by a single bit may be measured with arbitrary precision by increasing the received SNR. This sensor system is capable of meeting most of requirements for liquid-level measurements for a range of up to 50 feet with an accuracy of better than 1", and with added capabilities for multi-path rejection and self calibration.

SUMMARY

Design techniques evolved for single-chip integration of microwave transceivers may be applied to design of sophisticated radar front-ends for commercial/industrial sensor applications. Low-cost manufacturing techniques for packaging and testing, developed for sensors for ordnance fuze applications, are also applicable to production of commercial sensors. Of various potential applications of microwave sensors, a liquid-level sensor using a highly integrated MMIC chip is described as an example.

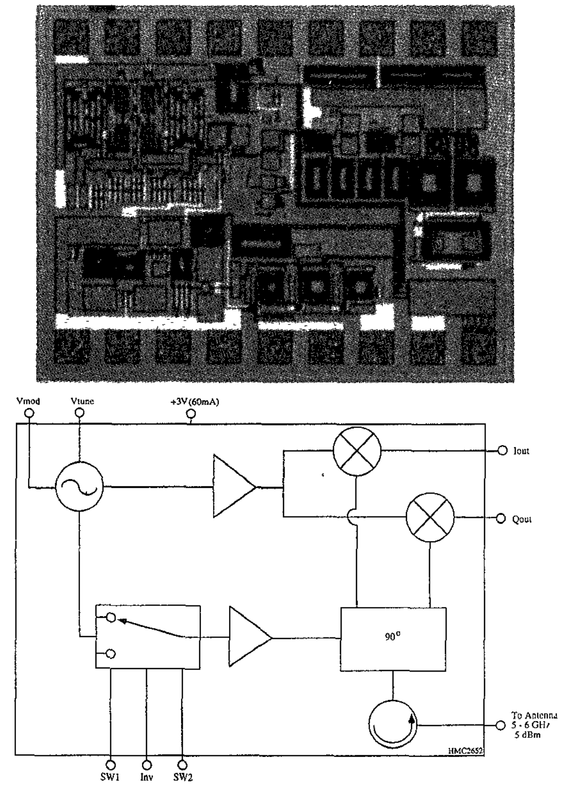

Figure 4. BPSK modulated transmitter/receiver chip.

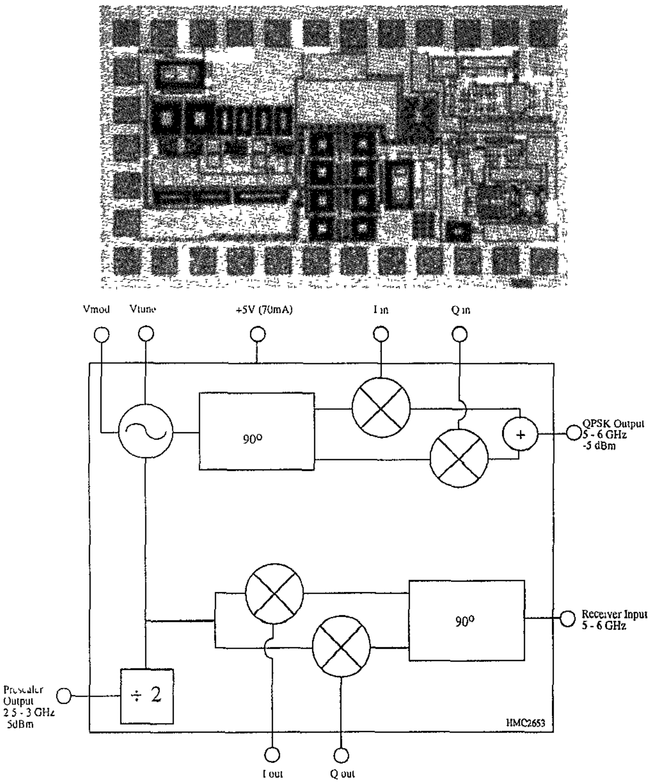

Figure 5. Integrated chip containing QPSK modulated transmitter and I/Q receiver.

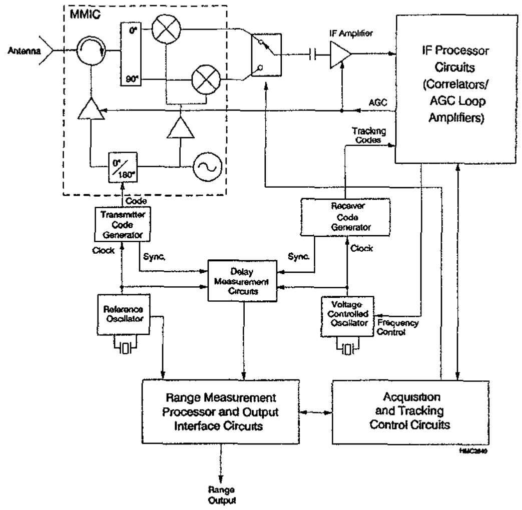

Figure 6. Simplified block diagram of PM-CW radar sensor.

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