Single-Chip FM-CW Radar Low-Cost Production Test

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ABSTRACT

In order to realize the low product cost potential of a single-chip FM-CW radar MMIC, an innovative production testing concept is developed in which the complete transmit/receive transfer function is verified in under one minute using the self-generated microwave signal in a simulated radar range environment. The test acceptance criteria are related to fundamental radar module specifications.

INTRODUCTION

Hittite Microwave is developing a single-chip MMIC FM-CW radar optimized for low-cost miniature range and velocity sensor applications as a part of the DARPA MIMIC Phase I program. All the microwave functions of a FM-CW radar have been integrated onto a single high-yield chip 1.3 x 1.75 x 0.25 mm operating at C-band; an early version of which has been reported previously [1].

In order to fully realize the low cost potential of MMIC fabrication, low cost packaging and testing concepts must also be used to minimize all cost factors. Our approach is a quick but comprehensive production testing concept in which the highly integrated chip almost tests itself. Instead of testing each circuit function independently by conventional time-consuming methods using expensive microwave test equipment, the complete transmit/receive transfer function of the packaged chip is verified using its self-generated microwave signal in a computer controlled simulated radar range environment in about 17 seconds. The only microwave signal incident upon the device under test is a portion of its own transmitter output, processed to replicate the actual field conditions.

TEST PROCEDURE

Low chip and packaging costs make it possible to eliminate all electrical testing prior to the final test. In our approach, the final acceptance test verifies that the radar module can measure distance to a target in a simulated range environment. The packaged chip is clamped into a special production test fixture, a 5 volt power supply for the device under test is switched on and monitored, and proper output frequency and power are verified. Processed IF output voltage is monitored as the range simulator is quickly stepped through a number of delay and attenuation states to replicate the target range, target velocity, target reflectivity, and antenna gain expected for a customer's application.

The FM-CW radar production test environment is shown in the Figure 1 diagram. The key components are an inexpensive frequency counter, power meter, DC power supply, range simulator with local oscillator, modulator/signal processor, and test fixture, as shown in the Figure 2 photograph. The complete test is defined by user friendly software run on a personal computer.

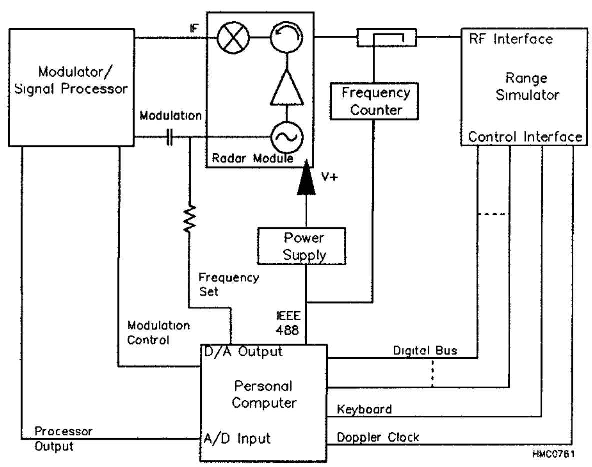

Figure 1. Low cost production test environment for FM-CW radar.

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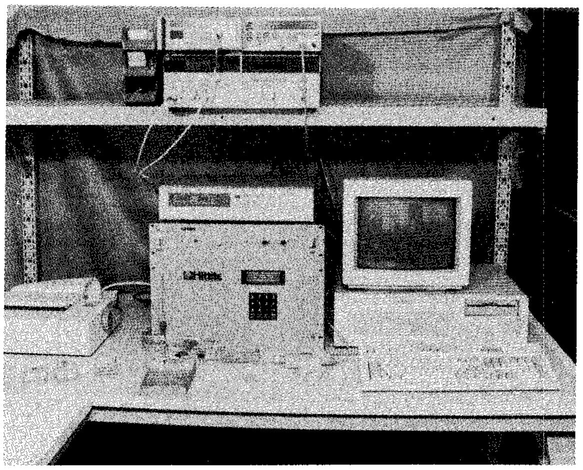

Figure 2. **Photograph of low cost production test station.**

The test flow diagram is shown in Figure 3. The procedure requires the operator to make initial device and lot identification entries upon starting the program. Special test parameters and acceptance criteria can be entered, or default values can be selected at this time. The operator thereafter loads devices and bins them according to computer instruction (pass or fail) until all the devices in the lot are tested. The software can automatically assign a serial number to each device in the lot if necessary. The operator is not required to make any computer entries after the initial ones. No RF test skills are required of the operator.

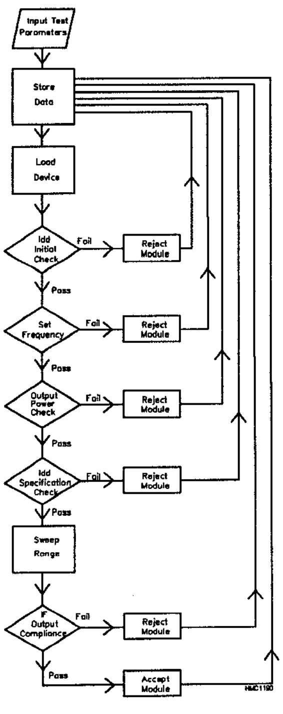

Figure 3. **Low cost radar production test procedure flow diagram.**

The test sequence makes an initial electrical continuity check, compares output power, output frequency and DC current drain to specification bounds, and performs the simulated range sweep. If the device fails any of the tests, the program loops back to the "load device" point without running subsequent tests in order to save time. Several data storage options are available, from lot summaries to a complete listing of processed IF voltage versus range.

RANGE SIMULATOR

The radar range simulator is housed in a compact enclosure 19 x 19 x 10.5 inches. Target return delay and attenuation appropriate for target distances between 1 and 120 meters in 1.87 meter increments are simulated. Doppler shift associated with approaching or receding target velocities between 0 and 4000 meters/second can also be introduced. A front panel keypad can be used to input operating parameters in a static operating mode. Simulation parameters are displayed on a front panel electro-luminescent display.

A simplified block diagram for the range simulator is shown in Figure 4. The radar transmitted signal is converted to a lower frequency and routed through delay and attenuation controlled by the computer. The reference frequency for the up-conversion process can be translated to simulate doppler shift in the target return signal when appropriate.

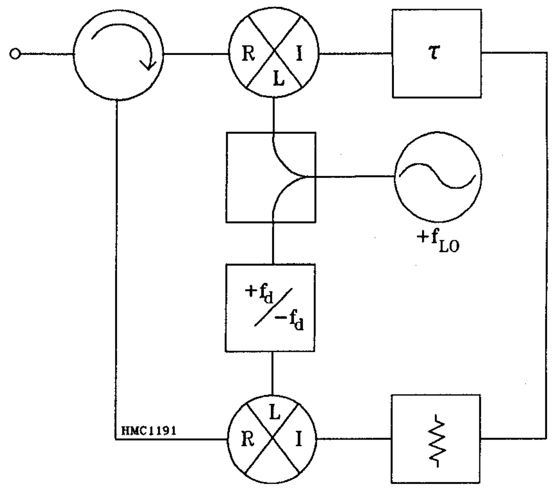

Figure 4. **Simplified block diagram of radar range simulator.**

MODULATOR/SIGNAL PROCESSOR

The modulator/signal processor provides a triangle wave modulation signal for the radar module, and operates as a fixed frequency receiver for the IF output signal. The radar module mixer output is band-limited, multiplied by a reference waveform, and integrated. The form of the theoretical range function is sin(x)/x [2]. The range associated with the peak in the range function bin can be adjusted by changing modulation or reference signal waveforms. Reference waveform design can provide suppression of range sidelobes. The signal processor output voltage is read by the computer A/D converter.

ACCEPTANCE CRITERIA

Acceptance criteria are formed by placing bounds around the expected processed IF output range function, and checking that the measured response falls within. The acceptance bounds are tied to radar module specifications such as transmitter modulation sensitivity and linearity, and receiver gain and noise level. Transmitter output power and frequency, and DC current drain are verified by direct measurement.

Present software and hardware are capable of verifying range measurement at multiple distances in one test sweep by changing the modulation signal amplitude and test acceptance bounds during the range sweep. Special application signal processors and acceptance criteria can also be used at customer's request.

TEST EXAMPLE

Figure 5 shows a typical plot of measured processed IF output voltage versus range as displayed on the computer screen during test. Three range measurement settings are tested in one sweep, centered at 9, 35, and 75 meters. The test seeks to verify that signal processor output voltage rises above the noise and range sidelobe levels within a range accuracy window.

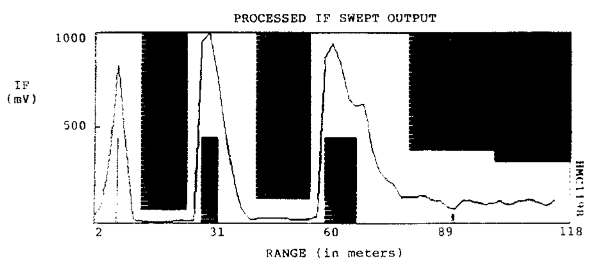

Figure 5. Typical processed IF voltage displayed on computer screen during test. Three range settings are tested in one test sweep.

The test acceptance bounds are seen as shaded areas in the plot. The lowest bound at maximum tested range is related to the radar receiver noise level specification. The remaining lower bounds are related to the range sidelobe level. The higher level horizontal bounds are related to the receiver gain specification. The vertical bounds are determined by the range measurement accuracy goal. Pre-production test trials using an interim version of the radar module have demonstrated 102 units/hour test throughput, including all module handling.

The directly measured performance parameters exhibit tightly grouped distributions. Figure 6 shows the distribution of RF output frequency for three pre-production assembly lots, operating at the 5.8 GHz FCC ISM band. The same VCO control voltage is used for all units. The standard deviation is 39 MHz, indicating that 93% of all units operated within ± 1% of the mean operating frequency with no adjustment.

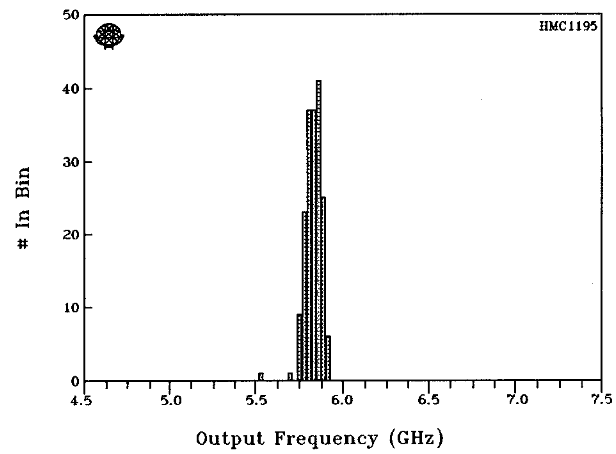

Figure 6. Distribution of radar module relative operating frequency test data from production test station.

Figure 7 shows the distribution of RF output power relative to the performance goal. The mean is 5.1 dB above the minimum acceptable level and the standard deviation is 0.45 dB. The distribution of DC current drain from the single 5 volt supply is shown in Figure 8. The mean value is 195 mA and the standard deviation is 20 mA, indicating that 89% of all units operating current falls within a 25% window, even though no electrical screening has been performed before this test.

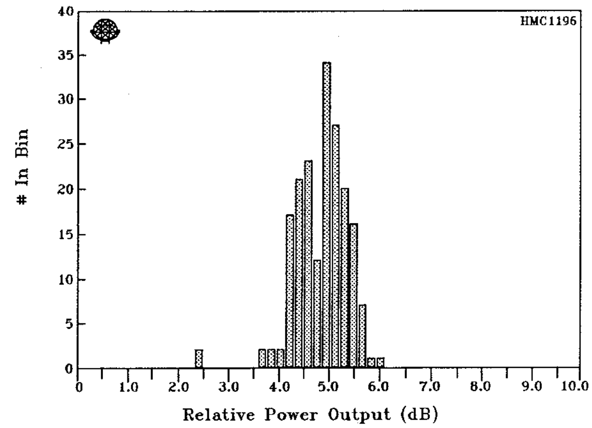

Figure 7. Distribution of radar module relative output power test data from production test station.

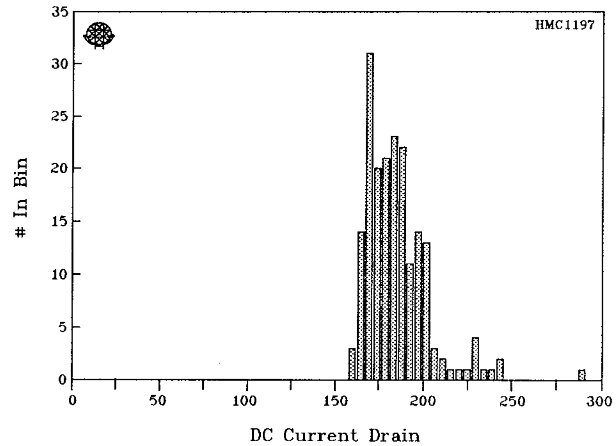

Figure 8. Distribution of radar module DC current drain from production test station.

As production quantities of radar modules become available, this test station will be used to provide a large performance and yield database for statistical process control as well as a final product acceptance test.

CONCLUSION

In order to realize the low product cost potential of a single-chip FM-CW radar MMIC, an innovative production testing concept is developed in which the complete transmit/receive transfer function is verified in 17 seconds using the self-generated microwave signal in a simulated radar range environment. The test environment, test acceptance criteria, and data storage are controlled by a personal computer. The test acceptance criteria are tied to the radar module specifications.

ACKNOWLEDGEMENT

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