Ka-Band MMIC-Based Transceiver For Battlefield Combat Identification System

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Abstract

This paper describes how the MMIC technology is utilized to meet the U.S. Army's need for near term solution in minimizing fratricide in the future engagement. One of the key assembly in the Battlefield Combat Identification System (BCIS) equipment set is the Ka-band MMIC transceiver unit. The MMIC transceiver is used to transmit and receive spread spectrum signal at 38 GHz. The design, integration and test of 13 GaAs MMIC chips in a single hermetically sealed housing (2.5 x 2.3 x 0.4 inches) is presented.

Introduction

In the recent Persian Gulf Desert Storm, over 20% of the causalities suffered by the American servicemen are due to "Friendly Fire". After the Desert Storm, the U.S. Army has been looking for near term solution to mitigate fratricide problem in the potential future engagements. Several different types of systems were evaluated and studied for the near term solution, ranging from infrared, laser, microwave, and millimeter-wave systems. It was concluded by the U.S. Army that the millimeter-wave system is best suited for the battlefield environments. The advantages of the millimeter-wave system are that it can operate in adverse environments, such as rain, fog, dust, smoke, and darkness. Because of it small size and lightweight, the millimeter-wave system can be easily integrated into the existing platforms with minimum impact.

The objective of the Battlefield Combat Identification System (BCIS) is to provide quick and positive target identification, either Friend or Unknown, without any additional impact to the platform operators. The shooter platforms, such as M1A1, M1A2 Abrams, M2A2 Bradley Fighting Vehicles and the FISTVs would be equipped with Interrogator/transponder equipment set, while the Scout HMMWV, Armored Personnel Carrier, and the Avenger alike would only have the transponder unit. The BCIS is initiated by the shooter platform by simply pointing the interrogator antenna and transmit Ka-Band spread spectrum signal to the potential target. If the potential target is also equipped with the BCIS equipment set, it would then receive the interrogation signal and respond to the query with the requester's and its own identification through the transponder unit. The shooter platform validates the returned transponder message and determine if it is a Friend or Unknown. The entire process of query and response takes

* This work was funded by U.S. Army Communications Electronics Command, Ft Monmouth, NJ

95CH3577-7/95/0000-0053$01.00

less than 1.0 second. One of the key assembly in the BCIS equipment set is the Ka-band MMIC transceiver unit. The MMIC transceiver is used to transmit and receive the 38 GHz frequency-hopping and spread spectrum signals for both the interrogator and transponder platforms. The design, fabrication, and the measured test results for the MMIC transceiver are presented in the following sections.

Transceiver Architecture Design

The key design parameters for the transceiver are listed in Table 1.0. The other critical requirement for the transceiver is that it must also be interchangeable for both the interrogator/ transponder and transponder only equipment set. The allowed time span from the design phase to the production of first MMIC-based transceiver is 12 months. The transceiver's functional block diagram is shown in Figure 1.0. Two levels of single-pole-double-throw switch (S1 & S2) are used to route the Ka-band signals to and from interrogator and transponder antennas during the query and response period. The received Ka-band signal is first amplified with two stages of low noise amplification before it is frequency downconverted to the IF frequency of 2.4 GHz. The transmit signal is provided by a phased-locked voltage-controlled oscillator (VCO) operating at 1/4 of the desired Ka-band frequency. The output from the VCO is then multiplied to Ka-band with 2 stages of X2 frequency multiplication. The first stage of frequency multiplication is provided by the X2 multiplier/frequency divider macrocell MMIC chip. The frequency divider is used for the phased-locked frequency synthesizer. The frequency synthesizer's phase-locked loop circuitry resides in a separate multilayer RF board assembly. After the first X2 multiplier, the transmit signal is then modulated with 0°/90° bi-phase modulator. The modulated signal is further amplified before it is multiplied to the Ka-band frequency. This path also provides the local oscillator (LO) source for the frequency downconverter mixer, except at a different frequency and without modulation. The required transmit output power level is provided by two stages of power amplification. During the receive operation, the two power amplifier stages are turned off to minimize dc power dissipation.

The entire transceiver architecture is accomplished using a total of 13 GaAs MMIC chips and a hybrid VCO. The critical millimeter-wave MMIC chips, such as the low noise amplifiers (LNA), output power amplifier (PA), mixer and the frequency multipliers were all designed and developed at TRW under the ARPA/Army Research Laboratory's (ARL) MIMIC Phase 2 Program. The LNA, power amplifier, and the Ka-band frequency multiplier chips were all developed using the Psuedomorphic High Electron Mobility Transistor (PHEMT) devices. The Heterojunction Bipolar Transistor (HBT) technology was also used for mixer and the frequency multiplier/divider chip development. The remaining MMIC chips in the transceiver were commercially available off-the-shelf components.

The 5-mil thick polished alumina substrates provided the 50 ohms line RF interconnection between the MMIC chips. Since the GaAs MMIC chips are typically 4-mil thick, any thicker substrates would require that the chips be mounted on a pedestal to help compensate the height difference. In addition to the 50 ohms line, all the bandpass filters for the transceiver were also designed and fabricated on 5-mil thick alumina substrate. The transceiver's Ka-band interfaces to the two antenna ports are provided by the waveguide-to-coaxial-to-microstrip transitions. Whereas, the low profile Gilbert connectors are used for the lower IF frequency interface ports.

Transceiver Fabrication

The BCIS transceiver housing was designed and fabricated based upon an alloy composition of 60% Aluminum and 40% Silicon, which is commonly referred to as A40. The selection of the A40 housing material was based upon the following factors: 1. The thermal properties 2. The coefficient of thermal expansion (CTE) match with GaAs chips and the alumina substrate. 3. Machineability and availability. All the MMIC chips, VCO, and the alumina substrates are all epoxied (conductive) directly to the floor of a single hermetically sealed C-frame housing. The direct attachment method eliminates the need for individual carriers, thus reduces the cost of fabricating the transceiver unit. At TRW, the hermetically sealed housing is commonly referred to as an IMA (integrated microwave assembly). The dc biases for the transceiver are all located on the bottom side of the housing floor. RF and dc glass bead feedthrus are used as hermetic interfaces between the MMIC chips and the outside environments. A photo of an unsealed BCIS Ka-band transceiver is shown in Figure 2.0. The overall dimensions of the transceiver are 2.5 x 2.3 x 0.4 inches.

Performance

The measured noise figure and gain for one of the typical BCIS production IMA over the temperature range from -40°C to +85°C are shown in Figure 3.0. The transponder's port noise figure is less than 8.5 dB with associated gain greater than 25 dB at the mounting baseplate temperature of +85°C. The minimum gain and maximum noise figure specifications for the IMA are also indicated on the graph. The noise figure and gain performance for the interrogator port are very similar to the transponder port as indicated by the graph shown in Figure 4.0. The measured output power from the transponder port is greater than +24 dBm at +85°C baseplate temperature across the frequency band (Figure 5.0). The IMA's dc power consumptions during receive and transmit mode are less than 7.3 watts and 12.8 watts, respectively.

Conclusion

A millimeter-wave transceiver has been designed, developed, and tested based upon the GaAs MMIC technology to meet the U.S. Army's near-term need for Combat ID system. The MMIC-based transceiver offers solution to an affordable and reliable millimeter-wave system. By further combing function of some of the microcells into macrocells, the overall complexity and cost of the transceiver can be reduced.

Acknowledgements

The authors would like to thank Tony Lissona, GaAs Production Line, and the HMD folks for their contributions in the MMIC chip fabrication, design layout and assembly of the IMA housings. The

TRW MMIC chips used in the IMA were funded by the U.S. Army ARPA under the MIMIC∅2 Program. Special thanks to Barry Allen, Mark Kintis, and CECOM for their technical support and encouragements throughout the integration and test of the BCIS system.

Table 1.0 Key Requirements for BCIS Transceiver

Parameters	Requirements
Operating Frequency	38 to 38.63 GHz
Noise Figure	9.5 dB max.
IF Frequency	2.37 to 2.40 GHz
RF-IF Gain	22 dB min.
Transmit Output Power	24 dBm min.
DC Power	12.8 watts max.
Operating Temperature Range	-40°C to +85°C

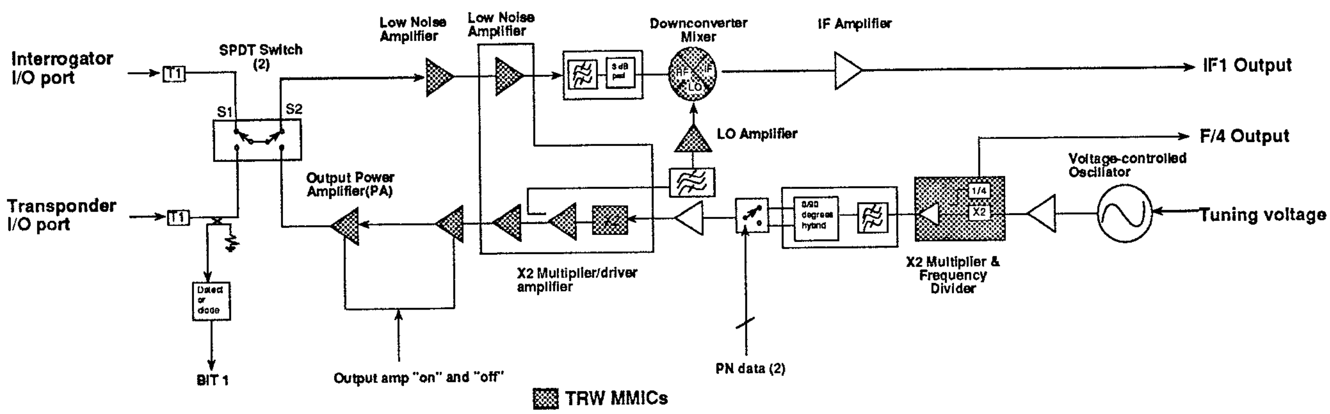

Figure 1.0 Ka-band transceiver block diagram

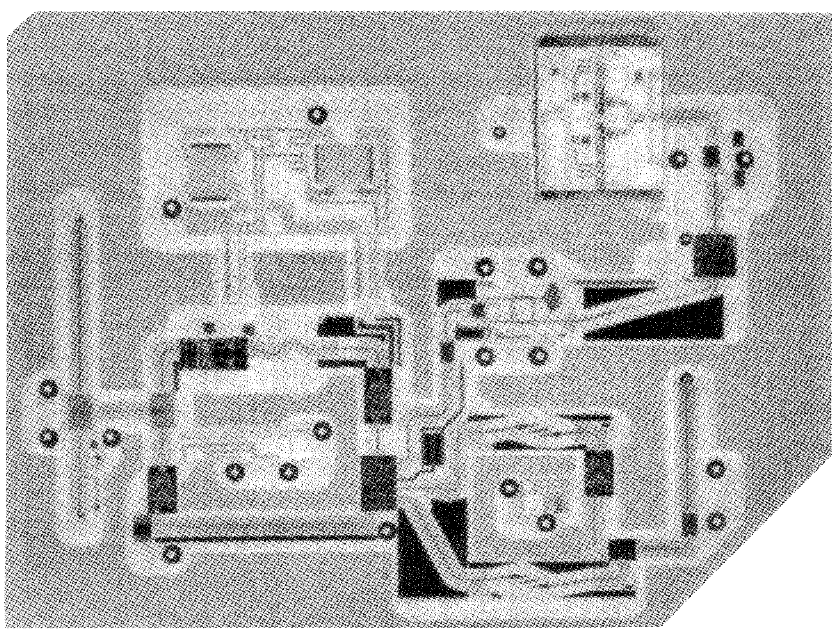

Figure 2.0 Photo of the production Ka-band transceiver

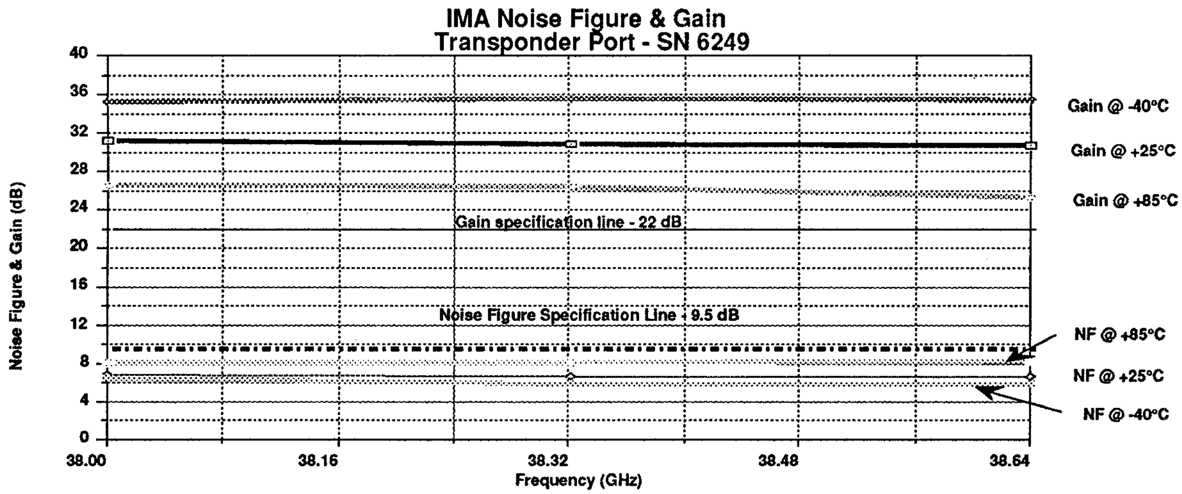

Figure 3.0 Measured NF & gain performance over temperature

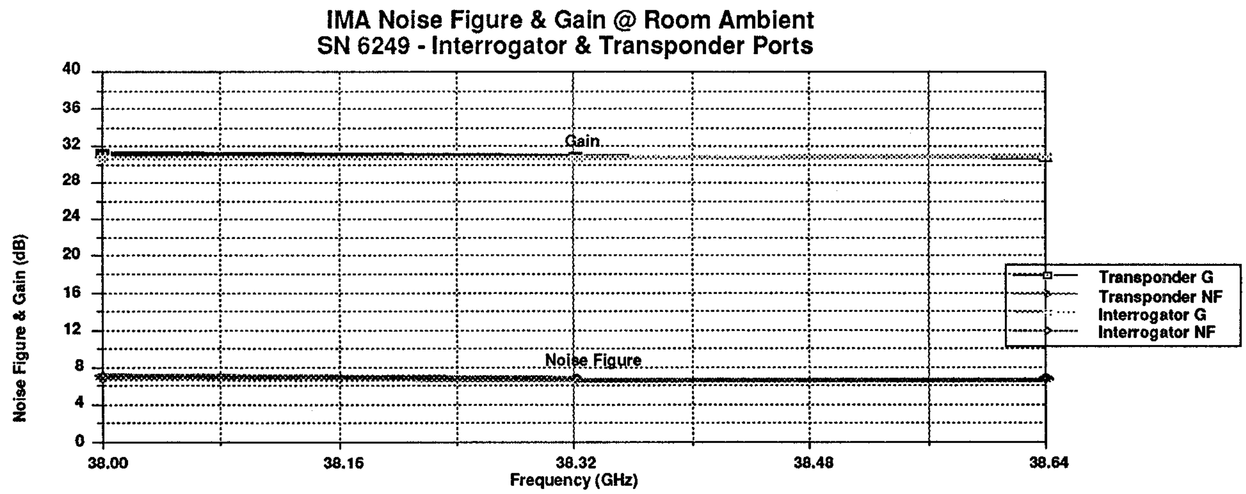

Figure 4.0 Measured NF & gain comparison between interrogator and transponder ports

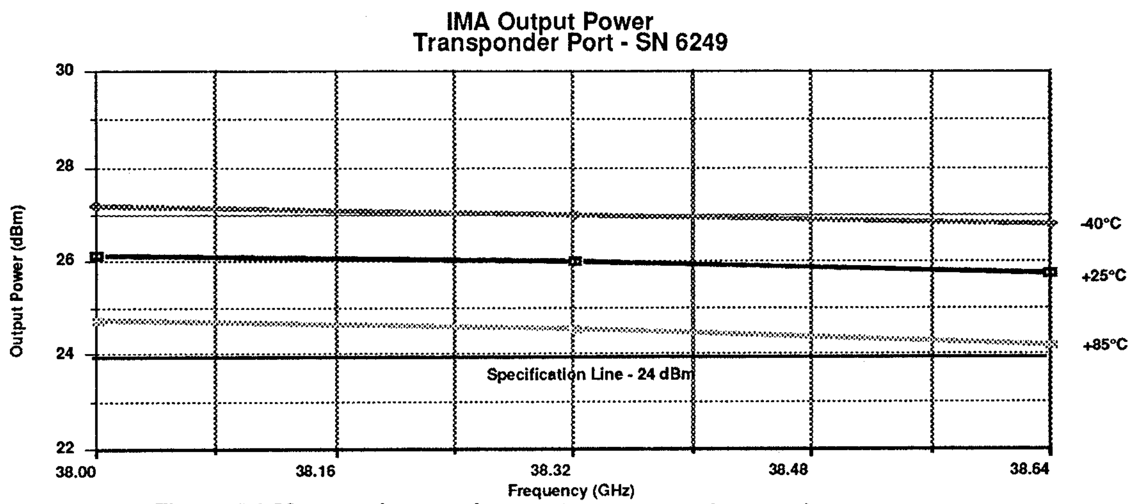

Figure 5.0 Measured transmit output power over temperature