A Compact Transceiver for Wide Bandwidth and High Power K-, Ka-, and V-Band Applications

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Abstract — **Using the state-of-the-art InP MMICs and advanced packaging techniques, we demonstrated a compact transceiver with wide bandwidth (13% to 54%) and high power (over 500 mW) in covering K-, Ka and V-band operating frequencies. This module consists of over 30 MMICs and over 200 components and is considered to be the most complex module reported in the millimeter-wave frequencies. This work has laid a good foundation for combining MMIC and packaging technologies for a versatile millimeter-wave transceiver module.**

I. Introduction

In many system applications, a versatile transmit/receive (T/R) module with high output power and broadband operation in millimeter-wave frequencies is very desirable. This T/R module provides a system designer the freedom in designing the system with various features in addressing increasing system needs. It will also allow the system to address future needs and hence a much long useful life. In addition, with the broad bandwidth and high output power, this T/R module can be used for many different applications and will facilitate the large quantity production and therefore reducing the module cost. To make this T/R module more feasible in its insertion into a system, all features have to fit into a compact housing. MMIC technologies with state-of-the-art material and solid-state devices have to be used. The advanced packaging techniques will also have to be developed. To further facilitate the implementation of this versatile T/R module, we break the frequencies into three key frequency bands – i.e., K-, Ka- and V-band. Although many previous papers reported good performance at these frequency bands [1] [2], wide band power amplifier is not available. Switching mechanism will be employed so that we can move among the three frequency bands effectively.

II. Module Architecture

Table 1 summarizes the required RF performance of this T/R module. To achieve these requirements, a trade study was conducted to analyze the frequency plan and architecture of the transceiver. Some of the design criteria are established to evaluate different frequency plans:

1. Spurs
   - Fixed In-Band Spurs From LO Harmonics (0,n)
   - Odd LO spur rejection (dBc) = 10 log (1/n)^2; where n is the no. of LO harmonics
   - Major 1,n In-Band Spurs From Mixers
   - When m>1, spur rejection can be improved by reducing the RF drive level
2. Transceiver Complexity
   - Number of components must be low

Based on the spur analysis, a relatively spur-free frequency plan was derived as shown in Figure 1. This plan uses 2 VCOs with LOs at 39 and 57 GHz and single frequency conversion on both Ka- and V-Band. Both x3 and x4 multipliers are used to obtained the required LO frequencies. The number of components required to implement this approach is high but acceptable. There is no major 1,n or 0,n spurs in-band except (-1, 2) spur. A 180 degree balanced mixer topology is used to provide some level of suppression on this –1,2 spur to make it acceptable. The other advantage of this frequency plan is that all the mixers are easy to implement.

Table 1. T/R Module RF performance Requirements

Parameters	Unit	Requirements
Frequency	GHz	
RF Input 1 / RF Output 1		57-65 GHz
RF Input 2 / RF Output 2		15-26 and 31-39
IF Output 1 / IF Input 1		15-26 GHz
Maximum Input Power	dBm	
RF Inputs		-20 dBm
IF Inputs		+7 dBm (signal)
RF Output Power	dBm	27 dBm
Input and Output VSWR		< 2:1
Noise Figure	dB	8 dB Max
Receive Gain	dB	–5 +/- 3 dB
Transmit Gain (linear)	dB	29 dB (max)

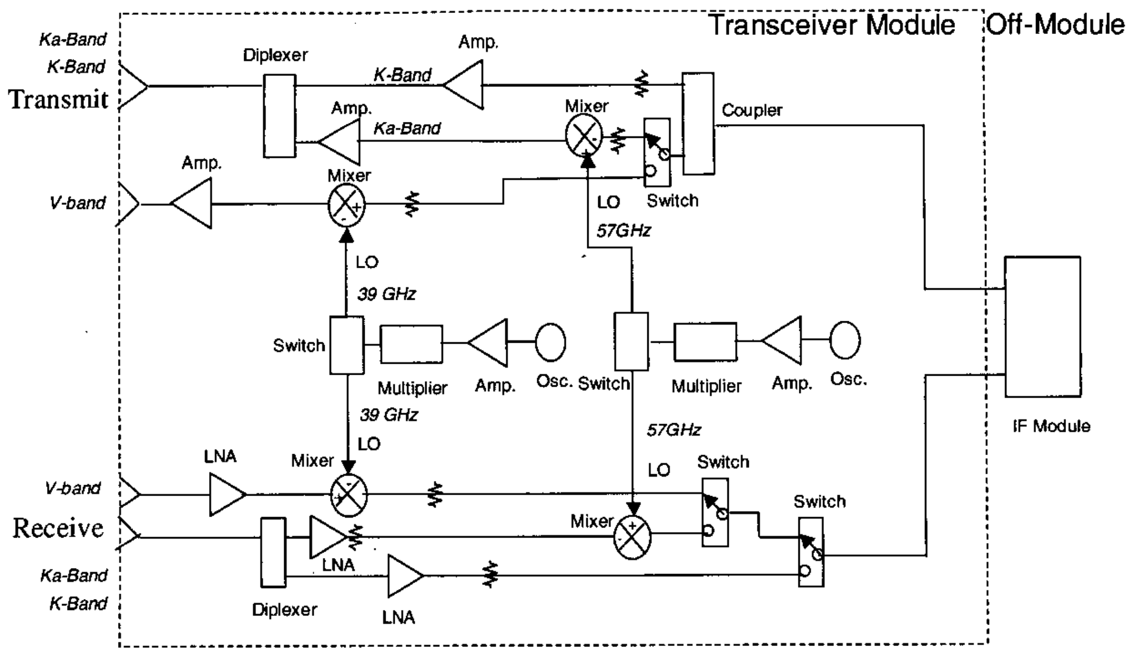

Figure 1. T/R Module Block Diagram

III. Component Requirements

Based on the module level performance requirement and the selected block diagram, we are able to establish a set of component requirements in implementing the T/R module. The following is a list of all key components and their performances to be developed:

- Power amplifier (PA) MMIC chips – for all K-, Ka- and V-Band frequencies, the PAs have output powers between 28 to 29 dBm. The drive power levels are ranging from 14 to 20 dBm. Input return loss is better than –12 dB. InP HEMTs are used as the baseline technology.
- Drive amplifier (DA) MMIC chips – for all three-frequency bands, the DAs have output powers between 14 to 20 dBm. The drive power levels are ranging from –2 to 7 dBm. They also need a return loss of better –12 dB. InP HEMTs are used as the baseline technology.
- Mixers – The V-Band mixer will operate with LO at 39 GHz, RF from 15 to 26 GHz and IF from 57 to 65 GHz. The conversion loss is no more than 10 dB LO power is at 10 dBm. The isolation from each port is 20 dB. The Ka-Band mixer will operate with LO at 57 GHz, RF from 15 to 26 GHz and IF from 31 to 39 GHz. Other requirements are similar to those of the V-Band one. InP HBTs are used as the baseline technology.
- Other components – This will include LNA MMICs, multiplier MMICs, diplexers and switches for all three-frequency bands. The design goals are to cover the bandwidth with minimum loss.

IV. Mechanical Design

To design a compact housing which will able to accommodate all functions described in the block diagram (Figure 1), we need to utilize both sides of the housing floor. A standard H-frame structure is selected. To facilitate the efficient routing, we put all DC circuitries on the backside while all RF circuitries, except one 57 GHz LO transmission line on the front side. RF feed thrus between front and backsides are developed by using 3-D simulation. Glass feed thrus are used. DC feed thrus are also employed to make connection between front and backside. The aluminum-silicon material and gold plated finishing are selected. To produce a compact module, we decide to use coax connectors for all RF connection – four V-Band spark plug connectors with feed thrus are used for two receive and two transmit ports. Two SSMA connectors with feed thrus are used for the two IF ports. For band switching command code, we use a compact connector to save space. Five ThunderlineZ DC terminals are used for DC bias input. In the front side, all RF passages are channelized to eliminate unwanted moding. The layout of all RF chains is flexible to accommodate MMIC chip size variation and additional chips if necessary. Due to the complexity of the module, we add RF probe in the V-Band transmit chain for troubleshoot purpose. In the backside, a seven-layer DC board is used to provide all the bias and connections. Several RF sub-covers are used to certain components to ensure the proper operations. The final RF cover is mechanically fastened to housing. The dimension of the entire module is 4.7x2.3x0.5 inches including all connectors.

V. Integration and Test

Since the module consists of more than 30 MMIC chips and more than 200 other components, the assembly of the module is a challenge. We established an assembly procedure, which governs the integration sequence of DC board, various substrates, MMICs, connectors, bonding, and sub-cover attachment. We also went through the build of a breadboard for functionality and a breadboard for final integration test before the build of the prototype modules. A completed prototype module is shown in Figure 2.

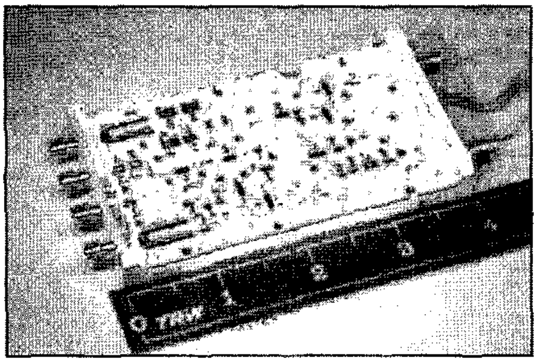

Figure 2. A completed T/R module.

In testing the module, we begin with the two LO chains. After obtain both correct LO frequencies, we then test the three receive chains individually. During this process, the command code and switching circuitries are also tested. Finally, we test the three transmit chain to determine the output power level. To facilitate an effective testing of this 3-band module, a test set was developed with its block diagram shown in Figure 3.

A test bench was set up to perform the module test. As illustrated in Figure 4, the test set is on a single bench and can effectively switch from one frequency band to another.

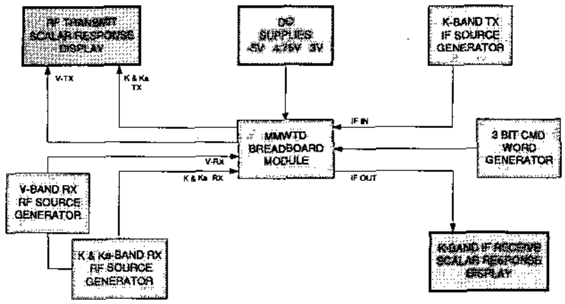

Figure 3. Module test block diagram.

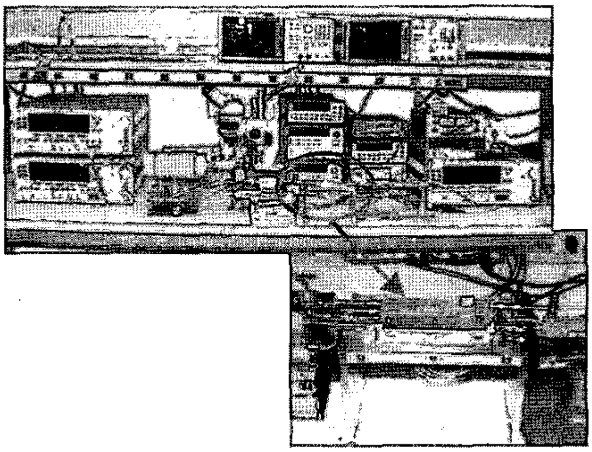

Figure 4. Test station for module testing.

VI. Measured Results

In addition to the breadboard, three prototype modules were built and tested. They all achieved very consistent measured results. In the K-Band transmit chain, we achieved an output power of greater than 27 dBm across the entire 15 to 26 GHz (Figure 5) at an input power of 7 dBm. For the K-Band receive chain, the module had an output power from –23.5 to –25.5 dBm and was within the required power level for the IF module. For the Ka-Band transmit chain, the module had an output power 23 to 28 dBm (Figure 6). We believe the power drop at the high end is caused by the diplexer. An investigation on improving the diplexer bandwidth coverage and searching for an alternate approaches has been underway. For the Ka-Band receive chain, the module had an output power from –23.0 to –31.5 dBm. The power drop at the low end is also caused by the diplexer. For the V-Band transmit chain, the module had an output power from 24.9 to 26.5 dBm (Figure 7) across the entire frequency band. We believe that this module is approaching the output power limit with the current technology for the required bandwidth of operation. For the V-band receive chain, we achieved an output power to the IF module from –22.5 to –27.5 dBm. The linear gains for all three transmit chains are below the 29 dB requirement. The measured noise figures are about 9 dB for all three bands.

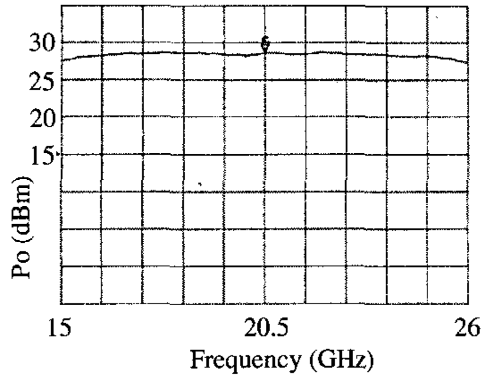

Figure 5. Measured transmit output power for K-Band.

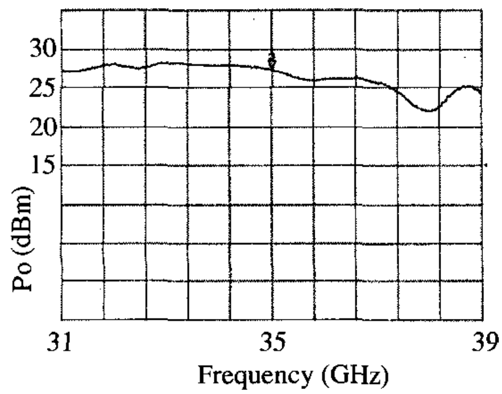

Figure 6. Measured transmit output power for Ka-Band.

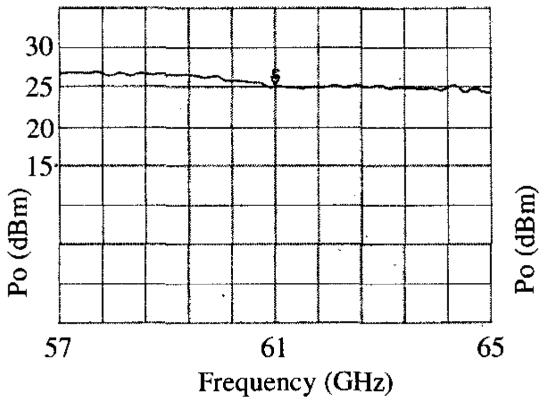

Figure 7. Measured transmit output power for V-Band.

VII. Conclusion

We have developed a compact, highly integrated T/R module operating in K-, Ka- and V-band frequencies. This module is capable of delivering a state-of-the-art performance in terms of combined output power and bandwidth requirements. With the successful demonstration of four modules build at this point with consistent RF performance, we believe that we have established an effective procedure to produce this highly complex module. The key factors for the success are the use of advanced InP HEMT technology and the enhanced packaging techniques. With the output power and the frequency coverage, we believe that this T/R module can be used in many applications.

Acknowledgement

The authors wish to acknowledge Dr. Barry Allen and Mr. George Schreyer for their review and suggestion of the module design.

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