Development and Transition-to-Production of a High-Volume Ka-Band SATCOM Outdoor Unit (ODU) Transmit Module

Roberto Alm, Ph.D.
Technical Director; mm-Wave Module Technology
Raytheon RF Components; Andover, Massachusetts U.S.A.
E-Mail: Roberto_W_Alm@rrfc.rytheon.com Telephone: 978.684.5450

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Abstract

This paper describes the design, development and transition to production of a GaAs MMIC-based Ka-Band commercial transmitter module as a demonstration of the techniques that were employed to successfully integrate Ka-Band GaAs MMIC technology into a high-volume commercial application. The end product is an up-link transmitter for a 30 GHz Commercial European Satellite System ground terminal that is presently being deployed in Europe. We describe the "lessons learned" in implementing high-frequency (Ka-Band) GaAs MMIC technology into products designed for high-volume manufacturing. Emphasis is placed on the design approach required to implement commercially available Ka-Band MMIC devices, and what was done to make the design consistent and manufacturable in high-volume. Further emphasis is placed on what techniques were used to minimize cost, and on what can be done in future designs to improve performance, increase manufacturing margins, and further reduce cost.

Figure 1: The Key Elements of the Outdoor Unit. The Sub-Reflector (Right) Faces the Feed (horn); the LNB is the Round Element, and the Transmit Module (with Heat Dissipation Fins) is Mounted Behind the LNB and Above the Boom.

INTRODUCTION

Ka-Band commercial satellite communications systems are being constructed in order to provide broadband services as well as enhanced entertainment services in areas where cable and / or fiber optic infrastructure is not practical. This includes vast rural areas throughout the world, Latin America, and Europe to name a few. In Europe, numerous Ka-Band satellites are already in orbit, the services infrastructure is ready, and the challenge has been to deploy cost-effective ground terminals that can provide two-way broadband communications with these satellites.

SYSTEM OVERVIEW

Figure 1 shows the completed outdoor unit as it is being deployed by SES in Europe. The outdoor ground terminal includes the main reflector antenna, the boom, the sub-reflector antenna, the feed, the receive path Low Noise Block (LNB), and the up-converter transmitter module, which is the focus of this paper.

The signal to be transmitted to the satellite arrives at the ground terminal as a 2.5–3.0 GHz QPSK modulated signal at a nominal (but variable) signal level of –24 dBm. This signal must be up-converted to 29.5–30.0 GHz with an output power level of 1.5 Watts. In addition, the transmit module needed to be low-cost, compatible with the system shown in Figure 1, and high-yielding at an off-shore (Asian) manufacturing partner.

Figure 2 shows the approach that was taken in the system

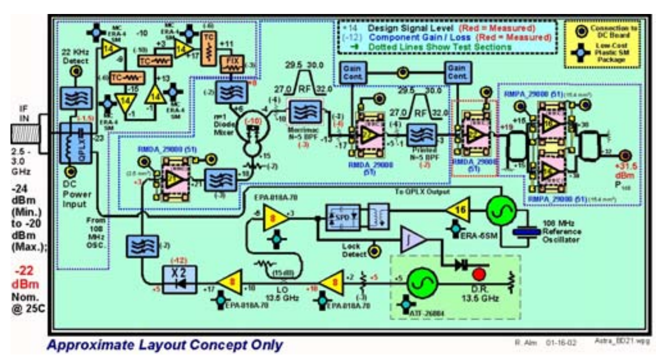

Figure 2: System Block Diagram Showing the Basic Functions of the Up-Converter Transmit Module.

design to achieve these goals. The system design consists of five basic functions: (1) the input quad-plexer and IF (2.5-3.0 GHz) amplifier chain; (2) the up-converter mixer, filter and driver amplifiers; (3) the RF Power Amplifier; (4) the phase-locked local oscillator and (5) the DC power supply and control section (not indicated in Figure 2.) The remainder of this paper will describe these functions and the design considerations that led to achieving the overall goals described above.

DESIGN CONSIDERATIONS

The key to making this system low-cost and manufacturable at the system level was to use standard components wherever available, to provide a platform that would be compatible with high-volume, automatic assembly methods, to account for expected variations in device and element performance with temperature and manufacturing variation at the fundamental design level, and to build flexibility into the design that would allow for compensation of these effects.

Rogers® 4003 8-mil soft-substrate material was selected as the foundation for all RF circuits, and a single-piece of substrate material was bonded to a baseplate. There were no walls or partitions to interfere with automatic assembly tools. (See Figure 3.)

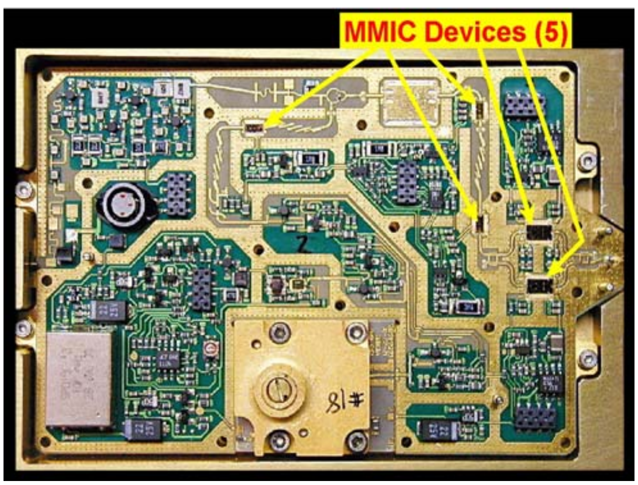

Figure 3: A Single Soft-Substrate Contains All RF Components. Prior to Bolting the RF Baseplate into the Module, Nothing Interferes with Automatic Assembly Tools in Manufacturing.

Module designers know that isolation must be provided between adjacent portions of the RF circuitry in order to meet spurious signal specifications and to prevent unwanted oscillations. The required isolation was provided by adding an RF sub-cover to the RF baseplate shown in Figure 3 as shown in Figure 4. The "bottom" side of the sub-cover contained all necessary chambers to provide isolation. The cover was fixtured in place for RF test, and could be easily removed for rework if required. In the final assembly, the indicated screws were assembled.

This approach was taken to minimize cost, as assembly, test and rework all form part of the cost model, as well as how much of a total assembly is lost when a serious assembly problem forces the scrapping of an entire component.

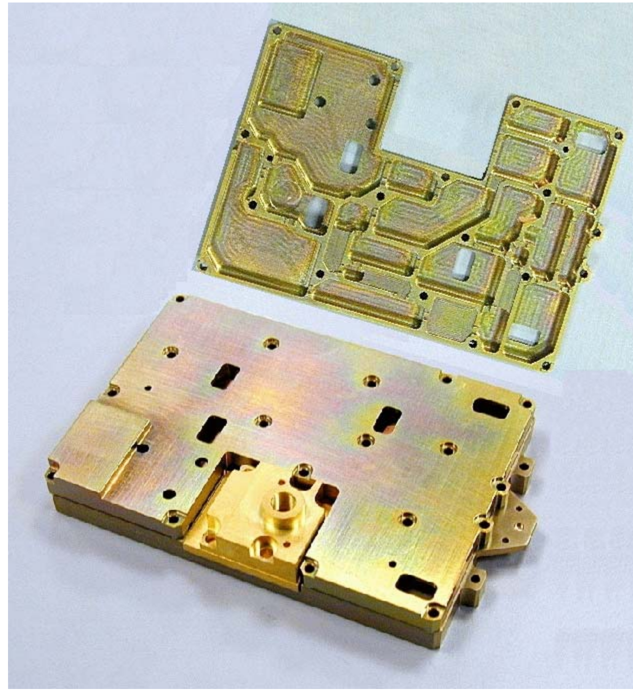

Figure 4: The RF Sub-Cover. The "Bottom" Contains Chambers Required to Provide RF Isolation, and is Laid on the RF Baseplate Assembly Shown in Figure 3 as Shown.

Another important element of the design was to minimize the different types of MMIC devices that were employed. A total of 5 GaAs MMIC amplifiers were used in the design as indicated in Figure 3. Of these, a Raytheon RMDA-20420 wideband (26-42 GHz) amplifier was used as the RF pre-driver, and RF driver and LO Amplifier. Two Raytheon RMPA-29000 27-32 GHz Power Amplifier devices were used to realize a balanced RF power output stage in order to ensure a good output impedance under all load conditions. Figures 5 and 6 show these two devices.

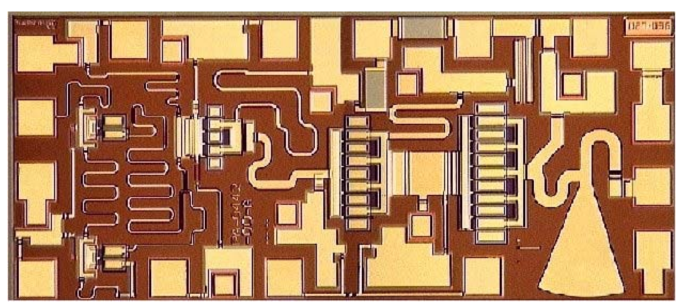

Figure 5: The MMIC Amplifier Used as the RF Pre-Driver, the RF Driver and the LO Amplifier at 29.5-30 GHz and at 27 GHz Respectively. This is a Wideband 20-42 GHz Device With a Nominal 20 dB of Gain and a Saturated Power Output of +22 dBm.

The specified operating temperature range for this outdoor unit was -50ºC to +85ºC, and the overall system gain was nominally 55 dB through a total of 15 stages of gain (distributed around other system elements). Very few systems can tolerate gain compensation through "derating" for this much gain through so many stages of gain, because

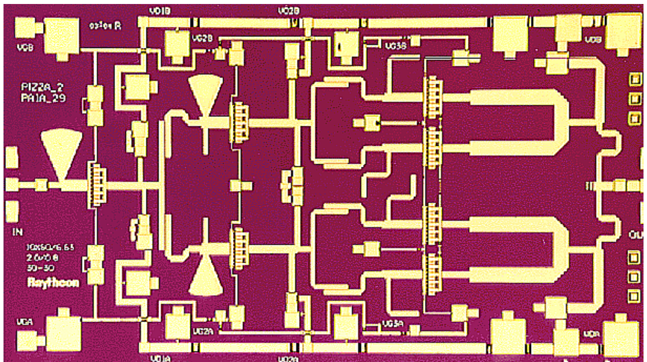

Figure 6: The MMIC Power Amplifier Used to Realize the Balanced RF Output Stage. This is a 27-32 GHz Device With a Nominal 17 dB of Gain and a Saturated Power Output of +30 dBm.

at cold temperature the gain would be so high that oscillation, saturation, spurious signal generation etc. all become serious problems.

In this system, temperature compensation elements were placed between the stages of the 2.5-3.0 GHz IF amplifier. (See Figure 2.) These devices accounted for a total of 12 dB of gain variation over the specified temperature range. This is more than the four stages of IF gain will vary over temperature, but at 2.5-3.0 GHz this compensation is much lower cost, requires no bias and is easy to implement, and this 12 dB partially compensates for the gain variation that the subsequent 11 stages (3 MMICs) of RF gain at 29.5-30 GHz will exhibit.

Another key element critical to the low-cost approach was the ability to up-convert the 2.5-3.0 GHz input signal to the desired 29.5-30.0 GHz output in a single up-conversion while still being able to meet all spurious output specifications. This required a very sharp bandpass filter

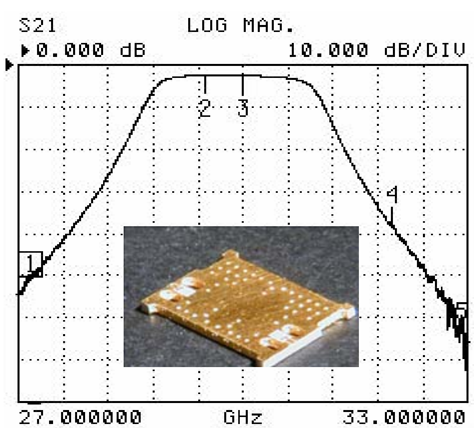

Figure 7: The Sharp Cutoff Bandpass Filter Realized Using Merrimac Industries' Multi-Mix® Technology. This Component Enabled Single-Up Conversion Critical to the Low-Cost Approach.

after the up-conversion mixer, but insertion loss needed to be kept low because MMIC gain at 30 GHz is expensive to "throw away" in filter loss. We worked with Merrimac Industries in West Caldwell, New Jersey to develop the high-Q, low-loss filter shown in Figure 7 that not only gave the sharp bandpass and low-loss characteristics, but also provided a highly repeatable, highly manufacturable element that otherwise would have been difficult to control.

In order to minimize manual gate bias adjustment and unnecessary device-to-device matching, active bias circuits were employed to bias the MMIC amplifiers. Two different types of circuits were used, one type for the medium power amplifiers and the other for the MMIC power amplifiers, for which a simplified diagram appears in Figure 8. In each case, the circuit monitors the drain current and generates a gate bias that is proportional to the drain current. In cases where variations in pinchoff voltage cause the quiescent drain bias to bee to high or too low, the active bias circuit adjusts the gate bias to compensate automatically. The module then becomes insensitive to MMIC devices from different wafers or different wafer lots, and devices from any

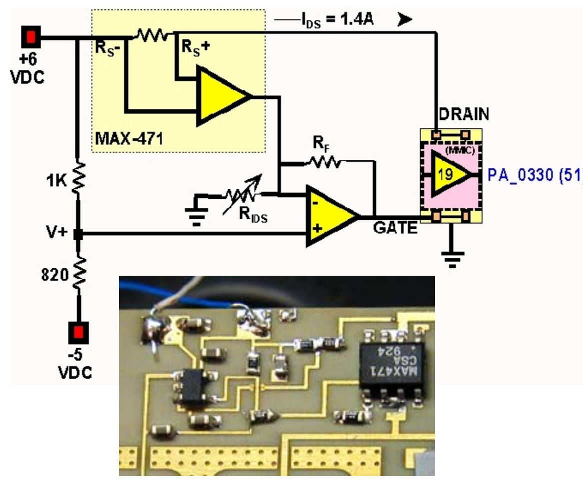

Figure 8: Active Bias Circuits Make MMIC Devices Insensitive to Pinchoff Voltage Variation and Can Also Help to Compensate for Gain Variation with Temperature.

lot can be used to replace a bad part in the manufacturing process.

Finally, in order to give the module a degree of flexibility at the final test stage, a microprocessor (on the DC power supply and control board) was used to control the gate bias of the MMIC RF pre-driver and MMIC RF driver amplifiers. This control was used to adjust the nominal gain of each of these devices by ±2 dB at the final test station. Figure 9 shows a plot that was taken from the final test station at the manufacturing facility that shows an overall range of module gain adjustment of about 7 dB, reduced by a dB or so by the saturation effects of the driver amplifier.

The capability to adjust module gain at the final test station was critical to the manufacturing and cost models that were employed. The ability to adjust module gain at the final test station (including after burn-in if necessary) means that the module does not need to be sent back to the manufacturing line and opened-up for gain adjustment, then sent back for testing again.

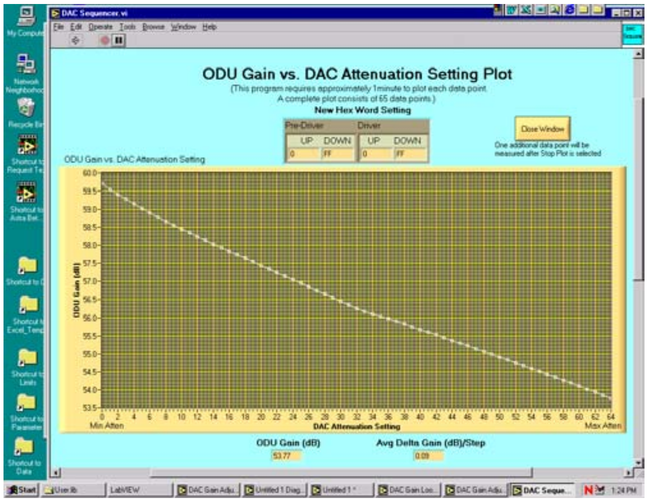

Figure 9: The Microprocessor Controlled MMIC Gate Bias Adjustment Gave the Module an Overall Gain Adjustment Range of about 7 dB.

PROTOTYPE TESTING

Figure 10 shows how each functional element of the block diagram indicated in Figure 2 was built and individually tested, then finally integrated to evaluate the overall system performance outside of the mechanical module environment. This level of evaluation is very useful in being able to troubleshoot a fully integrated module, and it is important for documenting the intermediate performance levels that are required for the test and troubleshooting procedures that must accompany a module design as part of a transition-to-production effort.

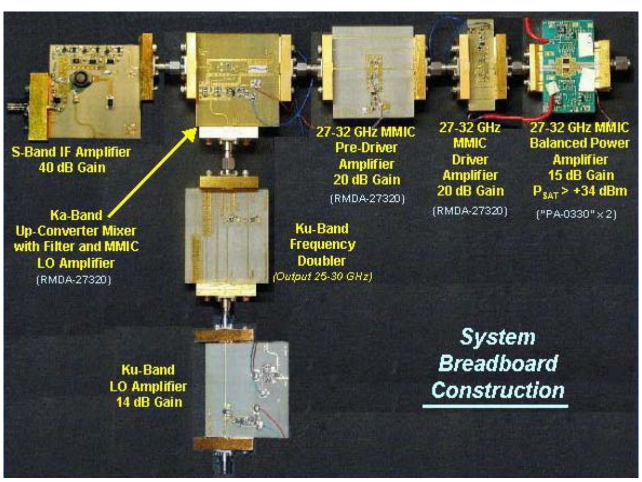

Figure 10: The Major Functions of the Block Diagram Shown in Figure 2 Are Built, Tested and Evaluated at the System Level.

Many plots are available showing that the output of the module meets power level requirements, phase noise requirements, flatness across the band, etc., but the best image is really that of a fully functional Ka-Band satellite communications system working as designed. Figure 11 shows the screen of a computer set up at a trade show with a split screen display, one screen showing the television feed, and the other showing an active internet connection operating at 2 MB/S over the communications hub. At the time this photo was taken, the outdoor ground terminal shown in Figure 1 was installed on the roof of the RAI convention center in Amsterdam, Holland, and communications were being ported via the SES Astra system in Luxembourg.

Figure 11: The Operating Ka-Band SATCOM System. The Rear Screen Shows the Television Feed, the Front Screen Shows an Active 2 MB/S Two-Way Internet Connection.

CONCLUSIONS

The conclusion we reach from this effort is that GaAs MMIC devices can be employed in high-volume applications, even at mm-Wave frequencies. We also proved that off-shore manufacturing did not pose a problem. It is critical that design-for-manufacture is considered from the outset of the design task, including the limitations that will be imposed by cost targets. It is also critical that device and temperature variations that will be experienced in real-life applications must be accounted for during the design phase. Under these conditions, we have proven that a successful product can be developed and manufactured and that reasonable cost targets can be met when considering the overall requirements of the cost model.

ACKNOWLEDGEMENTS

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ACRONYMS

QPSK: Quadrature Phase Shift Key (Modulation Type)