COMPACT FREQUENCY CONVERTERS FOR A KA-BAND TELECOMMUNICATIONS SATELLITE PAYLOAD

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ABSTRACT

A pair of frequency-converting, integrated microwave assemblies (IMAs) were developed for use in the Gen*Star broadband telecommunications payload that optimize placement of the primary frequency converting components in the payload. Uplink frequency downconverters may be placed directly behind their respective antenna feed horns minimizing the required waveguide and system noise figure impact. Downlink frequency upconverter may be placed next to the associated traveling wave tube amplifier (TWTA) greatly reducing the connection length. These factors are particularly critical to the operation of wideband Ka-Band systems due to the large number of closely spaced spot beams that are typically required in order to provide coverage to a large geographic region.

INTRODUCTION

A complete microwave monolithic integrated circuit (MMIC) chip set has been developed and fabricated using Gallium Arsenide (GaAs) high electron mobility transistor (HEMT) and heterojunction bipolar transistor (HBT) technologies for frequency conversion of Ka-Band up and downlinks to an intermediate frequency (IF) range from ultra high-frequency (UHF) through C-Band. A common IMA housing design (one for 30 GHz downconverters, one for 20 GHz upconverters) is used. These IMAs are slightly larger than a pack of matches weighing roughly 35 grams. They have internal filtering and voltage regulators. The downconverter contains full internal redundancy. Internal frequency doublers reduce local oscillator (LO) frequency distributed in the payload. These IMAs operate from a single supply voltage—the downconverter redundancy affected by the application of power to the required path. Through mixing of various MMIC chips with custom internal filters, the performance can be tailored to meet many different system frequency plans and requirements. The use of common housing and wideband MMIC designs greatly reduces production response time. The IF frequency MMIC amplifiers can also be used in monolithic packages as building blocks for IF signal processing and beam routing units within the payload.

LOW NOISE AMPLIFIER (LNA) DOWNCONVERTER

Broadband systems require numerous narrow spot beams (multi-tens) as opposed to older lower frequency systems that use few large distributed coverage beams (much less than ten). The conventional method of placing an LNA in the antenna and routing the amplified signal to a downconverter located in the payload has many drawbacks for Ka-Band operation, first of which is the frequency of operation. At 30 GHz, routing the signal via radio frequency (RF) coaxial cable creates a lot of signal loss. This could be countered by higher gain/3rd order intercept point (IP3) LNAs at the expense of direct current (DC) power and thermal dissipation. Larger lower loss cable might be used at the expense of weight, or the use of waveguide with its mechanical complexity associated with the large number of spot beams. The optimal answer is therefore to move the downconverters themselves up to the antenna. While this is possible with conventional "unit" approaches where a small number of beams are concerned, the large number required for broadband applications simply cannot reasonably fit on an antenna.

Another drawback of conventional approaches is the mechanical complexity of the downconverters themselves. The large number of spot beams multiplies cost, weight, and failure rate. In addition, conventional systems would use switchable circulator/isolator combinations to handle redundancy. The support electronics can be costly and must be hosted near the circulators themselves—again, increasing payload weight.

TRW's LNA downconverter IMA (Figure 1) has been developed with high performance, compactness, and flexibility as key design drivers. These IMAs—completely self-contained downconverters—are envisioned to be mounted in the antenna structure directly behind the associated feed horn. By combining outstanding noise figure performance with block downconversion, these high-reliability modules yield significant mission benefit of high gain/noise temperature (G/T). Full internal redundancy minimizes the number of required connections. The electrical interfaces consist of one WR-28 waveguide RF input, one coaxial style LO input, one coaxial style IF output, and two coaxial style DC inputs (one for primary and one for redundant power).

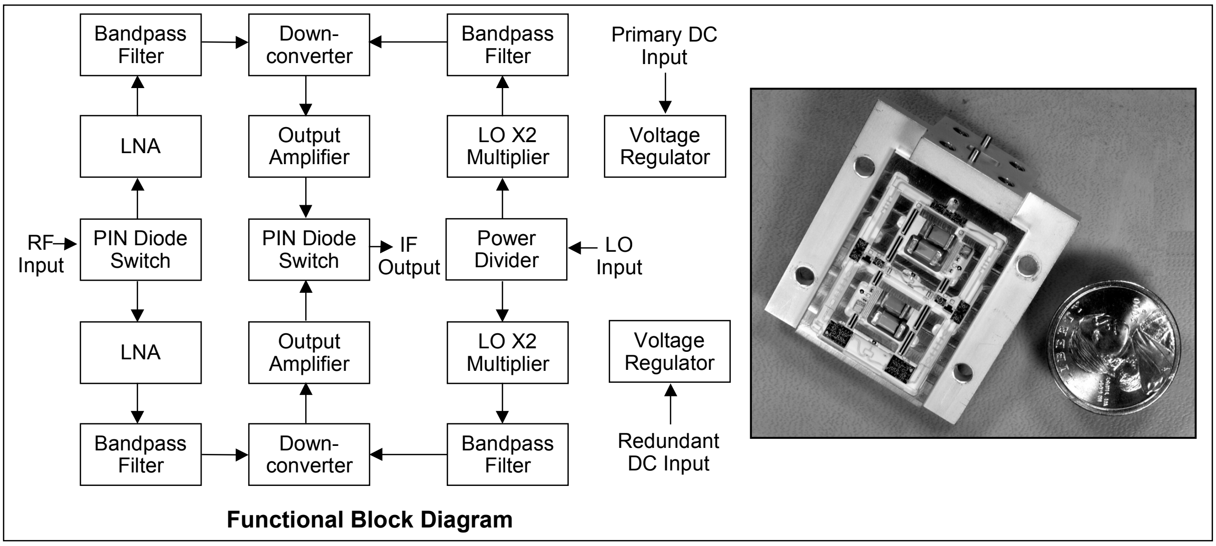

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Figure 1. TRW's LNA Downconverter IMA

Current performance places the IMA input noise figure just below 2.5 dB at 25°C (Figure 2). Nominal conversion gain is set at 40 dB. Conversion gain flatness is less than 0.3 dB/250 MHz. The output 3rd order intercept point (IP3) is greater than +20 dBm. The IMA operates with LO input power between –20 dBm and –5 dBm, and the DC current draw is typically 330 mA at +6.5 volts.

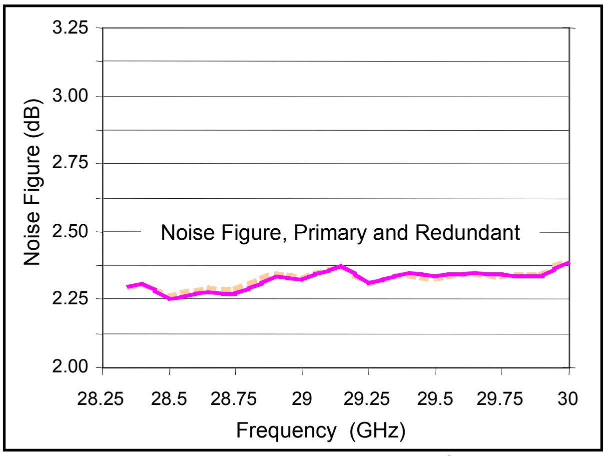

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Figure 2. LNA DC Noise Figure

The monolithic microwave integrated circuit (MMIC) chip set has been designed to work directly with IF output frequencies ranging from 500 MHz to 8 GHz. The necessary chips have also been developed for the simplest bent-pipe application of 28–30 GHz uplink band to the 18–20 GHz downlink band.

The RF input uses an E-plane coaxial pin/probe configuration yielding low transition loss and excellent voltage standing wave ratio (VSWR) across the 28 to 30 GHz uplink band. A ribbon launch to a small transition substrate where input return losses greater than 20 dB are achieved. An input MMIC redundancy switch (patent pending) arranged such that should any single component fail, the system noise figure is not compromised. This input MMIC redundancy switch adds only 0.1–0.2 dB to the system noise figure beyond that of a conventional waveguide switchable circulator/isolator triad without any of the size, weight, cost, or control electronics complexity.

Directly following the input redundancy switch are LNA MMICs. The current offering uses a three-stage amplifier using TRW's 0.1 μm GaAs HEMT process. An indium phosphide (InP) HEMT drop-in MMIC is in development for future reduction in noise figure performance.

Following the LNA MMIC is a microstrip image reject filter designed using TRW's patented architecture—yields a high performance filter in a compact size. The RF signal then enters the downconverting mixer macrocell MMIC. This MMIC is composed of an input amplifier to buffer the mixer from the image filter, an LO amplifier to buffer the mixer from the LO filter, and a star configuration double balanced mixer with HEMT diodes. This MMIC is fabricated in TRW's 0.15 μm GaAs HEMT process that gives the MMIC a wide dynamic range from its low noise input through its high IP3 mixer.

The LO signal enters the IMA and is split to the redundant sides using a microstrip Wilkinson Power Divider. The LO signal then enters an active X2 multiplier macrocell MMIC. This MMIC is comprised of an input limiting amplifier, a transistor multiplier, and an output limiting amplifier. An active transistor multiplier is used to minimize power dissipation for the antenna-mounted IMA. The use of an internal frequency doubler for the LO helps reduce losses associated with payload distribution of the LO signal to the antenna. This MMIC is fabricated in TRW's 0.15 μm GaAs HEMT process. The output of the multiplier MMIC is passed through a microstrip filter using the same design process as the image filter; then applied to the LO input of the downconverting MMIC.

The IF output of the downconverting MMIC is passed through a thermal attenuator that sets the overall gain of the IMA as well as providing gain temperature compensation. Next, the IF signal enters the output amplifier MMIC, which is a two-stage design using TRW's 1 μm GaAs HBT process for high IP3 performance and low DC power consumption. Finally, the IF signal enters a microwave integrated circuit (MIC) pin diode redundancy switch for output through the IF connector.

DC power is regulated internally with the use of a space qualified silicon integrated circuit (IC). The voltage regulator is a low overhead design minimizing the contribution to the IMA's thermal dissipation. Low equivalent series resistance (ESR) capacitors are used to ensure regulator stability. The use of an internal regulator mitigates radiated susceptibility on DC power lines and it also protects the MMICs from potentially harmful misvoltage application to the IMA.

All the MMICs have been designed for self-bias, and as such, require only a single positive DC voltage for operation. In addition, the input and output redundancy switches have been designed such that when DC power is applied to a single side, the RF path configures for low loss to that side and isolation for the non-powered side. Primary and redundant DC paths are sufficiently isolated so that a short on one side will not affect the operation of the other side. Also, DC power can be applied to both sides simultaneously without damage.

TRANSMIT UPCONVERTER IMA

The TRW upconverter IMA (Figure 3) has been developed with high performance, compactness, and flexibility as key design drivers. Envisioned to be mounted next to the traveling wave tube (TWT). These IMAs are completely self-contained upconverters. The electrical interfaces consist of one female SMA-style IF input, one female SMA-style LO input, one female SMA-style DC input, and one WR-51 waveguide RF output.

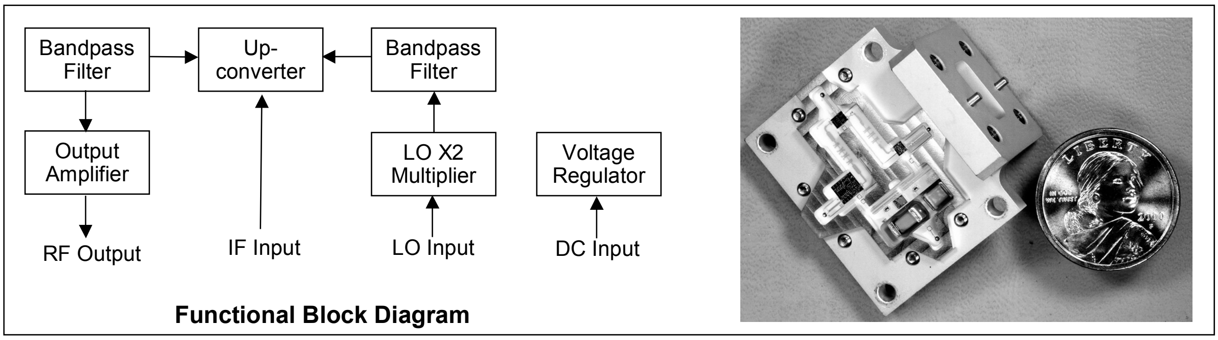

Figure 3. TRW's Transmit Upconverter IMA

Nominal conversion gain is set at 6 dB. Conversion gain flatness is less than 0.3 dB/ 250 MHz (Figure 4). The output IP3 is greater than +15 dBm. The IMA operates with LO input power between –20 dBm and –5 dBm, and the DC current draw is typically 230 mA at +6.5 volts.

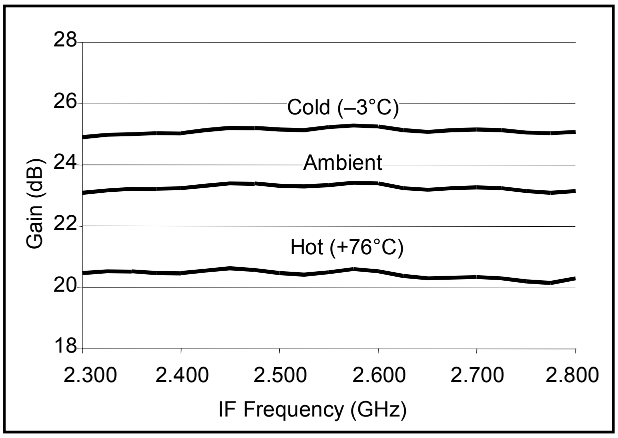

Figure 4. Upconverter Gain

The MMIC chip set has been designed to work directly with IF input frequencies ranging from 500 MHz to 8 GHz.

The LO signal enters the IMA to an active X2 multiplier macrocell MMIC. This MMIC is comprised of an input limiting amplifier, a transistor multiplier, and an output-limiting amplifier. An active transistor multiplier is used to help keep power dissipation low. The use of an internal frequency doubler for the LO reduces the losses associated with payload distribution of the LO signal. This MMIC is fabricated in TRW's 0.15 µm GaAs HEMT process. The output of the multiplier MMIC is passed through a microstrip filter designed using TRW's patented architecture that yields a high performance filter in a compact size. The LO is then applied to the LO input of the upconverting MMIC.

The upconverting MMIC macrocell is composed of an IF input amplifier, an LO input amplifier, and a patented double–balanced mixer design with HBT diodes. The amplifiers provide on-chip broadband terminations to the mixer ensuring the best intermodulation (IM) and spurious performance. This MMIC is fabricated in TRW's 1 µm GaAs HBT process for high IP3 performance and low DC power consumption. The RF output then passes through a microstrip filter using the same design process as the LO filter to reduce unwanted mixer products and LO bleedthrough.

Finally, the RF output is buffered through an output amplifier MMIC. This MMIC is fabricated in TRW's 0.15 µm GaAs HEMT process.

RF output of the IMA uses an E-plane coaxial pin/probe configuration yielding low transition loss and excellent VSWR across the 18–20 GHz downlink band. A ribbon launch from a small transition substrate where output tuning yields return losses greater than 20 dB.

DC power is regulated internally with a space-qualified silicon IC. The voltage regulator is a low-overhead design minimizing contribution to the IMA's thermal dissipation. Low ESR capacitors are used to ensure regulator stability. The use of an internal regulator helps mitigate radiated susceptibility on DC power lines. It also protects MMICs from potentially harmful misvoltage application to the IMA. All MMICs have been designed for self-bias, and as such, require only a single positive DC voltage for operation.

SUMMARY

Flight–qualified MMIC chips are in inventory. Over 200 flight LNA downconverters and 140 flight upconverters have been delivered for use in the Astrolink payloads. These building blocks enable future rapid deployment of new systems concepts—reduces risk by making the critical high frequency components virtually “off-the-shelf”.