ELECTRONICALLY-TUNABLE, LOW NOISE K_a-BAND PARAMP-DOWNCONVERTER SATELLITE COMMUNICATIONS RECEIVER

by

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Abstract

The K_a-band-to-UHF parametric amplifier-downconverter satellite communications receiver described herein provides less than 4 dB SSB noise figure over either electronically selectable sideband of the externally supplied ~37.5 GHz local oscillator, each of which is downconverted to a fixed 500-650 MHz IF output band. To achieve such widely tunable low noise performance, this receiver utilizes state-of-the-art varactors, a unique, solid-state pumped K_a-band paramp design and a low noise balanced mixer-transistor IF amplifier, incorporated with associated power supply and thermal stabilization in a self-contained 6" x 5" x 4" package.

Introduction

This paper describes the development* of a completely packaged low noise electronically tunable K_a-band receiver for satellite communication system usage in the 35-40 GHz low atmospheric attenuation "window". The less than 4 dB overall SSB noise figure provided by this receiver, arises from the use therein of K_a-band parametric preamplification, high quality GaAs varactors and Schottky mixer diodes and a unique mix of sophisticated millimeter wave, electronic, mechanical and thermal design techniques. The resulting receiver is the first reported self-contained nondegenerate K_a-band paramp-downconverter package that combines single sideband operation and wide electronic tunability.

Description of Receiver

The complete K_a-band receiver package, depicted in block diagram form in Figure 1, consists of the following closely integrated components:

- Single-stage, nondegenerate circulator-coupled K_a-band parametric amplifier, including 96 GHz Gunn oscillator/varactor multiplier pump source.
- Hybrid-coupled, K_a-band-to-UHF balanced mixer, the LO drive for which is provided externally.
- UHF transistor IF amplifier.
- DC power regulation and distribution circuits, including electronic tuning command driver.
- Thermal stabilization circuits, consisting of proportional controllers and local heaters.

Although widely tunable over the 36.5 - 38.5 GHz range, the receiver was specifically operated bimodally, e.g. single sideband but switch-tuned upon external voltage command, between the 150 MHz wide lower and upper sidebands of the ~37.5 GHz externally supplied LO, offset by the 500 - 650 MHz IF.

K_a-Band Parametric Amplifier

The single-stage, circulator-coupled, nondegenerate K_a-band parametric amplifier which establishes the low noise performance and widely tunable bandwidth of the overall receiver is shown in the schematic of Figure 2, to consist of the following closely integrated component parts:

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- Three-junction (five-port) K_a-band waveguide signal circulator, the resistively terminated first and third junctions serving as input and output isolators respectively, and exhibiting measured insertion loss/pass, isolation/pass and paramp port return loss of 0.3 - 0.4 dB, 23-27 dB and 22-30 dB, respectively, over the 36.5-38.5 GHz frequency range.
- Composite waveguide K_a-band paramp mount, utilizing a high quality GaAs varactor and operating at a nominal signal and idler band center of 37.5 and 58.5 GHz respectively and a pump frequency of 96 GHz.
- K_a-band Gunn-effect pump oscillator, providing 150 mW CW output power at 32 ± 0.1 GHz, including the insertion loss of the closely-integrated terminated-circulator output isolator.
- Low-loss 32 to 96 GHz varactor tripler, comprising in combination with the Gunn oscillator, the paramp pump source, and utilizing a similar high quality varactor and embedding structure as the paramp mount.

The varactors utilized in the paramp mount and the pump source tripler were similar high-quality LNR stud-mounted GaAs Schottky devices of optimum form factor and parasitic content having the following typical characteristics:

- Zero bias junction capacitance: 0.1 to 0.15 pF
- Operating cutoff frequency: 600 GHz (min.)
- Parallel self resonant (idler) frequency: 58-65 GHz

These varactors were incorporated in the paramp mount and tripler in similar composite WR-28/WR-8 waveguide embedding structures with unique mutually-isolated signal, idler and pump resonant circuits. In the paramp mount, the broadband signal and idler circuits resulting thereby, led to the realization of the wide measured high-gain tuning range depicted in Figure 3 and the following level of performance:

- Midband gain: 15 ± 0.5 dB
- Tuning range: 36.8 to 38.1 GHz
- Instantaneous -1 dB bandwidth: 150-200 MHz
- SSB noise figure: $\lesssim$ 3.5 dB
- Pump power requirement at 96 GHz: 25 mW (nom.)

The same paramp, operated at a higher pump drive level and with additional signal circuit broadbanding, yielded an instantaneous triple-tuned gain response with greater than 1000 MHz 1 dB equiripple bandwidth, as also depicted in Figure 3.

The pump source tripler is based upon an overdriven design having a nominal power output capability of 30 mW under 150 mW Gunn source input drive.

Mixer-IF Amplifier

The K_a-band/UHF balanced mixer-IF amplifier which follows the paramp in the overall receiver, shown schematically in Figure 4, consists of:

- Two reduced-height, K_a-band waveguide mixer diode mounts, combined side by side in a single housing and containing the required K_a-band input transformation sections as well as a UHF output matching and combining network.
- Balanced pair of high quality GaAs Schottky mixer diodes, of junction capacitance 0.05 pF and cut-off frequency above 500 GHz.
- In-phase folded hybrid K_a-band 3 dB signal/LO injection coupler, having less than 0.25 dB residual insertion loss, greater than 35 dB signal/LO isolation and greater than 22 dB parallel port isolation over the 36.5-38.5 GHz band.
- Low noise UHF transistor IF amplifier, exhibiting 26.5 ± 0.25 dB gain and 2.3 to 2.5 dB noise figure over the 500-650 MHz output band.

In order to accommodate either sideband of the 37.5 GHz externally supplied LO, the mixer was configured as a broadband image type with equal conversion loss at each sideband and no inherent image rejection. However, the overall receiver was actually operated in a single-sideband mode, with image rejection provided in a subsequent downconversion in the intended application.

The measured performance of the mixer-IF amplifier included, for each sideband:

- SSB noise figure: 8 to 9 dB
- RF input match: $<2{:}1$
- IF output match: $<1.5{:}1$
- LO drive level: 20 mW

The above level of SSB noise figure, contributed less than 0.5 dB to the overall receiver noise figure.

Packaging, Electronics and Thermal Stabilization

The overall receiver was packaged in a 6" x 5" x 4" enclosure, weighing less than 7 lbs., as depicted in the photograph of Figure 5. Included in this package, in addition to the previously described paramp/mixer/IF amplifier, were the DC power regulation and distribution, electronic tuning and thermal stabilization circuits. Operating from a single +28V DC prine power input, these included:

- DC power: Preregulator/DC-DC converter with input filtering and multiple outputs, followed by individual ±0.1 percent postregulators for the paramp and tripler varactor and Gunn oscillator bias voltages.
- Electronic tuning (band selection): Driver circuit to convert zero and +28V input band selection commands to the pair of paramp varactor bias voltages which tune to the two receiver sidebands.
- Thermal stabilization: Two parallel-connected miniature heaters, affixed to the Gunn oscillator housing and to the circulator/paramp/tripler respectively maintain these mutually thermally isolated structures at 60 ± 3° and 45 ± 10°C over an ambient (baseplate) temperature range of 0-50°C. Thermal control is provided by a transistorized proportional controller coupled to a thermal sensor affixed to the Gunn oscillator.

The overall receiver prime power drain on the 28 volt DC input voltage ranges between 20 and 60 watts over the 0 to 50°C baseplate temperature range.

Performance Of Total Receiver

The measured performance of the overall K_a-band receiver, electronically tuned "bimodally" to either sideband of the externally supplied ~37.5 GHz LO is characterized by the overall RF/IF conversion gain responses depicted in Figure 6, and is summarized as follows:

- Instantaneous RF/IF bandwidth: 150 MHz
- Overall conversion gain: 34 ± 1 dB
- Overall SSB noise figure: $\lesssim 4.0$ dB

Acknowledgement

The authors gratefully acknowledge the effort of J. Asmus and his group in providing the varactors and assembling the structure, J. Go in implementing the receiver electronics, K. Bittmann in performing the measurements and, finally, S. Okwit, for guidance and encouragement.

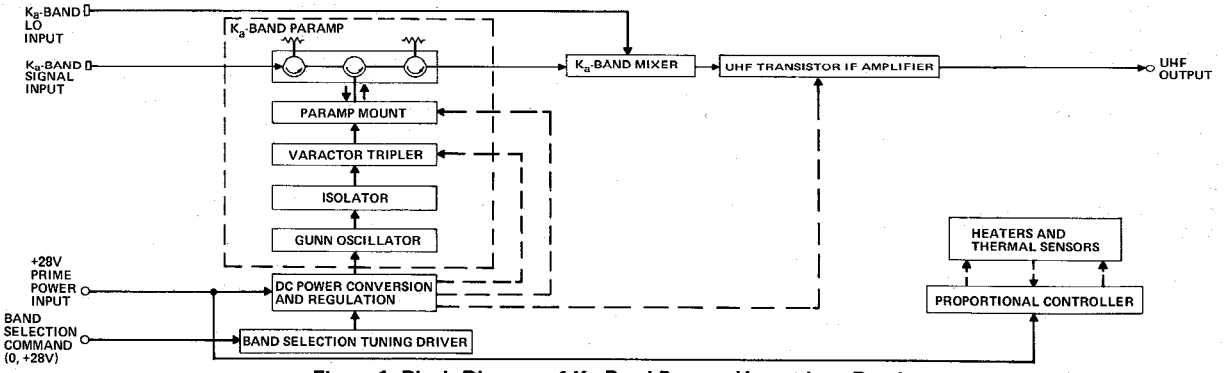

Figure 1 Block Diagram of K_a-Band Paramp-Heterodyne Receiver

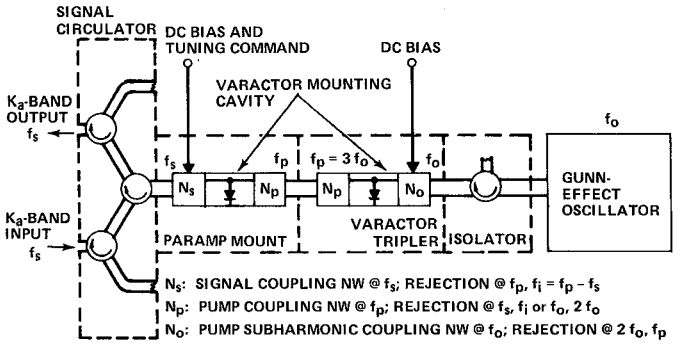

Figure 2 Schematic of K_a-Band Parametric Amplifier

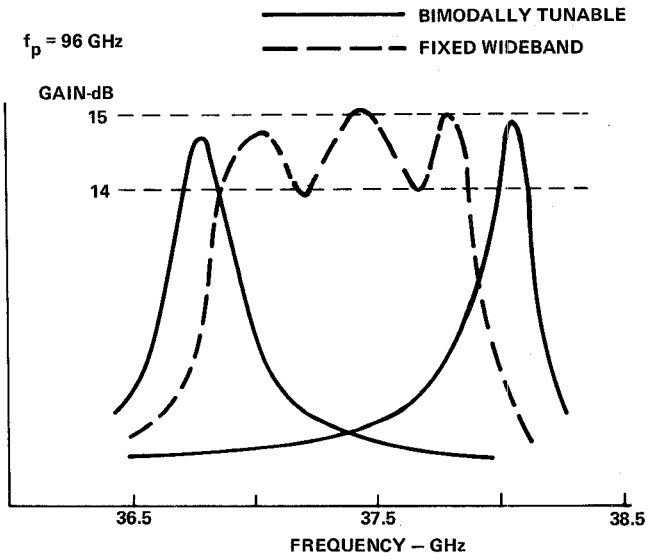

Figure 3 Measured Gain Response of K_a-Band Parametric Amplifier

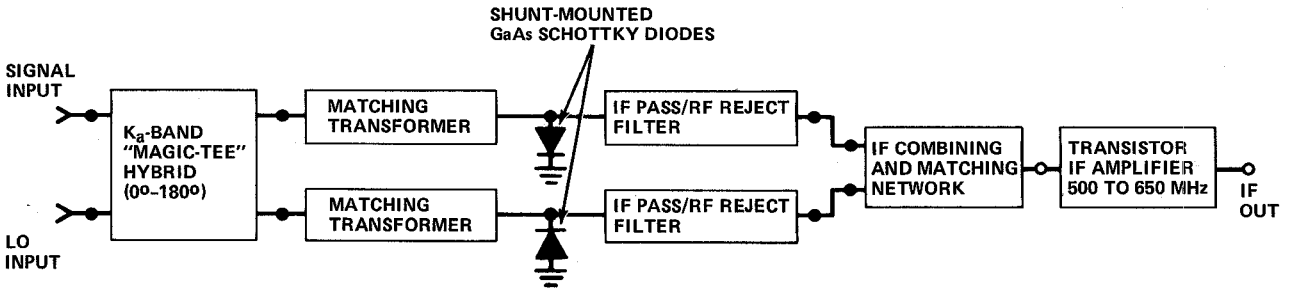

Figure 4 Schematic of K_a-Band/UHF Balanced Mixer – If Amplifier

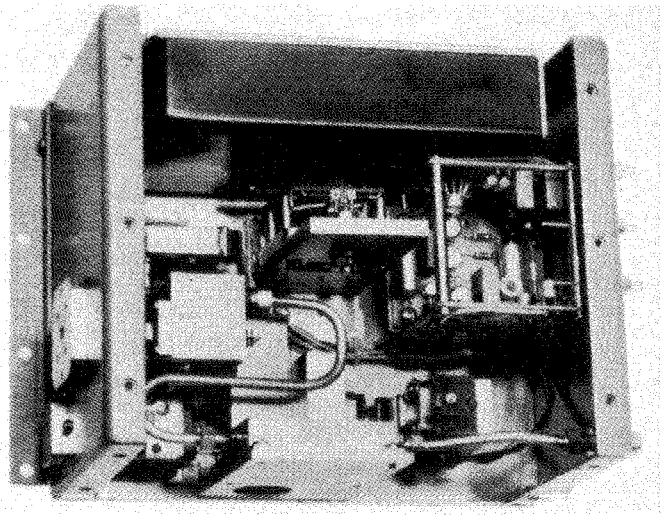

Figure 5 Photograph of K_a-Band Receiver Package (Top Cover Removed)

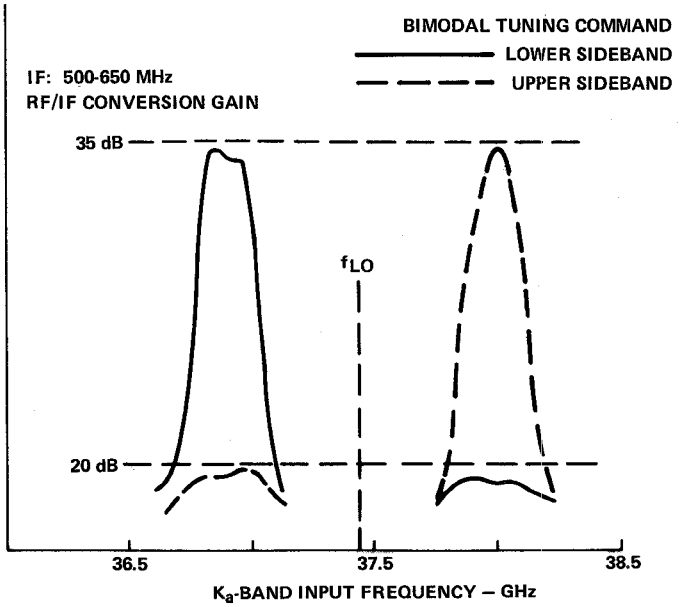

Figure 6 Measured Overall RF/IF Conversion Gain Responses of Bimodally-Tuned K_a-Band Receiver