MINIATURE SPACEBORNE S AND K_u-BAND LOW NOISE AMPLIFIERS FOR TDRSS

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ABSTRACT

Light weight, miniature spaceborne parametric and transistor low noise amplifiers (LNA's) have been developed for TRW and Western Union for use in NASA's Tracking and Data Relay Satellite System (TDRSS). The S and K_u-Band LNA's each employ a single stage parametric amplifier and provide state-of-the-art noise temperatures of less than 65K and 140K over their respective 2.2-2.3 GHz and 14.89-15.12 GHz frequency ranges.

Introduction

This paper describes the development and implementation for quantity manufacture of miniature S and K_u-band spaceborne low noise amplifiers (LNA's) for TRW and Western Union, for use in NASA's Tracking and Data Relay Satellite System.

The TDRSS program employs 4 satellites (3 operational and 1 spare) in a 24-hour synchronous orbit. Each satellite will have two steerable antennas for transmission of communications and telemetry information over the Ku and S band frequencies. Housed behind each of these antennas will be two S and two Ku-band low noise amplifiers.

Description of Overall LNA Configurations

The spaceborne S and Ku-band LNA's depicted in the photographs of Figures 1 and 2 and block diagrams of Figures 3 and 4 each consist of the following closely integrated components, incorporated within compact self-contained packages.

- Miniaturized signal frequency wye-junction circulator, implemented at S-band as a 4 port strip-line configuration and at Ku-band as a 5-port waveguide configuration.
- Microwave/millimeter wave paramp mount, consisting in each case of a high-cutoff frequency hermetically sealed GaAs varactor in a single-ended, raised idler embedding configuration (shown schematically in Figure 5).
- Millimeter wave solid state pump source including, in each case, a waveguide-cavity Gunn oscillator and its associated waveguide output isolator. The 45 GHz pump source for the S-band paramp includes a pump attenuator/thermal isolator at the paramp mount interface, whereas the 96 GHz pump source for the Ku-band paramp substitutes in its place a high-efficiency 48-to-96 GHz varactor doubler.
- Two-stage bipolar transistor amplifier (S band LNA only), including self-contained DC bias regulation, distribution and temperature compensation network within EMI-filtered and shielded housing.

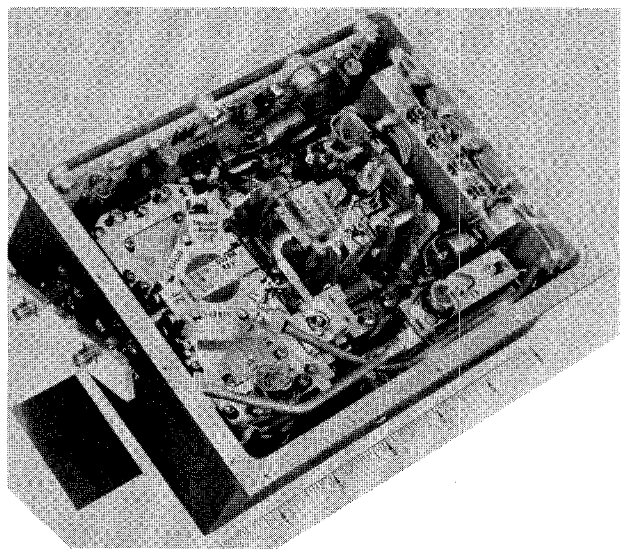

Figure 1: Photograph of S-Band LNA

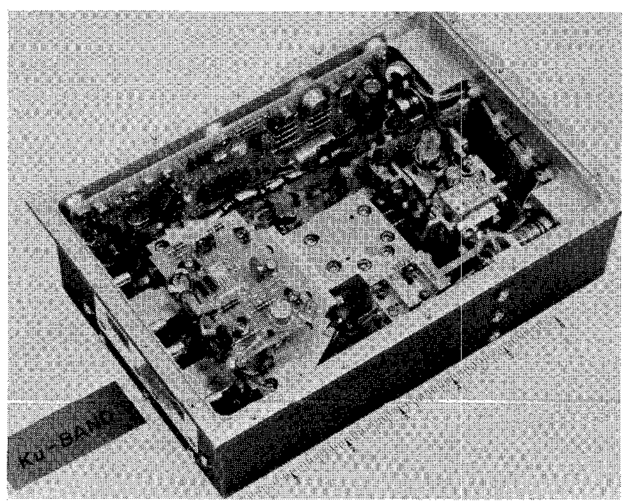

Figure 2: Photograph of Ku-Band LNA

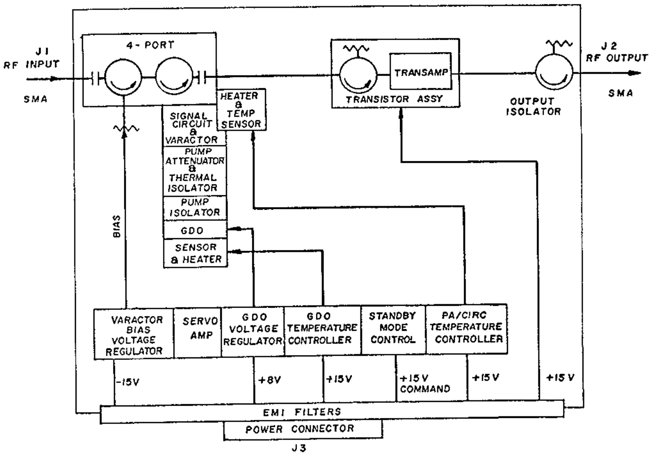

Figure 3: S-Band LNA Block Diagram

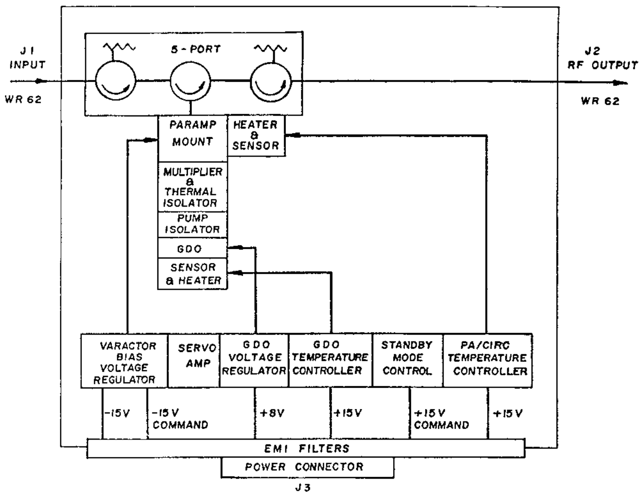

Figure 4: Ku-Band LNA Block Diagram

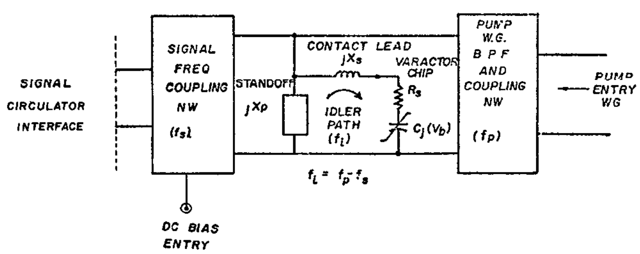

FIGURE 5 SCHEMATIC OF SINGLE-ENDED RAISED IDLER PARAMP MOUNT

- PC boards containing voltage regulators for the paramp varactor and pump source Gunn diode DC bias voltages, proportional controller circuits for separate heater-derived temperature stabilization of the Gunn oscillator and paramp/circulator structures, a pump level stabilization circuit to promote long-term paramp gain stability and control circuits to provide unpumped low power drain paramp "standby" mode operation upon external command.
- Compact. (~110 in^3, 3 lb.) EMI-shielded enclosure incorporating EMI filtering on DC power inputs.

The overall LNA RF interfaces consist of SMA coaxial and WR-62 waveguide input and output transducers for S and Ku-band respectively, whereas, in each case, a multipin DC connector is provided for primary power and command inputs.

All parts utilized in each LNA are subjected to rigorous selection, screening and inspection requirements consistent with high-rel design procedures and ability to withstand shock and vibration for use in severe vacuum environments.

Microwave Component Implementations

In order to implement the above configuration in high-rel form, the specific design approach for the S and Ku-band LNA's included the following:

1. S-Band LNA

The 2.2-2.3 GHz single-stage parametric amplifier, based upon an extension of a previous space qualified design,[1] utilizes an in-house hermetically-sealed high-rel GaAs varactor, embedded in a waveguide mounting cavity and operated in the single-ended raised idler mode (Figure 5) within a compact composite waveguide/TEM transmission line paramp mount. In this structure, the pump entry waveguide is coupled to the cavity-mounted varactor through a properly situated pump bandpass filter, whereas the TEM signal circuit incorporates a series tuning inductance and quasi-lumped transformation and broadbanding network. The resulting paramp mount configured for the best tradeoff between gain flatness and phase linearity, exhibited a slightly undercoupled 15 dB gain response over the 2.2-2.3 GHz frequency range.

The two-junction four-port signal circulator is embodied as a sheet center conductor balanced stripline structure, utilizing high permittivity dielectric loading for minimum circulator size and weight.

The resulting circulator structure incorporates input and output DC blocks, compact built-in termination and RF-isolated DC bias injection network on the isolated port of the input junction, and miniature, temperature stabilized ceramic disc magnets of sufficiently strong field intensity to provide the required bias field with reduced cross-sectional area and thickness. The measured performance of this circulator included less than 0.11 dB insertion loss per-pass, better than 25 dB interjunction isolation and less than 1.1:1 VSWR on all ports.

The all solid state pump source for the 2.2-2.3 GHz paramp consists of a 45.6 GHz Gunn oscillator, a miniature waveguide 45.6 GHz terminated-circulator type output isolator and a fixed pump level set attenuator.

Upon integration of the foregoing components, the measured gain and noise temperature responses for the resulting overall S-band paramp subassembly exhibited 13.9±0.2dB gain and 45-49K noise temperature over the 2.2 to 2.3 GHz frequency range.

The S-band transistor postamplifier comprised a two stage single-ended discrete component design utilizing high-rel bipolar transistors. The amplifier proper was designed for minimum noise figure, with input isolator and external output isolator. These isolators in turn, were configured as terminated strip-line three port circulators. The resulting measured isolator-coupled transistor amplifier characteristics included ~20.5 ±0.2 dB gain, 2.7 to 2.9 dB noise figure and <1.2:1 input and output VSWR.

2. Ku-Band LNA

The single-stage Ku-band paramp incorporates a in-house high quality (in 600) GHz cutoff) hermetically sealed GaAs varactor, embedded in a waveguide mounting cavity within a composite waveguide/TEM transmission line paramp mount structure similar to a state-of-the art paramp previously successfully developed for ground station usage,[2] but updated for spaceborne operation. Referring to the schematic of Figure 5, the paramp mount incorporates:

- Composite WR-62 waveguide/TEM transmission line Ku-band signal input circuit, including RF-isolated DC bias entry network and providing the required signal circuit varactor resonance, impedance transformation and broadbanding elements.

- "Raised Idler" series resonance at ~81 GHz (a value higher than ever previously demonstrated) formed around precisely selected varactor junction capacitance through reactances provided by the carefully dimensioned elements which couple the varactor to its associated mounting cavity. The latter, below cutoff in the idler band, and an idler choke resonator in the signal input circuit, prevent the coupling of idler current into the pump and signal circuit, respectively.

- Iris-coupled, high Q cavity filter section in WR-8 pump entry waveguide, providing impedance matching of pump source to varactor chip, and establishing by virtue of proper physical location, an open-circuit sum frequency termination at the varactor junction.

The five port signal circulator, a miniature lightweight high-rel version of a previously developed[2] state-of-the-art Ku-band waveguide circulator, is configured in an H-plane, WR-62 waveguide structure. Miniature waveguide terminations were used on the isolated ports of the input and output junctions. Following optimum matching at the external ports and the interjunction arms this circulator exhibited the following level of performance over the 14.2-15.12 GHz frequency range encompassing both the "on" (14.89-15.12 GHz) and "standby" (14.24-14.54) modes of operation:

- Insertion loss per pass less than 0.1 dB

- External port VSWR 1.05:1 ("on"mode)

  1.15:1("standby"mode)

The all solid state 96 GHz pump source for the Ku-band paramp stage consist of 48 GHz Gunn effect oscillator/varactor doubler cascade. The 48 GHz Gunn oscillator, provides over 80 mW output power over the entire operating temperature range in conjunction with a closely integrated 48 GHz miniature waveguide output isolator. The 48 to 96 GHz varactor doubler utilizes a high quality (~ 600 GHz cutoff) in-house GaAs hermetically sealed high-rel varactor in a composite WR-22/WR-8 Waveguide mounting structure[2], and provides over 20 mW CW output at 96 GHz, comprising more than sufficient pump drive for the Ku-band paramp stage.

Summary of Overall LNA Performance

The following describes the current measured RF performance and physical characteristics of the Engineering Model S and Ku-band LNA's, which are identical in form, fit and function to the final space qualified flight hardware.

1. RF Performance

Figure 6 depicts the measured gain/bandwidth response, and noise temperature of both the S and Ku-band LNA's.

As can be observed overall gains of 33.8 ±0.2 dB and 16.0 ±0.1 dB, and noise temperatures of 62^{o} to $63.5^{o}K$, and 130^{o} to $140^{o}K$ were measured over the frequency ranges 2.2 to 2.3 GHz and 14.89 to 15.12 GHz for the S and Ku-band LNA's respectively. Precise measurement of noise temperature was performed using hot/cold load assemblies developed by LNR.

The active input and output VSWR over the total band was measured to be better than 1.04 and 1.12 respectively for the S-band LNA an 1.11 and 1.25 respectively for the Ku-band LNA.

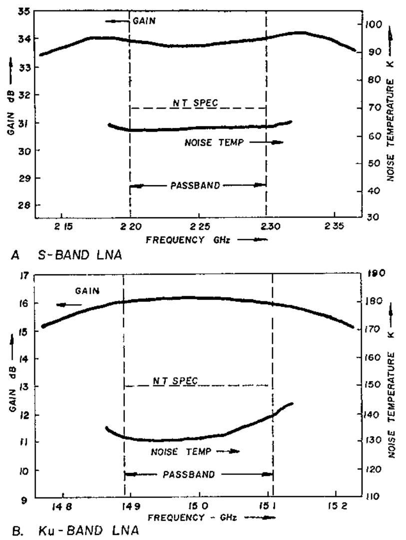

Figure 6: Measured LNA Gain and Noise Performance

Measurement of the third-order intermodulation (IM) product levels generated by the S and Ku-band LNA's in the presence respectively, of two in-band -63 dBm and -53 dBm input tones, indicated better than 70 and 56 dB IM rejection.

2. Physical Characteristics

The S-Band and Ku-Band LNA's were packaged in compact, EMI shielded enclosure of dimensions 7.1" x 6.5" x 2.5" and 7.6" x 5.75" x 2.5" and weighing about 2.9 and 3.1 lbs, respectively.

The total measured DC power drain of both the S and Ku-band LNA's over the extremes of baseplate temperature and DC prime input voltage variations is about 9 to 15^{W} and 1 to 7^{W}, respectively, for "on" and "standby" mode operation.

References

1) C. Allen, P. Lombardo et al - "Spaceflight Qualified Miniature S-Band Parametric Amplifier Assembly" - presented at NAECON, Dayton, Ohio, May 1977.

2) H. C. Okean, J. A. De Gruyl and E. Ng - "Ultra Low Noise, Ku-Band Parametric Amplifier Assembly," 1976 IEEE-MTT-S International Symposium Digest, pp 82-84, June 1976.