ULTRA LOW NOISE, Ku-BAND PARAMETRIC AMPLIFIER ASSEMBLY

by

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Abstract

This paper describes the development of an ultra-low noise two-stage Ku-band parametric amplifier assembly for space communication ground station receiver application. This paramp is designed for 75°K noise temperature capability over the 14.7 – 15.2 GHz frequency range without the use of cryogenic cooling. This extremely low noise performance is made possible by the use therein of ultra high quality, low parasitic content chip varactors, of exceptionally high idler (~ 80 GHz) and pump (~ 95 GHz) frequencies and of minimum loss, high isolation signal coupling circulators operated in the "single pass" configuration.

Introduction

The extremely low noise temperature capability required of ground station receivers in space communication links, provided in the past by cryogenically cooled parametric amplifiers has more recently been obtainable at the lower microwave frequencies from non-cryogenic paramps incorporating the latest advances in high quality varactor and millimeter wave solid state pump source technology. This paper describes the extension of this ultra low noise non-cryogenic paramp art to the Ku-band frequency range, as embodied in the development of a two stage, 14.7 – 15.2 GHz paramp assembly, designed for state-of-the-art 75°K noise temperature.

Basic Design Considerations

The two-stage Ku-band paramp design, depicted in block diagram form in Figure 1, is dictated foremost by the necessity to minimize all contributions to overall paramp noise temperature over the 14.7 – 15.2 GHz passband as formulated in the general noise budget of Figure 2. It is seen therein that overall two stage paramp noise temperature may be most directly reduced by increasing idler (and pump) frequencies and by decreasing physical temperature and/or total circulator insertion loss preceding the first stage paramp mount. This is borne out by the calculations presented in Figure 2, which indicate that, to maintain overall "worse-case" (at 15.2 GHz) paramp noise temperature less than 75°K the requirements of pump frequency, varactor cutoff, total circulator input insertion loss and first stage physical temperature, are greater than 90 GHz and 800 GHz and less than 0.1 dB and 250°K, respectively.

In order to implement the foregoing "state-of-the-art" parameters, the basic design approach for the two-stage Ku-band parametric amplifier includes:

- Ultra high quality GaAs Schottky chip varactor (cutoff frequency greater than 800 GHz) in an optimized single-ended raised idler embedding configuration formed in a unique composite waveguide/TEM transmission line paramp mount utilizing an advanced chip varactor embedding geometry which permitted the formation of an idler resonance at ~ 80 GHz and the use of a 95 GHz pump frequency.
- All solid state ~ 95 GHz pump source per paramp stage, each consisting of a ~ 47.5 GHz Gunn effect oscillator followed by a low conversion loss varactor doubler, and providing sufficient CW power output capability (~ 30 mW) at 95 GHz to fully pump the corresponding paramp varactor.
- State-of-the-art four-port (dual junction) waveguide signal circulators serving each paramp stage, with each paramp mount connected to the first junction of the corresponding four-port circulator. Made possible by the realization of extremely high circulator interjunction (⩾ 40 dB) and external port (⩾ 30 dB) isolation over the 14.7 – 15.2 GHz passband, this circulator deployment minimizes the total insertion loss preceding each paramp mount and, in particular, insures that the total first stage input insertion loss is below the 0.1 dB design objective.
- Thermoelectric (Peltier) stabilization of the first stage paramp mount (and pump source doubler) at about 250°K and of the second stage paramp mount and first and second stage signal circulators and pump sources at about 290°K. The extremely low single-pass insertion loss capability of the first stage waveguide signal circulator makes it unnecessary to reduce its physical temperature to 250°K along with the associated paramp mount.

The physical implementation and measured performance of the components comprising the two-stage Ku-band paramp assembly evolving from the foregoing general design approach is described in the following paragraphs.

Paramp Implementation and Performance

Paramp Mount

Each Ku-band paramp stage incorporates a state-of-the-art in-house high quality stud mounted GaAs Schottky chip varactor, embedded in a waveguide mounting cavity within a composite waveguide/TEM transmission line paramp mount structure similar to that previously successfully used at Ka-band[1]. Depicted schematically in Figure 3, this mount incorporates:

- Composite waveguide/TEM transmission line Ku-band (14.7 – 15.2 GHz) 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 ~ 80 GHz (a value higher than ever previously demonstrated) formed around precisely selected varactor junction capacitance (0.06 pF) through reactances provided by the carefully dimensioned elements which couple the varactor chip 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 pump entry waveguide, providing impedance matching at ~ 95 GHz of pump source to varactor chip, and establishing, by virtue of proper physical location, an open-circuit sum frequency (~ 110 GHz) termination at the varactor junction.

Each Ku-band paramp stage, consisting of a paramp mount configured as above and integrated with one of the aforementioned Ku-band four-port circulators, was aligned to provide a flat 13 dB gain response over the 14.7 – 15.2 GHz passband, as exemplified by that depicted in Figure 4. These paramp stages, therefore, demonstrate the ability to form an idler resonance at 80 GHz and to provide the proper signal and pump circuit coupling to an appropriate GaAs Schottky chip varactor for full drive with less than 25 mW pump power and with 500 MHz or greater bandwidth at the desired (~ 13 dB/stage) passband gain level. Moreover, the measured unpumped passband insertion loss responses of these stages, also exemplified in Figure 4, are consistent with the desired level of low noise performance. Specific data will be presented on the overall gain-bandwidth and noise temperature of the optimally aligned two stage cascade.

Circulator

A state-of-the-art Ku-band four-port signal circulator was developed for use in the Ku-band paramp assembly. Configured in an H-plane, waveguide structure, each junction consists of a partial-height ferrite rod, mounted in between two symmetrical composite metallic/dielectric transformer pedestals. The dimensions are chosen such that an optimum combination of radial and axial modes[2] is achieved for the required bandwidth. Following optimum matching at the external ports and the interjunction arm, this circulator exhibited the following level of performance over the 14.7 – 15.2 GHz frequency range:

- Insertion loss per pass $\leq$ 0.07 dB
- External port isolation $\geq$ 32 dB (all ports)
- Interjunction isolation $\geq$ 42.5 dB

Depicted graphically in Figure 5, this represents the lowest loss highest isolation circulator performance heretofore demonstrated over this Ku-band frequency range. An extremely compact waveguide termination developed for the output junction of each four port circulator, exhibited less than 1.05:1 VSWR over the 14.7 – 15.5 GHz range.

The extremely high interjunction and load isolations (as compared to the paramp mount reflection gain level) make possible the deployment of the paramp mount at the input junction in each stage, while still maintaining active input and output VSWR's of less than 1.2:1 per stage. The very low (< 0.07 dB) circulator insertion loss preceding each paramp stage in this "single-pass" deployment will contribute less than 6°K to total two-stage paramp noise temperature, thereby making it unnecessary to thermoelectrically stabilize the first stage circulator below room temperature.

Solid State Pump Source

The all solid state 95 GHz pump source for each Ku-band paramp stage consists of a ~ 47.5 GHz Gunn effect oscillator/varactor doubler cascade. The 47.5 GHz Gunn diode oscillator, is an available conventional waveguide cavity mounted structure, providing over 100 mW output power in conjunction with a closely integrated miniature waveguide output isolator. The 47.5 to 95 GHz varactor doubler utilizes a high quality in-house GaAs Schottky chip varactor in a composite waveguide mounting structure similar to the tripler structure previously used for the 96 GHz pump source in a Ka-band parametric amplifier[1]. This doubler provides over 30 mW CW output at 95 GHz under 100 mW input drive, which is more than sufficient to fully pump the previously described Ku-band paramp stage.

Overall Paramp Assembly

The overall two-stage Ku-band paramp assembly is mounted on a thermoelectrically stabilized plate (at ~ 290°K) which is in turn directly thermally contacted (through a multiplicity of series-connected thermoelectric modules) to a metallic baseplate heat exchanger, the latter forming the base of a completely sealed and insulated enclosure. As previously shown in Figure 1, the two paramp stage circulators and pump sources and the second stage paramp mount are mounted in direct thermal contact with the top side of this plate. The first stage paramp mount (and pump source doubler) is directly mounted on a small second thermally stabilized (at ~ 250°K) plate, which is coupled to the main plate through a "second stage" thermoelectric module. Internally plated stainless steel waveguide sections between the first stage paramp mount/pump source doubler and its associated signal circulator and pump source oscillator/isolator and between the overall paramp cascade and the enclosure input and output interface ports serve as thermal isolators.

A detailed description and complete performance data will be presented on the overall Ku-band paramp assembly, configured as above.

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References

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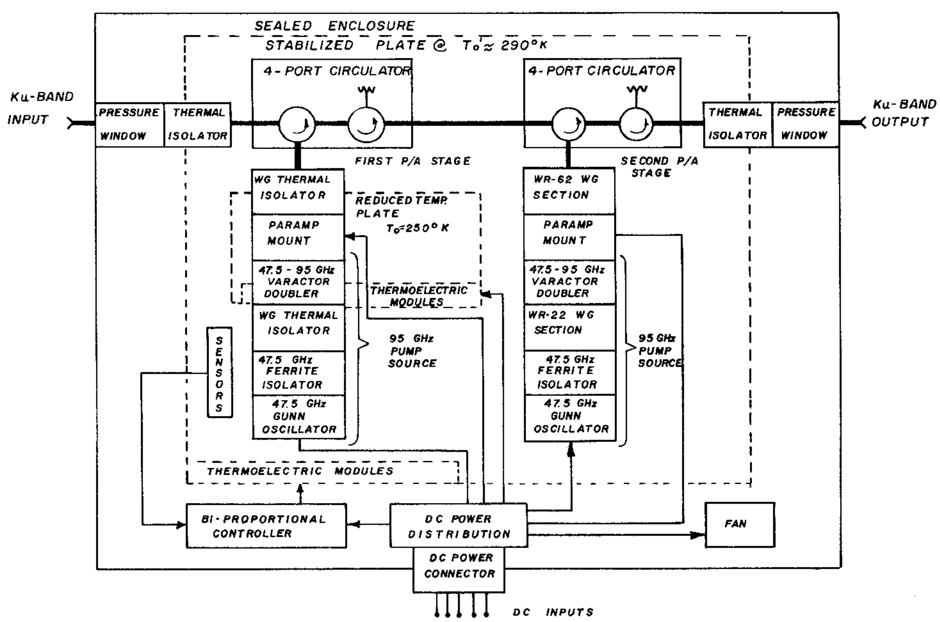

Figure 1 Block Diagram of Ku-Band Parametric Amplifier Assembly

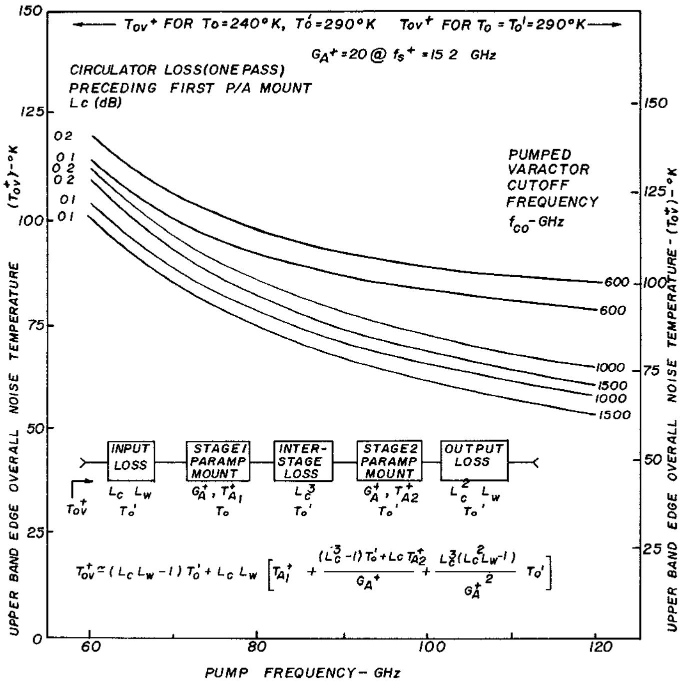

Figure 2 Theoretical "Worst-Case" Noise Performance of Two-Stage Ku-Band Paramp Assembly

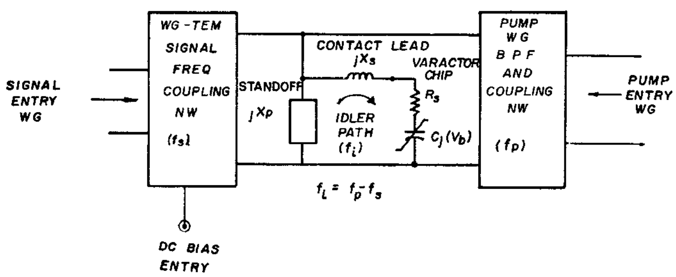

Figure 3 Schematic of Ku-Band Paramp Mount

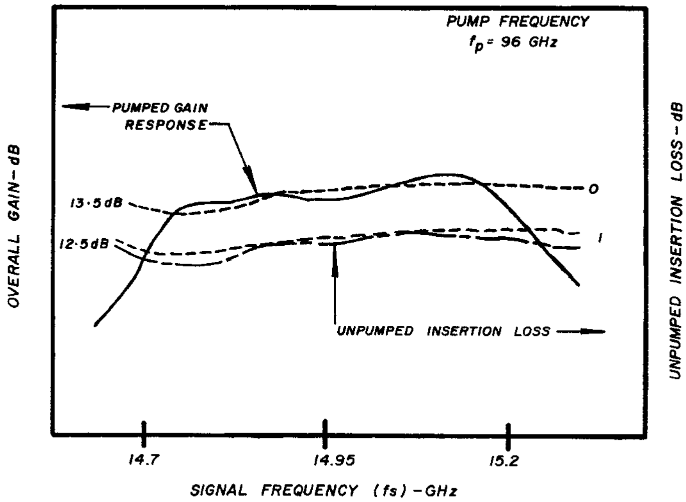

Figure 4 Measured Gain Response of Single Ku-Band Paramp Stage

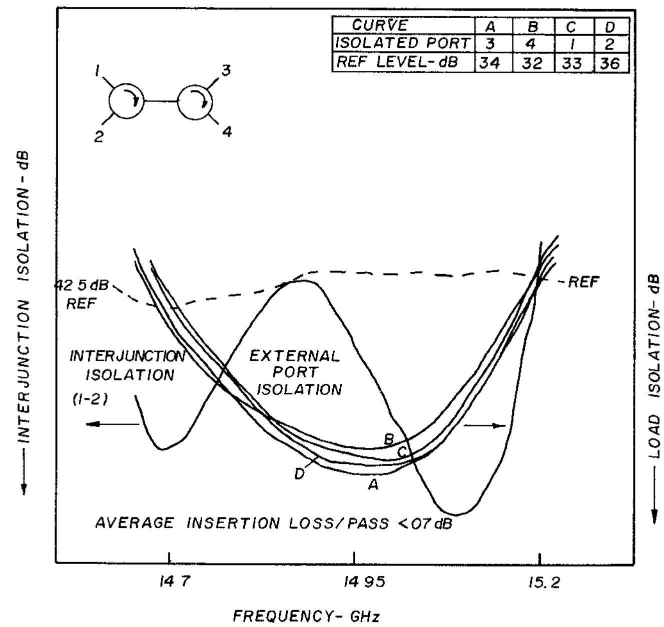

Figure 5 Measured Performance of Ku-Band Four-Port Signal Circulator