An Environmentalized Low-Noise Parametric Amplifier

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***Abstract*—A 14-oz low-noise, *X*-band parametric amplifier has been developed for an airborne environment (−55 to +71°C). This unit exhibits a 1.8-dB noise figure at 10 GHz and, at 18-dB peak gain, a 3-dB single-tuned bandwidth of 230 MHz that is electronically tunable over 700 MHz. A 1-dB gain compression occurs at −27-dBm input power. Performance is achieved through use of unique upper sideband terminated circuitry and a new low-parasitic, hermetic varactor package.**

I. Introduction

Low weight, low-noise figure, good dynamic range characteristics, and broad bandwidth have been successfully combined in a high-performance electronically tunable X-band parametric amplifier (paramp) designed for a stringent airborne environment. Broad bandwidth has been realized through the development of a new microdot low-parasitic hermetically sealed varactor package used in a balanced arrangement to achieve a high series resonant frequency for the idle frequency circuit. The problems usually encountered in paramps of unexplained gain reductions and noise figure increases over theoretical values have been solved with this unique amplifier configuration [1] that controls circuit impedances at all the major frequencies; signal, pump, idle, and upper sideband. Temperature stabilization has been incorporated to permit operation over the full −55 to +71°C temperature range. The design has not compromised dynamic range in its mechanization, as is evidenced by a 1-dB-gain compression point of −27-dBm input power at 18-dB gain.

II. Amplifier Module

Fig. 1 illustrates the 14-oz compact paramp module consisting of a five-port stripline circulator with integral waveguide input, varactor mount, pump, pump isolator, and heater plate with heat exchanger. A top heater plate (not shown) covers the circulator and varactor mount. The circulator exhibits a 0.3-dB loss from input to paramp port over 1 GHz with 40 dB of isolation (two circulator passes). The 49.0-GHz pump requires 3–4 V at 1.1 A and delivers 85 mW at 71°C. The oscillator uses a Gunn diode in a post-coupled waveguide cavity with a loaded Q of 50 designed for low cost and a smooth characteristic of output power versus input voltage. The pump isolator exhibits a 2-GHz bandwidth with a 0.5-dB loss, 1.2 : 1 VSWR, and 20 dB of isolation. The thermal control elements consist of the two heater plates (with vulcanized heater), a thermistor in

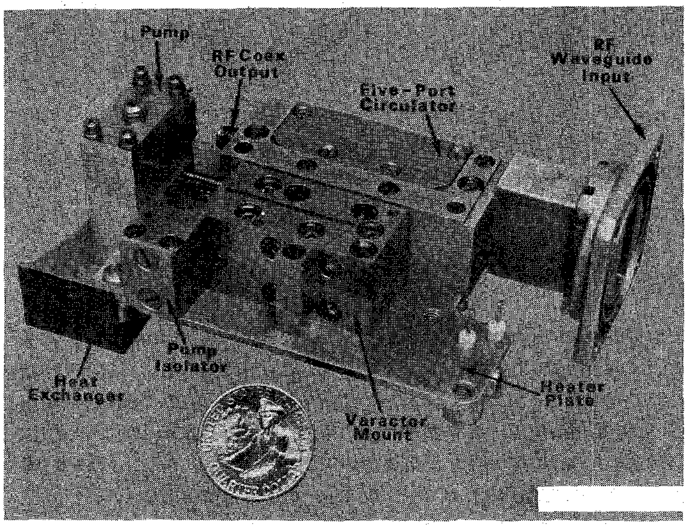

Fig. 1. Paramp module.

the pump, a heat exchanger under the pump, and a proportional temperature control circuit. Cooling air permits thermal decoupling of the unit to minimize warmup heater power and also to allow the unit to operate at its 71°C stabilization temperature for ambient temperatures of 71°C and above with the 4-W Gunn input power.

III. Theoretical Analysis

Unexplained gain reductions and noise figure discrepancies over anticipated values have in the past created black magic tuning of the amplifiers. Solutions of the basic equations [2] for paramp noise figure F and impedance Z have been expanded to include the effect of arbitrary idler and upper sideband frequency terminations with the following results:

$$F = 1 + \frac{T_d}{T_0}\frac{\omega_s}{\omega_i} \cdot \frac{1 + \left(\dfrac{\omega_i}{\gamma_i m_1 \omega_c}\right)^2 + \left(\dfrac{\omega_i}{\omega_u}\dfrac{\gamma_u}{\gamma_i}\right)^2}{1 - \dfrac{\omega_s \omega_i}{(\gamma_i m_1 \omega_c)^2} - \left(\dfrac{\omega_i}{\omega_u}\right)\left(\dfrac{\gamma_u}{\gamma_i}\right)^2}$$

$$\gamma_i = \frac{1}{\sqrt{1 + \left(\dfrac{X_i}{R_i}\right)^2}}$$

$$\gamma_u = \frac{1}{\sqrt{\dfrac{R_u}{R_i}\left(1 + \left[\dfrac{X_u}{R_u}\right]^2\right)}}$$

$$Z = R_s + jX_s - \frac{S_1 S_1^*}{\omega_s \omega_i}\left(\frac{1}{R_i - jX_i} - \frac{\omega_i/\omega_u}{R_u + jX_u}\right)$$

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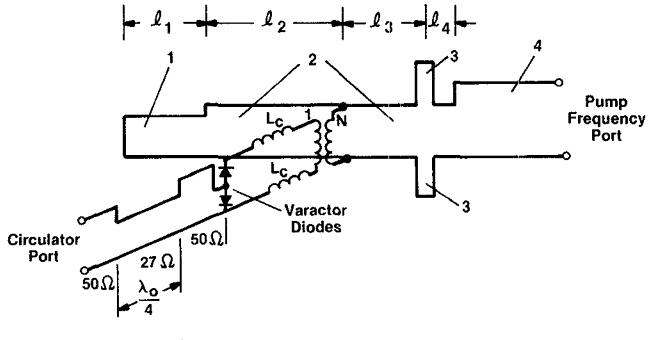

Fig. 2. Varactor mount schematic.

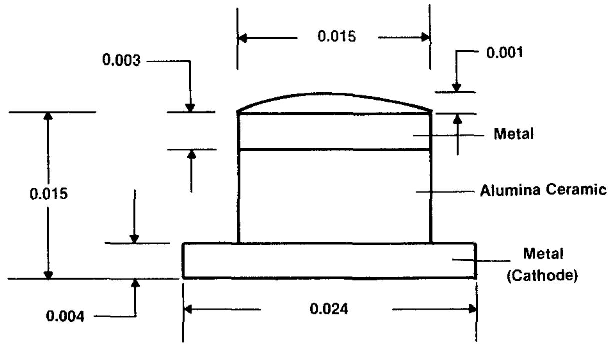

Fig. 3. Microdot package outline.

where

- T_d diode temperature;
- T_0 290 K;
- ω_s signal angular frequency;
- ω_i idler angular frequency;
- ω_u upper sideband angular frequency;
- R_s resistance of diode circuit at signal frequency;
- R_i resistance of diode circuit at idler frequency;
- R_u resistance of diode circuit at upper sideband frequency;
- X_s reactance of diode circuit at signal frequency;
- X_i reactance of diode circuit at idler frequency;
- X_u reactance of diode circuit at upper sideband frequency;
- $m_1 \omega_c$ $= S_1/\sqrt{R_s R_i}$;
- S_1 fundamental half-amplitude pumped elastance coefficient.

Lowest noise with high gain occurs with the idle circuit reactively tuned for maximum current flow at the idle frequency ($\gamma_i = 1$) and with the upper sideband frequency open circuited ($\gamma_u = 0$). Because of uncontrolled frequency terminations at the upper sideband frequency, circuits to provide the correct termination were found to be necessary. Detailed analysis using the foregoing equations reveals that the exact location of the circuit elements is not critical and that a broad low-noise high-gain area does exist with minimum noise figure degradation.

IV. Varactor Mount

Fig. 2, the varactor mount schematic, illustrates the unique circuitry for controlling all four of the major frequencies with low pump power. The matched varactor diodes are in series with the pump frequency port and in parallel with the signal frequency, which isolates the signal port for all frequencies generated in the diode. Furthermore, the diodes are located in waveguide 2, which is cut off from the idler frequency near the edge to transform the impedance at the pump frequency and also to provide a low inductance return for the varactor diodes. Waveguides 1 and 3 are cut off from the pump frequency, but they pass the upper sideband frequency to provide frequency-selective filtering and matching.

The quarter-wavelength short-circuited waveguide sections 3 are physically placed on the top and bottom of the low impedance guide 2 and are electrically about one-half wavelength from the diodes at the upper sideband frequency. These guides isolate the pump port from the diodes at the upper sideband frequency and provide open-circuit loading for this right-hand waveguide section. Waveguide section length l_2 is selected to be approximately 0.3 times the pump guide wavelength so that the inductive guide 1 impedance at the pump frequency adds a small amount of capacitive susceptance to help resonate the diode. With length l_2 fixed, the l_1 cutoff section is selected such that this shorted line is referred to the diode's plane as an open circuit at the upper sideband frequency. Finally, length l_4 is selected to minimize the VSWR of the pump frequency; its end is generally close to the guide 3.

This circuit has been successfully used for S- and X-band amplifiers with pump frequencies of 23.5 and 49 GHz, respectively, with excellent results. For this design, a pump port match was under 2.0 : 1 over 1 GHz for varactor bias voltages between 0.5 and 2.5 V. The pump power requirement was 40 mW with the varactor diodes back biased to 2.5 V.

The signal circuit consists of a 50-Ω line section from the varactor diode to a 27-Ω quarter-wavelength section. This 50-Ω length is adjusted so that the pumped impedance is resonated at the center operating signal frequency. At that location, minimum pump power and varactor voltage variation are required to electronically tune the amplifier. The amplifier can be electronically tuned over 700 MHz by varying the varactor and Gunn voltages from approximately 0.3 to 0.6 V with a typical 3-dB bandwidth of 230 MHz at 18-dB peak gain.

V. Microdot Hermetic Varactor Package

Fig. 3 illustrates the microdot hermetic package developed for this amplifier. Extremely low parasitics (0.045-pF package capacitance and 0.07-nH diode inductance) are achieved with this unit. These parasitics are 42 percent of the value for previous low parasitic hermetic packages like the Alpha 290-001 outline, which has a typical package capacitance and inductance of 0.11 pF and 0.16 nH, respectively. The typical DeLoach resonance frequency and cutoff frequency are 39 and 720 GHz, respectively, for 0.12-pF zero-bias junctions. In the microdot package with the diodes embedded in a 0.010-in-high waveguide

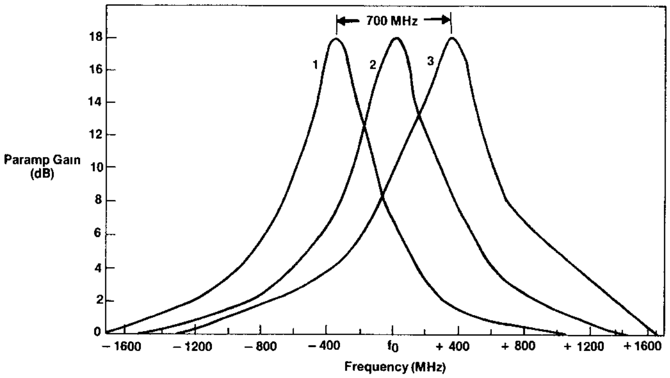

Fig. 4. Paramp gain versus frequency.

configuration edge mounted, the idler frequency resonance is approximately 39 GHz with the diodes fully pumped at a −0.8-V bias.

VI. Measured Performance

The measured performance may be summarized as follows:

Center frequency	9–11 GHz
Gain	18 dB
3-dB bandwidth	230 MHz
Noise figure	1.8 dB
Input and output VSWR	1.3 : 1 max
Dynamic range	1 dB gain compression at −27-dBm input power
Electronic tuning range	700 MHz
Recovery time for signal overload	150 ns

Fig. 4 shows the paramp gain versus frequency tuning curves for three sets of varactor-Gunn voltages. The amplifier may be electronically tuned to any center frequency in this 700-MHz band. The electronic tuning capability of this amplifier provides a wide frequency coverage with the added advantage of RF preselection. The conditions for these curves are given below:

Tuning Curve	Varactor Voltage (volts)	Gunn Voltage (volts)	Noise Figure (dB)	Bandwidth (MHz) 1 dB	Bandwidth (MHz) 3 dB
1	-1.171	2.967	1.75	105	200
2	-0.851	2.776	1.80	115	230
3	-0.790	3.219	1.85	130	235

VII. Conclusions

The combination of a new packaged varactor with low parasities and a microwave network that simultaneously controls circuit impedances at four frequencies has led to the development of an advanced parametric amplifier with predictable properties capable of meeting airborne military environment requirements.

Acknowledgment

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References

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[2] P. Penfield and R. Rafuse, *Varactor Applications.* Cambridge, MA: MIT Press, 1964.