SPACEFLIGHT-QUALIFIED TUNABLE C-BAND PARAMETRIC AMPLIFIER SYSTEM*

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Abstract

An integrated spaceflight-qualified tunable C-band parametric amplifier system has been developed. The amplifier system is a single small package and is designed for minimum power drain. It consists of temperature compensated bias circuits, a waveguide pump network, waveguide mounted varactors, and a microstrip 5-port circulator in a 5-in^3 aluminum housing weighing less than 0.5 lb. The measured performance of the system includes: 140 MHz minimum instantaneous 3-dB bandwidth, 17 dB minimum peak gain, $>$500 MHz tunable bandwidth, and 154 K maximum passband noise temperature.

This paper describes the design and performance of a spaceflight qualified tunable C-band parametric amplifier system. The system (Figure 1) is completely integrated as a single package of less than 5-in^3 volume and 0.5 lb weight. Tunability is accomplished with adjustment of only bias voltage. The system is intended for use aboard a NASA space shuttle vehicle. It is to be incorporated as part of the space shuttle's communication equipment. The system is designed to meet the severe environment factors associated with the vehicle's operations of launch, stationing and re-entry. A total of less than 10 watts power from a single voltage input is required to provide temperature compensated bias for both the fundamental frequency Gunn-effect oscillator and diode and the amplifier varactors.

The system, shown in block diagram form by Figure 2, incorporates the following closely integrated components:

- A waveguide balanced-varactor parametric amplifier mount with integral pump attenuator and pump transformer.

- A 5-port microstrip signal circulator, providing the nonreciprocal function, with the signal broadbanding circuit.

- A 26-GHz Gunn-effect oscillator that provides the pumping power.

- A waveguide isolator that effects a stable load for the solid-state pump source.

- A temperature compensated dc-bias distribution network which provides the bias voltages for the varactors and Gunn-effect diode from a single dc input.

A Gunn-effect oscillator, rather than an avalanche oscillator, is used as the fundamental pump source due to its superior spectral noise purity. Avalanche oscillators generally have been shown to degrade the small-signal sensitivity of a parametric amplifier when both large and small signals are received at the same time. Elaborate pump filtering of an avalanche oscillator output can reduce the small-signal sensitivity degradation. However, for this system, the increased size required to incorporate the filtering is prohibitive.

The balanced varactor configuration was chosen over the single varactor approach because the former exhibits the least amount of spurious reactance in the idler circuit, to the extent that the series inductance and varactor nonlinear capacitance are the predominant reactance components. Such a condition results in the greatest idler resonance frequency change with bias voltage change. When the amplifier signal-circuit bandwidth is set as broad as practical and the idler-circuit resonant frequency is caused to shift by bias voltage adjustment, the idler-circuit resonant frequency will shift much more than the signal circuit resonance frequency. Thus, the tuned gain-frequency response of the amplifier will follow the idler circuit resonance while maintaining approximately the same peak gain over the tunable bandwidth.

The amplifier system consists of a microwave integrated circuit structure comprised of thin-film microstrip and metallic waveguide components, closely integrated into an aluminum housing.

The microstrip portion is formed on a metallized 25-mil thick alumina substrate that comprises the five-port circulator, signal tuning circuits, microstrip terminations, bias entry, dc-blocks, and microstrip-to-coaxial input and output transitions. The K-band waveguide portion consists of an iris-coupled, Gunn oscillator, a miniature waveguide isolator, and a transformer that couples the pump energy into the waveguide-mounted varactor pair. The center point of the varactor pair is coupled to the microstrip by

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a high-impedance transmission line that conveniently serves as the signal tuning inductance. Beam-lead dc blocking capacitors are employed between the junctions of the input and output microstrip isolators to isolate the varactor bias from the external circuits.

The thin-film microstrip realization was chosen for the C-band components to minimize size and weight, whereas the waveguide realization for the K-band source and varactor mounting was chosen to provide a low-loss, single-mode propagation medium not possible with present thin-film microstrip realization techniques.

The 5-port microstrip circulator consists of three separate substrates. Each substrate contains a 3-port circulator. Two of the 3-port circulators have one of their ports terminated with a matched load. One of those circulators serves as an input isolator while the other serves as an output isolator. The third circulator provides the nonreciprocal function for the amplifier. A portion of the amplifier signal circuit is located on this circulator substrate. It consists of two parallel broadbanding stubs and the quarter-wave transformer section to which the stubs attach. The reactance of these signal-circuit items, together with that associated with the balanced varactor pair and the tuning inductance, accomplishes the required broadbanding of the signal circuit. The broadband signal circuit determines the limits of the tuning envelope. The signal circuit was designed for a tuning bandwidth of 900 MHz and an instantaneous bandwidth of 145 MHz.

The prototype system developed during the first phase of the program proved feasibility. Table 1 shows the actual performance. Tuning from 3.7 to 4.2 GHz was accomplished with varactor bias adjustment only. The increasing noise temperature with higher frequencies resulted from three factors. In the order of significance, those factors were varactor bias current, circulator ferrite losses, and radiation. The varactors were being pumped hard. They drew over 12 μA current when the amplifier was bias voltage-tuned to the high end of the frequency band.

The magnetic fields for the circulators were not all optimumly homogeneous. This is believed to have resulted in greater surface-wave radiation from the ferrite at the high end of the frequency band. Subsequent work at homogenizing the fields with homogenizing plates reduced those losses.

The performance of this prototype met all requirements. A fully space-qualified model is under construction. The results of this model under space simulated environment will also be presented.

TABLE 1. PROTOTYPE PERFORMANCE

Parameter	Actual	
Frequency tuning range (GHz)	3.5 to 4.25	
Tuned response minimum peak gain (dB)	17	
Instantaneous minimum 3-dB bandwidth (MHz)	140	
Input signal for 1-dB compression of output signal (dBm)	-35	
Noise temperature (K)	Ranged as follows:	
	MHz	K
	3700	105
	3825	112
	3950	129
	4050	110
	4125	135
	4200	154
Weight (lb)	0.44	
Volume (in^3)	5.5	

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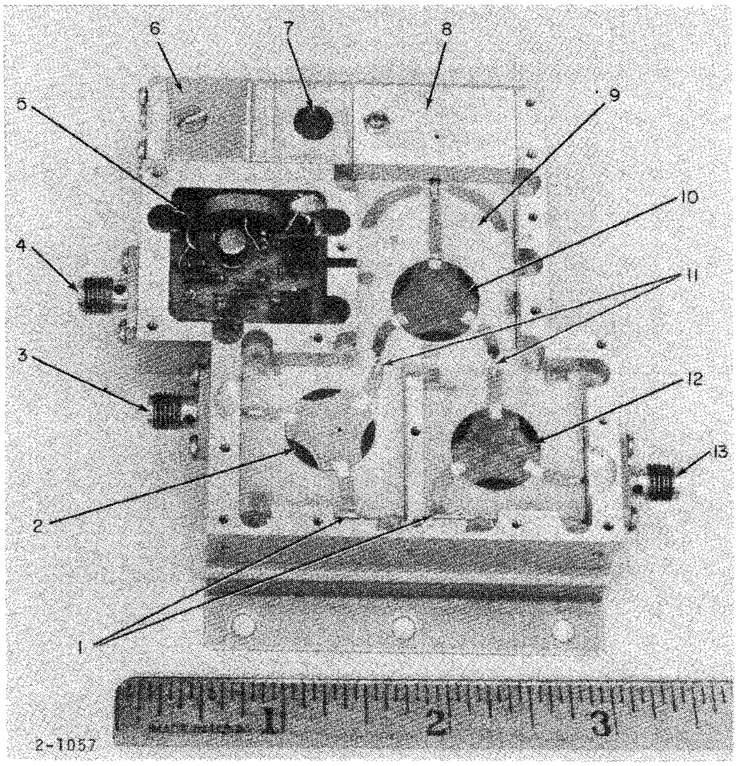

1. ISOLATOR TERMINATIONS
2. INPUT ISOLATOR
3. RF INPUT
4. DC INPUT
5. BIAS CIRCUITS
6. PUMP (GUNN EFFECT DIODE OSCILLATOR)
7. PUMP ISOLATOR (WAVEGUIDE)
8. AMPLIFIER MOUNT (BALANCED)
9. SIGNAL CIRCUIT
10. AMPLIFIER CIRCULATOR
11. DC BLOCKS
12. OUTPUT ISOLATOR
13. RF OUTPUT

FIGURE 1. PHYSICAL REALIZATION OF C-BAND INTEGRATED PARAMETRIC AMPLIFIER

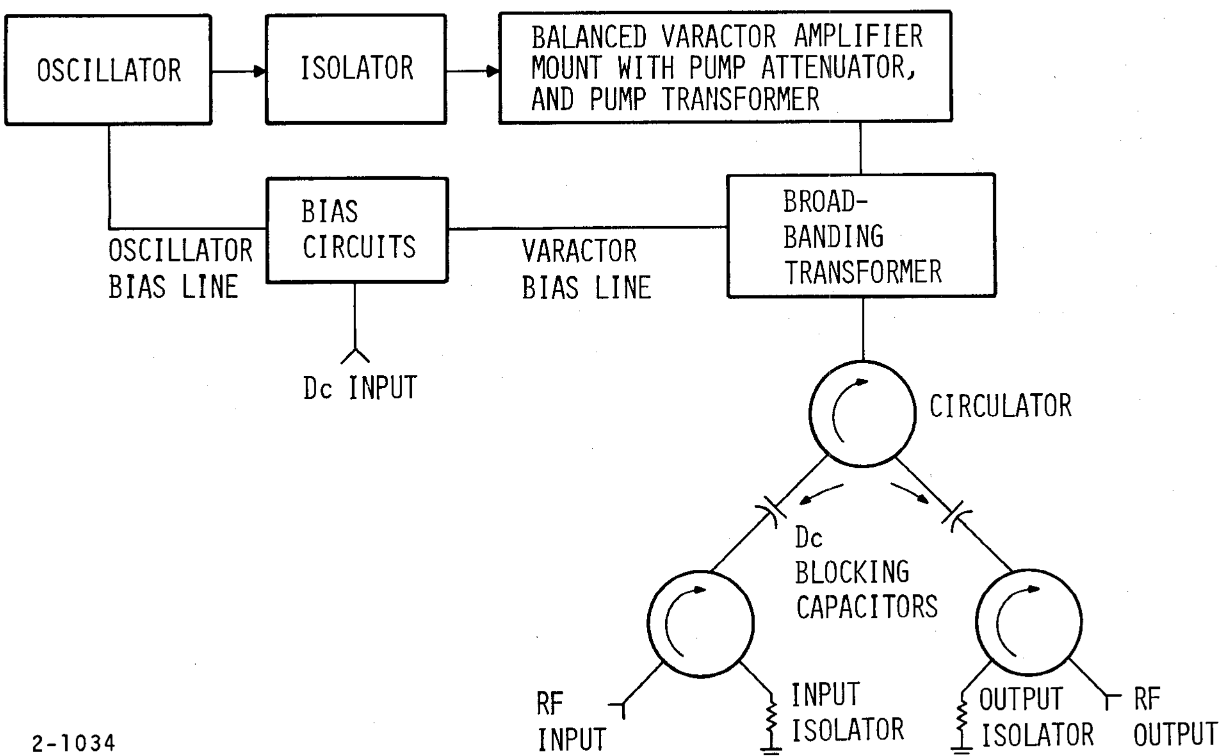

FIGURE 2. C-BAND INTEGRATED PARAMETRIC AMPLIFIER BLOCK DIAGRAM