SPACECRAFT INTEGRATED PARAMETRIC AMPLIFIER DEVELOPMENT

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SUMMARY

An integrated, all-solid-state paramp for utilization aboard the Space Shuttle has been developed through the initial prototype phase. The paramp is tunable over the entire 3.7 GHz to 4.2 GHz commercial satellite communications band, has an instantaneous bandwidth of 100 MHz minimum when tuned over the band, a gain of 17 dB, and a noise figure ranging from 104°K at the low end to 150°K at the high end of the band. The paramp utilizes a combination of microstrip, coax, and waveguide circuitry in an extremely compact and lightweight package. The paramp weighs seven ounces and has a volume of less than six cubic inches. It is completely operational when supplied with seven volts d.c. at 0.6 ampere. A comparison of the development of this second generation unit with a first generation S-Band paramp is presented. Measured test results of the two units are analyzed to show how deficiencies in the first generation paramp were eliminated in the second development. A prototype K_u-Band Spacecraft Paramp being developed for the TDRS Program is described.

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INTRODUCTION

At the Space Shuttle Technology Symposium in 1970, the development of a completely integrated, all-solid-state S-Band prototype paramp was reported.[1] That effort was the successful first step in establishing the feasibility of compact, lightweight, low noise paramps for utilization in spacecraft applications. Microminiature and hybrid integrated circuit techniques were employed, in conjunction with the technology of recently perfected solid state microwave power sources to produce an advanced paramp design. This design removed the obstacles previously preventing the development of a paramp having the potential suitability for use in an orbiting spacecraft.

The experience acquired during this first generation development has led to the successful completion of a second generation integrated C-Band paramp[2] for use in the Space Shuttle communications receiver. This latest prototype unit embodies improved packaging and performance characteristics which are a direct outgrowth of techniques developed during the first generation program. Areas which improved measurably are microstrip circulator design, solid state Gunn oscillator design, varactor mounting and broadband resonating, and integrated packaging design. These improvements have produced a paramp with improvements in noise figure, tunability, stability, and packaging.

A second phase of the current program is now under way. During this phase, the prototype paramp will undergo extensive re-design and testing with the purpose of producing a completely space-qualified paramp which is suitable for use aboard the Space Shuttle vehicle.

Also, a companion program to develop a prototype spacecraft paramp operating at K_u-Band is in progress. Some preliminary test results obtained thus far will be presented later in this paper.

REFERENCES:

1. NASA Technical Memorandum, NASA TMX-52876, Volume VI, Integrated Electronics, pp. 289.

2. This work was performed under Contract NAS5-21527 by Airborne Instruments Laboratory, Melville, Long Island, New York.

DESCRIPTION

S-Band Paramp

A brief review of the first generation S-Band integrated paramp will be presented in order to demonstrate how the second generation C-Band paramp resulted in greatly improved performance.

Originally, it was intended that the entire paramp be formed in microstrip circuitry in order to minimize the weight and volume characteristics. This approach was abandoned when it became evident that a stable, low noise pump oscillator could not be achieved using low-Q microstrip resonators. In addition, surface wave interaction between the pump and the varactor circuitry was found to be intolerable. Accordingly, it was decided upon an optimum compromise of waveguide for the pump components and microstrip for the circulator and varactor circuitry. Figure 1 is a photograph of the S-Band paramp showing the circulator-varactor portion in microstrip and the solid state pump source in K_u-Band waveguide. The microstrip utilizes thin film deposited copper conductors on a twenty-three mil thick glazed alumina substrate. All critical electrical connection points such as the circulator-paramp junction and the OSM coax-to-microstrip junctions are reinforced by small sections of gold ribbon parallel-gap-welded across the junction.

The circulator is a three port design consisting of a one inch diameter ferrite disc cemented into a one inch diameter hole in the alumina substrate with the "Wye" junction and matching transformers deposited on top of the ferrite-alumina combination. A one and one-quarter inch diameter permanent magnet having a field strength of 400 Gauss is cemented to the ground plane side of the circulator "Wye" junction.

A Sylvania Type 5147E varactor is employed in a single-ended circuit. Figure 2 depicts the method of shunt mounting the varactor through the microstrip substrate and shows how contacting to the varactor is effected by means of low temperature indium solder and a welded gold ribbon. Both the signal and idler circuits are composed of distributed element resonators in microstrip circuitry. A novel parallel-pair open-stub configuration is employed to achieve signal circuit broadbanding.

The pump source consists of a commercially available, gallium arsenide Gunn Effect Device mounted in a high-Q, K_u-Band waveguide cavity. The Gunn Oscillator has an RF power output capability of 100 milliwatts at 14 GHz. The d.c. power requirement is 7.7 volts at 0.5 ampere. The Gunn oscillator consists of a Varian VSU-9202D Gunn-Effect device post-mounted in a three-quarter wavelength resonant cavity. The output is coupled through a circular waveguide

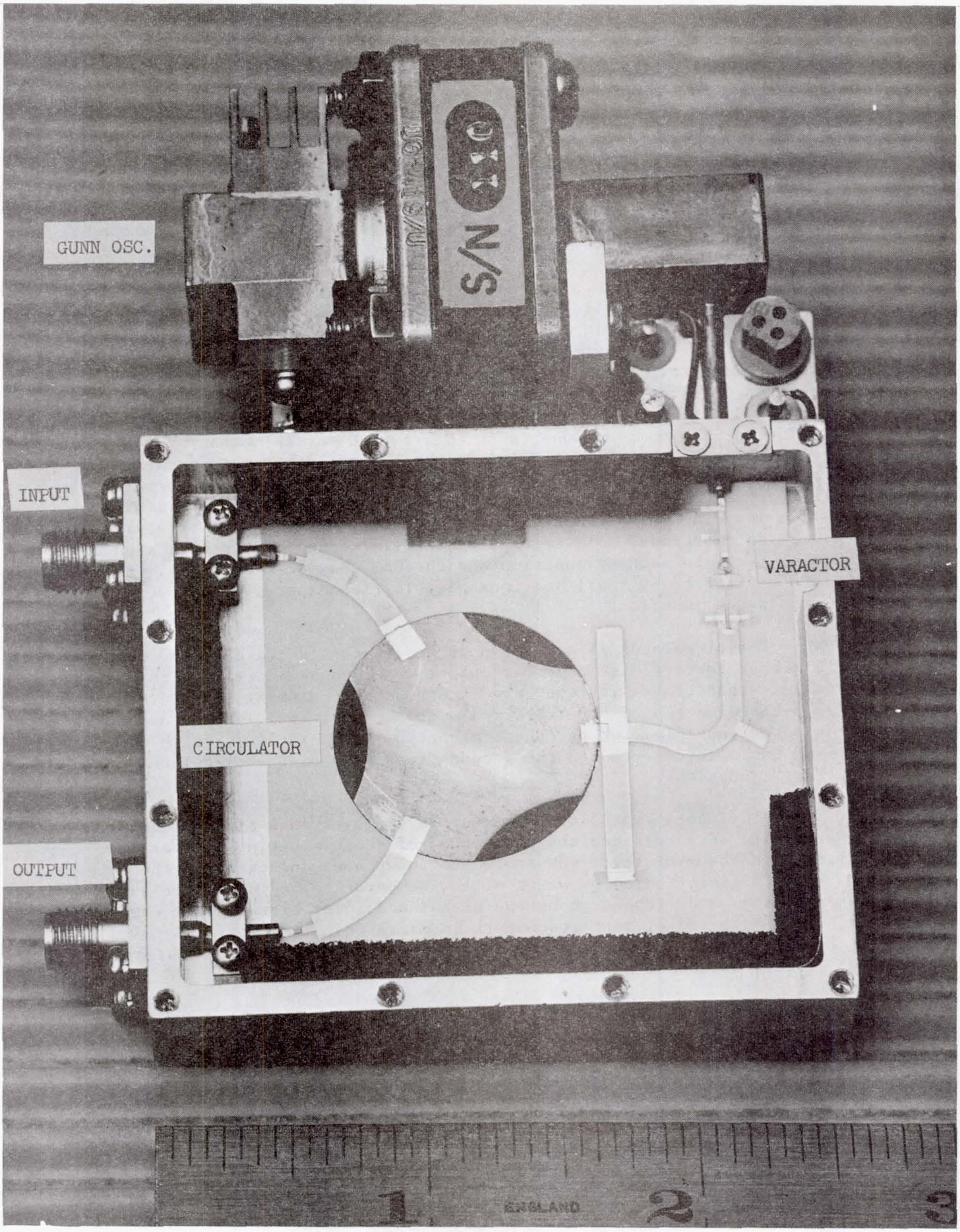
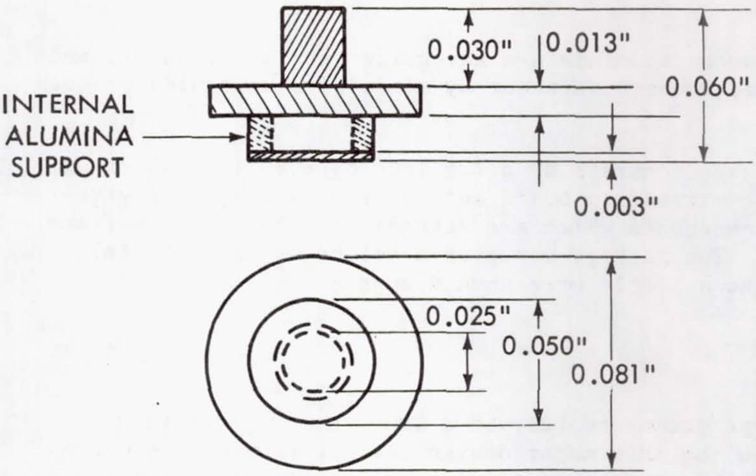
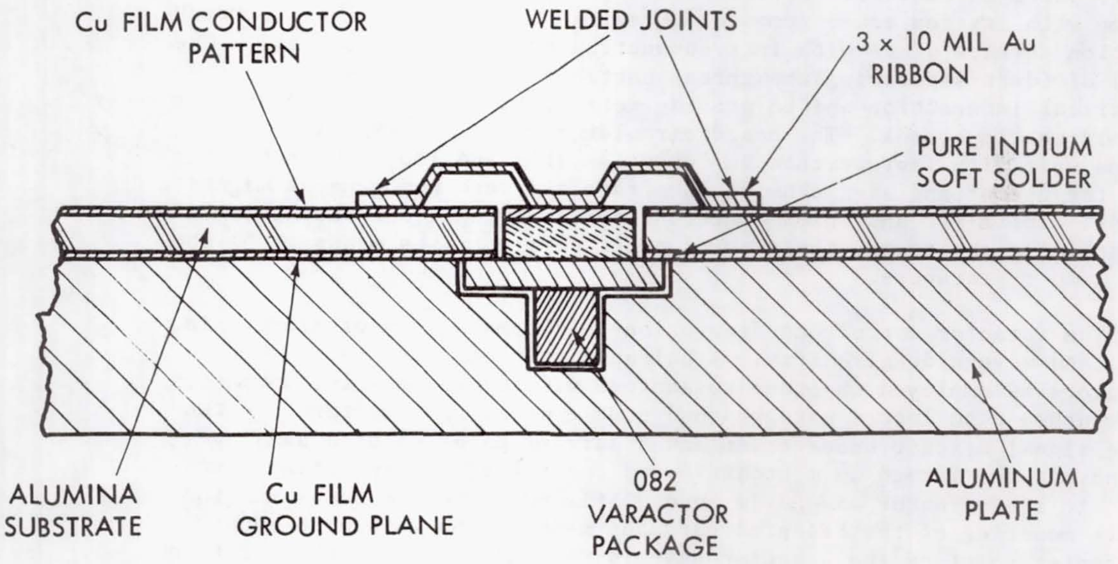


FIGURE 1



A - MICRO PILL (082) VARACTOR PACKAGE OUTLINE



B - SHUNT MOUNTING CONFIGURATION IN MICROSTRIP

FIGURE 2

iris, then through a commercial miniature waveguide ferrite isolator, and finally to the microstrip mounted varactor by means of a waveguide-to-coax probe adapter.

The mechanical package consists of a 2.5 inch by 2.25 inch aluminum frame which supports the microstrip board and the standard K_u-Band waveguide pump oscillator components which are attached to the aluminum frame along one of its edges. The package occupies a volume of approximately 6 cubic inches and weighs a little more than 9 ounces.

C-Band Paramp

The C-Band prototype paramp represents a true second generation development, inasmuch as the only major design changes from the S-Band unit were those which either corrected earlier deficiencies or improved the performance of the C-Band paramp or both. The areas in which these design changes were effected are; (1) the input-output circulator, (2) the varactor circuit configuration, (3) the varactor mechanical configuration, (4) the pump circuitry; and (5) the overall integrated packaging design.

To avoid the input VSWR problem encountered on the S-Band paramp and to improve the overall gain stability, a decision was made early in the design to employ a 5-port ferrite circulator composed of three 3-port units in cascade. Figure 3 is a photograph of the C-Band prototype paramp with its top cover removed. Clearly visible are the three "Wye" junction ferrite discs with interconnecting matching transformers. The metal dividers separating the three junctions serve both to prevent electrical interaction and to provide more rigid mechanical support for the microstrip boards. The basic circulator design is similar to the S-Band unit with improvements in insertion loss and isolation resulting from the use of unglazed alumina substrate and more homogeneous magnetic fields. The first and third junctions serve as input and output isolators, respectively, by having their third ports terminated by means of 50 ohm beam lead resistances.

The varactor circuit configuration is a combination of microstrip, coax, and waveguide circuitry. A balanced pair of Sylvania 5147E varactors is employed in order to achieve wide tuning and instantaneous bandwidth and to insure a rugged and stable mounting structure. A two-stage signal circuit transformer and a pair of parallel broadbanding resonators are formed in microstrip and connect the second stage circulator to the varactor waveguide mount. Figure 4 shows a cross section of the mounting of the balanced varactor pair in the waveguide mount. The center point of the varactor pair is coupled to the microstrip by a short length of high impedance coax transmission line that conveniently serves as the signal tuning inductance.

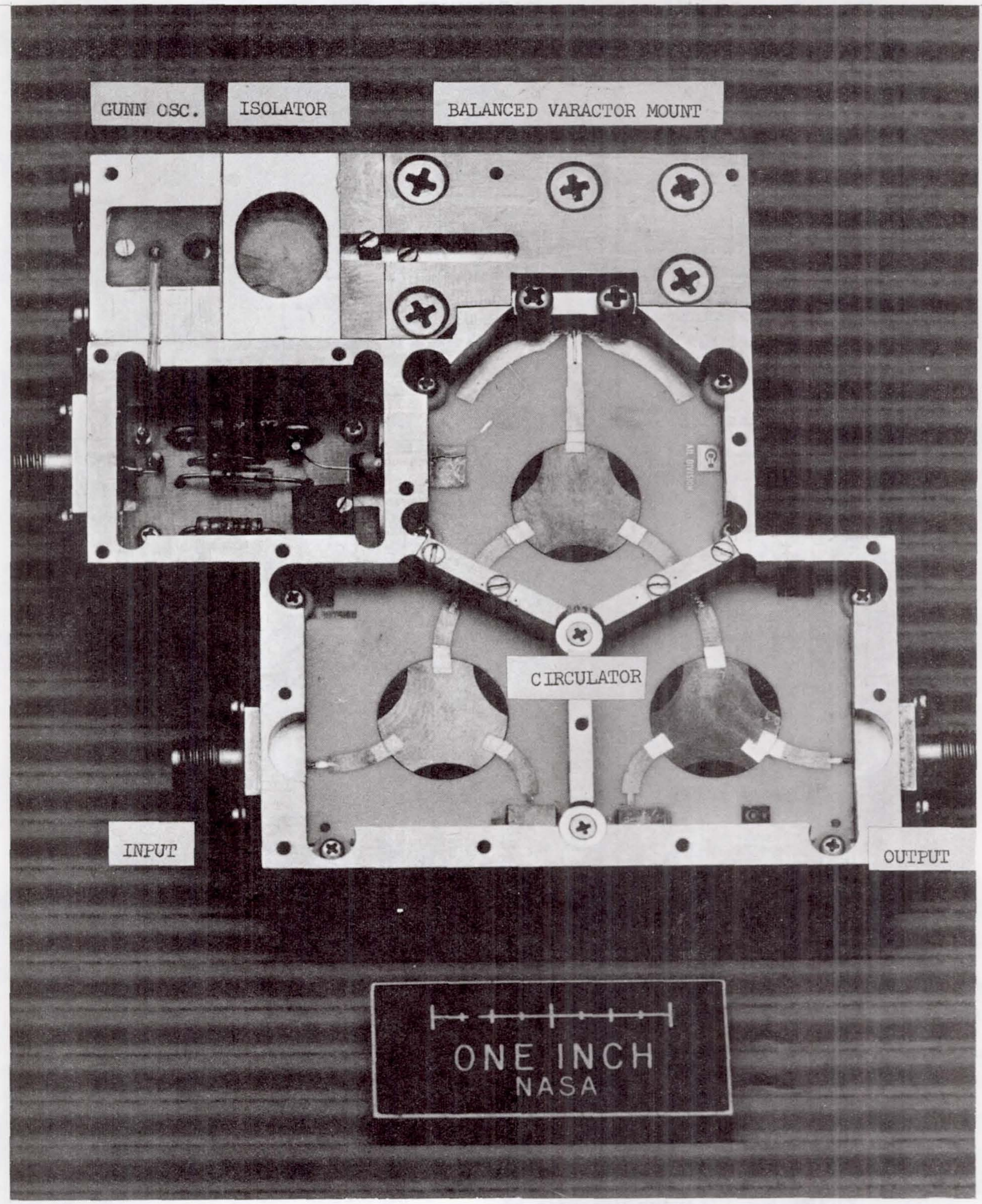

GUNN OSC.
ISOLATOR
BALANCED VARACTOR MOUNT
CIRCULATOR
INPUT
OUTPUT
ONE INCH
NASA

FIGURE 3

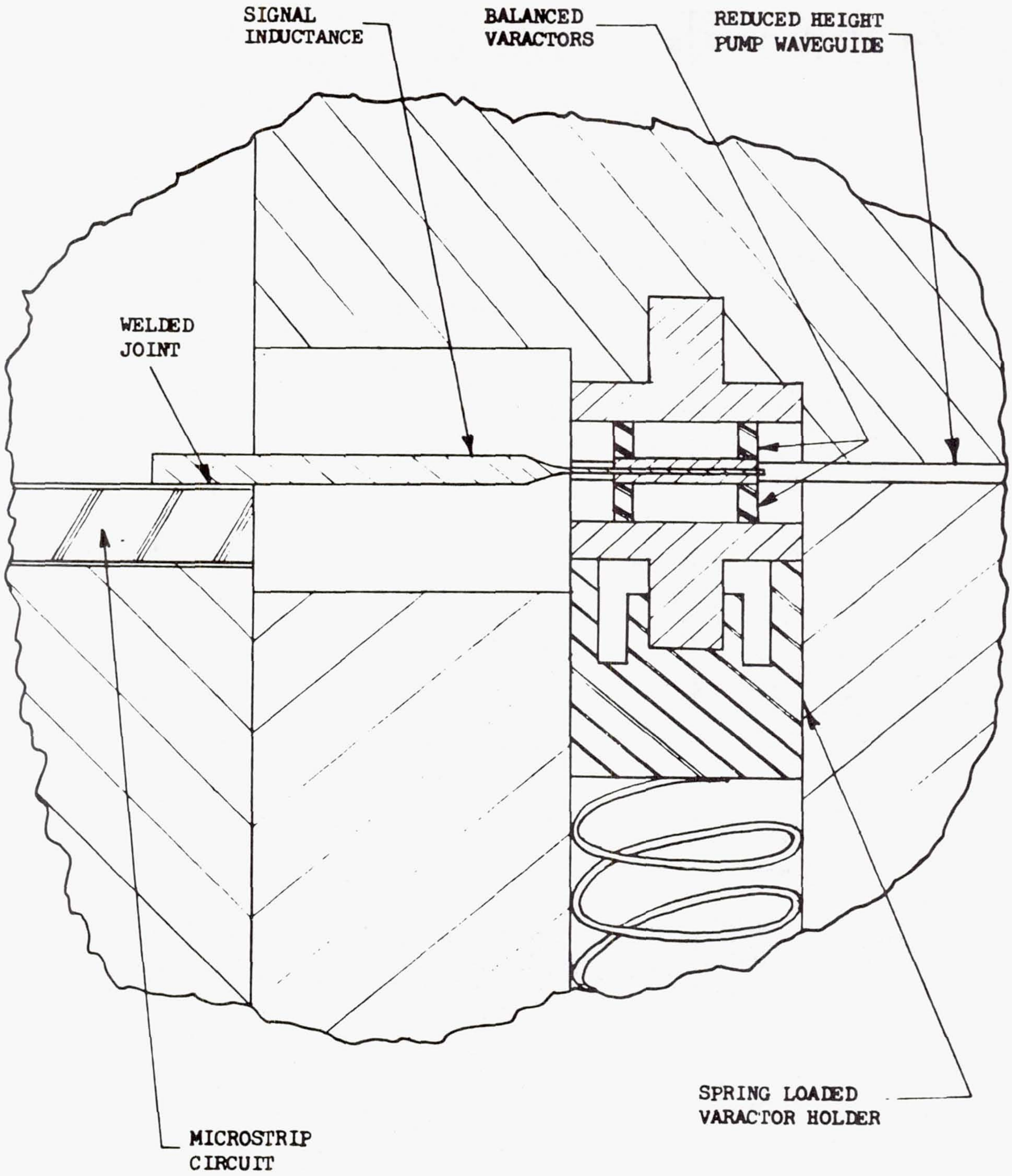


FIGURE 4 BALANCED VARACTOR MOUNTING CONFIGURATION

The back-to-back mounted varactors are operated so that their series self resonance form the idler circuit resonator required for parametric amplification. The pump waveguide is selected so that the idler frequency is below the cutoff of the guide, thereby confining the idler currents to the vicinity of the varactors. This enhances the bandwidth and eliminates the requirement of a lossy filter in the input line as is the case in a single ended configuration.

The pump section is composed of a cavity-mounted Gunn Effect oscillator, a coupling iris, a ferrite isolator, and a waveguide matching section. The Gunn oscillator is similar to the S-Band paramp oscillator except that the circuit is more simply tuned and consequently better behaved during initial turn-on. The commercially available Gallium Arsenide Gunn device used is supplied by Nippon Electric Company. The oscillator operates at 23.8 GHz which puts the idler frequency in the 20 GHz region. The selection of a higher pump frequency improves both the theoretical noise figure and bandwidth of the C-Band paramp as will become evident later.

The overall mechanical and electrical packaging represents a truly integrated design. Each component was designed to meet the required electrical performance while embodying a high degree of miniaturization and mechanical compatibility with the interrelated components. The basic unit is a milled-out aluminum frame with the varactor mount and pump components (also aluminum) attached along one edge of the frame. One-thirty-second inch thick aluminum plates cover both top and bottom to make a completely enclosed unit.

TEST RESULTS

The test results for the most important characteristics of the C-Band paramp are presented in Table 1. For the purpose of comparison, the S-Band paramp test results are also listed. The noise temperature measurement for both paramps was obtained by means of a very accurately calibrated hot and cold input termination setup. As can be seen from the table, the C-Band paramp meets or exceeds every major specification. Especially interesting is the 104°K noise temperature measured at 3.7 GHz. The theoretically minimum noise temperature contribution from a lossless varactor operating at a signal frequency of 3.7 GHz and an idler frequency of 20.1 GHz is

$$T = T_D \frac{F_s}{F_i}$$

where T_D = varactor physical temperature
F_s = signal frequency
F_i = idler frequency

	C-BAND		S-BAND
	SPECIFICATION	MEASURED	MEASURED
GAIN	17 DB	17 DB	15 DB
3 DB BANDPASS	75 MHZ	100 MHZ	120 MHZ
TUNING RANGE	3.7 GHZ - 4.2 GHZ	3.7 GHZ - 4.2 GHZ	2.25 GHZ FIXED
NOISE TEMP.	170 °K	104 °K at 3.7 GHZ 150 °K at 4.2 GHZ	139 °K
INPUT VSWR	1.5 to 1	1.3 to 1	4 to 1
1 DB COMPRESSION	-50 DBM	-35 DBM	- 38 DBM
GAIN STABILITY	± 1.0 DB/ 8 HRS.	± 0.1 DB/ 8 HRS.	± 0.2 DB/ 8 HRS.
WEIGHT	12 OUNCES	7 OUNCES	9 OUNCES
VOLUME	6 CUBIC INCHES	6 CUBIC INCHES	6 CUBIC INCHES
POWER CONSUMPTION	-----------	4 WATTS	4 WATTS

TABLE 1

TEST RESULTS FOR C-BAND AND S-BAND SPACECRAFT PARAMPS

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Figure 5

Inserting $T_D = 293^oK$, $F_s = 3.7$ GHz, and $F_i = 20.1$ GHz,

$$T = 54^oK$$

Using a circulator loss of 0.2 dB per pass or 0.4 dB total loss through 2 passes, the theoretically minimum paramp noise temperature calculates out to be 88.8^oK. The measured value of 104^oK compares quite favorably with the theoretical value with the difference due to finite losses in the varactor and some heating of the varactor by pump power.

The areas of major improvement of the C-Band paramp over the S-Band paramp are lower noise temperature, greatly improved input VSWR, improved stability, and lower volume and weight. The improved mechanical packaging is depicted in Figure 5 which is a photograph of the C-Band paramp and the S-Band paramp side-by-side.

CONCLUSION

The C-Band Spacecraft prototype paramp represents a significant improvement over the first generation S-Band paramp. The performance deficiencies of the latter have been entirely eliminated in the former by both electrical and mechanical redesign of several critical areas. The C-Band paramp program has now entered its second phase. This phase will extend the prototype design to the development and testing of a space qualified unit.

A program under TDRS funding for the development of a K_u-Band prototype spacecraft paramp is now nearing completion. Preliminary test results thus far indicate the following performance can be expected:

Gain	-	17 dB
3 dB BW	-	500 MHz
Bandpass	-	14.7 GHz to 15.2 GHz
Noise Figure	-	4 dB
Volume	-	6 cubic inches
Weight	-	12 ounces
Power	-	5 watts

This unit will be extended to a completely space qualified unit under Space Shuttle programming.

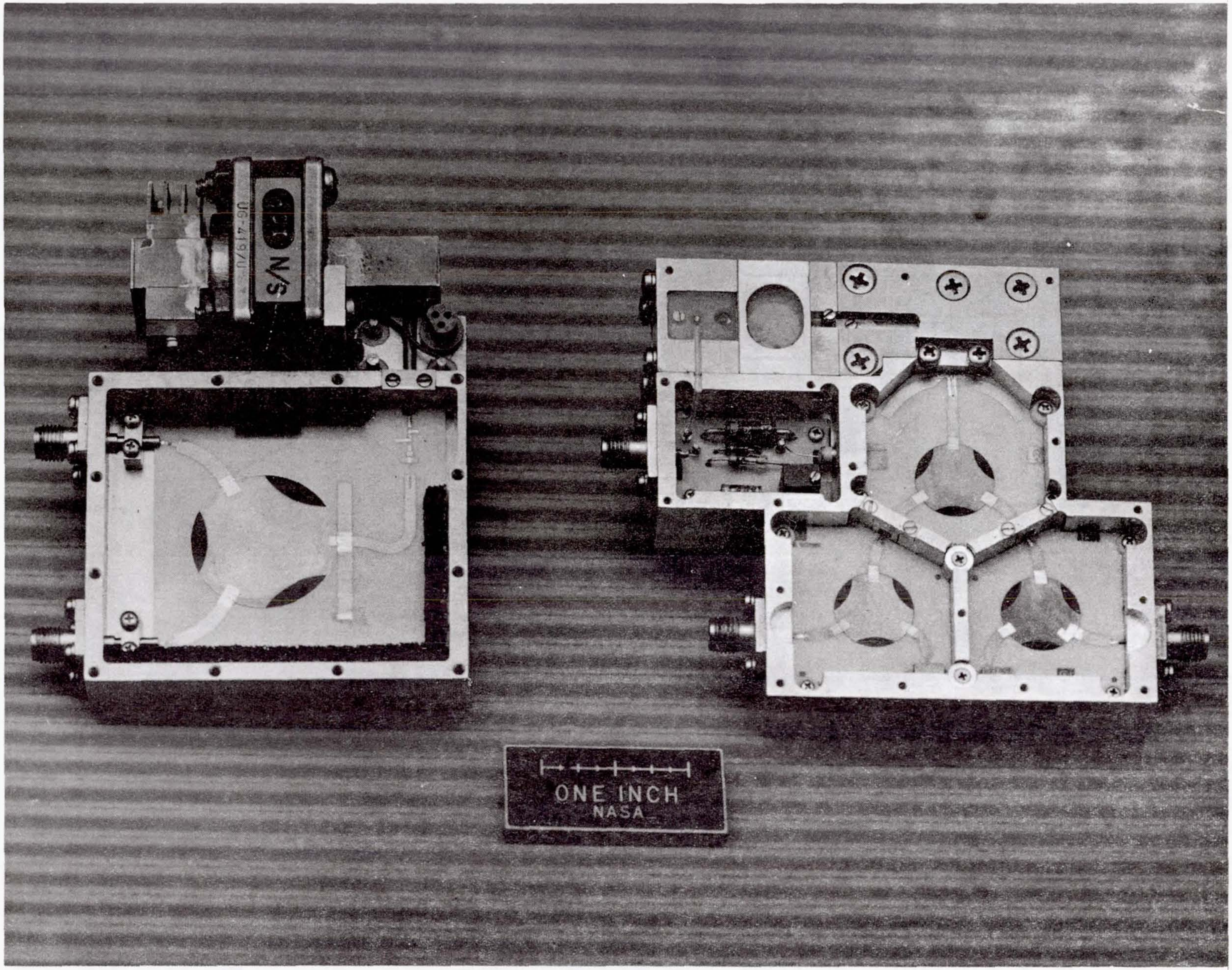

FIGURE 5