LOW NOISE, 94 GHz PARAMETRIC AMPLIFIER DEVELOPMENT

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Abstract

This paper describes the development of a 94 GHz non-degenerate parametric amplifier, the first of its kind. Included in this discussion is a description of the evolution of the state-of-the-art high-quality varactor, circulator and millimeter-wave circuit technology necessary for low noise 94 GHz paramp realization. Finally, a description of the physical embodiment of the overall 94 GHz paramp is presented along with relevant measured performance data.

Introduction

The increasing interest in the 94 GHz low atmospheric attenuation "window" for high resolution radar and radiometry, and for wideband, high data rate communications links has prompted the consideration of low noise 94 GHz parametric amplification employing latest millimeter and solid state technologies as a means of improving the noise performance of even the best 94 GHz mixer/microwave IF amplifier superheterodyne receiver presently utilized. Accordingly, this paper will describe a program* to develop the technology requisite to the realization of a feasibility model 94 GHz nondegenerate parametric amplifier, and to design, fabricate and evaluate said model.

Theoretical 94 GHz Paramp Performance

Two modes of parametric amplifier operation[1] applicable to low noise reception at 94 GHz are, for input signal passband $f_s^- \leq f_s \leq f_s^+$ and pump frequency f_p, the nondegenerate, single-sideband ($f_p > 2 f_s^+$ or $< 2 f_s^-$) and the quasi degenerate, double-sideband ($f_p = f_s^+ + f_s^-$) modes, the former being applicable to coherent radar and communications reception and the latter to radiometric (broadband noise) reception

For both the nondegenerate and degenerate configurations, the theoretical performance[1] of a generic 94 GHz parametric amplifier, is significantly constrained by limitations on device and circuit technology at millimeter and submillimeter frequencies. This is exemplified by representative theoretical performance curves depicting paramp noise temperature and bandwidth in terms of pump and varactor cutoff frequencies, as presented in Figures 1 and 2.

Theoretical analysis shows[1] (Figures 1 and 2) that the realization of reasonably low noise ($\leq 1000°$K SSB or DSB at room ambient) broadband (≥ 2 GHz half-power bandwidth) performance requires nondegenerate pump, varactor cutoff and varactor series and/or parallel idler self resonant frequencies of greater than 150, 600 and 55 GHz, respectively and CW pump power levels of greater than 10 to 40 mW for f_p increasing from 150 to 300 GHz

Therefore, the demonstration of parametric amplification at 94 GHz, necessitates the development of state-of-the-art varactor, circulator, millimeter wave structure and pump source technology, as will be described in the following paragraphs.

94 GHz Paramp Device and Component Considerations

A. Varactor Realization

The one key element that is essential to the realization of a low noise 94 GHz parametric amplifier is a state-of-the-art varactor which is several times higher in cutoff frequency and lower in parasitic content than the best commercially available units and which have been previously demonstrated in but a few laboratories[2,3]. Accordingly, the previously enumerated requirements have led to the development of ultra-high quality chip varactors having preliminary measured values of operating-bias junction capacitance and cutoff frequency $C_j < 0.1$ pF and $f_{cj} > 600$ GHz and parasitic series inductance and shunt capacitance $L_s < 0.1$ nH and $C_p < 0.05$ pF, respectively, as exemplified by the mounted varactor equivalent circuit of Figure 3.

In addition, for a typical reduced height 94 GHz waveguide cavity chip varactor mounting geometry, the above values and preliminary estimates of mounting parasitics (Figure 3) indicate the ability to accommodate idler and pump frequencies of about 55-145 and 150-240 GHz respectively, with their final choice dependent on pump source availability.

B. Circulator Realization

The requirement for a low-loss three-port 94 GHz signal frequency coupling circulator for the 94 GHz paramp is most readily met by the utilization of an H-plane wye-junction circulator, with a partial height ferrite post at its center. Such a circulator has been successfully realized in the 85 to 100 GHz frequency range as part of the 94 GHz paramp development effort, as described in detail in a separate paper.[4] Fabricated in WR-10 waveguide, it typically exhibited 0.5 to 1 dB insertion loss, 23 to 30 dB maximum isolation and 3 to 5 GHz, 20 dB isolation bandwidth, centered in the 85-100 GHz frequency range, with midband frequency dependent upon choice of ferrite and transformer dimensions.

C. Pump Source

The alternatives available in the realization of a CW pump source in the 150-300 GHz range with the required 10-40 mW power output capability are:

- Fundamental frequency klystron (50 to 10 mW at 150 to 200 GHz and BWO (≈ 1 watt at 150-300 GHz), with the former preferred on the basis of its superior spectral purity
- Lower frequency (75-150 GHz) klystron combined with high efficiency varactor doubler (150-10 mW at 150-300 GHz)
- Fundamental Si IMPATT oscillator (> 50 mW at 130 GHz) current laboratory state-of-the-art not sufficient for paramp pumping at > 150 GHz but further development is in progress
- Lower frequency Si IMPATT combined with N-th order (N = 2, 3, or 4) varactor multiplier (using same ultra high quality chip varactors as in paramp proper) can yield about 150 to 10 mW at 150 to 300 GHz.
- Subharmonic pumping[5] (at $\frac{f_{so} + f_{io}}{m}$) has its drawbacks, but is under consideration.

Whereas a solid state pump source is ultimately preferable, a tradeoff analysis on the nondegenerate 94 GHz paramp feasibility model between paramp performance, varactor self-resonance capability and pump source availability led to the choice of a fundamental commercially available, 25 mW, 170 GHz klystron as the pump source.

Overall 94 GHz Paramp Realization

On the basis of the preceding discussion, a single-stage, circulator-coupled nondegenerate 94 GHz paramp feasibility model was designed and fabricated utilizing a 170 GHz pump source and a single-ended chip varactor embedded in a waveguide cavity which was below-cut-off at the 76 GHz idler series resonance.

The physical implementation of the 94 GHz paramp model utilizes a combination of different fabrication techniques (including electroforming and split-block machining) to achieve the tight dimensional tolerances associated with the small waveguide sizes and the high degree of surface finish and tight coupling joints necessary to minimize

*This effort was supported by the Air Force Avionics Laboratory under Contract No. F33615-72C-1749 and under the cognizance of R. Runnels and D. McLaine, whose guidance is gratefully acknowledged.

circuit losses. Accordingly, the structural details of the paramp model, embodied in a modular "building block" dominant (TE_{10}) mode rectangular waveguide in-line configuration are depicted conceptually in Figure 4, and in the photographs of Figures 5 and 6.

It is seen therein that the 94 GHz paramp model consists of the in-line combination of the following components:

- WR-10 waveguide three port H-plane wye junction circulator.
- WR-10 waveguide dual quarter-wave signal circuit transformer.
- Resonant iris-coupled varactor mounting cavity which incorporates the GaAs chip varactor and the coaxial RF-isolated DC bias entry, and which is fabricated in reduced height WR-7 waveguide.
- WR-5 waveguide single quarter-wave transformer which interfaces with the 170 GHz klystron pump source.

Detailed data will be presented on the measured performance of this 94 GHz parametric amplifier model.

References

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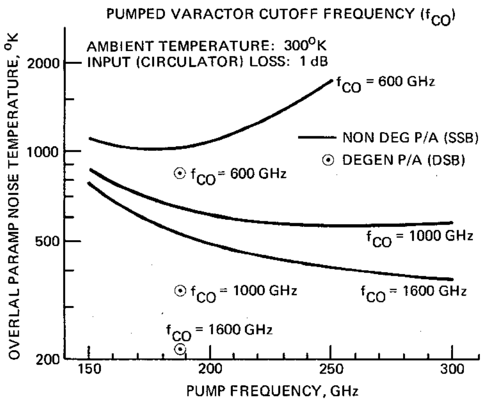


FIG. 1 THEORETICAL NOISE TEMPERATURE OF 94 GHz PARAMP

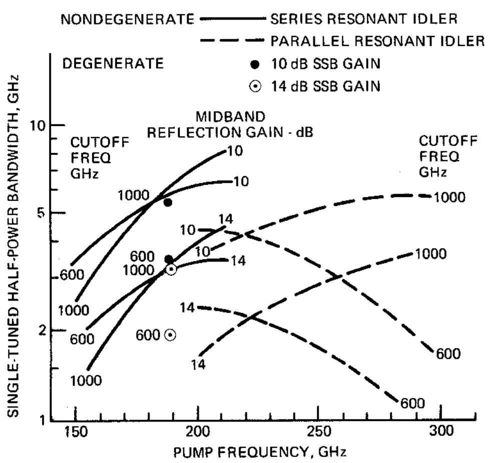
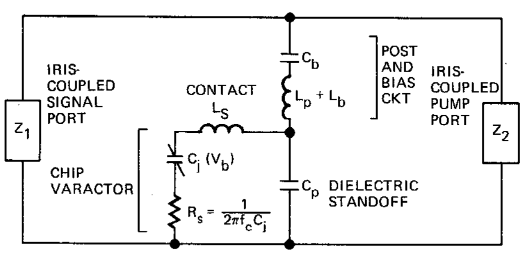


FIG. 2 THEORETICAL BANDWIDTH CAPABILITY OF 94 GHz PARAMP



$C_j\,(V_b) \approx 0.03\text{-}0.1$ pF, $C_p \approx 0.03\text{-}0.06$ pF, $C_b \approx 0.15\text{-}0.3$ pF

$f_c \approx 600\text{-}1600$ GHz, $L_S \approx 0.03\text{-}0.06$ nH, $L_p + L_b \approx 0.06\text{-}0.1$ nH

FIG. 3 CIRCUIT MODEL OF WAVEGUIDE - MOUNTED CHIP VARACTOR

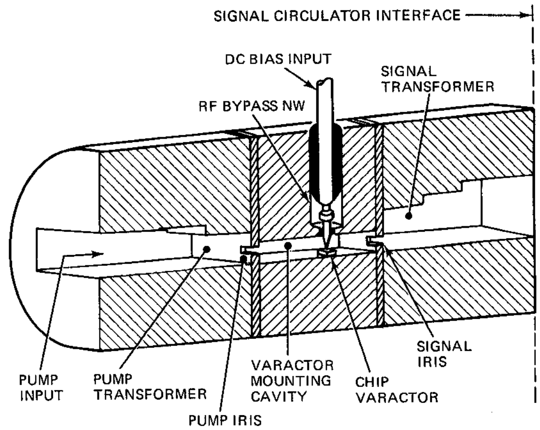


FIG. 4 CUTAWAY VIEW OF 94 GHz PARAMP MOUNT

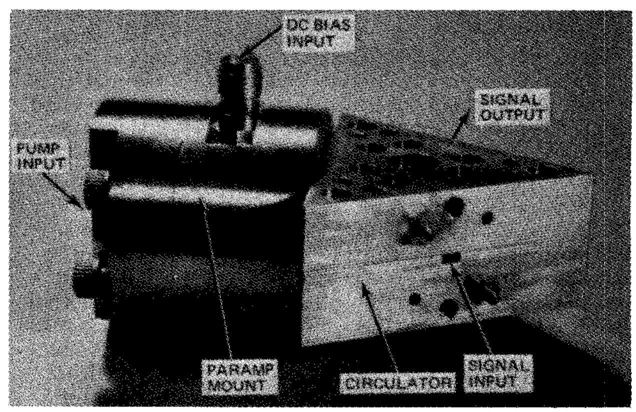


FIG. 5 PHOTOGRAPH OF 94 GHz PARAMETRIC AMPLIFIER

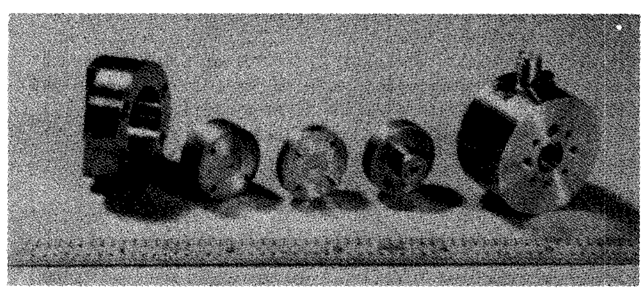


FIG. 6 PHOTOGRAPH OF 94 GHz PARAMP MOUNT (EXPLODED VIEW)