VARACTOR FREQUENCY DOUBLERS AND TRIPLERS FOR THE 200 TO 300 GHz RANGE

by

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ABSTRACT

An advance in the state-of-the-art of millimeter wave solid-state sources has been achieved with the development of a frequency tripler to 300 GHz with an output level of 2 mW. A frequency doubler to 200 GHz with an output power level of 10 mW has also been developed and tested. Efficient multiplication has been obtained by use of a new AIL high cutoff frequency varactor and specially developed circuit techniques.

Introduction

The practical utilization of the 200 to 300 GHz region of the spectrum for applications in the fields of communications, radio astronomy, and spectroscopy have heretofore been limited by the availability of solid-state sources with suitable output power level. For the first time, a solid-state source has been developed and tested which has an output frequency of 300 GHz and a cw output power level of 2 mW. The source consists of a varactor frequency multiplier in a tripler configuration. Doublers have also been developed and tested which deliver an output power of 10 mW at 200 GHz. These state-of-the-art multipliers use high cutoff frequency varactors made by AIL in conjunction with specially developed multiplier circuits which will be delineated.

Multiplier Design

The frequency multiplier to 300 GHz was designed as a tripler rather than as a doubler due to the lack of an input driver at 150 GHz (solid-state or thermionic) with a suitable output level. The design of the tripler is based on the model shown in Figure 1. The generator in Figure 1B represents an internal source at frequency $n\omega_0$ in the multiplier model of the varactor. The resistance R is the theoretical value of loading which is required at internal points 1-1 of the varactor and its value at input frequency (100 GHz) and output frequency (300 GHz) was obtained from the design data presented.[1] The elements R' and X' at 100 and 300 GHz are synthesized by using a combination of waveguide sections of different characteristic impedance and electrical length.

The first model of the multiplier was designed in sectionalized form to provide an experimental device which was amenable to a developmental approach for both doubler and tripler configurations. Figure 2 shows an assembled tripler. The various sections are assembled in a compression-type holder with dowel pins ensuring accurate alignment of the sections. The mount for the varactor is a section of double ridge waveguide. A demountable type construction was used for the varactor mount in the experimental model as it provides easy access to the waveguide embodiment of the varactor and bias circuit and permits circuit modifications to be readily made at the diode proper. The loss of this mount at 100 GHz was measured to be 1.8 dB.

Another multiplier design is based on a quasi-optical monopole approach. Figure 3 shows a 100 to 200 GHz doubler using this configuration. The design concept is based on the fact that a monopole antenna is an ideal transformer from a plane wave in a high impedance (400 to 600 ohms) medium, such as oversized waveguide, to a lower impedance (5 to 10 ohms) TEM two-terminal device such as a multiplier varactor. The monopole length-to-diameter ratio is chosen to provide the required impedance levels at the fundamental and harmonic for efficient operation. One advantage of the quasi-optical approach is that multiplier power-handling capacity can readily be increased by using multiple junctions on the semiconductor chip. This was demonstrated with a two varactor array on a single chip, shown in Figure 3, which was built and tested. Each varactor has its own monopole and the two monopoles constitute a two-element broadside array. Tuners are used at the input and output to provide adjustment of the circuit loading for best efficiency.

Results

Measurements at 300 GHz require special considerations since commercial test components are not available in this frequency range. The output frequency was measured with a commercial G-band (140 to 220 GHz) frequency meter whose calibration was extended to 300 GHz and was verified with a set of cutoff waveguide test sections. Power measurement at 300 GHz was made with a previously developed AIL broadband thermal detector which has a usable response from 1 micrometer to 4 millimeter wavelength. It was calibrated in the infrared region with a black body source and at 100 GHz by use of a commercially available calorimeter.

The dominant mode, double ridge type multiplier and the quasi-optical monopole type multipliers were each tested in both a tripler and doubler configuration. As a tripler, best performance to-date was achieved with the dominant-mode type multiplier which gave an output power of 2.1 mW at 300 GHz. The input power at 100 GHz was 150 mW and tripler efficiency was 1.4 percent. Input power was supplied by a klystron although, in the present state of the art, a solid-state source (Impatt diode oscillator) could be used. As a doubler to 200 GHz with the same mount and varactor, this multiplier type gave an output power of 10.2 mW at an input power level of 90 mW, corresponding to an efficiency of 11.4 percent. The maximum efficiency was 12.3 percent and occurred at an input level of 67 mW. Figure 4 shows the output power and efficiency as a function of input power.

The performance obtained with the quasi-optical monopole doubler configuration (Figure 3) is shown in Figure 5. The varactors were operated in a self-biased mode. The multiplier gave an output power of 10.5 mW at 200 GHz and the characteristic shows that saturation had not been reached at the maximum applied input drive of 252 mW. The input bandwidth at the half-power output points was 500 MHz. Improvements in the input/output matching network and the use of recently developed higher cutoff varactors are expected to improve the efficiency to the levels achieved in the double-ridge multiplier circuit.

Figure 6 shows cutoff frequency measurement data taken at 100 GHz on the AIL varactor in the double ridge multiplier mount. The determination of cutoff frequency was made by the procedure described by Sard.[2] The zero bias capacitance of the varactor was 0.075 pF and the cutoff frequency was determined to be 715 GHz at zero bias.

Summary

The design and performance of developmental solid-state sources for the 200 to 300 GHz frequency range has been described. The output power levels achieved to-date make these sources suitable for signal source and local oscillator applications. Based on the use of an electroformed construction rather than the sectionalized configuration used for the experimental multipliers and the realization of zero bias cutoff frequencies of 1000 GHz with AIL varactors presently being developed, it is expected that 30 mW minimum at 200 GHz and 10 mW minimum at 300 GHz will be achieved with these multiplier types in single varactor configurations. These sources would be suitable for use as a pump for a parametric amplifier. Higher output levels would be possible with multipliers containing a plurality of varactors as was demonstrated with the two varactor monopole multiplier.

Acknowledgements

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References

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2. E. Sard, "A New Procedure for Calculating Varactor Q From Impedance Versus Bias Measurements," IEEE Trans. Microwave Theory and Techniques, Vol MTT-16, No. 10, p 849-861, October 1968.

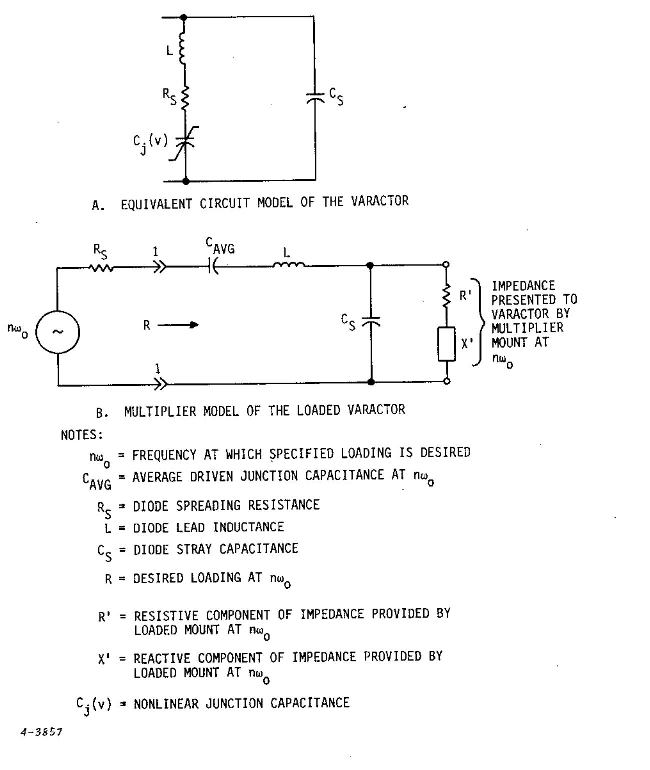

Figure 1. Design of the Tripler

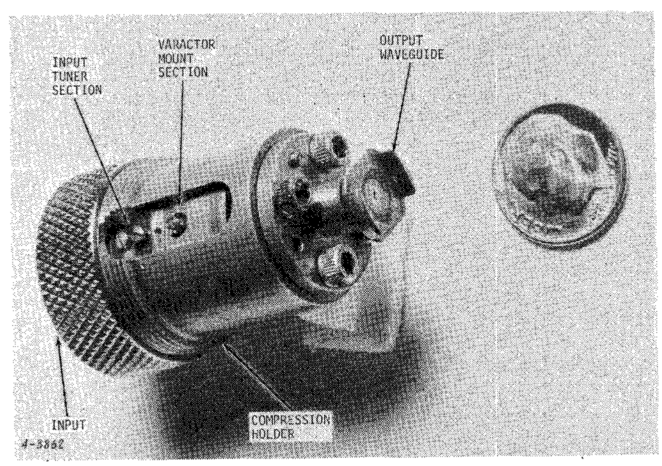

Figure 2. Assembled 100 to 300 GHz Tripler

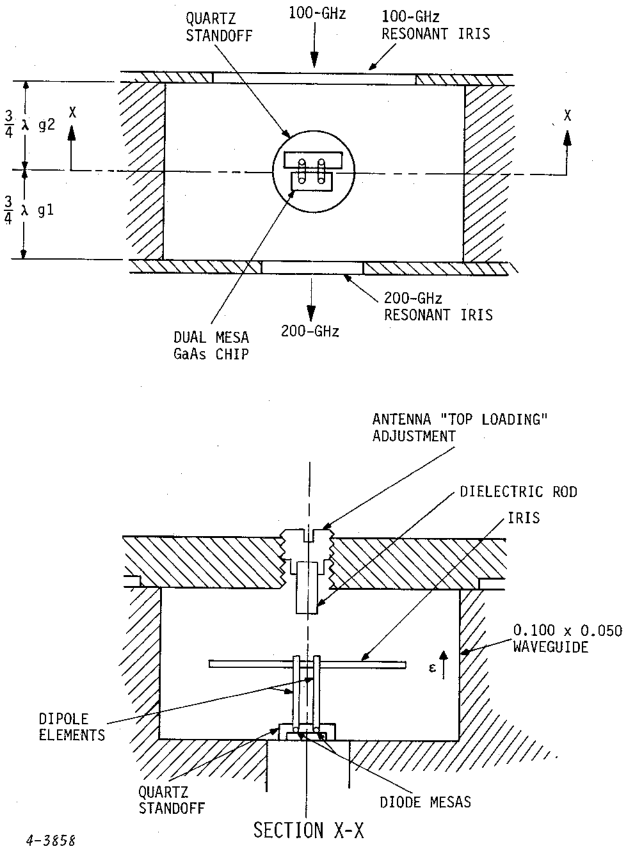

Figure 3. Monopole Quasi-Optical Doubler

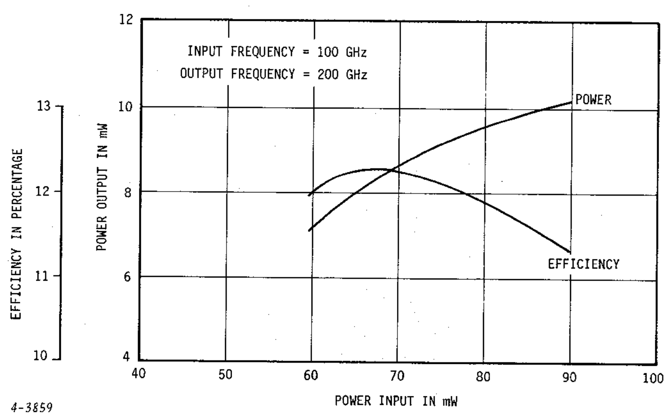

Figure 4. Power Output and Efficiency of Fundamental, Double Ridge Type Multiplier with AIL Varactor

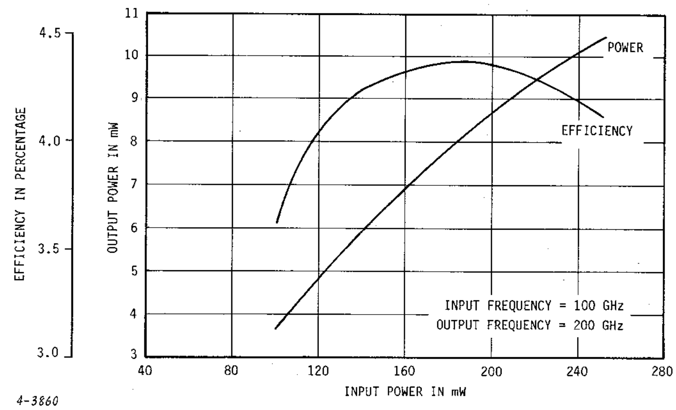

Figure 5. Quasi-Optical Monopole Doubler with Two AIL Varactors and Monopoles

MEASUREMENT FREQUENCY = 100 GHz
$C_{J(0)}$ = 0.075 pF
$F_{C(0)}$ = 715 GHz

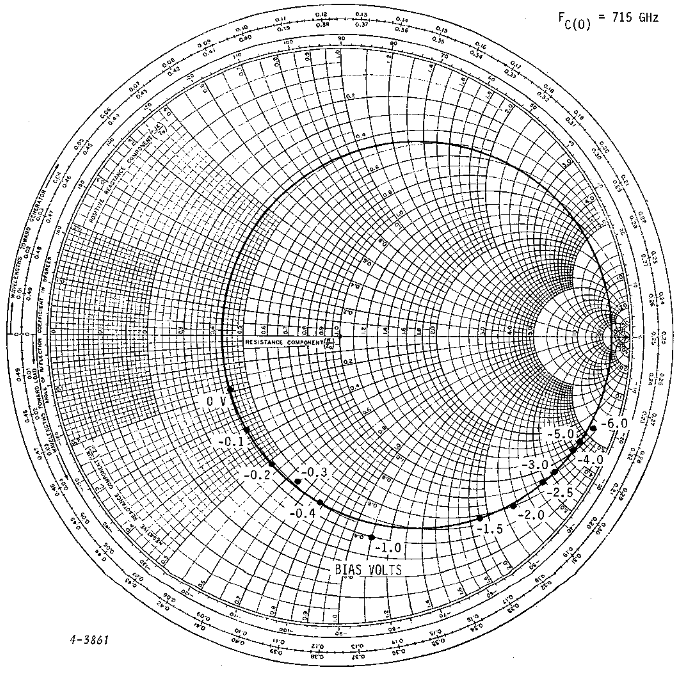

Figure 6. Cutoff Frequency Measurement Data for AIL Varactor in Double Ridge Mount of 300 GHz Multiplier