A High Performance Frequency Doubler for 80 to 120 GHz

J. W. ARCHER

***Abstract*—A frequency doubler for the 80- to 120-GHz output band is described. The device may be operated in either a fixed-tuned or a tuneable mode. When operated fixed-tuned, with a constant dc bias applied to the diode, the conversion loss for any output frequency between 80 and 120 GHz is 9.2 dB, ±1.2 dB. When used so that tuning and bias are optimized at each operating frequency, the doubler exhibits conversion loss less than 7.5 dB for any frequency between 90 and 124 GHz.**

I. Introduction

Millimeter-wave frequency doublers provide a low-cost, reliable alternative to fundamental frequency reflex klystrons as local oscillator sources for heterodyne receivers. The design of the doubler for the 80- to 120-GHz band, described in this paper, was based on devices constructed for higher operating frequencies [1], and incorporates improvements based on experience with these higher frequency versions. In particular, the fixed-tuned, fixed-bias operation of the doubler has been improved to provide useful performance over a full waveguide bandwidth without mechanical adjustment.

II. Mount Design

The split-block, crossed-waveguide mount, shown in Fig. 1, is a modified, scaled version of that used for the higher output frequency devices [1]. Pump power, incident in the full height WR-15 input waveguide is fed, via a waveguide to stripline transition, to a suspended substrate stripline low-pass filter, fabricated on 0.076-mm-thick crystalline quartz. The seven-section filter passes the fundamental frequency with low loss, but is cutoff for higher order harmonics. The low-pass filter also transforms the impedance of the pumped varactor at the input frequency to a convenient value at the plane of the waveguide to stripline transition.

Pump circuit impedance matching is achieved using two adjustable waveguide stubs with sliding contacting shorts. One stub acts as a backshort for the probe-type waveguide to stripline transition and a second as an E-plane series stub, located 4.95 mm (approximately $\lambda_g/2$ at 100 GHz) towards the source from the plane of the transition. For narrow-band operation of the doubler at any pump frequency between 40 and 62 GHz, the tuning configuration employed allows the pump circuit to be matched with a VSWR of 1.10:1 or better. When broad-band operation is desired, appropriate fixed positioning of the shorts results in VSWR of less than 2.0:1 over the same bandwidth.

The varactor diode chip, mounted in the half-height WR-8 output waveguide, is contacted by a 0.013-mm diameter, gold-plated phosphor-bronze whisker. The mount is matched to the impedance of the diode at the second harmonic of the pump with the aid of an adjustable contacting backshort in the reduced height guide.

A quarter-wave, three-section, step impedance transformer is used to couple the half-height guide to the full-height output guide. Extensive evaluation of the performance of higher frequency doubler mounts has shown that the design of this transformer, and its position relative to the diode plane, have a significant effect on the broad-band frequency response of a given doubler mount. At frequencies significantly higher than the normal guide operating range, the steps in waveguide height in the transformer excite nonevanescent, higher order waveguide modes in the output guide. The spurious mode coupling influences the mount embedding impedance seen by the diode at the third and higher harmonic and can result in degradation of the doubler performance at frequencies where the harmonic terminations are lossy in nature. The mount described here incorporates an empirically optimized transformer design (dimensions shown in Fig. 1), which results in improved, broad-band fixed-tuned doubler performance when compared with devices reported previously [1].

DC bias is brought to the diode via a transmission line bias filter. The outer shield of the bias line is a 0.25-mm-wide channel of square cross section milled into the surface of one of the blocks forming the mount. The center conductor is a length of 0.025-mm-diameter gold wire bonded at one end to a low impedance section of the low-pass filter. The line is then connected to a 100-fF metallized quartz dielectric bypass capacitor which is epoxied in a recess located 1.50 mm from the connection to the

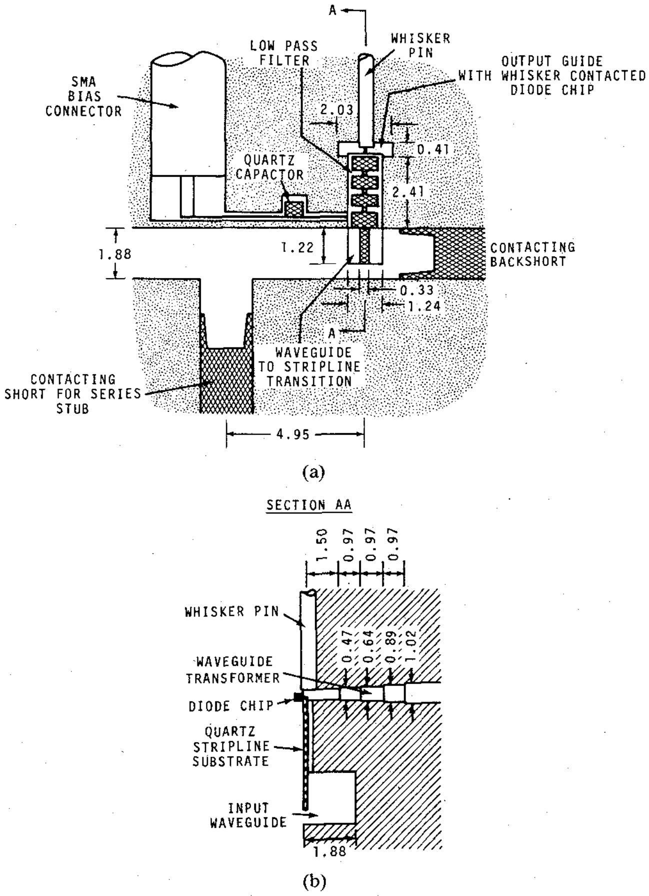

Fig. 1. (a) Schematic diagram showing the main features of the split-block, crossed-waveguide doubler for the 80–120-GHz band. All dimensions in millimeters. (b) Section showing waveguide transformer details.

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The author is with the National Radio Astronomy Observatory, 2015 Ivy Road, Charlottesville, VA 22903.
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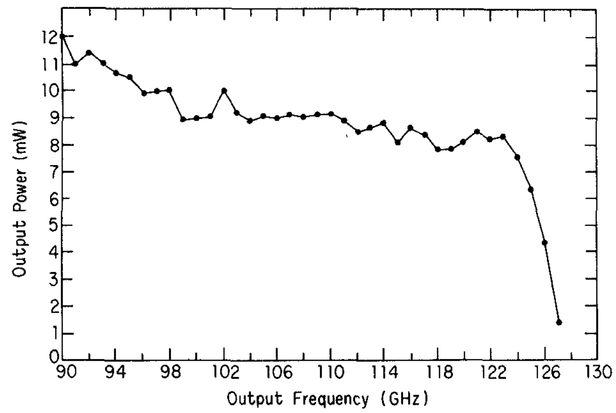

Fig. 2. Doubler performance between 90 and 130 GHz when tuning and bias are optimized at each operating frequency. Constant pump power of 50 mW.

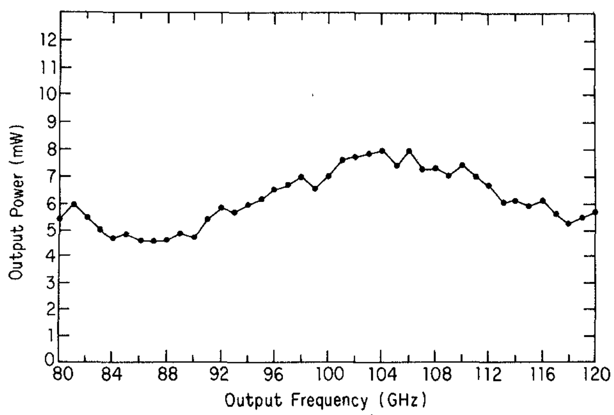

Fig. 3 Doubler performance between 80 and 120 GHz when tuning and bias are held fixed. Constant pump power of 50 mW.

low-pass filter. The line terminates on the center pin of the SMA bias connector. The section of bias line between capacitor and filter approximates, at 100 GHz, a quarter-wave short circuited stub of 140-Ω characteristic impedance.

The varactor diodes used in these devices are notch front GaAs Schottky-barrier diodes supplied by the University of Virginia. The epilayer doping is 2.6×10^{16} cm^{-3} and the epilayer thickness is 1.5 μm. The diode anode diameter is 5 μm, resulting in a zero bias capacitance of 21 fF, a dc series resistance of 8 Ω and a reverse breakdown voltage of 14.5 V. For reverse voltages of up to 12 V, the capacitance-versus-voltage law for these devices closely follows the inverse half-power law typical of abrupt junction varactors.

III. Performance

When tuning and bias are optimized at each frequency, the output power response shown in Fig. 2, as a function of output frequency with constant pump power of 50 mW, is obtained. Minimum conversion efficiency is 18 percent for output frequencies between 90 and 124 GHz. Typically, the bias voltage for optimum performance is in the reverse direction and of about 4-V magnitude. The rapid decrease in efficiency above 124 GHz is due to the high frequency cutoff of the pump circuit stripline low-pass filter. The doubler is capable of operating continuously without performance degradation at pump powers less than or equal to approximately 80 mW. Conversion efficiency changes by less than 1 percent at any frequency for pump powers greater than 40 mW, but below this power level the output power is approximately proportional to the square of the pump level.

The results shown in Fig. 3 were obtained with the doubler tuning fixed for both pump and output circuits. The dc bias supply was operated as a constant (3.0 mA) forward current sink. Under this condition, the reverse voltage applied to the diode varied between 2 and 6 V as the frequency was changed. Between 80- and 120-GHz output frequency with constant 50-mW pump power, the median conversion efficiency is 12 percent, with a total variation of less than 2.5 dB over this frequency range.

IV. Conclusion

An improved millimeter-wavelength frequency doubler has been described. The device exhibits good fixed-tuned broad-band performance, with a minimum output power of 4.2 mW, for 50-mW pump power, at any output frequency in the range 80 to 120 GHz. Maximum total variation in output power over this range is less than 2.5 dB when the pump power is held constant. The improvement in broad-band performance is attributed, firstly, to modifications made to the pump-frequency matching circuitry, with the addition of a series tuning stub and altered waveguide to stripline transition geometry. Secondly, empirical studies of the relationship between output waveguide impedance transformer dimensions and doubler performance gave rise to an improved transformer design which optimizes the effects of spurious mode coupling on broad-band conversion efficiency. Doublers similar to the unit described have operated reliably and continuously in operational receiver systems at the National Radio Astronomy Observatory for more than 10000 hours without failure.

Acknowledgment

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Spectral Domain Analysis of a Hexagonal Microstrip Resonator

ARVIND K. SHARMA, MEMBER, IEEE, and WOLFGANG J. R. HOEFER, SENIOR MEMBER, IEEE

***Abstract*—The capacitance of an open regular hexagonal microstrip resonator is calculated with the quasi-static spectral domain technique. From the capacitance values, the effective hexagon side and the effective dielectric constant are determined, yielding resonant frequencies which agree well with measured values. Numerical data for several dielectric**

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The authors are with the Department of Electrical Engineering, University of Ottawa, Ontario, K1N 6N5, Canada.

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