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A SUBMILLIMETER WAVE QUASI-OPTICAL FREQUENCY DOUBLER

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ABSTRACT

A 600 GHz source has been developed as the local oscillator for a submillimeter heterodyne radiometer. A quasi-optical Fabry-Perot interferometer is used to diplex the input and output frequencies while waveguide is used for the diode circuit.

Introduction

A 600 GHz source having an output power of about 50 μW has been developed as the local oscillator for a submillimeter wavelength heterodyne radiometer. The device, a frequency doubler from 300 to 600 GHz, consists of a varistor GaAs Schottky diode in a single-ended waveguide mount and a quasi-optical frequency diplexer. It is easily fabricated and could be scaled to operate at frequencies up to about 1000 GHz.

Multiplication of lower frequency sources provide the most practical local oscillator sources for submillimeter wavelengths. Ideally, these sources are characterized by output power adequate for pumping mixers, low noise, and tuneability. Fundamental sources with powers of about 10-100 mW are available to frequencies of about 200 GHz in the form of klystrons and to about 350 GHz in the form of carcinotrons. (Higher frequency carcinotrons are being developed but are not yet readily available.) Above 350 GHz the only fundamental sources are lasers which are unwieldy and not easily or continuously tuneable.

We have drawn on two different technologies to implement the frequency doubler design. Submillimeter waves are at the short wavelength end of the microwave region in which the dimensions of circuit elements are comparable to the wavelength involved and guided wave transmission line structures (coax, waveguide, stripline, and microstrip) play a dominant role in circuit implementation. Submillimeter waves are also at the long wavelength end of the optical region in which electromagnetic waves propagate in free space between optical surfaces (mirrors, lenses, and beam splitters) whose dimensions are much larger than the wavelength involved. Since the active size of the multiplier diode (~2 μm) is two orders of magnitude smaller than the wavelength (~500 μm), it is mounted in waveguide. However to minimize losses, a quasi-optical design is used to diplex the input and output powers at the fundamental and doubled frequencies.

Component Design

A schematic diagram of the submillimeter frequency doubler is shown in Figure 1. The 300 GHz input radiation from the carcinotron is reflected off a Fabry-Perot diplexer and focused by an off-axis mirror into an integral conical feedhorn. The multiplier diode is located at the feedhorn throat in circular waveguide that is single-moded at the input frequency but over-moded at 600 GHz. A moveable backshort is used to tune the circuit. The 600 GHz output power is radiated out the feedhorn, focused by the same off-axis mirror as the input signal, and transmitted through the Fabry-Perot diplexer. The Fabry-Perot diplexer, formed by two parallel free standing meshes, is used at 45° incidence to separate the input and output beams spatially as well as spectrally.

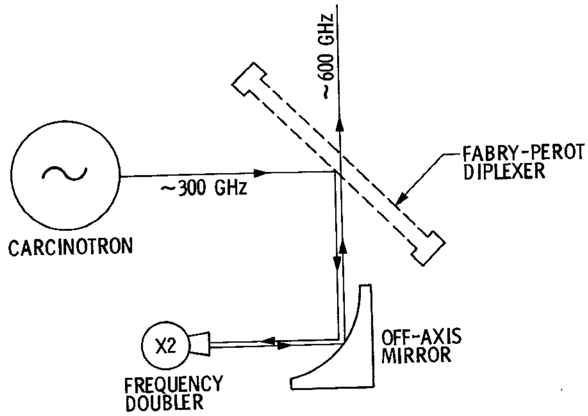

Figure 1: Schematic diagram of frequency doubler

The use of a Fabry-Perot interferometer for the input/output frequency diplexer takes advantage of the frequency dependence of the reflectivity and transmitivity of the free standing meshes that form the resonant cavity. In the short wavelength regime where λ is much smaller than the grid spacing, the transmittance of the mesh is simply its geometric through-put. In the long wavelength limit, the metallic mesh is almost totally reflective. In between these limits, a two dimensional mesh exhibits resonant properties and at a wavelength near the grid spacing has essentially 100% transmitivity. Detailed theoretical models based on first principles have been developed for metallic meshes and experimentally verified at infrared wavelengths. (For a review of this theory see Durschlag and DeTemple, 1981.)

For our application the Fabry-Perot has been designed so that the high pass band is near the single mesh resonance. At this frequency most of the signal is transmitted through the Fabry-Perot in one pass since the mesh reflectivity and Fabry-Perot finesse are both very small. On the other hand, at lower frequencies, where the grids become highly reflective, the Fabry-Perot finesse is large resulting in narrow transmission peaks. The Fabry-Perot is then a very good reflector at anti-resonance. The spacing between the two grids is not critical as long as it is chosen such that a low frequency transmission peak does not fall in the low pass reflection band. For the device reported here the mesh periodicity is 100 lines per inch giving a mesh resonance at 45° incidence of about 650 GHz. The spacing between the two meshes is 0.008". The transmittance of the Fabry-Perot at 45° incidence, for the polarization perpendicular to the plane of incidence, was measured from 200 to 750 GHz and is shown in figure 2. It has greater than 80% transmittance from about 520 to 650 GHz and less than 10% transmittance below about 400 GHz.

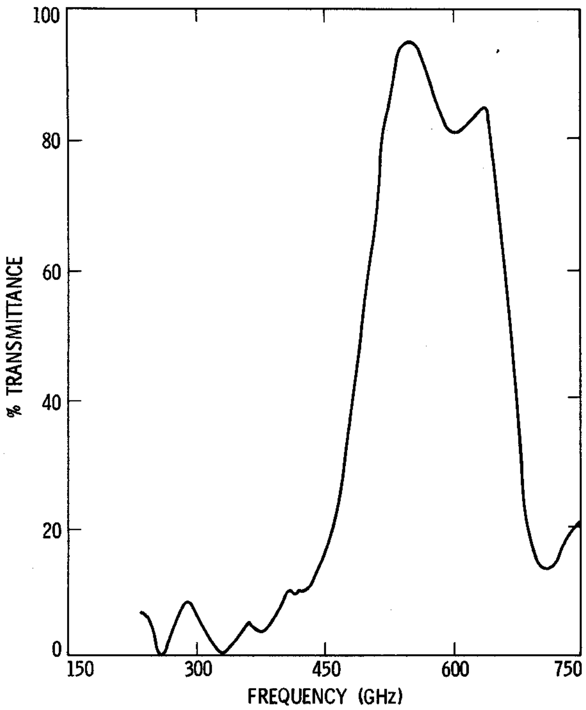

Figure 2: Measured transmittance of the Fabry-Perot diplexer at 45° incidence

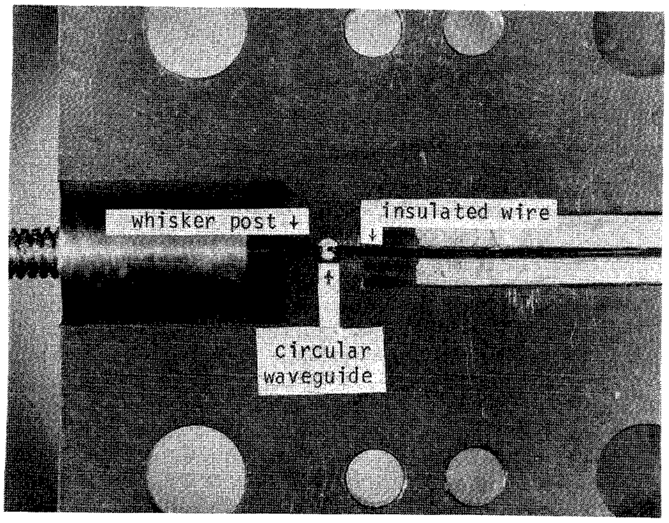

Figure 3: Frequency multiplier diode block

For ease of fabrication and assembly the multiplier mount is split into two blocks at the plane of the diode. One block consists of the electroformed conical feedhorn and the diode mounting and biasing structure while the other block supports a tuneable backshort. A photograph of the diode block is shown in figure 3. The feedhorn is designed to have a 3dB full width of 14°. The 0.026" diameter circular waveguide at the feedhorn throat has a cutoff frequency of 270 GHz. The multiplier diode is mounted 0.01" from the feedhorn throat and protrudes into the waveguide to aid in impedance matching. The diode is mounted on 0.008" diameter insulated wire that lies in a 0.010" diameter channel. This low impedance coaxial transmission line structure presents a mismatch to the higher impedance waveguide to minimize leakage of RF power. A blowup of the region in which the diode is mounted is shown in figure 4.

The GaAs Schottky diode is a high frequency mixer diode obtained from R. Mattauch at the University of Virginia (designated 2P12) and has a dc series resistance of 8 Ω and a zero-bias capacitance of 4 fF.

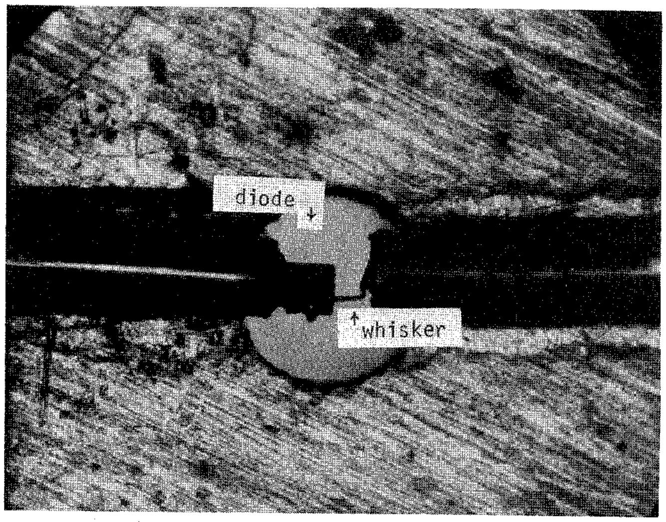

Figure 4: Whiskers contacted diode in frequency doubler

Multiplier Performance

The multiplier performance has been measured at 587 GHz using a Scientech 362 bolometer. The output power of the frequency doubler is about 50 μW for an input power at 295 GHz of 50 mW giving a conversion efficiency of 0.1%. The multiplier output power peaks when the diode is biased for forward conduction and is mixing in the resistive mode. A varactor type diode (designated 5M5) was also tried in the mount but did not give as much output power as the varistor diode. Theoretically the varactor should be more efficient but, at these high frequencies, the parasitic capacitance and resistance degrade its performance significantly.

Conclusion

This paper reports on the design and testing of a 300 to 600 Ghz doubler that is easily fabricated and could be scaled to operate at much higher frequencies. The design is implemented by two different technologies. Quasi-optics are used to diplex the input and output frequencies while waveguide is used for the diode circuit. A comparison of varactor and varistor type diodes shows that the diode with the smallest parasitics gives the best results.

Acknowledgement

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References

1. Durschlag, M.S. and DeTemple, T.A., (1981) "Far-IR Optical Properties of Freestanding and Dielectrically Backed Metal Meshes," Applied Optics, Vol. 20, #7, pg. 1245.