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A BROAD-BAND LOW-NOISE 205 GHz RADIOMETER FOR A SATELLITE RECEIVER

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ABSTRACT

A low-noise room temperature 205 GHz heterodyne radiometer has been designed and built for the Upper Atmosphere Research Satellite Microwave Limb Sounder instrument. The radiometer design features a low loss quasi-optical broad-band signal/LO coupler, a solid state local oscillator and a single-ended fundamental mixer.

Introduction

A prototype of a 205 GHz heterodyne radiometer has been designed, fabricated and tested for the Microwave Limb Sounder instrument. This instrument is scheduled to be flown on the Upper Atmosphere Research Satellite to measure the thermal emission from atmospheric $C\ell O$, H_2O_2 and O_3 at 204.4, 204.6 and 206.1 GHz, respectively. The global and temporal distribution of these molecular species in the stratosphere will be derived from these data to improve the current understanding of stratospheric chemistry.

To achieve the desired measurements the radiometer must have low noise with broad bandwidth, be space qualified and require low power. Therefore, a radiometer using a single-ended fundamental mixer with a solid-state local oscillator (LO) source was chosen for the basic design.

Radiometer Components and Design

A photograph and block diagram of the 205 GHz radiometer front end are shown in Figures 1 and 2. The incoming signal and LO powers are combined in a quasi-optical coupler whose output is fed into the mixer by an off-axis mirror and a dual-mode feedhorn. The IF signal is coupled from the mixer diode via a quartz microstrip RF choke to a duroid microstrip matching and IF diplexing circuit. The 203.3 GHz LO source is a frequency tripler driven by a Gunn diode oscillator at 67.8 GHz and fed into the quasi-optical coupler through a dual-mode feed horn and an off-axis mirror.

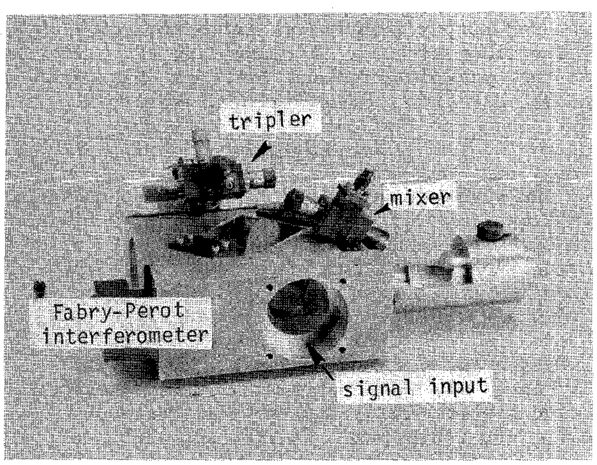


Figure 1. 205 GHz radiometer front end

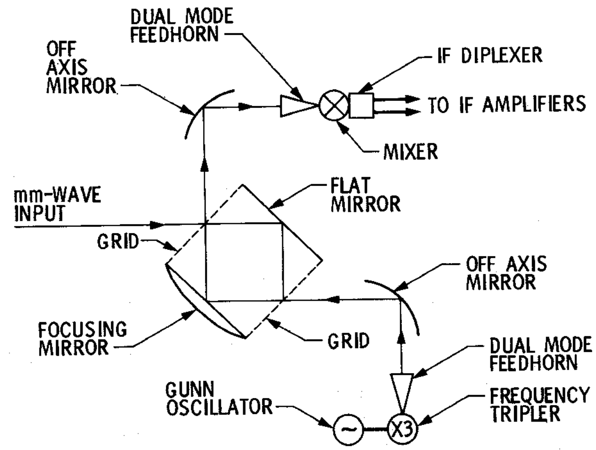


Figure 2. Block diagram of 205 GHz radiometer front end

The mm-wave quasi-optical coupler is a Fabry-Perot ring-resonator based on a design by Gustincic (1). The transmission and reflection characteristics of a Fabry-Perot interferometer are ideally suited to this diplexing task since the broad-band input signal is reflected off the Fabry-Perot interferometer with very low loss, while the monochromatic LO signal is transmitted through the tuned cavity with minimum loss. One of the mirrors in the folded cavity has been curved to refocus the beam to eliminate diffraction losses for the transmitted LO signal as suggested by Pickett and Chiou (2). To further reduce loss in the LO path, while maintaining the filter sharpness to pass the $C\ell O$ emission line, the free spectral range of the Fabry-Perot interferometer was reduced by placing an additional transmission peak between the $C\ell O$ and H_2O_2 channels and the O_3 channel as shown in Figure 3. The mm-wave Fabry-Perot coupler, with a finesse of 14, has a measured loss of about 1 dB in the LO path. The loss in the signal path is estimated to be less than 0.3 dB.

The LO source consists of a commercially available Gunn diode oscillator which pumps a crossed waveguide frequency tripler. The solid-state Gunn diode oscillator is used in this application because it has low power consumption, long lifetime and relatively small size and weight. A schematic drawing of the frequency tripler is shown in Figure 4. It is based on the design reported by Archer (3) with a few modifications. The non-linear element is a Schottky barrier GaAs varactor diode fabricated by R. Mattauch at the University of Virginia (designated 6P1) and has a zero-bias capacitance of 21 fF and a dc series resistance of 11 Ω. The reverse bias breakdown voltage is 16.5 V. These devices have a highly non-linear capacitance versus voltage law that approximates the behavior of an ideal abrupt-junction varactor. The input power at 67.8 GHz is coupled from full height WR 15 waveguide to a 0.003" thick quartz suspended stripline low pass filter which passes the 67.8 GHz pump frequency but is cut off for the higher harmonics. An adjustable contacting backshort is used to tune the input circuit. The whisker contacted varactor diode is mounted on the quartz substrate in reduced height waveguide as shown in figure 5. This waveguide can support fundamental modes at both the doubled (idler) frequency and the tripled frequency. A waveguide impedance transformer to WR 4 output waveguide is placed about $\lambda_g/2$ at the idler frequency from the diode. This forms an idler cavity since the output waveguide is cutoff for the idler frequency. A dual backshort allows tuning of both the idler and the tripled frequencies. The output power of the frequency tripler was measured to be about 2 mW at 203.3 GHz for an input power of 60 mW at 67.8 GHz giving a conversion efficiency of 3.3%.

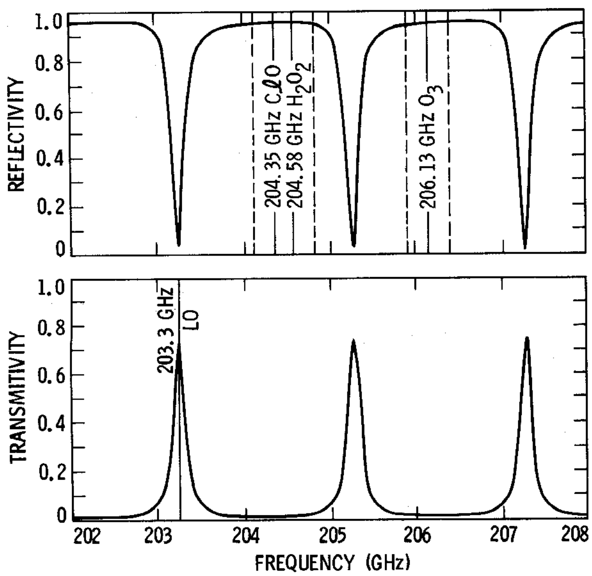


Figure 3. Theoretical response of the 205 GHz signal/LO coupler. The upper graph shows the reflectivity as a function of frequency. The molecular line frequencies are indicated by the solid lines and the band edges by the dashed lines. The lower graph shows the transmitivity as a function of frequency with the LO source freqnency indicated by the solid line.

The mixer is a single-ended fundamental mount also based on a design by Archer (4). A schematic drawing is shown in Figure 6. The signal and LO powers are fed into the mount by a dual mode feedhorn (5). A transition from full height WR 4 waveguide to 1/4 height waveguide is accomplished by a smooth sinusoidal taper. The GaAs Mott type mixer diode (obtained from R. Mattauch and designated 1E2) has a dc series resistance of 6.5 Ω and a zero-bias capacitance of 3.5 fF. It is soldered to a 0.003" thick quartz dielectric microstrip RF choke and contacted by a 0.004" long phospher bronze whisker. The 0.050" long choke is a low impedance - high impedance type low pass filter in which the diode forms the first capacitive section. The impedance of the mixer at the output of the RF choke is (190-j40) ohms at 1.1 GHz and (40-j70) ohms at 2.9 GHz.

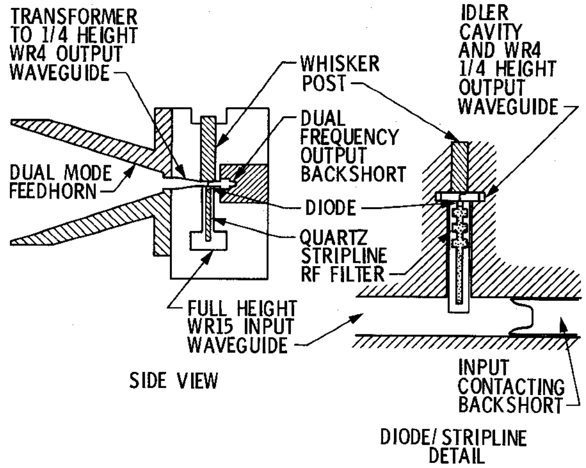


Figure 4. Frequency tripler cross section

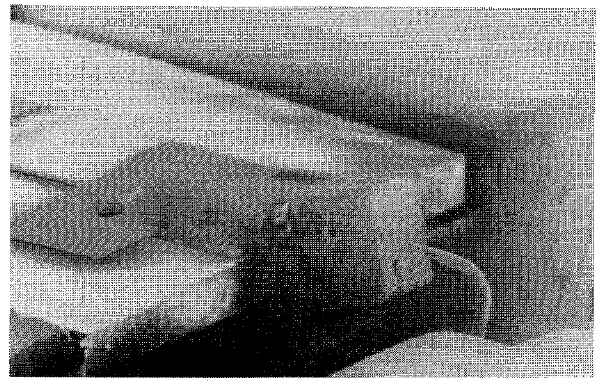


Figure 5. SEM photograph of whisker contacted diode in frequency tripler

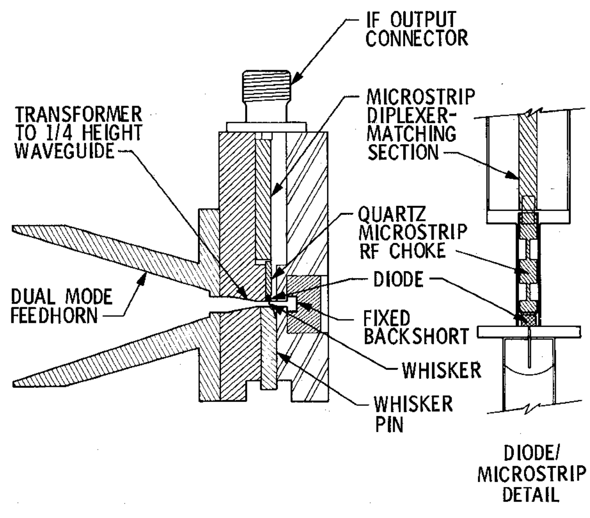
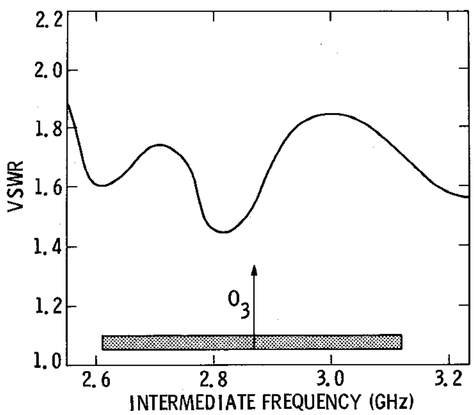


Figure 6. 205 GHz Mixer cross section

The IF port of the mixer is matched to 50 Ω and then diplexed into two bands, one from 800 to 1500 MHz for the CℓO and H_2O_2 channels and the other from 2600 to 3100 MHz for the O_3 channel. The matching network, a three section impedance transformer, was optimized for these two bands using a computer aided design program. The diplexer uses complementary Chebyschev high and low pass filter prototypes. The low pass section is implemented using a transmission line open circuited stub design while the high pass section consists of series lumped element capacitors separated by lengths of transmission line. The insertion loss for the low pass arm of the diplexer is less than 0.3 dB while that for the high pass arm is less than 0.7 dB. The VSWR of the mixer and IF circuit at the output of the diplexer is less than 2:1 in both bands as shown in figure 7. Both the matching network and the diplexer are made on 0.030" duroid.



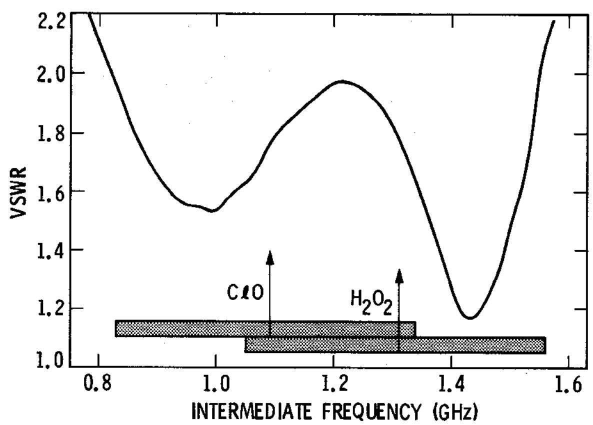


Figure 7. VSWR at output of IF diplexer. The upper graph shows the CℓO and H_2O_2 channels, while the lower graph shows the O_3 channel.

Radiometer Performance

The 205 GHz mixer performance was measured at IFs of 1.1 and 2.9 GHz with a 500 MHz bandwidth using room and liquid N_2 temperature loads. The SSB mixer temperature (DSB temperature x2), with no correction for loss in the mm-wave signal/LO coupler is 1250K and 1450K at the two IFs respectively. The SSB conversion loss and voltage reflection coefficient, Γ, referenced to the output of the IF diplexer are 7-8 dB and 0.25. The RF loss, L_{rf}, of the Microwave Limb Sounder instrument, mainly due to a dichroic plate used to diplex a 63 GHz signal from the 205 GHz signal, is predicted to be about 1 dB in the worst case. With IF amplifiers having noise temperatures of 130K and 220K for the low and high frequency bands respectively, the expected SSB system noise temperatures will be about 2300K in the CℓO-H_2O_2 channel and 3200K in the O_3 channel. The performance of the radiometer is summarized in Table 1.

Table 1: 205 GHz Radiometer Performance

IF	1.1 GHz	2.9 GHZ
T_{mix}	1250 K	1450 K
L_{conv}	7.1 dB	7.6 dB
Γ	.25	.25
L_{rf}*	1 db	1 db
T_{if}	130 K	220 K
T_{sys}	2300 K	3200 K
ΔT(2s, 1 MHz)	1.6 K	2.3 K

* assumed value

Conclusion

This paper reports on the design and fabrication of a prototype 205 GHz radiometer for a satellite receiver system. Two broad signal bands are coupled with the monochromatic LO signal into the mixer by a mm-wave quasi-optical Fabry-Perot ring resonator. The broad reflection and narrow transmission bands that characterize the Fabry-Perot interferometer are ideally suited to this task. These two bands are separated in the IF line by a low loss diplexer before being amplified. A Gunn diode oscillator pumping a crossed waveguide frequency tripler is used for the 203.3 GHz solid-state LO source. The receiver has exibited state-of-the-art performance and is capable of being space qualified.

Acknowledgement

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