A 0.9 MM HETERODYNE RECEIVER FOR ASTRONOMICAL OBSERVATIONS*

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ABSTRACT

A complete receiver for astronomical observations in the 0.9 mm region is described. The mixer uses a 2μ Schottky diode in fundamental mode waveguide. The local oscillator from a BWO is injected into the mixer with a low-loss quasi-optical diplexer. Overall system sensitivity is about 4000-5000 K SSB, over the range of 318-348 GHz.

Introduction

This paper describes a complete receiver used for astronomical observations in the 0.9 mm region, primarily of the J = 3 → 2 transition of the molecule CO at 346 GHz. The mixer consists of a Schottky diode in a waveguide structure, a BWO (carcinotron) is the local oscillator (L.O.) and a modified Michelson interferometer is the L.O.-signal diplexer.

Other receivers have been built at this frequency using quasi-optical techniques to couple to a Schottky diode,[1] and using a hot electron bolometer,[2] but this paper presents the first application of more conventional waveguide techniques to the submillimeter range.

Mixer

The mixer is shown schematically in Figure 1. The waveguide horn is 4 mm x 6 mm, producing a f/3.2 beam,

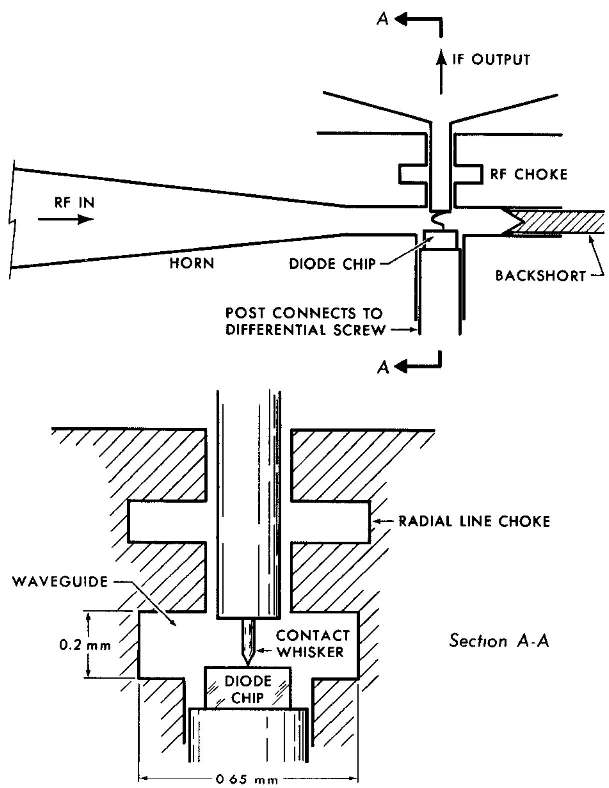

Fig. 1. Side view and cross section of the 0.9 mm mixer.

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and the waveguide tapers down to .2 mm x .65 mm at the plane of the diode. A .25 mm diameter hole in the top allows insertion of a .037 mm diameter electrosharpened phosphor bronze whisker, which is soldered to the center conductor of the I.F. port. Thinner whiskers (.025 and .012 mm diameter) have been tried and are found to produce significantly poorer performance. To prevent leakage of R.F., the I.F. port contains a filter consisting of a quarter-wave low impedance section followed by a radial line choke. The filter is followed by 50Ω coax. The bottom wall of the waveguide has a .37 mm diameter hole through which the diode chip is inserted. The post to which the diode is soldered fits closely in this hole. This construction does not allow the contacting process to be observed, due to the small waveguide dimensions.

The backshort is a piece of phosphor-bronze shim, which has been slit and split apart by scribing with a sharp tool. The backshort and all other mixer parts are gold plated.

The Schottky diodes are 2μ diameter metallizations on GaAs with a series resistance of 5Ω and a zero bias capacitance of 9fF. Their ideality factor, η, is about 1.2.

Most of the mixer dimensions were initially tested by constructing a model at 3.5 GHz.

Local Oscillator

The L.O. is a CSF COE-10 carcinotron (BWO). Two tubes have been used, one with an output power of about 10 mW at 318 GHz and relatively weak output elsewhere, and the other with an output of 10-20 mW over the range 337-348 GHz. Frequency stabilization is accomplished by phase locking to a harmonic mixer.

Diplexer

The diplexer consists of a Michelson interferometer with an offset between the incident and returning beams, and has been largely described elsewhere.[3] It has less than .2dB insertion loss for both signal and L.O. and about -20 dB rejection of L.O. noise. Its operation is shown schematically in Figure 2 which shows the paths taken by the signal and L.O. By setting the path difference between the two arms to half the I.F. wavelength, nearly total transmission of the signal can be accomplished, with accompanying high L.O. transmission. Some L.O. leakage to the phase-lock mixer occurs because the beam splitter (a wire mesh) has unequal reflection and transmission. The required leakage for phase locking is found to be about 1%-5% of the total L.O. power.

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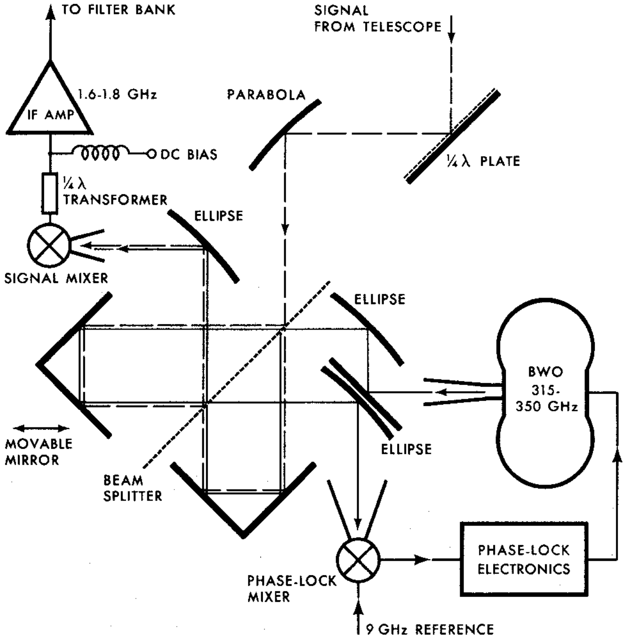

Fig. 2. Schematic diagram of the complete receiver, showing the paths of the signal and L.O. beams.

Optics

All optical elements of the system are mirrors to avoid the absorption and reflection losses of lenses. Identical ellipsoidal mirrors are used on the signal mixer, phase-lock mixer and L.O. ports of the diplexer, while a parabola is used to match the signal port to the f/16 beam coming from the telescope secondary. The final optical element is a quarter-wave plate constructed using a wire grid-metal mirror pair spaced so that the reflections in the two polarizations undergo a relative phase shift of 90°. This plate helps to isolate the receiver from reflections due to the secondary mirror, which cause resonances and result in baseline ripples.

System Sensitivity

System sensitivity measurements have been made using a 1.6-1.8 GHz I.F. amplifier with a noise temperature of 100 K (FET input). With the L.O. at 318 GHz a system noise temperature of 4000 K (SSB) has been measured. The conversion loss is 9.3 dB (SSB) and the resultant mixer noise temperature is 3100 K. (This mixer noise includes diplexing losses but does not include the I.F. amplifier contribution.) At this frequency the effective sideband noise temperature of the L.O. is only 5000 K.

At frequencies between 337 GHz and 348 GHz the conversion loss is 9.4-9.8 dB while the system noise varies between 4300 K and 5100 K. This higher system noise is believed due to the much higher L.O. noise of the higher frequency BWO, which is not completely rejected by the diplexer. Noise power from this tube varies with frequency but is typically 20,000 - 60,000 K at 1.7 GHz from the carrier. It has been found that this noise does not fall off rapidly nor monotonically with increasing separation from the carrier. Since the mixer accepts both sidebands, 20 dB rejection of 50,000 K still leaves 1000 K SSB noise contribution to the system.

All noise temperatures were measured using room temperature and liquid nitrogen cooled absorbers, and for the conversion loss measurements an isolator was inserted between the mixer and I.F. amplifier to eliminate effects of changing source impedance. The noise on the L.O. was measured by setting the path difference in the diplexer to near zero. This keeps the L.O. power constant but also couples all the L.O. noise to the mixer. The resultant rise in system total power is then a measure of the total noise power on the L.O.

The I.F. port impedance of the mixer has been measured using a slotted line and is found to be about 100Ω over a wide range of L.O. power, at optimum D.C. bias. The I.F. port includes a quarter wave transformer to correct this mismatch.

The relative sideband sensitivity has been measured by including a Fabry-Perot interferometer in the signal beam and scanning across the two sidebands. With a 2.25 GHz I.F., sensitivity is found to be the same in both sidebands to within 5%.

Observations

The receiver has been operated at Mt. Lemmon, Arizona using the NASA/LPL 152 cm telescope in January 1978, and the U. Minn./UCSD 152 cm telescope in March 1978. The 346 GHz CO line was detected in many interstellar clouds, as well as in the earth's atmosphere. Maximum observed zenith transmission was 85% and typical clear sky values about 50%. Thin high cloudiness was found to cause only a small additional attenuation.

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