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# The Low-Noise 115-GHz Receiver on the Columbia-GISS 4-ft Radio Telescope

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***Abstract*—The superheterodyne millimeter-wave radiometer on the Columbia-GISS 4-ft telescope is described. This receiver uses a room-temperature Schottky diode mixer, with a resonant-ring filter as LO diplexer. The diplexer has low signal loss, efficient LO power coupling, and suppresses most of the LO noise at both sidebands. The receiver IF section has a parametric amplifier as its first stage with sufficient gain to overcome the second-stage amplifier noise. A broad-banded quarter-wave impedance transformer minimizes the mismatch between mixer and paramp. At 115 GHz, the SSB receiver noise temperature is 860 K, which is believed to be the lowest figure so far reported for a room-temperature receiver at this frequency.**

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## I. INTRODUCTION

THE COLUMBIA-GISS 4-ft radio telescope was constructed for the purpose of surveying the distribution of carbon monoxide in the interstellar space of our Galaxy. The telescope, a Cassegrain with an effective $f/D$ ratio of 2.8, has a half-power beamwidth of 8 arc min at 115 GHz, the frequency of the fundamental rotational transition line of carbon monoxide. The receiver front-end is of the superheterodyne type using a room-temperature Schottky diode mixer, followed by a 1.39-GHz parametric amplifier with a noise temperature of 50 K and a gain of ~17 dB. At 115 GHz, the single-sideband noise temperature of this receiver is 860 K, which we believe to be the best performance reported at this frequency for a room-

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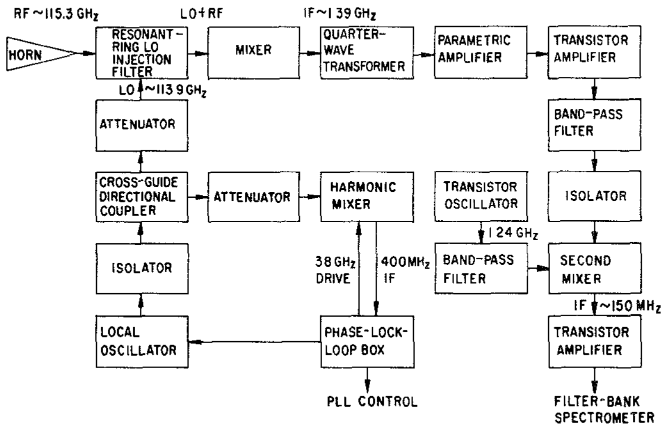


Fig. 1. Block diagram of the 115-GHz receiver front-end.

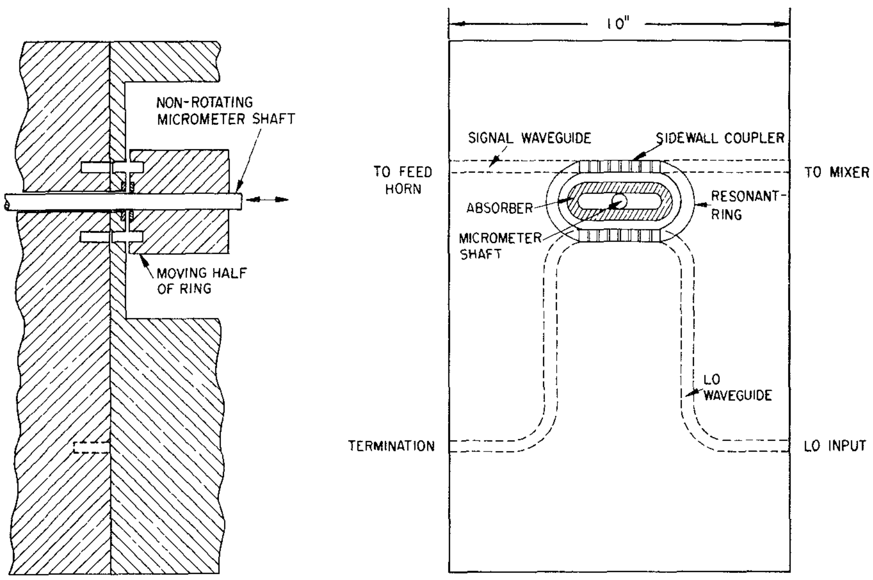


Fig. 2. Cross section of the resonant-ring LO injection filter. The moving part of the resonant ring is driven by a differential micrometer (not shown) with a nonrotating shaft.

temperature radiometer. This paper will briefly describe the various parts of the receiver, emphasizing in particular the steps taken to reduce the noise contributions from individual components of the system.

The block diagram in Fig. 1 shows the major components of the receiver front-end. The incoming 115-GHz signal from the feed horn and the local oscillator (LO) power are coupled into the mixer through the resonant-ring filter to produce an intermediate frequency (IF) signal of ~1390 MHz, which is sent to the parametric amplifier. The succeeding stages consist mainly of a transistor amplifier (gain ~30 dB) followed by a second mixer which further converts the 1390-MHz IF signal to ~150 MHz. This second IF signal is then amplified by another transistor amplifier (gain ~34 dB) before it is sent to the filter-bank spectrometer (currently 256 channels of $\frac{1}{4}$-MHz filters). The phase-lock system for stabilizing the LO frequency is similar to the one designed by Weinreb [1]. The LO is locked according to $f_{\mathrm{LO}} = Nf_o \pm$ 400 MHz, where $f_o$ is the frequency (~3.8 GHz) of the phase-locked solid-state oscillator which drives the harmonic mixer, and $N = 30$ for $f_{\mathrm{LO}} = 114$ GHz.

## II. Resonant-Ring LO Diplexer

Fig. 2 shows a cross section of the resonant-ring filter which couples the incoming signal and LO power into the mixer while preventing noise generated by the LO at the signal and image frequencies from reaching the mixer. The principle of the resonant-ring filter has been described by various authors [2], [3], and only the essential details will be described here. The signal and LO waveguides are each coupled to the oval waveguide ring by sidewall couplers. The ring is fabricated in two parts, whose separation, and hence the waveguide width, can be adjusted by a differential micrometer to tune the filter. Since this type of filter has multiple passbands, it is

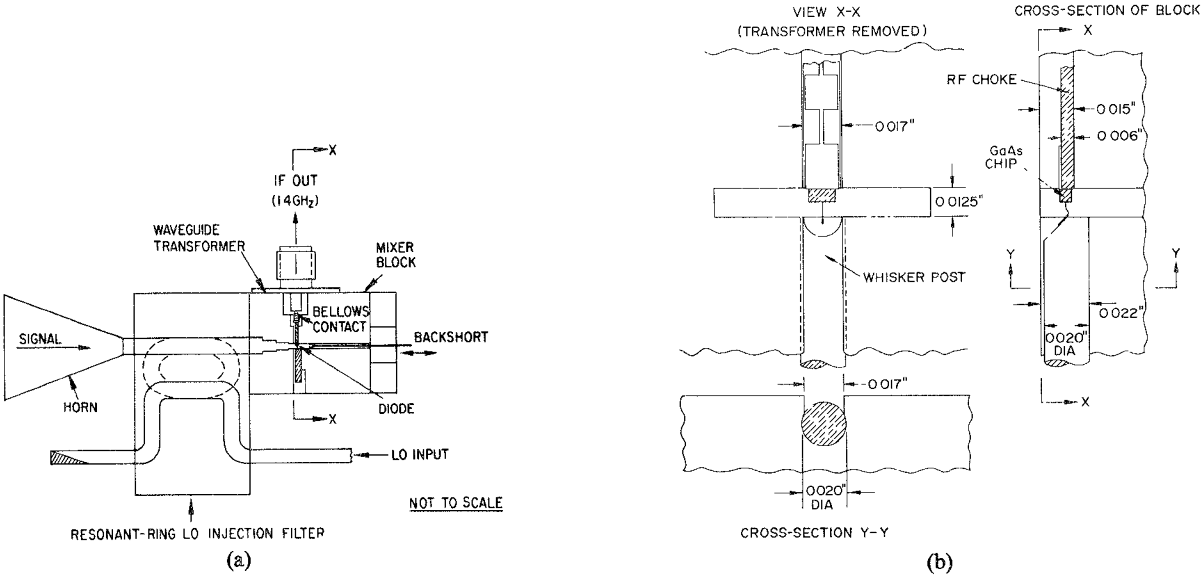


Fig. 3. (a) Cross section of the mixer and injection filter showing the LO and signal paths. (b) Details of the mixer diode mount.

necessary to choose the length of the waveguide ring so that the desired sideband noise rejection can be achieved. In this case, IF's of 1.39 and 3.95 GHz were required, so the ring length was chosen to give passbands about every 8 GHz.

The oval shape of the ring was chosen to allow a straight signal waveguide of minimum length (1.0 in), and hence minimum loss, to be used. For this reason also, the couplers consist of eight equal rectangular holes the full height of the waveguide, a configuration which maximizes coupling for a given length at the expense of directivity. To facilitate machining of the coupling holes it was necessary to split the signal waveguide along the plane of one sidewall, a situation giving an initial insertion loss of ~0.6 dB. Conducting epoxy[1] applied along the waveguide edges during final assembly reduced this to 0.25 dB. A spurious resonance in the gap between the halves of the resonant ring was suppressed by inlaying some absorbing material[2] in this region. The LO-to-mixer insertion loss is 4 to 6 dB over the frequency range from 90 to 120 GHz, and the rejection at the signal and image frequencies is typically 15 dB (in addition to the insertion loss) with 1.39-GHz IF, and greater than 20 dB with 3.95-GHz IF.

## III. Mixer

The mixer is of the broad-band type using a single GaAs Schottky diode mounted across a quarter-height WR-10 waveguide. The diode is tuned by an adjustable waveguide short-circuit behind the diode, and coupled to the IF and dc connector by a quartz microstrip RF choke (see Fig. 3). The electrical design of the mixer is similar to that described in [4], and the construction is in many ways the same as the WR-5 mixer reported in [5]. The diode was fabricated by the Semiconductor Device Laboratory of the Electrical Engineering Department of the University of Virginia, and has a dc resistance of 8 Ω, ideality factor $\eta = 1.1$, and zero-bias capacitance of 7 fF. Using the IF noise radiometer/reflectometer described in [6], we measured an SSB mixer noise temperature ($T_M$) of 440 K, and a conversion loss ($L$) of 5.3 dB at 114-GHz LO frequency. This mixer was the best of three using diodes from the same batch; values of $L$ and $T_M$ for the other mixers were 5.2 and 5.7 dB, 530 and 520 K. Normally, a dc bias of 0.5 V is applied to the diode, and the LO power is adjusted until a total current of 2.0 mA is reached. The LO power needed at the mixer input to achieve this rectified current is ~1.5 mW.

## IV. IF Transformer

Since the VSWR looking into the mixer IF output port is generally 3 or 4, a matching network between the mixer and paramp is required. At an IF of 1.4 GHz, the mixer impedance is slightly capacitive at the plane of the SMA connector on the mixer block (see Fig. 3). This impedance can be transformed to a pure resistance through a short coaxial line, and then to 50 Ω. Originally, we used a simple quarter-wavelength impedance transformer, consisting of a brass rod as the center conductor inside a square aluminum outer conductor, which gave a VSWR between 1 and 1.6 in the IF range from 1350 to 1430 MHz. A broad-band, partially tunable transformer was subsequently constructed (see Fig. 4). Two striplines, soldered at the input end of the quarter-wave transformer, form a broad-banding resonator which is adjustable by

[1]Epoxy Technology Inc., #H20E.

[2]Emerson Cuming Co., Eccosorb #116, ground to powder and mixed with (nonconducting) epoxy.

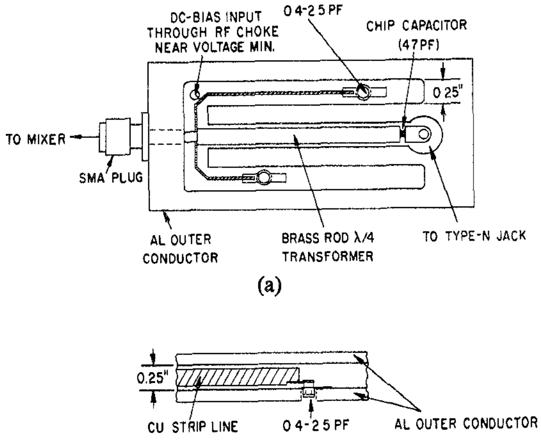


Fig. 4. (a) Sketch of the quarter-wave IF transformer. (b) Detail of a broad-banding stub.

capacitors[3] at the ends of the stubs. The design was optimized by computer to give an almost flat double-tuned response. The resulting VSWR is between 1.03 and 1.09 over the 80-MHz bandwidth. This impedance transformer also provides a terminal for dc biasing the mixer diode through a small RF choke coil. A 47-pF chip capacitor[4] soldered at the output end of the quarter-wave transformer serves as a dc block.

## V. Remainder of Signal Path

The output of the IF transformer has a type-N connector. Ideally, the paramp input, also a type-N connector, should be connected directly to the transformer. However, owing to physical constraints, an 8-in semirigid cable (0.141-in diameter) with type-N connectors on both ends was used between the IF transformer and the parametric amplifier. The second stage of the IF system is a bipolar transistor amplifier,[5] whose noise figure is 2.24 dB. The total IF noise temperature, measured at the input connector of the semirigid cable, is 65 K.

## VI. Performance

At the LO frequency of 114 GHz the single-sideband system noise temperature, referred to input aperture of the feed horn, is 860 K measured using room temperature and 77 K absorbers in front of the horn. Fig. 5 shows the contributions of the various components to the overall receiver noise. Noise generated at the signal and image frequencies by the LO, a Varian VRT-2123A19 klystron, is mostly suppressed by the resonant-ring filter, and contributes ~40 K to the total system noise temperature. An example of a spectral line received by the 4-ft telescope is given in Fig. 6.

[3]Johanson Electronics, #C72480A5, 0.4–2.5 pF.
[4]American Technical Ceramics, #100-A-470-J-P-50, 47 pF.
[5]Watkins-Johnson, #WJ-737-142.

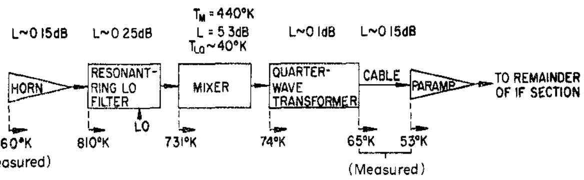


Fig. 5. Breakdown of the receiver noise temperature (SSB) at various points along the signal path (note that losses ahead of the mixer contribute noise in *both* sidebands).

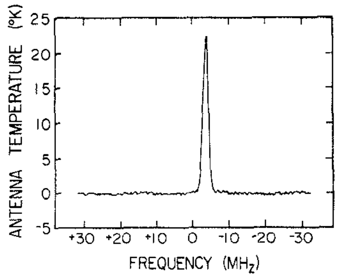


Fig. 6. Carbon monoxide emission ($f_o$ = 115271.2 MHz) from Orion A, observed with the Columbia-GISS 4-ft telescope. The filter bank has 256 $\frac{1}{4}$-MHz channels. This spectrum is raw data and has had no corrections or smoothing other than the removal of a linear baseline.

## VII. Summary

Although the mixer itself contributes a substantial part of the total receiver noise, the effects of waveguide loss, IF mismatch, cable loss, and klystron noise also make essential contributions. For the millimeter-wave radiometer on the Columbia-GISS 4-ft telescope, efforts to reduce noise contributions from various parts of the receiver have resulted in what we believe to be the lowest noise room-temperature radiometer so far reported at 115 GHz.

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