

## MMA MEMORANDUM # 72

**CIRCULAR POLARIZATION AND MULTI-BAND OPERATION:  
IMPLICATIONS FOR MMA RECEIVER DESIGN**

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It is desirable that the MMA operate with circular polarization. Also, the ability to operate simultaneously in two frequency bands is important for some astronomical measurements. This note considers these requirements from the viewpoint of receiver design.

On a millimeter-wave radio telescope a number of operations can be performed quasi-optically before the signal beam enters single-mode waveguide. These include:

- Separation of the incoming beam into individual frequency bands for routing to different receivers.
- Conversion of left and right circular polarization to two linear polarizations, as required by most millimeter wave mixers and amplifiers.
- Termination of the image frequency in a cold load to prevent atmospheric image noise degrading the system sensitivity during spectral line observations.
- Coupling the local oscillator power into the receiver.

While it is possible, in principle, to perform most of these functions in single-mode waveguide or TEM circuits, it is probably not practical at millimeter wavelengths, especially where wide tuning ranges are required. Quasi-optical components are fairly easy to design and construct, have very low loss, and are easily tunable over wide frequency ranges. They are also relatively easily moved into and out of the optical path as needed.

Fig. 1 shows three possible arrangements of quasi-optical components which would perform all or most of the above functions. Fig. 1(a) allows observations with dual circular polarization using a frequency band diplexer with circularly polarized input and output beams (e.g., a dichroic plate). Fig. 1(b) is also for dual circularly polarized observations, but in this case the beam from the telescope is split into its left and right circular components using a circular polarizer with linearly polarized output beams (e.g., a Martin-Puplett interferometer). Fig. 1(c) is used for dual linearly polarized observations. The incoming beam is split into its linear polarization components using a linearly polarized beam splitter (e.g., a wire

grid). The realization of each functional block is considered below.

The discussion here applies primarily to receivers with single-ended double-sideband mixers. If image separation mixers turn out to be practical, an image filter will not be needed. If balanced mixers can be developed, the LO diplexer will not be necessary. Low noise transistor amplifiers will eventually eliminate the need for both at the longer millimeter wavelengths.

### The Martin-Puplett Interferometer

Most of the functions in the above list can be performed very well by the quasi-optical Martin-Puplett interferometer [1], an easily fabricated device which has been widely used in millimeter wave receivers as a sideband filter and as a LO diplexer [2,3]. The interferometer is simply tuned by moving a single reflector. As a circular polarizer, it can receive left and right circularly polarized signals from the telescope and convert them to linearly polarized signals at separate output ports. As an image filter, it can be adjusted to suppress the upper or lower sideband, or to allow both to be received. Its image port can be coupled quasi-optically to a cold load. It can also operate as frequency band diplexer.

The M-P interferometer is normally operated with a polarizing grid at its output (or input) port to separate (or combine) two linear polarizations. Linear polarization is necessary as there is no circularly polarized equivalent of the wire polarizing grid.

### Polarization Diplexers

*Linear Input Polarization/Linear Output Polarization.* For separation of two linear polarizations, a wire grid is almost ideal. It is easily made, and can have a useful frequency range of several octaves. A pair of intersecting grids can perform the same function, with the advantage of added symmetry: both polarizations pass through and are reflected off grids and emerge perpendicular to the input beam, having traversed identical path lengths. This dual-grid type of beam splitter has been successfully used on SIS receivers on the NRAO 12-m telescope [4]. (Formulas and programs for the design of wire grid beam splitters and polarizers are given in [5]).

*Circular Input Polarization/Linear Output Polarization.* For separation of left and right circular polarizations, at centimeter wavelengths, septum-type square waveguide polarizers give dual linear outputs in separate waveguides with an axial ratio  $AR \leq 1$  dB over ~20% bandwidth (about half a waveguide band). At millimeter wavelengths, the use of this kind of polarization diplexer would preclude the use, ahead of the feed horn, of (practical) quasi-optical image filters and LO diplexers, which are linearly polarized. Furthermore, because of their small critical dimensions, it is probably impractical to make septum-type circular polarizers for wavelengths less than a few millimeters.

Other options: On SIS receivers at some observatories, the LO power is injected by reflection from a thin mylar sheet inclined at 45° to the signal beam. The thickness of the mylar is usually chosen to give ~20 dB LO coupling loss and ~0.04 dB signal loss. Present SIS receivers on the NRAO 12-m telescope use waveguide LO couplers with ~20 dB LO loss. For the MMA with its very wide frequency coverage, LO power will be at a premium, and it would be unwise to plan on an unnecessary LO loss of ~20 dB.

## Discussion

Figs. 5-7 show three possible MMA receiver configurations corresponding to those in Figs. 1(a)-(c). In Fig. 5, the incoming circularly polarized signals are split into separate frequency bands, still circularly polarized, using a dichroic plate. These beams are converted to linear polarization by a Martin-Puplett interferometer. In Fig. 6, the incoming circularly polarized signals in both desired frequency bands are converted to linear polarization using a Martin-Puplett interferometer. Each resulting linearly polarized beam is separated into the desired frequency bands by a second Martin-Puplett interferometer. In Fig. 7, the linearly polarized input signals are separated by a wire grid (or pair of crossed grids [4]), and each resulting linearly polarized beam is separated into its desired frequency bands by a Martin-Puplett interferometer.

The choice of receiver configuration for the MMA will depend on detailed studies of these and other possible configurations. The implications for multi-frequency operation of the small gaps in the frequency coverage of the Martin-Puplett interferometer when used as a broadband circular polarizer or as a frequency band diplexer, must be assessed.

The possibility of using linearly polarized receivers and synthesizing circular polarization at the back end needs to be considered. This would permit the simplest receiver configuration, that of Fig. 7, to be used.

This discussion has assumed ideal quasi-optical components with negligible ohmic, scattering, and diffraction loss. However, with so many grids and mirrors in series, loss may turn out to be significant. Ohmic loss, and its noise contribution, could be reduced by cryogenically cooling the quasi-optical components, an option to be avoided if possible.

## References

- [1] D.H. Martin and E. Puplett, "Polarized interferometric spectrometry for the millimeter and submillimeter spectrum," Infrared Physics, vol. 10, pp.105-109, 1969.
- [2] N. R. Erickson, "A Very Low-Noise Single-Sideband Receiver for 200-260 GHz," IEEE Trans. Microwave Theory Tech., vol. MTT-33, no. 11, pp. 1179-1188, Nov. 1985.
- [3] J. M. Payne, "Millimeter and submillimeter wavelength radio astronomy,"

At millimeter wavelengths, an attractive circular polarization diplexer is the Martin-Puplett interferometer. The left and right circular inputs are converted to linear outputs at separate ports. An axial ratio less than 1 dB is possible over a 15% bandwidth, as shown in Fig. 2.

The Martin-Puplett polarization diplexer can be tuned to operate simultaneously in dual frequency bands. Fig. 3 shows the frequency coverage for which the axial ratio is under 1 dB. Frequency is normalized to the center of the upper band. The interferometer path difference, shown on the vertical axis, is increased in steps of half a wavelength at the upper frequency. The horizontal bars indicate the bands over which the axial ratio is less than 1 dB. It is seen that most frequency combinations are possible, but that a number of integer-ratio frequencies are not possible. Does this make this form of polarization diplexer inappropriate for use on the MMA? For dual-frequency observing, is it essential to be able to operate at frequencies with these particular integer ratios?

### Frequency Band Diplexers

*Dichroic Plates.* Dichroic plates can be designed to operate with circular or linear polarization. For circular polarization, the axial ratio can be under 1 dB over a bandwidth of ~10% when operated at an angle of incidence of 30° [6]. For linear polarization, wider operating bands should be possible.

*Martin-Puplett Interferometer.* The frequency coverage of a Martin-Puplett interferometer operated as a frequency band diplexer is shown in Fig. 4. Frequency is normalized to the center of the upper band. The interferometer path difference, shown on the vertical axis, is increased in steps of half a wavelength at the upper frequency. The horizontal bars indicate the bands over which the diplexer loss is less than 0.1 dB. It is seen that complete frequency coverage is possible except for a small gap at  $f = 0.33$ .

### Image Filter and Local Oscillator Diplexer

Each of these functions can be performed quasi-optically by a Martin-Puplett diplexer. Two arrangements are possible: the LO diplexer can be inserted between the image cold load and the image filter, as shown in Fig. 1, or it can be between the image filter and the mixer. The former is preferable as the loss of the LO diplexer is removed from the main telescope signal path. With the configuration of Fig. 1, the loss between the LO and mixer is ~3 dB (or 0 dB if the image filter is tuned for DSB operation).

The image rejection bandwidth of a Martin-Puplett interferometer depends on the choice of IF [7]. For a 1-2 GHz IF, the image rejection is only 16 dB at the band edges. For a 3-4 GHz IF, the image rejection  $\geq 19$  dB across the band.

- [4] J. M. Payne, private communication.
- [5] A. R. Kerr, "Programs for analysis of wire grid beam-splitters and the folded Mach-Zehnder diplexer", Electronics Division Technical Note No. 148, National Radio Astronomy Observatory, Charlottesville, VA 22903, October 20, 1988.
- [6] S. Srikanth, private communication.
- [7] A. R. Kerr, "Image frequency suppression on the MMA," Millimeter Array Memorandum #70, National Radio Astronomy Observatory, Charlottesville VA, Dec. 1991.

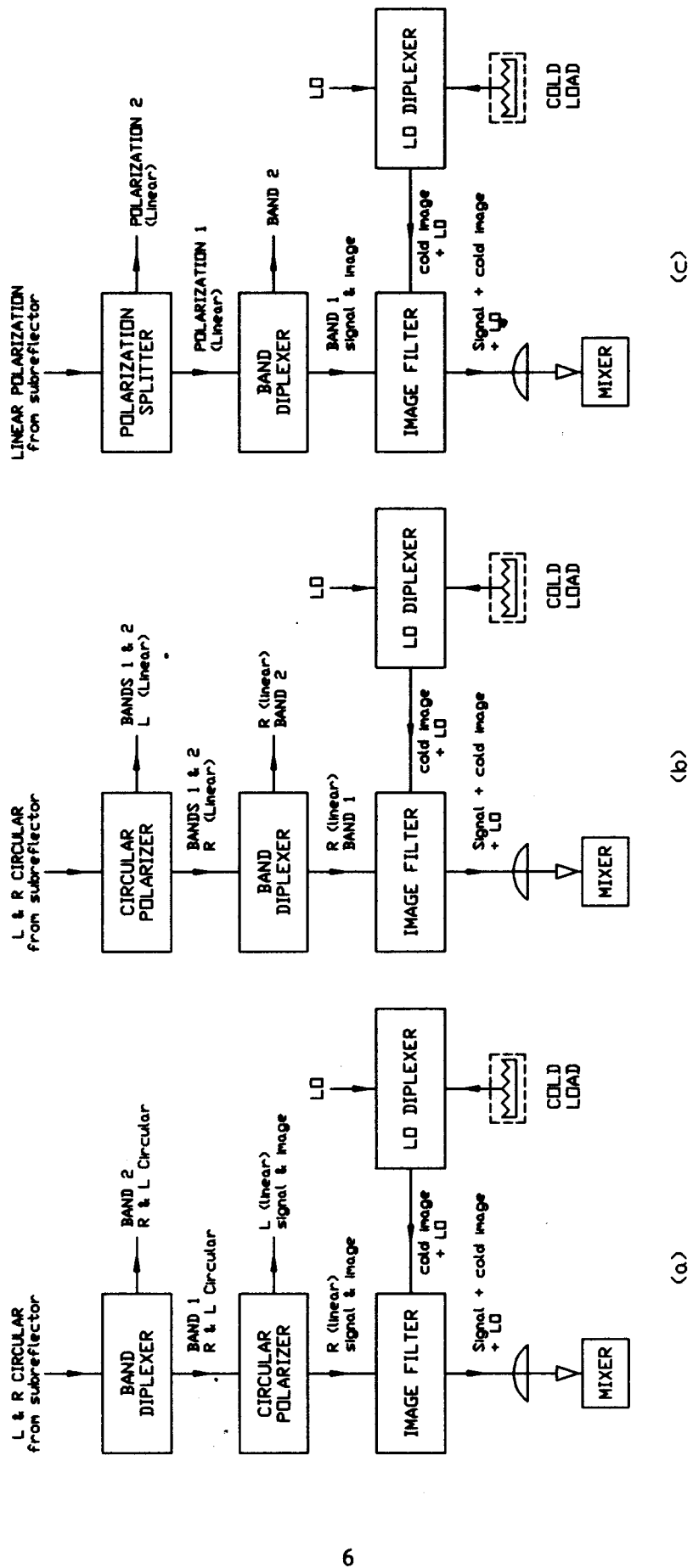


Fig. 1. Three possible arrangements of quasi-optical components.

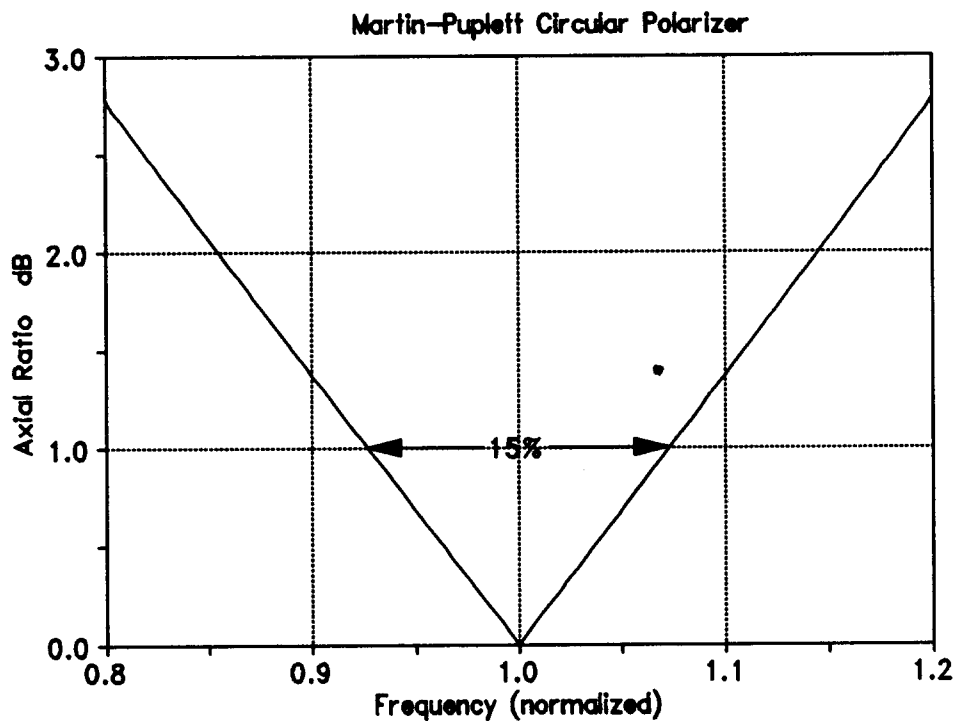


Fig. 2. Axial ratio of a Martin-Puplett interferometer used as a circular polarizer. L & R circular input signals are converted to linear outputs.

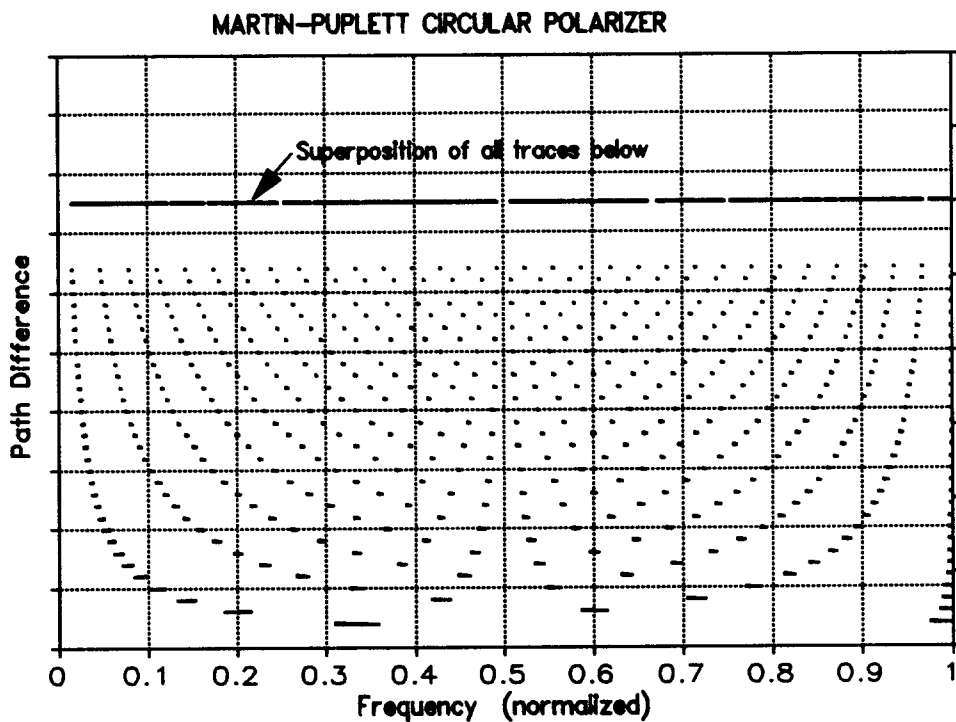


Fig. 3. Frequency coverage of a Martin-Puplett circular polarizer, as a function of interferometer path difference. Axial ratio  $\leq 1$  dB.

### MARTIN-PUPLETT DIPLEXER

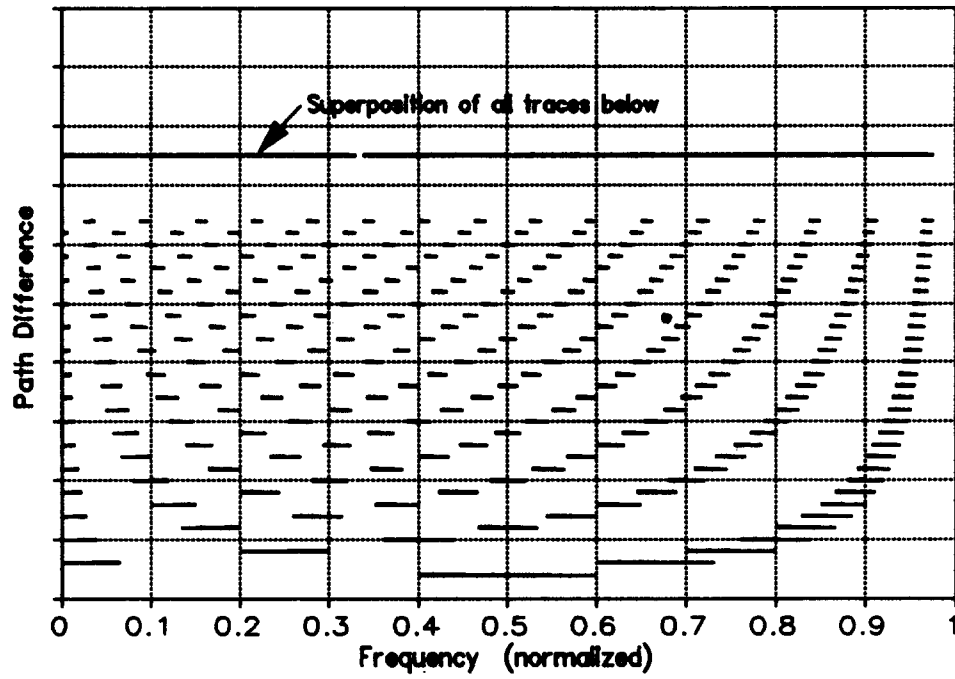


Fig. 4. Frequency coverage of a Martin-Puplett frequency band diplexer, as a function of interferometer path difference. Transmission loss  $\leq 0.1$  dB.



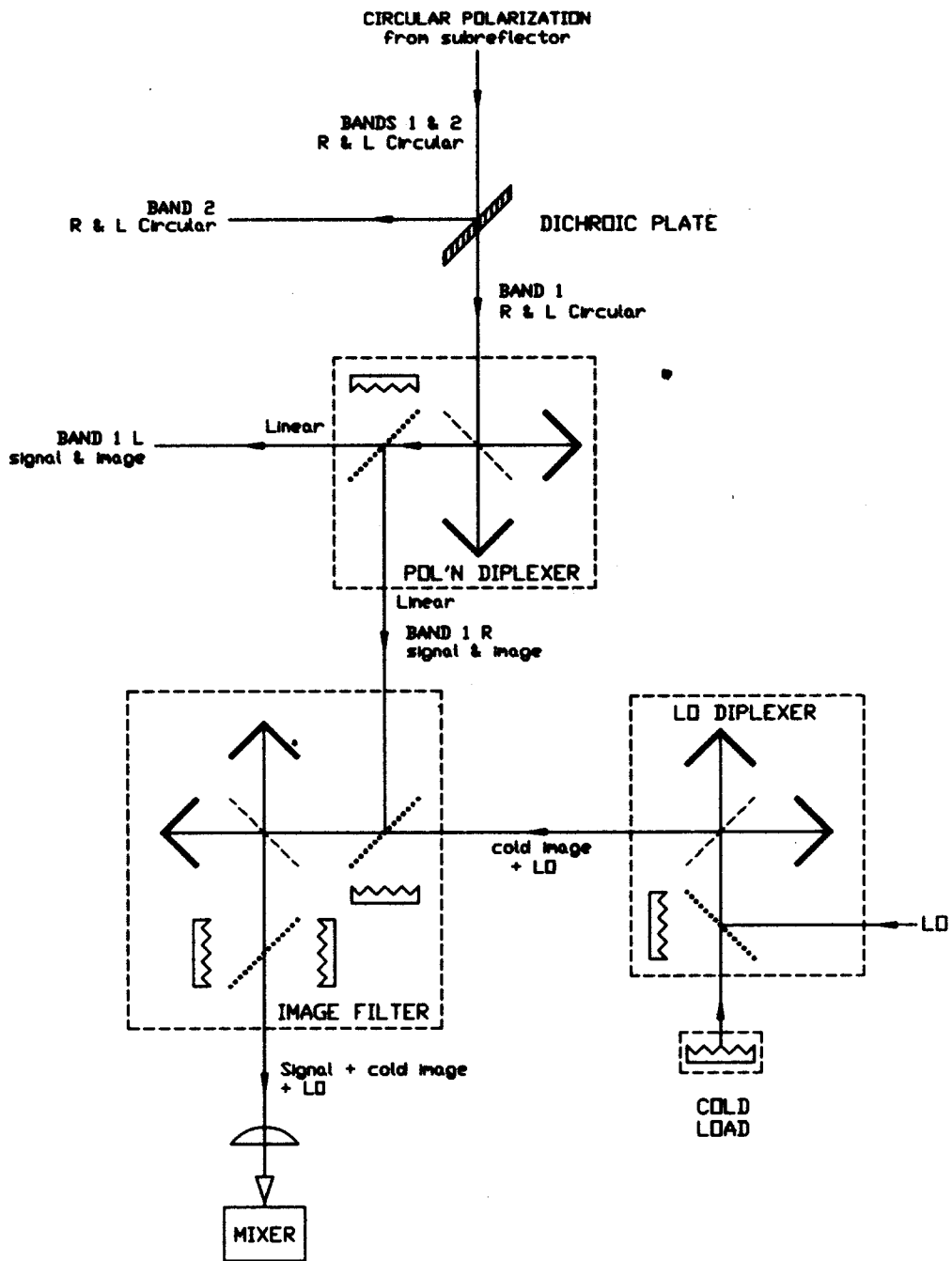


Fig. 5. A possible MMA receiver configuration corresponding to that in Fig. 1(a). The incoming circularly polarized signals are split into separate frequency bands, still circularly polarized, using a dichroic plate.

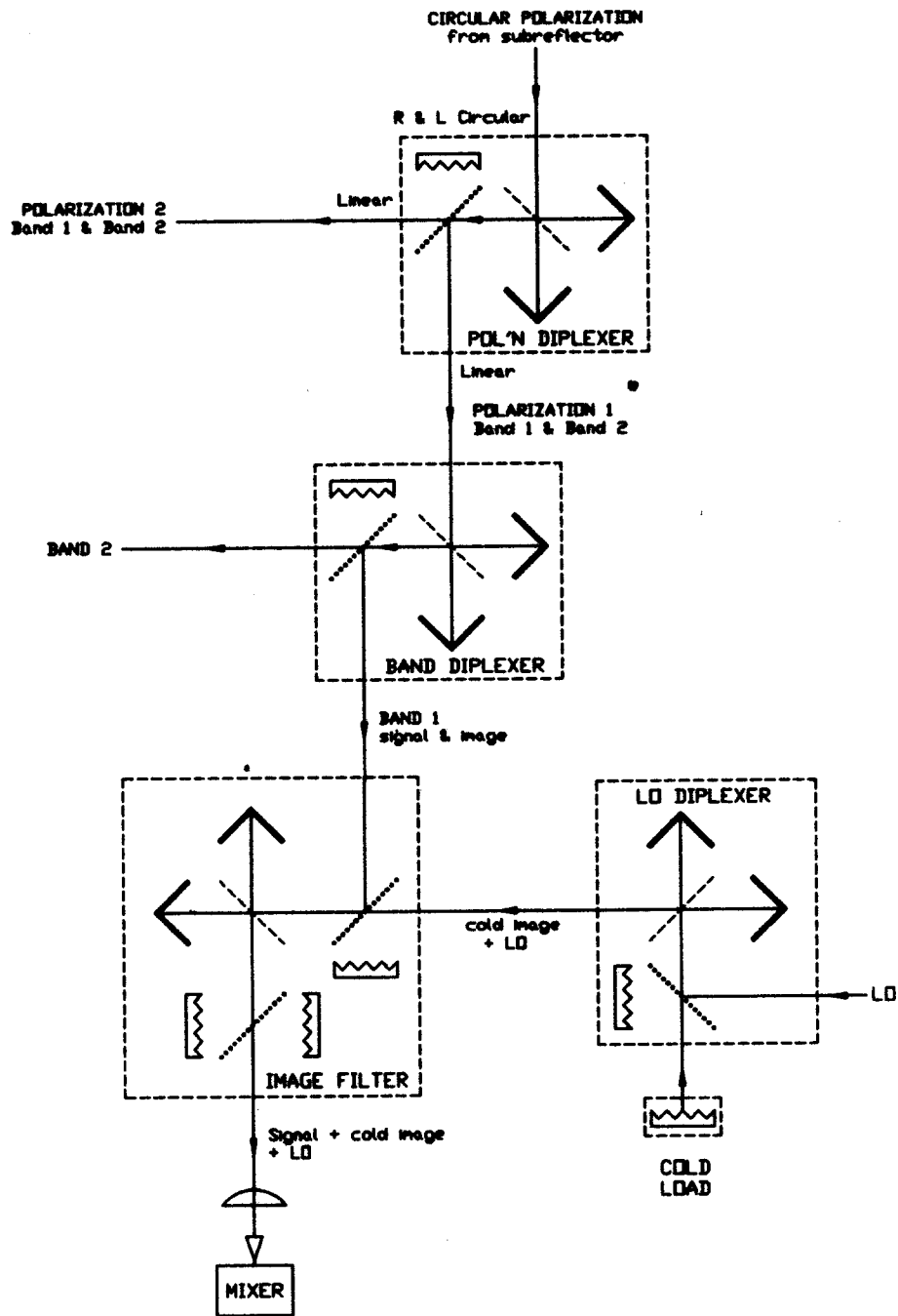


Fig. 6. A possible MMA receiver configuration corresponding to that in Fig. 1(b). The incoming circularly polarized signals in both desired frequency bands are converted to linear polarization using a Martin-Puplett interferometer.

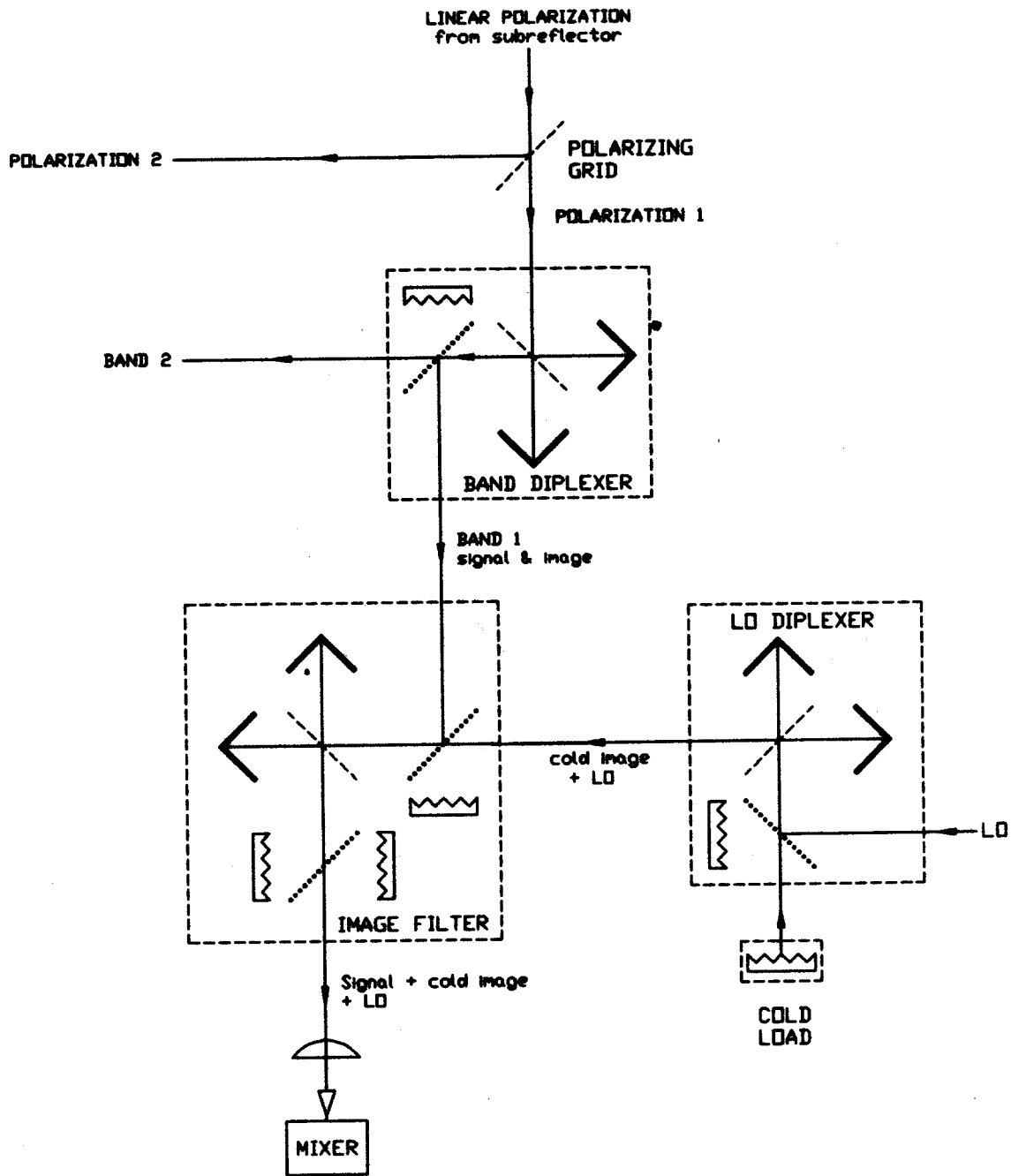


Fig. 7. A possible MMA receiver configuration corresponding to that in Fig. 1(c). The linearly polarized input signals are separated by a wire grid (or pair of crossed grids [4]).