SINGLE SIDEBAND MIXING AT SUBMILLIMETER WAVELENGTHS

Junji Inatani (1), Sheng-Cai Shi (2), Yutaro Sekimoto (3), Harunobu Masuko (4), and Satoshi Ochiai (4)

(1) National Space Development Agency, Tsukuba, Ibaraki 305-8505, Japan
(2) Nobeyama Radio Observatory, National Astronomical Observatory, Nobeyama, Nagano 384-1305, Japan
(3) University of Tokyo, Hongo, Tokyo 113-0033, Japan
(4) Communications Research Laboratory, Ministry of Posts and Telecommunications, Koganei, Tokyo 184-8795, Japan

Abstract

Two quasi-optical circuits are proposed and compared for single sideband mixing at submillimeter wavelengths. First one is a quasi-optical version of the conventional microwave technique for image rejection. Two mixers are combined by means of a single wire-grid polarizer, which works as an RF and LO hybrid simultaneously and also as an RF/LO diplexer. A reflecting-type circular polarizer is used at the LO input port to generate a 90-degree phase-difference between two perpendicular components.

Second approach is a dual polarization usage of the well-known Martin-Puplett Interferometer (MPI). We propose a pair of mixers be used in combination with a single MPI for receiving the upper sideband (USB) and lower sideband (LSB) at the same time. Another MPI is coupled to this configuration for LO injection and image termination to a cold load.

The first approach is superior in realizing a broader RF bandwidth without necessity of mechanical tuning, while the second gives a higher coupling efficiency for LO injection.

Introduction

Low-noise mixers at millimeter and submillimeter wavelengths usually receive signals in upper sideband (USB) as well as in lower sideband (LSB). In astronomical and atmospheric molecular line observations, this property may result in several troubles such as (i) difficulty in precise calibration of line intensity. (ii) increase of the system noise temperature, and (iii) complexity of the IF band due to superposition of signals from both sidebands. To remove these troubles. Martin-Puplett interferometers (MPI) have been used as an image-rejection filter [1]. Since MPI is a high-Q filter, fine mechanical tuning is often required to optimize MPI for each observation frequency. Such mechanical tuning is, however, not desirable for the receiver system which is remotely operated in space or other places of difficult accessibility. Here we would like to propose two quasi-optical circuits for sideband separation, which have no mechanical tuners and are available at submillimeter wavelengths.

Quasi-optical Image-Rejection Circuit

Principle

Operational principle of our first circuit is exactly the same as the conventional microwave image-rejection mixer, which is shown in **Fig.1** [2]. If we apply this principle to the submillimeter mixer, the critical problem is what kind of transmission lines and RF hybrids are available without increasing the insertion loss in the RF path. We propose here to use a quasi-optical Gaussian beam and a polarization beam-splitter. Such quasi-optical image-rejection circuit is shown in **Fig.2**. A piece of wire-grid is used in common as an RF in-phase hybrid and as an LO 90-degree hybrid. If precisely described, there is an additional phase slip of 180 degrees between the transmitted and reflected field, but that does not affect the operation of this circuit. A reflecting-type circular polarizer is used to generate a 90-degree phase-difference between vertical and horizontal components of LO field. The wire-grid used as the RF/LO hybrid also has a role of RF/LO diplexer, although the RF polarization plane is perpendicular to that of LO in both branches. But this is not a problem. If the polarization plane of the mixer input port is slightly tilted from that of the RF beam, the mixer will be coupled efficiently with the RF beam and partially with the LO beam.

As for the IF hybrid, the Lange coupler has been designed to realize a broad

IF bandwidth. Calculated coupling loss and phase difference are shown in **Fig.3** for a center frequency of 2 GHz. This IF circuit could be installed in a single mixer-mount which involves two mixers back-to-back in the geometrical configuration of **Fig.2**.

Characteristics

This new quasi-optical image-rejection mixer is expected to have a very broad bandwidth in RF as well as in IF, in spite of that there is no mechanical tuners. RF bandwidth of a wire-grid for RF/LO hybrid will be sufficiently broad. So a band-limiting factor should be a wire-grid circular polarizer for LO injection. At this device, phase-difference between two perpendicular components is determined by a gap between a wire-grid plane and a flat reflecting mirror. The phase difference therefore changes linearly as LO frequency.

In **Fig.4 (a)** and **(b)**, the coupling efficiencies between RF and IF are calculated for SIGNAL band and IMAGE band separately. The designed IF characteristics of the Lange coupler is included in this calculation. This efficiency is normalized to the ideal one which is realized when the RF and LO are divided in precise amplitude and phase, the two mixers have the same conversion gain, and the IF coupler is perfectly balanced. Changes of IF characteristics are shown with six different curves in each panel of **Fig.4**, which correspond to different LO frequencies from 400 GHz to 500 GHz. The LO circular polarizer is optimized at 500 GHz. So this result shows that the relative RF bandwidth of this quasi-optical image-rejection circuit is more than 30-40 %.

More practical factor of deterioration will be imbalance between two mixers. When the two conversion gains are different by 0.5 dB, for example, the IF characteristics of SIGNAL band suffer about 0.3 dB loss, as shown in **Fig.4 (c)**. But the IMAGE band is not affected by this level of imbalance.

Another possible factor of deterioration is a difference in optical path-length between two branches. However, in this quasi-optical configuration, both the RF and LO beam propagate along the same path between the RF/LO hybrid and the mixer device. So if there is an additional phase in RF due to some path-length difference between two branches, it would be canceled by the similar additional phase in LO. Such path-length difference could affect the image-rejection only when it is large enough compared with the IF wavelength. Actually the IF characteristics shown in **Fig.4** are not affected even if there exists a path-length difference as large as 1 % of the IF wavelength. This means that a fine mechanical tuning of the path-length is not necessary. A fixed configuration which is finished by usual mechanical engineering will be enough to realize a good performance.

Dual-Polarization MPI Circuit

Principle

Our second approach is to use a pair of Martin-Puplett Interferometers in combination with two mixers and a single LO source (**Fig.5**). One MPI works for sideband separation, and the other for LO injection and image termination. Since two mixers receive perpendicular polarizations each other, MIX-1 looks at the Antenna Port in USB and at the Cold Load Port in LSB, while MIX-2 looks at the Antenna Port in LSB and at the Cold Load Port in USB. LO power is delivered into two mixers through two MPIs with the insertion loss of 3 dB.

Characteristics

RF characteristics of this dual-polarization-utilized MPI can be calculated based on the well-known MPI's formula. However, if we want to evaluate the image rejection level, we have to take a non-ideal property of a wire-grid into our consideration. An ideal wire-grid in MPI should have a perfect transmission efficiency for electric field perpendicular to its wire direction, and at the same time, a perfect reflection efficiency for electric field parallel to the wire direction. Even if we optimize geometrical parameters of the wire-grid, there will still remain undesirable reflection for perpendicular field and undesirable transmission for parallel field, which is estimated to be about 1 % in power [3].

We have designed a dual-polarization MPI as shown in **Fig.5** for JEM/SMILES, a submillimeter mission on the International Space Station, where the LO frequency is 638.5 GHz and the nominal IF band is 9-15 GHz. So the LSB is 623.5-629.5 GHz, and the USB is 647.5-653.5 GHz. **Fig.6** shows several insertion losses of this dual-polarization MPI system, which are calculated by assuming 1 % undesirability for the wire-grid. **Fig.6 (a), (b), (c), (d)** show the insertion losses between the Mixer Port (MIX-1 and MIX-2) and the Antenna Port (main polarization and cross polarization). This result shows that there appears some loss even at the center of LSB for MIX-2, and at the center of USB for MIX-1, due to the undesirable transmission and reflection of the wire-grid. **Fig.6 (b), (d)** also show that the image-rejection level is affected by a more efficient coupling between the Mixer Port and the cross polarization at the Antenna Port.

Fig.6 (e), (f), (g), (h) show the insertion losses between the Mixer Port and the Cold Load Port (main polarization and cross polarization). The insertion loss is larger than that for the Antenna Port due to two MPIs used in series. This is not negligible, because it increases the thermal noise injected into the image band, which results in the increase of the SSB system noise temperature. From these calculations, we find it is important to keep the undesirability of the wire-grid less than 1 % in power.

Comparison

Two kinds of quasi-optical sideband separation techniques described above have several advantages and disadvantages. They are summarized in **Table 1**. The quasi-optical image-rejection circuit is superior in broad instantaneous RF bandwidth, which is realized without necessity of mechanical tuning. It is possible to use the dual-polarization MPI in a fixed setting, but in that case we have to fix the LO frequency, so the RF bandwidth is also fixed within the IF bandwidth. The image-rejection circuit also has a broader IF bandwidth, if a broad IF hybrid such as the Lange coupler is available. The IF bandwidth of the dual-polarization MPI is limited by the cosine function of MPI.

As for the LO injection loss, the dual-polarization MPI is superior. Its theoretical value is only 3 dB, which is inevitable because the LO power is supplied to two mixers. But in the quasi-optical image-rejection circuit, the LO power is divided into two components at first (3 dB), and then each component is only partially coupled to the mixer. We have to keep this coupling efficiency less than about 5 % (13 dB loss), in order not to sacrifice the more important RF coupling to the mixer.

There is also an important difference in mixer operation mode. Two mixers should be well balanced in the image-rejection circuit, but they are operated independently in the dual-polarization MPI. Even in an extreme case when one of the two mixers had a failure, the other mixer could work properly in the single sideband mode in the latter circuit. This is of practical importance in space applications, to avoid a complete damage of the system.

Conclusions

We have proposed two techniques of quasi-optical sideband separation which could be available for submillimeter mixing. One is a quasi-optical version of the conventional microwave image-rejection circuit, and the other is a dual polarization usage of the well-known Martin-Puplett interferometer. The former technique is superior in realizing a broader RF bandwidth without necessity of mechanical tuning, while the latter gives a higher coupling efficiency for LO injection. Further experimental investigations are needed for both techniques.

References

[1] D. H. Martin and E. Puplett, Infrared Physics, 10, 105-109, 1970

[2] e.g. S. A. Maas, "Microwave Mixers," Artech House, Inc., 1986

[3] W. G. Chambers, A. E. Costly and T. J. Parker, International Journal of Infrared and Millimeter Waves, 9, No.2, 157-172, 1988

	Quasi-Optical Image-Rejection Circuit	**Dual-Polarization MPI Circuit**
RF Bandwidth (Instantaneous)	Broad [Limited by LO circular polarizer.]	Narrow [Limited by MPI.]
RF Bandwidth (Tuning Coverage)	N/A	Broad [Limited by wire-grid and beam diversion.]
IF bandwidth	Broad [Limited by IF hybrid.]	Moderate [Limited by MPI.]
RF Insertion Loss (N wire-grids inserted)	Small [Three wire-grids]	Small [Four wire-grids]
LO Injection Loss	> 16 dB	3 dB
Mechanical Tuning	None	Necessary for broad RF coverage.
Two Mixers	should be balanced.	are independent.

Table 1 Comparison of two quasi-optical circuits for sideband separation.

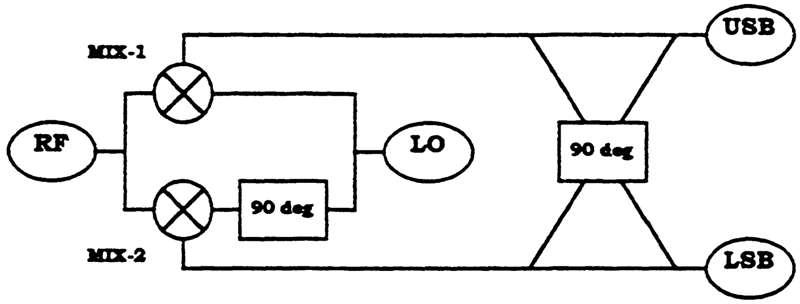

Fig.1 Principle of the conventional microwave image-rejection mixer circuit.

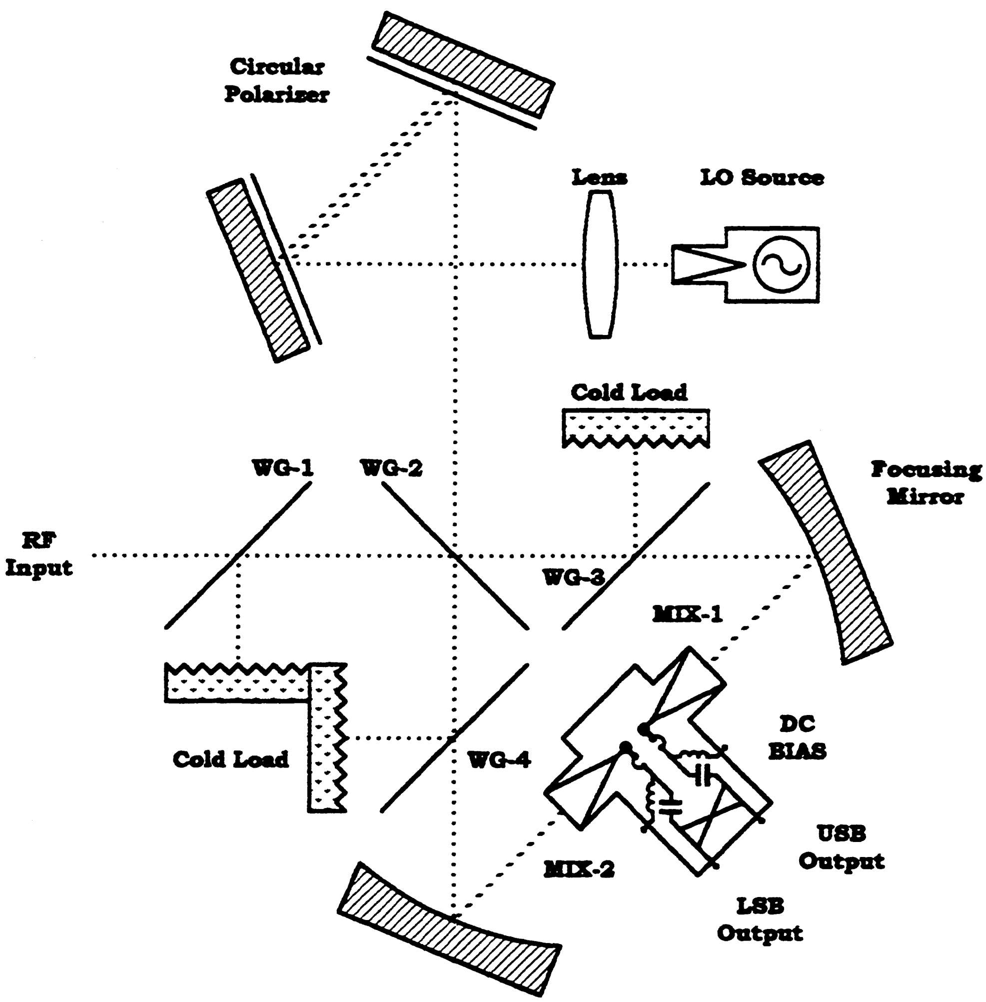

Fig.2 Quasi-optical image-rejection circuit. Role of each wire-grid (WG) is as follows: WG-1 to define the RF input polarization (cross polarization is terminated to a cold load), WG-2 to split RF as well as LO, WG-3 and WG-4 to define the mixer input polarization. Reflected LO power is terminated to absorbers.

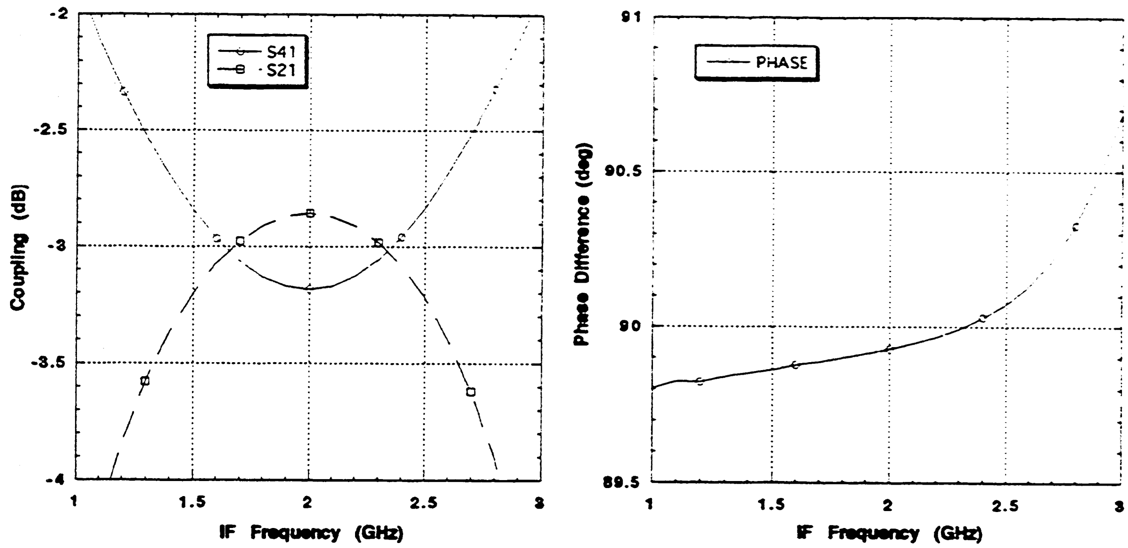

Fig.3 Calculated coupling and phase-difference of the Lange coupler which is designed for a center frequency of 2.0 GHz.

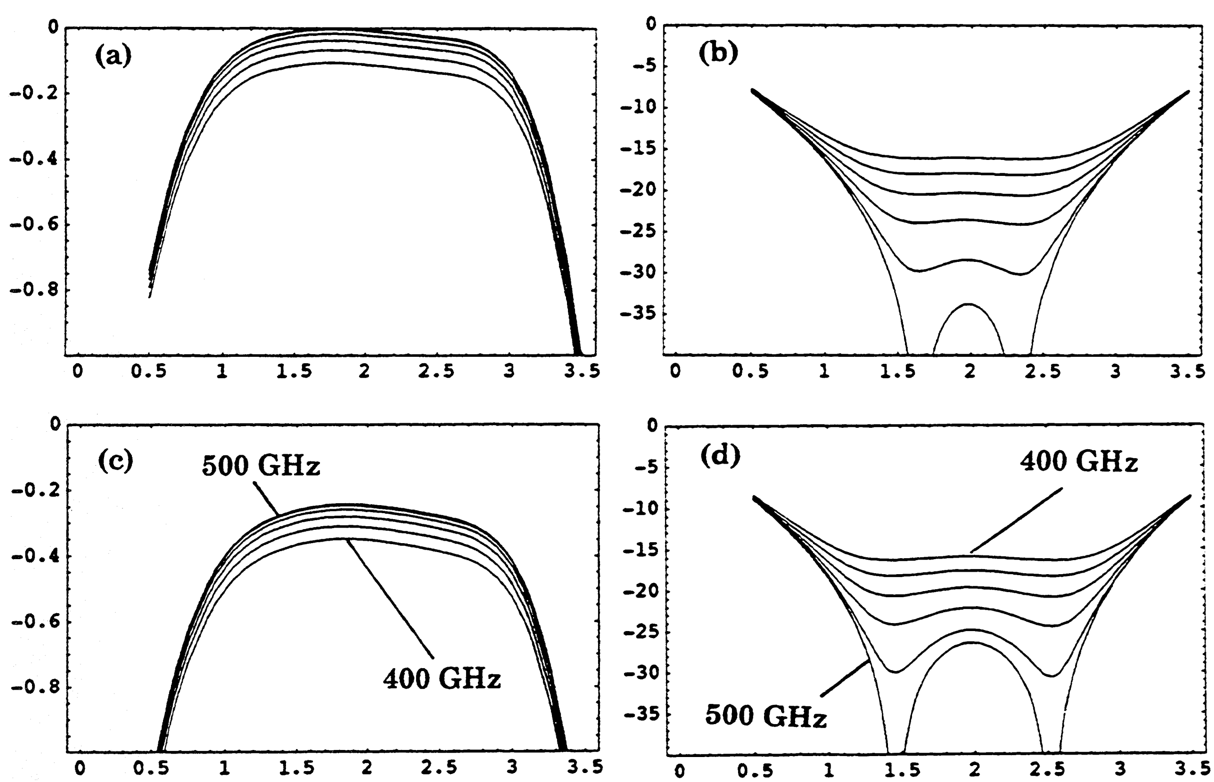

Fig.4 (a) Coupling efficiency in the SIGNAL band between RF and IF through the quasi-optical image-rejection circuit in Fig.2. **(b)** Same in the IMAGE band. **(c)** Same in the SIGNAL band when 0.5 dB gain difference exists between two mixers. **(d)** Same in the IMAGE band for 0.5 dB difference.

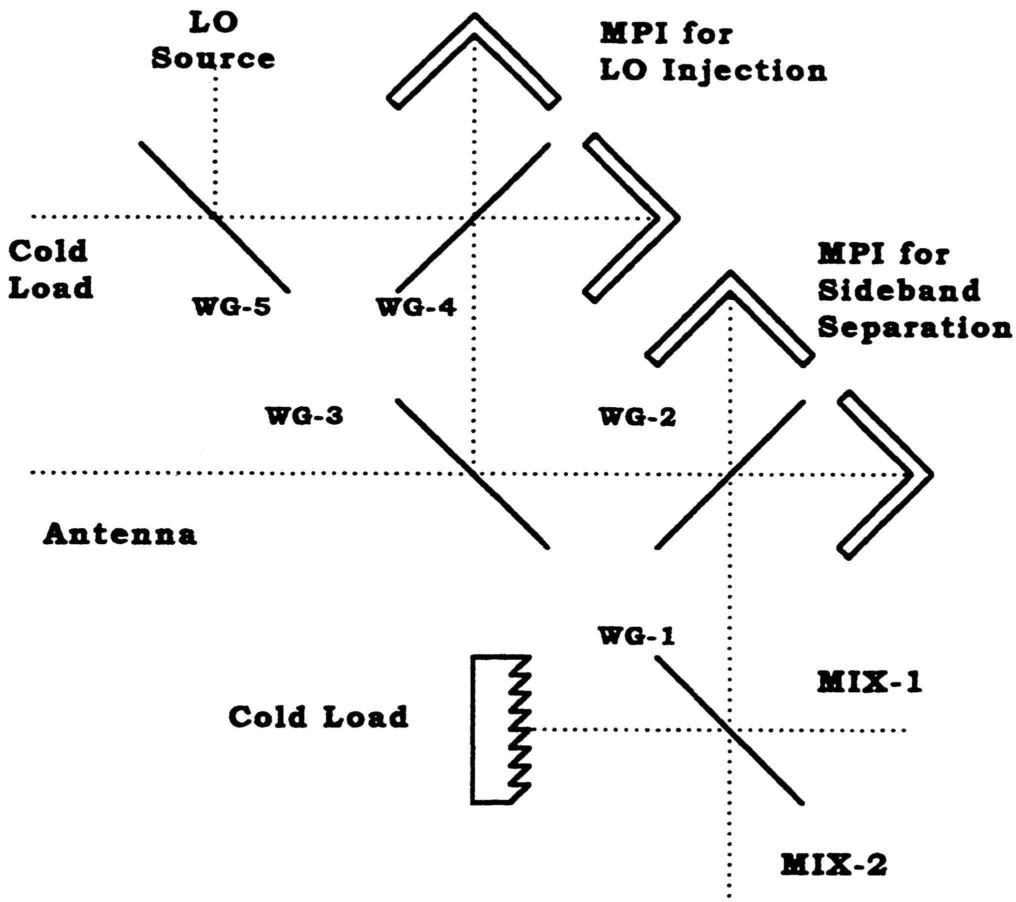

Fig.5 Dual-polarization-utilized MPI circuit. WG-1 to WG-5 are wire-grids. MIX-1, receiving a horizontal polarization, looks at the Antenna Port in the USB and at the Cold Load in the LSB, while MIX-2, receiving a vertical polarization, looks at the Antenna Port in the LSB and at the Cold Load in the USB.

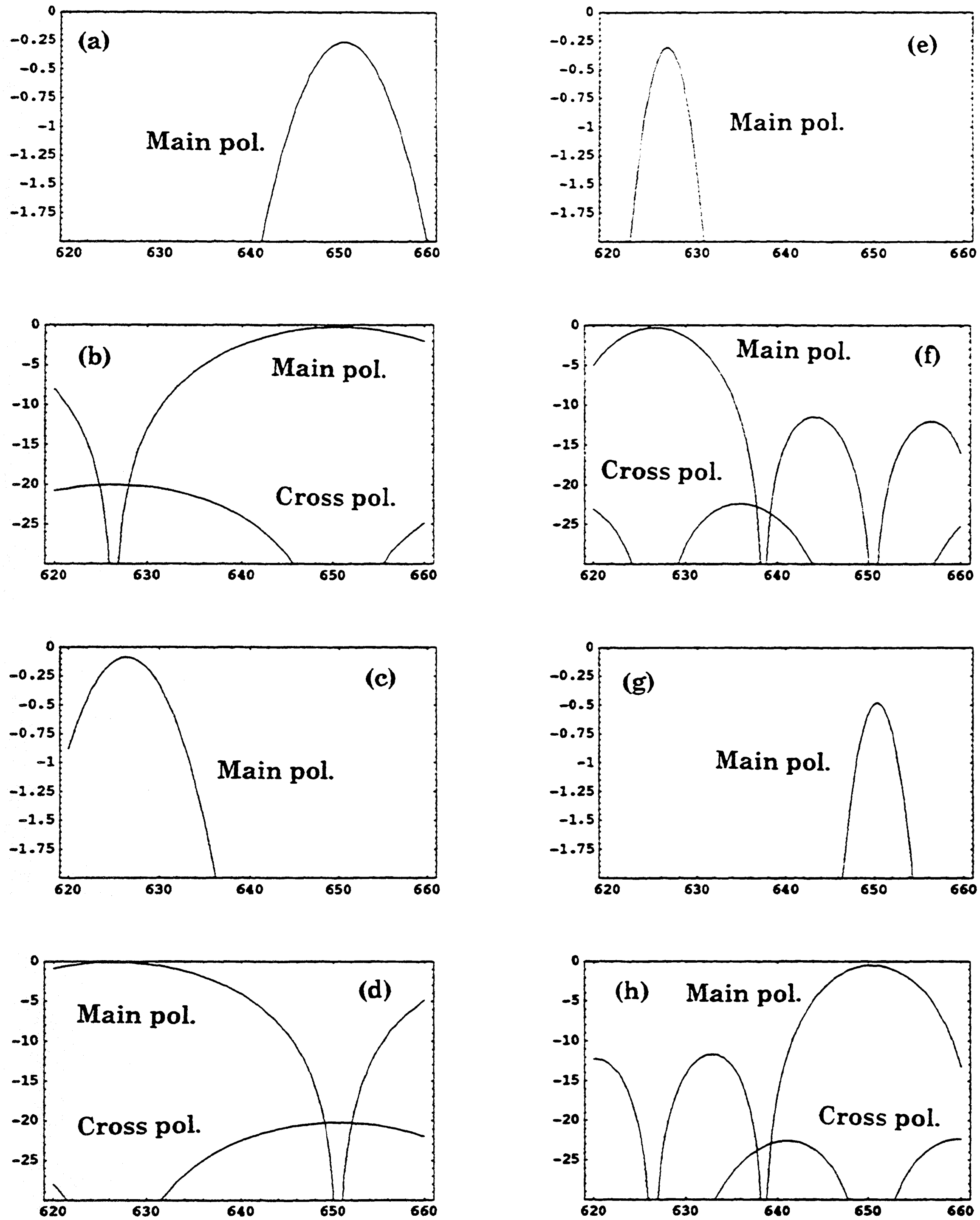

Fig.6 **(a),(b)** Insertion losses (dB) between MIX-1 and the Antenna Port in its main and cross polarizations. **(c),(d)** Same for MIX-2. **(e),(f)** Insertion losses (dB) between MIX-1 and the Cold Load Port in its main and cross polarizations. **(g),(h)** Same for MIX-2.