Multi-layered chiral filters response at oblique incidence

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Abstract

The response of multi-layered chiral filters is investigated at oblique incidence. It is found that there is a slight degradation with respect to the same filter operating at normal incidence. A possible application is proposed for this device: a reflector or a subreflector fed at two different frequencies by two feeds situated on each side of a multi-layered chiral filter functioning as a frequency selective surface. The response of this device is well-behaved and is similar for TE and TM modes.

1 Introduction

The theory of thin-film optical dielectric filters is well established [1]. The multi-layered chiral filters response in the microwave frequency range has been studied at normal incidence by Cory and Rosenhouse [2]. These devices are intended to replace their dielectric counterparts [3, 4], when the synthesis of the latter has yielded values of refractive indices which are not available, and, what is more, they are able to rotate the plane of polarization of the transmitted wave by a given angle. These features are due to the extra degree of freedom provided by the chirality admittance. The purpose of this communication is to study the response of the multi-layered chiral filters at oblique incidence and to propose a possible application of these devices. The reflection and the transmission coefficients of chiral slabs and of multi-layered chiral structures have been studied intensively [5, 6, 7, 8]. Our study is based on a full-wave analysis due to Altman and Cory [9], from which practical designs have been derived for various chiral devices [10]. In this analysis, the roots of the Booker quartic appearing in the expressions of the reflection and the transmission coefficients are simply replaced by the wave numbers of the circularly polarized waves propagating in each slab. This filter is an additional device turning to account the useful properties of chiral materials for engineering purposes [11, 12].

2 The Filter Response at Normal Incidence

At the basis of our method [2] is the requirement that the characteristic impedances and effective widths of the slabs composing the equivalent chiral filters be equal to those of the corresponding dielectric filters. The characteristic impedance of a slab is given by $Z = \sqrt{\mu/(\varepsilon+\gamma^2\mu)}$ while its effective width is given by $EW = \omega_0\sqrt{\mu\varepsilon+\gamma^2\mu^2}\,d/2\pi$, where d, ε, μ, and γ are its width, permittivity, permeability and chirality admittance, respectively, ω_0 being generally the central frequency in the frequency range under consideration. For a dielectric slab, $\gamma = 0$, evidently. The width of the chiral slab is normalized in such a way as to secure an equivalent dielectric slab with an identical impedance Z so that the two slabs possess the same reflection coefficient at normal incidence [2], whence the chiral filter bandwidth is identical to that of its dielectric counterpart. It is possible to determine the angle of rotation of the plane of polarization of the electromagnetic wave emerging from the chiral filter, by a suitable choice of the signs of the chirality admittances of the various slabs constituting it. An accurate model which considers lossy frequency-dependent parameters [13] has been used to design a wide stop-band filter, whose features are given in Table 1.

Number of layer	1	2	3	4	5	6	7	8
Relative permittivity	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Effective width	0.1712	0.788	0.25	0.25	0.25	0.25	0.25	0.25
Chirality admittance [mmho]	11.9	-11.9	-7.7	5.3	-3.6	2.5	-1.7	1.1

Table 1: The parameters of the layers constituting a chiral filter having a substrate of relative permittivity 2.31 and resulting in a zero rotation coefficient.

3 The Filter Response at Oblique Incidence

The filter described in the previous section has been designed for normal incidence. The filter response (transmittance and polarization), will be different at oblique incidence. The change in transmittance is due to a change in the layers effective width and to a change in the reflection and transmission coefficients at the layers interfaces. At oblique incidence, the effective width is larger so that the filter central frequency tends towards lower frequencies. In the region surrounding a normalized frequency equal to one, the change in frequency does not modify the filter response so that the observed effects are due only to the changes of the reflection and the transmission coefficients at the layers interfaces. The filter response (transmittance) as a function of the normalized frequency is given in Fig. 1 for various angles of incidence in the TE and the TM modes.

4 Application

A frequency selective surface (FSS) is a device that transmits or reflects specific frequency bandwidths. At microwave frequencies the usual implementation of the device is by thin metallic periodic patterns lying on a supporting substrate. Its main drawback is that its performance is impaired by absorption and reflection effects. On the other hand, the implementation of the device by chiral layers is simple, and is much less sensible to these drawbacks. A practical application of the device is given as follows: a reflector or a subreflector can be fed at two different frequencies (f_1 and f_2) by two horn feeds situated on each side of a FSS as shown in Fig. 2. The device must strongly reflect at f_1 and strongly transmit at f_2 in order for this configuration to constitute an effective frequency selective surface. At a given angle of incidence, the reflection or the transmission coefficients are identical when impinging on either side of the surface, for a filter having a symmetric structure. We shall analyze a thirteen-layers filter having the parameters described in Table 2. The angles of incidence are 15°, 20° and 25°, and the modes of propagation are TE and TM. The losses have been calculated for the parameters $K_\varepsilon = 0.005$ and $K_\gamma = 0.01$ where K_ε and K_γ are the ratios of the imaginary parts to the real parts of the permittivity and of the chirality admittance, respectively. The transmittance and the reflectance of the above mentioned filter are given as a function of the normalized frequency in Figs. 3 and 4 for TE and TM modes.

Number of layer	1	2	3	4	5	6	7	8	9	10	11	12	13
Relative permittivity	3	2	3	2	3	2	3	2	3	2	3	2	3
Effective width	0.125	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.125
Chirality admittance [mmho]	3	0	-3	0	3	0	-3	0	3	0	-3	0	3

Table 2: The parameters of the filter used for the configuration shown in Fig. 2.

5 Conclusion

The response of a multi-layered chiral filter has been investigated at oblique incidence. We have seen that for a filter which has been properly designed at normal incidence, there is a slight degradation when the angle of incidence grows. But in some cases, as in the above-mentioned application, oblique incidence is required. The response is slightly better for lower angles of incidence, but anyhow, it is remarkably well-behaved and serves its purpose as expected. Finally, it should be noted that the response is very similar for TE and TM modes, which is a very desirable feature of the device.

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Figure Captions

Figure 1: The transmittance as a function of frequency for the filter given in Table 1. The angle of incidence is shown as a parameter.

a) TE incident waves.

b) TM incident waves.

Figure 2: A configuration for a reflector or subreflector feeding with two horn antennas at different frequencies separated by a frequency-selective chiral multi-layered structure.

Figure 3: The transmittance and the reflectance as a function of frequency for the filter given in Table 2 for TE modes. The angle of incidence is shown as a parameter.

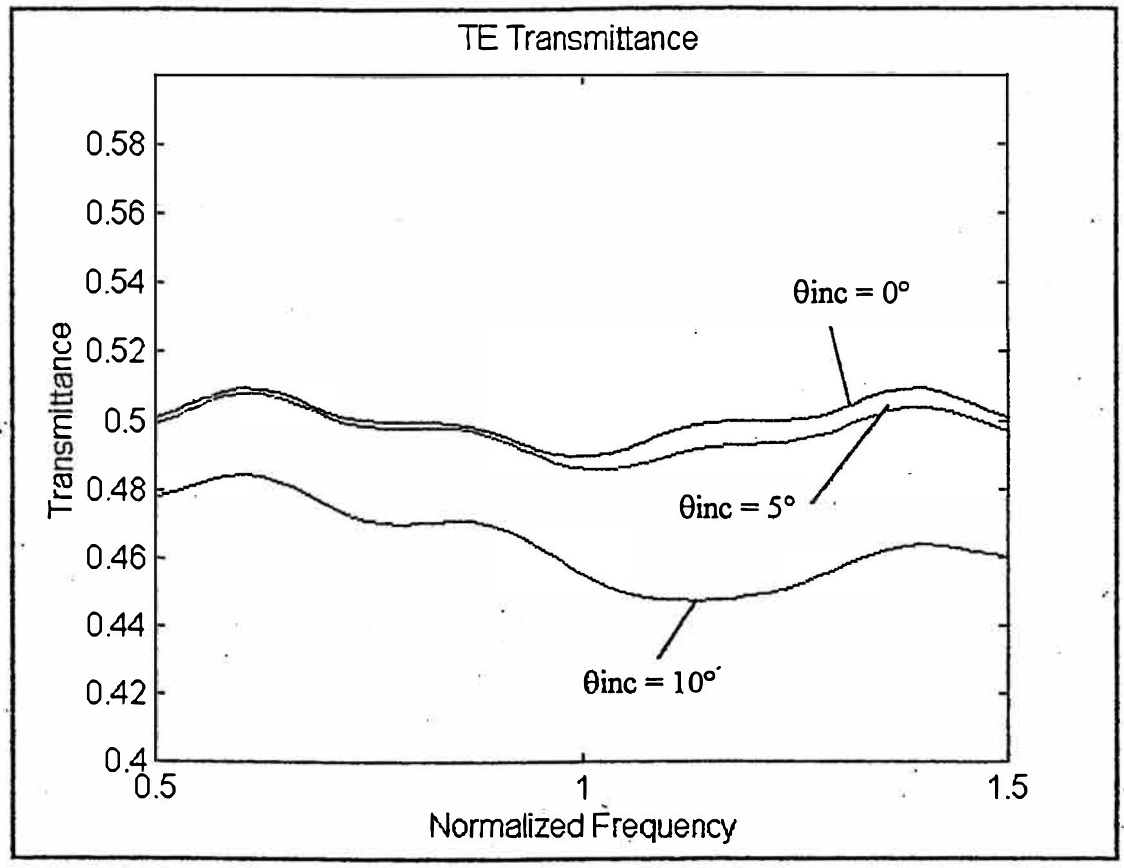
a) Transmittance.

b) Reflectance.

Figure 4: The transmittance and the reflectance as a function of frequency for the filter given in Table 2 for TM modes. The angle of incidence is shown as a parameter.

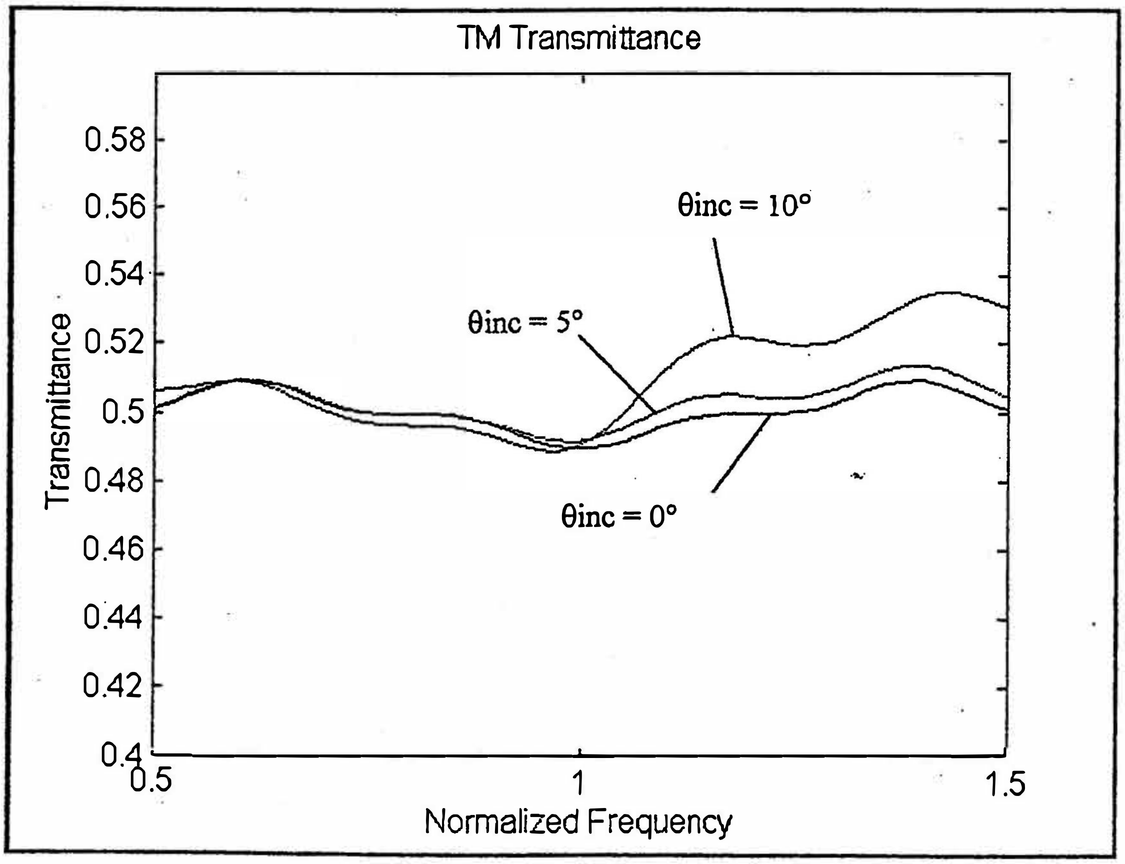
a) Transmittance.

b) Reflectance.



TE Transmittance
Transmittance
Normalized Frequency
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
0.5
1
1.5
θinc = 0°
θinc = 5°
θinc = 10°

a



TM Transmittance
Transmittance
Normalized Frequency
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
0.5
1
1.5
θinc = 10°
θinc = 5°
θinc = 0°

b

Figure 1

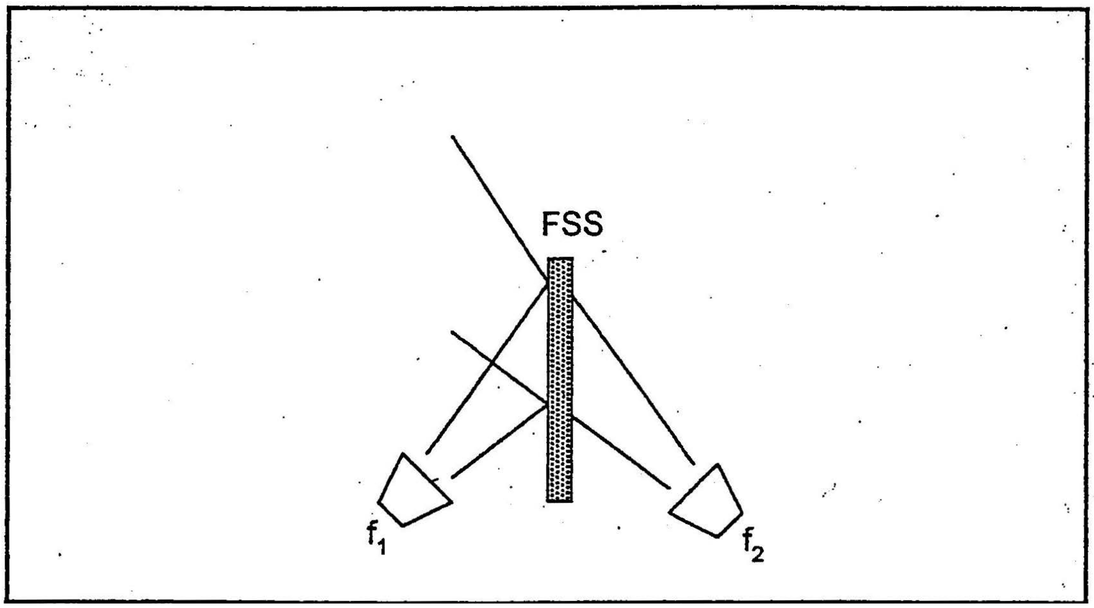
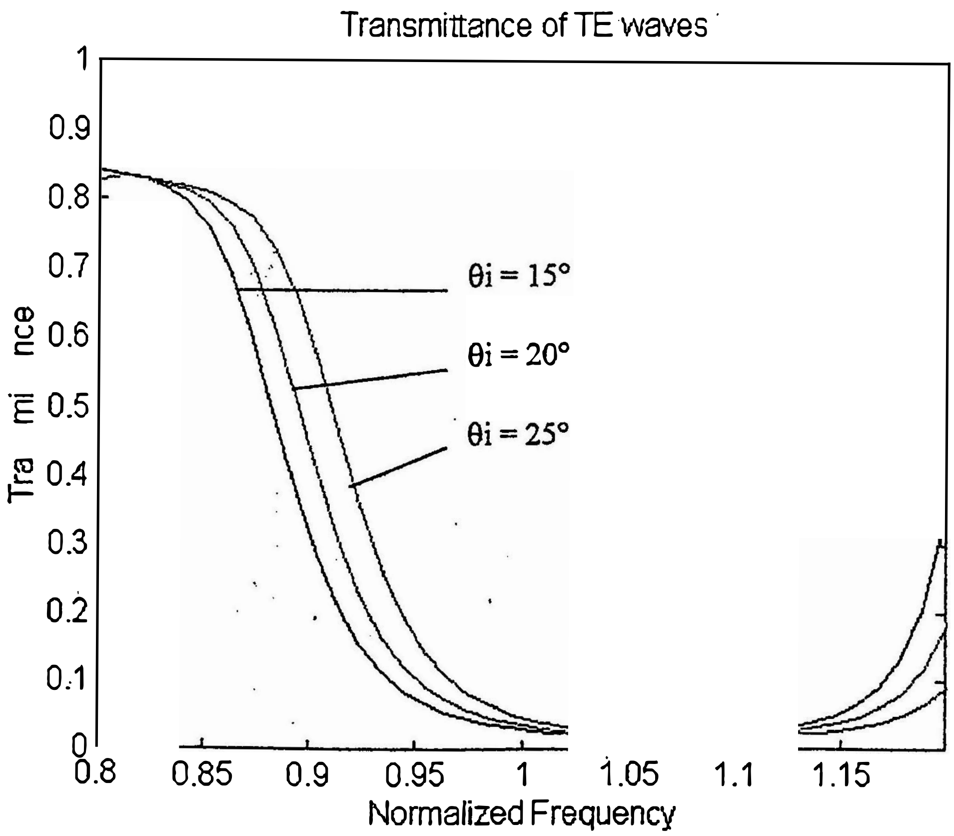
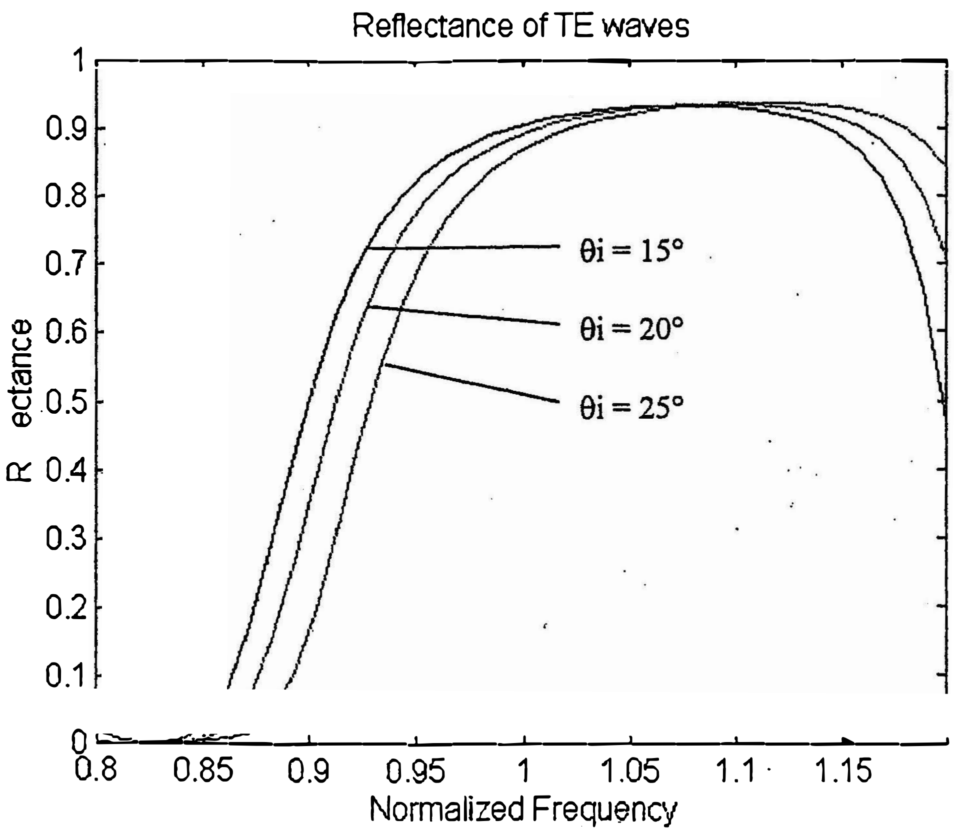


Figure 2

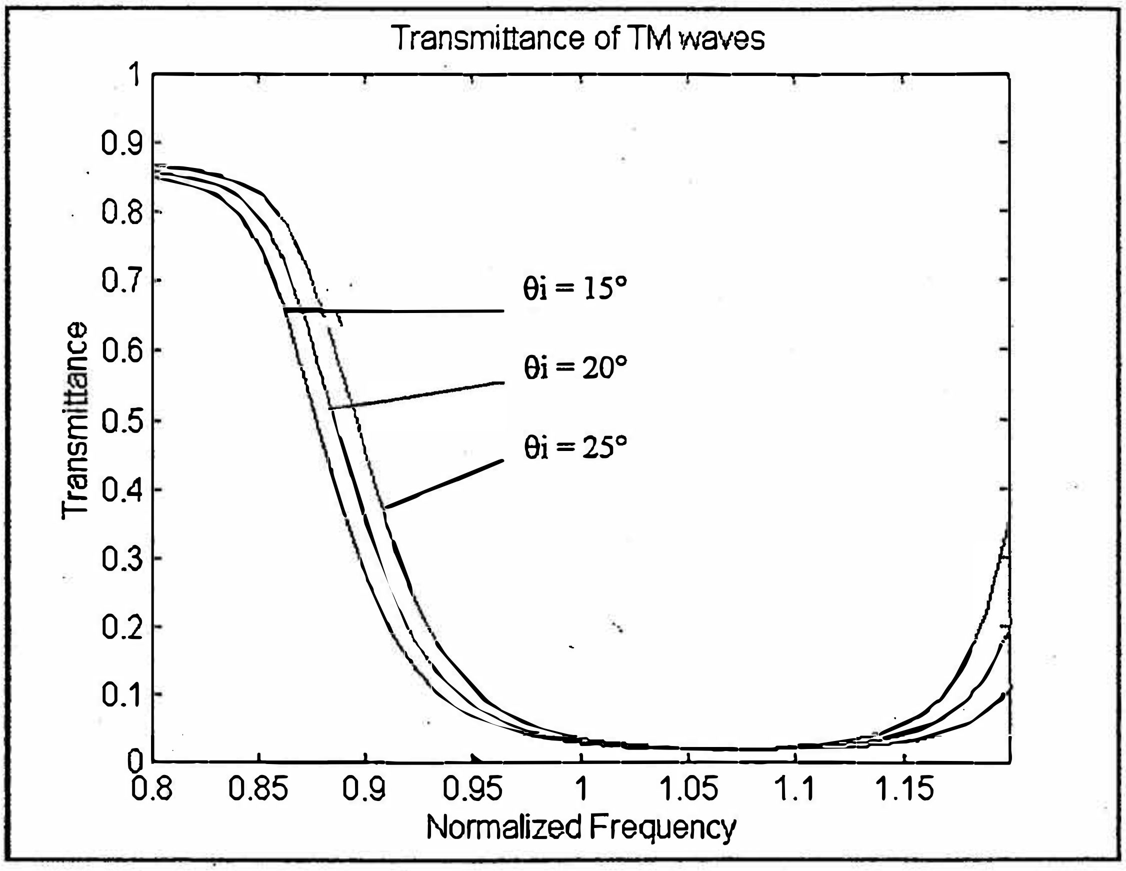

Transmittance of TE waves
Tra mi nce
θi = 15°
θi = 20°
θi = 25°
Normalized Frequency
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15

a

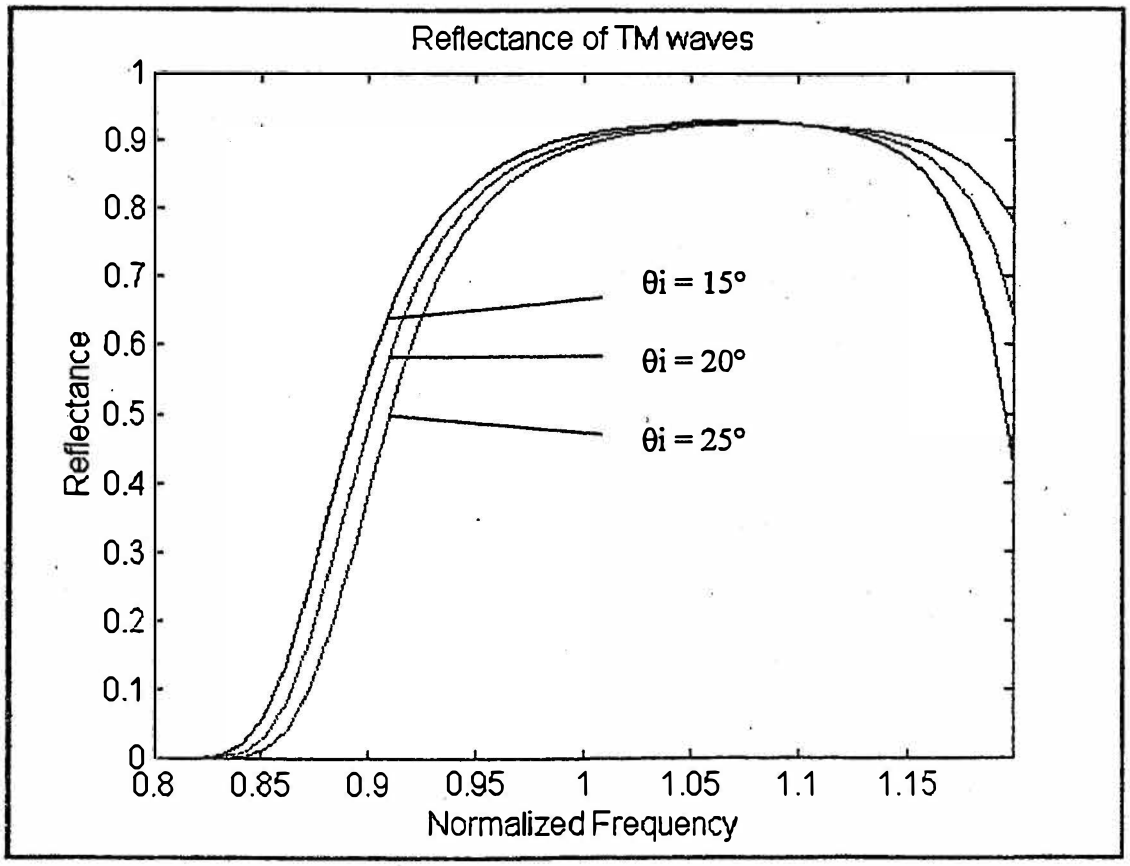

Reflectance of TE waves
R ectance
θi = 15°
θi = 20°
θi = 25°
Normalized Frequency
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15

b

Figure 3


Transmittance of TM waves
Transmittance
Normalized Frequency
θi = 15°
θi = 20°
θi = 25°
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15

a


Reflectance of TM waves
Reflectance
Normalized Frequency
θi = 15°
θi = 20°
θi = 25°
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15

b

Figure 4

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