DESIGN OF THICK FREQUENCY SELECTIVE SURFACES WITH COMPLEX APERTURES: DICHROICS WITH CROSS-SHAPED AND STEPPED RECTANGULAR APERTURES†

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I. Introduction

The unit cell shape of a thick frequency selective surface, or dichroic plate, is dependent on its frequency requirements. One aperture shape may be chosen to give wider bandwidths, and another chosen for sharper frequency roll-off. This is analogous to circuits where the need for differing frequency responses determines the circuit topology. Acting as spatial frequency filters, dichroics are a critical component in supporting the Deep Space Network(DSN) for spacecraft command and control up links as well as spacecraft down links. Currently these dichroic plates separate S-Band at 2.0 - 2.32 GHz from X-band at 8.4 - 8.45 GHz. But new spacecraft communication requirements are also calling for an up link frequency at 7.165 GHz. In addition future spacecraft such as Craf/Casssini will require dichroics effectively separating K_a-band frequencies in the 31-35 GHz range.

The requirements for these surfaces are low transmission loss of < 0.1 dB at high power levels. Also it is important to maintain a minimal relative phase shift between polarizations for circular polarization transmission. Even in the past these demanding requirements caused the dichroic designs to change from circular apertures to pyle apertures. More current work has shown the successful demonstration of design techniques for straight, rectangular apertures at an incident angle of 30°[1]. The plates are air-filled due to power dissipation and noise temperature considerations. Up-link frequency powers approach 100 kW making dielectrics undesirable.

Here we address some of the cases in which the straight rectangular shape may have limited usefulness. For example, grating lobes become a consideration when the bandwidth required to include the new frequency of 7.165 GHz conflicts with the desired incident angle of 30°. For this case, the cross shape's increased packing density and bandwidth could make it desirable; see Figure 1. When a sharp frequency response is required to separate two closely space K_a-band frequencies, the stepped rectangular aperture shown in Figure 2 might be advantageous.

II. The Dichroic with Cross-Shaped Apertures

In order to diplex the X-band down link at 8.425 GHz and the new up link of 7.165 GHz, cross-shaped apertures in a dichroic plate have been investigated. Figure 1 shows the geometry. The analysis consisted of an integral equation method of moments solution[2, 3]. The model consists of a thin-walled cross on a

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skewed grid. This method solves for the currents along the walls inside the cross, including those along the hole depth in the z direction[4].

The transmission results for an air filled, cross-shaped aperture with dimensions $a_x = 2.65$ cm, $b_x = 0.6$ cm, $a_y = 2.76$ cm, $b_y = 0.7125$ cm, an aperture depth of 3.5 cm, a skewed grid angle of $\Omega = 33.95°$, and incident angle of $\theta = 30°$ are shown in Figure 3. Because cross-shaped apertures pack more tightly than rectangular apertures, it is possible to obtain a dichroic with the desired dual X-band pass bands grating lobe free. In contrast this could not be done with the air-filled rectangular shape without the introduction of grating lobes because the minimum unit cell size is the size of the aperture. Tightly packed cross shaped elements overlap in the x direction, reducing the unit cell size in the x direction to less than the length of the cross arm a_x.

The current design dimensions give a plate that will be grating lobe free to $\theta = 44°$ at $\phi = 0°$(i.e. from the more tightly packed x direction) and frequency of 8.625 GHz. This design also gives a minimum phase shift between the two transmitted polarizations at the more critical down-link frequency of 8.425 GHz. The phase difference at the down-link frequency is small, 2.93°, but the tradeoff is a phase difference at the up link of 16.9°. If more phase shift is allowed at the up-link frequency, which could be compensated for by a polarizer, a slightly different design would allow for slightly more bandwidth. The current disadvantage of this analysis is the thin wall approximation.

III. The Dichroic with Stepped Rectangular Apertures

A dichroic is needed to separate the K_a-band down link at 31.8 - 32.3 GHz (reflecting band), from the K_a-band up link at 34.2 - 34.7 GHz (pass band) in the Deep Space Network's Beam Waveguide Antenna. The reflective band is the down link, a weak signal from deep space. At the same time the dichroic is required to pass 34.2 - 34.7 GHz with low insertion loss. Therefore the apertures should be small enough to cut off the low frequency band, yet big enough to pass the high frequency band. A dichroic with straight rectangular apertures may not separate these two closely spaced frequency bands. Hence a thick dichroic with stepped waveguides which function as cavity filters is chosen.

The analysis is based on the modal matching method. The free space region is represented by Flouquet modes and the waveguide region is represented by rectangular waveguide modes. First, the scattering matrix at the interface between the free space and waveguide region is calculated using the method of moments[1]. Next, the scattering matrix of the stepped waveguide region is computed[5]. Finally, cascading these matrices gives the scattering matrix of the thick frequency selective surface with stepped rectangular apertures. Figure 4 shows the magnitude of the transmission coefficients for the TE and TM polarizations. The curves indicate -50 dB transmission for the K_a-band down link and about -0.5 dB for the K_a-band up link. It is not a fully optimized design.

The difficulty of this stepped design is the tolerance sensitivity. Half-thousandth inch tolerance or better is required. And here again since the signal used in the Deep Space Network is a circularly polarized wave, the relative phase shift between the TE and TM polarizations is important. Further studies on these two topics are needed.

IV. References

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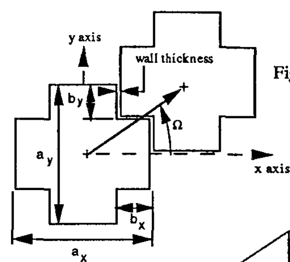

Figure 1. Geometry of a Dichroic Consisting of Cross Shaped Apertures, Top View

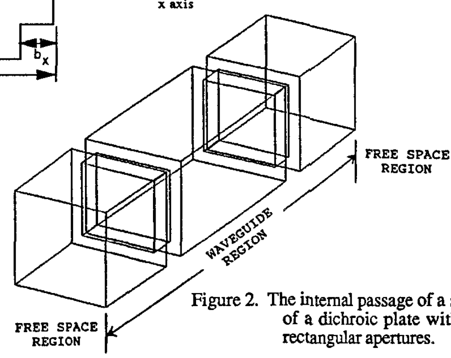

Figure 2. The internal passage of a single cell of a dichroic plate with stepped rectangular apertures.

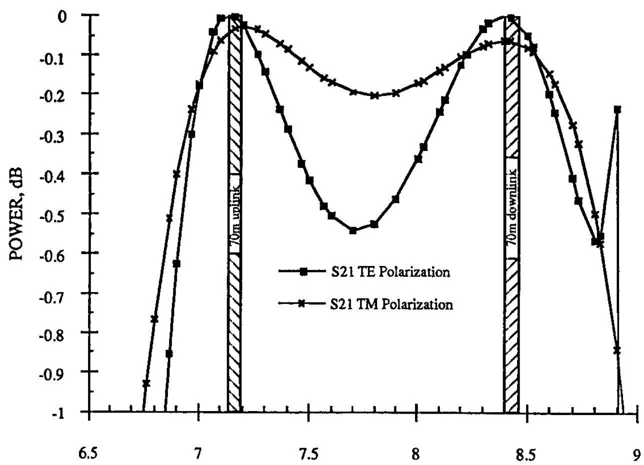

Figure 3. The power transmission coefficients for a dichroic plate with cross-shaped apertures.

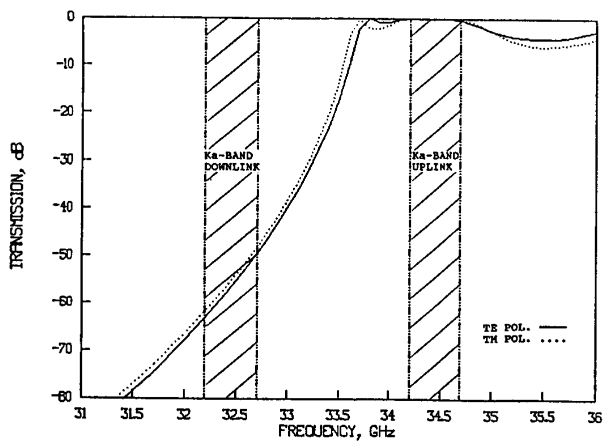

Figure 4. The transmission coefficients for a dichroic plate with stepped rectangular apertures.