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[54] **MULTIPLE BAND FREQUENCY SELECTIVE REFLECTORS**

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[52] **U.S. Cl.** **343/909,** 343/779, 343/837
[51] **Int. Cl.** **H01q 19/14**
[58] **Field of Search** 343/756, 909, 779, 837

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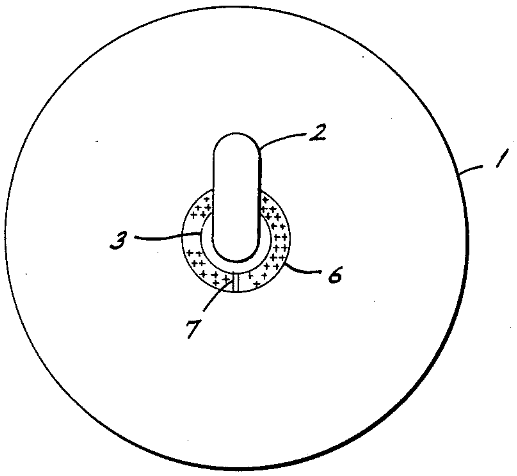
[57] **ABSTRACT**

Polarization independent resonant elements are arrayed in a common plane to form a frequency selective reflective surface for electromagnetic energy. By employing an interspersed array of multiple frequency elements, sufficiently decoupled to permit independent operation, reflections in multiple bands are possible. This makes it possible to operate the reflector at two widely separated frequencies or, by critical separation in terms of frequency, to operate the reflector as a broadband device.

10 Claims, 7 Drawing Figures



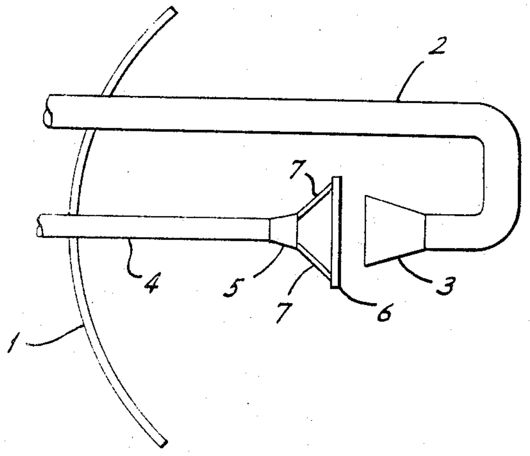


FIG. 1.

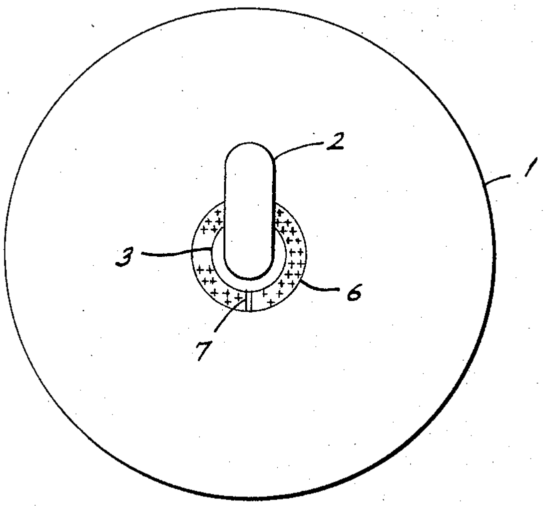


FIG. 2.

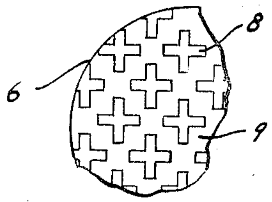


FIG. 3.

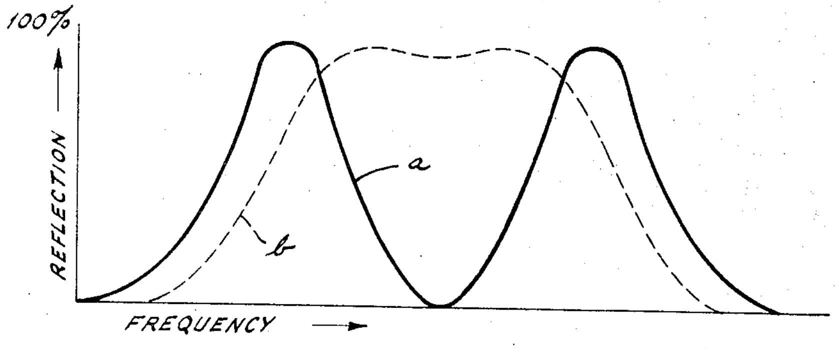


FIG. 5.

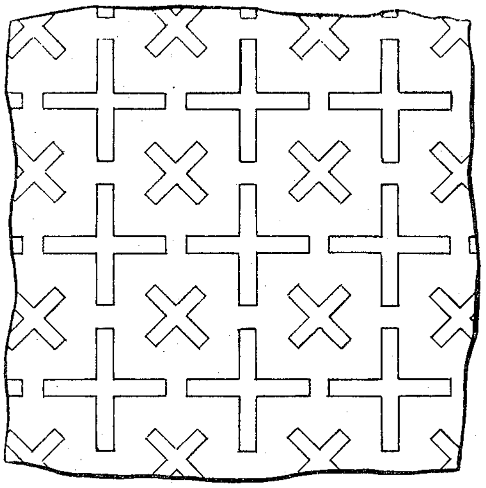


FIG. 4.

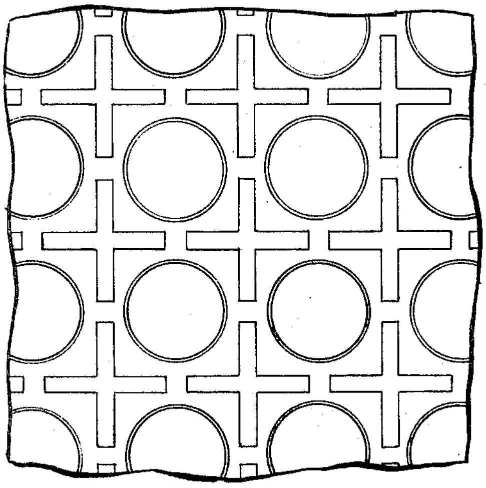


FIG. 6.

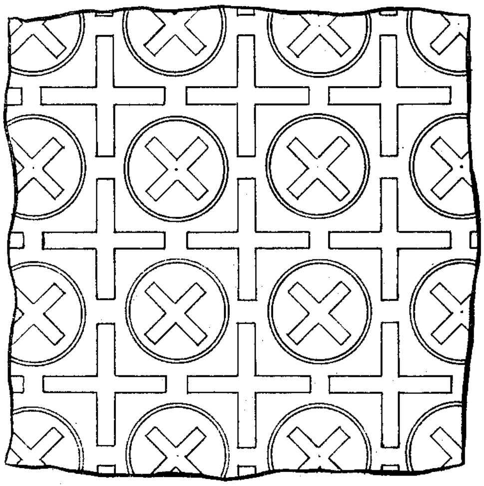


FIG. 7.

MULTIPLE BAND FREQUENCY SELECTIVE REFLECTORS

BACKGROUND OF THE INVENTION

Frequency selective reflectors have been used to advantage in the prior art, particularly in the antenna art. In large parabolic reflector type antennas it has been found expedient to operate the antenna at more than one frequency. It is often not practical to locate a plurality of different-frequency feed assemblies at the reflector focus. One solution to the problem is to locate a frequency selective plane reflector near the antenna focus so that feeds can be mounted on both sides of the plane reflector, one at the regular focus and one at the focus image formed by the plane reflector.

In a typical antenna feed a low frequency feed array is located at the reflector focus and aimed at the reflector. A resonant reflector tuned to a substantially higher frequency and hence transparent to the lower frequency is located between the feed and the reflector. A second or high frequency feed operating at the frequency of the resonant reflector is located between it and the parabolic reflector and is aimed away from the parabolic reflector. In effect, the focus of the parabolic reflector at the high frequency is imaged at the location of the high frequency feed. Thus both feeds are effectively located at the parabolic reflector focus. The plane reflector must be essentially transparent at one frequency and highly reflective at a second frequency. In the past such reflectors have been achieved by polarization selection. That is, a polarization selective reflector is used in conjunction with polarized feeds. Such a system will not work with circularly polarized signals or unpolarized signals.

It has been found that if conductive resonant elements (typically, cross-shaped conductive elements), having no polarization preference, are arranged on a dielectric surface, the array of crosses will be reflective at the frequency of resonance and transmissive at frequencies sufficiently removed from resonance. Alternatively if a reflective surface is provided with an array of apertures having a resonant character independent of polarization it will be transmissive at the frequency of resonance and reflective at frequencies sufficiently removed from resonance. The degree of resonant transmission or reflection will be a function of the density of resonant elements involved and can be made substantial with reasonable structures.

Attempts to broadband such resonant reflectors or to operate them at two frequencies have been largely unsuccessful. When similar apertures of two different resonances are interspersed on a common surface they tend to couple together to result in a single sharp resonance.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an unpolarized resonant reflector which is reflective at two different frequencies.

It is a further object to provide a broadband unpolarized resonant reflector.

These and other objects are accomplished by interspersing on the reflector different groups of unpolarized resonant elements, each group having a different resonant frequency. These elements of different resonant frequency must be sufficiently decoupled to permit self resonance. If the reflective surface is to be

composed of cross-shaped elements, this can be achieved by interspersing high and low frequency crosses oriented at about 45° with respect to each other. Alternatively the reflective surface can be formed of an array of crosses interspersed with an array of rings so as to minimize the coupling between arrays. In a third embodiment, rings and interspersed crosses are combined with smaller crosses inside the rings with the smaller crosses oriented at about 45° with respect to the larger crosses. This gives a triple resonance effect.

FIG. **1** shows an antenna and feed structure in which the present invention may be employed;

FIG. **2** is a front view of the structure of FIG. **1**;

FIG. **3** is an enlarged section of a plane reflector of a type known in the prior art for use in the system of FIGS. **1** and **2**;

FIG. **4** is a fragmentary view of the improved reflector structure for two frequency operation;

FIG. **5** is a graph showing the transmission characteristics of a two frequency device according to the invention;

FIG. **6** is a fragmentary view of the improved reflector structure using interspersed rings and crosses; and

FIG. **7** is a fragmentary view of an improved reflector structure designed for three frequency operation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. **1** and **2** show a known form of antenna system employing a frequency selective reflecting surface. Parabolic reflector **1** is provided with two radio frequency waveguide and horn feeds. Waveguide **2** is terminated in a horn **3** which is located at the reflector focus. Waveguide **4** is terminated by horn **5** and operates at a substantially higher frequency. Frequency selective reflector plate **6** is secured to horn **5** by means of low loss dielectric rods **7**. Plate **6** is made to be highly reflective to the energy from horn **5** and highly transmissive to energy from horn **3**. Thus the energy from horn **5** is reflected from plate **6** to illuminate reflector **1** while the energy from horn **3** illuminates the same reflector directly. The effect is as if both feed horns were located at the reflector focus.

As shown in FIG. **3** plate **6** comprises a series of metal elements **8** mounted on a low loss dielectric substrate **9**. These elements are cruciform in shape and act like crossed dipole antennas. The elements actively reflect electromagnetic energy for which they are approximately one half wavelength. Such a structure will reflect energy having any polarization. By employing a relatively large number of such elements, plate **6** will be largely reflective at the frequency of resonance and harmonics thereof. At other frequencies, and particularly frequencies lower than the fundamental resonance, the plate will be highly transmissive. The elements in plate **6** can have other shapes. For example they may have narrower or wider conductors, with the narrow conductors resulting in sharper resonances thereby producing narrower operating bandwidth. Some broadbanding of the elements can be achieved by using dumbbell shapes or a version of the Maltese cross. Also ring shapes will produce the desired unpolarized resonance where the periphery of the ring establishes a fundamental resonance at one wavelength.

The frequency selective plate can be fabricated in several ways. The simplest method useful for low power operation is to construct plate **6** from metal coated low loss dielectric stock such as is used in printed circuit fabrication. The desired metal pattern can be produced by conventional photolithographic techniques wherein the unwanted metal is chemically removed. For high power structures the metal elements are constructed separately and secured by stand-off insulators to a dielectric support plate.

While the above description is directed to a plate that is reflective to resonant frequency energy, an alternative arrangement employs a plate exhibiting resonant transmission. For such structures the metal-dielectric patterns are reversed. For example an array of cruciform holes (the shape of the dipoles in FIG. **3**) is cut into a dielectric mounted metal plate, using, for example, the photolithographic process mentioned above. At the frequency for which the holes are resonant, such a structure will be highly transmissive. For nonresonant conditions it will be substantially reflective. If such a plate were to be used in the FIG. **1** showing, the resonant frequency of plate **6** would be at the frequency of the energy in waveguide **2.** Since the energy in waveguide **4** would not be resonant, plate **6** in this alternative arrangement would be reflective.

It has been found that such resonant plates are difficult to operate over a substantial band of frequencies. As mentioned above, if the resonant elements are made rather wide or are suitably shaped, some broadbanding will occur but this effect is limited. If crosses having a two-frequency distribution are interspersed they ordinarily tend to couple together to produce a single response having a resonance that is intermediate between the two frequencies.

If the pattern of FIG. **4** is employed, two frequency operation of the resonant reflector is feasible. A high frequency pattern is arrayed inside the spaces between elements of a low frequency pattern. The smaller crosses are rotated about 45° to minimize cross coupling. Such an array does in fact show two resonances, one each for the two sizes of crosses.

FIG. **5** shows the reflection pattern for an array of elements shaped like those in FIG. **4.** The crosses represent conductive material on a low loss dielectric substrate. When the two resonant frequencies are sufficiently separated, two reflection peaks are seen as indicated by the solid line *a*. Such a reflector is operable at two discrete frequencies. If the two resonant frequencies are closely spaced, the reflection curve of dashed line *b* in FIG. **5** occurs. The resonance curves complement each other to produce a broad flat reflection curve. It has been found that for single resonance peaks such as shown in curve *a* the 97 percent reflection bandwidth is ordinarily less than 10 percent. For the broadband version of curve *b*, a 97 percent reflection bandwidth of 20 percent is achievable. This broadbanding action is greatly desired in modern communications systems and is the preferred mode of practicing our invention.

FIG. **6** shows an alternative pattern of two-frequency resonant elements that are sufficiently decoupled to permit discrete or broadband operation. The rings are fundamentally resonant to the frequency for which their periphery is approximately one wavelength (two half wavelengths back to back).

FIG. **7** shows a three-frequency resonant structure that permits even greater broadbanding and constitutes a combination of the structures of FIGS. **4** and **6.** The inner crosses represent the highest frequency elements and the rings the lowest frequency elements.

The foregoing description has shown the fundamental concepts and applications associated with resonant surface reflection devices and other equivalents and applications will occur to those skilled in the art. Accordingly, it is intended that the scope of the invention be limited only by the following claims:

We claim:

1. In a resonant electromagnetic energy reflector structure having a plurality of polarization insensitive resonant elements, said elements being in a common plane and in sufficient number to render said plane electrically active at the frequency of resonance of said elements, the improvement comprising:

interspersing spaced polarization insensitive resonant elements of a plurality of resonant frequencies, said elements being configured and spatially rotated to minimize the electrical coupling between elements of different resonant frequencies.

2. The improvement of claim **1** wherein said plurality of resonant frequencies is two, and said resonant elements comprise crosses of one size interspersed between crosses of a larger size, said crosses of said one size being oriented at about 45° with respect to said crosses of said larger size.

3. The improvement of claim **1** wherein said plurality of resonant frequencies is two, and said resonant elements comprise crosses resonant at a first frequence interspersed with rings resonant at a second frequency.

4. The improvement of claim **1** wherein said plurality of resonant frequencies is three and said resonant elements comprise rings resonant at a first frequency interspersed between crosses resonant to a second frequency and an array of crosses resonant to a third frequency located so that each ring encloses a cross, said crosses inside said rings being oriented at about 45° with respect to said crosses resonant to said second frequency.

5. The improvement of claim **1** wherein said resonant elements comprise conductive forms on an insulating substrate and said elements produce frequency selective energy reflection.

6. The improvement of claim **1** wherein said resonant elements comprise apertures in a conductive surface and said elements produce frequency selective energy transmission.

7. A resonant electromagnetic energy reflector structure comprising:

a first array of polarization insensitive elements dispersed substantially uniformly over a common plane, said elements being resonant at a first frequency, and

a second array of polarization insensitive elements spaced from said first array and also dispersed substantially uniformly over said plane, the elements in said second array being resonant at a second frequency and interspersed uniformly among the elements of said first array, said reflector structure being characterized in that the elements of said second array are spatially rotated to be sufficiently de-coupled electromagnetically from the elements of said first array to permit operation of the reflector at discrete frequencies represented by the resonant frequencies of the two arrays.

8. A resonant electromagnetic energy reflector structure as claimed in claim **7**, wherein said two resonant frequencies are sufficiently closely spaced as to produce a reflector having a broad frequency response characteristic.

9. A resonant electromagnetic energy reflector structure as claimed in claim **7**, wherein said first and second arrays comprise crosses, said second array crosses being smaller and oriented at about 45° with respect to those of said first array.

10. A resonant electromagnetic energy reflector structure as claimed in claim **7**, wherein said first array comprises crosses and said second array comprises rings.

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