

[54] **THIN FILM POLARIZATION
ROTATION MICROWAVE
REFLECTORS**

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[52] U.S. Cl. **343/18 B, 343/6.5 SS**

[51] Int. Cl. **H01g 15/14**

[58] Field of Search **343/18 B, 6.5 SS**

[56] **References Cited**

UNITED STATES PATENTS

3,161,879	12/1964	Hannan et al.	343/18 B
3,366,952	1/1968	Mori	343/6.5 SS

Primary Examiner—Benjamin A. Borchelt

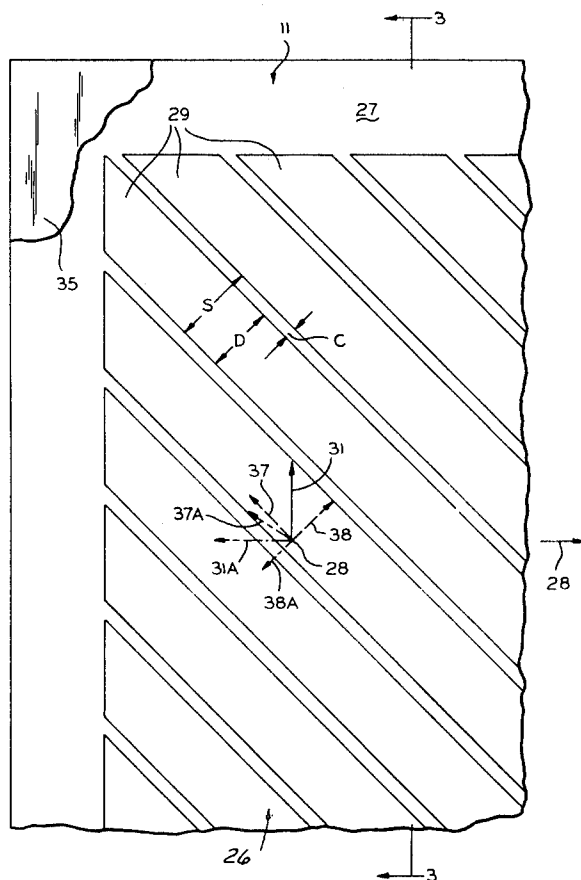
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[57] **ABSTRACT**

A reflector target for reflecting an impinging microwave beam with a 90° change in polarization; the target comprises a layer of high dielectric constant material having a conductive backing and having one or more thin film conductive line grids on its front surface. The thickness of the dielectric layer is less than one-quarter wavelength, as measured in the dielectric, at the chosen microwave frequency, and the grid lines are oriented at 45° to the polarization of the impinging beam. The width of the conductive grid lines is about equal to or greater than the width of the inter-line spaces.

11 Claims, 9 Drawing Figures



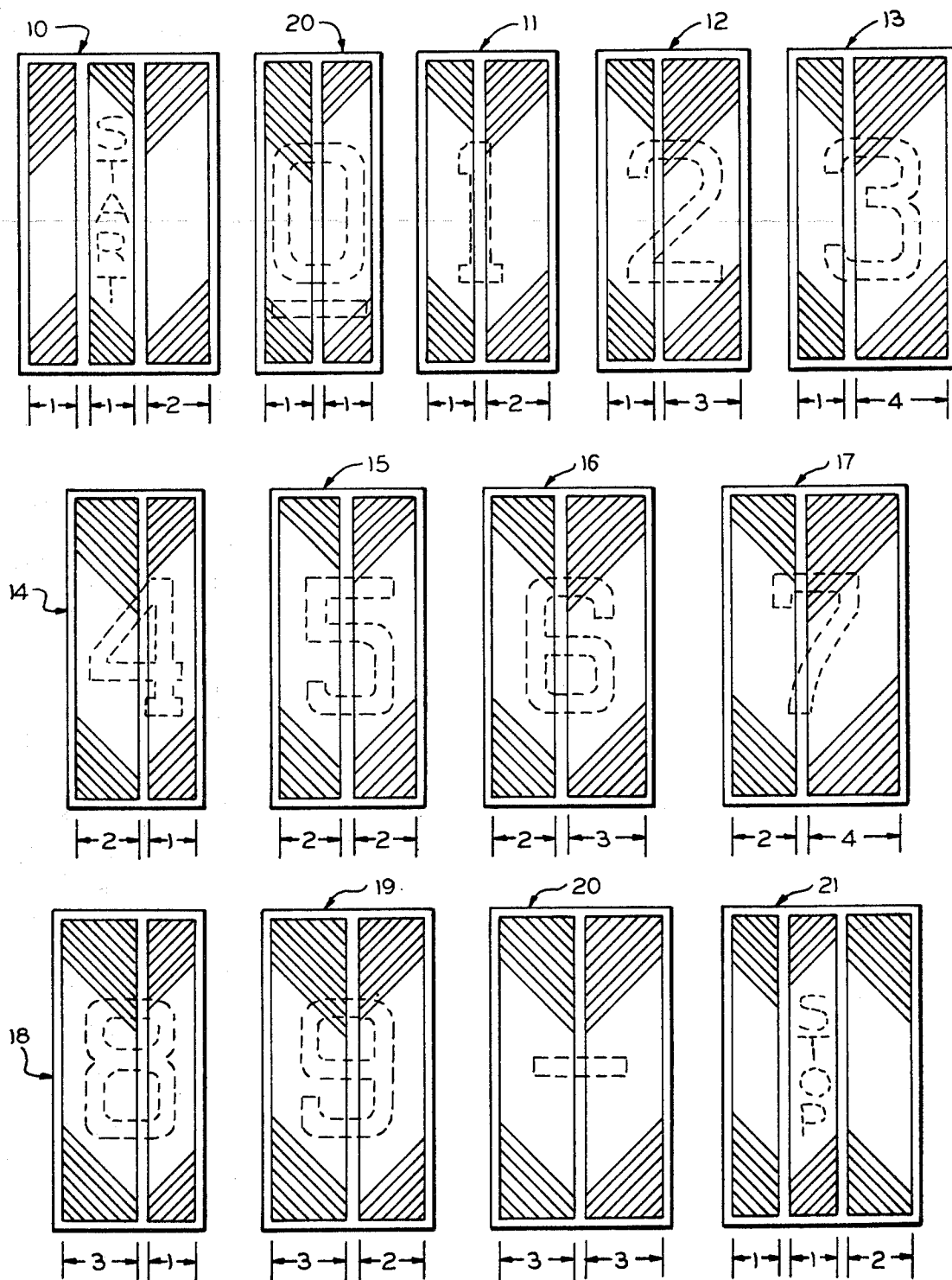


FIG. 1

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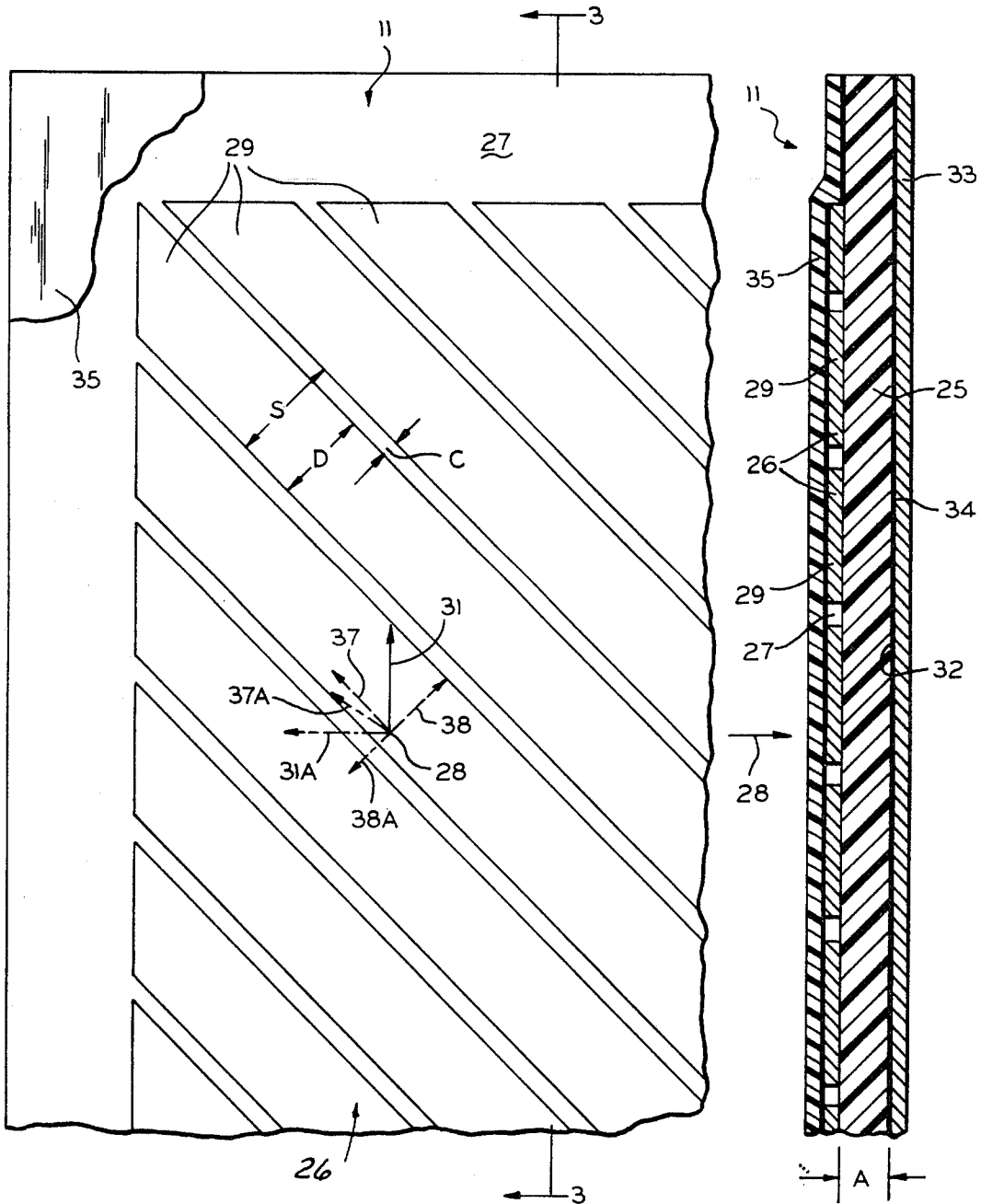


FIG. 2

FIG. 3

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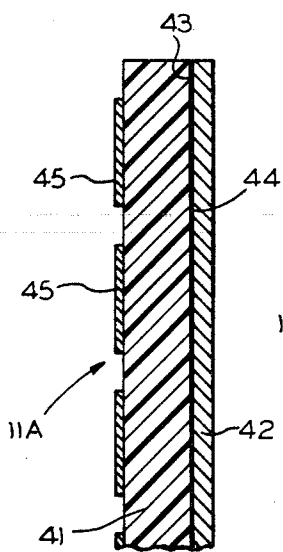


FIG. 4

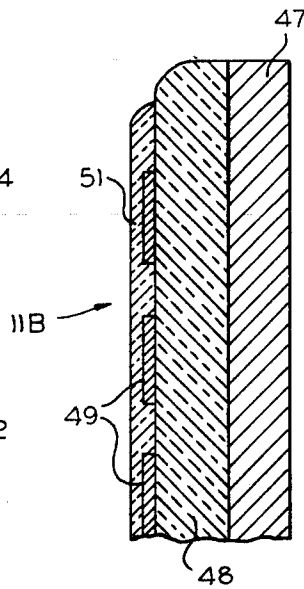


FIG. 5

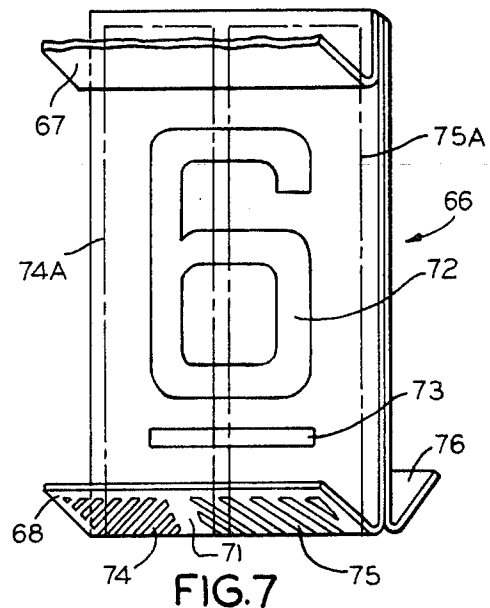


FIG. 7

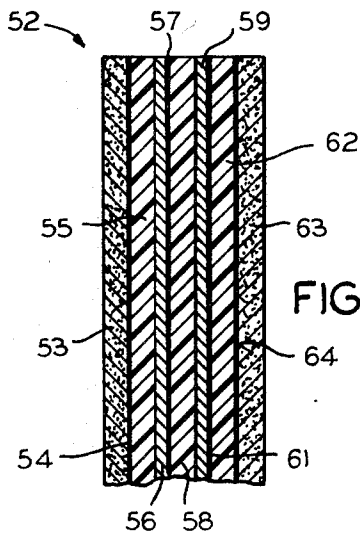


FIG. 6

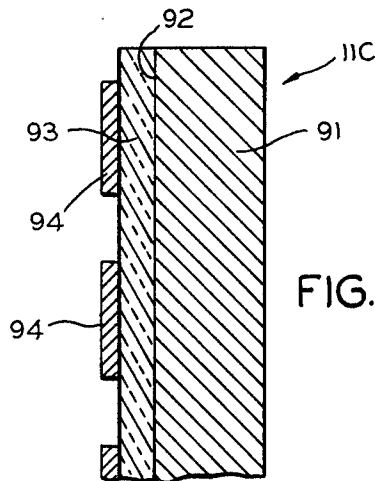


FIG. 9

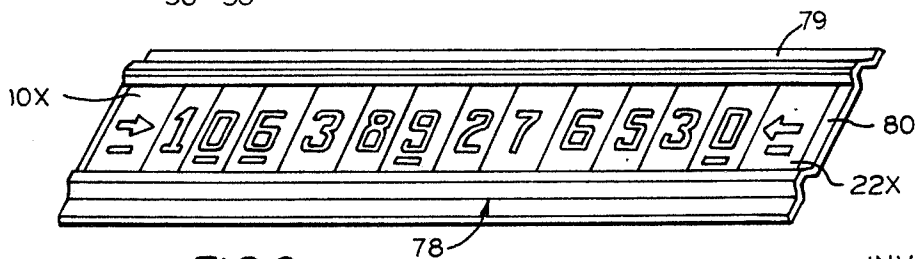


FIG. 8

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THIN FILM POLARIZATION ROTATION MICROWAVE REFLECTORS

CROSS REFERENCE TO RELATED APPLICATION

A preferred method of manufacturing the reflector targets of the present invention is disclosed in the co-pending application of Gary C. Smith, Ser. No. 32,840 filed Apr. 29, 1970.

BACKGROUND OF THE INVENTION

There are many systems for the identification of vehicles and other moving objects in which each object requiring identification carries a target or tag that identifies that specific object. In some of these systems, the target is scanned with a light beam; others use scanning beams in other portions of the spectrum. The present invention relates to systems in which the reflector targets are scanned by microwave beams. Thus, the reflector targets of the present invention may be utilized in microwave systems of the type disclosed in U.S. Pat. No. 3,247,509 of Hamann and Boyd, and U.S. Reissue Pat. No. Re. 26,292 of Bradford et al.

It is a common characteristic of microwave systems of the kind under consideration that the reflector targets must effect a substantial change in polarization of the scanning beam, so that the reflected microwave energy can be adequately distinguished from the original beam. In some instances, a polarization change of 45° has been used, but most systems require that the polarization be changed through an angle of 90°. One form of microwave reflection target, suggested in the Hamann and Boyd patent, utilizes individual resonant dipoles that reflect an impinging microwave beam with a polarization change of approximately 45°. In another target intended for the Bradford et al. system, as disclosed in Molnar et al. U.S. Pat. No. 3,247,510, a 90° change in polarization is effected by the use of corner reflectors appropriately oriented with respect to the scanning beam. A more effective and efficient corner reflector target is described in Mori U.S. Pat. No. 3,366,952.

Another structure that will effectively alter the polarization of an impinging microwave beam by approximately 90° is disclosed in Hannan et al U.S. Pat. No. 3,161,879. The "Twistreflector" of the Hannan patent comprises a conductive surface with a wire grid located in spaced relation to that surface. The Hannan structure requires that the grid be displaced from the conductive surface by more than a quarter wavelength, and utilizes a grid wire diameter that is substantially greater than the spacing between wires. A dielectric of low dielectric constant may be interposed between the grid and the conductive surface.

The microwave reflector targets of prior art identification systems have presented a number of manufacturing and operational problems. The dipole targets tend to exhibit a poor reflection efficiency and are limited in frequency range. The dipole and the corner reflector targets both tend to be relatively expensive, particularly when compared with the printed targets used in the systems of object identification that use optical scanning. All of the targets of the prior art, and the reflector material of the Hannan patent, require an appreciable thickness in the completed structure, increasing the possibility that the reflector target may be damaged or dislodged from the object on which it is mounted.

SUMMARY OF THE INVENTION

A principal object of the present invention, therefore, is to provide a new and improved thin reflector target for reflecting an impinging microwave beam with a 90° change in polarization.

A specific object of the invention is to provide a new and improved microwave reflector target for an automatic object identification system that provides an accurate effective polarization rotation of 90° and that is readily manufactured from thin plastic film and other inexpensive materials.

A further object of the invention is to provide a new and improved microwave reflector target that can be conveniently manufactured by printed circuit fabricating techniques.

Accordingly, the invention relates to a reflector target for an identification system of the kind in which the target is scanned by a microwave beam of given frequency polarized in a given direction. The target comprises a thin layer of a dielectric material having a high dielectric constant, the thickness of the dielectric layer being substantially smaller than one-quarter wavelength, at the microwave frequency. At least one conductive line grid is mounted on the front surface of the dielectric facing toward the microwave beam; this grid includes a multiplicity of thin film grid elements which are parallel to each other and are aligned at an angle of about 45° to the direction of beam polarization. The other surface of the dielectric layer is provided with a conductive backing, with the complete target affording a polarization rotation of approximately 90° in reflecting the microwave beam.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevation view of a set of reflector targets constructed in accordance with the invention;

FIG. 2 is a detail elevation view of a fragmentary portion of one of the targets of FIG. 1, drawn to a greatly enlarged scale;

FIG. 3 is a detail sectional view taken approximately along line 3—3 in FIG. 2;

FIGS. 4, 5 and 6 are detail sectional views, similar to FIG. 3, of other embodiments of the invention;

FIG. 7 is a perspective view, partially disassembled, of a further embodiment of the invention; FIG. 8 illustrates a complete reflector target assembly using a plurality of the targets shown in FIG. 8; and

FIG. 9 is a detail sectional view, like FIG. 3, of another target embodying the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates a plurality of individual reflector targets 10 through 22 constructed in accordance with the present invention. The code arrangement for reflector targets 10—22 is discussed in greater detail hereinafter. Each of the individual reflector targets 10 through 22 can be constructed in accordance with any of the several structural embodiments discussed hereinafter in connection with FIGS. 2 through 7 and 9.

The basic construction for one embodiment of the reflector targets 10—22 (FIG. 1) is shown in detail in FIGS. 2 and 3. The limited portion of the target shown in FIG. 2 corresponds to the upper left-hand corner of the target 11 of FIG. 1.

The reflector target 11A (FIGS. 2, 3) comprises a thin layer 25 of a dielectric material having a dielectric constant substantially greater than unity. The thickness A of the dielectric layer 25 is made substantially smaller than one-quarter wavelength of a microwave beam at the operating frequency to be used in connection with the reflector target. Within this limitation, the thickness A can vary to a substantial extent, as indicated by the specific examples presented hereinafter and can even approach zero, for ideal materials.

A conductive grid 26 is supported upon the front surface 27 of the dielectric layer 25. The front surface 27 is taken as the surface of the dielectric layer that faces the direction from which target 11 is scanned by an incident microwave beam, the beam being generally indicated by arrow 28 in FIG. 3. It may be assumed that the scanning beam 28 impinges upon target 11 from a direction normal to surface 27; some departure from the normal can be tolerated without adversely affecting the operation of the target.

Grid 26 comprises a multiplicity of individual thin film conductive grid elements 29. Grid elements 29 may be formed on the dielectric surface 27 by silk screening or other conventional printed circuit techniques. The grid elements should be kept as thin as possible consistent with maintenance of effective conductivity along their lengths. The grid elements 29 are oriented at an angle of approximately 45° to the direction of polarization of the scanning beam; in FIG. 2, the direction of initial polarization of the impinging microwave beam 28 is indicated by the arrow 31.

The rear surface 32 of dielectric layer 25 is provided with a conductive backing 33. In the construction illustrated in FIGS. 2 and 3, the conductive backing 33 comprises a layer of copper or aluminum foil that is bonded to the dielectric surface 32 by means of an appropriate adhesive 34. In FIG. 3, the conductive backing 33 is shown as an extremely thin foil, but the conductive backing may be much heavier, particularly if it is utilized as a support for the reflector target as in some of the embodiments described hereinafter.

The dimensions of the components of the conductive line grid 26 of reflector target 11 are of substantial importance with respect to the operational characteristics of the target. As shown in FIG. 2, the conductive grid elements 29 are of uniform width D. The spacing C between adjacent grid elements is also uniform. For effective operation, the total distance S for one of the grid elements and one of the spaces ($S = D + C$) should be held to less than one-quarter wavelength of the scanning microwave beam. Furthermore, the conductive element width D should be at least about equal to and preferably is larger than the spacing C between adjacent grid elements. The conductive grid may be protected by a covering film 35, as particularly shown in FIG. 3, to protect the grid against adverse environmental conditions.

The impinging beam 28, initially polarized in the direction indicated by the arrow 31, may be considered to comprise two orthogonal components having polarizations as indicated by the dashline arrows 37 and 38. The first component 37 is parallel to the grid lines 29; the other component 38 is perpendicular to the grid lines. To change the beam polarization by 90°, as reflected from target 11, at least one of the vectors 37 and 38 must be changed substantially. Actually, both components 37, 38 undergo some rotation, as indicated

by vectors 37A and 38A, the greatest rotation occurring for the perpendicular vector 38. The reflected microwave energy is polarized as indicated by the phantom line arrow 31A.

The effective rotation of polarization from the incident direction indicated by the arrow 31 to the reflected direction indicated by the dash arrow 31A takes place, in the thin film target structure 11 illustrated in FIGS. 2 and 3, by the maintenance of apparent short circuits for the two orthogonal components 37 and 38 which are apparently displaced by odd multiples of a quarter wavelength in a direction normal to the plane of the target. Because the electric field vector for a microwave beam is parallel to its polarization vector, perfectly conducting sheets could be placed parallel to the two orthogonal vectors 37, 38 without disturbing the field. Within the parallel plate transmission lines formed by such sheets, the conductive strips 29 of the target grid 26 form capacitive and inductive irises. It can be shown that these irises produce capacitive (positive) susceptance for the perpendicular component 38 and inductive (negative) susceptance for the component 37 parallel to the grid lines 29. That is,

$$B_{\perp}/Y_0 \approx j(4S/L_g) \ln(\operatorname{cosec} \pi C/2S), \quad (1)$$

and

$$B_{\parallel}/Y_0 \approx -j(L_g/S) \cot^2 \pi C/2S \quad (2)$$

where

$B_{\perp}$ = susceptance for perpendicular component 38

$B_{\parallel}$ = susceptance for parallel component 37

Y_0 = admittance of free space

L_g = wavelength in dielectric employed.

These irises are backed by the conducting foil 33 that is located the distance A from the grid elements 29. By conventional transmission line theory, the short circuit represented by the conductive foil 33 has an inductive (negative) susceptance B_s at a distance A determined by:

$$B_s/Y_0 = -j \cot 2\pi A/L_g \quad (3)$$

If the two orthogonal components 37 and 38 are to be effectively short-circuited a quarter wavelength apart, they must have reciprocal admittances at any common reference plane. That is,

$$Y_{\perp} = 1/Y_{\parallel} \quad (4)$$

If the reference plane is chosen at the plane of the grid 26, which is to say at the plane of the dielectric surface 27, then

$$Y_{\perp}/Y_0 = j[(4S/L_g) \ln(\operatorname{cosec} \pi C/2S) - \cot 2\pi A/L_g] \quad (5)$$

and

$$Y_{\parallel}/Y_0 = -j[(L_g/S) \cot^2 \pi C/2S - \cot 2\pi A/L_g] \quad (6)$$

By substituting Equations (5) and (6) into Equation (4), it can be seen that

$$(7) \quad \frac{4s}{L_g} \ln \left(\operatorname{cosec} \frac{\pi c}{2s} \right) - \cot \frac{2\pi A}{L_g} = -\frac{1}{s} \frac{L_g}{\cot^2 \frac{\pi c}{2s} - \cot \frac{2\pi A}{L_g}}$$

This equation gives the general relationship between the width D of the conducting strips 29, the spacing C between the strips, and the thickness A of the dielectric material. Equation (7) is a good basis for approximation; however, some experimentation is usually necessary for any specific target. The value of the distance S should be substantially less than a wavelength as measured in air, and preferably is between one-fifth and one-twentieth of a wavelength.

Experimentally, an effective polarization-rotating target structure has been constructed, for use at 36 Ghz, with the following dimensions:

$A = 0.004$ inch polyvinyl fluoride plus 0.004 inch acrylic pressure sensitive adhesive
 $D = 0.075$ inch
 $C = 0.015$ inch.

For this target structure, silver was used for the grid lines 29 and a polyvinyl fluoride film 35 was applied over the outer surface of the grid lines, the thickness of that film being 0.001 inch.

In another working target structure, using an epoxy glass laminate material having a dielectric constant of about 4.7 at 36 Ghz, the following dimensions have been found to afford effective operating results:

$A = 0.031$ inch
 $D = 0.035$ inch
 $C = 0.040$ inch.

Yet another workable target structure has been constructed, using a ceramic material having a dielectric constant of 6, with the following dimensions:

$A = 0.02$ inch
 $D = 0.025$ inch
 $C = 0.025$ inch.

From the foregoing exemplary data, and from Equation (7), it will be apparent that the use of an appropriate ratio of D to C results in a thin dielectric layer; a high dielectric material in layer 25 makes it possible to reduce the thickness of the dielectric layer even more. The dielectric constant layer 25 should be in excess of unity in order to obtain the full benefits of a thin, easily protected target structure.

The foregoing mathematical analysis of the target structure is based upon a recognition that the positive susceptance for the perpendicular component 38 increases with any increase in the ratio of D/C . The negative susceptance for the parallel component 37 also increases with any increase in the ratio of D/C . Moreover as a thickness A of dielectric layer 25 increases from zero to L/v , the reflected negative susceptance decreases, when A exceeds $L/4$, the reflected susceptance for the parallel component becomes positive. When the thickness of layer 25 reaches $L/2$, the grid susceptance is of negligible effect and there is no change in polarization of the effective signal.

FIG. 4 illustrates a minor variation of the basic structure shown in FIG. 3. In this instance, the target reflector 11A is a self-supporting structure comprising a thin sheet 41 of epoxy glass laminate that serves as the dielectric for the target. A copper film 42 is bonded to the back surface 43 of the layer 41 by an appropriate adhesive 44. A conductive grid structure comprising the grid elements 45 is applied to the front surface 46 of the dielectric 41 by silk screening or other appropriate means. The target structure may then be completed by painting the grid 45 and the surface 46 to protect the grid against environmental damage. Targets of this con-

struction have been successfully employed in tests in a system for the automatic identification of railroad cars.

The target reflector 11B shown in FIG. 5 comprises a sheet metal support member 47 on which a ceramic layer 48 has been bonded. An adhesive bond is not necessary; in accordance with known techniques, the ceramic 48 can be deposited upon the metal support 47 and then baked, bonding the ceramic directly to the metal. The ceramic layer 48 is the dielectric for the reflector and has a conductive line grid comprising the grid elements 49 silk screened or otherwise formed on its surface. A thin layer 51 of ceramic material can be applied to the surface of the reflector, over the grid elements 49, to complete an all metal-ceramic reflector that is thin but rugged in construction.

FIG. 6 illustrates a subassembly 52 that can be utilized in the fabrication of a target structure in accordance with the present invention. The assembly 52 is a multi-layer subassembly for subsequent mounting on a dielectric-coated conductive substrate. The various layers of the subassembly 52, from front to back, comprise a layer of handling paper 53 bonded by an adhesive 54 to a thin film of polyvinyl fluoride 55. The other surface of the film 55 is coated with a layer of paint 56 comprising an identifying number or other character for visual reading. The painted film 55 is bonded by an adhesive 57 to another thin film 58 of polyvinyl fluoride. A conductive line grid 59, comprising a series of conductive elements like the conductive elements 29 illustrated in FIG. 2 is silk screened or otherwise deposited upon the dielectric film 58. The grid-carrying film 58 is bonded by an adhesive layer 61 to an additional thin film of polyvinyl fluoride 62, film 62 being secured to a sheet of handling paper 63 by a pressure sensitive adhesive 64.

The subassembly 52 illustrated in FIG. 6 is used in conjunction with a separate dielectric-coated conductive substrate. When the subassembly is to be mounted in position of operation, the back surface handling paper 63 is stripped away. The adhesive layer 64 should be one with a preferential bond for the dielectric film 62 rather than the paper, so that the adhesive remains on the dielectric film when the handling paper 63 is removed. The subassembly can then be applied directly to the dielectric surface of a support to complete a target reflector.

FIG. 7 illustrates a character identification target subassembly 66, with the several layers forming the subassembly 66 partially peeled away from each other. The front outwardly facing element of the target subassembly 66 is a thin polyvinyl fluoride film 67. Film 67 affords a protective cover for the surface of a second polyvinyl fluoride film 68. The front surface of film 68 is imprinted with a visually-readable identification character 72, in this instance the numeral six. The visually readable portion of the target subassembly 66 may include an additional element, such as a bar 73 to distinguish the character six from the character nine.

The rear surface 71 of film 68 carries two conductive grids 74 and 75 of different widths which cover substantially all of the web surface 71. The overall extent of the conductive webs is indicated more fully by the phantom outlines 74A and 75A. The subassembly 66 further includes a release liner 76. The release liner 76 is preferably formed of paper and is mounted on the rear surface 71 of the dielectric film 68 by a pressure sensitive adhesive having a preferential characteristic

favoring adherence to the polyvinyl fluoride film 68 rather than to the paper 76. This makes it a relatively easy matter to peel away the release liner 76 when the subassembly 66 is to be used in fabrication of a complete identification target.

FIG. 8 illustrates a complete object identification target 78 assembled from a plurality of the individual sub-assemblies 66 of FIG. 7. The identification member 78 includes a conductive base 79 that may be formed, for example, from thin gauge aluminized steel. The central depressed portion 80 of the base 79 is provided with a surface coating of dielectric material. One dielectric that has been used for this purpose is an ethylene vinyl acetate copolymer available from United States Steel Corporation under the designation PQE-1. This material is quite suitable for outdoor applications, retaining its stability over a wide range of changes in temperature, humidity, and other environmental factors. The dielectric constant of the material is 2.7 at a frequency of 36 Ghz; the dissipation factor at that same frequency is 0.006. Other dielectric materials that may be used for coating the central portion 80 of the base 79 include polyvinyl chloride and polyvinyl fluoride. Base 79 could also be constructed from a self-supporting dielectric material, such as an epoxy glass laminate, with a conductive foil coating on the rear surface.

To assemble the complete identification target 78, a group of individual reflector targets corresponding in construction to the target subassembly 66 of FIG. 7 are selected. The initial character is the start target subassembly 10X, corresponding to the target 10 (FIG. 1) but constructed in accordance with the structural arrangement described above for the subassembly 66 (FIG. 7). The next character in the identification sequence is the numeral one, provided by the target subassembly 11X. The remaining target subassemblies are mounted on the base down to the final "stop" character 22X. Each character subassembly is mounted on the dielectric coated portion 80 of the base 79 simply by stripping away the release film (film 76 in FIG. 7) and pressing the subassembly into place on the base.

FIG. 9 illustrates a microwave target 11C fabricated in accordance with a quite different technique but affording the same kind of operating structure as the other targets fabricated in accordance with the invention. The target 11C comprises a sheet of aluminum 91 having a front surface 92 upon which a thin layer 93 of aluminum oxide of uniform thickness has been formed. Layer 93 may be appropriately formed by anodizing the aluminum. A conductive grid comprising individual grid elements 94 is disposed upon the outer surface of the aluminum oxide layer 93 and may be formed by silk screening or other appropriate application techniques. The same structures with respect to grid element dimensions and the thickness of the dielectric layer 93 apply as in the previously described embodiments.

The code arrangement employed to identify individual identification characters, in the microwave targets illustrated in FIG. 1, is a form of binary coded decimal notation. In each target, there are at least two conductive grids; the start and stop targets 10 and 22 each include three conductive grids. Larger numbers of grids can be used for individual targets if necessary, as in a system affording full alpha-numeric capability.

The numerical value for each grid is determined by its width, the targets being employed in a pulse-width-modulation system. The narrowest of the grids, a "1"

width grid as exemplified by the left-hand grid in target 11, has a binary value of 00. The next largest grid, a "2" width grid such as the grid on the right-hand side of the target 11, has a binary value 01. The next larger "3" width grid, exemplified by the grid on the right-hand side of target 12, has a binary value 10. The largest of the grids, in the illustrated coding arrangement, is the "4" width grid at the right-hand side of the target 17, having a binary value of 11. The widths for the grids are marked below each grid; the binary values given above can be compared with each combination of grid widths and will be seen to give a binary count corresponding to the numerical value marked on each target. The start target 10 is arbitrarily encoded with the value 00001 and the stop target 22 is encoded as 000000. In a typical system, the widths for the target grids may be:

width "1" = 0.75 inch
width "2" = 1.00 inch
width "3" = 1.25 inch
width "4" = 1.50 inch

In each of the targets illustrated in FIG. 1, with the single exception of the start target 10, the left-hand grid of the target is oriented at an angle of 45° counterclockwise from the vertical, whereas the right-hand grid on the same target is oriented at an angle of 45° clockwise from the vertical. With this arrangement, regardless of how the targets are arranged, as long as the start and stop targets are not interposed in the middle of an identification array, adjacent grids are always aligned at 90° relative to each other. This correlation between the grids of individual target members and between the grids on adjacent target members is of material assistance in maintaining effective differentiation between scanning pulses produced by the individual grids in the operation of an identification system.

We claim:

1. A reflector target for an identification system of the kind in which the target is scanned by an incident microwave beam of given frequency polarized in a given direction, comprising:

a thin layer of a dielectric material, having a dielectric constant substantially greater than unity, the thickness of the dielectric being substantially smaller than one-quarter wavelength, at said given frequency;

at least one conductive line grid on the front surface of said dielectric facing said microwave beam, comprising a multiplicity of thin film conductive grid elements, said grid elements being aligned at an angle of about 45° to said direction of polarization;

and a conductive backing on the other surface of said dielectric layer,

said target affording a polarization rotation of approximately 90° in reflecting said microwave beam.

2. A reflector target for a microwave identification system, according to claim 1, in which each conductive element of said grid has a width D and is separated from adjacent grid elements by a space of width C and in which $D \geq C$.

3. A reflector target for a microwave identification system, according to claim 2, in which $S = D + C$ and in which S is less than one-quarter wavelength at said given frequency.

4. A reflector target for a microwave identification system, according to claim 1, including a plurality of

said grids, each of given width in the scanning direction, representative of a given code quantity.

5. A reflector target for a microwave identification system, according to claim 4, in which the conductive grid elements of adjacent grids are consistently oriented at angles of approximately 90° relative to each other.

6. A reflector target for a microwave identification system, according to claim 1, in which the front surface of said target, including said grid, is covered by a thin protective film of dielectric material.

7. A reflector target for a microwave identification system, according to claim 1, in which said conductive backing comprises a self-supporting aluminum plate, and said dielectric layer is a layer of aluminum oxide.

8. A reflector target for a microwave identification system, according to claim 1, in which said dielectric material is fiberglass, and in which said conductive backing is a thin metal foil.

9. A reflector target for a microwave identification system, according to claim 1, in which said dielectric material is polyvinyl fluoride.

10. A reflector target for a microwave identification system, according to claim 2, in which $D \approx 0.075$ inch, $C \approx 0.015$ inch, the dielectric constant of the dielectric layer is about 9, and the total thickness of the dielectric layer is about 0.06 times the wavelength of the microwave beam.

11. A reflector target for a microwave identification system, according to claim 3, in which the basic dimensions of the target are determined in accordance with the expression

$$\begin{aligned} & (4S/Lg) \ln (\operatorname{cosec} \pi C/2S) - \cot 2\pi A/Lg \\ & = 1/[(Lg/S) \cot^2 (\pi C/S) - \cot (2\pi A/Lg)] \end{aligned}$$

where Lg = wavelength in the dielectric.

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