12-18-73 OR 3,780,374

United States Patent [19]

Shibano et al.

[11] **3,780,374**

[45] **Dec. 18, 1973**

[54] **RADOME WITH MATCHING LAYERS**

[75] Inventors: **Yoshizo Shibano; Shohachiro Yamashita,** Konshana-ku, Osaka, Japan

[73] Assignee: **Sumitomo Electric Industries, Ltd.,** Osaka, Japan

[22] Filed: **Mar. 8, 1972**

[21] Appl. No.: **232,897**

[30] **Foreign Application Priority Data**

Mar. 11, 1971 Japan 46/13622

[52] **U.S. Cl.** **343/872,** 343/911

[51] **Int. Cl.** **H01q 1/42**

[58] **Field of Search** .... 343/872, 872 R, 909, 343/911

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Primary Examiner—Eli Lieberman
Attorney—Carothers and Carothers

[57] **ABSTRACT**

A radome wall with matching layers wherein a single layer dielectric plate having a dielectric constant of ϵ_r is sandwiched by two dielectric matching layers having the dielectric constant of $\sqrt{\epsilon_r}$. One form of providing the matching layers is with strips of the same dielectric material as the plate. The strips may be spaced in parallel or parallel lattice form with a spacing pitch P between adjacent strips in order to obtain the equivalent dielectric constant of the matching layer $\sqrt{\epsilon_r}$. The thickness of the core is also determined to be an odd multiple of $\lambda/4$ in order to obtain broader frequency band characteristics.

8 Claims, 11 Drawing Figures

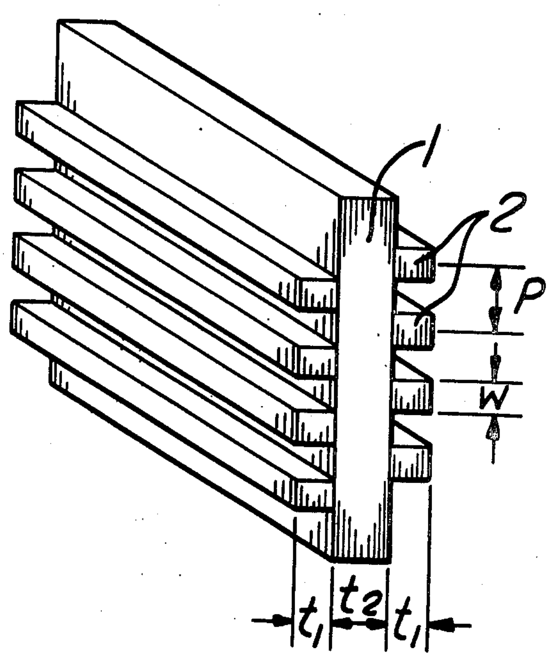


Fig. 1a

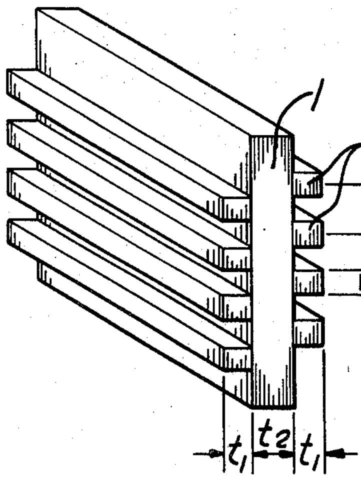


Fig. 1b

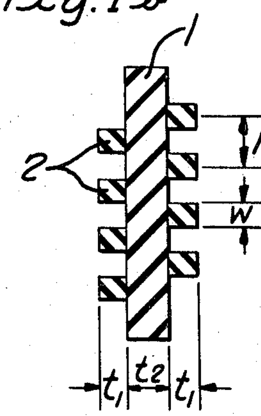


Fig. 2

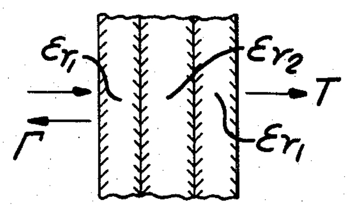


Fig. 3

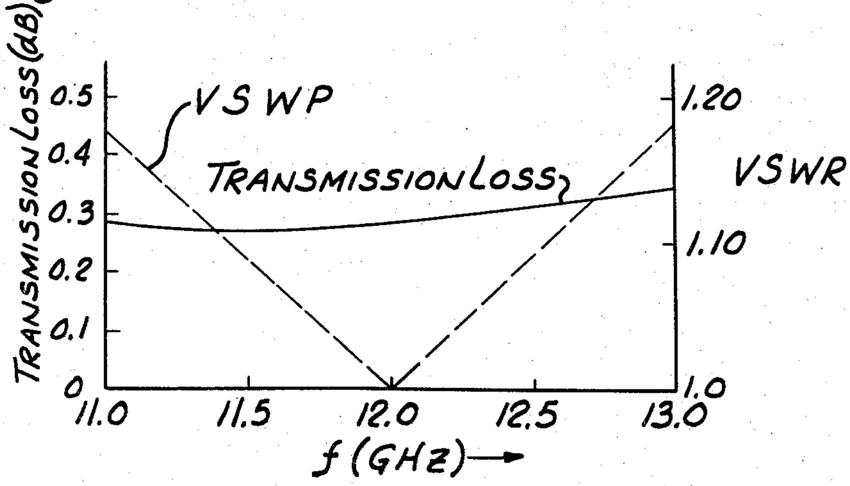


Fig. 4

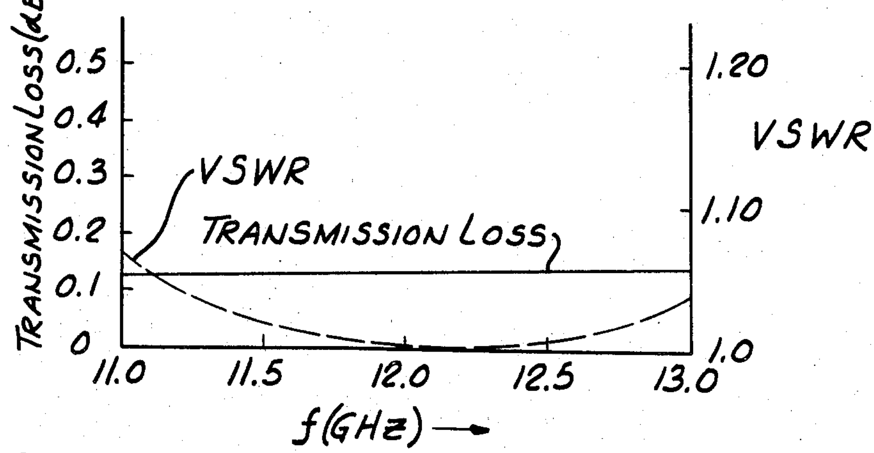


Fig. 5

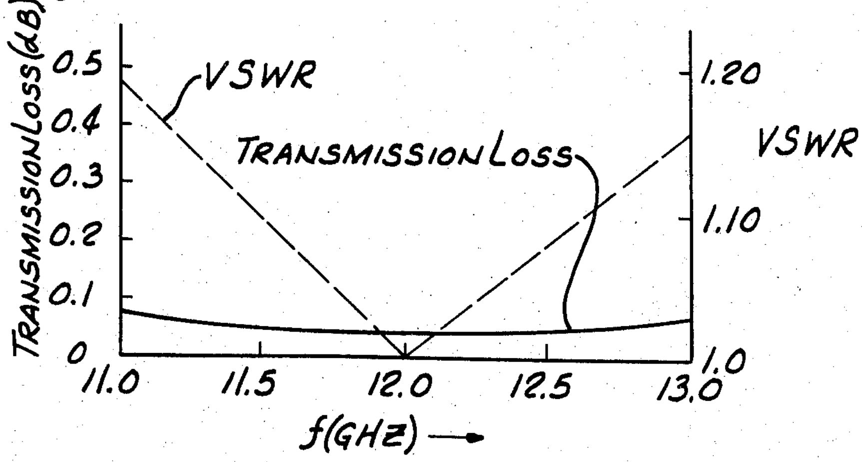


Fig. 6a Fig. 6b Fig. 6c

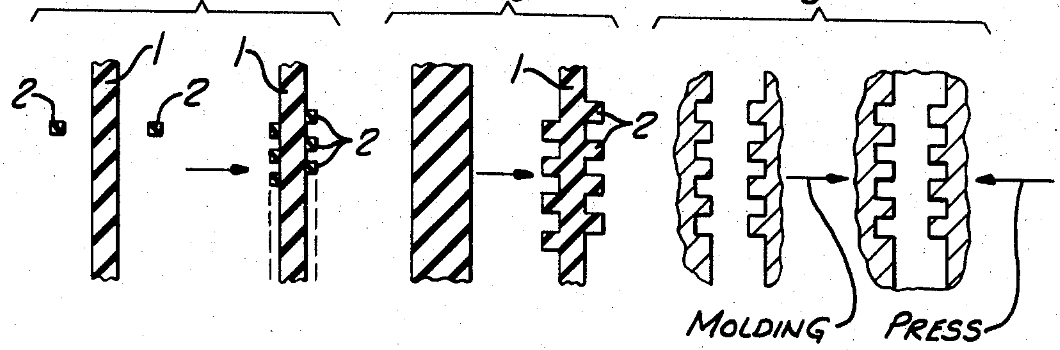


Fig. 7

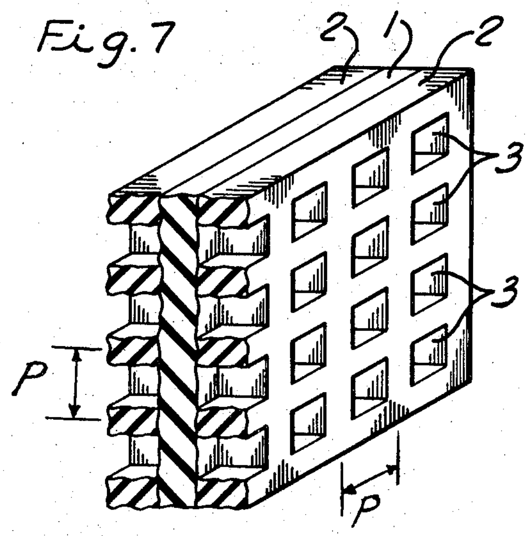
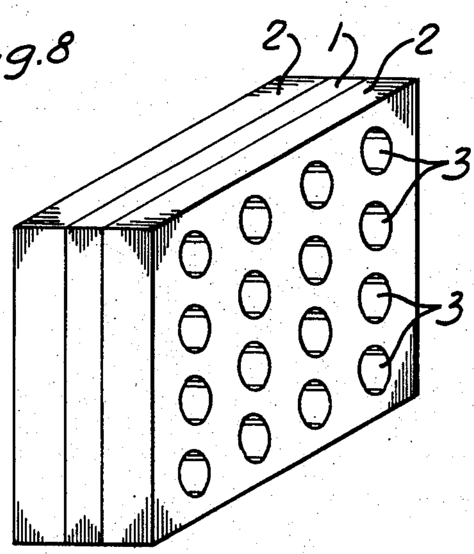


Fig. 8



RADOME WITH MATCHING LAYERS

This invention relates to a radome with matching layers. Conventional radomes now in use for antennas are usually constructed of thin plates of material or the like. That is to say, they are made of dielectric plates having a uniform single layer with a thickness shorter than the wavelength of an operating wavelength. When the wavelength is sufficiently large as is the case with the VHF and UHF bands, the use of a thin dielectric plate for constructing a radome which crosses the path of the radiation wave from an antenna scarecely affects the electro magnetic properties of the radiation wave. However, in the case of a frequency band in use in which the wavelength of a selected frequency is extremely short, as for example in the case of 12 GHz, if the radome is designed to have a single layer of a 0.4 mm thickness of F.R.P. (Fiber Reinforced Plastic) for the purpose of mechanical strength for the radome structure, the VSWR (Voltage Standing Wave Ratio) for a frontal incidental wave will generally become as high as 1.2.

In such a situation matching between the dielectric plate of the radome and the air is hardly obtainable. Even if the VSWR is made lower, the matched frequency band becomes very narrow and the power transmission loss becomes great.

Consequently, for such single layer radomes utilized in this high frequency range, as the thickness of the layer of the radome is comparable to the wavelength of the operating frequency, it is not practical for use.

On the other hand, the thickness of the layer of a radome is required to be as thick as possible with respect to mechanical strength.

However, it may not be possible to increase the thickness of the layer of a radome because of the restrictions of the VSWR, transmission loss and other requirements on the electric properties. As one solution of this problem, a sandwich radome is well known. It is, however, difficult to make such a radome, because there are various problems in the designing and manufacturing techniques.

The present invention provides a new radome with matching layers which is free from the drawbacks of conventional techniques as mentioned above. The purpose of the present invention is to provide a radome which has a low VSWR over a broad frequency band and a small transmission loss, and further has a radome layer thickness with sufficient mechanical strength.

The explanation in detail of this invention will be followed with reference to the drawings.

FIG. 1 shows the construction of an embodiment of the present invention.

FIG. 1*a* is a perspective view and *b* a view in cross section of the structure shown in FIG. 1*a*.

FIG. 2 is a diagrammatic section view of the structure shown in FIG. 1 for explaining the electric properties of the radome of the present invention.

FIG. 3, FIG. 4 and FIG. 5 are graphic illustrations showing the transmission loss versus frequency range curve and VWSR to frequency range curve in accordance with changing thickness of the plate of unilayer radome of the present invention.

FIGS. 6*a*, 6*b*, and 6*c* are cross sectional views of the radome wall of the present invention for explaining the methods of manufacturing the radome according to the teachings of the present invention.

FIG. 7 is a perspective view in partial cross section showing a lattice construction of the single layer radome of the present invention.

FIG. 8 is a perspective view of an embossed type construction of the single layer radome of the present invention.

FIG. 1*a* is a slant view of the radome of the present invention with matching layers. FIG. 1*b* shows a section of the radome shown in FIG. 1*a*. In these Figures, 1 denotes a dielectric plate which constitutes a single layer radome and 2 impedance matching layers. The matching layers (2) are made of strips having width W and thickness t_1 of a dielectric material which are arranged in parallel and attached to the surface of the single layer radome plate having the thickness t_2 with the spacing pitch P.

In this radome, the direction of the strips is in conformity with the direction of the polarized electric field.

Where the electric field has two perpendicular components it will be better to use the lattice like structure shown in FIG. 7 or 8. As shown in FIG. 1, P is the pitch of the strips. If P is given a sufficiently small value in comparison with the wavelength of an operating frequency, the matching layers (2) which are made of the arrangement of strips of the material of a dielectric constant ϵ_r, may be equivalent uniform dielectric layers having the dielectric constant ϵ_e. There will be found a relation between ϵ_r and ϵ_e as follows:

$$\epsilon_e = 1 + (\epsilon_r - 1)\ W/P \tag{1}$$

where W is the width of the strip and P is the pitch of strips.

Thus the matching layer of a thickness t_1 may be equivalently converted into a uniform dielectric layer of thickness t_1 having an equivalent dielectric constant ϵ_e. The function of the matching layers is to provide an intermediate impedance layer between the plate (1) forming a single layer radome and free space in order to match the impedance of the plate of the radome to the characteristic impedance of the free space. In the circuit theory, such an impedance conversion is widely known as a 1/4 wavelength transformer.

As is well known, the characteristic impedance of the dielectric plate of the specific dielectric constant ϵ_r where, that of free space is 1, will be given by $1/\sqrt{\epsilon_r}$.

Accordingly, the characteristic impedance of the matching layer will be given as follows:

$$1/\sqrt{\epsilon_e} = \theta \quad \sqrt{\epsilon_r}$$
$$\epsilon_e = \sqrt{\epsilon_r} \tag{2}$$

When ϵ_e is given by formula (2), W/P can be obtained from formula (1).

If the materials of the matching layer and the plate of the radome are different from each other, the ϵ_r of formula (1) is not the same as the ϵ_r of formula (2). The thickness t_1 of the matching layer being effectively ¼ the wavelength is given by the free space wavelength λo and the equivalent dielectric constant ϵ_e or the dielectric constant ϵ_r as follows.

$$t_1 = \lambda o/4\ \sqrt{\epsilon_e} = \lambda o/4^4\ \sqrt{\epsilon_r} \tag{3}$$

The value of pitch P may be selected freely under the condition that P is sufficiently smaller than the wavelength λ in the material of the equivalent dielectric constant ϵ_e (where $\lambda = \lambda o/\sqrt{\epsilon_e}$).
For practical purposes, it may be around a value of $\lambda/4$.

In an embodiment of the present invention, the plate of the unilayer radome and strips for the matching layer are made of the same material, F.R.P. (Fiber Reinforced Plastic), the operating frequency is 12 GHz and ϵ_r is 4.

From formula (2), $\epsilon_e = 2$. From formula (1), W/P will be given as ⅓. When P is selected to be $\lambda o/4 =$ 6.25 mm (where $\lambda 0 = 25$ mm at 12 GHz), W will be calculated as 2.08 mm. t_1 is obtained from Formula 3 as 4.42 mm.

We will explain about the transmission coefficient T and reflection coefficient Γ of the radome with the matching layers of the present invention.

The transmission characteristics of the radome with matching layers will be given by the transmission characteristics of a 3 layer structure having the electric properties ϵ_{r_1} and ϵ_{r_2} as shown in FIG. (2).

The four-terminal constants of the circuit theory of the matching layer will be given by the following formulae, where the transmission loss is ignored.

$$A = D = \cos\,(2\,\pi\,\sqrt{\epsilon_{r_1}}\,t_1/\lambda o)\ .\ (4)$$

$$B = j\,1\,/\,\sqrt{\epsilon_{r_1}}\,\sin\,(2\,\pi\,\sqrt{\epsilon_{r_1}}\,t_1/\lambda o)\ .....\ (5)$$

$$C = j\,\sqrt{\epsilon_{r_1}}\,\sin\,(2\,\pi\,\sqrt{\epsilon_{r_1}}\,t_1/\lambda o)\ .....\ (6)$$

The four-terminal constants of the plate of the unilayer radome will be given by the following formulae, where the transmission loss thereof is taken into account;

$$\begin{aligned} A &= D \\ &= \cos\,(2\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda o)\,\cosh\,(\tfrac{1}{2}\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda o\,\tan\,\delta) \\ &\quad + j\,\sin\,(2\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda o)\,\sinh\,(\tfrac{1}{2}\,2\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda\,\tan\,\delta) \qquad (7) \end{aligned}$$

$$\begin{aligned} B &= 1/\sqrt{\epsilon_{r_2}}\cos\,(2\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda o\,)\,\sinh\,(\tfrac{1}{2}2\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda o\,\tan\,\delta) \\ &\quad + j\,1/\sqrt{\epsilon_{r_2}}\sin\,(2\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda o)\,\cosh\,(\tfrac{1}{2}2\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda o\,\tan\,\delta) \qquad (8) \end{aligned}$$

$$\begin{aligned} C &= \sqrt{\epsilon_{r_2}}\cos\,(2\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda o\,)\,\sinh\,(\tfrac{1}{2}2\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda o\,\tan\,\delta) \\ &\quad + j\,\sqrt{\epsilon_{r_2}}\sin\,(2\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda o)\,\cosh\,(\tfrac{1}{2}2\,\pi\,\sqrt{\epsilon_{r_2}}\,t_2/\lambda o\,\tan\,\delta) \qquad (9) \end{aligned}$$

Four terminal circuit constants Ao, Bo, Co and Do equivalent to the three serially connected four-terminal circuits will be given easily from the above constants. The transmission coefficient T and reflection coefficient Γ of the radome with matching layers will be given as follows:

$$1/T = Ao + Bo + Co + Do/2 \qquad (10)$$

$$\Gamma = Ao - Do + Bo - Co/Ao + Bo + Co + Do \qquad (11)$$

The transmission loss in dB and the VSWR for the normal wave incident the radome of the present invention are calculated and illustrated in FIGS. **3, 4** and **5** over the frequency range 11.0 GHz to 13.0 HGz, where the material of radome plate and matching layers are both F.R.P., $P = 6.3$ mm and $W = 2.1$ mm.

Under such conditions, when the t_2 of the plate of the unilayer radome is made 6.25 mm, 3 mm and 1 mm, the curves of the transmission loss and the VSWR are shown in FIG. **3**, FIG. **4** and FIG. **5** respectively.

As is easily understood from FIGS. **3, 4** and **5**, there will be found an optimum value for the thickness t_2 of the unilayer radome. In the examples of these calculations, when t_2 is 2 mm, the broadest band is obtained. The fact that t_2 is 3 mm shows that the thickness of the unilayer radome is approximately $\lambda/4$. It is seen from the above that the thickness of the plate of the unilayer radome will be optimum if it is approximately an odd number multiple of $\lambda/4$, as well as would be the thickness of the matching layers.

According to this invention, as already stated, both surfaces of a dielectric plate having a dielectric constant of ϵ_r may be provided with matching layers made of the same or a different material and the surfaces are given a lattice-like or embossed construction as shown in FIGS. **7** and **8** with parts of the matching layers left missing so as to make the average dielectric constant of the matching layers $\sqrt{\epsilon_r}$, the thickness of the matching layers being equivalently made ¼ wavelength. In the afore-mentioned examples, an instance where the directions of polarization of the matching layers and electric field are made to coincide with each other was described in detail. In the case where the electric field has components of two directions perpendicular to each other, it is preferable to use matching layers of a lattice-like shape. See FIG. **7** for example. If convenient for the manufacture or for the use of the radome, the matching layers may be given a regular spacingly embossed configuration as shown in FIG. **8**.

The manufacturing method of the radome of the present invention will be briefly explained. FIGS. **6***a*, **6***b* and **6***c* are sketches for the purpose of explaining the manufacturing processes. FIG. **6***a* shows, as an example, a method wherein matching layers (dielectric strips) **2** are attached to a dielectric plate **1** by means of an interposed material of an adhesive or the like. FIG. **6***b* shows a method wherein cutting is done into a dielectric plate of a large thickness to form the matched layers. FIG. **6***c* shows a method wherein a plastic material is moulded by means of metal moulds conforming to the shape of the matching layers.

It is very easy to make the construction of this invention by the methods described above. It can provide radomes with matching layers which are found highly effective when used for various kinds of antennas.

What we claim is:

1. A radome wall with matching layers comprising a single layer dielectric plate of any desired thickness having a dielectric constant of ϵ_r, and two dielectric matching layers sandwiching said plate therebetween, each of said matching layers having the average dielectric constant of $\sqrt{\epsilon_r}$ and a thickness which is an odd number multiple of $\lambda/4$ where λ is the wavelength in the matching layer.

2. The radome wall with matching layers as claimed in claim **1** wherein said two matching layers are made of a dielectric material which is different from said plate.

3. The radome wall with matching layers as claimed in claim **1** wherein said two matching layers are made with strips of the same dielectric material as the plate, said strips having the width W and the thickness t_1 and arranged in parallel with each other with a spacing pitch P where P is sufficiently smaller than the wavelength of an operating frequency so as to make the equivalent dielectric constant of the matching layer $\sqrt{\epsilon_r}$.

4. The radome wall with matching layers as claimed in claim 3 wherein said two matching layers are made of a dielectric material which is different from the plate.

5. The radome wall with matching layers as claimed in claim 1 wherein the thickness of the plate of the radome is approximately an odd number multiple of $\lambda/4$ where λ is the wavelength of the plate.

6. The radome wall with matching layers as claimed in claim 1 wherein said matching layers have an embossed configuration with regular spacing.

7. The radome wall with matching layers as claimed in claim 1 wherein said matching layers have a lattice like structure having a distance P from center to center of adjacent parallel frames of said lattice where P is sufficiently smaller than the wavelength of an operating frequency.

8. The radome wall with matching layers as claimed in claim 2 wherein said two matching layers are integrally formed with said plate.

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