MICROWAVE APPLICATIONS OF THIN MAGNETIC RESISTIVE SHEETS

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Abstract

A magnetic resistive sheet — a ferrite tile backed with a metal foil or plate — is recognized as a new type lossy device in the microwave field. Its new applications — absorbing wall, matched loards , attenuators and line filter — are introduced in this paper, especially very thin microwave absorbers (1.7mm in thickness, with V.S.W.R. ≤1.2, in 8.6 - 10.2 GHz) and a novel variable coaxial attenuator are presented.

(1) Introduction

Since a broadband absorbing wall for VHF range utilizing thin ferrite tiles was presented by K. SUETAKE one of the authors in the National Convention of IECE Japan, 1966, many papers ---more than 30--- related to it have been presented until now.

This absorbing wall has a distinguished merits, that is, the thickness of the wall is very thin (almost $\lambda_0/100$) where λ_0 is wavelength in free space, and it has wide working frequency range $\Delta f/f = 2$. The reason for the wall having such merits is that K. SUETAKE used the ferrite material in the region above the point of its magnetic resonance frequency (f_r).

The typical frequency response is illustrated in Fig. 1, where μ' and μ'' are the real and imaginary part of the complex permeability of a ferrite material $\dot{\mu}_r = \mu' - j\mu''$ respectively, and the region A, B in the figure correspond to an old use of ferrite material, that is , A was used for inductors and transformers, and B was used for attenuators and absorbers for microwave power. However, K. SUETAKE first pointed out that the new region C was very useful to construct the magnetic resistive sheet mentioned here.* In the region C, $\mu' \ll \mu''$ and μ'' decreases inversely as frequency increases, and when one use a ferrite tile being backed with metal sheet in this region, he can get a very thin absorbing wall whose thickness $t = (\lambda_0/2\pi)/\mu''$ is about $(\lambda_0/100)$. One example of the wall is shown in Fig. 2. According to his idea, the new "absorbing wall utilizing ferrite tile" was given as the dual version of well-known "electric resistive sheet".

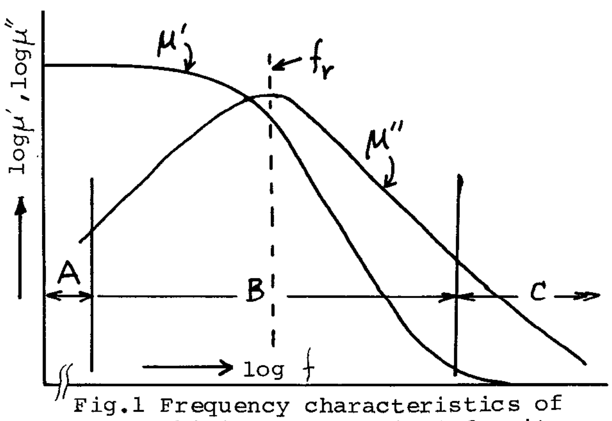


Fig.1 Frequency characteristics of permeability of a typical ferrite

* In 1967, K. SUETAKE has made the physical meaning of such a thin absorbing wall clear under the spot-light of the way of thinking "DUALITY" in the G-MTT International Microwave Symposium, Boston, Mass. as an invited paper.

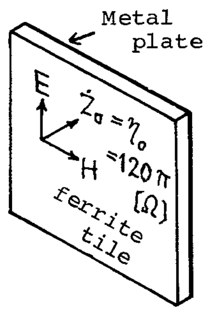


Fig.2 Absorbing wall utilizing a ferrite tile

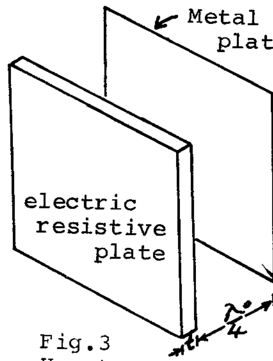


Fig.3 How to construct a real electric resistive sheet

(2) comparison of electric resistive sheet and magnetic resistive sheet under the way of thinking "DUALITY"

The dual relationship between the "electric resistive sheet" and the "magnetic resistive sheet" is shown in table 1. Generally speaking, in two systems being in the dual relation each other, there are the same type formulae or equations to express the characteristics or situations of the system.

In the table 1, electric resestive sheet (Fig. A) is constructed with a resistive plate (made of lossy dielectric material) having width t and being backed with a "fictional" plate which has zero admittance. The fictional plate can be realized by putting a metal plate at the position separated by a quarter wavelength from the back of the resistive plate as shown in Fig. 3. In this case, the imput admittance of the sheet $\dot{Y}_0$ is given by the formulae (1e), and its frequency response is not even, because the real back admittance $\dot{Y}_b$ changes as frequency changes.

On the contrary, the new magnetic resistive sheet as shown in Fig. B of Table 1, being the dual version of the electric resistive sheet, is constructed with a magnetic lossy plate (made of lossy magnetic material such as a ferrite tile) having width t and being backed with a conducting plate which has zero impedance. In this case, the back impedance of the magnetic resistive sheet $\dot{Z}_b$ is always constant being zero.

At a glance on the table 1, one can easily get the conditions to make the sheets pure resistive and keep their resistance constant, as shown in the formulae (3e) to (5e) and (3m) to (5m).

According to the common sense of electrical engineers, the formula (g = constant (4e)) may be understandable for the aim to keep the resistive value of

Table 1 Comparison of electric resistive sheet and magnetic resistive sheet under the way of thinking "DUALITY"

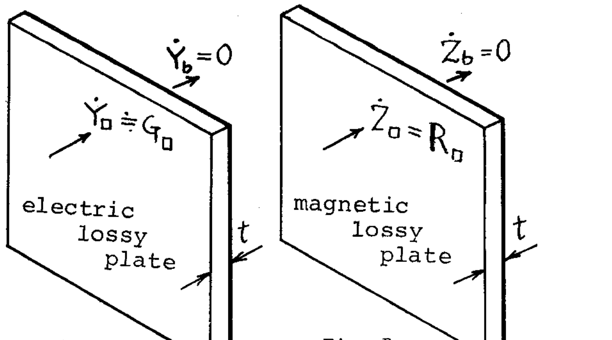


Fig. A Electric resistive sheet	Fig. B Magnetic resistive sheet
$\dot{Y}_\square = G_\square + jB_\square = (g + j\omega\varepsilon)t = j\omega\varepsilon_0(\varepsilon' - j\varepsilon'')t$ (1e)	$\dot{Z}_\square = R_\square + jX_\square = (r_\mu + j\omega\mu)t = j\omega\mu_0(\mu' - j\mu'')t$ (1m)
$G_\square = gt = \omega\varepsilon_0\varepsilon''t = 2\pi\xi_0\varepsilon''t/\lambda_0$ (2e)	$R_\square = r_\mu t = \omega\mu_0\mu''t = 2\pi\eta_0\mu''t/\lambda_0$ (2m)

The condition to make the sheet pure resistive and to keep the resistance constant:

$g \gg \omega\varepsilon$ or $\varepsilon'' \gg \varepsilon'$ (3e)	$r_\mu \gg \omega\mu$ or $\mu'' \gg \mu'$ (3m)
g = const. (4e)	r_μ = const. (4m)
or $\varepsilon'' = G_\square/\omega\varepsilon_0 t = G_\square\lambda_0/2\pi\xi_0 t$ (5e)	or $\mu'' = R_\square/\omega\mu_0 t = R_\square\lambda_0/2\pi\eta_0 t$ (5m)

where g: conductance, r_μ: magnetic resistivity
$\dot{\varepsilon}_r$: $\varepsilon_r' - j\varepsilon''$ permitivity, $\dot{\mu}_r = \mu' - j\mu''$ permeability
ξ_0: wave conductance in free space $= \sqrt{\varepsilon_0/\mu_0}$
η_0: wave impedance in free space $= \sqrt{\mu_0/\varepsilon_0}$

the sheet constant, however, the formula ($\varepsilon'' \propto 1/f$ (5e)) may not be considered so populer. In the same sense, formulae (r_μ = constant (4m)) or ($\mu'' \propto 1/f$) may be taken as the new concept by them. And the condition to realize these formulae was found by SUETAKE as one of new ferrite applications in microwaves in the region C of the Fig. 1.

(3) Special feature of the magnetic resistive sheet

The magnetic resistive sheet mentioned above has several good merits as follows

A. The surface resistivity is given as

$$R_\square = \omega\mu_0\mu''t = 2\pi\eta_0\mu''\frac{t}{\lambda_0} .$$

An arbitrary value of resistance can be available by simply changing thickness t, after getting the ferrite material whose characteristics as shown in the region C exists in the proposed working frequency range . The value of resistance obtained is almost constant in this frequency range.

B. Thickness of the sheet is very thin (about $\lambda_0/100$). (See the foot note in the next page.)

C. It may be used in a high power operation, because it is very easy to make the sheet cool at the outer side of metal plate.

D. The sheet can be used in any kinds of shapes at applications of microwave engineering. For example, it can be used in the shape of a circular cylinder as lossy elements for attenuators and matched loads in coaxial lines. In this case, the usual electric resistive sheet have been used only in a portion of the inner conductor, however the magnetic resistive sheet mentioned here can be used in both portions of inner or outer conductor. Therefore, various kinds of applications of the magnetic resistive sheet can be obtained such as (A) an absorbing wall for microwave dark room as shown in Fig. 2, (B) matched loads for waveguides and coaxial lines (Fig. 4-a, b, c) (C) fixed attenuator in coaxical lines (Fig. 4-d) and line filters (Fig. 4-e).

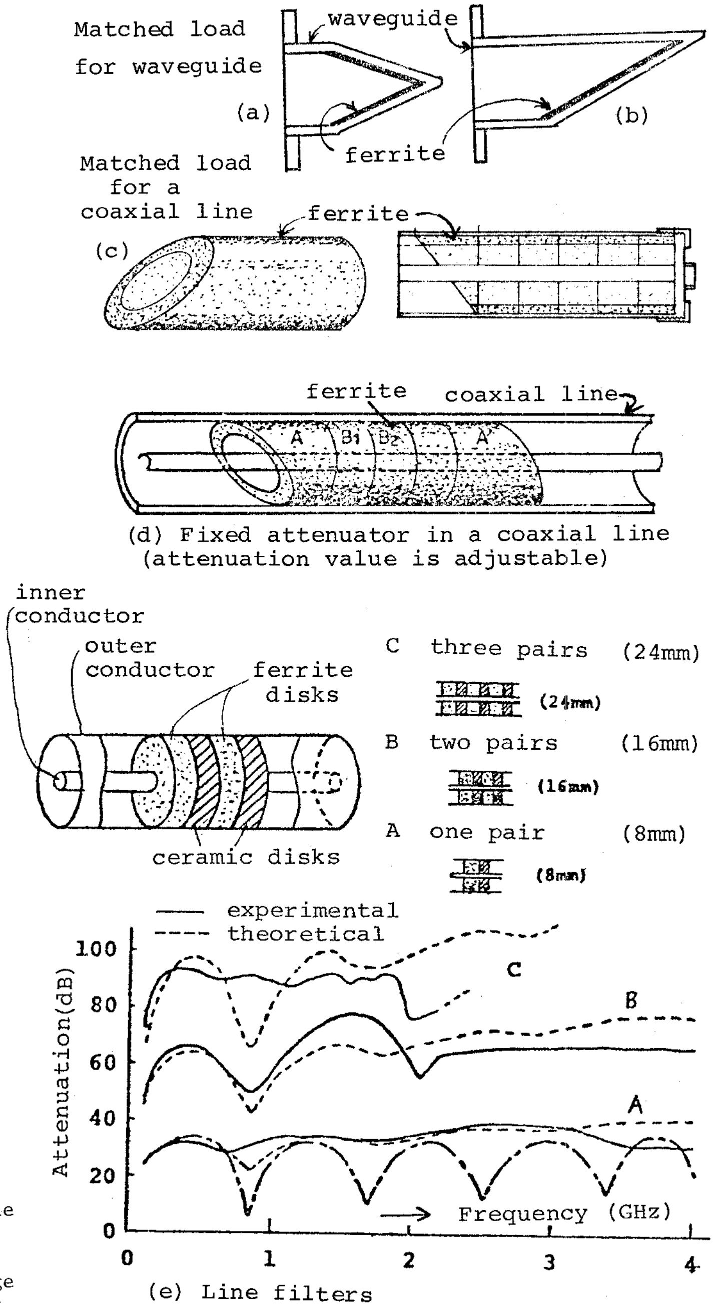


Fig.4 Various applications of the magnetic resistive sheet

The last is very useful to prevent leaking microwave power through lines suppling A.C. power from some high power microwave equipments such as microwave oven. Its size is very small, only 24mm length as shown in Fig. 4-e, but attenuation is very large --- higher than 80 dB in the range 100 to 4000 MHz for example. In the next sections two new applications of magnetic resistive sheets are introduced.

(4) A new variable coaxial attenuator

This variable attenuator as shown in Fig. 5 offers the following special features.

1) Mechanical construction of the attenuator is very simple as shown in the figure.

2) The frequency characteristics of the attenuation is superior (V.S.W.R. less than 1.2 in the working frequency range 1-4GHz).

3) Since reflection caused by the sliding conductor mask is small, the insertion loss is less than 0.2 dB.

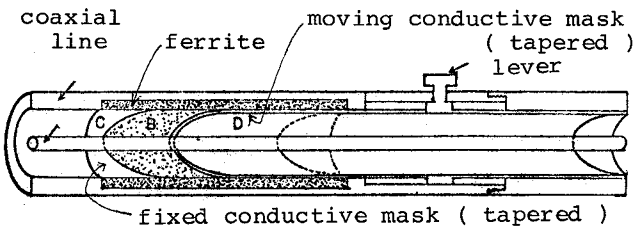


Fig.5 A slide type variable coaxial attenuator (1~4 GH_z)

New type of matching section: In section (3), a simple matching section for a fixed type coaxial attenuator was presented. Fig.4(d) illustrates such a matching section in which obliquely cut ferrite cylinder was used. In the variable coaxial attenuator presented here, the same idea is used in its further developed form. Fig.6(a) shows the new matching section made of tapered thin metalic foil adhered to the inner wall of ferrite cylinder. And further a similar type of matching section made of thin metallic pipe cut obliquely at both its ends can also be used by inserting it at the junction portion between the ferrite cylinder and the outer conductor of the coaxial line as shown in Fig.6(b). Theoretical and also experimental works shows that the taper length of these matching section t' should be more than $\lambda_o/4$ to keep good V.S.W.R. characteristics less than 1.2, where λ_o is the wavelength as shown in Fig.6(c).

Optimum ferrite thickness: The attenuation characteristics required for designing the dimensions of the ferrite cylinder are theoretically examined. The result shows that there exists an optimum ferrite thickness l_{opt} of the ferrite cylinder in order to provide fairly large attenuation as well as flat frequency characteristics in connection with permeability $\dot{\mu}_r$($=\mu' - j\mu''$) of the ferrite material.

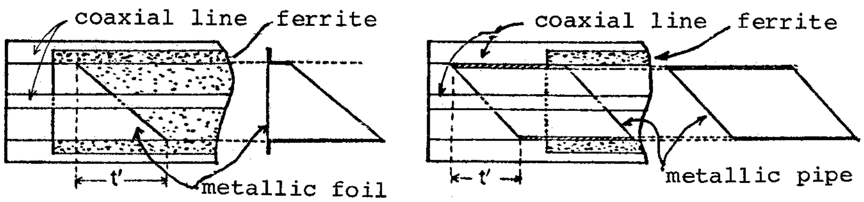
In the case of 20D coaxial line,

i) l_{opt} should be taken as 0.3 - 0.4 cm, when $\mu' \geq 1.5$ in the working frequency range above 2.0 GHz.

ii) l_{opt} should be taken as 0.2 cm, when $\mu' = 1.0$ in the working frequency range from 1.0 to 4.0GHz.

In both case, it is important to choose μ'' as large as possible in order to maintain large attenuation.

Prototype of the attenuator: A new variable coaxial attenuator is designed by using the material M_3S ($M_g - Z_n$ ferrite) and M_8C ($N_i - Z_n$ ferrite) both producted by T.D.K. The measured frequency charateristics of the prototype as the parameter of the sliding length t are shown in Fig. 7. It shows that linearity is very good and V.S.W.R. characteristics are superior.



(a) Metallic foil type (b) Metallic pipe type

Fig.6 Matching sections

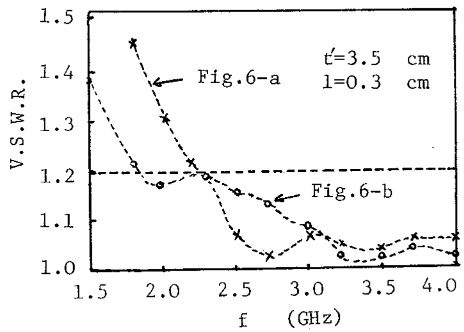


Fig.6(c) Frequency characteristics of matching sections

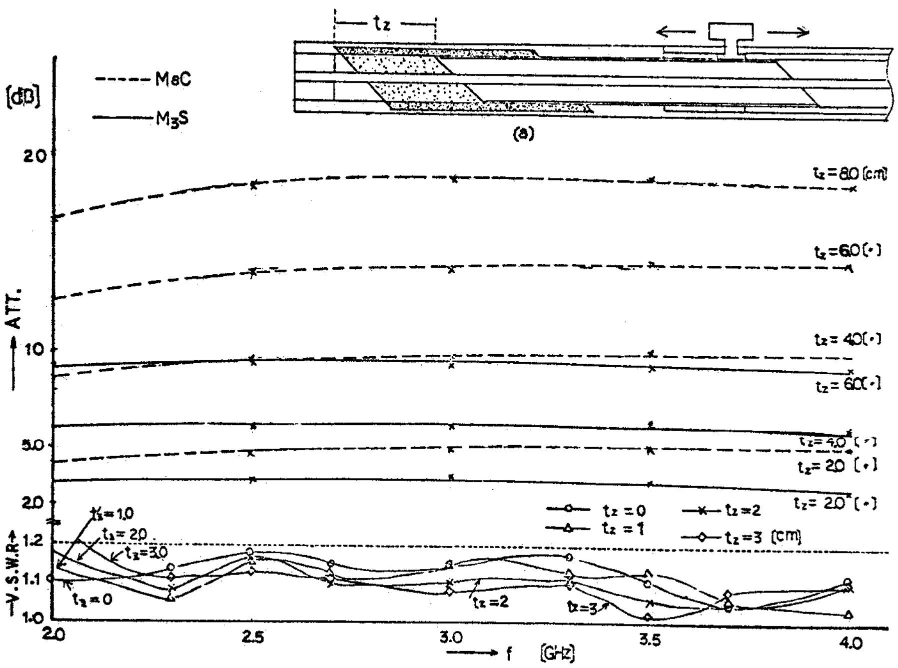


Fig.7 (a) Characteristics of a slide type variable coaxial attenuator

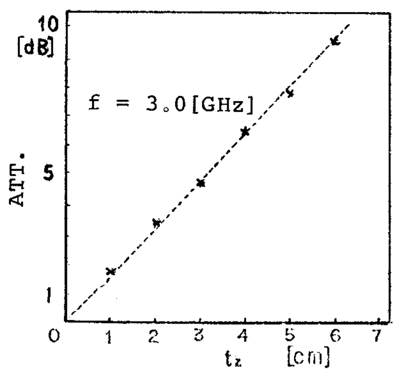


Fig.7(b) Linearity of the attenuator

FOOTNOTE

It can be applied for preventing TV ghost caused by reflected waves from tall buildings.

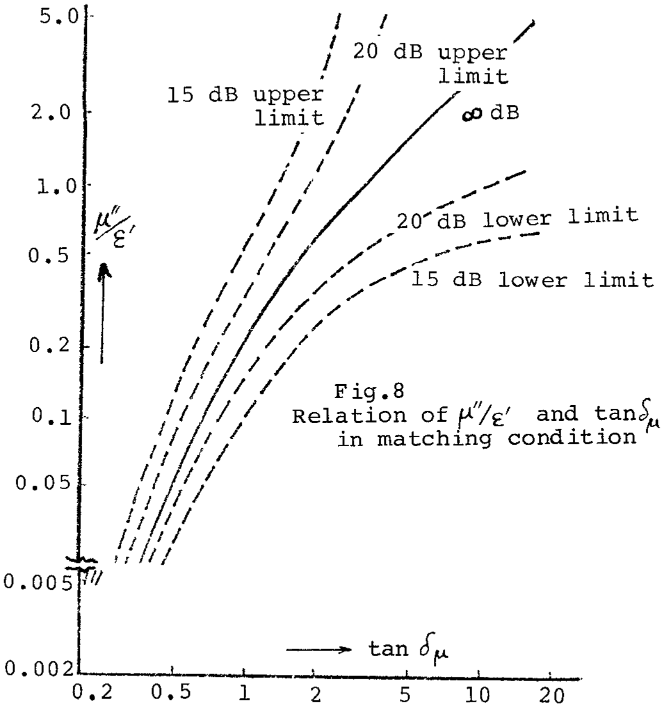


Fig.8 Relation of μ''/ε' and $\tan\delta_\mu$ in matching condition

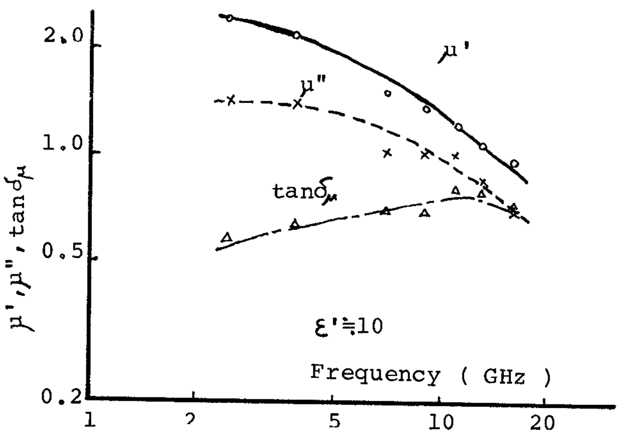


Fig.9 Magnetic properties of the material

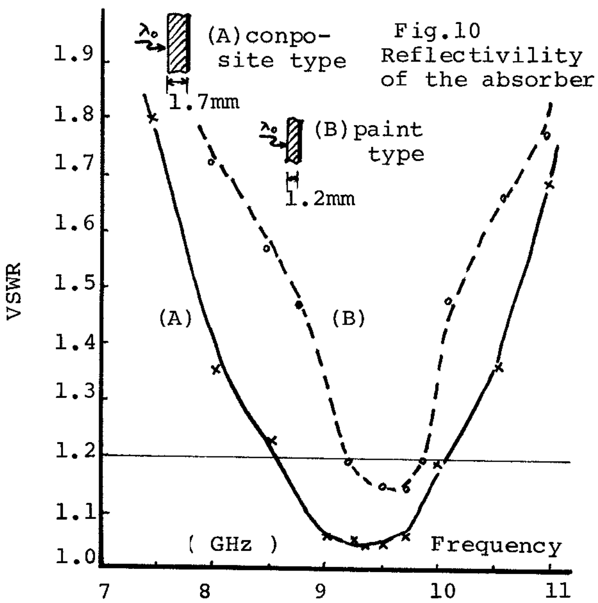


Fig.10 Reflectivility of the absorber

(5) Very Thin Magnetic Microwave Absorbers

The basic idea for the design of magnetic microwave absorbers mentioned above has the utilization of large μ'' in the frequency range above its resonant frequency f_r where μ'' varies inversely proportional to frequency and further permittivity ε' of the material was neglected. However, in the real absorber, especially made of composite material as mentioned here μ'' is not so large and ε' plays an important role in its characteristics. In this section, an exact design of a thin microwave absorber is given taking the effects of ε' into consideration of its design as well as μ' and μ''.

The absorber is constructed of ferromagnetic sheet having complex permeability $\dot{\mu} = \mu' - j\mu''$, permittivity $\dot{\varepsilon} = \varepsilon' - j\varepsilon''$ and thickness d and it is backed with a conducting plate as shown in Fig. 2.

The reflection coefficient of this absorber $\dot{\Gamma}$ can be expressed by the reflection coefficient at the front surface of the material having infinite length $\dot{\Gamma}_0 = |\dot{\Gamma}_0| e^{-j\phi}$ as follows.

$$\dot{\Gamma} = \frac{\dot{\Gamma}_0 - e^{-2\dot{\gamma}d}}{1 - \dot{\Gamma}_0 e^{-2\dot{\gamma}d}}$$

where $\dot{\gamma} = \alpha + j\beta = j\omega\sqrt{\dot{\varepsilon}_0\dot{\mu}_0}$ is the propagation constant inside the material.

Then, the matching condition ($\dot{\Gamma} = 0$) may be expressed by the following formulae.

$$\dot{\Gamma}_0 = e^{-2\alpha d}, \quad \phi = 2\beta d$$

Further, we rewrite the above conditions in terms of $\tan\delta_\mu (= \mu''/\mu')$, $\tan\delta_\varepsilon (= \varepsilon''/\varepsilon')$ and μ''/ε', because these quantities are more familiar for material engineers. After taking some mathematical treatments μ''/ε' can be expressed by a function of $\tan\delta_\mu$ as shown in Fig.8($\tan\delta_\varepsilon$ is neglected in this procedure as it is very smaller than other quantities). This design chart is very useful for material engineers to estimate the quality of ferrite and to find out the most suitable one so that the ratio μ''/ε' is on the heavy line in the figure over wide frequency range. On the other hand, the thickness of the absorber can be expressed as follows.

$$d = k \cdot \frac{\sqrt{2}}{\sqrt{\varepsilon' \cdot \mu'} \cdot \sqrt{\sqrt{1+(\tan\delta_\mu)^2} + 1}} \cdot \lambda_0$$

where λ_0 is wavelength in the free space, and k is a function of $\tan\delta_\mu$, however its value is almost constant practically being almost equal to 0.2 when $\tan\delta_\mu$ is less than 1.5.

A new composite microwave absorber is developed as a mixture of Ni - Zn ferrite powder and synthetic rubber by the procedures mentioned above. The frequency characteristics of each quantities of the material are shown in Fig. 9. This absorber with only 1.7 mm thickness has shown good performance such that the VSWR is less than 1.2 in the wide frequency range from 8.6 to 10.2 GHz as shown in Fig. 10A.

In addition, we developed also a new paint-type magnetic absorbing material under the same idea mentioned above. This paint absorber with only 1.2 mm thickness has good performance such that the VSWR is less than 1.5 in the wide frequency range from 8.8 to 10 GHz as shown in the same figure.

(6) Conclusion

The new idea of a magnetic resistive sheet constructed with a magnetic lossy plate such as ferrite tiles, or mixture of ferrite powder and plastics being backed with metal sheet is described, and various type novel and useful applications utilizing this sheet done by the author are introduced. The authors think the applications of this sheet will be wide and successful use in future.