INSERTION LOSS ANALYSIS OF SMALL ISOLATOR FOR PORTABLE PHONES

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ABSTRACT

The insertion loss of lumped element isolator for portable phones was analyzed using the developed circuit simulator, which includes three loss factors: linewidth ΔH of garnets, resistance R of central conductors and dielectric loss, $\tan\delta$ of capacitors. By comparison between the experimental results and calculations, the contribution ratios of ΔH and R towards insertion loss, in 7mm square isolators at 941.5 MHz, were each determined to be almost 50%, and that of $\tan\delta$ to be negligibly small.

INTRODUCTION

In recent days, miniaturization and weight reduction of portable phones is proceeding at an accelerated pace. For this purpose, small and thin type isolators have been in strong demand. However, generally speaking, it is very difficult to obtain small isolators with wide bandwidth and low insertion loss. The insertion loss of the isolator, especially, relates directly to the discharge time of the battery of the portable phone. Recently, the extent to which insertion loss of small isolators could be reduced, has become a main concern for engineers developing small portable phones. In order to obtain low insertion loss, it is necessary to make clear, the loss mechanism in small isolators. Unfortunately, this was discussed only qualitatively until now. More quantitative arguments, based on material properties and mechanical structure, are required. In this paper, a method of insertion loss analysis and the result will be reported.

CIRCUIT SIMULATOR

The circuit simulator, developed to analyze the insertion loss, is based on the symmetrical lumped element circulator[1], for which the analysis based on the eigen mode excitation method is possible. The equivalent circuit for simultaneous excitation mode is shown in Fig.1(a) and that for circular excitation modes in Fig.1(b). C is a capacitor, $L\pm$ are the inductances for

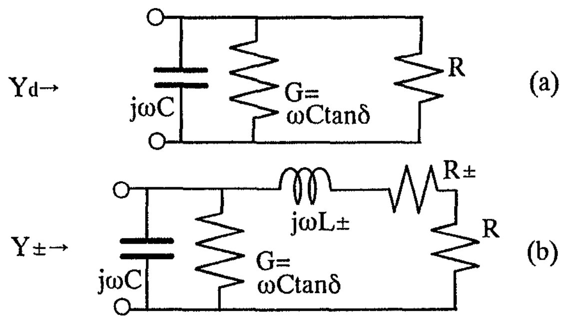

Fig.1 Equivalent circuits for eigen mode excitation (a)simultaneous mode, (b)circular modes

circular($\pm$) excitations. It is assumed that the inductance for simultaneous mode is zero. Three loss factors are introduced. The first is resistance $R[\Omega]$ of central conductors and case(ground). The second is magnetic loss $R\pm=\omega K\eta\mu\pm''[\Omega]$, where ω is angular frequency, K is air core inductance[nH], η is a ferrite filling factor, while $\mu\pm''$ are the imaginary parts of relative permeability of garnet, direct results of linewidth ΔH in case of circularly polarized excitations, as determined by the Polder equation. The third loss factor is dielectric loss, $\tan\delta$, of capacitors.

The admittance Y_d, $Y\pm$ for eigen mode, easily lead to the reflection coefficients Γ_d, $\Gamma\pm$ and to the S parameters, in turn as follows:

$$S_{11}=(1/9)\,|\,\Gamma_d+\Gamma_+ +\Gamma_-\,|^2$$
$$S_{21}=(1/9)\,|\,\Gamma_d+\Gamma_+ e^{-j2\pi/3}+\Gamma_- e^{j2\pi/3}\,|^2 \qquad (1)$$
$$S_{31}=(1/9)\,|\,\Gamma_d+\Gamma_+ e^{j2\pi/3}+\Gamma_- e^{-j2\pi/3}\,|^2$$

where S_{11}, S_{21} and S_{31} are return loss, insertion loss and isolation loss respectively.

PROCEDURE OF ANALYSIS

Fig.2 shows the flow chart of insertion loss analysis by the developed circuit simulator. Initially, the central frequency f_0 of the examined isolator, saturation magnetization $4\pi M_s$ of garnet, air core inductance K are input. The ferrite filling factor η is defined as

$$L\pm=K\{\eta\mu\pm'+(1-\eta)\} \qquad (2).$$

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η=0.75 is always constant in this report. From these variables, the simulator calculates the operating field σ (normalized by $H_{res}=\omega_0/\gamma$), specific 20 dB band width w of S_{31}, and value of capacitor C. By comparison between experiments and calculations, the most optimum K is decided. σ is defined as

$$\sigma=\gamma\{H_{ext}-(N_z-N_x)4\pi Ms\}/\omega \quad (3)$$

where γ is the gyromagnetic ratio, H_{ext} is the external field, N_z, N_x are the demagnetization factors along z- and x-axis, determined by using the equation for ellipsoids[2], with diameter D and thickness h of garnet, as parameters.

Next, the loss factors of resistance R, of the central conductor, linewidth ΔH of the garnet and $\tan\delta$ of capacitor C are input individually. The frequency characteristics of R and $\tan\delta$ are expressed as:

$$R=R_0(f/f_0)^{1/2} \quad (4)$$

$$\tan\delta=\tan\delta_0(f/f_0) \quad (5)$$

considering skin effect and dielectric losses respectively. It is assumed that ΔH is constant over the band width. From Polder equation, $\mu_\pm''$ are expressed as follows;

$$\mu_\pm''=\alpha P/\{(-\sigma\pm1)^2+\alpha^2\} \quad (6)$$

where $P=\gamma 4\pi Ms/\omega$, $\alpha=\gamma\Delta H/2\omega$. By calculating the frequency characteristic of insertion loss S_{21}, at room temperature, and comparing it with experimental results, a rough estimate of contribution ratios of loss factors can be obtained.

In order to improve the accuracy, the comparisons are carried out over a wide temperature range from -35℃ to +85℃. In the calculations, 4πMs, C, ΔH, $\tan\delta$, H_{ext} are temperature dependent variables. The 4πMs of garnet was measured by VSM. The C and $\tan\delta$ were obtained by experiments of series resonant circuits. R has a temperature coefficient given by

$$\alpha_r=+3800 \text{ [ppm/℃]}$$[3]

because of the silver coating on the central conductors. According to the reference[4], the temperature coefficient of ΔH can be used as

$$\delta_h=-5255 \text{ [ppm/℃]}.$$

The effects of R and ΔH on insertion loss are opposite to each other. It must be considered that though the temperature dependence of H_{ext} may follow that of the residual flux density of a ferrite magnet with α_h= -2000[ppm/℃], in such small isolators, the same value can not be used by itself due to the large leakage of flux from the magnetic circuit. Its value should be determined by the comparison between experiment and calculation. Thus, by extending the area of comparison

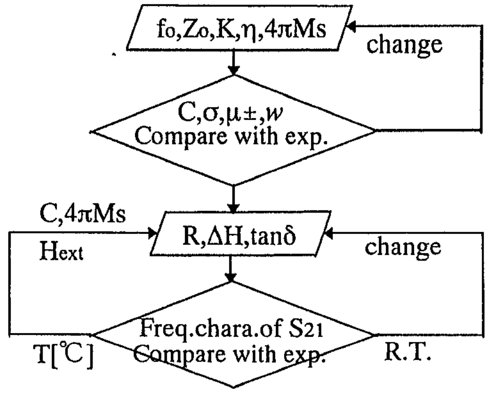

Fig.2 The flow chart for insertion loss analysis

to a wide temperature range, the contribution ratio of each loss factor becomes clearer.

FUNDAMENTAL PROPERTIES OF CIRCULATOR WITH LOSS

In this circuit simulator, the symmetrical loss free circulator is a starting point. Each of the loss factors will be introduced to this isolator independently. Fig.3 shows the variation of S parameters due to introduction of only R. In the loss free (R=0) case, the reflection loss S_{11} and the isolation loss S_{31} are infinite and the insertion loss, S_{21} is zero at center frequency f_0. When R is introduced, S_{21} increases and S_{11}, S_{31} are degraded, and shift in frequency, towards HF in the case of the former, and LF in case of the latter. This "frequency shift" trend tends to reverse in case only ΔH loss is introduced into the simulator, and is nearly absent in case of $\tan\delta$.

The changes of S_{11} and S_{31} with magnetic field are shown in Fig.4. σ_0 refers to the normalized magnetic field in loss free circulator. S_{11} is improved by slightly raising the field, while S_{31} by slightly lowering the field. This tendency is the same, irrespective of the source of loss (R, ΔH or $\tan\delta$). Consequently, in case of a lossy symmetrical circulator, it is impossible to make S_{11} and S_{31} infinite simultaneously.

Fig.5 shows the frequency dependence of S_{11} obtained by introducing each loss factor individually (R=0.117[Ω], ΔH=51[Oe], $\tan\delta$=0.0107) so as to obtainS_{21}=0.4[dB] at f_0. Where f_0=941.5 [MHz], K=1.15 [nH], 4πMs=900 [G]. The loss free curve is also shown for reference. This curve has a "right shoulder up" shape.

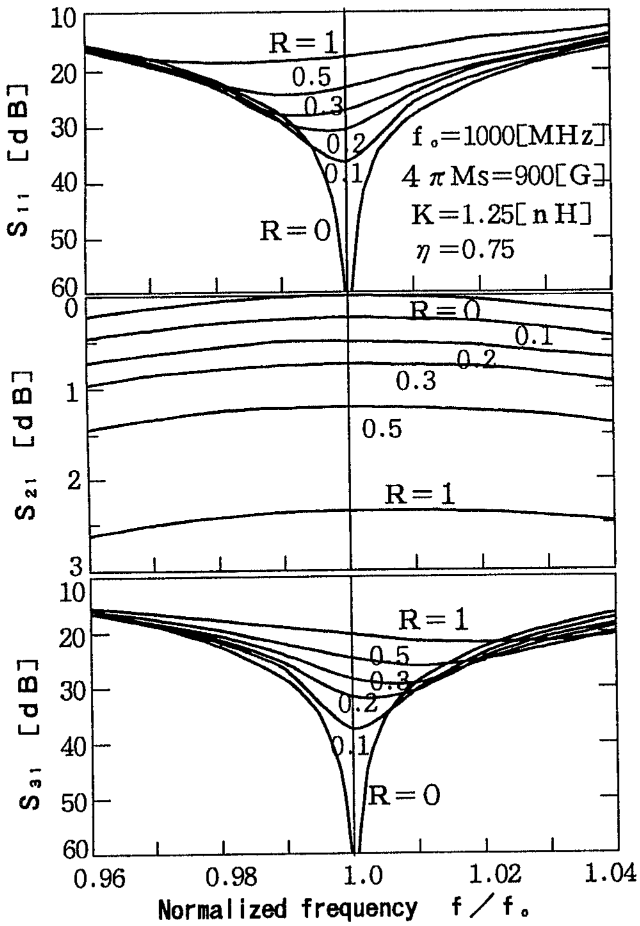

Fig.3 The changes of S parameters by the introduction of R only

By introducing only ΔH, this "right shoulder up tendency" becomes stronger. The curve for the tanδ case is almost symmetrical and that for R lies between above two curves. Therefore, by comparison of the measurements of S_{21} near f_0 with the calculations, the contribution ratio of loss factors, at room temperature, can be roughly estimated.

INSERTION LOSS ANALYSIS OF SMALL ISOLATOR

Two samples of 7mm square isolators, A and B, of 2mm thickness and 941.5 MHz frequency rating, were examined. The peak value of insertion loss in isolator A was 0.38[dB] and increased with temperature from -35℃ to +85℃. The capacitor C had a temperature

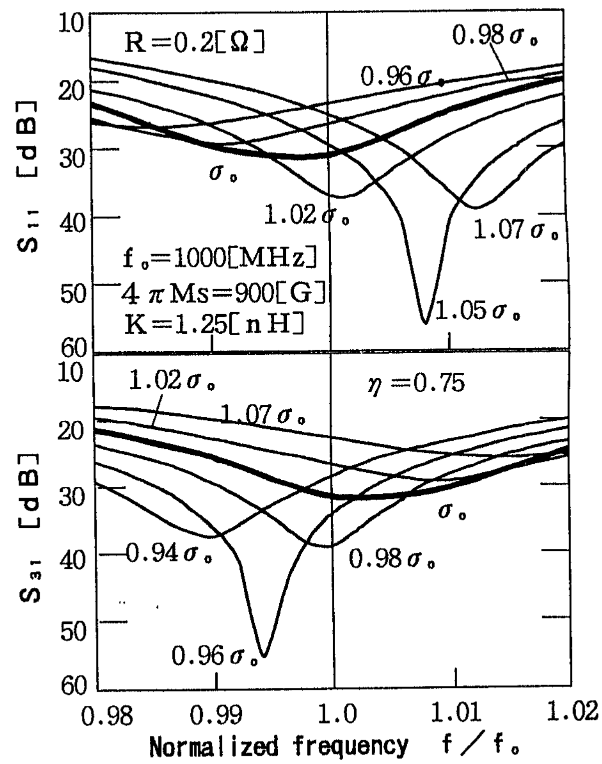

Fig.4 The changes of S parameters by magnetic field

coefficient, α_c, of -76[ppm/℃] and tanδ of a non-negligible value. In isolator B, the insertion loss peak value did not vary with temperature. Capacitor parameters were as follows: α_c=200[ppm/℃], tanδ=0. The physical quantities for each of the isolators used for simulation are shown in Table 1.

In order to improve the accuracy of contribution ratio of loss factor to insertion loss, the temperature characteristics of S_{21} were examined. The comparison between experiments and calculations were implemented by varying each of the parameters such as R[Ω], ΔH[Oe] and tanδ, and temperature coefficient α_h of external magnetic field. The values of tanδ and 4πMs of garnet at each temperature were determined experimentally. Fig.6 shows the comparison of S_{21}, between experiment and calculation in isolator A. By letting α_h=-1600[ppm/℃], good agreements were obtained.

The results of the comparison are shown in Table 2. The contribution ratios of ΔH and R are determined to be almost 50%, and that of tanδ to be negligibly small at room temperature. Effects of ΔH are more pronounced

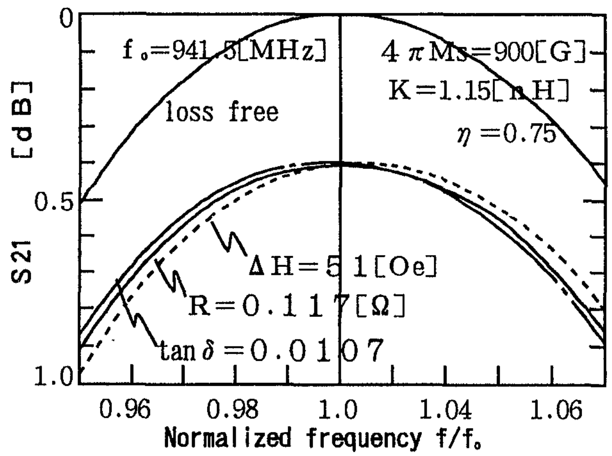

Fig.5 The frequency dependence of S21 when loss factors were introduced individually.

at low temperatures while those of R, at higher temperatures. The reason why S_{21} shows only small changes over a wide temperature range, is that the effects of R and ΔH cancel each other out.

The values of ΔH=18-26[Oe] are very similar to the measured material constant at resonance. However, in actual "above resonance type" isolators, the operating field is 2-3 times higher than the resonant field and ΔH_{eff} may be within a few oersteds. It can be reasonably interpreted, that the derived ΔH reflects the non uniformity of magnetic field in the garnet as well as material properties. The 3-D simulation of magnetic field distribution in a garnet realized the same order of non uniformity of magnetic fields at the top and bottom surfaces.

SUMMARY

In order to reduce the insertion loss, it is important to reduce the effects of R and ΔH respectively. The former requires use of central conductors with high Q, achieved by improving their shapes and structures. In the latter case we believe that lower ΔH situation could be obtained by optimizing the dimensions of garnet and magnet. Hence, further investigation will be necessary for designing the optimum magnetic circuits of small isolators. Finally, we greatly appreciate the efforts of Mr. H. Itoh, Mr. S.Yamamoto and Mr. T.Takashima for collecting the valuable data.

1)Y.Konishi; IEEE MTT-13 pp.852-864 (1965)

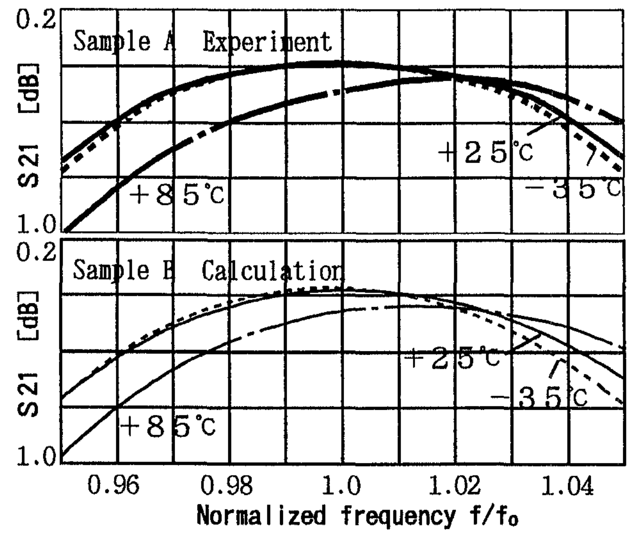

Fig.6 Comparison between experiments and calculations for small isolator

Table 1 Physical quantities used for simulation

Sample	T(℃)	4πMs(G)	tanδx10^3	D	h
A	-35	979	0	3.9 (mmϕ)	0.5 (mm)
	+25	883	0.382		
	+85	767	1.69		
B	-35	1155	0		
	+25	1025	0		
	+85	885	0		

Sample	K(nH)	ΔH(Oe)	R(Ω)	α_c[ppm/℃]
A	1.30	18	0.087	-73
B	1.23	26	0.080	+200

Table 2 The contribution ratios of loss factors to insertion loss

Sample	A			B		
T(℃)	-35	+25	+85	-35	+25	+85
S21(dB)	0.38	0.38	0.44	0.43	0.42	0.42
Δ H(%)	48	38	23	59	49	35
R(%)	52	59	64	41	51	65
tanδ	0	3	13	0	0	0

2)S.Chikazumi; "Physics of Ferromagnetism" Shoukabo (1991)
3)Rigaku Nenpyou (1998)
4)A.S.Boxer et al; "Handbook of Microwave Ferrite Materials" Academic Press (1965)