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Development of Ni-Zn Ferrite Materials with Improved Ingress Noise for Telecommunications

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The compositions of Ni-Zn ferrites have been investigated in order to achieve suitable frequency characteristics of impedances for the distributors or directional couplers to convey high frequency signals at desired transfer rates in CATV networks. The results show that some sharp peaks in the impedance-frequency profiles arise at certain frequencies closely related to the dimensions of the cores which have been magnetized presumably by noise currents induced by thunderbolts, electrical appliances placed close to the networks, and so on. It has been found that the magnetostriction constants of the materials of the cores affect the heights of the peaks in the impedance-frequency profiles, which suggests a kind of enhancement in the occurrence of the sharp peaks due to the contribution of magnetostrictive vibration coupled with the fundamental mode of the mechanical vibration of the core, the resonant frequency of which is decided by its diameter and modulus of elasticity.

Key words: Ni-Zn ferrite, impedance, magnetostriction, CATV, ingress noise.

1. INTRODUCTION

The broad-band accesses are playing more and more important roles in telecommunications since high transfer rate is required in order to handle large size of electronic files with informations such as documents, photographs, musics, and movies. Among these accesses, CATV network system is well known as the system which can be used not only for television broadcastings but also for telecommunications.

The CATV network system(Fig.1) basically consists of interactive, tree-and-branch structures where the down-link is used for transferring informations from the Head End to terminals and the up-link is for the information transfers in the opposite direction[1]. In case of the up-link telecommunications, noises arising at numerous terminals tend to induce ingress noises which may limit the data transfer speed when various kinds of noises merge at nodes and/or the Head End.

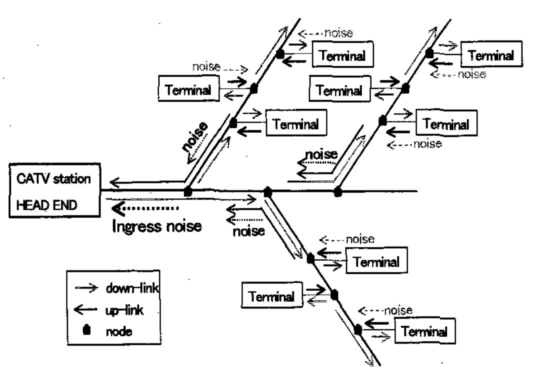

Fig.1 CATV network system

Ni-Zn ferrites are widely used as the materials for magnetic cores with applications to transformers for telecommunications and power supplies, inductors for electronic circuits, etc. For these applications, high frequency characteristics of Ni-Zn ferrite cores are important especially in the application to transformers for distributors and directional couplers in CATV network systems.

In order to improve the ingress noises which occur in the above systems where the current materials are used, new compositions have been investigated.

2. EXPERIMENTS

Ni-Zn ferrites were prepared by the ordinary ceramics techniques. The mixtures of raw materials, Fe_2O_3, NiO, CuO, and ZnO, were calcined at 1173K for 1.5h, and milled using stirred bead mills for 1h. After drying, the powders were granulated, pressed, and sintered at 1373K for 1.5h.

The initial permeability of the samples in toroidal shapes, with outer diameter(OD) of 3 to 4 mm, inner diameter(ID) of 1 mm, and height of 1.5 to 4.5 mm, was measured using a LCR meter and the frequency characteristics of the above toroidal samples were measured using an impedance analyzer.

3. RESULTS AND DISCUSSION

As shown in Fig.1, when the signal is transmitted from CATV station to each terminal, it is necessary to distribute the signal at each node where ferrite cores are used. It has been recently found that once the ferrite cores have been magnetized by large currents induced by thunderbolts, electrical appliances, and so forth, the ingress noise increases and the signal transmittance speed goes down accordingly.

After exposing the ferrite core to this phenomenon, it has been clarified that sharp peaks appear in the frequency characteristics of the impedance of the ferrite core magnetized by the current described above (Fig.2).

It seems that the frequencies where the sharp peaks appear in the frequency characteristics of the impedance are closely related to the frequency f_0 calculated from the mechanical resonance of the ferrite core with the fundamental natural mode of vibration of a toroid[2] with average radius R, Young's modulus E, and density ρ as shown in Fig.3.

One of the observed frequencies, the lower frequency peak of 772 kHz in Fig.2 almost coincides with the calculated frequency f_0 of 814 kHz of the ferrite core, as shown in Fig. 3, with Young's modulus E of 173 GPa, density ρ of 5220 kg/m^3, and average radius R of 1.125 mm.

According to the data, collected on a few different kinds of Ni-Zn ferrite cores with conventional compositions, regarding the peaks as the above which appear in the frequency characteristics of the impedance, the heights of the peaks seem to have some relationships with magnetostriction constants of the ferrites investigated.

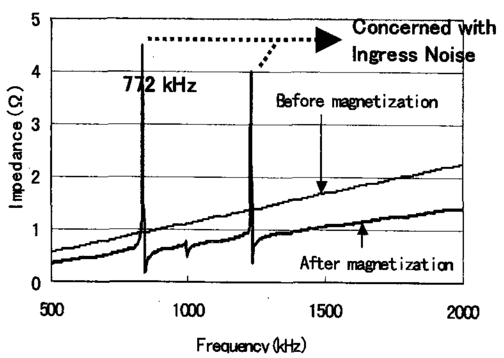

Fig. 2 Frequency characteristics of impedance

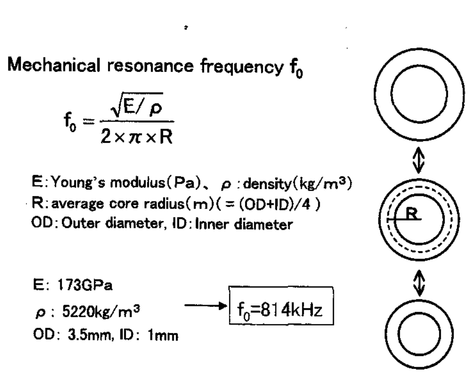

Fig. 3 Vibration mode of ferrite core

It is known that saturation magnetostriction constants of ferrites can be estimated by calculating the contributions from all the elements composing ferrites, referring to their compositions[3]. Table I shows the saturation magnetostriction constants of the simple ferrites used for calculating the saturation magnetostriction constants of the Ni-Zn ferrites to investigate the relationship between the heights of the peaks in the frequency characteristics of the impedance and the magnetostriction constants of the ferrites with various compositions listed in Table II in order to improve the ingress noises in CATV network systems.

Table I Saturation magnetostriction constants of simple ferrites.

Simple ferrite	λ_{100} (10^{-6})	λ_{111} (10^{-6})	λ_s (10^{-6})
$ZnFe_2O_4$	—	—	—
$NiFe_2O_4$	-46	-22	-32
$CuFe_2O_4$	—	—	-10
$FeFe_2O_4$	-20	+87	+40

Table II Experimental compositions and calculated saturation magnetostriction constants of ferrites

	No.	Fe_2O_3 (mol%)	ZnO (mol%)	NiO (mol%)	CuO (mol%)	λ_s* ($\times 10^{-6}$)
New composition	1	47.20	30.00	14.80	8.00	-7.09
	2	48.60	31.90	11.70	7.80	-7.09
	3	49.00	32.00	11.20	7.80	-7.35
	4	49.60	32.00	10.70	7.70	-7.78
	5	48.60	32.30	11.30	7.80	-6.84
	6	49.10	32.40	10.70	7.80	-7.11
	7	49.50	32.50	10.20	7.70	-7.36
	8	48.30	32.80	11.00	7.90	-6.25
	9	48.80	33.00	10.40	7.80	-6.53
	10	49.30	33.00	9.90	7.80	-6.94
	11	48.30	33.30	10.50	7.90	-5.89
	12	48.80	33.40	10.00	7.80	-6.20
Conventional composition	13	52.00	21.00	27.00	0.00	-17.68
	14	48.00	25.00	19.00	8.00	-10.77
	15	47.50	23.00	21.50	8.00	-11.58
	16	49.85	28.95	15.20	6.00	-10.74

* Calculated saturation magnetostriction constant

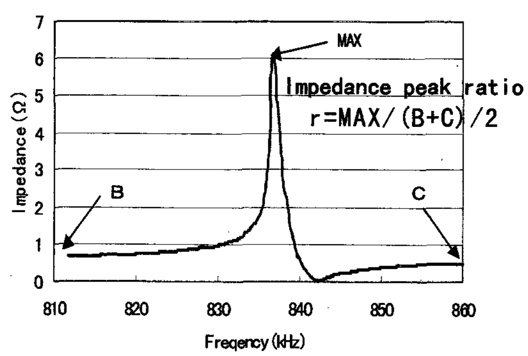

Fig. 4 Impedance peak ratio

"Impedance peak ratio", as defined in Fig. 4, has been introduced to try to compare the heights of the peaks in the frequency characteristics of the impedance of various samples semi-quantitatively.

The following is the procedure to calculate "impedance peak ratio".

1)Find out the highest peak in the frequency characteristics of the impedance.
2)Scan around the highest peak with the span of 50 kHz and the pitch of 0.125 kHz.
3)The maximum impedance value "MAX", the value "B" at the lowest frequency, and the value "C" at the highest frequency are used for the calculation of the impedance peak ratio according to the formula shown in Fig. 4.

As expected from the calculated saturation magnetostriction constants of the ferrites with the new compositions, the impedance peak ratios of the samples from No. 1 to No. 12 show relatively small values, ranging from 1.04 to 3.59, as compared to those of the samples from No. 13 to No. 16, ranging from 5.46 to 9.67.

The above difference can be seen if the peak of the sample No. 13 with the conventional composition shown in Fig. 5 and that of the sample No. 6 with the new composition shown in Fig. 6 are compared. The impedance ratios are 9.67 and 1.18, for No. 13 and No. 6, respectively.

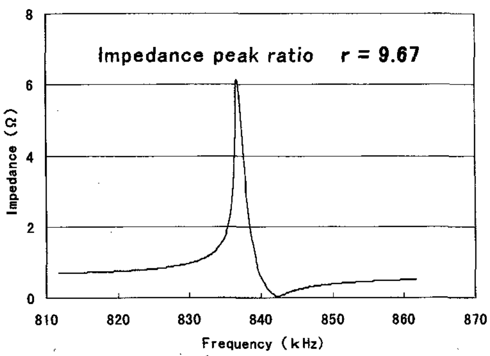

Fig. 5 Impedance peak of the sample No. 13

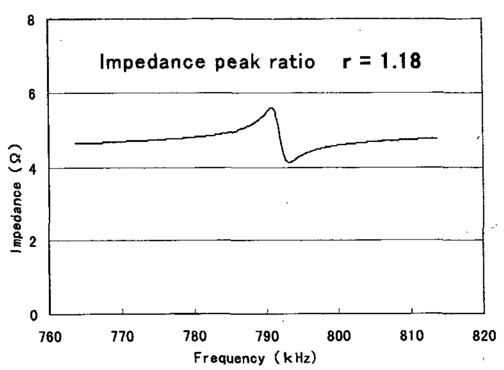

Fig. 6 Impedance peak of the sample No. 6

Fig.7 shows the relationship between the impedance peak ratios and the absolute values of calculated saturation magnetostriction constants of the samples listed in Table II. Although it is not a linear relationship, the correlation between them seems to be good, which suggests the magnetostrictions of the samples affect the amplitudes of the fundamental natural mode of vibrations of the toroids driven by magnetizing currents at frequencies basically decided by average radii of the toroids. Fig. 8 and Fig. 9 show the results of magnetostriction measurements to confirm the above relationship based on the calculated saturation magnetostriction constants. These measurements have been done using semiconductor type of strain gauges to detect

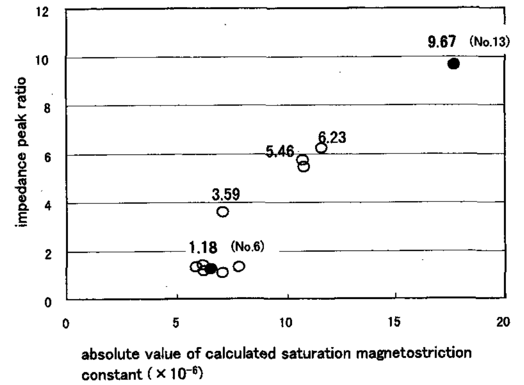

Fig. 7 Impedance peak ratio vs absolute value of calculated magnetostriction constant

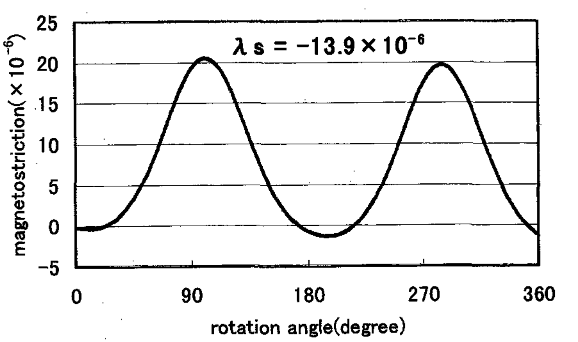

Fig. 8 Magnetostriction measurement of the sample No. 13.

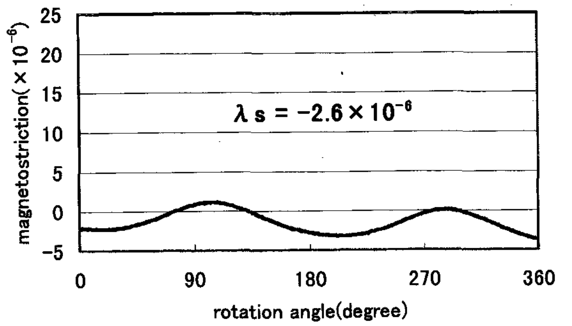

Fig. 9 Magnetostriction measurement of the sample No. 6.

shrinkage and expansion of the samples referring to the maximum and minimum values of the curves by rotating the electromagnet from 0 degree to 360 degree around the samples. Here the minimum value of magnetostriction at about 0 degree means that λs has negative sign.

The measured saturation magnetostriction constants of the samples No. 13 and No. 6 are -13.9×10^{-6} in Fig. 8 and -2.6×10^{-6} in Fig. 9, respectively. The absolute values of these constants are small in comparison with the calculated ones of the above two samples in Table II, -17.68×10^{-6} and -7.11×10^{-6}, respectively. On the other hand, the ratio of the impedance peak ratio of No. 13(Fig.5) to that of No. 6(Fig.6) is 8.2(=9.67/1.18) while the ratio of the above measured saturation magnetostriction constant of No. 13 to that of No. 6 is 5.3(=13.9/2.6).

In order to investigate this difference between the ratio of the impedance peak ratios and that of the observed saturation magnetostrictions, minor hysteresis loop measurements have been performed. The results are shown in Fig.10 and Fig.11. The hysteresis loop of the sample No. 13 is rather square type with the remanent flux density Br of 0.190T at the magnetic field H of 150 A/m as compared to that of No. 6 with relatively low Br of 0.091T which is about half the Br value of the sample No. 13. The magnetic field of 150 A/m used here is large enough since the minimum magnetic field to induce the peaks in the frequency characteristics of the impedance of the sample No. 13 is about 70 A/m. At 70 A/m, sharp peaks exist but the impedance peak ratio is small, and then it increases with the magnetic field applied, suggesting the magnetostriction

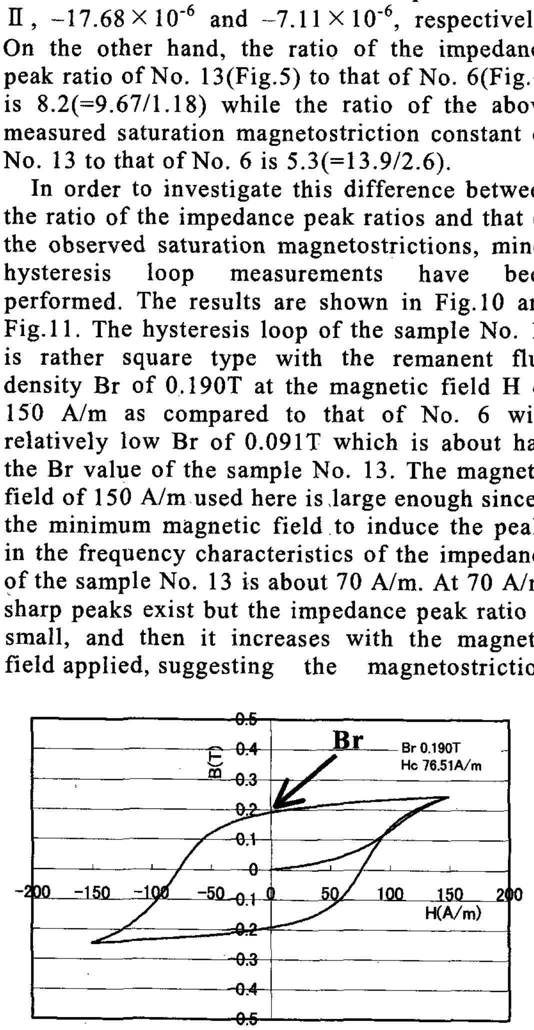

Fig. 10 Hysteresis loop of the sample No. 13.

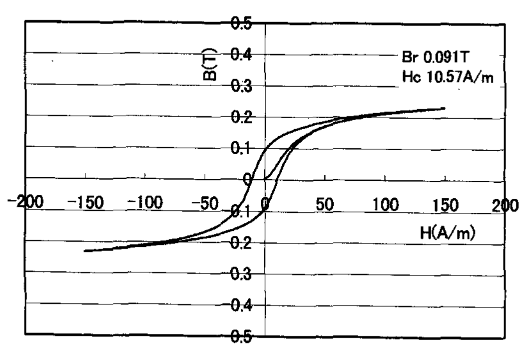

Fig. 11 Hysteresis loop of the sample No. 6.

starts to remain at around 70 A/m even after removing the applied field.

In case of the sample No. 13, the above high Br may contribute to the large value of the impedance peak ratio, 9.67, due to its relatively large squareness ratio of the hysteresis loop, which means the difference in the impedance peak ratio between the above two samples can be more than that in the measured saturation magnetostriction constants of both samples, resulting in the large difference in the level of ingress noise in the CATV network systems.

The impedance peak ratio is considered to be dependent not only on the magnetostriction at Br but also on the slope of hysteresis loop at Br. If the sample No. 6 and the sample No. 13 are compared in the above point of view, the slope of the former is steeper than that of the latter and its contribution to the impedance peak ratio can be more, but the coercivity(Hc) of the former, 10.57 A/m, is much smaller than that of the latter, therefore the magnetization of the former is more easily reduced than that of the latter by the demagnetizing field and its direction of the magnetization can be reversed even by the RF field of about 17 A/m during the measurement, resulting in the smaller magnetostriction. Although it seems that the slope at Br of the sample No. 13 is gentle and its magnetostriction is saturated, its Br value still increases to 0.234T at the magnetic field of 300 A/m, keeping its slope at certain value, which leads to the stable vibration due to the magnetostriction.

Since the intensity of the ingress noise depends on the heights of the sharp peak(s) in the frequency characteristics of the impedance, the developed materials such as No.6 and No.1, with initial relative permeabilities of 1300 and 500, respectively, can become candidates for the magnetic cores to be applied to the transformers for the distributors and directional couplers in the CATV network systems.

4. CONCLUSION

It has been clarified that the sharp peaks in the frequency characteristics of the impedance of the Ni-Zn ferrite cores magnetized are related to the mechanical resonances induced by the RF driving currents which cause magnetostrictions. The developed Ni-Zn ferrite materials with relatively small saturation magnetostriction constants can improve the ingress noises in the CATV network systems and become candidates for the magnetic cores to be applied to the transformers for the distributors or directional couplers in these systems.

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