Possibility of Ultra Fine Isolator for Portable Phone

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Abstract — **There exists a trade-off relationship between miniaturization of an isolator for portable phones and its specific bandwidth. In this paper, we introduce a new way to increase bandwidth over 13% in spite of reduction in garnet dimensions by one tenth, by the addition of LC impedance matching circuits. In the preliminary experiments, we obtained a 4mm square isolator with 4.1% bandwidth at 836MHz using LTCC technology.**

I. INTRODUCTION

Miniaturization and weight and thickness reduction of portable phones is proceeding very rapidly. Consequently, the miniaturization of isolator has also been accelerated. Currently, isolators measuring 5mm square are widely used, while the 4mm square isolators are emerging. Furthermore, launches of 3.5mm and 3.0mm square isolator are also expected in the near future.

The limit to which isolators could be miniaturized is an important concern not only to designers of isolators but also to design engineers of portable phones.

However, it is well known that there is a trade-off relationship between miniaturization and specific bandwidth in an isolator. It was very difficult for us to obtain improvements in both simultaneously.

In this paper, we would like to introduce a new method to resolve this contradiction using a proprietary circuit simulator. We conclude that by adding LC impedance matching circuits, an isolator with enough bandwidth for practical use could be realized with a diameter of garnet reduced to $1/10^{th}$, if enough capacitance could be built into the package, which is considerably realistic.

II. PROBLEMS WITH MINIATURIZATION

The lumped element isolator consists of a three-port circulator with a dummy resistor connected to one of its three ports. The circulator has a basic structure consisting of a garnet disk biased by a ferrite magnet and enclosed by three conductors at an angle of 120 degrees to each other.

In order to obtain a small-sized isolator, each element: garnet, magnet and capacitors, need to be miniaturized.

An ideal circulator with parallel LC resonant circuits behaving as BPF usually models the circulator. Then, the bandwidth of transmitting characteristics will become narrower with smaller inductance L. The inductance L is also directly proportional to garnet size and, as a result, smaller garnet size inevitably causes a narrower bandwidth of circulator.

A need to keep bandwidth constant even in case of smaller inductance, is the main motivation of this study. One of the answers is to lower the characteristic impedance Z in a measurement system for a circulator.

For example, in order to keep bandwidth constant, even after halving the inductance, the characteristic impedance also needs to be halved. Consequently, the capacitance needs to be doubled to maintain the resonant frequency.

III. IMPEDANCE MATCHING CIRCUIT

Even if the smaller isolator optimized for lower characteristic impedance Z could be realized, we cannot use it in an actual apparatus because of impedance mismatching that would result with usual 50ohm transmission lines.

Therefore matching circuits are necessary for normal operation. If the volume of the circuit required is very large, development of small isolator with this technique does not make sense. Minimizing the volume of this circuit is the most important issue for obtaining an ultra fine isolator.

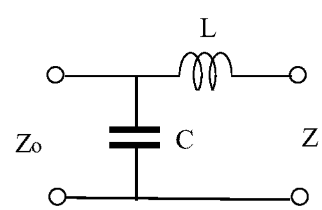

Fig.1 Impedance matching circuit

We adopted the LC circuit as shown in Fig.1 as matching circuit. This circuit consists of L and C without R and is essentially lossless. However, transformation of purely-real impedance is possible only at the resonant frequency f_o. At other frequencies, the transformed impedance contains an imaginary part, making the circuit appear unmatched, which would lower its bandwidth under usual circumstances. On the contrary, we found this circuit can widen the bandwidth of a circulator operating at above-resonance because of mutual cancellation of the impedances of the circulator and the matching circuit.

First, we explain the matching circuit shown in Fig.1. The impedance change ratio Z/Z_o (less than one), the value of L&C and the operating frequency f_o relate to each other as follows.

$$C^2=(1/\omega Z_o)^2(Z_o/Z-1) \quad [F] \qquad (1),$$
$$L^2=(Z/\omega)^2(Z_o/Z-1) \quad [H] \qquad (2),$$

where $\omega=2\pi f_o$.

When $Z/Z_o=0.5$, L attains a maximum value of L_{max} as follows.

$$L_{max}=(3979\times10^6)/f_o \quad [nH] \qquad (3).$$

Fig.2 shows the relationship between C&L and Z/Z_o at f_o=836[MHz]. As noted from this figure, there is a maximum value of L_{max}=4.76[nH] in L. The value of C becomes larger and larger with smaller Z/Z_o. This tendency is very favorable to the design of small matching circuits because it is difficult to produce large inductance and much easier to produce high capacitance in a small space area.

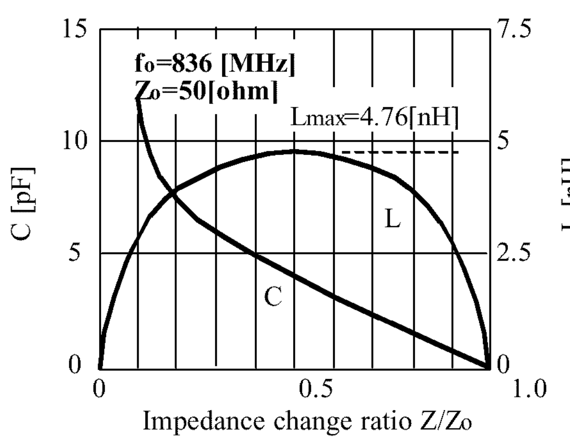

Fig.2 Relationship between C&L with Z/Z_o at 836 [MHz]

Possible ways could be through use of high dielectric materials, reduction of thickness of ceramics and employing a multi-layered structure.

IV. RESULTS OF SIMULATION

In the proprietary circuit simulator reported earlier[2)3)], the garnet size is expressed by air core inductance K. It is desirable to set a normalized magnetic field of about σ=2 for the optimal design of isolator. If the operating frequency f_o, the characteristic impedance Z and the saturation magnetization $4\pi Ms$ of garnet are determined in advance, the value of K, namely the garnet size, will be determined automatically. When K_o in a system of Z_o=50[ohm] and K in Z[ohm], the relation of $K/K_o=Z/Z_o$ holds under the condition of constant σ.

We investigated the behavior of such a low impedance circulator with matching circuits in a 50[ohm] system using the developed circuit simulator.

Fig.3 shows the equivalent circuit of lumped element circulator with LC matching circuits. The central portion denotes a three-port low impedance ideal circulator with LiCi parallel resonant circuits, where $Li=\mu K$ and μ is a permeability of the garnet biased by magnet.

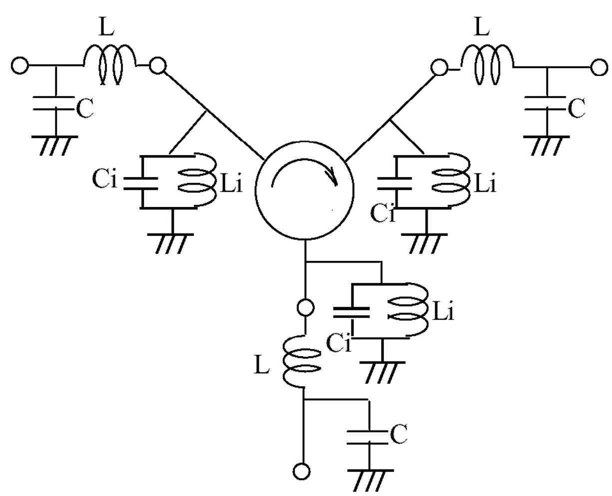

Fig.3 Equivalent circuit of lumped-element circulator with matching circuits.

Fig.4 shows the broadening effect of bandwidth in S parameter diagrams accompanying the matching circuits. The dotted lines show the characteristics without matching circuit, with other parameters calculated to ensure enough bandwidth for practical use.

In this calculation, the used parameters are as follows; f_o=836[MHz], air core inductance K_o 1.6[nH], Z_o=50[ohm], ηr=1, ηt=0.5, ϕ=0.8, $4\pi Ms$=900[G]. Under these conditions, we obtained σ=2.1 and w=5.2%. The bandwidth is defined as the frequency range with over 20[dB] of isolation loss. ηr and ηt are the ferrite filling factors defined in a previous report[3). And ϕ is a circular polarization occupation ratio.

On the other hand, the solid lines in Fig. 4 show the case of circulator with one tenth of garnet size, K=0.16[nH], with the matching circuit between 50[ohm] and 5[ohm]. Even in this case, the normalized field σ=2.1 in the garnet is still maintained.

As is evident from Fig.4, in spite of the reduction of garnet size to one tenth, the bandwidth of insertion loss has become wider and the isolation loss shows a double hump character. The achieved specific bandwidth was over 13[%]. The widening effect is extremely large in higher frequency band.

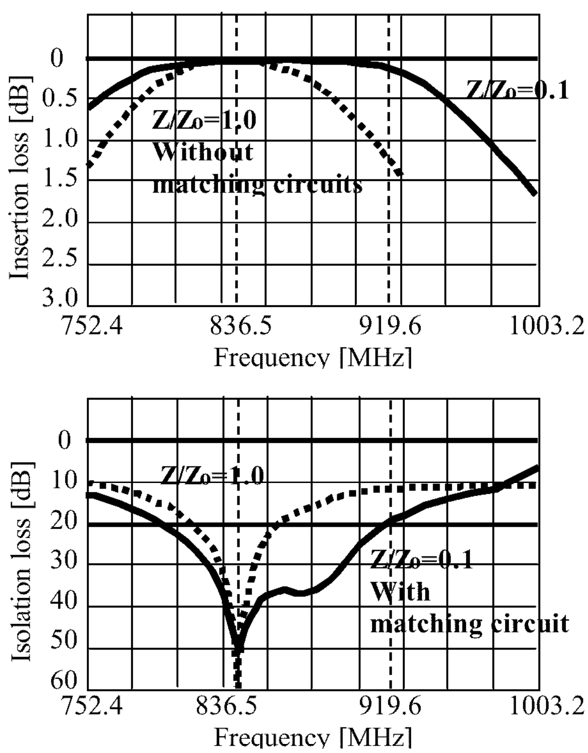

Fig.4 Broadening effect of bandwidth with garnet size reduction obtained by circuit simulation

Fig.5 depicts the above relationship, with the horizontal axis as the impedance change ratio and the vertical axis as the specific bandwidth. The internal field is kept constant as σ=2.1. The specific bandwidth gradually increases with decrease of impedance change ratio and has a maximum value at one tenth of the ratio. This point requires L=2.72[nH] and C=12.1[pF] for the matching circuit. The broadening effect is remarkable at ratio values under 0.3.

Fig.6 shows the change in capacitor Ci of parallel resonant circuit connected to the low impedance circulator. The value of Ci being inversely proportional to impedance change ratio Z/Z_o, becomes larger as the ratio decreases.

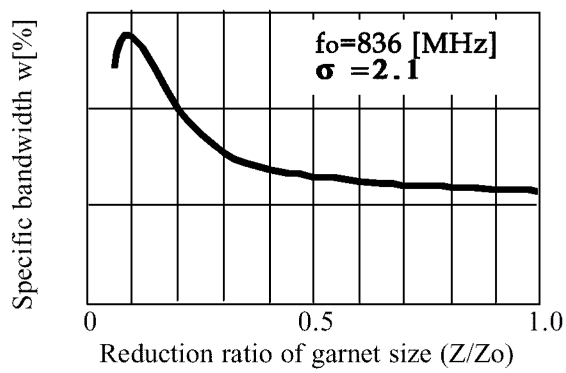

Fig.5 Change of bandwidth with reduction of garnet size obtained by circuit simulation

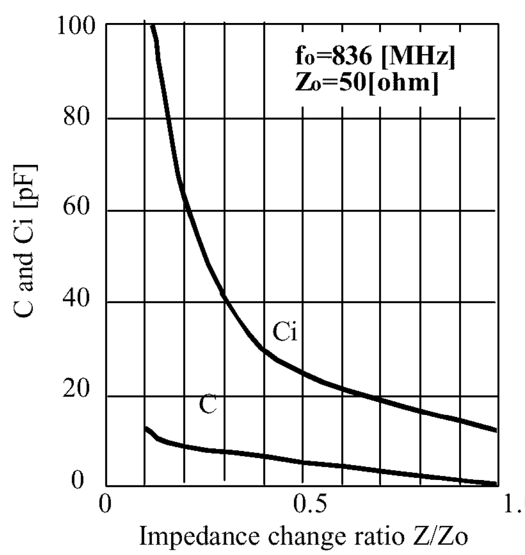

Fig.6 Relationship between C&Ci and Z/Z_o at 836 [MHz]

Especially, at Z/Zo=0.1, the value of Ci needed is over 100[pF] and hence miniaturization of the capacitor is an important subject in itself, for realization of ultra fine isolator.

V. EXPERIMENTAL RESULTS

The above discussions only discuss simulated results. In order to verify the above prediction, preliminary experiments of 4mm square isolator were performed using low temperature co-fired ceramics (LTCC) technology.

A 4mm square Isolator cannot contain a large garnet, with a diameter of 2.2mm being the limit. Using this size of garnet, the 4mm square isolator was built with no matching circuit, directly connecting to 50[ohm]. This showed narrower specific bandwidth of 2.7[%] as shown as the dotted lines in Fig.7.

On the other hand, the solid lines in Fig.7 refer to the case of an isolator with matching circuit between 50[ohm] and 37.4[ohm], using LTCC technology. In this case, significantly wider bandwidth of 4.1[%] was obtained. This case required C=2.2[pF], L=4.1[nH] and Ci=19.2[pF]. Simultaneously, the insertion loss has also improved.

The internal magnetic field in garnet without matching circuit is stronger than with matching circuit. In case of the former, conduction loss forms the major portion of the insertion loss. With the matching circuit, the magnetic field becomes weaker and conduction loss decreases. As the result, we obtained lower insertion loss. However, the peak value of 0.7 [dB] achieved in a new 4mm square isolator is not sufficient for practical use because the current 5mm square isolator offers nearly 0.4[dB]. The matching circuit introduces most of this loss and hence, developing a matching circuit with lower loss is a subject for further study.

VI. CONCLUSIONS

In order to realize an ultra fine isolator for portable phones, a new method has been introduced in this paper. Using a proprietary circuit simulator, we confirmed the effect of the new method that shows ability to increase bandwidth over 13[%] even with the reduction of garnet dimensions to one tenth, by adding the LC impedance matching circuits.

In order to verify the above prediction, the preliminary experiments of 4mm square isolator were performed using low temperature co-fired ceramics (LTCC) technology. We obtained the bandwidth of 4.1[%]. From these results, we believe that the estimation from theory is correct. Therefore, if we can fabricate the matching circuit with low loss in a small area, we may accomplish an ultra fine isolator mountable on the same printed board of a power amplifier for portable phone. Furthermore, from the point of view of magnetic loss, so long as the magnet size is not reduced, the miniaturization of garnet implies an improvement in uniformity of the magnetic field distribution within the garnet. Hence, it may introduce a positive effect on insertion loss. Miniaturization does not necessarily causes bad effects.

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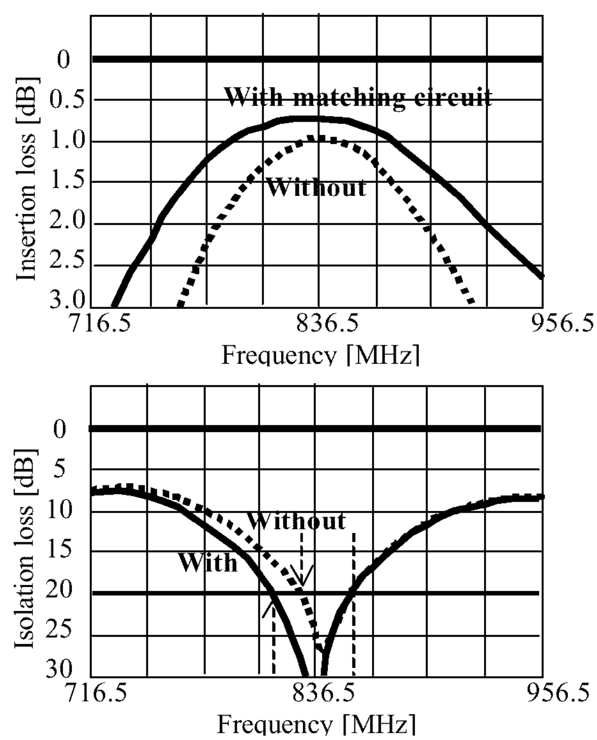

Fig.7 Preliminary experimental results of 4 mm square Isolator with and without matching circuits