MINIATURIZED HAIR-PIN RESONATOR FILTERS AND THEIR APPLICATIONS TO RECEIVER FRONT-END MICS

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ABSTRACT

This paper describes the newly-developed miniaturized hair-pin resonator filters suitable for microwave integrated circuits(MICs).

The size of the experimental filters has been reduced to one-half of the conventional hair-pin resonater filter, without increasing insertion losses.

Trial receiver front-end MICs using these filters have also been developed and shown good characteristics, such as low noise and high image suppression ratio.

INTRODUCTION

The microstrip-line hair-pin resonator[1] has been put to practical use, because its structure is adequate for MICs.

The authors have previously reported that microstrip-line split-ring resonators[2] have excellent characteristics such as compact size, lower radiation losses, and applicability to MICs.

In order to reduce the size of the conventional hair-pin resonator, we recently devised a new hair-pin shaped split-ring resonator with parallel coupled lines to replace the lumped element capacitor. The filter using this resonator is less than one-half the size of conventional hair-pin resonators. It can also be applied to a much higher frequency than previously described.[2)3)] This filter has the abvantage that frequency adjustment can be easily achieved by trimming the length of parallel coupled lines.

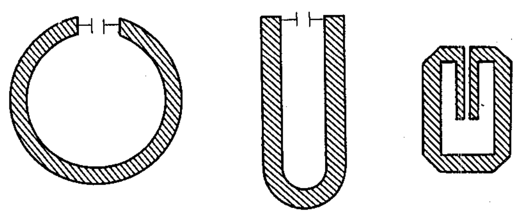
For verification of practical application, an experimental L-band mixer, using a diplexer composed of these filters, was also designed and fabricated. The measured results showed that it has good electrical performance as receiver front-ends.

RESONATOR STRUCTURE

The split-ring resonator is composed of a transmission-line and a capacitor which connects at both ends of the line, as shown Fig.1(A). Fig.1(B) shows a hair-pin shaped split-ring resonator. It is desirable to choose a hair-pin shaped structure, when designing compact multi-stage filters, which have a parallel coupled section for interstage coupling.

Fig.1(C) shows a newly-developed hair-pin shaped split-ring resonator, which has an improved structure as compared with Fig.1(B); parallel coupled lines with an open-circuited end have been adopted in place of the lumped element capacitor. This configration is suitable for MICs.

Some advantages of this type of resonator are:
(1) Small size, with no Q-value degradation.
(2) Expansion of the applicable frequency range.
(3) Easy adjustment of resonance frequency.
(4) Low cost.



(A) Ring (B) Hair-Pin (C) New-Type Hair-Pin

Fig.1 The structure of the resonator

RESONANCE CONDITION

The resonator to be considered here can be analyzed using the following parameters, as also shown Fig.2.

- Zs : characteristic impedance of the line
- θs : electrical length of the line
- Zpe, Zpo : even and odd mode impedance of the parallel coupled lines
- θp : electrical length of the parallel coupled lines

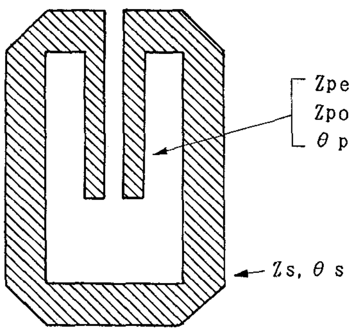


Fig.2 Electrical parameters of the miniaturized hair-pin resonator

Using these parameters, the resonance condition can be expressed as follows:

$$(Z_{pe}Z_{po}\cot\theta p - Z_s^2\tan\theta p)\sin\theta s + Z_s(Z_{pe}+Z_{po})\cos\theta s - Z_s(Z_{pe}-Z_{po}) = 0$$

Fig.3 shows one of the calculated relationships between resonance frequency and the electrical length of the parallel coupled lines, where Zs=50ohm, θs=100deg, Zpe=97.6ohm, $Zpo=Zs^2/Zpe$=29.5ohm.

These results clearly indicate that fine frequency tuning can be easily achieved by adjusting the length of the parallel coupled lines during the manufacturing process.

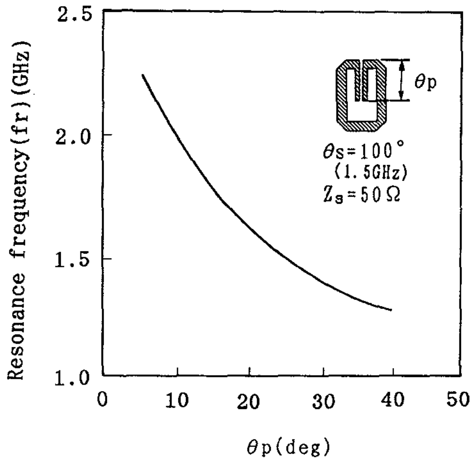


Fig.3 Calculated results of resonance frequency

FILTER DESIGN PARAMETERS

To design bandpass filters, it is necessary to obtain various parameters, such as unloaded-Q(Qo) the external Q(Qe), and the interstage coupling factor(k).

These parameters can be calculated using a general-purpose microwave circuit simulator. Fig.4 shows the calculated results of these parameters. In this trial, input and output coupling and interstage coupling between resonators are realized by tapping and parallel line coupling respectively.

APPLICATIONS

Fig.5 shows the MIC layouts of two experimental filters designed with the same electrical specifications such as center frequency, band width, and attenuation. One (the upper pattern) is a conventional hair-pin resonator filter, and the other (the lower pattern) is a newly-developed miniaturized hair-pin resonator filter.

The filter design parameters for the miniaturized hair-pin resonator are as follows (f=1.5GHz):

resonator parameters : Zs= 50 ohm, θs=100deg.
Zpe=97.6ohm, Zpo=29.5ohm, θp=26deg.
filter parameters : interstage coupling
Zoe=57.2ohm, Zoo=43.7ohm. θc=31.9deg.
tapping position θtap=13.8deg.

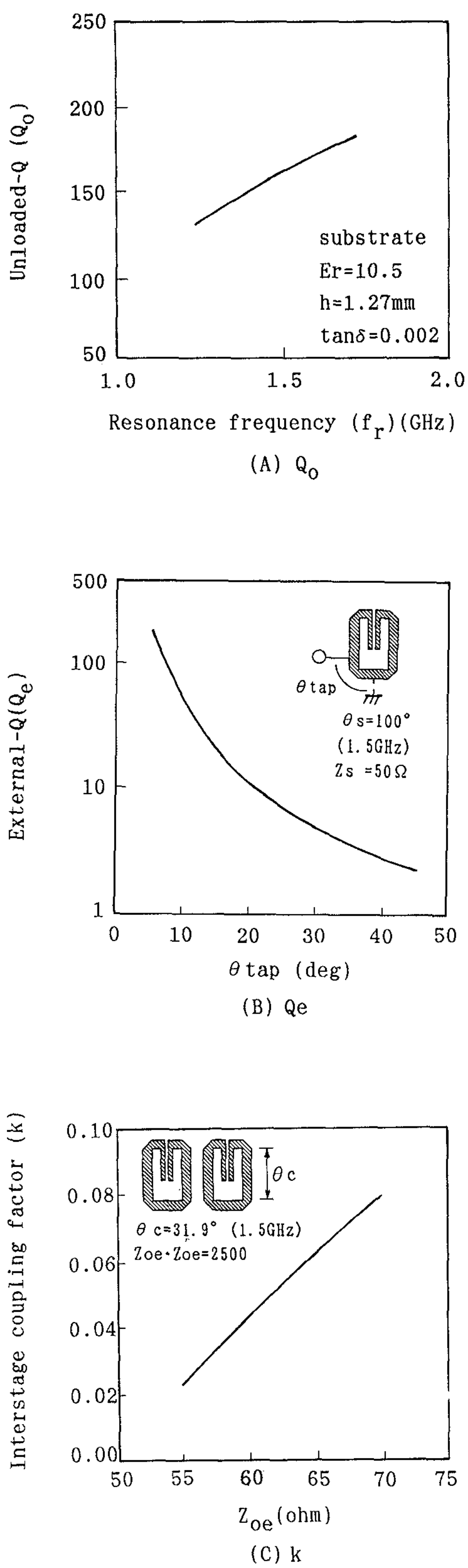
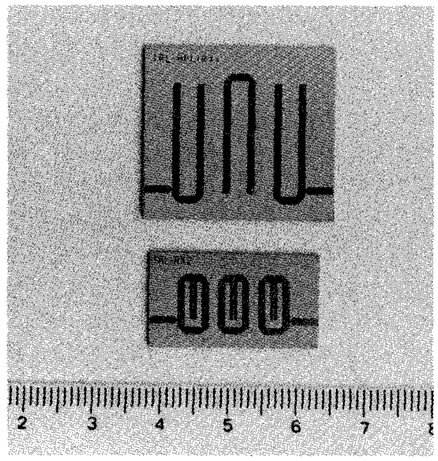


Fig.4 Filter design parameters



Upper pattern : Conventional hair-pin resonator filter

Lower pattern : Newly-developed hair-pin resonator filter

Fig.5 A photograph of the experimental filter

The filter was fabricated with a substrate having a dielectric constant of Er=10.5 and a thickness of 1.27mm. The spacing between the resonators becomes narrow because the length of the parallel coupling lines is considerably less than the 90deg, which is typical of conventional hair-pin resonator filters.

Fig.6 shows the measured response of the newly-developed 3-stage band pass filter (BPF). These frequency responses agree well with the computer simulation results.

The pass band insertion loss is approximately the same as that for conventional hair-pin BPFs. Thus, it can be concluded that miniaturization of the resonator does not degrade the unloaded-Q(Qo) values.

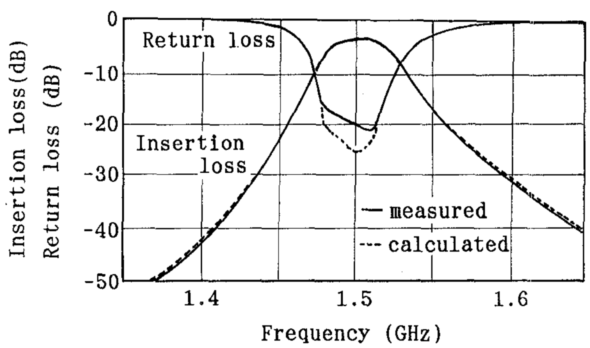


Fig.6 Characteristics of the experimental filter

Fig.7 shows the experimental transistor mixer, which uses a diplexer composed of a receiver and a local BPF. This mixer is developed for receiver front-ends in mobile communication equipment, which must be compact, low cost, and have low power comsumption. This mixer utilizes a silicon bipolar transistor, and is fabricated on a printed circuit board, the same as that of the experimental BPF. Fig.8 shows the measured data of this mixer. These data show that the conversion gain is 12.6dB, and NF is 7.4dB when local power is 0dBm. This mixer also has good image suppression characteristics, of more than 41.5dB. The net NF value of this mixer subtracted the receiver BPF losses should be about 3.5dB, which approximately corresponds to the amplifier NF value using the same transistor. This mixer configuration is applicable to a higher frequency range above the L band.

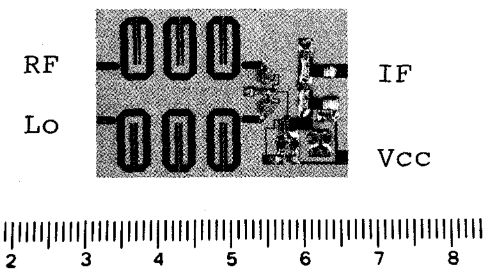


Fig.7 a photograph of the experimental mixer

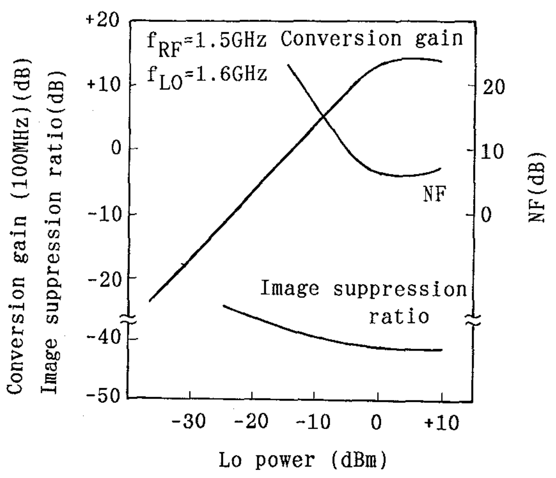


Fig.8 Characteristics of the experimental mixer

CONCLUSION

The compact hair-pin shaped split-ring resonator with parallel coupled lines was newly developed and its resonance properties were analytically derived. As well, its applications for bandpass filters and receiver front-ends were demonstrated. The performance results of these trial components showed exellent characteristics.

It is clear that these components can provide many applications for mobile radio equipment in the L and S bands.

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REFERENCES

(1) E.G.Cristal and S.Frankel : "Hair-pin-line and hybrid hair-pin-line/half-wave parallel-coupled-line filters", IEEE Trans. on M.T.T, Vol MTT-20, No.11, pp.719-728 Nov.1972
(2) M.Makimoto and M.Sagawa : "Varactor Tuned bandpass filters using microstrip-line ring resonators", 1986 IEEE MTT-S Symposium Digest, Q-4, pp.411-414
(3) M.Sagawa, I.Ishigaki, M.Makimoto and T.Naruse : "Dielectric split-ring resonators and their application to filters and oscillators", 1988 IEEE MTT-S Symposium Digest, W-2, pp.605-608