# Small-Sized Wideband CVT- and CCT- Ring Filters

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*Abstract*---Two types of small-sized wideband CVT- (constant VSWR impedance transformer) and CCT- (constant conductance impedance transformer) ring filters are introduced, designed, simulated and one of two, a CCT-ring filter, is tested. They consist of CVTs and CCTs, and two short stubs are connected at 90° and 270° positions of each ring. The circumference of the ring can be reduced theoretically up to 60° and two of many cases having about 300° circumferences are simulated. The simulated results show more than 100% fractional bandwidth, which can be obtained with more than 5 stages in conventional design techniques. A CCT ring filter suggested in this paper has been fabricated in microstrip technology and the measured results show good agreement with the simulated ones.

## I. Introduction

It is well known that ring resonators have low radiation loss, high $Q$ factors and two orthogonal resonant modes. Because of these special properties, ring resonators have widely been used for the measurements [1], [2], band-pass filters and duplexers [3]. Microstrip open- and closed-ring resonators were intensively discussed [4], [5] and mixers, oscillators and tuning filters have been realized based on circuit theory concepts [6]. However, these circuits suffer from high insertion loss due to the gap discontinuities and inaccurate analyses of the gap capacitances, which can not be neglected.

The band-pass design techniques have been discussed based on quarter wave impedance transformers and the design bandwidths may range from narrow band on up to such wide bandwidths, their fractional bandwidths greater than 135 % [7]. In this paper, wideband, small-sized ring filters are introduced, designed and measured. The ring filter was for the first time introduced as a wideband 180° phase shifter [8] where feeding lines are directly coupled to a ring to reinforce high insertion loss and two short stubs are connected at 90° and 270° points of the ring to reject DC and even-multiples of a design center frequency. To reduce the size of the ring filters, four 90° transmission lines are replaced with small-sized impedance transformers, CVTs and CCTs [9], [10] and the two types of small-sized ring filters are named CVT- and CCT-ring filters. The circumference of the ring can be reduced up to 60° and two cases having about 300° circumferences are simulated, compared. The simulated results show more than 100 % fractional bandwidths with return losses less than −15 dB, which can be obtained with more than 5 stages in conventional filter design techniques. To verify the performances, a CCT ring filter has been measured and the measured results show good agreements with the simulated ones.

## II. Analyses

A conventional ring filter [8] is depicted in Fig. 1 where the feeding lines are directly connected to the ring. The circumference of the ring is one wavelength and two short stubs are each $\lambda/4$ long. The power excited at port ① is divided depending on the power ratio, $d_1$ to $d_2$ and the divided power is combined at port ②. If the two short stubs do not exist, all the power excited at port ① will be delivered to port ② at all frequencies with a perfect matching at multiples of a design center frequency. Therefore, each stub is necessary to reject the power at the even multiples of the design center frequency and to achieve a filter characteristic as a resonator. Therefore, the ring filter can be understood in such way that two filters are connected in parallel. With the design method of ring hybrids or three-port power dividers with arbitrary termination impedances and power divisions [11]-[14], the characteristic impedances of the transmission lines are



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$$Z_{ca} = \sqrt{Z_1\left(\frac{Z_1 + Z_2}{2}\right)\frac{d_1^2 + d_2^2}{d_1^2}},\qquad (1)$$

$$Z_{cb} = \sqrt{Z_2\left(\frac{Z_1 + Z_2}{2}\right)\frac{d_1^2 + d_2^2}{d_1^2}},$$

$$Z_{cc} = \sqrt{Z_1\left(\frac{Z_1 + Z_2}{2}\right)\frac{d_1^2 + d_2^2}{d_2^2}},$$

$$Z_{cd} = \sqrt{Z_2\left(\frac{Z_1 + Z_2}{2}\right)\frac{d_1^2 + d_2^2}{d_2^2}}.$$

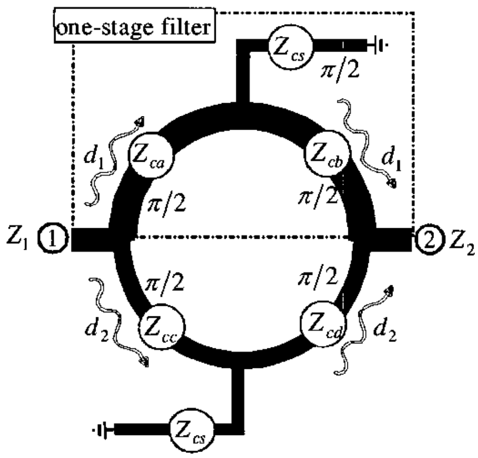


Fig. 1. A conventional ring filter.

The 90 ° transmission lines with $Z_{ca}$, $Z_{cb}$, $Z_{cc}$ and $Z_{cd}$ in Fig. 1 are all the impedance transformers to transform a real impedance into another one. To reduce the size of them, two types of small-sized impedance transformers, CVTs and CCTs [9], [10] are good candidates. Fig. 2 shows three different impedance transformers. All the impedance transformers in Fig. 2 are those to transform a real impedance $IR$ into unity. Thus, the $IR$ means an impedance transformation ratio. A quarter wave impedance transformer with its characteristic impedance $\sqrt{IR}$ is shown in Fig. 2(a), whereas a CVT and CCT in Fig. 2. (b) and (c), respectively. All the values of $z_a$, $z_b$, $z_c$ and $z_d$ together with $\Theta_a$, $\Theta_b$, $\Theta_c$ and $\Theta_d$ may be calculated on a Smith chart and how to derive numerically are explained [9].

$z_{L,CVT}$ and $z_{L,CCT}$ in Fig. 3 are given as

$$z_{L,CVT} = z_a \frac{IR + jz_a \tan\Theta_a}{z_a + jIR\tan\Theta_a},\qquad (2)$$

$$z_{L,CCT} = \frac{z_c IR}{jIR\tan\Theta_c + z_c}.$$

(2) expresses both of real and imaginary parts of $z_{L,CVT}$ are changed at the same time with a different value of $z_a$ but that only imaginary part of $z_{L,CCT}$ is varied with the changes in $z_c$. Thus, $z_a$ must be unity as demonstrated in the previous work [9] but $z_c$ can have other values including the unity.

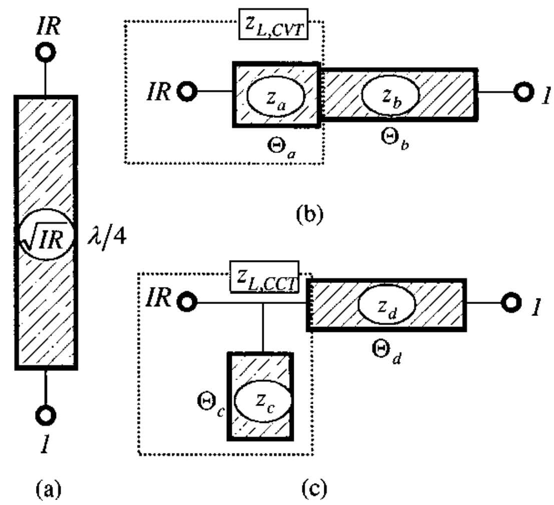


Fig. 2. Three types of impedance transformers.

(a) A quarter wave impedance transformer.

(b) CVT.

(c) CCT.

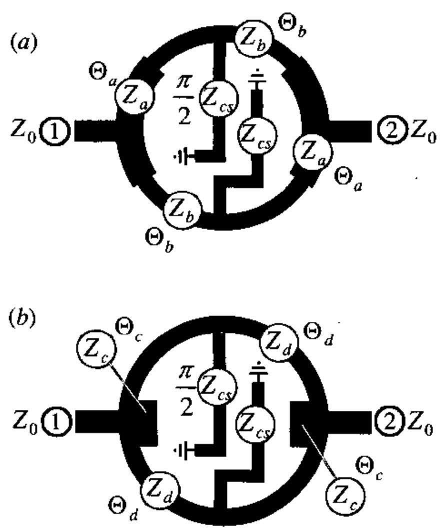


Fig. 3. Small-sized wideband ring filters.

(a) A CVT ring filter.

(b) A CCT ring filter.

Table I.

DESIGN DATA AND SIMULATED RESULTS FOR A CONVENTIONAL RING FILTER, CVT- AND CCT-RING FILTERS.

| Con. Ring filter | CVT Ring filter | CCT ring filter |
|---|---|---|
| $Z_1 = Z_2 = 50\,\Omega$<br>$Z_{cs} = 85\,\Omega$ | $Z_0 = 50\,\Omega$<br>$Z_{cs} = 85\,\Omega$ | $Z_0 = 50\,\Omega$<br>$Z_{cs} = 85\,\Omega$ |
| $Z_{ca} = Z_{cb}$<br>$= Z_{cc} = Z_{cd}$<br>$=70.71\ \Omega$ | $Z_a = 50\,\Omega$<br>$\Theta_a = 10^o$<br>$Z_b = 72.4\,\Omega$<br>$\Theta_a = 68.7^o$ | $Z_c = 30\,\Omega$<br>$\Theta_c = 5^o$<br>$Z_d = 71.8\,\Omega$<br>$\Theta_d = 75.89^o$ |
| Bandwidth with insertion loss less than –0.1dB | | |
| 0.47-1.53 GHz | 0.48-1.52 GHz | 0.48-1.52 GHz |
| Bandwidth with return loss less than –15 dB | | |
| 0.46-1.54 GHz | 0.43-1.57 GHz | 0.44-1.56 GHz |

The four transmission lines with a quarter wave long in Fig. 1 are impedance transformers and they can therefore be replaced with the CVTs and CCTs. The resulting ring filters are shown in Fig. 3.

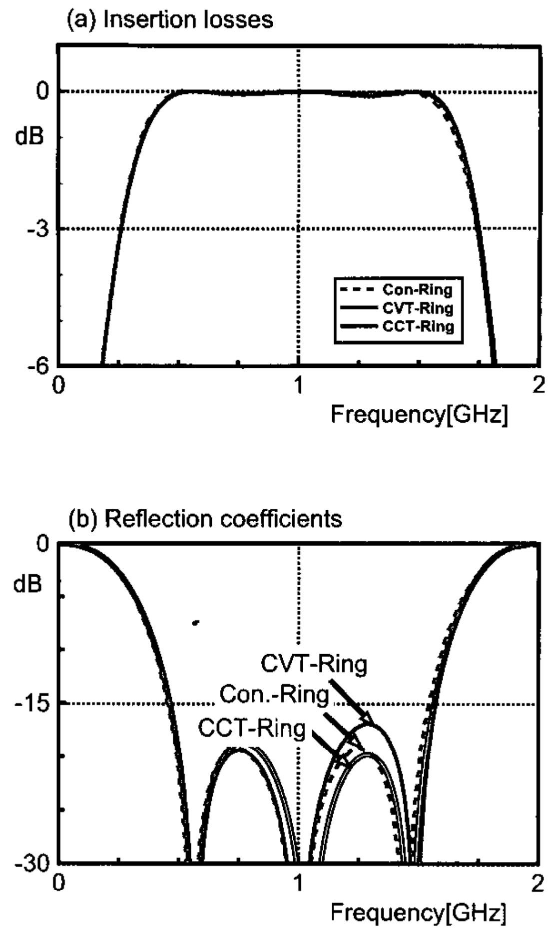


Fig. 4. Simulated results of three ring filters.

(a) Insertion losses.

(b) Return losses.

The CVT ring filter is illustrated in Fig. 3(a) and the CCT ring filter in Fig. 3(b).

All the data needed for the design of three ring filters, a conventional, CVT and CCT ring filters are given in Table I and simulated results of them are plotted in Fig. 4 where "Con-Ring" is the conventional ring filter shown in Fig. 1 and "CVT-Ring " and "CCT-Ring" are the CVT- and CCT-ring filters in Fig. 3 (a) and (b), respectively. The insertion loss frequency responses are plotted in Fig. 4(a) and reflection coefficients in Fig. 4(b). They both are also summarized in Table I. The output results of the three ring filters show about same performances even if the length of each transmission line and the circuit configurations are different from each other. As given in Table I, all the three ring filters have more than 100 % fractional bandwidth with less than 0.1 dB attenuation and less than −15 dB reflection coefficients. The relation between the fractional bandwidth and VSWR is defined as VSWR= $1+(2\omega)^2$ [7] where $\omega$ is a fractional bandwidth. The formula can be applicable for the narrow band filter with $\omega \leq 0.2$ but implies that the filters with more than 100 % fractional bandwidths and reflection coefficients less than −15 dB can not easily be achieved.

Based on the design data, a CCT ring filter has been fabricated in microstrip technology. It has been designed at the center frequency of 3 GHz and measured performances are plotted in Fig. 5.

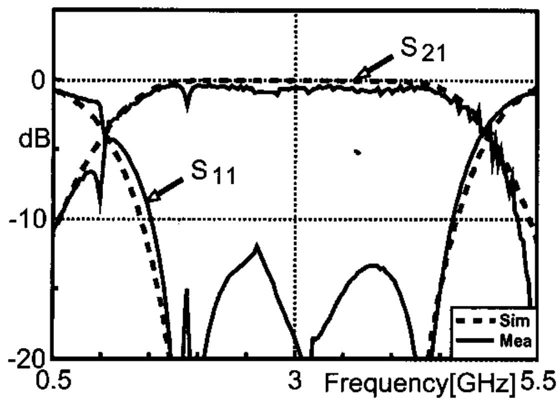


Fig. 5. Measured results of the CCT- ring filter.

## III. Conclusions

In this paper, small-sized wideband ring filters are introduced, designed and tested. They consist of two types of small-sized impedance transformers, CVTs and CCTs and two short stubs are connected at 90° and 270° positions of the ring to reject even-multiples of the design frequency and DC. They are designed in such way that the power excited at input is divided and the divided power is combined at output. Therefore, they may have wideband properties which can be achieved with more than 5 stage filters in conventional filter design techniques.

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