A Transversal Filter Using CPW Directional Couplers

Yutaka Ida, Nobuaki Imai, and Eiichi Ogawa

***Abstract*—A transversal filter using coplanar waveguide (CPW) directional couplers and no active devices has been proposed. It aims to be free from the noise figure problems found in an active transversal filter and also aims to show it can be easily realized with a single-layer structure when the bandwidth is narrower than about 30%. Two types of CPW directional couplers were employed. When using G-S-G-S-G-type directional couplers, connecting section influences between strong and weak couplers were successfully suppressed.**

I. Introduction

A TRANSVERSAL filter usually uses active devices as weighting elements [1], [2]. The use of active devices, however, may have a negative impact on noise figure. On the other hand, we proposed transversal filters that use directional couplers and no active devices previously [3]–[5]. These transversal filters have the following advantages. First, the increase in insertion loss due to a decreasing Q-factor is less than that of a resonator filter. Second, the characteristic impedance of the transversal filter can be easily matched to the external impedance. These transversal filters used a 3-dB coupler with a multilayer structure to realize a wide passband. When the bandwidth is narrow, however, the transversal filter can be realized with a single-layer structure such as coplanar waveguide (CPW). Thus, we propose two types of transversal filter using CPW directional couplers. One consists of only G(ground)-S(strip)-S-G CPW directional couplers (Fig. 1), and the other uses G-S-G-S-G CPW directional couplers as delay line elements. The latter filter aims to suppress the influences of the connecting sections between strong and weak couplers. This letter presents fabricated results of the transversal filters using CPW directional couplers.

II. Fundamental Design

Directional couplers function both as weighting and delay line elements. Accordingly, transversal filters can be obtained by using cascaded directional couplers. The weighting coefficients of a transversal filter usually need both positive and negative values [1], but coupling coefficients k_i of the directional couplers are physically positive. Thus, this transversal filter uses weighting coefficients having only positive values although the filter characteristics degrade in some degree.

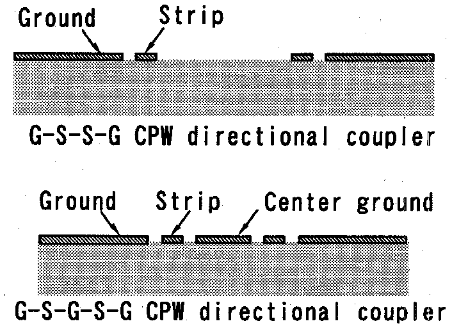

Fig. 1. Cross-sectional views of two types of CPW directional couplers.

The k_i are designed as follows [5]: First, initial k_i are derived from discrete values of $h(t)/f_0$ (f_0: center frequency) with t in a range from $-1/bw$ to $1/bw$ (bw: bandwidth). Here, the $h(t)$ is an impulse response of a rectangular window function and it is positive there. Next, the k_i of the weighting elements are multiplied by a generalized Hamming window function [6] to tune the transmission characteristics. Finally, the k_i are optimized using a computer program that compares transmission characteristics with each perturbed k_i. When bw_{3dB} is 30%, for example, the maximum k_i is 0.4 and a coupling of $k = 0.4$ can be realized in CPW directional couplers.

III. Filter 1

First, only G-S-S-G CPW directional couplers were used for the transversal filter. These couplers can vary the spacing between two coupled lines with their characteristic impedance kept invariant provided that the ratio of line width to the spacing between lines is fixed. To suppress disturbance of couplings and impedance mismatching in connecting sections between strong and weak couplers, a design method was adopted in which the difference ($\equiv \Delta S$) of line spacings between strong and weak couplers is minimized. Fig. 2 shows calculated results for the connecting section with an EM-field simulator. As ΔS becomes small, simulated curves become closer to an ideal one that was calculated with a circuit simulator. Using a process rule that sets minimum gap width at 30 μm (case B, Fig. 2), a transversal filter with an f_0 of 15 GHz, a bw_{3dB} of 24% and the number of couplers n_c of 15 was fabricated on an Al_2O_3 substrate (Fig. 3). Grounding wires are bonded on the connecting sections to suppress the

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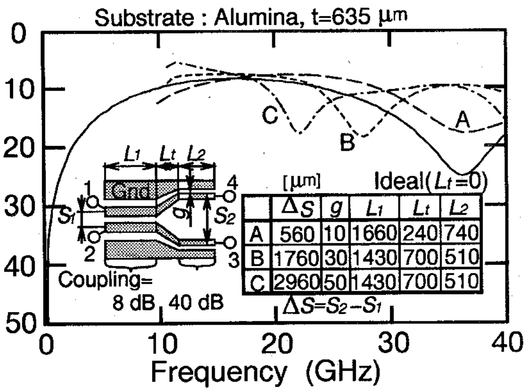


Fig. 2. Results of connecting section analysis. The curves A, B, and C were calculated with an EM-field simulator in conditions listed in the table. The solid curve was calculated with a circuit simulator with the condition that two coupled sections were directly connected without bend structure.

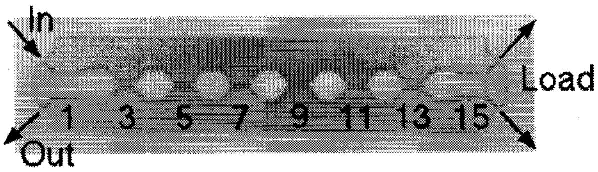


Fig. 3. Microphotograph of the fabricated transversal filter 1, using only G-S-S-G CPW directional couplers. Its size is 28.2 mm × 5.6 mm.

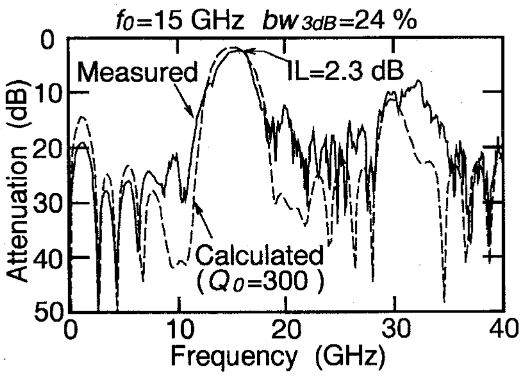


Fig. 4. Measured and calculated transmission characteristics of the fabricated transversal filter 1.

generation of higher propagation modes. Fig. 4 shows the measured and calculated (with a circuit simulator) transmission characteristics. Some disagreements between measured and calculated values are assumed to be caused by the influences of the connecting sections (case B, Fig. 2). These degraded characteristics should be improved by using a more precise process rule (case A, Fig. 2).

IV. Filter 2

Next, G-S-G-S-G CPW directional couplers were employed as delay line elements. The width of a G-S-G-S-G CPW directional coupler is narrower than that of a G-S-S-G one because couplings are weaker. Thus, the influences of the connecting sections due to a difference of line spacings between strong and weak couplers should be suppressed. A transversal filter with an f_0 of 18 GHz, a $bw_{3\mathrm{dB}}$ of 27%, and an n_c of 15 was

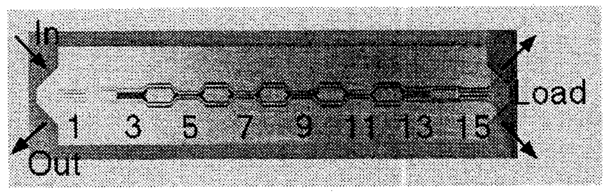
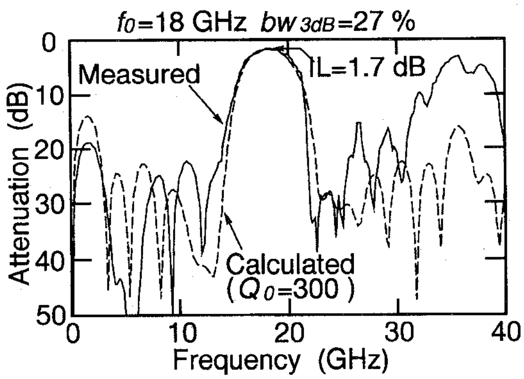
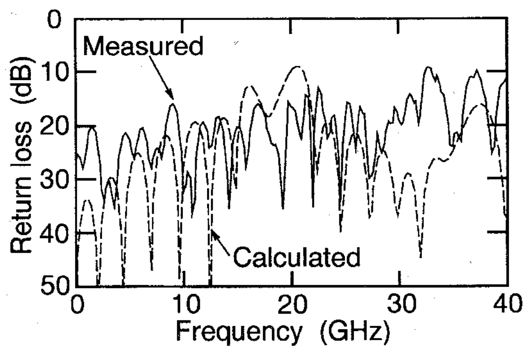


Fig. 5. Microphotograph of the fabricated transversal filter 2, using G-S-G-S-G CPW directional couplers as delay line elements.



(a)



(b)

Fig. 6. Measured and calculated performance of the fabricated transversal filter 2. (a) Transmission characteristics. (b) Return loss.

fabricated with the same process rule (Fig. 5). Center grounds are wire-bonded to outer grounds. The maximum coupler width S defined in Fig. 2 is 1.0 mm, half as much as the former filter. As shown in Fig. 6(a), a spurious response beside the passband on the higher-frequency side was improved to 28 dB from 12 dB in comparison with the measured values in Fig. 4, and insertion loss was improved to 1.7 dB from 2.3 dB. Return loss was also improved to 13 dB from 8 dB in the frequencies below $f_0 \times 1.5$ [Fig. 6(b)]. These improvements confirmed that the influences of connecting sections between strong and weak couplers can be suppressed by using G-S-G-S-G CPW directional couplers as delay line elements.

V. Conclusion

Two types of transversal filter using CPW directional couplers and no active devices have been proposed. They can be easily realized with a single-layer structure. Using only G-S-S-G CPW directional couplers, the EM-field simulated results showed that the influences of connecting sections between strong and weak couplers could be suppressed by using a more precise process rule. When using a G-S-G-S-G type as delay-line elements, those influences were successfully suppressed. These transversal filters are expected to be applied to MMIC's with a single-layer structure.

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