A NOVEL ACCURATE DESIGN METHOD FOR THE HAIRPIN TYPE COUPLED LINE BANDPASS FILTER

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ABSTRACT

In this paper, the novel design formula is proposed for the design of a hairpin type coupled-line bandpass filter, which has arbitrary coupled-line lengths and image impedance. Employing the derived design formula promotes a convenience for the design and implementing the hairpin type coupled-line bandpass filter. Measured results on fabricated hairpin type coupled-line bandpass filters including the duplexer show good agreements with theoretic results.

INTRODUCTION

The rapid growth of wireless communications has placed an increasing demand for the design techniques for a planar bandpass filters to meet the various needs such as size reduction, performance, cost requirement, and so on. For this purpose, there has recently been increasing interest in a hairpin type coupled-line bandpass filter with various configurations. Several researches and design methods for the parallel coupled-line bandpass filters, which have 90-degree coupled-line sections, have been reported. [1] - [3] Some reported design methods for a coupled-line type bandpass filter could be applicable to design of a hairpin type coupled-line bandpass filter. However, these design methods might require some optimizing efforts to correct a degradation of the filter performance because that the hairpin type coupled line type bandpass filter has arbitrary coupled-line lengths and image impedance levels to implement meander line sections. In this paper, in order to design accurately the hairpin type coupled-line bandpass filter, the general design formula is newly derived based an inverter theory. By using the presented design formula, several hairpin type coupled-line bandpass filters have been designed and fabricated for IMT-2000 applications. Measured results on fabricated hairpin type coupled-line bandpass filters including the duplexer show good agreements with theoretic results.

DESIGN THEORY

Fig.1 show the equivalent circuit representation of the hairpin type coupled-line bandpass filter with arbitrary coupled-line lengths and image impedance levels. Each resonator is divided by three sections having different electrical lengths and admittance levels as shown in Fig.1. The first and third transmission line sections of each resonator represent the coupled-line sections in a hairpin type bandpass filter. Presence of the parallel susceptance in the first -resonator is due to the non-quarter wavelength coupled-line section with non-50-ohm characteristic impedance. [4]

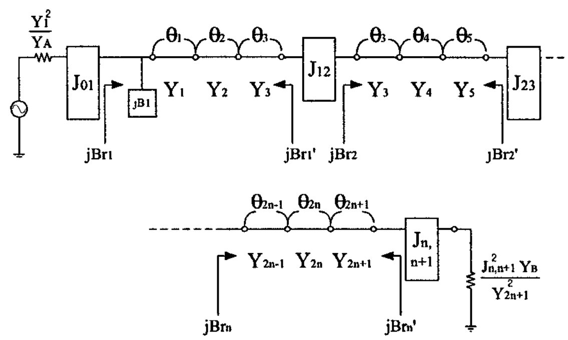

Fig.1. Equivalent circuit of proposed hairpin type coupled-line bandpass filter.

In order to obtain the design formula for the hairpin type coupled-line bandpass filter, the susceptances of each resonator seen in Fig.1 should be derived. The susceptances of each resonator are given by

$$jB_{r1} = jB_a + jY_1 \tan(\theta_1 + \beta_1) \quad (1)$$

where, $\beta_1 = \tan^{-1}\left\{\frac{Y_2}{Y_1}\tan(\theta_2 + \alpha_1)\right\}$, $\alpha_1 = \tan^{-1}\left\{\frac{Y_3}{Y_2}\tan\theta_3\right\}$

$$jB_{r1}' = jY_3 \tan(\theta_3 + \gamma_1) \quad (2)$$

where, $\gamma_1 = \tan^{-1}\left\{\frac{Y_2}{Y_3}\tan(\theta_2 + \zeta_1)\right\}$, $\zeta_1 = \tan^{-1}\left\{\frac{Y_1}{Y_2}\tan\theta_1\right\}$

if $jB_a << 1$, $\theta \cong \frac{\pi}{2}$,

$$jB_{r1} = jY_1 \tan(\theta_1 + \beta_1)$$

$$jB_{r1}' = jY_3 \tan(\theta_3 + \gamma_1),\ \gamma_1 = \tan^{-1}\left\{\frac{Y_2}{Y_3}\tan(\theta_2 + \theta_1)\right\}$$

$$jB_{r2} = jY_3 \tan(\theta_3 + \beta_2) \quad (3)$$

where, $\beta_2 = \tan^{-1}\left\{\frac{Y_4}{Y_3}\tan(\theta_4 + \alpha_2)\right\}$, $\alpha_2 = \tan^{-1}\left\{\frac{Y_5}{Y_4}\tan\theta_5\right\}$

$$jB_{r2}' = jY_5 \tan(\theta_5 + \gamma_2) \quad (4)$$

where, $\gamma_2 = \tan^{-1}\left\{\frac{Y_4}{Y_5}\tan(\theta_4 + \zeta_2)\right\}$, $\zeta_2 = \tan^{-1}\left\{\frac{Y_3}{Y_4}\tan\theta_3\right\}$

$$jB_{ri} = jY_{2i-1} \tan(\theta_{2i-1} + \beta_i) \quad (5)$$

where,

$$\beta_i = \tan^{-1}\left\{\frac{Y_{2i}}{Y_{2i-1}}\tan(\theta_{2i} + \alpha_i)\right\},\ \alpha_i = \tan^{-1}\left\{\frac{Y_{2i+1}}{Y_{2i}}\tan\theta_{2i+1}\right\}$$

$$jB_{ri}' = jY_{2i+1} \tan(\theta_{2i+1} + \gamma_i) \quad (6)$$

where,

$$\gamma_i = \tan^{-1}\left\{\frac{Y_{2i}}{Y_{2i+1}}\tan(\theta_{2i} + \zeta_i)\right\},\ \zeta_i = \tan^{-1}\left\{\frac{Y_{2i-1}}{Y_{2i}}\tan\theta_{2i-1}\right\}$$

$$jB_{rn} = jY_{2n-1} \tan(\theta_{2n-1} + \beta_n) \quad (7)$$

where,

$$\beta_n = \tan^{-1}\left\{\frac{Y_{2n}}{Y_{2n-1}}\tan(\theta_{2n} + \alpha_n)\right\},\ \alpha_n = \tan^{-1}\left\{\frac{Y_{2n+1}}{Y_{2n}}\tan\theta_{2n+1}\right\}$$

$$jB_{rn}' = jY_{2n+1} \tan(\theta_{2n+1} + \gamma_n) \quad (8)$$

where,

$$\gamma_n = \tan^{-1}\left\{\frac{Y_{2n}}{Y_{2n+1}}\tan(\theta_{2n} + \zeta_n)\right\},\ \zeta_n = \tan^{-1}\left\{\frac{Y_{2n-1}}{Y_{2n}}\tan\theta_{2n-1}\right\}$$

By employing these resonator susceptances, the *J*-inverter formula can be obtained as follows

$$J_{01} = \sqrt{\frac{\frac{Y_1}{2}\pi \cdot \omega \cdot \frac{Y_1^2}{Y_A}}{\omega_1' g_0 \cdot g_1}} = \frac{Y_1}{Y_A}\sqrt{\frac{\pi \cdot \omega \cdot Y_1 \cdot Y_A}{2\omega_1' g_0 \cdot g_1}} \quad (9)$$

$$J_{12} = \sqrt{\frac{\omega \cdot \frac{Y_3}{2}\pi \cdot \omega \cdot \frac{Y_3}{2}\pi}{\omega_1'\omega_1' g_1 \cdot g_2}} = \frac{Y_3 \cdot \pi \cdot \omega}{2\omega_1'}\sqrt{\frac{1}{g_1 \cdot g_2}} \quad (10)$$

$$J_{i,i+1} = \frac{Y_{2i+1} \cdot \pi \cdot \omega}{2\omega_1'}\sqrt{\frac{1}{g_i \cdot g_{i+1}}} \quad (11)$$

$$J_{n,n+1} = \frac{Y_{2n+1}}{Y_B}\sqrt{\frac{\pi \cdot \omega \cdot Y_{2n+1} \cdot Y_B}{2\omega_1' g_n \cdot g_{n+1}}} \quad (12)$$

$$J_{01} = Y_1\sqrt{\frac{\frac{Y_1}{Y_A} \cdot \frac{\pi}{2} \cdot \omega}{\omega_1' g_0 \cdot g_1 - \frac{Y_1}{Y_A}\left(1 - Y_1^2\right) \cdot \frac{\pi}{4}}} \quad (13)$$

These design formula can be directly employed to design the hairpin type coupled-line bandpass filter.

SIMULATION AND EXPERIMENTS

In order to show the validity of the presented design formula for the hairpin type coupled-line bandpass filter, we have designed and fabricated several bandpass filters and duplexer for IMT-2000 applications. Specifications of designed hairpin type coupled-line bandpass filters are shown in table 1. Furthermore, design results for the given specifications are shown in table 2. Substrate for fabrications was chosen to be TLC-32-TACONIC, which has dielectric constant of 3.2 with 31mils thick.

Table 1. Specifications of designed hairpin type coupled-line bandpass filter.

Specifications	RX-Band	TX-Band
Center Freq.	1950 MHz	2140 MHz
Bandwidth	1920~1980MHz	2110~2170MHz
Ripple level	0.01dB	
Number of poles	3	

Table 2. Design parameters for RX and TX-band hairpin type coupled line bandpass filter

RX-band	J_{01}=0.0047	J_{12}=0.0013
	90 degree	78.8 degree
	Z_{oe}=72.89 ohm Z_{oo}=44.46 ohm	Z_{oe}=53.53 ohm Z_{oo}=46.91 ohm
TX-band	J_{01}=0.0047	J_{12}=0.0047
	90 degree	77.7 degree
	Z_{oe}=76.80 ohm Z_{oo}=49.44 ohm	Z_{oe}=53.26 ohm Z_{oo}=47.12 ohm

Fig.2 and Fig.3 show the comparisons of simulations and measurements on the fabricated hairpin type coupled-line bandpass filters for the RX- and TX-application, respectively. As shown in these data, the measured results on fabricated hairpin type coupled-line bandpass filters show good agreements with simulations.

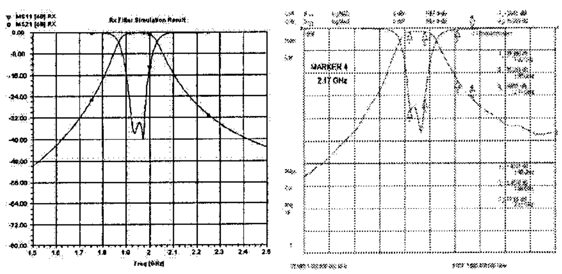

Fig.2. Comparison of simulation and measurement on the fabricated hairpin type coupled-line bandpass filter for the RX-band application.

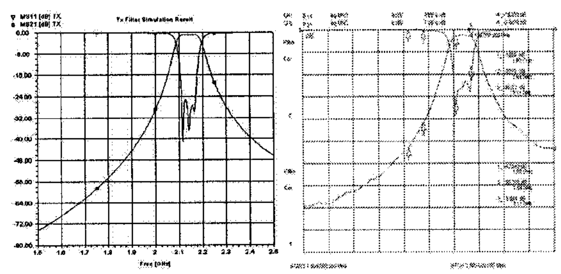

Fig.3. Comparison of simulation and measurement on the fabricated hairpin type coupled-line bandpass filter for the TX-band application.

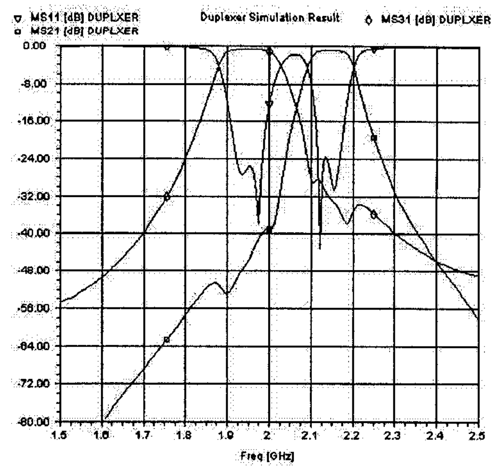

Fig.4. Simulation on the designed hairpin type coupled-line duplexer for IMT-2000 application.

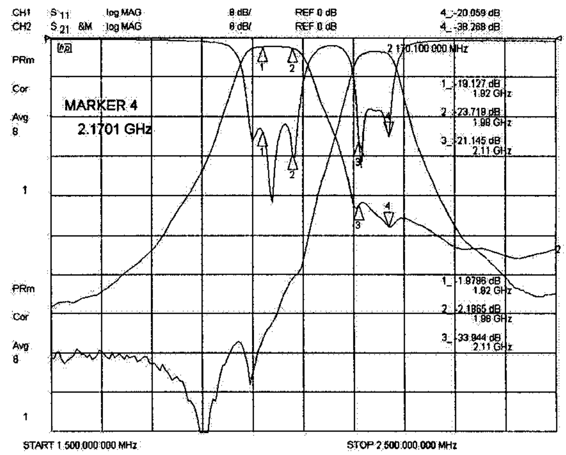

Fig.5 Measurement on the fabricated hairpin type coupled-line duplexer for IMT-2000 application.

Furthermore, along with the presented design method for hairpin type coupled-line filter, we have also designed and fabricated a duplexer for IMT-2000 applications. Fig.4 and Fig.5 show the simulation and measured result on the fabricated hairpin type duplexer, respectively. Both results are excellently matched as shown in Fig.4 and Fig.5. The duplexer design is another issue because that the design procedure for a duplexer requires another design considerations. However, we expect that the results for the hairpin-type duplexer show pertinently the validity of the proposed design formula.

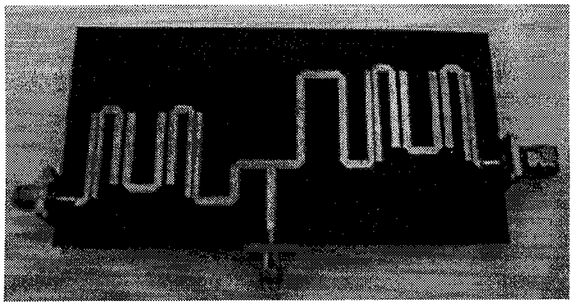

Fig.6 Photograph of the fabricated duplexer.

CONCLUSION

We have presented an effective design formula for the design of the hairpin type coupled-line bandpass filters, which have arbitrary coupled-line lengths and image impedance levels to implement meander line sections. The design formulas have been derived for the equivalent circuit of the hairpin type coupled-line bandpass filters based on simple inverter theory. Several simulations and experiments have demonstrated that the presented design formula is extremely effective in designing the hairpin type coupled-line bandpass filters.

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