Novel Generalized Synthesis Method of Microwave Triplexer by Using Non-Resonating Nodes

Y. L. Zhang, T. Su, Z. P. Li and C. H. Liang
School of Electronic Engineering, Xidian University, Xi'an, 710071, China.
Corresponding author: namarzhang@163.com.

Abstract-**This paper presents a novel generalized method for synthesizing microwave triplexers composed of TX, MX and RX channel filters. The channel filters are then synthesized by using Non-resonating nodes (NRNs). By introducing NRNs, the topology of the channel filters is simple (inline topology) and the number of the finite transmission zeros can achieve as many as the degree of channel filter. The finite transmission zeros of each channel filter are placed arbitrarily and the topology of triplexer is more flexible. A synthesized example show the validity of the technique presented in this paper.**

I. INTRODUCTION

In recent years, a multiplexer is an important component for channel separation in microwave front-end systems for various applications such as communication, radar and other transceiver systems. Multiplexers provide isolation between transmit and receive channels by assigning a different frequency band to each channel and can operate over a wide bandwidth. There have been many efforts to develop various kinds of multiplexers so far, such as duplexers [1-2]. However, The requirements for the antenna combiner networks used in base stations for radio mobile communication have undergone a twofold path: first, selectivity and insertion loss requirement have become more and more stringent; second, complexity (in terms of number of filters and ports) of such devices has increased beyond the typical duplexer structure [3-4]. Because of the interaction of the three filters composing the triplexer, the characteristics of a triplexer are different from the responses of the individual three filters. The complexity of the interaction makes the design of a triplexer complicated.

For the design of microwave triplexers, the traditional approach is to design the three channel filters individually and then to design a distributed network. The distributed network is designed by cut-and-try or optimization method. The convergence could also become problematic due to the large number of "local minima", which characterizes the error function to be minimized. Generally speaking, the distributed network configuration has drawbacks of large volume and time-consuming.

The purpose of this study is to present a general synthesis procedure for triplexer employing RX, MX and TX channel filter with inline topology by introducing the NRNs. The interaction between the channel filters through the specific four-port junction employed in the triplexer is taken into account during the synthesis and the best performances are obtained when the three channels of the triplexer are very close (and even contiguous). The procedure begins with the iterative evaluation of the polynomials associated to the overall triplexer once suitable constraints are imposed on the reflection and transmission parameters of the triplexer. The characteristic polynomials [5-6] of the three channel filters are then evaluated with a polynomial fitting technique, and the synthesis of these filters is realized separately from the triplexer by extracted-pole configuration.

Traditionally, the channel filters are implemented with cross-coupled topology. In this paper, the channel filters are realized by using extracted-pole technique. Because of this, the synthesis of the channel filters is simpler and the topologies of channel filters are inline configuration. Inline configurations in which each finite transmission zero is generated and independently controlled by a dedicated element. A good feature of the extracted-pole configuration is easily tunable of the channel filters (the resonant frequency of the extracted resonators coincides with the imposed finite transmission zeros).

To the best of the authors' knowledge, there is no exact synthesis procedure in the literature for triplexers employing inline configuration filters with NRNs.

This paper is organized as follows. In Section 2, the characteristic polynomials of the triplexer are calculated. It takes the interaction of the channel filters into account, so the characteristic polynomials are accurately obtained. A triplexer example is synthesized to show the validity of the technique in Section 3. A conclusion is drawn in Section 4.

II. CALCULATION OF TRIPLEXER CHARACTERISTIC POLYNOMIALS

A microwave triplexer is generally composed of three bandpass filters with three input ports connected through a four-port junction. The general schematization of the triplexer is shown in Figure 1.

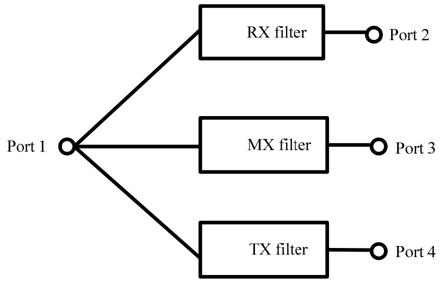


Figure 1 The general schematization of the triplexer

The three low-pass prototype filters (RX, MX and TX) in the normalized frequency domain can be characterized separately from the triplexer through their characteristic polynomials as:

$$
\begin{aligned}
S_{11}^{RX} &= \frac{F_{RX}(s)}{E_{RX}(s)} & S_{21}^{RX} &= \frac{P_{RX}(s)}{E_{RX}(s)} = \frac{p_{0RX}P_{RXn}(s)}{E_{RX}(s)} \\
S_{11}^{MX} &= \frac{F_{MX}(s)}{E_{MX}(s)} & S_{21}^{MX} &= \frac{P_{MX}(s)}{E_{MX}(s)} = \frac{p_{0MX}P_{MXn}(s)}{E_{MX}(s)} \\
S_{11}^{TX} &= \frac{F_{TX}(s)}{E_{TX}(s)} & S_{21}^{TX} &= \frac{P_{TX}(s)}{E_{TX}(s)} = \frac{p_{0TX}P_{TXn}(s)}{E_{TX}(s)}
\end{aligned}
\tag{1}
$$

The polynomials $E_{RX}(s)$ and $F_{RX}(s)$ have degree N_{RX} (order of RX channel filter), the polynomials $E_{MX}(s)$ and $F_{MX}(s)$ have degree N_{MX} (order of MX channel filter), the polynomials $E_{TX}(s)$ and $F_{TX}(s)$ have degree (order of TX channel filter). The finite transmission zeros of RX, MX and TX channel filters can completely define the polynomials $P_{RXn}(s)$, $P_{MXn}(s)$, and $P_{TXn}(s)$. The coefficients p_{0RX} , p_{0MX} , and p_{0TX} are determined by the return loss at passband limits [5].

The S-parameters of the triplexers can be defined using four polynomials as follows

$$
\begin{aligned}
S_{11} &= \frac{N(s)}{D(s)} & S_{21} &= \frac{p_{0r}P_r(s)}{D(s)} \\
S_{31} &= \frac{p_{0m}P_m(s)}{D(s)} & S_{41} &= \frac{p_{0t}P_t(s)}{D(s)}
\end{aligned}
\tag{2}
$$

The highest degree coefficients of $N(s)$, $D(s)$, $P_r(s)$, $P_m(s)$ and $P_t(s)$ are imposed equal to 1 with p_{0r}, p_{0m} and p_{0t} suitable normalizing coefficients. Note that the roots of $D(s)$ represent the poles of the network, the roots of $N(s)$ are the reflection zeros at the common node of the triplexer (port 1 in Figure 1), and the roots of $P_r(s)$, $P_m(s)$ and $P_t(s)$ are the transmission zeros in the RX, MX and TX path, respectively.

The triplexer polynomials can be derived using the admittances at the input ports of the RX, MX and TX channel filters, taking into account the interaction between the channel filters through junctions. The following expressions can be obtained:

$$
\begin{cases}
N(s) = S_{TX}S_{RX}S_{MX} - D_{TX}S_{RX}S_{MX} - D_{RX}S_{TX}S_{MX} - D_{MX}S_{TX}S_{RX} \\
D(s) = S_{TX}S_{RX}S_{MX} + D_{TX}S_{RX}S_{MX} + D_{RX}S_{TX}S_{MX} + D_{MX}S_{TX}S_{RX} \\
P_r(s) = P_{RXn}S_{TX}S_{MX}, \quad p_{0r} = p_{0RX} \\
P_m(s) = P_{MXn}S_{TX}S_{RX}, \quad p_{0m} = p_{0MX} \\
P_t(s) = P_{TXn}S_{RX}S_{MX}, \quad p_{0t} = p_{0TX}
\end{cases}
\tag{3}
$$

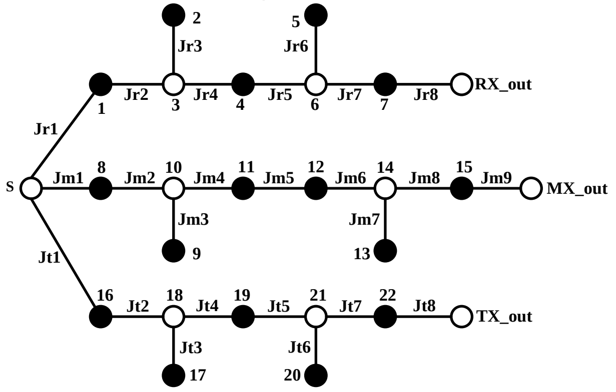
where

$$
\begin{cases}
S_{RX} = \dfrac{E_{RX} + F_{RX}}{2}, & D_{RX} = \dfrac{E_{RX} - F_{RX}}{2} \\
S_{MX} = \dfrac{E_{MX} + F_{MX}}{2}, & D_{MX} = \dfrac{E_{MX} - F_{MX}}{2} \\
S_{TX} = \dfrac{E_{TX} + F_{TX}}{2}, & D_{TX} = \dfrac{E_{TX} - F_{TX}}{2}
\end{cases}
\tag{4}
$$

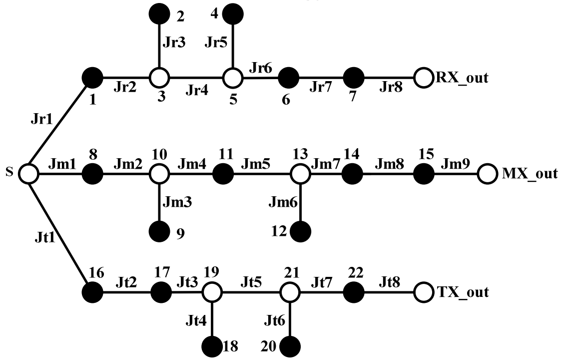
In this paper, once the triplexer polynomials are obtained, the channel filters are synthesized by extracted-pole technique [7]. The example is shown in the next section.

III. SYNTHESIS EXAMPLE

In order to demonstrate the validity of the triplexer synthesis technique presented in this paper, a triplexer is synthesized in the following part.



(a) Topology one



(b) Topology two

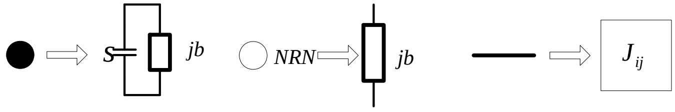


Figure 2 The topology of the triplexer

The topology of the triplexer is shown in Figure 2, By introducing NRNs, the topology of the channel filters is simple (inline topology) and more flexible. The specification of the triplexer is listed in table I.

Table I. The specifications of the triplexer example

	RX channel filter	MX channel filter	TX channel filter
Pass-band	1890MHz-1910MHz	1920MHz-1940MHz	1950MHz-1970MHz
Filter order	5	6	5
Return loss	20 dB	20 dB	20 dB
Finite zeros	1870MHz, 1930MHz	1900MHz, 1960MHz	1940MHz, 1980MHz

The characteristic polynomials of the channel filters are evaluated with technique illustrated in Section II, obtaining the following values (the polynomial coefficients are reported in descending order):

$$F_{RX}=[1\quad -0.0248+3.8633j\quad -5.8955-0.0446j\quad 0.0127-4.4341j\quad 1.6403-0.0128j\quad 0.0058+0.2383j]$$
$$E_{RX}=[1\quad 0.5407+3.8633j\quad -5.7496+1.6520j\quad -1.8394-4.1055j\quad 1.4013-0.8823j\quad 0.1536+0.1823j]$$
$$F_{MX}=[1\quad 0.0515-0.0607j\quad 0.0955-0.0028j\quad 0.0033-0.0040j\quad 0.0022-0.0001j\quad 0\quad 0]$$
$$E_{MX}=[1\quad 0.4493-0.0607j\quad 0.1951-0.0226j\quad 0.0447-0.0080j\quad 0.0089-0.0015j\quad 0\quad 0]$$
$$F_{TX}=[1\quad -0.0267-3.9016j\quad -6.0181+0.0527j\quad 0.0239+4.5797j\quad 1.7163+0.0067j\quad 0.0046-0.2529j]$$
$$E_{TX}=[1\quad 0.5233-3.9016j\quad -5.8816-1.6152j\quad -1.8204+4.2687j\quad 1.4872+0.8858j\quad 0.1568-0.1985j]$$

From the characteristic polynomials of the channel filters above evaluated, the normalized low-pass prototypes can be synthesized using, for instance, the technique in [7]. The result is shown as follows:

For figure 2 (a), the result is

$$\begin{aligned}
&[Jr1, Jr2, Jr3, Jr4, Jr5, Jr6, Jr7, Jr8]\\
=\;&[0.5318,1,3.4252,0.7573,1,4.4467,1.3714,0.5072]\\
&[b1, b2, b3, b4, b5, b6, b7]\\
=\;&[0.922,1.5133,17.0456,0.7488,-0.0105,-28.74,0.6822]\\
&[Jm1, Jm2, Jm3, Jm4, Jm5, Jm6, Jm7, Jm8, Jm9]\\
=\;&[0.446,1,3.8263,0.8078,0.1454,1,4.6058,1.3918,0.4986]\\
&[b8, b9, b10, b11, b12, b13, b14, b15]\\
=\;&[0.0365,0.7454,21.1157,0.017,-0.0361,-0.7545,-31.1822,-0.0717]\\
&[Jt1, Jt2, Jt3, Jt4, Jt5, Jt6, Jt7, Jt8]\\
=\;&[0.5244,1,2.1564,0.7767,1,2.6956,1.3771,0.4993]\\
&[b16, b17, b18, b19, b20, b21, b22]\\
=\;&[-0.7829,-0.2596,11.5653,-0.7557,-1.2443,-18.9269,-0.8553]
\end{aligned}$$

For figure 2 (b), the result is

$$\begin{aligned}
&[Jr1, Jr2, Jr3, Jr4, Jr5, Jr6, Jr7, Jr8]\\
=\;&[0.5318,1,3.4252,1,0.9782,0.22,0.2175,0.5074]\\
&[b1, b2, b3, b4, b5, b6, b7]\\
=\;&[0.922,1.5133,16.2903,-0.0105,-1.324,0.7123,0.7476]\\
&[Jm1, Jm2, Jm3, Jm4, Jm5, Jm6, Jm7, Jm8, Jm9]\\
=\;&[0.446,1,3.8263,0.8078,1,4.8281,1.0481,0.2101,0.4986]\\
&[b8, b9, b10, b11, b12, b13, b14, b15]\\
=\;&[0.0365,0.7454,21.1157,-0.0124,-0.7545,-33.9752,-0.0419,-0.0085]\\
&[Jt1, Jt2, Jt3, Jt4, Jt5, Jt6, Jt7, Jt8]\\
=\;&[0.5244,0.1982,1,2.7762,1,0.4532,0.2316,0.4985]\\
&[b16, b17, b18, b19, b20, b21, b22]\\
=\;&[-0.8694,-0.7138,17.5572,-0.2596,-0.478,-1.2443,0.8553]
\end{aligned}$$

The extraction of a coupling matrix of the triplexer network that contained both resonating nodes and NRNs is fundamentally identical to the synthesis of the standard coupled resonator triplexers [4]. The prototypes must be then de-normalized, imposing the physical configuration of actual resonators and coupling structures. The coefficients are given by the following expressions:

Resonant-Resonant Coupling:

$$k_{ij}=FBW*J_{ij}$$

Resonant-Nonresonant Coupling:

$$k_{ij}=sqrt(FBW)*J_{ij}$$

Nonresonant-Nonresonant Coupling:

$$k_{ij}=J_{ij}$$

The responses of the two circuits in Figure 2 can be calculated from a simple nodal analysis and is shown in Figure 3. We can see that the two responses are plotted simultaneously along with the ideal characteristic polynomials, but they are all indistinguishable. It can be clearly seen that all the specifications of the triplexer are met.

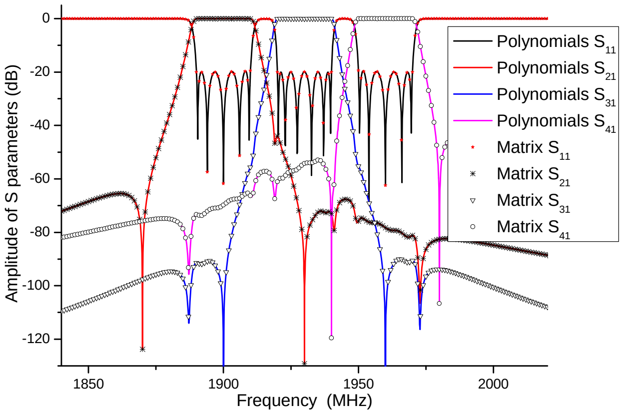


Figure 3 The responses of the two circuits in figure 2

IV. CONCLUSIONS

A novel generalized technique for synthesizing microwave triplexer is presented in this paper. The characteristic polynomials of the triplexer are evaluated and the interactions between the channel filters are taken into account. Then the characteristic polynomials of channel filters are obtained from the triplexer. The extracted-pole technique is used to synthesis the channel filter. The circuit responses (coupling matrix response) agree with the characteristic polynomials well. A synthesized example shows the validity of the new technique.

ACKNOWLEDGMENT

This work was supported by the National High Technology Research and Development Program of China (863 Program) No.2012AA01A308 and the National Natural Science Foundation of China (NSFC) under Project No.61271017.

REFERENCES

[1] Macchiarella, G., Tamiazzo, S. Novel approach to the synthesis of microwave diplexers. IEEE Trans. Microwave Theory Tech., Dec. 2006, vol. MTT-54, no. 12, p. 4281-4290.

[2] K. L. Wu and W. Meng, “A direct synthesis approach for microwave filter with a complex load and its application to direct diplexer design,” IEEE Trans. Microwave Theory Tech., vol. 55, no. 5, pp. 1010–1017, May 2007.

[3] G. Macchiarella and S. Tamiazzo, “Design of triplexer combiners for base stations of mobile communications,” IEEE MTT-S Int. Microw. Symp. Dig., Anheim, CA, May. 2010. pp. 429-432.

[4] G. Macchiarella and S. Tamiazzo, “Synthesis of star-junction multiplexers,” IEEE Trans. Microw. Theory Tech, Vol.58, pp. 3732-3741, Dec. 2010.

[5] Richard J. Cameron, “General coupling matrix synthesis methods for chebyshev filers functions,” IEEE Trans. Microwave Theory Tech., Vol. 47, pp.433-442, April. 1999.

[6] Richard J. Cameron, “Advanced coupling matrix synthesis techniques for microwave filter,” IEEE Trans. Microwave Theory Tech., Vol. 51, pp.1-10, Jan. 2003.

[7] Smain Amari, Giuseppe Macchiarella, “Synthesis of inline filters with arbitrarily placed attenuation poles by using Non-resonating nodes,” IEEE Trans. Microwave Theory Tech., Vol. 53, pp.3075-3081, Oct. 2005.