# RFT Based Multiband Matching Network Design with Foster Resonance Sections

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## Abstract

**A new method for a multi band matching network design is introduced in this paper. Foster resonance sections are used to create transmission zeros. This effect brings gain degradation at Transducer Power Gain (TPG) of the matching circuit at assigned frequencies of resonance sections. Single matching problem is concerned. It has been shown that proposed method gives good control on creating multiband characteristics.**

## 1. Introduction

With increasing development in electronics and wireless technology, it has become a necessity to being able to operate in several frequency bands for RF or Microwave units. The infrastructure technology behind the standards such as, Bluetooth, GSM, EDGE, WCDMA, TD-SCDMA, CDMA2000, HSPA, LTE, IS-95, etc., is needed to be designed to settle these standards concurrently.

For being able to switch between these standards it may be required to use multiple RF/MW units that work separately or a single unit that can work in some of or all of these standards.

In these regard matching network design in multiband become a necessity. In this paper we presented a method which are promising in this field to get multiband concurrent matching.

Multiband matching network brings some of design prerequisites such as frequency bands, linearity and phase concerns and bandwidth or the size of circuit board. Many method has been presented in literature to provide some of these prerequisites. If there would be a classifications of these methods it might be the one with made according to used elements.

Such as proper design structures of lumped LC tuner elements [1]. Even they are easy to design when the operating frequency is increased the parasitic effects of lumped elements become a problem. Other passive elements like tunable varactor or inductors [2]. These kind of matching circuit brings some control circuit and also concurrent matching property is not possible. Or there can be switches [3]. Using switches makes impedance matching automatically reconfigurable. These switches are generally used for putting varactors, inductors or separated passive networks into use. With increasing frequency, lumped element don't give good performance. Elements size come to become as a big concern to designer. The solution is using transmission lines in circuit instead of lumped elements. Matching network that designed with transmission lines, is a popular research area nowadays [4]. Several researchers studied on adaptive impedance matching using IC unit. There many publications. These approaches need processing time and it break the concurrent operation [5].

Using distributed structure in matching network design is very popular. There are many studies. In some of them there are only used distributed structures. And in some of them there are mixed structures like lumped and distributed elements used in design of matching network [6].

Another multiband matching network design technique is using MEMS as a switching operator. Using MEMS makes matching network reconfigurable. There are many studies at literature [7].

In this paper, it has been presented a design method that simply include lumped band pass matching network and foster resonance sections. Foster sections are used to create the multiband response. Real Frequency Technique direct approach is used to design and optimize the values of elements. In following sections it will be introduced general RFT techniques and foster reactance theorem. In this regard also a working example will be presented.

## 2. Real Frequency Techniques for Multi Band Matching

Real Frequency Technique is introduced by Carlin and Yarman [8] and developed by many researchers. It is used to design microwave circuits for a long time. These techniques are very practical since generation of network function is based on measured load's data. After load data is introduced, nonlinear optimization simulator optimizes coefficients of a realizable network function for maximum gain transfer [9].

There have been completed several designs of multi-band antenna matching and switch networks for cellular communication systems [10, 11, 12]. It has been intended to approach to multiband matching problem by creating notches in overall gain response. This is possible with using real frequency transmission zeros. Two of special case of Foster sections which are Darlington C and Darlington D sections can be used for this goal [13]. But lumped realization of these sections are big problem. It is possible to bypass it by using Foster resonance sections since lumped design of these sections are possible in low frequencies. The design of the matching network is realized by using the real frequency design techniques. Foster resonance sections are inserted to the design and element values of overall network is optimized to get multiband response.

Real Frequency Direct Approach (RFDT) is used for the sake of easy initialization. Since this algorithm uses denominator coefficient to synthesis circuit. Zeros of the network is provided by designer and poles are produced by the algorithm. The form of immitance function [14] is expressed as;

$$Z(p)=\frac{a_1p^n+a_2p^{(n-1)}+\ldots+a_n+a_{n+1}}{b_1p^n+b_2p^{(n-1)}+\ldots+b_n+b_{n+1}} \quad (1)$$

The real part of immittance function is expressed as;

$$R(-p^2)=\frac{A_0p^{2ndc}\prod_{i=1}^{nz}(p^2+w_i^2)^2}{B_1p^{2n}+B_2p^{2(n-1)}+\ldots+B_np^2+1};\ \forall p=jw \quad (2)$$

It is assumed that $R(-p^2)$ includes only real transmission zeros. Denominator coefficient $B_1$, $B_2$, $B_3$,…. are optimized by using Levenberg-Marquardt algorithms for the high and flat transducer power gain over the given frequency range.

## 3. Foster Reactance Theorem

Foster forms are canonical forms of a realizable reactance function. Foster reactance theorem states that the impedance of a passive, lossless network always increases with frequency [15]. This theorem is quite general; in particular, it applies to distributed element circuits although Foster formulated it in terms of discrete inductors and capacitors. Foster theorem applies both impedance and admittance of a passive, lossless one-port network.

### 3.1. Parametric representation of Foster Functions

Foster functions can be written in terms of its poles as

$$F(p) = k_\infty p+\frac{k_0}{p}+\sum_{i=1}^{N}\frac{k_i}{p-j\omega_i} \quad (3)$$

$$k_\infty = \lim_{p\to\infty}\frac{1}{p}F(p) \geq 0,\ k_0 = \lim_{p\to 0} pF(p)\geq 0$$

$$k_i = k_{iR}+jk_{iX} = \lim_{p\to j\omega_i}(p-j\omega_i)F(p);\ \ k_{iR}\geq 0$$

In the above equations, $k_\infty$ is the residue of the pole at infinity $k_0$ is the residue of the pole at zero and $k_{iR}$ is the real part of the residues at the complex conjugate poles located at $p=\pm j\omega_i$. They are real and must be non-negative. i.e. $\{k_\infty,k_0,\ k_{iR}\geq 0;i=1,2,..n\}$.

### 3.2. Foster Residue Theorem

All the residues $k_\infty$, $k_0$ and $k_i$ of a rational function described as Foster function must be real and non-negative.

### 3.3. Synthesis of a Foster Function

If Foster function describes an impedance function then, it can be realized as; series connections of an inductance $L=k_\infty$, a capacitor $C=1/k_0$ and parallel tank circuits with resonance frequencies $\omega_i=\frac{1}{L_iC_i}$ with $2k_i=\frac{1}{C_i}$ as shown in "Fig. 1".

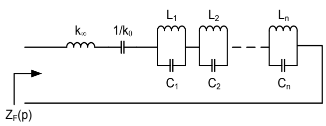


**Fig. 1.** Foster I realization of a Foster impedance function

If there is no pole at DC and infinity which means the series inductance and capacitance is removed then only series resonance sections are concerned.

## 4. From Band Pass to Multiband with Foster Sections

When two or more distinct frequency bands are needed to be performed at a same platform, two options come up. First one of that is using ultra-wideband structures that includes both bands. Second one is using multi band design method which can work at these bands even it does not perform at the band between them.

Multi band matching network design is strongly relative with shifting band pass characteristics to desired bands or creating notch at specific frequencies. In this manner using foster resonance sections in a matching network design brings transmission zeros in overall TPG function. These sections can be easily realized in lumped and distributed domain. In next section a lumped design example is presented.

## 5. Design Example

In this section, a multiband matching network design example is presented. A wideband PIFA antenna as shown in "Fig. 2" [16] is taken as a load to match with 50Ω generator. The antenna has a wide band characteristic as shown in the "Fig. 3". Its impedance characteristics are plotted in "Fig. 4" and "Fig. 5".

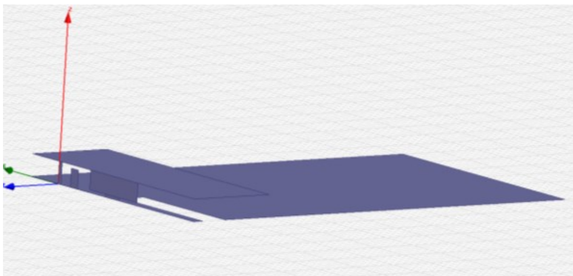

**Fig. 2.** UWB PIFA antenna

A UWB PIFA antenna is designed according to study at [16]. It has 100mm x 50mm ground plane and a radiation plate plus with parasitic pin and shorting pin. It has also cavities at ground planes.

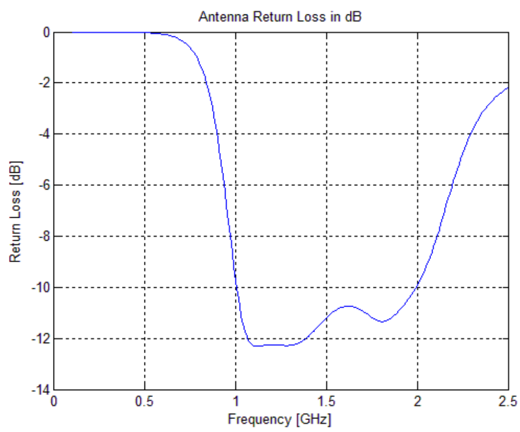


**Fig. 3.** Return Loss characteristics of the UWB PIFA antenna

The PIFA antenna has a wide band characteristic. When feeding the PIFA with 50Ω generator it has fairly good matching performance between 1 GHz - 2 GHz. This band includes GSM900, GSM1800 and UMTS. It has a good testing load type for creation of multiband characteristics for these bands.

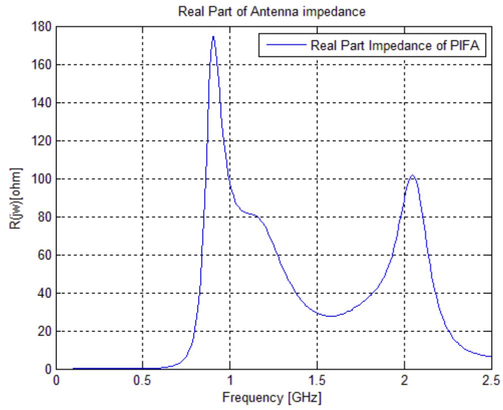


**Fig. 4.** Real part of impedance of the UWB PIFA antenna

The real part impedance of PIFA antenna has a characteristic as above. The impedance variation is between 35-175Ω in intended bands.

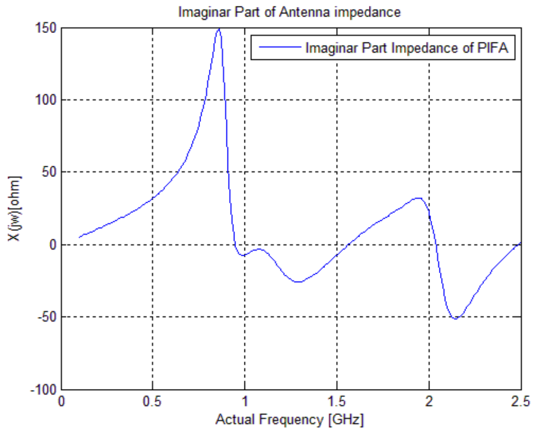


**Fig. 5.** Imaginer part of impedance of the UWB PIFA antenna

The imaginer part impedance of PIFA antenna has a characteristic as above. The impedance variation is between -50Ω and 35Ω in intended bands.

## 6. Single Band Matching Network Design via RFT Direct Approach

To show the insertion effects of foster resonance sections first a matching network design is presented with using RFT direct approach technique. In the design of single band matching network, it is considered a seventh degree driving point impedance function for the matching network, with two transmission zeros at DC and five transmission zeros at infinity. Using RFT direct approach [17, 18], transducer power gain of the antenna is optimized over 0.87 GHz - 2.2 GHz band to yield a flat gain characteristics.

As a result of optimization, the input impedance Z(p) of the matching network is obtained. TPG characteristic and synthesis of this impedance are shown in "Fig. 6" and "Fig. 7" respectively.

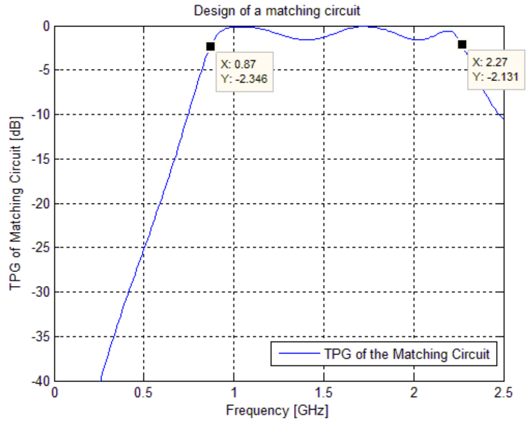


**Fig. 6.** TPG performance of the single band matching circuit

The matched PIFA antenna has very good power transfer performance in between 1 GHz – 2 GHz.

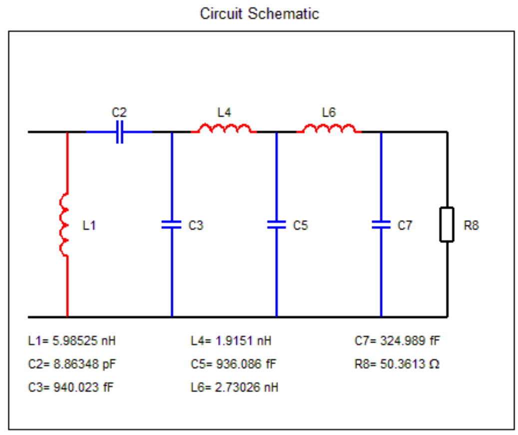


**Fig. 7.** Lumped circuit model of the single band matching network

The matching network is synthesized with using extensive RFT tools provided by Yarman [18]. It has low pass and high pass sections. These sections squeeze the power in the intended band.

## 7. Multiband Matching Network Design via RFT Direct Approach

Single band design of matching network is presented above. Next step is creating multiband characteristic by inserting foster resonance sections. For this manner an eleven degree driving point impedance function for the matching network is considered. It has two transmission zeros at DC and two transmission zeros at the normalized frequencies $f_1 = 1.4$ and $f_2 = 2.5$, corresponding to 1.4 GHz and $f_2 = 2.5$ GHz. Five transmission zeros are at infinity. Using RFT direct approach [17, 18], and inserting foster resonance sections to the design, transducer power gain of the antenna is optimized over 0.87 GHz – 1.25 GHz and 1.73 GHz – 2.2 GHz frequency bands which are the bands of GSM900, GSM1800 and UMTS. An excellent non-linear optimization function provided by MATLAB called "lsqnonlin" which minimizes the user supplied objective function with employing Levenberg-Marquad algorithm, is used. This objective function is described as an error function at each frequency of the band. We optimized TPG level over the frequency regions which are classified as first; power band (GSM900), second; suppression band, third power band (GSM1800, UMTS). We weighted the error function with different coefficients for these three bands. Basically we increased the error contribution for power bands and decreased it for the suppression band in overall error. Also we introduced different target TPG level for these bands. After all this optimization approach gave a contribution to the creation of multiband characteristic with insertion of real frequency transmission zeros in the band.

As a result of the optimization, the input impedance Z(p) of the matching network is obtained. TPG and return loss characteristic are shown as "Fig. 8" and "Fig. 9".

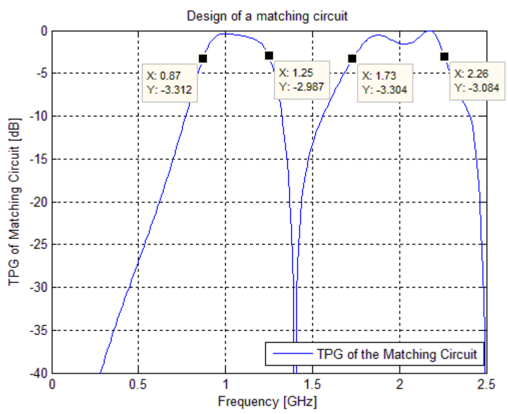


**Fig. 8.** TPG performance of the multiband matching network

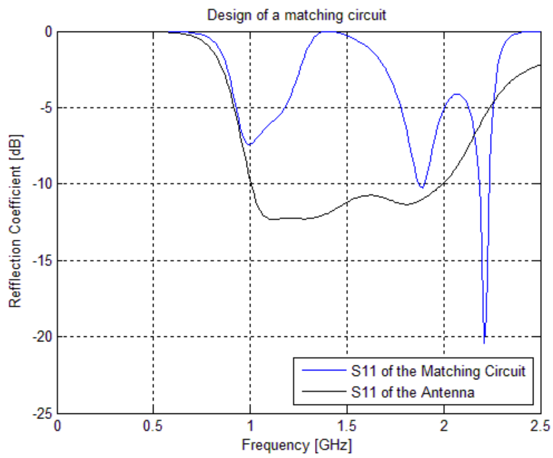


**Fig. 9.** Return loss performance of the multiband matching network

As shown above the new matching circuit creates double band characteristic over the complex impedance of the PIFA antenna at around GSM900 and GSM1800 bands. With foster section insertion, the real frequency zeros give a gain drop at the middle of these bands as expected.

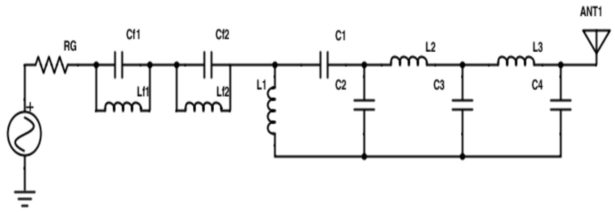


**Fig. 10.** Lumped circuit model of the matching network Lf1=1.27nH, Lf2=4.06nH, Cf1=3.183pF, Cf2=3.183pF, L1=5.985nH, C1=8.863pF, C2=940fF, L2=1.915nH, C3=936.1fF, L3=2.73nH, C4=325fF, RG=50.36Ω.

As shown above in "Fig. 10" it has two foster resonance sections with band pass extension network. Overall matching network has multiband characteristic. Foster sections is used for gain drop one at middle band and one at band edge. This design don't need a transformer between generator and matching network. AWR simulations are also shown below in "Fig. 11" and "Fig. 12".

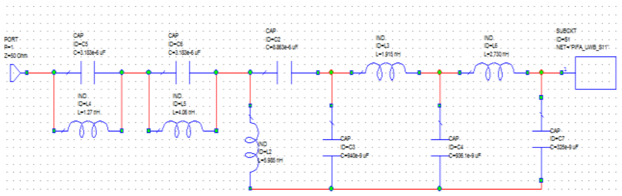

**Fig. 11.** AWR realization of the multiband matching network

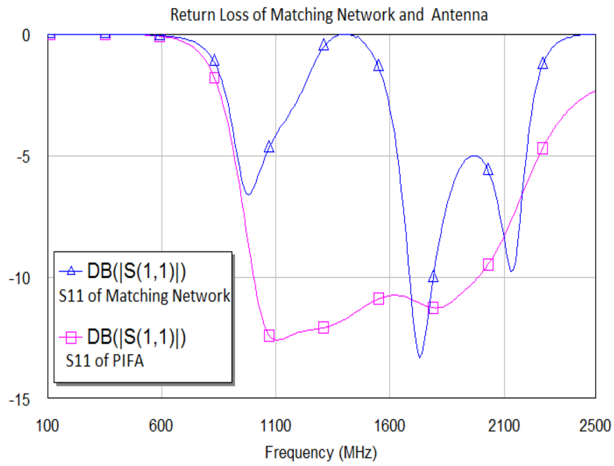


**Fig. 12.** Return loss performance of the multiband matching network

## 8. Conclusion

In this paper, a multiband concurrent matching network design is presented. Foster resonance sections are used to extract multiband characteristic from single wide band characteristic of the PIFA antenna. RFT direct approach is used to synthesize the impedance function of matching network. Transducer power gain is selectively optimized over the two power bands and one suppression band. TPG level is drastically falls over suppression band beside that, TPG level at power bands is bigger than -3dB.

## 9. References


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