Bandpass filter modeling employing Lorentzian distribution

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transmission lines. The presentation of EGPSC and the corresponding relationship enhances the comprehensiveness of generalized Smith charts theory, and simultaneously brings the applications of EGPSC to a higher level. Based on this work, it can be expected that more graphical applications of EGPSC in microwave aided design will be researched in further.

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BANDPASS FILTER MODELING EMPLOYING LORENTZIAN DISTRIBUTION

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ABSTRACT: *This letter takes a close outlook of modeling a bandpass filter performance with the Lorentzian distribution function. Lorentzian function parameters are correlated with the filter parameters, namely, its bandwidth and center frequency. The zeros and poles of the filter are extracted from the closed form expression of the Lorentzian function, which is used to construct the rational model of the filter. This procedure is expected to optimize the overall filter performance and to construct a consistent equivalent circuit from its computed poles and zeros.* © 2009 Wiley Periodicals, Inc. Microwave Opt Technol Lett 51: 1167–1169, 2009; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.24288

Key words: *extracted poles; filter; Lorentzian distribution; synthesis*

1. INTRODUCTION

A microwave filter is a two-port network used to control the frequency response at a certain point in a microwave system by providing transmission at frequencies within the passband and attenuation in the stopband [1]. As all other physical structures, it has natural frequencies. These resonances are of great interest because their functional form depends only on the geometry of the structure itself. So far, many general and multiple processing techniques for finding resonances and poles using rational functions are presented in literature [2–14]. The Lorentzian distribution is often appropriate for describing resonant behavior such as a mechanical or electronic oscillator [15]. A resonance curve can be represented as a function of the driving frequency by the Lorentzian function.

This letter describes how the Lorentzian function can be used for extracting the complex frequency zeros and poles of electromagnetic bandpass filter. The measured filter performance is modeled by Lorentzian function. This model could identify the effective parameters of the structure for a given response.

2. LORENTZIAN MODELLING APPROACH

A general Lorentzian function could be expressed as follows:

$$y = y_0 + \frac{2A}{\pi} \frac{w}{4(x-x_c)^2 + w^2} \tag{1}$$

where y_0 is an offset, x_c is the center, and A is the area of the plot. w is the full width at half maximum. These set of parameters are correlated with bandpass filter parameters, such that x_c represents the center frequency f_0 of the filter and w models the filter with 3 dB bandwidth, $\Delta\omega$. Figure 1 shows a measured filter performance. The filter with three coupled microstrip lines, which is reported in [16], was chosen as a demonstrator.

As it is often desirable, in passive network synthesis techniques, to work with the reflection coefficients, the Lorentzian curve fitting superimposed with the measured return loss $S_{11}(f)$ is shown in Figure 2. The fitting error is less than 0.0015. In many practical situations, the filter performance magnitude may be all that available, and it is of interest to have a procedure that still permits the poles and zeros to be obtained. Next, to find the zeros of the Lorentzian function, x_{zero}, Eq. (1) is set to zero, i.e., $y = 0$, which yields

$$x_{\text{zero}} = x_c + J\sqrt{\frac{w^2}{4} + \frac{wA}{2\pi y_0}} \tag{2}$$

whereas the poles, x_{pole}, could be approximately found by setting (1) to infinity, i.e., $y = \infty$, which produces

$$x_{\text{pole}} \approx x_c + J\frac{w}{2} \tag{3}$$

Since the synthesis procedure requires the availability of rational functions, (1) can be rewritten in terms of poles and zeros as

$$y_m \approx R_\alpha \frac{(x - x_{\text{zero}})}{(x - x_{\text{pole}})} \tag{4}$$

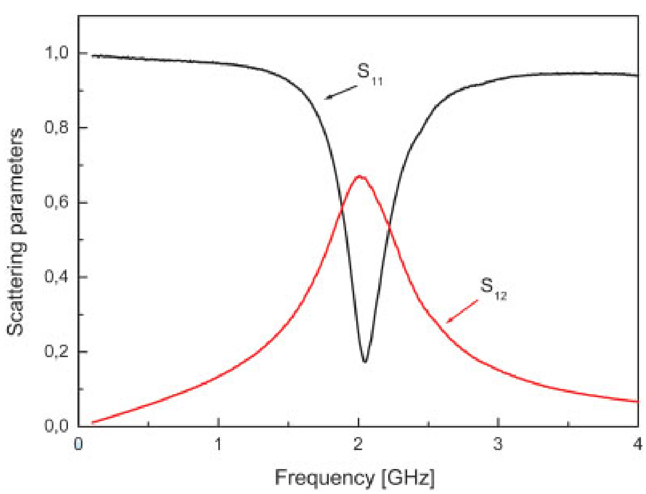

Figure 1 Measured three coupled lines microstrip filter response [16]. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

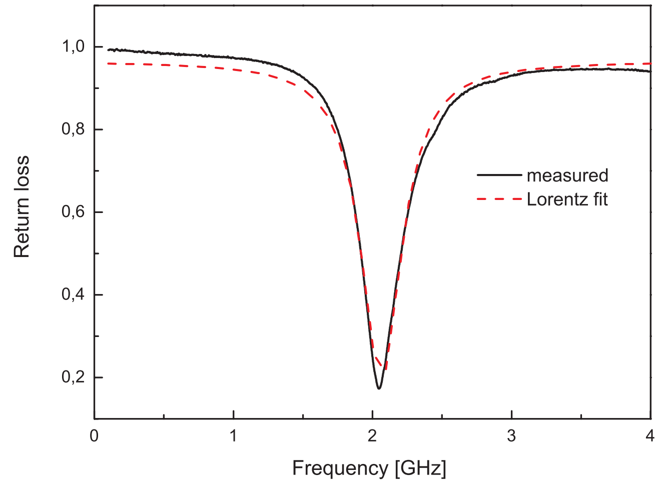

Figure 2 Fitting data in S_{11}: A, x_c, w, and y_0 are −0.4288: 2.0633, 0.35228, 0.35228, and 2.0633, respectively. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

where R_α denotes the magnitude of the complex frequency pole. Figure 3 shows the rational model performance superimposed with the measurements.

3. TIME DOMAIN REPRESENTATIONS

The Lorentzian modeling will provide the complex frequency zeros and poles of electromagnetic resonating structure from its measured scattering parameters. Thus with the help of (4) and (6), the Laplace transformation, which is related to the frequency domain, is developed and written as

$$F(s) \approx \sum_{n=1}^{N} \frac{R_{\beta_n}}{(s - s_{\beta_n})} \tag{5}$$

where N is the total number of poles, s is the Laplace variable, and s_{β_n} is the complex frequency resonance whose amplitude is R_{β_n}. Thus, the time response of the structure is simply expressed as

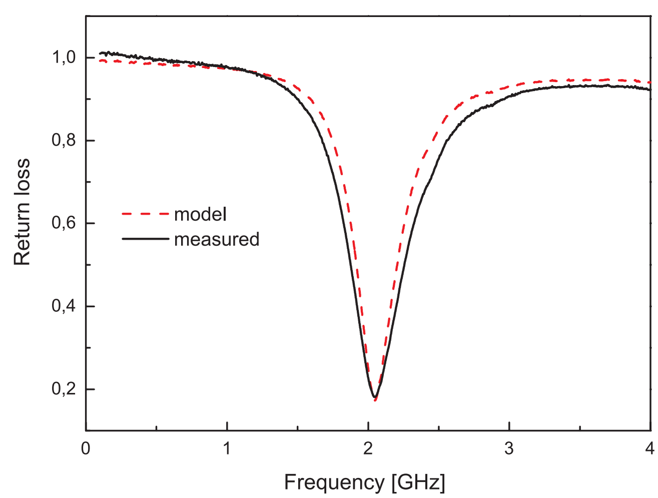

Figure 3 Rational representation with R_α, x_{zero}, and x_{pole} are 2, 2.0633 + J 0.07828, and 2.0633 + J 0.17614, respectively. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

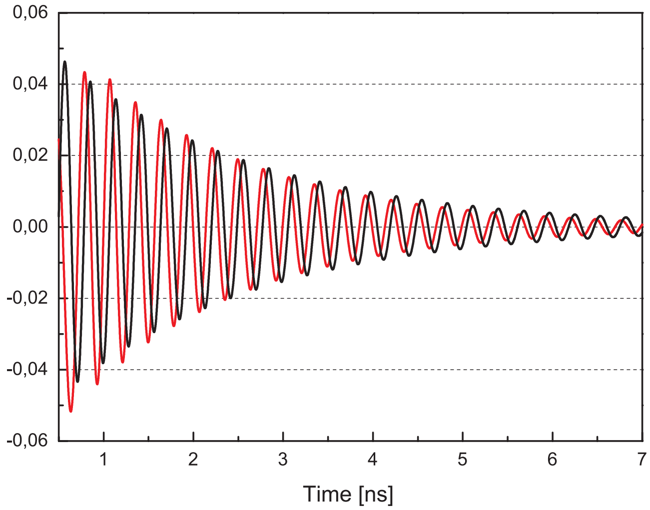

Figure 4 Time domain response: simulated with CST and computed signals. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

$$f(t) \approx \sum_{n=1}^{N} R_{\beta_n} \exp(s_{\beta_n} t) \tag{6}$$

$f(t)$ is a real function and each $\exp(s_{\beta_n} t)$ term represents a source-free solution.

On the other hand, inverse Fourier transformation can be applied to (4) to determine the time domain response of the filter, i.e.,

$$f(t) = R_\alpha \int \frac{(f - x_{\text{zero}})}{(f - x_{\text{pole}})} \exp(J2\pi t f)\, df \tag{7}$$

which yields

$$\begin{aligned} f(t) \approx{} & \frac{R_\alpha}{J2\pi t} \exp(J2\pi t f) + (x_{\text{pole}} - x_{\text{zero}}) R_\alpha \\ & + \exp(J2\pi t x_{\text{pole}}) \times [ln(f - x_{\text{pole}})] \\ & + \exp(J2\pi t x_{\text{pole}}) \times \left[\sum_{k=1}^{\infty} \frac{(J2\pi t)^k (f - x_{\text{pole}})^k}{k \times k!} \right] \end{aligned} \tag{8}$$

and since $f(t)$ is a real function,

$$f(t) \approx R_\alpha \pi \left(w/2 - \sqrt{\frac{w^2}{4} + \frac{wA}{2\pi y_0}} \right) \times \exp(-\pi w t) \cos(2\pi t f_0) \tag{9}$$

Thus, the filter center frequency and bandwidth are reflected on the time domain response. The fabricated three coupled line filter has been simulated in CST Microwave Studio tools [17], which is a time domain technique that provides the time domain response of the filter. Then, (11) is used to calculate the time domain response based on the Lorentzian function parameters. Figure 4 shows the simulated time domain response superimposed with the computed response. The results obtained by the proposed approach and the numerical model show an excellent agreement with each other.

4. CONCLUSION

In this work, it has been shown how the Lorentzian function can be used for extracting the complex frequency zeros and poles of electromagnetic bandpass filter from its measured scattering parameters. This model can be used for any type of microwave resonating structures, to identify the effective parameters of the structure for a given response. It has been found that the Lorentzian function parameters are correlated with the filter parameters, namely, its bandwidth and center frequency. Finally, the inverse Fourier transformation is used to compute the time domain response of the structure from its modeled Lorentzian function parameters. This model could be of help to determine the effective poles and zeros from a measured time domain response and to construct a consistent equivalent circuit.

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