STABILITY DIAGNOSIS OF MICROWAVE RECURSIVE STRUCTURES USING THE NDF METHODOLOGY

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ABSTRACT

In this paper, we verify and validate the new important concepts developed by A.Platzker in [1], by comparing the NDF method to classical low frequency concepts which, under some assumptions, can be applied to microwave recursive structures [2]. We proceed with the examples of a first-order and a second-order recursive filters and show how the NDF expression for this kind of filter can be easily identified.

INTRODUCTION

Active filters have, for many years, been associated, at low frequency, with accurate high-order filter design. The main methodology have focused on operational amplifier approaches because of the abilities of such components to compensate for the intrinsic losses of passive components, and for the overall amplification also provided. Such structures are particularly appropriated for monolithic design context, obviously resulting in compact size. Although the physical constraints are strongly different, these advantages carry over to microwave frequencies, thus showing an increasing interest in adapting these low frequency techniques for use in microwave systems. One of these techniques includes the design, at microwaves, of recursive and transversal filters, which, until now, have generally been designed using a distributed approach [3]. As compared with the most recently published papers, we have presented a methodology for filter design with no deviation from classical low frequency principles, thus allowing a complete and simple analysis of stability for this kind of filters. Measurements have been presented in [2], validating these concepts and our approach. In this article, we use our methodology and the corresponding recursive filter topology to validate the method developed by A.Platzker which introduces the NDF function. We perform the stability diagnosis for a first-order filter, for which measurements have been made, and complete our approach with the analytical results of a second-order structure, using the same topology. We identify the resulting NDF function as the denominator of the theoretical transfer function H(f) of the corresponding recursive structure.

I - Stability analysis using low frequency concepts

We present here the direct identification of digital low frequency recursive principles, in the analog domain, at microwaves, for the stability analysis purpose. Recursive and transversal filters are governed by the following time and frequency domain equations, where $x(t)$ and $X(f)$ [$y(t)$ and $Y(f)$] are the input [output] of the system :

$$y(t) = \sum_{k=0}^{N} a_k\, x(t-k\tau) - \sum_{p=1}^{P} b_p\, y(t-p\tau)$$

$$H(f) = \frac{Y(f)}{X(f)} = \frac{\sum_{k=0}^{N} a_k\, e^{-2j\pi f k\tau}}{1+\sum_{p=1}^{P} b_p\, e^{-2j\pi f p\tau}} = \frac{N(f)}{D(f)} \qquad (1)$$

Implementation of such structures requires multiple constant delay increments τ, amplitude weighting elements $\{a_k\}$ and $\{b_p\}$, and a mean of combining the elementary delayed signal components. We note that $H(f)$ is periodic with period $f_0=1/\tau$. Stability can then be derived by considering the z-notation of the transfer function for the same (N;P) order filter, where $\{h_n\}$ is the impulse response of the filter :

$$H(z) = \frac{\sum_{k=0}^{N} a_k\, z^{-k}}{1+\sum_{p=1}^{P} b_p\, z^{-p}} = \sum_{n=0}^{+\infty} h_n\, z^{-n}$$

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The necessary and sufficient condition for a linear filter of response $\{h_n\}$ to be stable implies :

$$|H(z)| \leq \sum_{n=0}^{+\infty} |h_n| |z^{-n}| < \infty \qquad \text{for } |z| \geq 1$$

Consequently, the stability of the recursive model requires that poles of H(z) (i.e. zeros of D(z) ; see (1)) are within the circle $|z|=1$. Following all these principles, we have shown in [2] that recursive and transversal structures can be built, at microwaves using 50Ω power dividers/ combiners for the elementary signal summation, and 50Ω matched microwave amplifiers for the weighting elements. We have demonstrated our approach for a first-order filter which topology is given in figure 1.

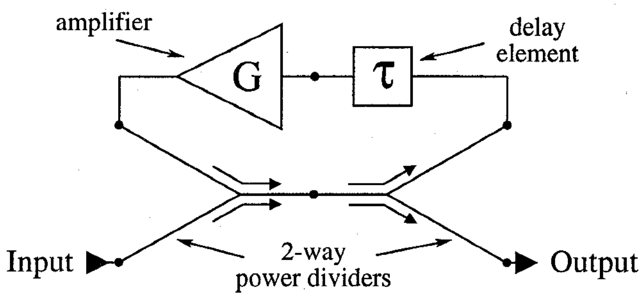

Figure 1 : First-order recursive filter topology

The corresponding transfer function is then :

$$S_{21}(f) = \frac{|S_{a21}|/2\, e^{j\phi(f)}}{1 - |S_{a21}|/2\, e^{-2j\pi f\tau}} = e^{j\phi(f)} \frac{a_0}{1 + b_1\, e^{-2j\pi f\tau}} = \frac{N(f)}{D(f)} \qquad (2)$$

where

$$\begin{cases} \tau \text{ is the global delay - time parameter} \\ |S_{a21}| \text{ is the magnitude of the amplifier gain} \\ \phi(f) \text{ is a linear frequency - dependent function} \\ a_0 \text{ and } b_1 \text{ are the weighting parameters} \end{cases}$$

This filter has been designed in hybrid technology. Figure 2 presents the measured response of the filter in the [1-4.5GHz] band and illustrates the pseudo-periodical aspect of the response $S_{21}(f)$ and the potential instability at 2.33GHz due to an amplifier gain value of nearly 6dB at this frequency. Indeed, as previously mentioned, the filter is stable if the pole of the filter (here $z=b_1$) is located within the circle $|z|=1$ in the complex plan :

$$|b_1| < 1 \quad \Rightarrow \quad |S_{a21}| < 2 \quad (6\,\text{dB})$$

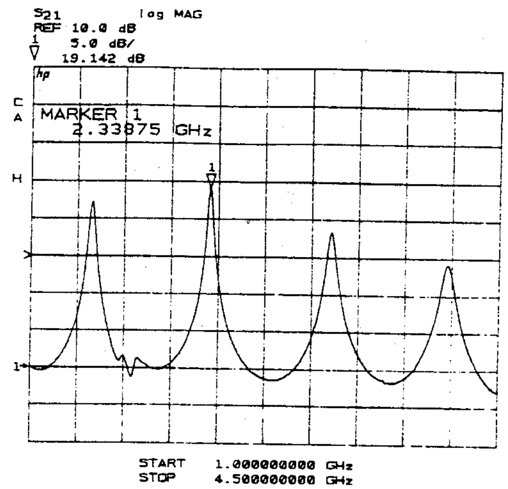

Figure 2 : Measured response of the filter in the [1-4.5GHz] band

II - Stability analysis using Platzker's method

1 - First-order recursive filter analysis

In this paragraph, we consider the first-order filter discussed in paragraph I. As described in [1], the prediction of stability by the NDF function analysis can be easily performed with the help of classical microwave CAD softwares for circuits which contain controlled sources. So, we first model the ideal amplifier in figure 1 with a single voltage-controlled current source terminated with two 50Ω impedances. In accordance to the circuit discussed in I, the equivalent amplifier is matched to 50Ω and its corresponding S_{21} parameter can be expressed as:

$$S_{21} = -\frac{g_m Z_0}{2}$$

where $\begin{cases} Z_0 = 50\,\Omega \\ g_m \text{ is the transconductance of the source} \end{cases}$

In figure 3, we present the circuit of figure 1, where the ideal amplifier has been replaced by the equivalent dependent source. Due to the unilateral property of this source, we now obtain, a new "open-loop" two-port device loaded by a generator of internal impedance 50Ω at the input, and with a 50Ω impedance at the output. As explained in [1], the current source is now controlled by an external voltage V_{ext}.

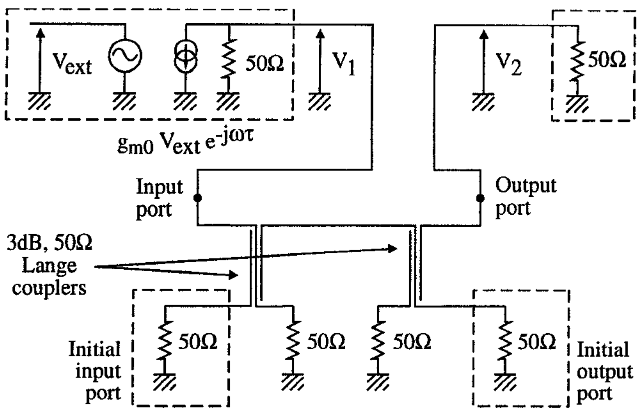

Figure 3 :
New "open-loop" equivalent two-port circuit

Note moreover that, the initial input and output ports are also assumed to be terminated with a 50Ω impedance. At this point, we set V_1 and V_2 the voltage values at the new input and output ports, and the NDF function is then defined by :

$$NDF = 1 - \frac{V_2}{V_{ext}} = 1 + RR$$

where RR is called the "Return Ratio". This expression can be easily evaluated by considering the properties of the (3dB, 50Ω) power combiners. Referring to the schematic in figure 3, it can be derived that :

$$RR = -S_{21}(f) = \frac{S_{a21}}{2} e^{-2j\pi f\tau}$$

$$\Downarrow$$

$$NDF(f) = 1 + \frac{S_{a21}}{2} e^{-2j\pi f\tau} = 1 - \frac{|S_{a21}|}{2} e^{-2j\pi f\tau}$$

$$= D(f) \qquad (S_{a21} < 0 \ ; \ \text{see (2)})$$

The study of zeros location in the complex plan for NDF(f) is then equivalent to the study of zeros location for D(f) the denominator of the initial transfer function H(f), or in other words, to the study of poles location for H(f). As demonstrated in [1], a given circuit is unstable if its corresponding NDF function encircles the origin in the complex plan, in the clockwise direction, when the frequency f varies from -∞ to +∞. In our example, the NDF function clearly describes, in the complex plan, a circle in the clockwise direction and is seen to be periodic with period $f_0 = 1/\tau$, the period of the initial filter mentioned in I. Consequently, the stability diagnosis only requires here a plot of the NDF function in the complex plan over a period f_0, for example in the $[0, f_0]$ band. In that case, the origin is encircled when $|S_{a21}| > 2$, which is coherent with paragraph I.

2 - Second-order recursive filter analysis

Using the same principles, we now consider a second-order recursive filter, which schematic is given in figure 4, where G_1 and G_2 are two amplifiers substituted with dependent current sources.

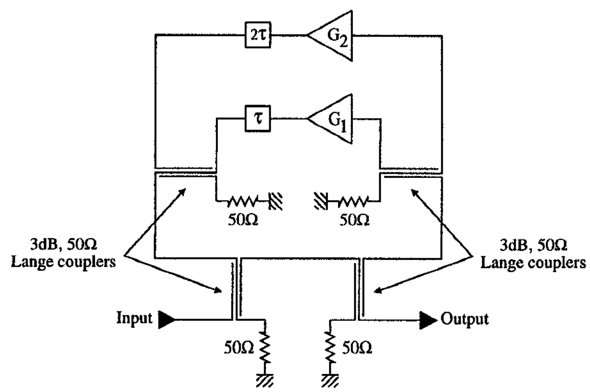

Figure 4 : Second-order recursive filter

The corresponding transfer function H(f) can then be written in the following form :

$$H(f) = \frac{N(f)}{D(f)} = \frac{1/2}{= 1 + \frac{G_1}{4} e^{-2j\pi f\tau} - \frac{G_2}{4} e^{-4j\pi f\tau}} \qquad (3)$$

In this case, the use of Platzker method requires to load the initial input and output ports with 50Ω impedances. By controlling the current source of the equivalent amplifier G_1 with an external voltage V_{ext1}, we derive a first return ratio $RR_1 = -V_2 / V_{ext1}$. In the next step, the transconductance g_{m1} is set to zero and we control the other dependent current source corresponding to G_2 with an external voltage V_{ext2}. This leads to the expression of a second return ratio $RR_2 = -V'_2/V_{ext2}$. Relatively to RR_1 and RR_2, the resulting NDF function can then be expressed as :

$$NDF(f) = (1 + RR_1(f))(1 + RR_2(f))$$

$$= 1 + \frac{G_1}{4} e^{-2j\pi f\tau} - \frac{G_2}{4} e^{-4j\pi f\tau} = D(f)$$

Here again, the expression of the NDF function is the same as the expression of D(f) the denominator of the initial transfer function H(f). Figure 5 shows how unstability can be predicted when the NDF encircles the origin for $G_1 = -5$ and $G_2 = -2$. In the same manner, figure 6 illustrates the stable state of the circuit, when the NDF does not encircle the origin for $G_1 = -4$ and $G_2 = -2$. As presented in figure 7, when $G_2 = 0$, the NDF plot turns back to a circle and verifies $|G_1| < 4$ (i.e. $|b_1| < 1$), the stability condition found for the first-order case.

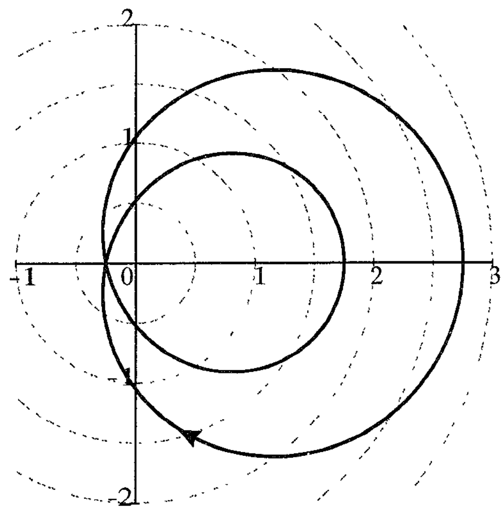

Figure 5 : Unstable case
NDF plot for $G_1 = -5$ and $G_2 = -2$

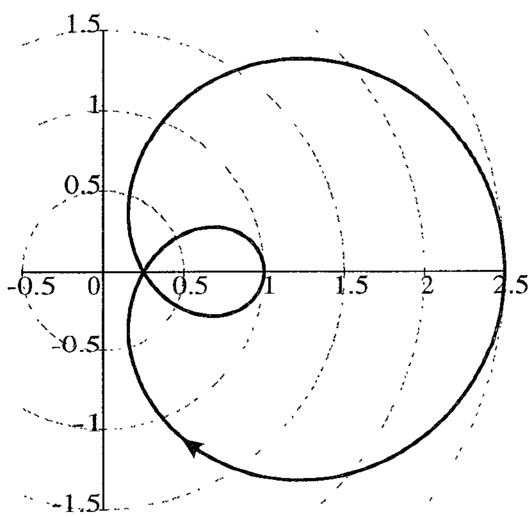

Figure 6 : Stable case
NDF plot for $G_1 = -3$ and $G_2 = -3$

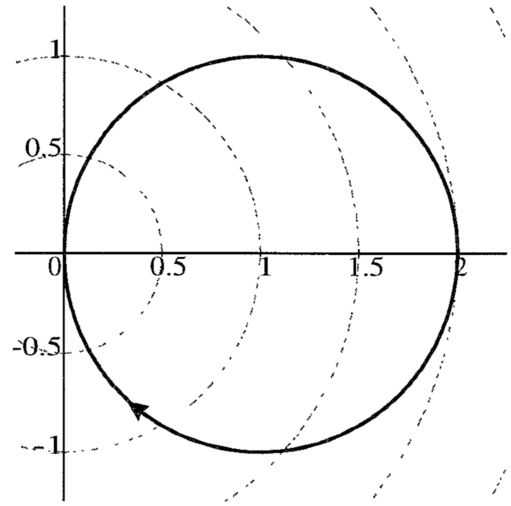

Figure 7 : limit of stability
NDF plot for $G_1 = -4$ and $G_2 = 0$

CONCLUSION

In this paper, we have presented first, the classical method using a set of low frequency concepts, generally employed to perform the stability analysis of recursive structures. Then, the use of the NDF method has been discussed for the same first-order case and verified with the stability analysis of a second-order recursive filter of the same type. This have then lead to a very simple solution for the NDF expression, thus avoiding the use of classical microwave CAD software for the analysis of these particular filters. Besides, all the properties of the NDF function presented in [1] have been easily verified, thanks to the periodic response of recursive structures and, more generally, to the ease in obtaining analytical solutions with our approach.

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