COMPUTER-SIMULATED DESIGN OF AN ACTIVE MICROWAVE ALLPASS NETWORK

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ABSTRACT

A new microwave active allpass network is proposed. In a computer simulation, it is shown that the network, even with markedly non-ideal transistors, can provide a true allpass response over 8 - 12 GHz.

Introduction

Microwave filters are most commonly implemented as passive networks of waveguide and transmission-line elements. Active network components have rarely been used in microwave filters, although active filters have enjoyed great popularity in systems at frequencies up to a few megahertz. One reason for this situation is that low-frequency active filters use inexpensive operational amplifiers or transistors whose imperfections can be assumed, for most purposes, to be negligible. At microwave frequencies, however, only bipolar and field-effect transistors are available as gain elements, and these devices can hardly be assumed to be ideal above 1 GHz. Nevertheless, it is clear that microwave active filters would be most desirable as system components for the following important reason: Microwave active filters would most likely be implemented as networks of high performance GaAs FET's and lumped and/or distributed circuit elements. In the form of microwave integrated circuits, such filters would be much smaller and lighter than their conventional passive counterparts. Size is obviously an important consideration in the design of modern aircraft and satellite systems, for example.

Over the past twenty-five years, a wealth of knowledge has become available about low-frequency active filters. It would be most useful if this information could be adapted for use at microwave frequencies. This paper is concerned with a special case of adapting a low-frequency, active-filter design to the microwave region. Specifically, we consider an FET filter whose response with ideal elements is that of a second-degree allpass network with a center frequency of 10 GHz. In a computer simulation, we let the FET's have scattering parameters equal to those specified by the manufacturer for an NEC 388 GaAs FET. This causes the network response to substantially deviate from that of an ideal allpass. We then show that it is possible to optimally adjust the other circuit elements so that the network provides the desired allpass response from 8 to 12 GHz. The components in the optimized network are of values which are readily realizable with current MIC technology. (See [1] and [2] for examples of typical, realizable MIC component values.)

The Ideal Circuit

The active allpass network that we propose is shown in Fig. 1. It is basically an FET version of a network using bipolar transistors described by Orchard[3] and Calfee[4].

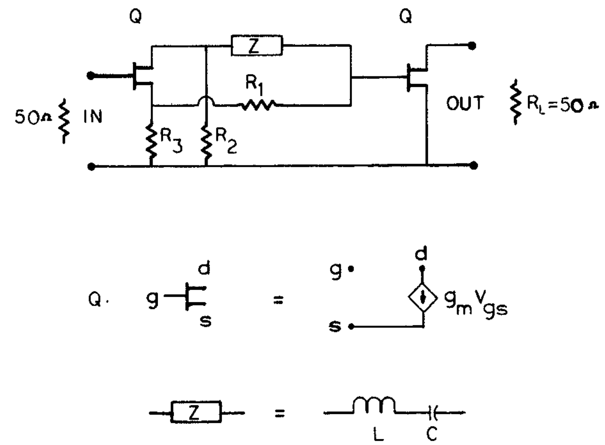

Figure 1: Active Allpass Network (Bias Circuitry Omitted)

For our network, S_{21} is given by

$$S_{21}=-\left[\frac{2g_m^2R_3R_L}{1+g_mR_3}\right]\cdot\left[\frac{Z-R_1R_2/R_3}{Z+R_1+(R_1+R_2)/(1+g_mR_3)}\right] \quad (1)$$

With Z as a series connection of an inductor L and a capacitor C, the second bracketed factor in (1) becomes

$$\frac{s^2-(1/L)(R_1R_2/R_3)s+1/(LC)}{s^2+(1/L)[R_1+(R_2+R_3)/(1+g_mR_3)]s+1/(LC)} \quad (2)$$

Hence the condition for an allpass response is

$$R_1R_2/R_3 = R_1 + (R_2+R_3)/(1+g_mR_3) \ .$$

Comparing (1) and (2) to the following general form of an allpass transfer function

$$T(s)=Ke(-s)/e(s), \quad e(s)=s^2+(\omega_o/q)+\omega_o^2 ,$$

we obtain

$$K=-2g_m^2R_3R_4/(1+g_mR_3)$$

$$\omega_o=1/\sqrt{LC}$$

and $$q=[R_3/(R_1R_2)]\sqrt{(L/C)} \ .$$

A higher-degree allpass network could be obtained, of course, by using a higher-degree lossless impedance for Z of Fig. 1. However, it is better practice to realize an active allpass network as a tandem connection of second-degree, ideally non-interacting sections, as such an arrangement usually reduces the sensitivity of the network to component tolerances.

In the next section, we shall consider two special sets of element values for the ideal, second-degree allpass network of Fig. 1. These values are as follows:

(Case 1) $K=-1$, $f_o=10$ GHz, $q=1$;
$R_1=50$, $R_2=150$, $R_3=50$ ohms;
$C=0.106$ pF, $L=2.387$ nH;
$g_m= 20$ mmhos.

(Case 2) $K=-3$, $f_o=10$ GHz, $q=3$;
$R_1=16.7$, $R_2=50$, $R_3=16.7$ ohms;
$C=0.106$ pF, $L=2.387$ nH;
$g_m= 60$ mmhos.

The Optimization

Using the computer program COMPACT[5], we first determined the effect of substituting NEC 388 GaAs FET's for the ideal transistors in the network of Fig. 1. (COMPACT has a library of tabulated, manufacturer-specified, S-parameters for microwave transistors.) In both cases 1 and 2 above, this substitution caused the network response to deviate greatly from that of an ideal allpass. These results are shown on the next page in Figs. 2 and 3. Using COMPACT, we then attempted to vary the passive elements of our network to achieve a flat magnitude response and the required allpass phase response. In case 1, we were able to restore the network to the desired allpass response over 8-12 GHz. In this frequency range, the magnitude and phase deviation from an ideal allpass response was less than 0.6 dB and 1.5 deg, respectively, as illustrated in Fig. 4. The resulting element values were found to be: $R_1=64.06$, $R_2=170.88$, $R_3=38.69$ ohms; $C=0.169$ pF; $L=3.433$ nH.

For case 2, in addition to optimizing the passive element values, it was necessary to replace each FET in our network with the composite transistor of Fig. 5 below in order to restore the network to an allpass response from 8.25 to 11.25 GHz.

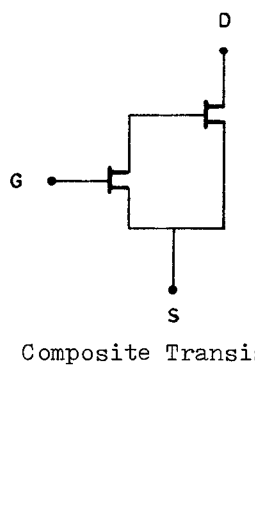

Figure 5: Composite Transistor

Over this frequency range, the deviation from allpass was then less than 1.5 dB and 5.2 deg, respectively, as illustrated in Fig. 6. The corresponding optimized element values were found to be: $R_1=30.89$, $R_2=49.52$, $R_3=11.05$ ohms; $C=0.106$ pF; $L=2.58$ nH.

Conclusions

It has been shown that a low-frequency, active-filter design can be adapted for use in the microwave region. Over a finite frequency range, it has been demonstrated that the passive component values of an active allpass network can be optimally adjusted to compensate for the distortion in the frequency response introduced by the use of non-ideal microwave transistors. The success of this procedure raises significant hope that more of the well-established techniques of low-frequency, active-filter design can be effectively utilized at microwave frequencies.

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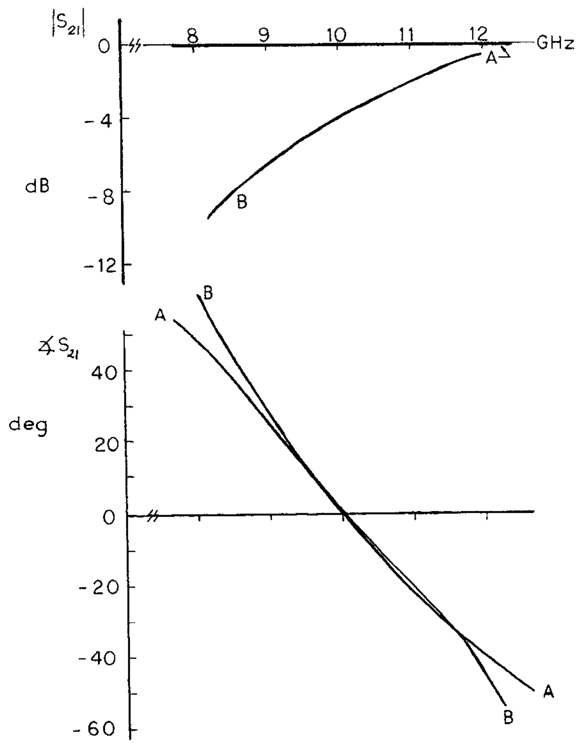

Figure 2: Comparison of Allpass Response with (A) Ideal Transistors and (B) NEC 388's, Case 1. (B is normalized to zero phase shift at 10 GHz.)

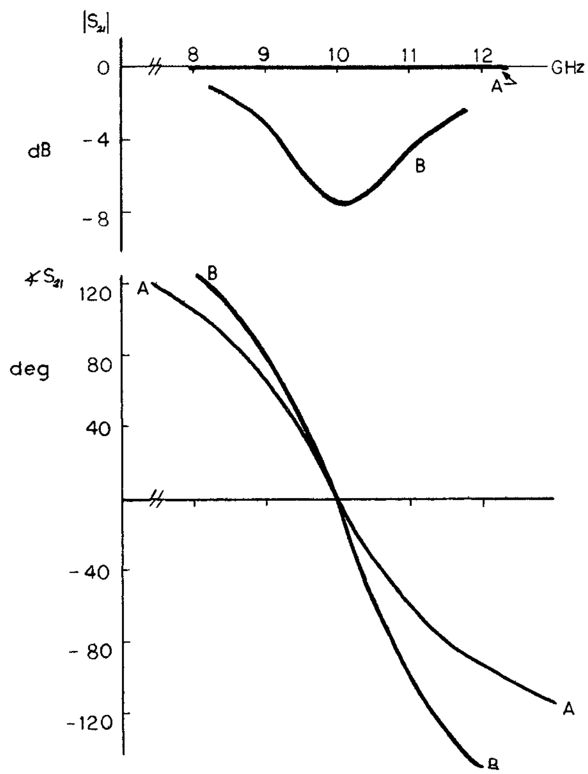

Figure 3: Comparison of Allpass Response with (A) Ideal Transistors and (B) NEC 388's, Case 2. (A is scaled to 0 dB gain; B is normalized to zero phase shift at 10 GHz.)

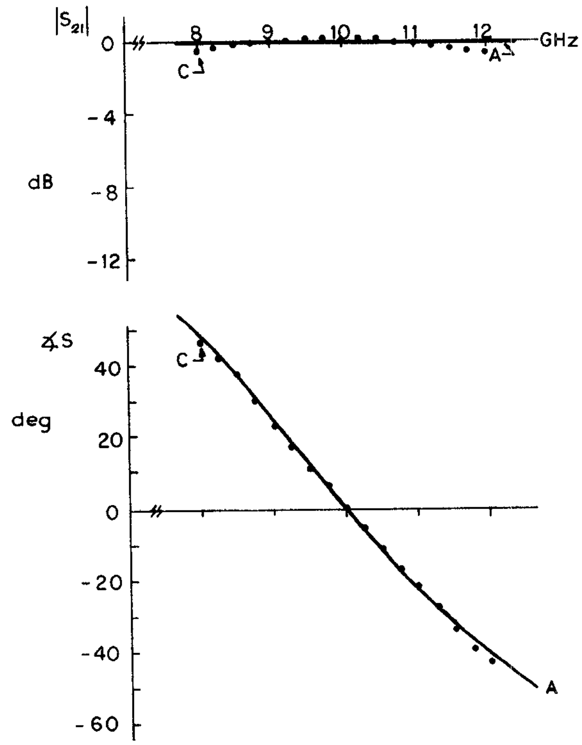

Figure 4: Comparison of (A) Ideal and (C) Optimized Allpass Response, Case 1. (C is normalized to zero phase shift at 10 GHz.)

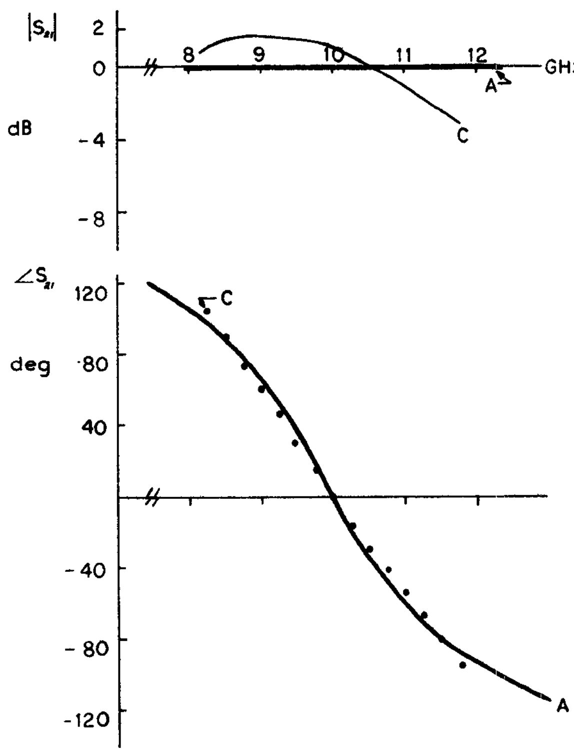

Figure 6: Comparison of (A) Ideal and (C) Optimized Allpass Response, Case 2. (A is scaled to 0 dB gain; C is normalized to zero phase shift at 10 GHz.)