ODD ORDER IMPEDANCE MATCHING NETWORKS FOR LOW COST MICROWAVE INTEGRATED CIRCUITS*

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ABSTRACT

A new odd order impedance matching network with reduced sensitivity to active device capacitance variations is presented. A synthesis procedure for these networks is presented and experimentally verified with the construction of a microwave amplifier. These networks are useful in the development of low cost microwave integrated circuits since they reduce the harmful effects of device variations.

Introduction

In this paper a general analytic method is presented that extends network synthesis to include both even and odd order low-pass impedance matching filters. Previous network synthesis procedures for impedance matching filters were based on the use of even order filter structures. These odd order networks are important since they are relatively insensitive to variations in the capacity associated with a load impedance lower than the generator impedance. The insensitivity of these networks to capacitance variations can minimize or eliminate the costly tweaking of circuits caused by variations in the active devices. Two classes of polynomials are presented so that both broad-and narrow-band circuits may be designed.

Discussion

The development of even order matching filters [1] has proved very useful in amplifier design. It will be shown in this paper that odd order filters are unique in that they provide an insensitive circuit element instead of broadening the bandwidth of the impedance match.

The design procedure is based upon consideration of the fundamental relationship

$$|S_{11}(\omega)|^2 + |S_{21}(\omega)|^2 = 1, \tag{1}$$

with

$$S_{11}(p) = \frac{D(p)}{H(p)}, \tag{2}$$

$$S_{21}(p) = \frac{1}{\sqrt{\varepsilon}\, H(p)}, \tag{3}$$

and

$$\varepsilon = \frac{(R_g - R_\ell)^2}{4 R_g R_\ell} \tag{4}$$

where $p = \sigma + j\omega$. The terms R_g and R_ℓ are the generator and load resistances, respectively. The characteristic function, D(p) may be defined by

$$D(p) = (1 + bp) M(p^2), \tag{5}$$

where the parameter b is proportional to the square of the parasitic capacity associated with the device to be matched. This parameter is set to zero for even order networks. The even polynomial, $M(p^2)$, may be defined according to the transformation presented in [1] for broad-band matching, or it may use the coefficients of the binomial expansion for narrow-band matching. During synthesis, the polynomial $M(p^2)$ determines the bandwidth and ripple of the impedance match, and approximate formulas for b in terms of the load capacity may be derived which thus define $S_{21}(p)$. Once $S_{21}(p)$ is defined, the derivation of a network is straightforward.

Theoretical Results

The relative insensitivity of the odd order low pass matching filters to variations in a shunt capacitor on the low impedance side of the filter may be demonstrated both analytically and experimentally. For the analytic case, the circuit of Fig. 1a was designed from a Cebysev prototype with b=1 and a fractional bandwidth of 31%. The VSWR plots in Fig. 1b were then obtained from the input of the filter as the capacitor on the low impedance side was varied ±50%. Fig. 2a shows an even order (n=4) Cebysev matching filter with the same parameters as the circuit in Fig. 1a except that b=0. By comparing Figs. 1b and 2b one may see that the synthesized filters give nearly identical response (solid curves), but that the ±50% variations in the component nearest the load causes much greater variations in the VSWR of the even order filter. For example, the midband VSWR is designed as 1.1, but reaches 1.67±.08 under variations in the even order filter while only becoming 1.34±.05 under variations in the odd order filter. The odd order matching filter thus uses the additional element for insensitivity instead of bandwidth.

Experimental Results

An amplifier using a Motorala MRF 901 bipolar transistor has been designed using a fifth order Cebysev matching network for the input circuit, and the lossy gain equalization circuit described in [2] for the output circuit. Fig. 3a shows the amplifier designed for operation from 650 MHz to 900 MHz at a bias current of 5 mA and 5v V_{CE}. The parameters of the input circuit design were b=3, R_ℓ = 13 ohms, f_o = 800 MHz and A = .3115. This circuit design produced a theoretical and experimental gain of 15.9±.8 db from 650 to 900 MHz.

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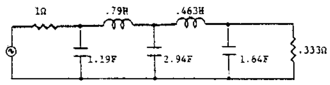

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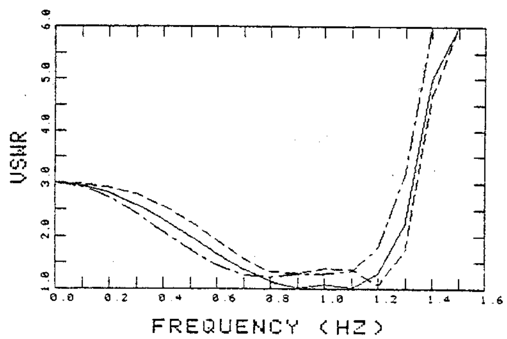
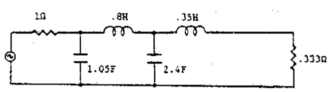


(b)

Fig. 1 (a) Odd order (n=5) Cebysev low-pass matching filter with a bandwidth parameter, A, of .31.

(b) The input VSWR of this network as the 1.64F capacitor, C_5, is varied ±50%. The solid dashed and alternating lines are for C_s = 1.64F, 2.46F and .82F respectively.



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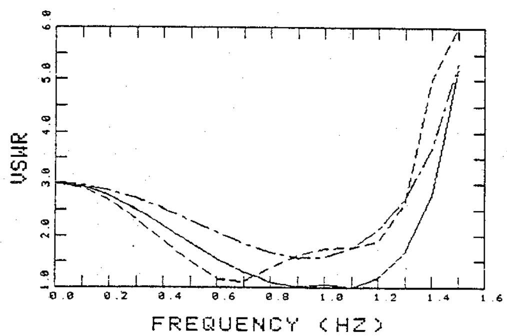
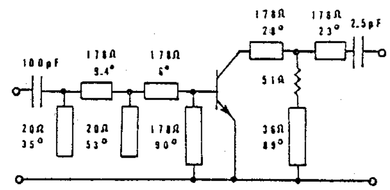


(b)

Fig. 2 (a) Even order (n=4) Cebysev low-pass matching filter with a bandwidth parameter, A, of .31. This is the filter of Fig. 1(a) with b=0.

(b) The input VSWR of this network as the .35H inductor, L_4, is varied ±50%. The solid, dashed and alternating lines are for L_4=.35H, .525H and .175H respectively.

The insensitivity of the odd order matching network to changes in the device's input capacity is illustrated in Figs. 3b,c which compares the odd order matching network with an ideal transformer. Fig. 3b shows the VSWR of the amplifier with an odd order matching network in theory and experiment as well as with an ideal transformer of 1.58:1 turns ratio. The curves are represented by solid, dashed and alternating lines, respectively. While Fig. 3b shows reasonable VSWR response in all cases, it is Fig. 3c which shows the need for odd order matching filters. Fig. 3c shows the change in VSWR when a 5 pF capacitor, giving approximately 30% more input capacity, is placed in parallel with the transistor's base-emitter junction. The change in VSWR for the ideal transformer matched amplifier is obviously greater, and thus more sensitive, than the changes in both the theoretical and experimental odd order matching filter. This is because the shunt capacitor on the low impedance side of the filter does not contribute to the impedance increase needed for matching.



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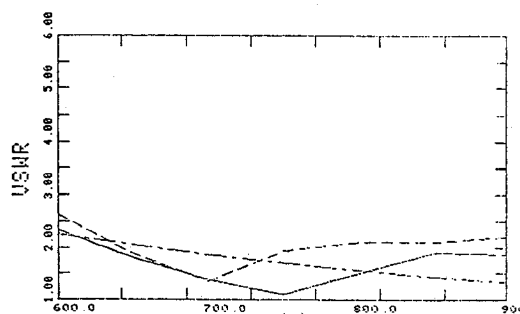

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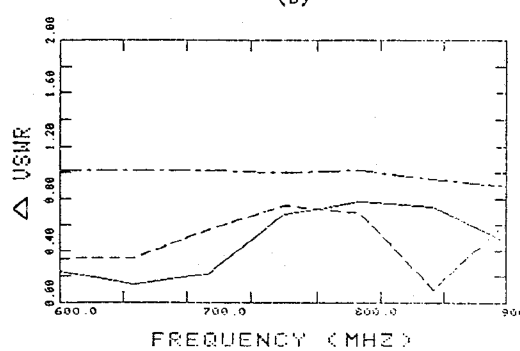

(c)

Fig. 3 (a) MRF-901 amplifier with distributed fifth order matching filter. Note the 100 pF blocking capacitor and 90° long transmission line are for the bias network only.

(b) VSWR of MRF-901 amplifier in theory (solid line), experiment (dashed line) and when the input network is replaced by a 1.58:1 ideal transformer (alternating line).

(c) Change in VSWR of MRF-901 amplifier as a 5 pF capacitor is placed across its base-emitter junction. Same line equivalences as in (b).

These networks can also be used to improve the insensitivity of broadband F.E.T. feedback amplifiers. Such an amplifier was designed using an Avantek AT-8111 F.E.T. chip biased at approximately 35 mA and 4v V_{DS}. The circuit shown in Fig. 4a produces 5±.3 db gain from 1 to 10 GHz and an input VSWR shown by the solid curve in Fig. 4b. The dashed, alternating and double alternating curves in Fig. 4b represent variations of the circuit in Fig. 4a with no matching network, a Smith chart matching network design, and a fifth order Cebysev matching filter; respectively. Note how the circuit exhibits a rising VSWR versus frequency with no matching network (dashed curve), and a VSWR which goes to 1:1 and then rises sharply above 8.2 GHz for the tuned characteristics of the Smith chart matching network (alternating curve). The analytic matching networks of third and fifth order both exhibit smooth VSWR curves oscillating around 1.5:1 and never exceeding 1.82:1. The capacitor in the matching network nearest the device is actually the intrinsic device capacity, and thus is accounted for in the design but not present in the circuit layout. The Smith chart design method inherently accounts for the device input capacity, and so forms an odd order matching network albeit of nonoptimal design. The curves of Fig. 4c show the change in VSWR of each circuit when the F.E.T. input capacitance is raised by 30% (.195 pF). Note how the circuit with no matching network exhibits a rising change in VSWR versus frequency, while all the odd order matching networks exhibit a very low change in VSWR up to some break frequency. Thus, these matching networks trade insensitivity at most frequencies for an increased sensitivity at very high frequencies. The Smith chart matching netwrok (alternating curve) has the lowest break frequency and highest sensitivity at 10 GHz as shown in Fig. 4c, and so is not the optimal matching network. The fifth order network (double alternating curve) shows a very low VSWR change up to 9 GHz which makes it the optimum network for increases in capacity. The poor performance of the fifth order network for reductions in capacity may make this network less than optimum in some situations. The analytically designed third order network gives an overall improvement over the Smith chart matching network, and no matching network in all capacitance variations. Thus, this method of analytic matching network design is shown to yield improved and relatively insensitive circuit designs.

Conclusion

In conclusion, the theory of low pass matching filters is extended to include odd order networks. The analytic theory presented here should be of particular use in designing internal matching networks for bipolar transistors and F.E.T.'s. These odd order networks offer reduced sensitivity to parasitic capacity variations in active devices, thus potentially reducing the cost of monolithic circuits by eliminating tuning.

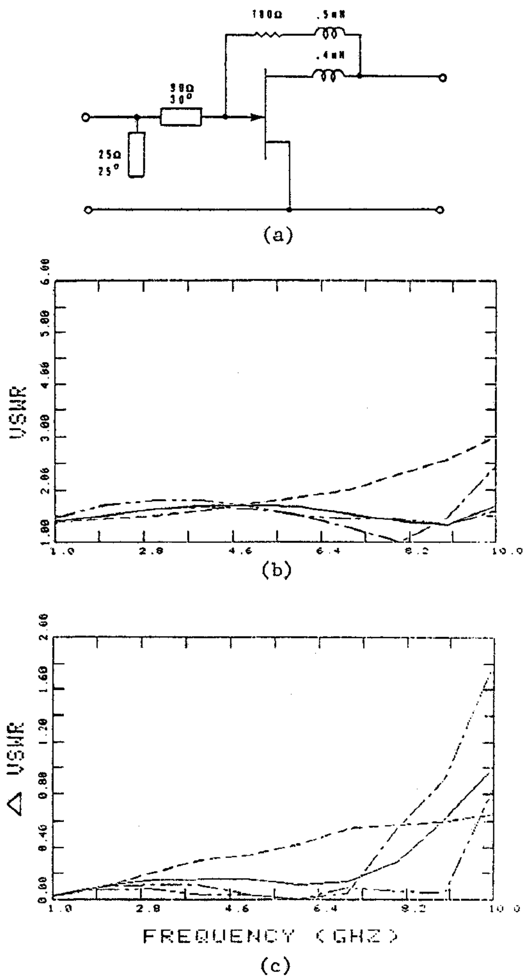

Fig. 4 (a) Avantek AT-8111 broad-band F.E.T. amplifier with a distributed third order matching filter.
(b) VSWR of AT-8111 amplifier for input networks consisting of third order matching filter (solid line), no matching network (dashed line), Smith chart designed matching network (alternating line), and fifth order matching filter (double alternating line).
(c) Change in VSWR of AT-8111 amplifier as a .195 pF capacitor is placed across its gate-source leads. Same line equivalences as in (b).

References

[1] G. L. Matthaei, "Tables of Chebysev Impedance-Transforming Networks of Low-Pass Filter Form," Proc. IEEE, vol. 52, pp. 939-963, August 1964.

[2] A. N. Riddle and R. J. Trew, "A Broad-Band Amplifier Output Network Design," IEEE Trans. Microwave Theory Tech., vol. MTT-30, pp. 192-196, Feb. 1982.

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