IMPROVED HAIRPIN-LINE FILTERS

Ulrich H. Gysel*
Stanford Research Institute
Menlo Park, California 94025

ABSTRACT

A new theory is presented for hairpin-line and hybrid hairpin-line/half-wave parallel-coupled-line filters that leads to a better physical understanding of the filter response. Improved performance is obtained. In particular, the bandwidth can be controlled closely. Results are compared with previous designs.

INTRODUCTION

The hairpin-line filter of Types A and B (see Fig. 1) are both basically a folded version of the half-wave parallel-coupled-line filter. They make more compact filters, but otherwise behave much like the latter. Recently, Cristal and Frankel[1] gave design equations for Type A filters. These designs, while giving satisfactory practical results, leave some theoretical questions unsolved. Their design theory is based on the assumption of a sparse inductance matrix for the array of coupled lines. But a sparse capacitance matrix would be a much more realistic assumption. In addition the design in Ref. 1 needs an empirically determined bandwidth contraction factor depending on the hairpin resonator coupling.

This paper presents a new design theory for odd-order filters that (a) is based on the capacitance matrix of the array of coupled lines constituting the filter and (b) gives the exact bandwidth in all practical cases. It explains the bandwidth contraction described in Ref. 1 and shows that it is independent of the order of the filter, or the passband ripple, and to a large extent of the bandwidth. Beside treating all-hairpin-line realizations, accurate design information is given on how to build a large variety of hybrid hairpin-line/half-wave parallel-coupled-line filters of odd as well as even order filters.

BASIC CONSIDERATIONS

The new design is based on the general n-wire line, as discussed by Matsumoto.[2] An n-port network is created by looking into the n-ports at the input end of an n-wire line that is terminated in an ideal transformer bank at the output. Another transformer bank at the input of the n-wire line transforms the n-port into an m-port. The two transformer banks are determined in such a way as to make a hairpin-line filter out of the n-wire line. The equivalent circuit of the m-port is developed. It is shown in Figure 2a for a Type A filter. Neglecting the small coupling elements that extend beyond adjacent nodes (which is the only approximation used in the whole design) a simplified circuit, shown in Figure 2b, is developed.

Networks containing unit elements, cannot be frequency scaled in general in the prototype frequency variable $s = j \tan \theta$. However, a cascade connection of two unit elements scaled in frequency can be realized as a microwave C-section, which introduces coupling between two formerly uncoupled lines. The same process leads from half-wave parallel-coupled-line filters to hairpin-line filters. It can be shown that frequency-scaling of any odd-order half-wave parallel-coupled-line filter results in a hairpin-line filter. The equivalent circuit for a half-wave parallel-coupled-line filter of Type A and of odd-order, i.e., with an even number of unit elements, is shown in Figure 3. First an elastance matrix transformation is performed in such a way as to produce pairs of cascaded unit elements with no series capacitors between them. Then the circuit is frequency-scaled by α, where $s' = \alpha s$ and s and s' are the frequency variables of the unscaled and scaled prototype networks, respectively. Now, the scaled circuit can be related to that of Figure 2b. This circuit leads immediately back to the capacitance matrix of the n-wire line network that makes the hairpin-line filter.

The coupling between those lines constituting a hairpin resonator that are folded on the output end of the original n-wire line is directly controlled by the frequency scale factor α. It is necessary that $\alpha \geq 1$ to guarantee realizability of the n-wire line. In most cases $\alpha = 1.1$ to 1.2 is adequate (this corresponds to 20 to 15 dB coupling). The coupling between the other hairpin resonators, i.e., those folded on the input end of the n-wire line, can be varied independently. In particular, it can be made zero, which results in a number of hybrid forms. In practice the few design steps are easily programmed on a small digital computer. Design equations for half-wave parallel-coupled-line filters[3] or extensive tables[4] are readily available.

The design for Type B hairpin-line filters follows in a similar way, the only changes necessary are those for the input and output of the filter.

NUMERICAL AND EXPERIMENTAL RESULTS

The validity of the new design theory was checked by a number of trial designs, based on an exact equivalent circuit. The numerical results for four different designs, all of order 5, ripple 0.1 dB and fractional bandwidth $w = 0.2$ are shown in Figure 4. The design (a) has no hairpin coupling between those resonators folded on the input side of the n-wire line. This

* The author is a Postdoctoral Fellow at SRI, with a grant from the Swiss National Science Foundation.

can be shown to be an exact design. All other designs show only minor deviations except case (c) which has an α too large for the particular bandwidth shown. Below $w = 0.10$ all designs checked were virtually exact for any reasonable value of α. Note that the bandwidth was correctly predicted in every case.

A practical stripline version was built and tested as shown in Figure 5. It is a hybrid filter with five resonators, $w = 0.05$, $\alpha = 1.1$, 0.1 dB ripple and a center-frequency of 1.5 GHz. The measured results, shown in Figure 6, are in very close agreement with theory, particularly the bandwidth, which was $w = 0.049$ between points of 16.5 dB return loss (VSWR = 1.36).

CONCLUSIONS

New and better design equations for hairpin-line and hybrid hairpin-line/half-wave parallel-coupled-line filters have been derived. The new design theory gives a better understanding of the process that leads to the bandwidth contraction as the resonators of a half-wave parallel-coupled-line filter are folded to form hairpin resonators. This process is accomplished by a frequency scaling of the filter response such that a smaller passband results. (Frequency scaling of any filter is independent of passband ripple, order of filter and fractional bandwidth.) Comparing the new results with those given by Cristal and Frankel[1] shows an improved passband VSWR for comparable designs, beside the precisely maintained bandwidth.

REFERENCES

1. E.G. Cristal and S. Frankel, "Hairpin-Line and Hybrid Hairpin-Line/Half-Wave Parallel-Coupled-Line Filters," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-20, pp. 719-729 (November 1972).

2. A.Matsumoto, Editor, "Microwave Filters and Circuits," Supplement 1 to Advances in Microwaves, Academic Press, New York and London (1970).

3. E.G. Cristal, "New Design Equations for a Class of Microwave Filters," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-19, pp. 486-490 (May 1971).

4. R.J. Wenzel and M.C. Horton, "Exact Design Techniques for Microwave Filters," Bendix Research Lab, Southfield, Mich., Final Report, Contract DA28-043-AMC-00399(e) (February 1-April 30, 1965).

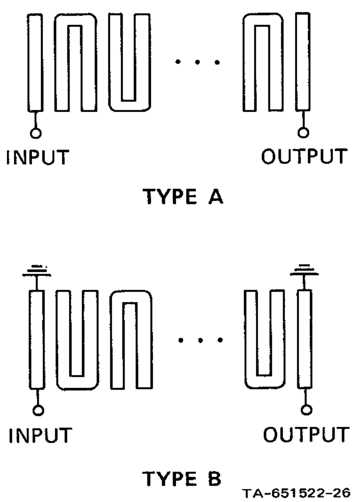

FIG. 1 HAIRPIN-LINE FILTERS

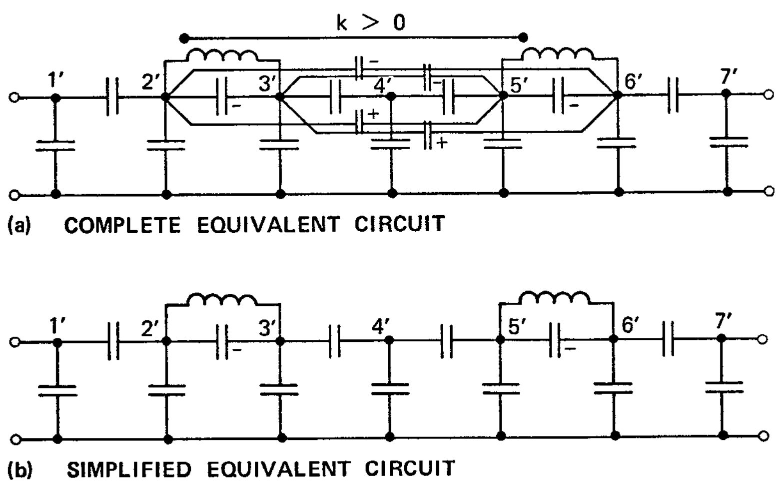

FIG. 2 EQUIVALENT CIRCUITS FOR HAIRPIN-LINE FILTERS

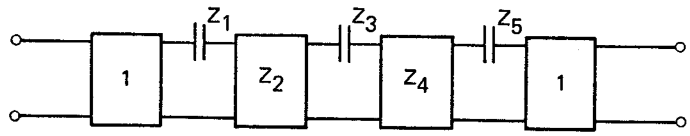

FIG. 3 EQUIVALENT CIRCUIT FOR HALF-WAVE PARALLEL-COUPLED-LINE FILTER (THIRD ORDER WITH AUGMENTED UNIT ELEMENTS AT THE INPUT AND OUTPUT)

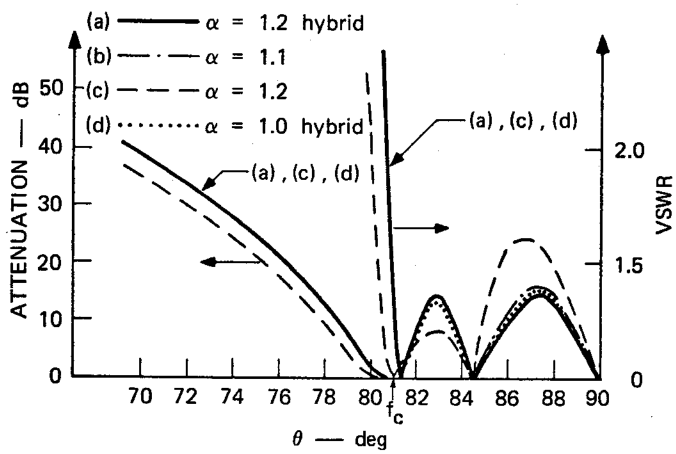

FIG. 4 COMPUTED RESPONSE FOR HAIRPIN-LINE FILTERS TYPE A USING EXACT EQUIVALENT CIRCUITS (FIFTH ORDER FILTER, w = 0.2)

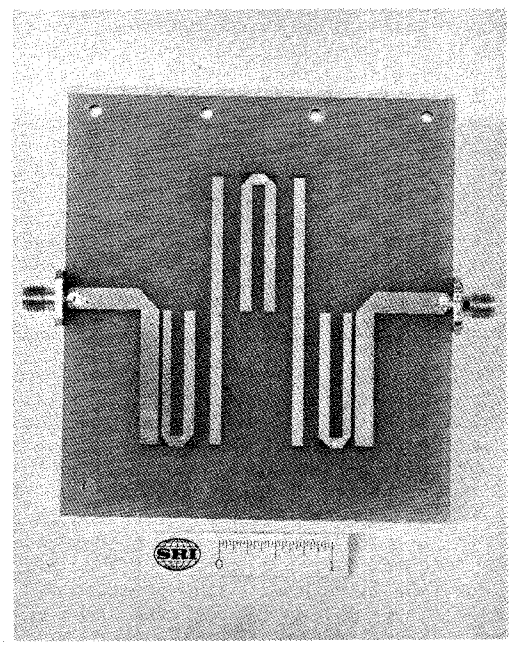

FIG. 5 HYBRID HAIRPIN-LINE/HALF-WAVE PARALLEL-COUPLED-LINE FILTER ($w = 0.05$, $f_o = 1.5$ GHz)

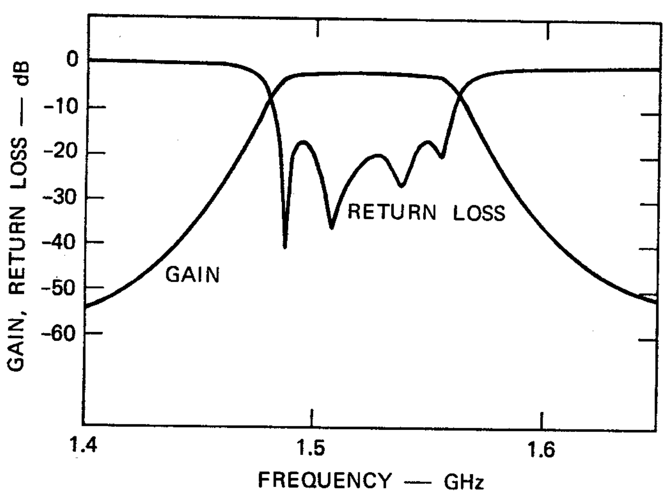

FIG. 6 MEASURED RETURN LOSS AND ATTENUATION FOR TRIAL HYBRID FILTER OF FIG. 5