LOGARITHMIC-PERIODIC CONTIGUOUS-CHANNEL MICROWAVE MULTIPLEXERS

Christen Rauscher

Naval Research Laboratory
Washington, DC 20375-5000

Abstract — The issue pursued in this study is the applicability of logarithmic-periodic principles to the design of microwave multi-port networks. It is demonstrated, in particular, how such principles can be put to use in solving microwave multiplexing problems. Practicability of the approach is illustrated with the help of two five-channel contiguous-band multiplexer designs and an experimental realization of one of these circuits covering most of C- and X-band. The experimental circuit is believed to represent the first successfully implemented and reported logarithmic-periodic microwave multi-port circuit.

INTRODUCTION

The design of microwave multiplexer circuits can present quite a challenge, especially if low transmission losses and high channel selectivities are to be achieved in conjunction with contiguous channel operation. Combined requirements like these inherently translate into significant interdependences among individual frequency-selective segments of the multiplexer, which may result in having to account for an unconveniently large number of circuit variables simultaneously. Part of the challenge is hence to seek a systematic procedure that allows the dimensionality of the problem to be contained without compromising multiplexer performance.

The approach pursued here centers on logarithmic periodicity. The underlying concept is one developed some thirty years ago for the purpose of realizing ultra-wideband antennae. A logarithmic-periodic structure, theoretically, is made up of an infinite cascade of topologically identical segments, with determining parameters of one segment related to those of the next through an invariant scaling factor. This feature gives rise to associated performance characteristics that—when recorded as a function of the frequency logarithm—exhibit periodically varying excursions from their nominal target responses. Through appropriate design measures, the periodic excursions typically can be made quite small, thus permitting nearly-frequency-independent behavior over extremely wide frequency ranges.

The idea to adopt logarithmic-periodic principles in the design of microwave multiplexer circuits stems from the anticipation of attractive benefits to be derived through such an approach, and from the observed functional relationship between a multiplexer and its suggested antenna counterpart. Both the multiplexer and the logarithmic-periodic antenna each involve an assembly of stagger-tuned frequency-selective subelements which communicate with a common port. The similarity becomes particularly evident when multiplexers with contiguous channels of equal fractional bandwidth are considered, as their individual channel responses invariably conform to a logarithmic-periodic pattern. The application of logarithmic-periodic principles to the multiplexer design then suggests not only the potential for covering very wide frequency ranges; it also suggests the possibility of defining an entire multiplexer circuit with an arbitrary number of channels by merely having to specify the parameters describing one of the channel subcircuits. Theoretically, the only other parameter required is an appropriate value for the logarithmic-periodic scaling factor. The approach thus provides an unusually efficient and elegant means for minimizing the number of design variables.

Despite the plausibility of the proposed concept, the open literature appears to contain no references to successful implementations of the approach. This is astonishing, considering how long the basic principles have been around. The only major reference on the topic of logarithmic-periodic circuits is a paper by DuHamel and Armstrong [1], dealing primarily with one-port situations. There exist rather few practical applications for logarithmic-periodic one-port networks, though, as problems of interest tend to fall almost exclusively into the domain of multi-port circuits. The fact that no successfully implemented logarithmic-periodic multi-port circuits of any kind—not just multiplexer circuits—seem to have been reported until now, gives rise to the suspicion that the procedures involved might not be as straightforward as anticipated. The following sections will demonstrate that multiplexers based on logarithmic-periodic principles are practicable, nevertheless, exhibiting all the desirable features expected of them.

MULTIPLEXER DESIGN CONCEPT

A logarithmic-periodic multiplexer circuit, in its pure form, encompasses an infinite cascade of systematically scaled three-port network segments, with each of these associated with a different real or fictitious multiplexer channel.

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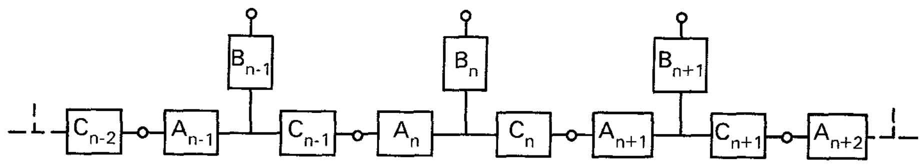

Fig. 1 — Block diagram of a cascade connection of logarithmic-periodically scaled three-section multiplexer segments.

This is illustrated in Fig. 1, where the segments have been further decomposed into two-port sections A_i, B_i, and C_i, $i = \ldots, n-1, n, n+1, \ldots$, for the purposes of the current discussion. The B-sections represent channelizing filters, whose main responsibility is to define the individual channel responses. The other sections share in this responsibility, but are primarily tasked with signal distribution and impedance transformation. True to logarithmic-periodic principles, the circuit parameter values and characteristic frequencies defining a particular composite segment are rigidly linked to the corresponding quantities of a neighboring segment through the logarithmic-periodic scaling factor. For contiguous-band multiplexers, this factor is equal to unity plus the specified fractional channel bandwidth.

The input-signal to the multiplexer is always introduced in a manner that allows the signal to propagate in the direction of segments with decreasing characteristic frequencies. If the multiplexer is implemented with the help of distributed circuit elements, the input port becomes geometrically defined by the apex of the structure on which the segments converge as the channel frequencies increase. From the input port, the signal is guided, in effect, by a nonuniform, reactively loaded transmission line, defined by the cascade of highest-frequency segments with resistively terminated channelizing filters all operating below cut-off. The signal propagates along this line until it reaches the filter whose passband encompasses the frequency of the signal. At that point it gets channeled off, assisted by the predominantly reactive properties of the remaining lower-frequency portion of the structure.

The selection of a suitable type of filter for the channelizing B-sections constitutes probably the most critical design decision. Thinking in terms of a microstrip implementation, an obvious first choice would be the parallel-coupled-line bandpass filter with open-circuited resonator ends. When arranged to form a logarithmic-periodic structure, in conjunction with compatible A- and C-sections, filters of this type appear to possess all the essential attributes. Foremost, they exhibit capacitive driving point impedances at frequencies below their respective passbands. An incident signal entering at the apex of the multiplexer structure will hence encounter a capacitively loaded transmission line to guide it. This is analogous to the manner in which a logarithmic-periodic antenna operates and represents a prerequisite for realizing wideband performance. The filters also perform at frequencies above their passbands in a manner consistent with the application.

Although the outlined approach sounds appealing, the suggested implementation turns out to incorporate a serious flaw. Upon closer consideration, one realizes that the driving point impedance characteristics of the selected parallel-coupled-line filters exhibit shunting series-type resonances in the vicinity of their band edges. The effect of these resonances is to destructively interfere, on a frequency-selective basis, with an incident signal proceeding along the multiplexer structure toward its assigned destination. At least in contiguous-band situations, such behavior proves unacceptable.

The parallel-coupled-line example illustrates how the design of logarithmic-periodic multiplexers is, indeed, not as straightforward as might initially have been assumed. This conclusion is further underlined by the observation that actually the majority of common microstrip-compatible filter structures display troublesome resonance behaviors. Resonances of one kind or another are, of course, a necessity, as they are instrumental in producing sharp filter transition regions. The crucial issue is hence to find a bandpass filter that achieves channel selectivity through driving point impedance poles at the band edges, rather than through nulls.

Fortunately, the capacitively end-coupled strip resonator filter offers just such a possibility. Its only drawback is that it produces a satellite passband in the vicinity of twice the base band center frequency, thus imposing fairly restrictive constraints on frequency range coverage in wideband multiplexer applications. One way around this limitation is to replace the conventional constant-impedance transmission line resonators with dog-bone combinations composed of three shorter transmission line segments that comprise a low-high-low characteristic impedance profile. This arrangement conveniently moves the satellite passband to frequencies around three times the original baseband center frequency. Any remaining conflict may be dealt with by assigning low-pass or quasi-low-pass properties to the associated A- and C-sections within the multiplexer array, thus preventing possible stray components of the incident signal from inadvertently reaching a lower-frequency filter with a commensurate satellite passband.

To physically realize a multiplexer of this type, the logarithmic-periodic structure, which theoretically involves an infinite number of segments, must be bounded in some reasonable fashion. This can be achieved by allowing all segments not directly associated with a designated channel to be represented by appropriately chosen equivalent substitution networks. One of these substitutions concerns the input side of the multiplexer where the converging infinite cascade of dispensable high-frequency segments is replaced by a two-port equivalent lead-in circuit. Using numerical-based approximation and synthesis techniques, the circuit must be designed to mimic the composite characteristics of the deleted portion of the original structure. It is often convenient, thereby, to include in the substitution circuit a continuation of the logarithmic-periodic structure by one or two additional segments, with respective channelizing filters terminated in dummy loads. Likewise, an equivalent one-port circuit must be derived to replace the diverging array of segments beyond the lowest-frequency channel of interest and make it seem, for the core portion of the multiplexer, as if the array extended out toward infinity. Although the accuracies with which the substitution networks describe the deleted sub-arrays is generally not all that critical, deviations from ideality will generate a non-logarithmic-periodic ripple superimposed on the otherwise purely logarithmic-periodic behavior.

MULTIPLEXER EXAMPLES

Based on the outlined approach, a five-channel contiguous-band multiplexer was designed for microstrip implementation on a 0.25-mm-thick fiberglass-reinforced Teflon substrate. The hardware realization of this circuit is shown in Fig. 2. The B-section channelizing filters used in the implementation consist of capacitively end-coupled dog-bone strip resonators. Two such resonators are used in each filter to achieve channel responses with twenty-percent fractional bandwidths and double-tuned passbands. The small coupling capacitors, whose values are relatively critical, were made out of copper-clad 0.125-mm-thick fiberglass-reinforced Teflon. Each C-section comprises a low-pass cascade connection of four transmission line segments and an open-circuited stub. No A-sections are used in this context. The lead-in two-port substitution network is composed of various cascaded transmission lines and stubs, in addition to a two-segment extension of the logarithmic-periodic structure. This extension relies on internal 50-ohm loads to properly terminate the respective bandpass filters. The low-frequency substitution network, on the other hand, was deliberately omitted in order to demonstrate the insensitivity of overall performance characteristics to such an abrupt termination of the array.

The exclusion of transmission line losses in the initial design iteration led to calculated channel responses with average passband attenuations of less than 1 dB, cross-overs at almost exactly the 3 dB-down points, and an input reflection coefficient maximum of .35 over the entire multiplexing frequency range. After realistically accounting for microstrip losses in the multiplexer structure and in the connecting transmission lines, and after recognizing the approximately .3 dB of additional loss introduced by each coaxial-to-microstrip launcher, the net filtering characteristics shown in Fig. 3 were predicted. The combined effects of these loss contributions manifest themselves in somewhat higher passband and shoulder attenuation values, and cross-overs at around 3.5 dB below average passband transmission. Of particular interest is the result of abruptly truncating the logarithmic-periodic structure right after the lowest-frequency-channel segment. The only noticeable influence is

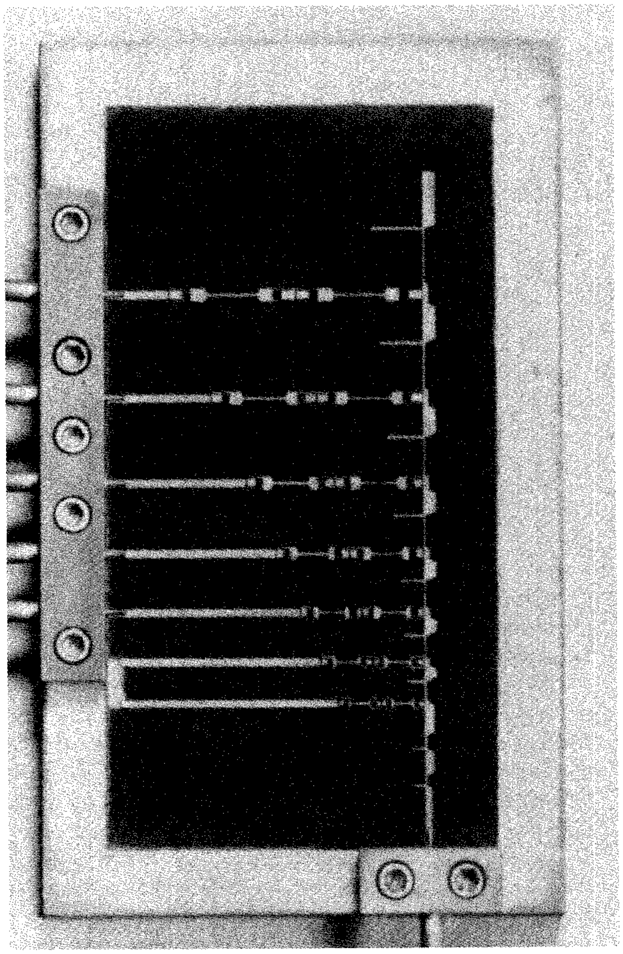

Fig. 2 — Experimental contiguous-band five-channel multiplexer.

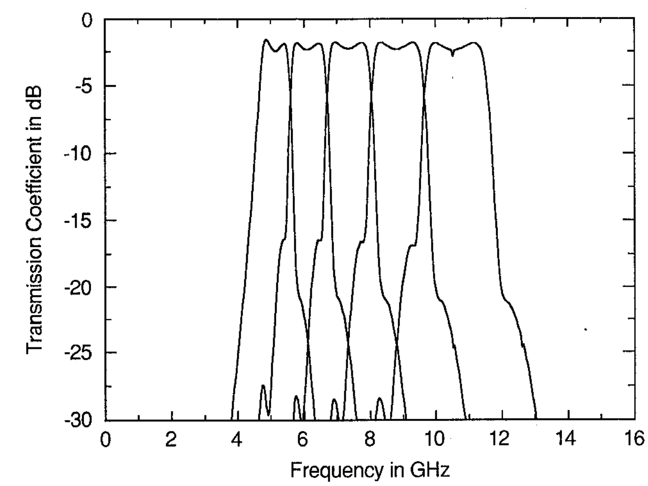

Fig. 3 — Calculated characteristics of the multiplexer example with twenty-percent-fractional-bandwidth channels.

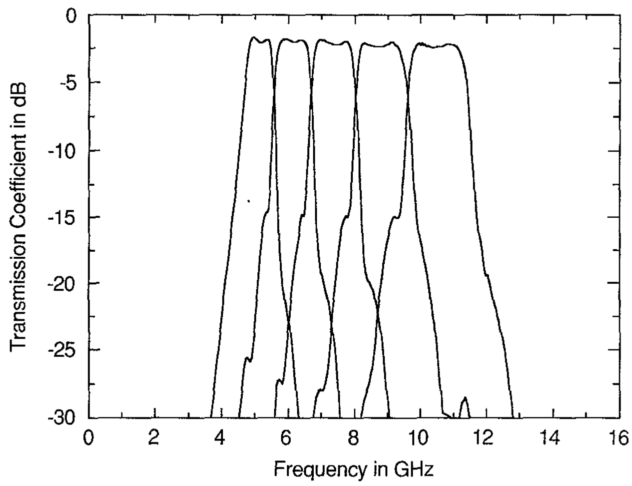

Fig. 4 — Measured performance of the experimental multiplexer circuit.

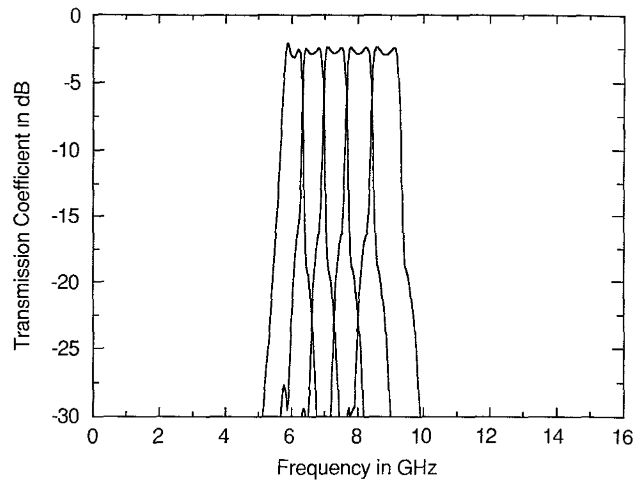

Fig. 5 — Calculated characteristics of a multiplexer with ten-percent-fractional-bandwidth channels.

a slight perturbation of the response of this last channel. The predicted responses of all channels are nicely confirmed by measurements, as illustrated in Fig. 4.

A convenient feature of the selected design is that it can be very easily adapted to accommodate most any desired fractional bandwidth. To demonstrate this feature, the multiplexer was redesigned for ten-percent fractional bandwidths. The calculated results are given in Fig. 5, based on the exact same overall topology and the same loss assumptions used in the wider-band case. Furthermore, all transmission line characteristic impedances remained invariant, without exception. Actually, the entire C-section of the middle-range segment remained invariant, as well. The only parameters to be adjusted were the respective transmission line lengths of all other circuit components, and the filter coupling capacitors.

CONCLUSIONS

The previous examples demonstrate how logarithmic-periodic principles, developed three decades ago for wide-band antenna purposes, can be put to good use in the design of microwave multiplexer circuits. The approach, which is applicable to both contiguous-band and non-contiguous-band situations, distinguishes itself by its ability to cope with almost any number of channels, while requiring only a minimum set of design variables. As confirmed by the examples, the solutions achieved with this technique exhibit excellent physical realizability and can, furthermore, be readily adapted to accommodate specific bandwidth requirements. The described experimental circuit is believed to represent the first successful implementation of a logarithmic-periodic microwave multi-port circuit.

REFERENCE

[1] R. H. DuHamel and M. E. Armstrong, "Log-periodic transmission line circuits—Part I: One-port circuits," IEEE Trans. Microwave Theory Tech., Vol. MTT-14, pp. 264-274, June 1966.