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# NASA TECH BRIEF



## Design of Dissipative Linear Phase Filters

The use of linear phase filters has become rather common over the past few years. Some of their applications include pulse shaping networks, amplifiers with good waveform response and low phase distortion, and amplifiers with Gaussian frequency response.

On the other hand, the design of linear phase filters is a tedious operation, especially when designing to optimize some particular characteristic of the filter, such as insertion loss.

A set of design curves has been constructed for the purpose of eliminating most of the work involved in designing linear phase filters. These curves are normalized in such a way as to apply to low-pass, band-pass, and high-pass filters of any bandwidth. While the curves are for filters with a maximum of four poles, it is possible to plot similar curves for any number "n" of poles by solving a system of "n" simultaneous equations.

The design is maximally flat delay only for low-pass filters. When the frequency variable is transformed from low-pass to band-pass or high-pass some delay distortion is introduced by the transformation. The amount of distortion may be determined from the curves. For narrow band-pass filters the distortion is negligible. For high-pass filters, it is considerable.

One disadvantage of this particular set of design curves is that they do not provide a minimum loss design for low-pass and high-pass filters. This comes about because all internal Q's are assumed to be equal. Therefore, branches which contain only a capacitor must be shunted by a resistance which introduces some loss. This loss, however, in most practical cases is insignificant.

The design of maximally flat and Chebishev type dissipative ladder filter networks by equating the coefficients of the Butterworth and Chebishev polynomials respectively to the coefficients of the transfer impedance polynomial of the network has been described by Dishal. This is accomplished by expressing the coefficients of the transfer impedance of the network in terms of the $(n-1)$ coefficients of coupling between poles and the "n" decrements of the poles. In the usual case, the internal decrements and the bandwidth are known; therefore, the net result is a system of "n" equations with $(n+1)$ unknowns; the $(n-1)$ coefficients of coupling and the first and last decrements. One of these unknowns may be specified arbitrarily, within certain limits, and the others determined from the "n" simultaneous equations that remain. For instance, it may be desirable to choose one of the elements to give a minimum (or any designated amount) of insertion loss. Taub and Bogner have published a similar set of curves for the design of 3-pole Butterworth filters for the condition of minimum insertion loss.

This paper deals primarily with a similar design for the case of 2-, 3-, and 4-pole maximally flat delay ladder networks. The Dishal network coefficients are equated to those of the $n^{th}$ order Bessel polynomial for maximally linear phase. This polynomial has an amplitude frequency characteristic that approaches Gaussian shape and a delay-frequency characteristic that approaches zero as "n" increases indefinitely. Of the $(n+1)$ coefficients required to specify the $n^{th}$ degree polynomial, one is used to adjust the gain and one is used to specify bandwidth, leaving $(n-1)$ coefficients to adjust flatness of delay.

After equating the Dishal coefficients to those of the Bessel polynomial, the resulting equations are normalized to the fractional 3 db bandwidth. Then the normalized end decrements and normalized coefficients

(continued overleaf)

of coupling are plotted using the normalized internal decrements, all equal, as a parameter. The insertion loss curves plotted with the normalized unloaded decrement as a parameter assume, in addition, that all unloaded decrements, including the first and last are equal. The amplitude-frequency and delay-frequency curves are plotted as a function of normalized fractional bandwidth. This set of curves gives a complete solution to any valid design problem within the scope of this type of network.

**Notes:**

1. While the idea presented is not new, the set of curves employed is believed to be the only one of its kind in existence.
2. Documentation for the innovation is available from:

   Clearinghouse for Federal Scientific
   and Technical Information
   Springfield, Virginia 22151
   Price $3.00
   Reference: B68-10572

**Patent status:**

No patent action is contemplated by NASA.

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