PREDISTORTED WAVEGUIDE FILTERS FOR USE IN COMMUNICATIONS SYSTEMS

ROBERT M. LIVINGSTON
COLLINS RADIO COMPANY

Predistortion is a standard technique for correcting the effects of energy dissipation in filters, making their response conform to that of ideal filters. The problem of dissipation is particularly noticeable in narrow-band bandpass filters used in microwave communications systems. Dissipation makes the passband edges slump downward, as shown in Figure 1, which can cause distortion and intermodulation.

In predistorting a filter, we allow for dissipation in the initial design. A response approximating the ideal response can be approximated at the price of increased insertion loss. The flat response of predistorted filters is advantageous when used in high-capacity microwave communications systems; however, the filters have an additional property which makes them especially attractive for certain applications in microwave communications systems.

Consider the diplexing scheme shown in Figure 2, in which several filters tuned to different frequencies are connected to a common transmission line with circulators. This scheme works quite well if there is a wide spacing between the frequencies to be separated. When the frequencies are close together, however, the differential time delay of a signal reflecting off a filter tuned to a nearby frequency will be affected. Frequencies closer to the filter frequency will have more group time delay, as shown in Figure 3. Here, we see the differential group delay of a signal reflected off a 7-cell, 37-MHz bandwidth, maximally-flat filter. The signal is 60 MHz above and below the filter frequency. The differential delay across a 24-MHz bandwidth amounts to 3 nanoseconds, which can cause severe intermodulation distortion and crosstalk on high-capacity communications systems.

NOTES

It has been found that this group delay tilt is inversely proportional to the loaded Q of the end cavity of the filter from which the signal reflects. It happens that predistorted waveguide filters of the type described are asymmetrical with regard to end-cavity Q's. The cavity on one end will be higher in Q and the cavity on the other end lower in Q than that of a conventional, maximally-flat, filter end cavity. By arranging the filter such that the high Q cavity is always next to the circulator, it is possible to reduce the reflected group differential delay to 1 nanosecond, as shown in Figure 4.

This reduced delay tilt is much easier to correct, and the additional advantage of amplitude flatness within the passband makes this type of filter attractive for high-density communications systems.

Predistorted waveguide bandpass filters can be designed using a lowpass prototype filter, just as can conventional Butterworth and Tchebyscheff waveguide filters.

The procedure for designing a bandpass filter is as follows:

1. Calculate or estimate unloaded Q_u of filter resonator.
2. Define $\delta = \frac{f}{Q_u BW}$, where f is the frequency and BW is the 3-db bandwidth.
3. Synthesize the desired lowpass prototype filter, with its poles shifted toward the jw axis by the amount, δ.

For example, suppose we want to design a 5-cell waveguide bandpass filter with the following characteristics:

Response:	Maximally flat
Frequency:	6450 MHz
3-db Bandwidth:	44 MHz

The unloaded Q of the filter cavities can be determined from the insertion loss of an existing filter using the relation given by Cohn[1]:

$$L = 4.343 \frac{w_1'}{W} \sum_{i=1}^{n} \frac{gi}{Qi} \qquad (1)$$

where:

L = insertion loss in db

w_1' = cutoff frequency of lowpass prototype filter

W = fractional bandwidth

Qi = the unloaded Q of the ith cavity

gi = the ith element value of lowpass prototype

Suppose, for instance, we have a 5-cell, conventional, maximally-flat filter which has a 0.762-db insertion loss at 6450 MHz and a 3-db bandwidth of 35 MHz. Then, Q_u, if it is the same for all cavities, $= \frac{4.343 \times 6450}{35 \times 0.762}$ $(0.618 + 1.618 + 2.000 + 1.618 + 0.618) = 6800$.

Then, $\delta = \frac{6450}{6800 \times 44} = 0.0216$.

Now, shift the poles of a 5-element, maximally-flat, lowpass prototype toward the jw axis by an amount, 0.0216, as shown in Figure 5. These poles are now used to synthesize a doubly-terminated LC filter. The lowpass prototype is shown in Figure 6.

Finally, to determine the waveguide filter dimensions, we use the formulas by Cohn[2]:

$$X_{01} = \frac{\sqrt{\frac{\Omega}{g_1}}}{1 - \frac{\Omega}{g_1}} \qquad X_{ij} = \frac{\frac{\Omega}{\sqrt{g_i g_j}}}{1 - \frac{\Omega^2}{g_i g_j}} \qquad X_{56} = \frac{\frac{\Omega}{\sqrt{g_5 g_6'}}}{1 - \frac{\Omega^2}{g_5 g_6'}} \qquad (2)$$

$$\phi j = 180° - \frac{1}{2} [\tan^{-1} (2X_{ij}) + \tan^{-1} (2X_{jk})]$$

where:

$$\Omega = \pi \frac{\lambda g_1 - \lambda g_2}{\lambda g_1 + \lambda g_2} = 0.01930 \qquad \lambda g_1 = \lambda g \text{ @ } 6450 - 22 \text{ MHz}, \quad \lambda g_2 = \lambda g \text{ @ } 6450 + 22 \text{ MHz}$$

g_1	= 1.4940	g_4	= 0.8600		
g_2	= 1.4697	g_5	= 0.5541		
g_3	= 2.4214	g_6	= 1.3622	g_6'	$= \frac{\Omega}{g_6}$

From these equations, we find:

X_{01}	= 0.1151	ϕ_1	= 172.77°
X_{12}	= 0.01303	ϕ_2	= 178.67°
X_{23}	= 0.01023	ϕ_3	= 178.65°
X_{34}	= 0.01338	ϕ_4	= 177.63°
X_{45}	= 0.02798	ϕ_5	= 166.11°
X_{56}	= 0.2287		

Table 1 gives lowpass prototype element values for 5- and 7-element, maximally-flat filters, for different values of δ.

The synthesis procedure used is the conventional, doubly-terminated, LC network theory, as described, for instance, by Guillemin[3].

The predistorted bandpass filters described have the advantages of a more ideal response and of reduced differential group delay of signals reflected off the filter; however, the filters have two disadvantages which have to be considered. First, the filters have a large VSWR in the center of the passband. The flatness of response is achieved only by reflecting power in the passband center, which is not absorbed as much as power toward the passband edges. This means the filter has to be isolated from unmatched sources and loads. A second disadvantage is the high sensitivity of the element values. The filter appears to be more sensitive to incorrect element values than conventional, maximally-flat filters.

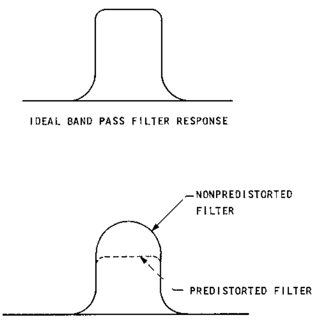
TABLE 1

5-ELEMENT DATA

δ	g_1	g_2	g_3	g_4	g_5	g_6
0 005	1 1745	1 7585	2 0236	1 0878	0 4731	1 1164
0 010	1 2940	1 6574	2 1417	0 9970	0 4950	1 1945
0 015	1 3871	1 5705	2 2605	0 9305	0 5194	1 2675
0 020	1 4691	1 4930	2 3818	0 8758	0 5454	1 3392
0 025	1 5452	1 4223	2 5068	0 8285	0 5728	1 4114
0 030	1 6181	1 3569	2 6366	0 7862	0 6017	1 4849
0 035	1 6892	1 2959	2 7718	0 7478	0 6320	1 5605
0 040	1 7595	1 2385	2 9132	0 7124	0 6640	1 6387
0 045	1 8299	1 1844	3 0616	0 6795	0 6978	1 7199
0 050	1 9008	1 1330	3 2177	0 6486	0 7335	1 8045

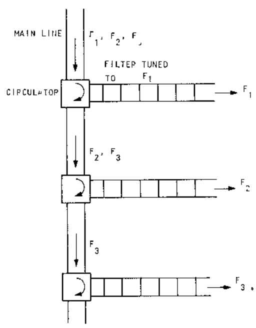
7-ELEMENT DATA

δ	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8
0 005	1 2521	1 6015	2 3313	1 4182	1 5395	0 6741	0 3261	1 1936
0 010	1 4311	1 4647	2 5708	1 2648	1 6783	0 5983	0 3549	1 3219
0 015	1 5765	1 3511	2 8037	1 1510	1 8199	0 5434	0 3846	1 4441
0 020	1 7088	1 2525	3 0409	1 0574	1 9672	0 4989	0 4158	1 5669
0 025	1 8355	1 1648	3 2878	0 9769	2 1223	0 4609	0 4487	1 6935
0 030	1 9604	1 0854	3 5480	0 9057	2 2870	0 4274	0 4838	1 8258
0 035	2 0859	1 0129	3 8245	0 8416	2 4631	0 3974	0 5214	1 9655
0 040	2 2137	0 9460	4 1204	0 7832	2 6523	0 3701	0 5619	2 1139



NONPREDISTORTED AND PREDISTORTED FILTER RESPONSES REAL FILTERS WITH DISSIPATION LOSSES

FIGURE 1



DIPLEXING SCHEME USED IN MICROWAVE SYSTEMS

FIGURE 2

REFLECTED TIME DELAY OF CONVENTIONAL 7 CELL, 37MHZ BW, MAXIMALLY FLAT WAVEGUIDE FILTER 60MHZ FROM CENTER FREQUENCY OF FILTER (MEASURED DATA)

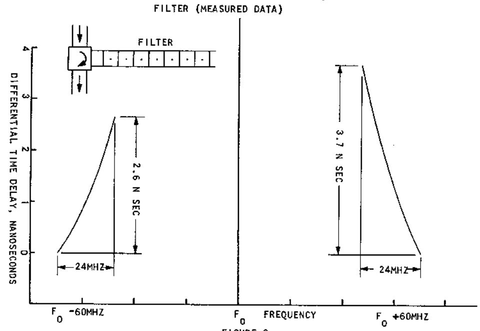


FIGURE 3.

REFLECTED TIME DELAY OF PREDISTORTED 7 CELL, 37MHZ BW, MAXIMALLY FLAT WAVEGUIDE FILTER 60MHZ FROM CENTER FREQUENCY OF FILTER (MEASURED DATA)

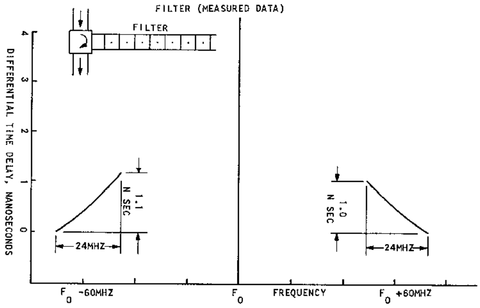


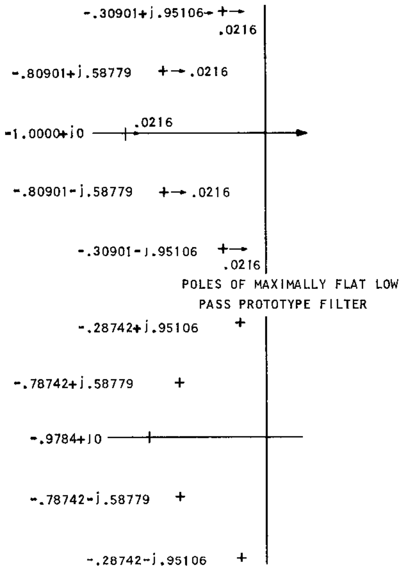
FIGURE 4.

REFERENCES

1. Cohn, S. B., "Dissipation Loss in Multiple Coupled Resonator Filters," Proceedings of IRE, August 1959.

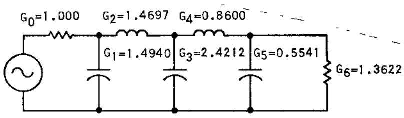
2. Cohn, S. B., "Direct-Coupled Resonator Filters," Proceedings of IRE, February 1957.

3. Guillemin, E. A., Synthesis of Passive Networks, John Wiley & Sons, 1957.



POLES OF PREDISTORTED LOW PASS PROTOTYPE FILTER

FIGURE 5.



5 ELEMENT PREDISTORTED LOW PASS PROTOTYPE FILTER, WITH MAXIMALLY FLAT RESPONSE.
δ=0 0216

FIGURE 6