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Echo Distortion in Bandpass Filters

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This article illustrates how echo distortion can occur in multi-resonator bandpass filters, and offers suggestions for correcting these effects to avoid degradation of communication system performance

In communications systems, signal transmission performance can be degraded by amplitude and/or differential group delay distortion in the usable passband of a bandpass filter. Additional degradation, via echo distortion, can occur when long transmission lines are operated between mismatched source and load impedances (1). When bandpass filters use a substantial number of coupled resonators, mismatched source and load impedances can also cause echo distortion. This article presents some quantitative information for a echo distortion in a typical IF bandpass filter used in satellite communications earth station equipment.

Multiresonator Bandpass Filter and Nominal Passband Behavior

A typical multiresonator bandpass filter, used at Ku band earth stations, has the following characteristics:

Center frequency (nominal): 1.1 GHz
Number of poles: 11
Passband ripple: 0.01 dB
Three dB bandwidth: 90 MHz
Usable passband: 54 MHz transponder
Impedance: 50 ohms (source and load)

This type of combline filter construction, using coupled round rods between ground planes, has been previously described (2). The multiresonator direct coupled bandpass filter can be characterized in terms of normalized parameters such as input/output singly loaded Q and interstage coefficients of coupling. This is illustrated in Figure 1. The normalized parameters of the symmetrical filter appear in Table 1.

Normalized Parameter	Nominal Value
Q_1	0.871
k_{12}	0.867
k_{23}	0.581
k_{34}	0.529
k_{45}	0.512
k_{56}	0.506

Table 1 · Normalized singly loaded Q and coefficients of coupling for a lossless 11-pole, 0.01 dB ripple bandpass filter.

Normalization of frequency, impedance, and coupling parameters has been described adequately in a classic reference (3). All normalization used herein has been referenced to the filter three dB bandwidth. Arithmetic symmetry has been assumed and filter response shapes have been tabulated for the upper half of the filter passband. The upper edge of the usable filter passband is defined by a normalized frequency of 0.6.

For resonator unloaded Qs of 1000, simulated filter passband responses are shown in Table 2. It can be seen that the center frequency insertion loss is close to 1 dB. For usable passband, the insertion loss and group delay responses are monotonic with amplitude variation of about 0.2 dB and differential group delay variation almost 6 nsec. Passband VSWR ripples correspond to return losses of about 26 dB.

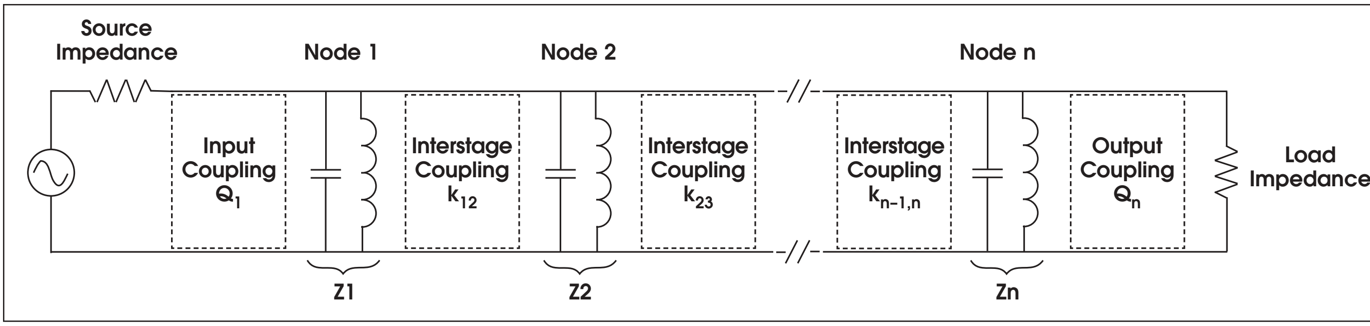

Figure 1 · Analytical drawing of a multiresonator direct coupled bandpass filter, illustrating resonator locations and input, output and interstage coupling coefficients.

Bandpass Filter Performance with Source/Load Mismatches

For tapped input/output couplings and resistive source/load mismatches, normalized singly loaded Qs are directly proportional to source and load resistance levels (4). Normalized resistive mismatch levels are obtained from the intersections of centered VSWR circles with the resistive axis of the Smith chart.

The effects of source and load mismatches can be evaluated by perturbations in the singly loaded Qs of the first and last resonators. Resistive source and load levels have been arbitrarily selected in opposite directions with high impedance source resistances and low impedance load impedances. Two levels of mismatch have been considered. Moderate mismatches entail source and load VSWRs of 1.25 (19 dB return loss). Significant mismatches entail source and load VSWRs of 1.5 (14 dB return losses). Resistive interface normalized mismatches will correspond to perturbed normalized singly loaded Qs as shown in Table 3.

Simulated filter response shapes for moderate source/load mismatches are shown in Table 4. Within the usable passband, amplitude ripple is close to 0.3 dB and group delay ripple is about 0.2 nsec. Usable filter passband VSWR is ≤1.51.

Simulated filter response shapes for significant source/load mismatches are shown in Table 5. Within the usable passband, amplitude ripple is close to 0.6 dB and differential group delay ripple is about 3 nsec. Usable filter passband VSWR ≤2.10.

Table 5 responses exhibit significant degradation. Passband amplitude and differential group delay ripples are echo distortion similar to those encountered with mismatched transmission lines.

Alternate Bandpass Filters

Useful information on combline

Normal. Freq.	Offset (MHz)	L (dB)	VSWR	Group Delay (nsec)
0	0	0.98	1.01	0
0.05	2	0.98	1.05	-
0.1	5	0.99	1.08	0.04
0.15	7	0.99	1.09	0.15
0.2	9	1.00	1.06	0.37
0.25	11	1.00	1.02	0.70
0.3	14	1.02	1.04	1.09
0.35	16	1.04	1.08	1.53
0.4	18	1.06	1.09	2.07
0.45	20	1.08	1.07	2.77
0.5	23	1.10	1.02	3.66
0.55	25	1.14	1.05	4.68
0.6	27	1.18	1.09	5.87
0.65	29	1.23	1.08	7.35
0.7	32	1.29	1.03	9.28
0.75	34	1.37	1.06	11.70
0.8	36	1.49	1.09	14.79
0.85	38	1.64	1.04	19.21
0.9	41	1.91	1.09	25.97
0.95	43	2.54	1.17	38.52
1.0	45	5.95	3.13	58.22

Table 2 · Simulated passband responses for the 1.1 GHz bandpass filter.

Mismatch	VSWR	Source Res.	Q_1	Load Res.	Q_n
Moderate	1.25	1.250	1.089	0.800	0.697
Significant	1.50	1.500	1.307	0.667	0.581

Table 3 · Conditions for bandpass filter source/load mismatches. Note: nominal normalized single-loaded Q1 = Qn = 0.871 which correspond to source and load VSWRs of 1.

and other bandpass filter structures is available in the classic reference (5). Formulation using normalized singly loaded Qs and coefficients of coupling is applicable to cavity, interdigital, strip transmission line, and waveguide bandpass filters. These coupling parameters are amenable to simple experimental techniques at microwave frequencies as described in (6).

Normal. Freq.	Offset (MHz)	L (dB)	VSWR	Group Delay (nsec)
0	0	1.17	1.51	0
0.05	2	1.14	1.46	-
0.1	5	1.07	1.32	0.46
0.15	7	1.02	1.16	1.11
0.2	9	1.03	1.17	1.55
0.25	11	1.10	1.34	1.58
0.3	14	1.19	1.47	1.39
0.35	16	1.23	1.51	1.46
0.4	18	1.19	1.41	2.15
0.45	20	1.13	1.22	3.43
0.5	23	1.13	1.08	4.83
0.55	25	1.21	1.26	5.78
0.6	27	1.34	1.44	6.31
0.65	29	1.42	1.48	7.23
0.7	32	1.41	1.33	9.34
0.75	34	1.41	1.08	12.60
0.8	36	1.55	1.17	16.11
0.85	38	1.80	1.38	19.72
0.9	41	2.06	1.39	25.67
0.95	43	2.59	1.30	39.35
1.0	45	6.10	3.11	59.09

Table 4 · Simulated passband responses for perturbed 1.1 GHz bandpass filter (normalized single loaded Qs for moderate mismatch.

Normal. Freq.	Offset (MHz)	L (dB)	VSWR	Group Delay (nsec)
0	0	1.60	2.10	0
0.05	2	1.50	1.96	-
0.1	5	1.27	1.61	1.36
0.15	7	1.09	1.24	3.24
0.2	9	1.11	1.29	4.21
0.25	11	1.34	1.68	3.50
0.3	14	1.58	2.00	2.02
0.35	16	1.65	2.08	1.32
0.4	18	1.50	1.84	2.31
0.45	20	1.27	1.41	4.84
0.5	23	1.18	1.13	7.45
0.55	25	1.39	1.51	8.21
0.6	27	1.70	1.92	7.25
0.65	29	1.84	2.02	6.98
0.7	32	1.69	1.70	9.46
0.75	34	1.50	1.18	14.56
0.8	36	1.68	1.34	19.07
0.85	38	2.16	1.83	20.80
0.9	41	2.41	1.82	25.01
0.95	43	2.71	1.42	41.16
1.0	45	6.45	3.29	61.02

Table 5 · Simulated passband responses for perturbed 1.1 GHz bandpass filter (normalized single loaded Qs for significant mismatch.

Methods of Analysis

ABCD matrix analysis is conveniently applicable to all pole ladder circuits which are minimum phase shift networks. ABCD and nodal analysis can be used with general filters which employ bridging couplings between non-adjacent resonators. The general filters are non-minimum phase shift networks which can be designed as elliptic function filters or self-equalized filters.

Echo Distortion Prevention and Correction

Echo distortion, in bandpass filters, becomes more severe when filter selectivity is sharpened by increasing the number of poles. Echo distortion can be prevented or reduced to acceptable levels by buffering at both input and output filter interfaces. This can be achieved using ferrite isolators or isolation amplifiers. Precision impedance matching, associated with complete subsystem or system integration, can also provide improvement. Use of swept frequency alignment, with adjustable filter resonators and couplings, can sometimes reduce echo distortion to acceptable levels. Filter tunability has been discussed in a recent article (7).

Impedance matched low ripple bandpass filters have inherent amplitude and differential group delay distortion that is usually linear and/or parabolic. Over a usable passband, transmission aberrations can be equalized either internally or externally. For mismatched bandpass filters, echo distortion is periodic similar to transmission line echo distortion in satellite earth station interfacility links. This type of distortion is somewhat more difficult to equalize.

Summary

1) It has been shown that echo distortions, such as amplitude and differential group delay ripples, can occur when bandpass filters—with multiple resonators—are operated between source and load impedances with significant mismatches.

2) In communications systems, the transmission impairments due to these echos depend upon the filter performance, the type of information, and the specific modulation being used. Standard system level measurements for video and/or digital data are used to evaluate the impact of mismatched filters upon transmission quality.

3) In some cases, performance specifications can tolerate the use of bandpass filters with poorly matched interfaces, but more stringent transmission requirements could necessitate use of preventive and/or corrective techniques. Each application must carefully consider appropriate cost and performance tradeoffs as the basis of design decisions.

4) Computer simulation is essential for convenient analysis of the effects of tolerances on multiresonator filter responses.

References

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