CHI CES Engineering

ELECTRONIC SYSTEM DESIGN

PART 2: ANALOG FILTERS

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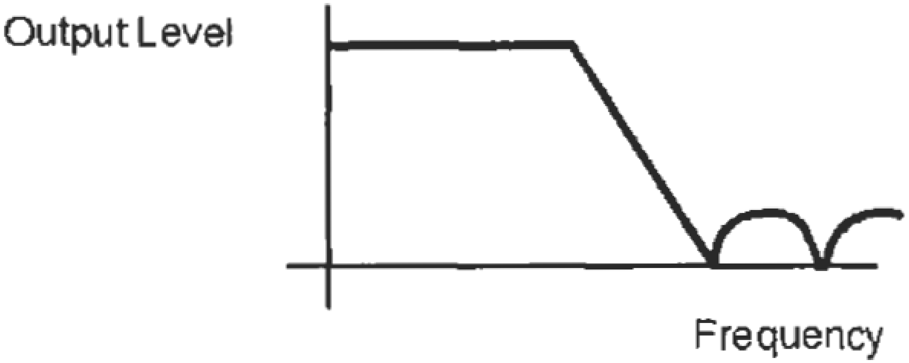
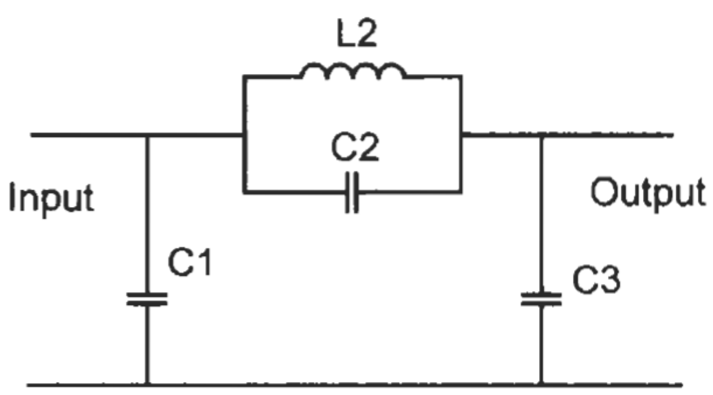
Inverse Chebyshev Response

- Smooth passband and nulls in the stopband
  - This combination is a compromise that gives a reasonably sharp roll-off in the frequency response and a reasonably low overshoot in its impulse response
- For any given frequency response, the filter order required for an Inverse Chebyshev will be the same as required for a Chebyshev filter

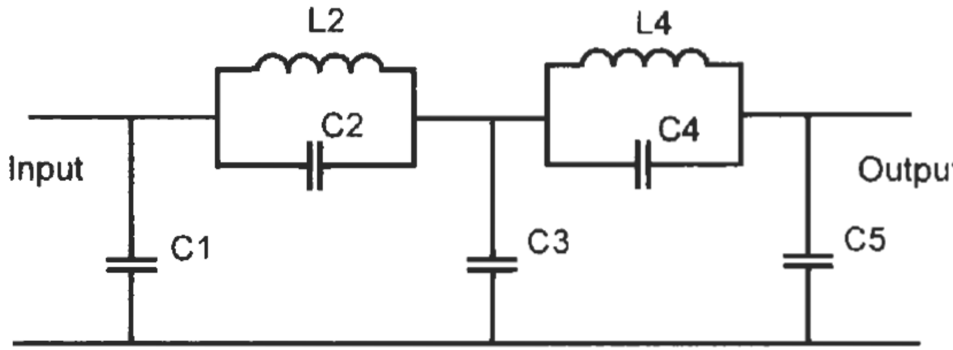


Passive Third-Order Inverse Chebyshev



Atten	C1	L2	C2	C3
20	1.171717	2.343437	0.320043	1.171717
25	1.49178	2.983563	0.251377	1.49178
30	1.866437	3.732877	0.200918	1.866437
35	2.309844	4.619692	0.162349	2.309844
40	2.838492	5.676988	0.132112	2.838492
45	3.471945	6.943896	0.108009	3.471945
50	4.233615	8.467236	0.088577	4.233615
55	5.151636	10.30328	0.072792	5.151636
60	6.259915	12.51984	0.059905	6.259915
65	7.599384	15.19878	0.049346	7.599384
70	9.219512	18.43904	0.040675	9.219512
75	11.18013	22.36028	0.033542	11.18013
80	13.55366	27.10734	0.027668	13.55366
85	16.42774	32.85551	0.022827	16.42774
90	19.90854	39.8171	0.018836	19.90854
95	24.12459	48.24921	0.015544	24.12459
100	29.23161	58.46326	0.012829	29.23161

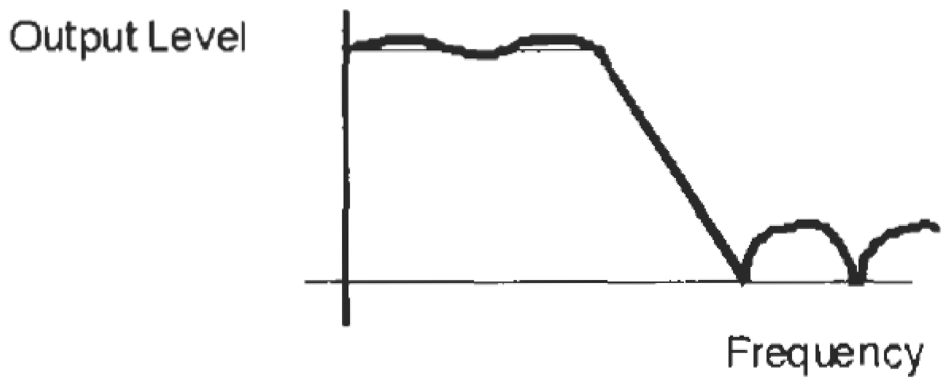
Passive Fifth-Order Inverse Chebyshev



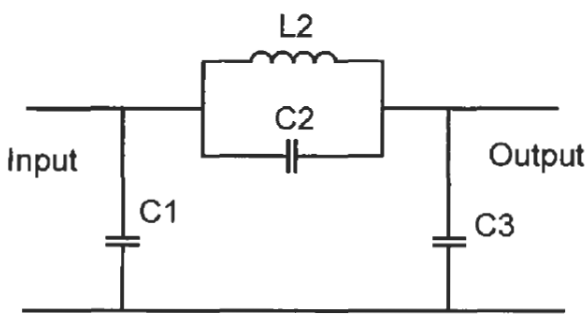
Atten	C1	L2	C2	C3	L4	C4	C5
25	0.034826	0.976387	0.926384	1.997745	1.53603	0.224925	0.479829
30	0.200989	1.250222	0.723478	2.227904	1.752054	0.197192	0.573384
35	0.357922	1.542176	0.586514	2.499294	1.989518	0.173656	0.674494
40	0.512368	1.855072	0.487587	2.810959	2.25281	0.15336	0.784536
45	0.669038	2.192623	0.412524	3.164524	2.545923	0.135704	0.904982
50	0.831614	2.559145	0.353442	3.563026	2.872931	0.120257	1.037435
55	1.003257	2.959464	0.305633	4.010791	3.238221	0.106692	1.183653
60	1.18689	3.398898	0.266118	4.513096	3.64663	0.094743	1.345577
65	1.385372	3.883307	0.232922	5.076139	4.103559	0.084193	1.525356
70	1.601619	4.419142	0.20468	5.707146	4.615038	0.074862	1.725375
75	1.838693	5.013537	0.180413	6.414394	5.187834	0.066596	1.948289
80	2.099869	5.674402	0.159402	7.207034	5.829529	0.059266	2.197056
85	2.388703	6.410517	0.141098	8.095517	6.548621	0.052758	2.474977
90	2.709089	7.231668	0.125076	9.091458	7.354638	0.046976	2.785739
95	3.065322	8.148752	0.111	10.20834	8.258267	0.041836	3.133466
100	3.462159	9.173953	0.098595	11.46061	9.271494	0.037264	3.522772

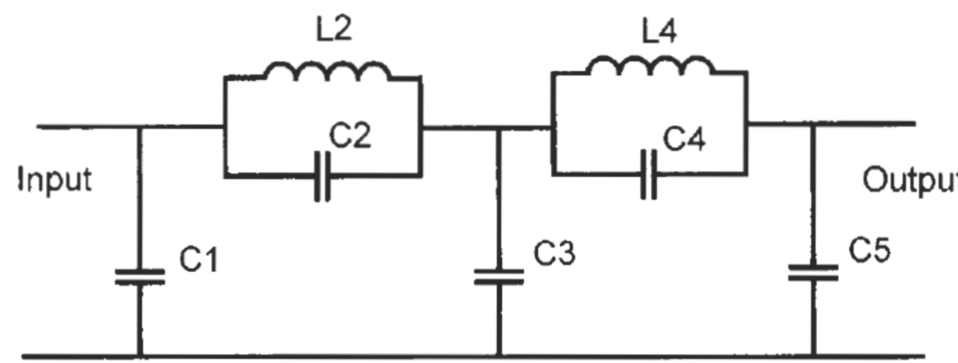
Cauer (Elliptic) Response

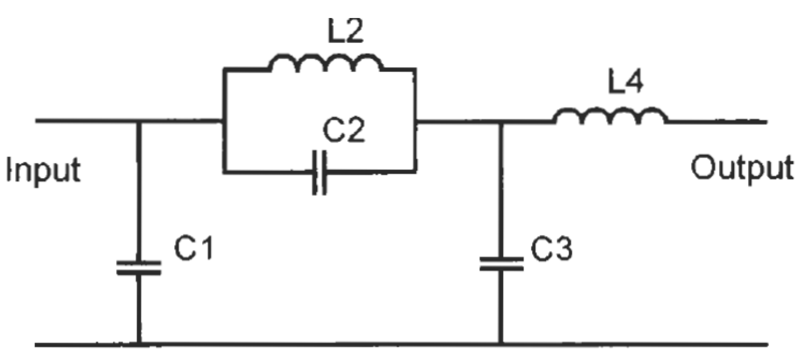
- Cauer response has ripple in the passband and in the stopband
- Cauer filters are used where it is necessary to have a sharp transition between the passband and stopband, that is, a very steep skirt response

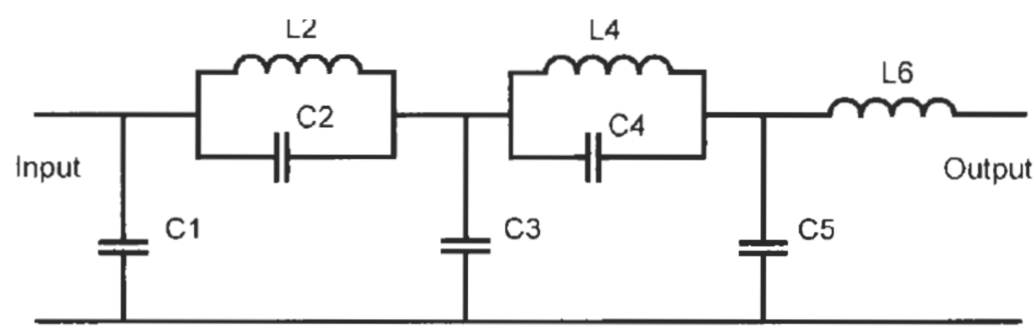


Cauer Filter Designs







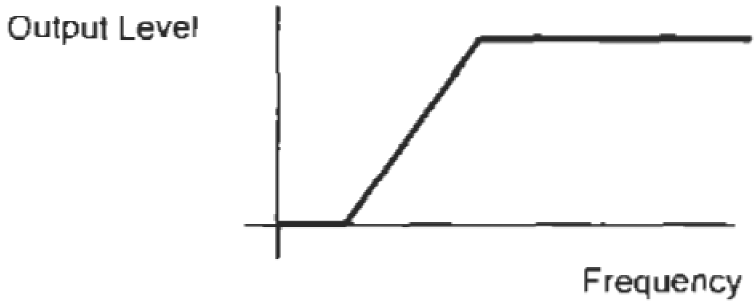


Cauer Filter Normalized Components

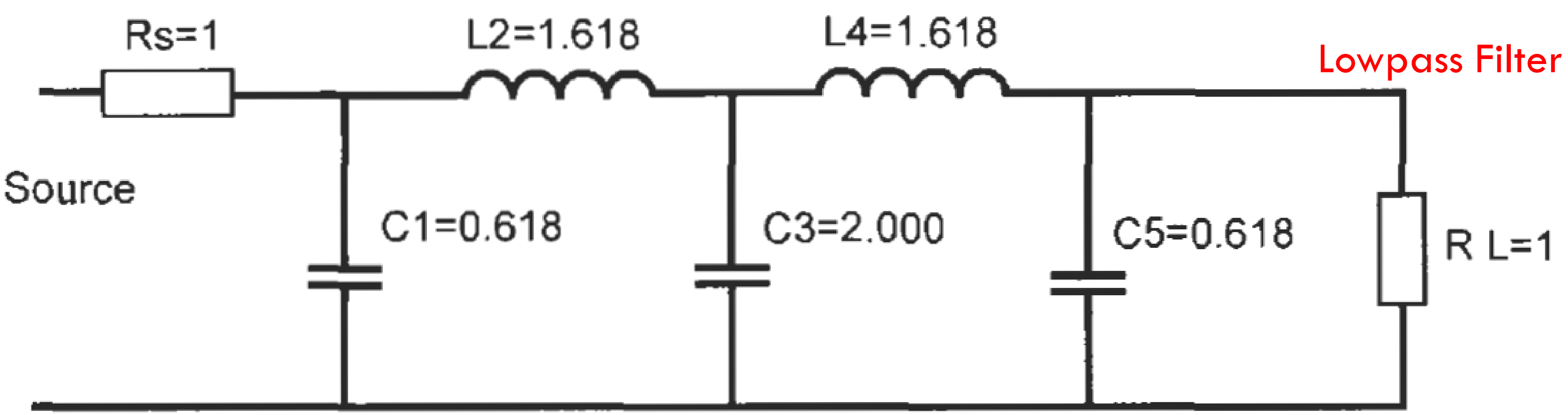
Loss (dB)	Stopband	Order	C1	L2	C2	C3	L4	C4	C5	L6	C6	C7
30	2.5	3	0.9472	1.0173	0.1205	0.9472						
30	2	4	0.7755	1.1765	0.1796	1.3347	0.9338					
40	2.5	4	0.8347	1.2744	0.1053	1.3722	0.9325					
40	1.5	5	1.0279	1.2152	0.1513	1.6318	0.9353	0.4408	0.8155			
50	2	5	1.0876	1.2932	0.07317	1.7938	1.1433	0.20038	0.9772			
50	1.5	6	0.8659	1.2740	0.1855	1.4311	1.2723	0.33007	1.2825	1.0332		
50	1.2	7	1.0503	1.2487	0.16123	1.4838	0.8287	0.81542	1.2872	0.8743	0.58918	0.7539
			L1′	C2′	L2′	L3′	C4′	L4′	L5′	C6′	L6′	L7′

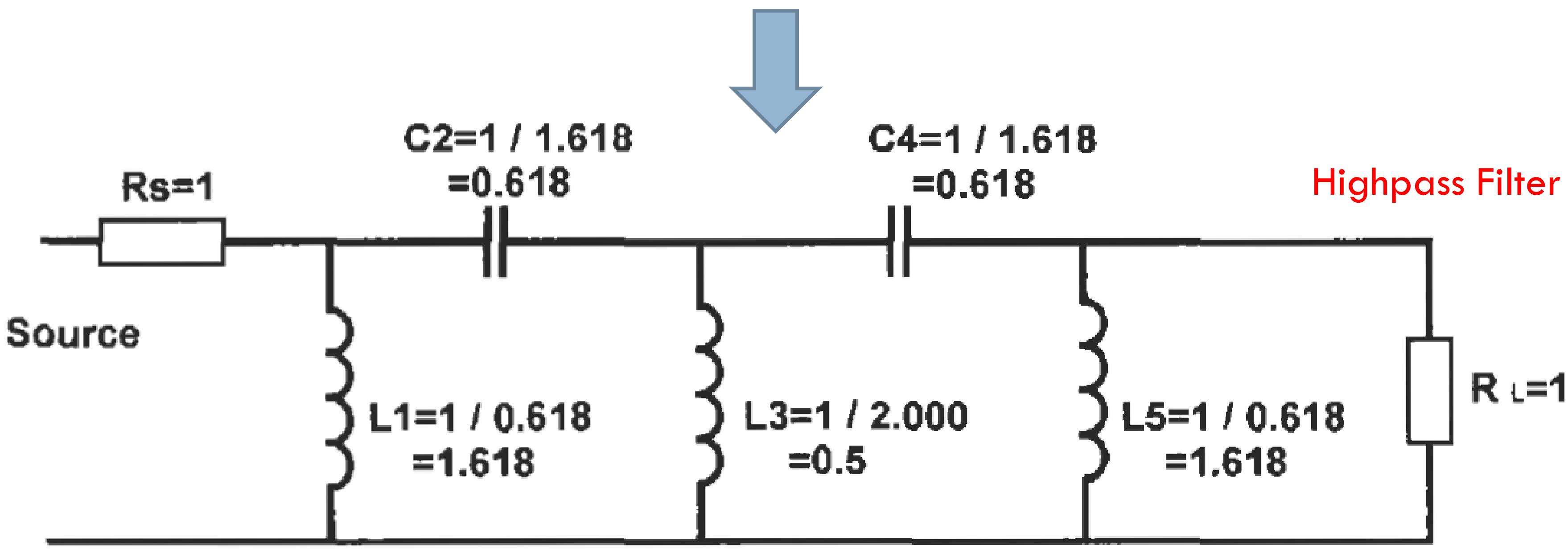
Highpass Filter Design

- Passive highpass filters are designed using the normalized lowpass model
- Model is normalized for a passband that extends from DC to l rad/s and is terminated with a 1 R load resistance
- Strategy is straightforward in all-poles filters
  - Butterworth or Chebyshev: replace each inductor by a capacitor and each capacitor by an inductor in the lowpass model



Highpass Filter Design: Example





Highpass Filter Component Denormalization

- Similar to that for lowpass filters but with inductance value proportional to inverse of normalized lowpass capacitance value and capacitance value proportional to inverse of normalized lowpass inductance value

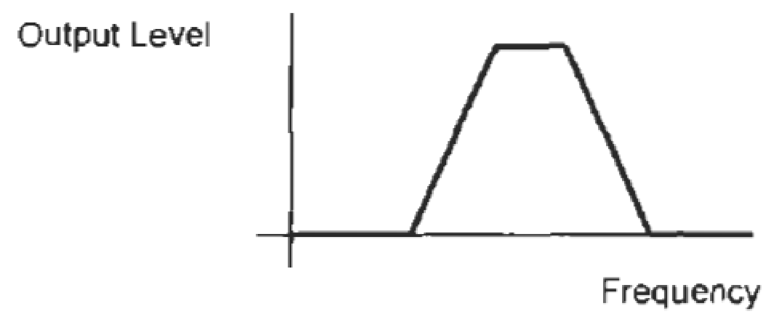
$$L = \frac{R}{2\pi F_c C^*}$$

$$C = \frac{1}{2\pi F_c R L^*}$$

L^* and C^* are the normalized lowpass component values, L and C are the final values after scaling.

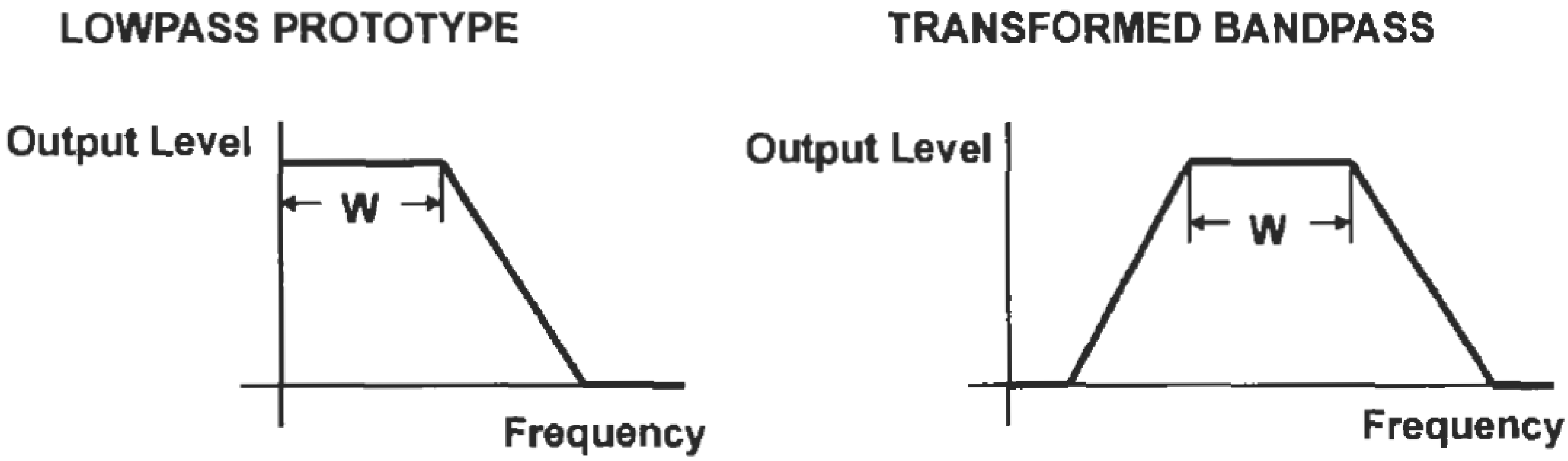
Bandpass Filters

- Two categories of bandpass filters: wideband and narrowband
- Filters are classified as wideband if their upper and lower passband cutoff frequencies are more than an octave apart
  - That is, upper frequency is over twice that of the lower frequency



Lowpass to Bandpass Transformation

- To obtain a particular bandwidth in a bandpass filter, first scale the normalized lowpass design to have this bandwidth. and then transform this into a bandpass filter design



Lowpass to Bandpass Transformation

- To frequency translate the scaled lowpass prototype into a bandpass model you must resonate each branch of the ladder at the center frequency, F_o
  - Series inductors become series LC circuits, and shunt capacitors become parallel tuned LC circuits.

$$F_O = \frac{1}{2\pi\sqrt{LC}}$$

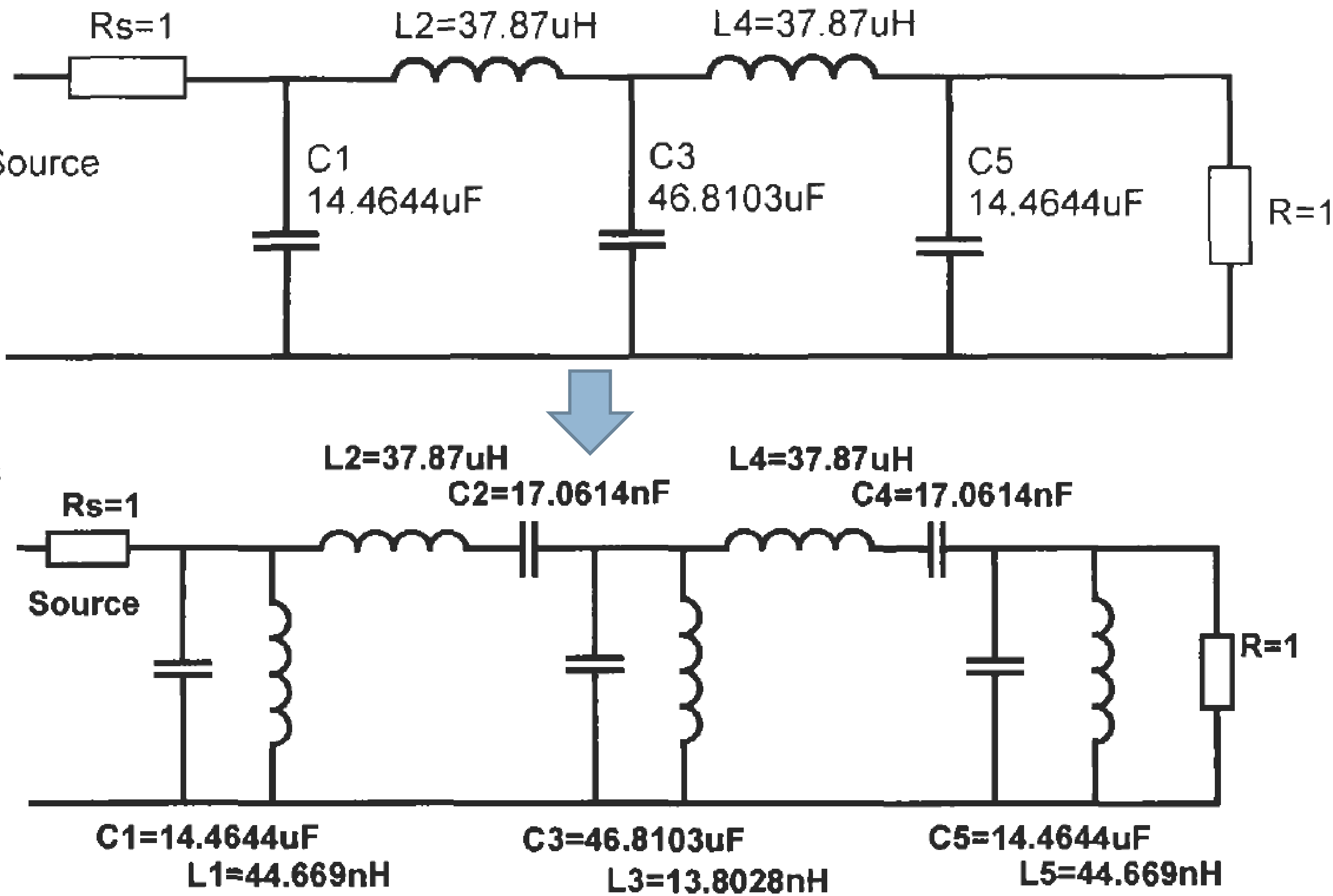
$$L_{BP} = \frac{1}{4\pi^2 Fo^2 C_{LP}}$$

$$C_{BP} = \frac{1}{4\pi^2 Fo^2 L_{LP}}$$

Lowpass to Bandpass Transformation: Example

Lowpass Filter

Bandpass Filter



Formulae for Passive Bandpass Filter Denormalization

- Series and parallel subscripts indicate which circuit element is being considered.
- Factor X is the normalized lowpass element value taken from tables
  - Same value of X must be used for both components in a single branch since each branch in the lowpass filter has one component, while branches in the bandpass have two components that are either series or parallel resonant
  - Both components in a single branch are related to a single component value in the lowpass prototype

$$C_{Series} = \frac{F_U - F_L}{2\pi F_U F_L R X}$$

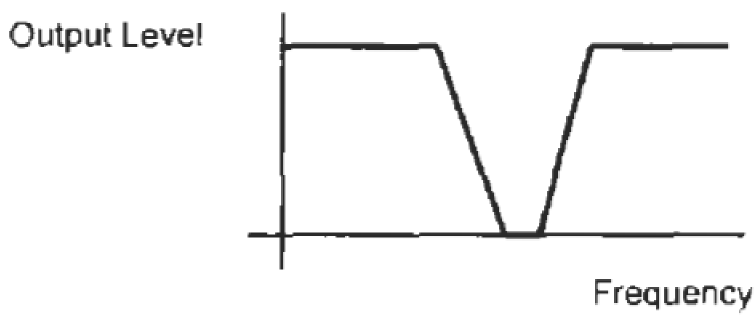
$$L_{Series} = \frac{RX}{2\pi.(F_U - F_L)}$$

$$C_{Parallel} = \frac{X}{2\pi.(F_U - F_L).R}$$

$$L_{Parallel} = \frac{(F_U - F_L).R}{2\pi F_U F_L X}$$

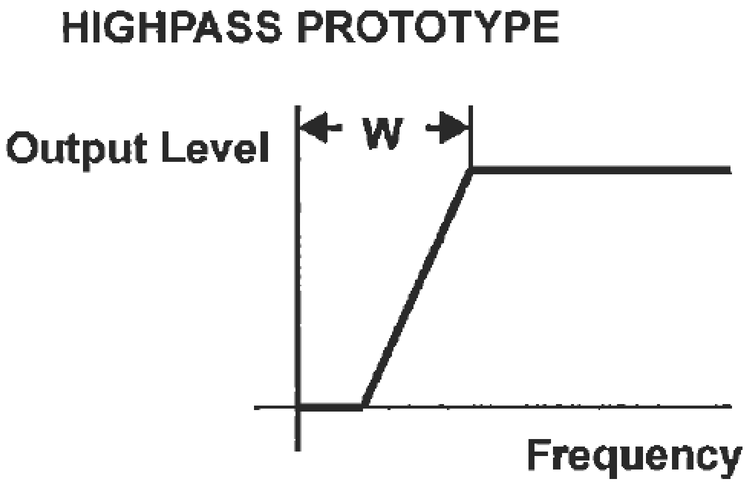
Bandstop Filters

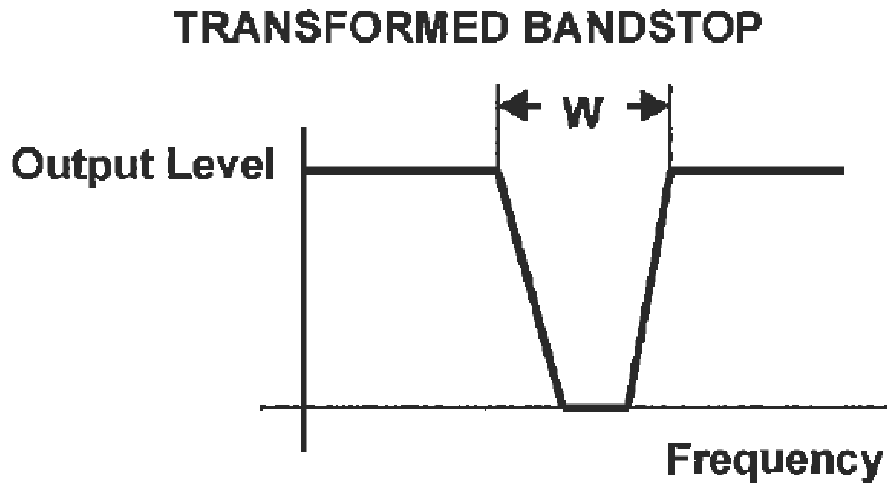
- Two categories of bandstop filters: wideband and narrowband
- Filters are classified as wideband if their upper and lower passband cutoff frequencies are several octaves apart
  - Upper frequency is many times that of lower frequency
- Wideband filters are ideally constructed from odd-order lowpass and highpass filters connected in parallel



Bandstop Filters

- Bandstop filter design starts with normalized component values, which are converted into normalized highpass values then translate frequency



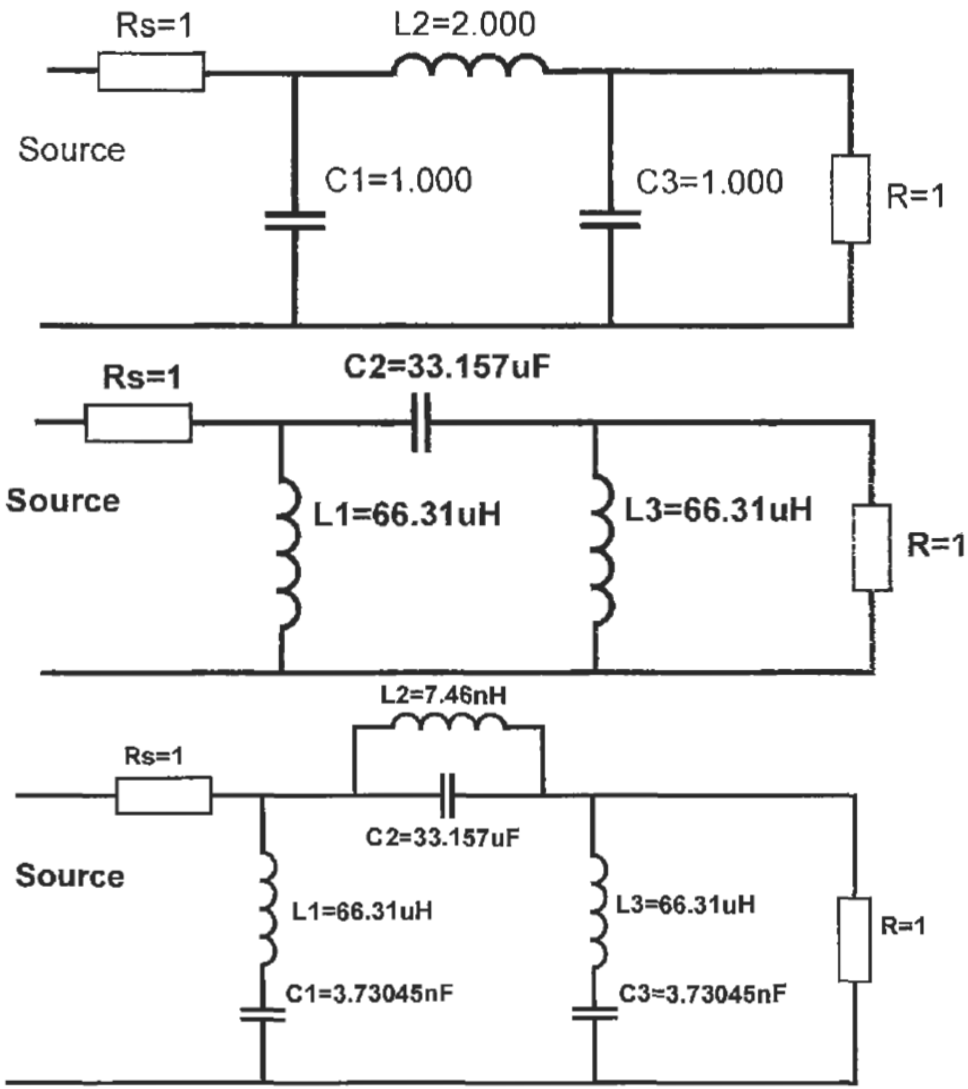


Bandstop Filters

Lowpass

Highpass

Bandstop



$$F_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$L_{BS} = \frac{1}{4\pi^2 F_O^2 C_{HP}}$$

$$C_{BS} = \frac{1}{4\pi^2 F_O^2 L_{HP}}$$

Formula for Passive Bandstop Filter Denormalization

- Series and shunt subscripts indicate which circuit element is being considered
- Factor X is the normalized lowpass element value taken from tables
  - Same value of X must be used for both components in a single branch
  - Each branch in the all-pole lowpass filter has one component, while branches in the bandstop have two components that are either series or parallel resonant

$$C_{Series} = \frac{1}{2\pi.[F_U - F_L]RX}$$

$$L_{Series} = \frac{[F_U - F_L].RX}{2\pi F_U.F_L}$$

$$C_{Shunt} = \frac{[F_U - F_L].X}{2\pi.F_U F_L.R}$$

$$L_{Shunt} = \frac{R}{2\pi.[F_U - F_L].X}$$

Assignments

- Design a highpass filter with a cutoff frequency of 1 kHz and stopband attenuation of 50dB at 100 Hz with a load resistance of 50 Ω.
- Design a bandpass filter that has a lower and upper cutoff frequencies of 1 and 200 Hz respectively and attenuation of 40db at 500 Hz and assuming a 1 kΩ load resistance.
- Design a bandstop filter that has a lower and upper cutoff frequencies of 45 and 55 Hz respectively and assuming a 100 Ω load resistance.