EE4-18
EE9-AO6

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2013

MSc and EEE PART IV: MEng and ACGI

Corrected Copy

RADIO FREQUENCY ELECTRONICS

Tuesday, 14 May 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR questions.

All questions carry equal marks

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : S. Lucyszyn
Second Marker(s) : A.S. Holmes

Special instructions for invigilators

This is a closed book examination.

Special instructions for students

$$Boltzmann's\ constant = 1.38 \times 10^{-23}\ W.s/K$$

The Questions

1. An LNB has the following measured electrical specifications:

Frequency Band:	10.95 to 11.70 GHz
Input V.S.W.R.:	2.5 : 1
Conversion Gain:	55 dB
IMD3:	40 dBc (at -15 dBm IF Output)
Noise Figure (To = +25 C):	0.7 dB
Local Oscillator Leakage Levels:	-50 dBm
Output Frequency:	0.95 to 1.70 GHz
Output V.S.W.R.:	2.0 : 1
Output Impedance:	75 Ohm

Using the above specifications and stating any assumptions, calculate the following:

a) -3 dB fractional bandwidths and loaded quality factors for both the input and output BPFs. What low cost resonator technologies can be employed to realise the input and output BPFs?

[3]

b) Calculate both the input and output return losses. Discuss the practical significances of these measured values.

[3]

c) With an output 1 dB compression point of -15 dBm, calculate the input power, IP_3 and 3^{rd} order intermodulation power. What is the corresponding 3^{rd} order intermodulation output voltage?

[3]

d) At the 1 dB compression given by 1(c), calculate both the input and output signal-to-noise (S/N) ratios, assuming the antenna noise temperature is equal to the ambient temperature of +25 C. What is the significance of the input S/N to output S/N ratio?

[6]

e) Briefly explain why LO leakage is important for a military radar system. If the above LNB is used with an antenna having a gain of 35 dBi, calculate the EIRP from the receiver.

[2]

f) State the Friis Link equation. If both the radar and electronic counter measure (ECM) receiver have 35 dBi gain antennas, using the EIRP calculated in 1(e), determine the maximum distance at which the radar can be detected by an ECM having a minimum receiver signal level of -120 dBm.

[3]

2. a) State the simple expression for differential-phase group delay, given the transfer function for a linear 2-port network. What is the transfer function for an ideal delay element?

[3]

b) Briefly explain the importance of differential-phase group delay when designing RF circuits and briefly explain the related issue of causality.

[2]

c) The attenuation of a signal through a narrow-band BPF can be approximated by the expression given in (2.1):

$$\propto(\omega) \approx e^{-\left(\omega_o \tau(\omega) / Qu(\omega_o)\right)} \quad \text{[Np]} \qquad (2.1)$$

All variables have their usual meaning.

From (2.1), derive a simple approximation for excess insertion loss (from the ideal), stating any assumptions. Given a frequency-independent average unloaded quality factor of 1,500, sketch the frequency response for the excess insertion loss.

[10]

d) Figure 2 shows frequency responses for a filter.

(i) By observation of the ideal insertion loss performance, state which family of filter approximations this filter belongs to and state its order. Also estimate the fractional bandwidth and loaded quality factor for this filter.

[2]

(ii) By observation from the measured results, and using the expression derived in 2(c), estimate the minimum unloaded quality factor for the filter's components.

[3]

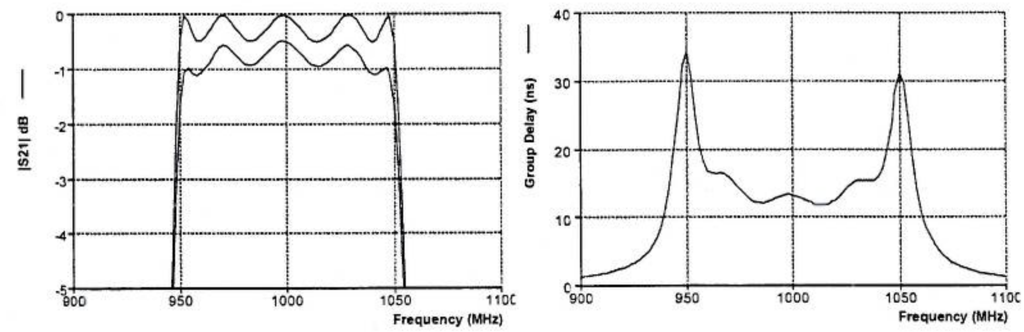


Figure 2: (Left) Insertion losses – ideal (top) and measured (bottom);

(Right) Measured differential-delay group delay

3. a) (i) For a lossless linear two-port network, state the simple equation that show the relationship between insertion loss and return loss.

[3]

(ii) Using the equation stated in 3(a)(i), calculate the return loss when insertion loss is -1 dB.

[2]

b) Draw a 3-channel frequency de-multiplexer and a 3-channel frequency multiplexer, employing circulators and band-pass filters.

[5]

c) Employing the topologies given in 3(b), draw a unilateral 3-channel amplifier. Assume that for each frequency band the associated filters and amplifiers have the same -1 dB band edge frequencies.

[3]

d) Employing the topology from in 3(c), use simple power loss budget analysis to calculate the overall gain, given that the insertion loss of each circulator is -0.1 dB, the mid-band insertion loss of the filters is 0 dB and the mid-band gain of the amplifiers is 10 dB. State any simplifying assumptions.

(i) Calculate the gain at mid-band, assuming that the transition frequency bandwidth is insignificant.

[2]

(ii) Calculate the gain at the -1 dB frequency band edge, assuming that the ideal upper -1 dB band edge frequency for one channel is the same as the ideal lower -1 dB band edge frequency for the adjacent channel.

[3]

(iii) Using the results from 3(d)(i) and (ii), comment on the resulting frequency response over the entire bandwidth of the 3 channels.

[2]

4. a) Draw the simple block diagram containing an antenna, linear receiver and demodulator. Clearly indicate the appropriate associated variables for signal power level, noise power level, power gain, bandwidth, input impedance, noise figure and noise temperature.

[2]

b) Using the block diagram from 4(a), derive expressions for both the input and output noise powers.

[6]

c) From first principles, prove that the noise factor of the receiver is equal to the signal-to-noise power ratio at the input divided by the signal-to-noise power ratio at the output when the antenna noise temperature is equal to the ambient temperature.

[2]

d) Derive expressions for the minimum detectable signal (MDS) power in terms of the minimum output signal-to-noise ratio and also sensitivity. Briefly explain why MDS does not depend on the gain of the receiver.

[4]

e) The first generation analogue Advanced Mobile Phone System (AMPS) has a minimum output signal-to-noise ratio of 18 dB, 30 kHz channel bandwidth, and 6.2 dB noise figure. Assume that the antenna noise temperature is the same as the ambient temperature. Calculate the minimum detectable signal power and sensitivity for this receiver. Assume typical values for ambient temperature and antenna input impedance.

[6]

5. For a -0.1 dB worst-case pass band insertion loss, design a lumped-element L-C band stop filter (BSF) to meet the following specifications:

Lower pass band -3 dB cut-off frequency:	9.25 GHz
Upper pass band -3 dB cut-off frequency:	10.75 GHz
Band stop attenuation:	> 110 dB
Stop band bandwidth:	150 MHz
Source impedance, Z_S:	25 Ω
Load impedance, Z_L:	50 Ω

a) Calculated the centre frequency, pass band bandwidth Bp and prototype f/fc ratio.

[3]

b) From the standard filter curves and tables supplied, determine the normalised component values for the low-pass prototype that meet the required specification. Justify your choice of curve and table.

[5]

c) Draw the topology for the BFP and calculate the component values.

[10]

d) Comment on the range of component values and suggest more practical methods for implementing the filter.

[2]

BSF

12:00

6. a) Draw the block diagram of a simple 2-channel I-Q vector modulator and explain the basic principle of operation. Also, give two examples of applications for this circuit. [3]

b) Using simple S-parameter analysis, derive equations for all the S-parameters for the simple I-Q vector modulator in 6(a). HINT: assume that directional couplers are lossless and reciprocal. Also, treat the bi-phase amplitude modulators as simple S-parameter blocks. [5]

c) Draw the block diagram for a simple bi-phase reflection-type amplitude modulator. [3]

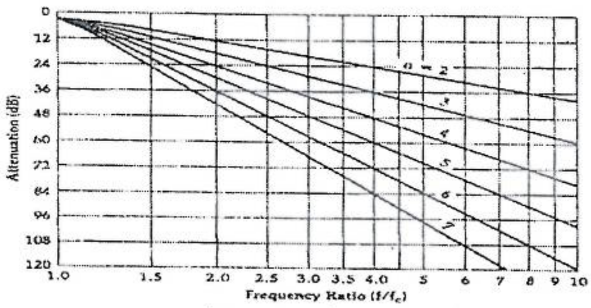
d) Using simple S-parameter analysis, derive equations for all the S-parameters for the simple bi-phase amplitude modulator in 6(c). HINT: assume that directional couplers are lossless and reciprocal. [5]

e) Calculate the power insertion loss for the complete 2-channel I-Q vector modulator having the following conditions:

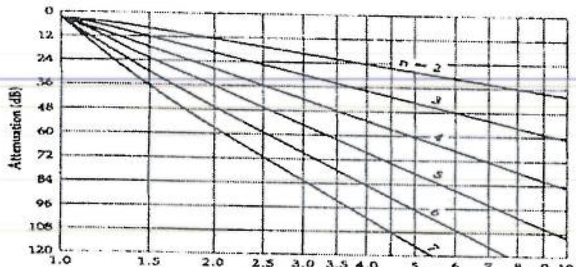
(i) All reflection terminations are short circuits [2]

(ii) The in-phase reflection terminations are short circuits and the quadrature-phase reflection terminations are impedance matched to the coupler. [2]

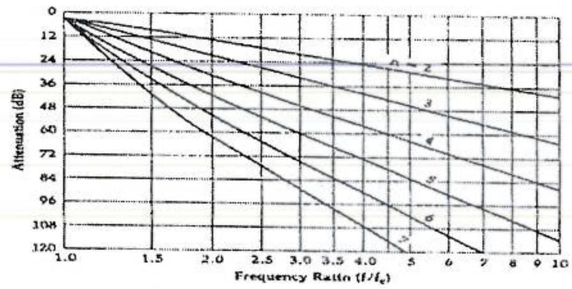
Standard Filter Curves and Tables



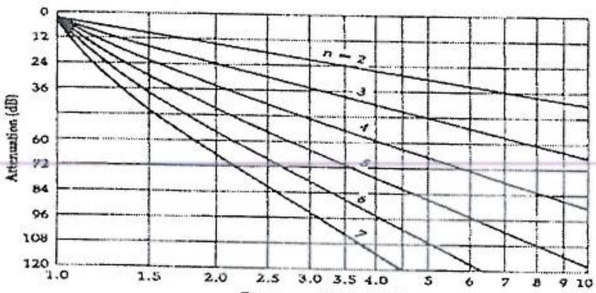
Attenuation characteristics for Butterworth filters.



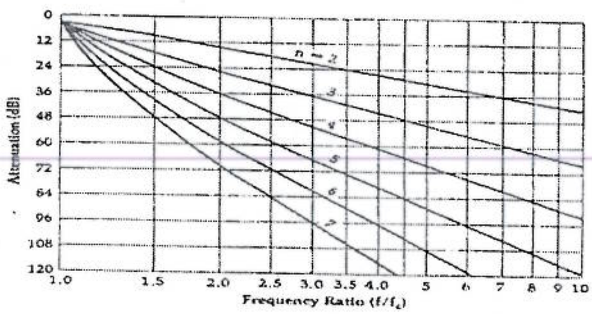
Attenuation characteristics for a Chebyshev filter with 0.01-dB ripple.



Attenuation characteristics for a Chebyshev filter with 0.1-dB ripple.

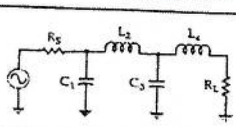


Attenuation characteristics for a Chebyshev filter with 0.5-dB ripple.

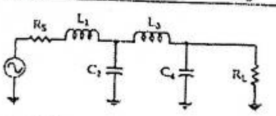


Attenuation characteristics for a Chebyshev filter with 1-dB ripple.

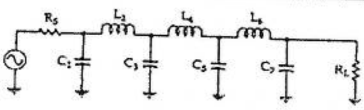
Chebyshev Low-Pass Prototype Element Values for 1.0-dB Ripple



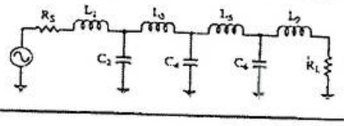
R_s/R_L	C_1	L_2	C_3	L_4
3.000	0.572	3.132		
4.000	0.365	4.600		
8.000	0.157	9.658		
∞	1.213	1.109		
1.000	2.216	1.088	2.216	
0.500	4.431	0.817	2.216	
0.333	6.647	0.726	2.216	
0.250	8.862	0.680	2.216	
0.125	17.725	0.612	2.216	
∞	1.652	1.460	1.108	
3.000	0.653	4.411	0.814	2.535
4.000	0.452	7.083	0.612	2.848
8.000	0.209	17.164	0.428	3.281
∞	1.350	2.010	1.488	1.106
R_L/R_S	L_1	C_2	L_3	C_4



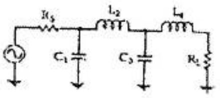
Chebyshev Low-Pass Prototype Element Values for 1.0-dB Ripple



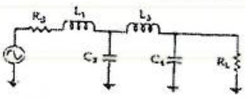
n	R_S/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	1.000	2.207	1.128	3.103	1.128	2.207		
	0.500	4.414	0.565	4.653	1.128	2.207		
	0.333	6.622	0.376	6.205	1.128	2.207		
	0.250	8.829	0.282	7.756	1.128	2.207		
	0.125	17.657	0.141	13.961	1.128	2.207		
	∞	1.721	1.645	2.061	1.493	1.103		
6	3.000	0.679	3.873	0.771	4.711	0.969	2.406	
	4.000	0.481	5.644	0.476	7.351	0.849	2.582	
	8.000	0.227	12.310	0.198	16.740	0.726	2.800	
	∞	1.378	2.097	1.890	2.074	1.494	1.102	
7	1.000	2.204	1.131	3.147	1.194	3.147	1.131	2.204
	0.500	4.408	0.566	6.293	0.895	3.147	1.131	2.204
	0.333	6.612	0.377	9.441	0.798	3.147	1.131	2.204
	0.250	8.815	0.283	12.588	0.747	3.147	1.131	2.204
	0.125	17.631	0.141	25.175	0.671	3.147	1.131	2.204
	∞	1.741	1.677	2.155	1.703	2.079	1.494	1.102
n	R_L/R_S	L_1	C_2	L_3	C_4	L_5	C_6	L_7



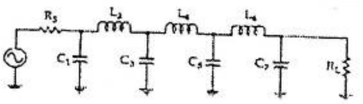
Butterworth Low-Pass Prototype Element Values



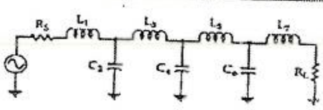
n	R_S/R_L	C_1	L_2	C_3	L_4
2	1.111	1.035	1.835		
	1.250	0.849	2.121		
	1.429	0.697	2.439		
	1.667	0.566	2.828		
	2.000	0.448	3.346		
	2.500	0.342	4.095		
	3.333	0.245	5.313		
	5.000	0.156	7.707		
	10.000	0.074	14.814		
	∞	1.414	0.707		
3	0.900	0.808	1.633	1.599	
	0.800	0.844	1.384	1.926	
	0.700	0.915	1.165	2.277	
	0.600	1.023	0.965	2.702	
	0.500	1.181	0.779	3.261	
	0.400	1.425	0.604	4.064	
	0.300	1.835	0.440	5.363	
	0.200	2.669	0.284	7.910	
	0.100	5.167	0.138	15.455	
	∞	1.500	1.333	0.500	
4	1.111	0.466	1.592	1.744	1.469
	1.250	0.388	1.695	1.511	1.811
	1.429	0.325	1.862	1.291	2.175
	1.667	0.269	2.103	1.082	2.613
	2.000	0.218	2.452	0.863	3.187
	2.500	0.169	2.986	0.691	4.009
	3.333	0.124	3.883	0.507	5.336
	5.000	0.080	5.684	0.331	7.940
	10.000	0.039	11.094	0.162	15.642
	∞	1.531	1.577	1.082	0.383
n	R_L/R_S	L_1	C_2	L_3	C_4



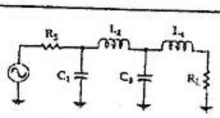
Butterworth Low-Pass Prototype Element Values



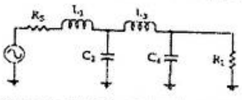
n	R_S/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	0.900	0.442	1.027	1.910	1.756	1.369		
	0.800	0.470	0.866	2.061	1.544	1.738		
	0.700	0.517	0.731	2.285	1.333	2.108		
	0.600	0.588	0.609	2.600	1.126	2.552		
	0.500	0.686	0.496	3.051	0.924	3.133		
	0.400	0.838	0.388	3.736	0.727	3.965		
	0.300	1.094	0.285	4.884	0.537	5.307		
	0.200	1.608	0.186	7.185	0.352	7.935		
	0.100	3.512	0.091	14.095	0.173	15.710		
	∞	1.545	1.694	1.382	0.894	0.309		
6	1.111	0.289	1.040	1.322	2.054	1.744	1.335	
	1.250	0.245	1.116	1.126	2.230	1.550	1.688	
	1.429	0.207	1.236	0.957	2.499	1.346	2.062	
	1.667	0.173	1.407	0.801	2.858	1.143	2.509	
	2.000	0.141	1.653	0.654	3.369	0.942	3.094	
	2.500	0.111	2.028	0.514	4.141	0.745	3.931	
	3.333	0.082	2.656	0.379	5.433	0.552	5.280	
	5.000	0.054	3.917	0.248	8.020	0.363	7.922	
	10.000	0.026	7.705	0.122	15.786	0.179	15.738	
	∞	1.553	1.759	1.553	1.202	0.758	0.259	
7	0.900	0.299	0.711	1.404	1.489	2.125	1.727	1.296
	0.800	0.322	0.606	1.517	1.278	2.334	1.546	1.652
	0.700	0.357	0.515	1.688	1.091	2.618	1.350	2.028
	0.600	0.408	0.432	1.928	0.917	3.005	1.150	2.477
	0.500	0.480	0.354	2.273	0.751	3.553	0.951	3.064
	0.400	0.590	0.278	2.795	0.592	4.380	0.754	3.904
	0.300	0.775	0.206	3.671	0.437	5.761	0.560	5.258
	0.200	1.145	0.135	5.427	0.287	8.526	0.369	7.908
	0.100	2.257	0.067	10.700	0.142	16.822	0.182	15.748
	∞	1.558	1.799	1.659	1.397	1.055	0.656	0.223
n	R_L/R_S	L_1	C_2	L_3	C_4	L_5	C_6	L_7



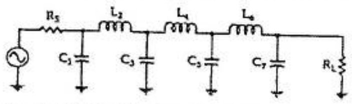
Chebyshev Low-Pass Element Values for 0.01-dB Ripple



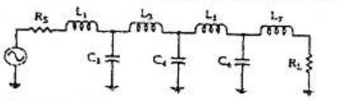
n	R_S/R_L	C_1	L_2	C_3	L_4
2	1.101	1.347	1.483		
	1.111	1.247	1.595		
	1.250	0.943	1.997		
	1.429	0.759	2.344		
	1.667	0.609	2.750		
	2.000	0.479	3.277		
	2.500	0.363	4.033		
	3.333	0.259	5.255		
	5.000	0.164	7.650		
	10.000	0.078	14.749		
	∞	1.412	0.742		
3	1.000	1.181	1.821	1.181	
	0.900	1.092	1.660	1.480	
	0.800	1.097	1.443	1.806	
	0.700	1.160	1.228	2.165	
	0.600	1.274	1.024	2.598	
	0.500	1.452	0.829	3.164	
	0.400	1.734	0.645	3.974	
	0.300	2.216	0.470	5.280	
	0.200	3.193	0.305	7.834	
	0.100	6.141	0.148	15.390	
	∞	1.501	1.433	0.591	
4	1.100	0.950	1.938	1.761	1.046
	1.111	0.854	1.946	1.744	1.165
	1.250	0.618	2.075	1.542	1.617
	1.429	0.495	2.279	1.334	2.008
	1.667	0.398	2.571	1.128	2.461
	2.000	0.316	2.994	0.926	3.045
	2.500	0.242	3.641	0.729	3.875
	3.333	0.174	4.727	0.538	5.209
	5.000	0.112	6.910	0.352	7.813
	10.000	0.054	13.469	0.173	15.510
	∞	1.529	1.691	1.312	0.523
n	R_L/R_S	L_1	C_2	L_3	C_4



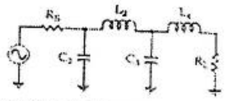
Chebyshev Low-Pass Element Values for 0.01-dB Ripple



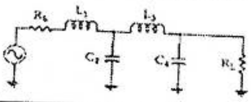
n	R_S/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	1.000	0.977	1.685	2.037	1.685	0.977		
	0.900	0.880	1.456	2.174	1.641	1.274		
	0.800	0.877	1.235	2.379	1.499	1.607		
	0.700	0.926	1.040	2.658	1.323	1.977		
	0.600	1.019	0.863	3.041	1.135	2.424		
	0.500	1.166	0.699	3.584	0.942	3.009		
	0.400	1.398	0.544	4.403	0.749	3.845		
	0.300	1.797	0.398	5.772	0.557	5.193		
	0.200	2.604	0.259	8.514	0.368	7.826		
	0.100	5.041	0.127	16.741	0.182	15.613		
	∞	1.547	1.795	1.645	1.237	0.468		
6	1.101	0.851	1.796	1.841	2.027	1.631	0.937	
	1.111	0.760	1.782	1.775	2.094	1.638	1.053	
	1.250	0.545	1.864	1.489	2.403	1.507	1.504	
	1.429	0.436	2.038	1.266	2.735	1.332	1.899	
	1.667	0.351	2.298	1.061	3.167	1.145	2.357	
	2.000	0.279	2.678	0.867	3.768	0.954	2.948	
	2.500	0.214	3.261	0.682	4.667	0.761	3.790	
	3.333	0.155	4.245	0.503	6.163	0.568	5.143	
	5.000	0.100	6.223	0.330	9.151	0.376	7.785	
	10.000	0.048	12.171	0.162	18.105	0.187	15.595	
	∞	1.551	1.847	1.700	1.598	1.190	0.469	
7	1.000	0.913	1.595	2.002	1.870	2.002	1.595	0.913
	0.900	0.816	1.362	2.089	1.722	2.202	1.581	1.206
	0.800	0.811	1.150	2.262	1.525	2.465	1.464	1.538
	0.700	0.857	0.967	2.516	1.323	2.802	1.307	1.910
	0.600	0.943	0.803	2.872	1.124	3.250	1.131	2.359
	0.500	1.080	0.650	3.382	0.928	3.875	0.947	2.948
	0.400	1.297	0.507	4.156	0.735	4.812	0.758	3.790
	0.300	1.669	0.372	5.454	0.546	6.370	0.568	5.148
	0.200	2.242	0.242	8.057	0.360	9.484	0.378	7.802
	0.100	4.701	0.110	15.872	0.178	18.818	0.188	15.652
	∞	1.559	1.867	1.866	1.765	1.563	1.161	0.456
n	R_L/R_S	L_1	C_2	L_3	C_4	L_5	C_6	L_7



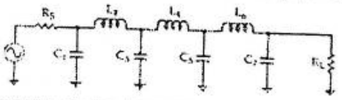
Chebyshev Low-Pass Prototype Element Values for 0.1-dB Ripple



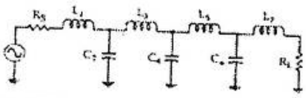
n	R_S/R_L	C_1	L_2	C_3	L_4
2	1.355	1.209	1.638		
	1.429	0.977	1.982		
	1.667	0.733	2.489		
	2.000	0.560	3.054		
	2.500	0.417	3.827		
	3.333	0.293	5.050		
	5.000	0.184	7.426		
	10.000	0.087	14.433		
	∞	1.391	0.819		
3	1.000	1.433	1.594	1.433	
	0.900	1.426	1.494	1.622	
	0.800	1.451	1.356	1.871	
	0.700	1.521	1.193	2.190	
	0.600	1.648	1.017	2.603	
	0.500	1.853	0.838	3.159	
	0.400	2.186	0.660	3.968	
	0.300	2.763	0.486	5.279	
	0.200	3.942	0.317	7.850	
	0.100	7.512	0.155	15.466	
	∞	1.513	1.510	0.716	
4	1.355	0.992	2.148	1.585	1.341
	1.429	0.779	2.348	1.429	1.700
	1.667	0.576	2.730	1.185	2.243
	2.000	0.440	3.227	0.967	2.856
	2.500	0.329	3.961	0.760	3.698
	3.333	0.233	5.178	0.560	5.030
	5.000	0.148	7.607	0.367	7.614
	10.000	0.070	14.887	0.150	15.230
	∞	1.511	1.768	1.455	0.673
n	R_L/R_S	L_1	C_2	L_3	C_4



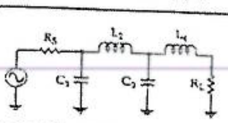
Chebyshev Low-Pass Prototype Element Values for 0.1-dB Ripple



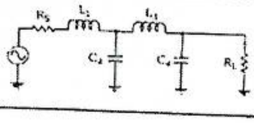
n	R_S/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	1.000	1.301	1.556	2.241	1.556	1.301		
	0.900	1.285	1.433	2.380	1.488	1.488		
	0.800	1.300	1.282	2.582	1.382	1.736		
	0.700	1.358	1.117	2.868	1.244	2.062		
	0.600	1.470	0.947	3.269	1.085	2.454		
	0.500	1.654	0.778	3.845	0.913	3.055		
	0.400	1.954	0.612	4.720	0.733	3.886		
	0.300	2.477	0.451	6.196	0.550	5.237		
	0.200	3.546	0.295	9.127	0.366	7.669		
	0.100	6.787	0.115	17.957	0.182	15.745		
	∞	1.561	1.807	1.766	1.417	0.651		
6	1.355	0.942	2.080	1.659	2.247	1.534	1.277	
	1.429	0.735	2.249	1.454	2.544	1.405	1.629	
	1.667	0.542	2.600	1.183	3.064	1.165	2.174	
	2.000	0.414	3.068	0.958	3.712	0.979	2.794	
	2.500	0.310	3.765	0.749	4.651	0.778	3.645	
	3.333	0.220	4.927	0.551	6.195	0.580	4.996	
	5.000	0.139	7.250	0.361	9.261	0.384	7.618	
	10.000	0.067	14.220	0.178	18.427	0.190	15.350	
	∞	1.534	1.884	1.831	1.749	1.394	0.638	
7	1.000	1.262	1.520	2.239	1.680	2.239	1.520	1.262
	0.900	1.242	1.395	2.361	1.578	2.397	1.459	1.447
	0.800	1.255	1.245	2.548	1.443	2.624	1.362	1.697
	0.700	1.310	1.083	2.819	1.283	2.942	1.233	2.021
	0.600	1.417	0.917	3.205	1.209	3.384	1.061	2.444
	0.500	1.595	0.753	3.764	0.928	4.015	0.914	3.018
	0.400	1.885	0.593	4.618	0.742	4.970	0.738	3.855
	0.300	2.392	0.437	6.054	0.559	6.569	0.557	5.217
	0.200	3.428	0.286	8.937	0.369	9.770	0.372	7.890
	0.100	6.570	0.141	17.603	0.184	19.376	0.186	15.813
	∞	1.575	1.858	1.921	1.827	1.734	1.370	0.631
n	R_L/R_S	L_1	C_2	L_3	C_4	L_5	C_6	L_7



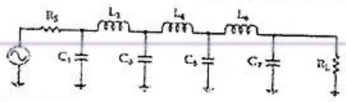
Chebyshev Low-Pass Prototype Element Values for 0.5-dB Ripple



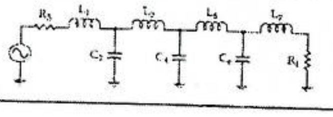
n	R_S/R_L	C_1	L_2	C_3	L_4
2	1.984	0.983	1.950		
	2.000	0.909	2.103		
	2.500	0.564	3.165		
	3.333	0.375	4.411		
	5.000	0.228	6.700		
	10.000	0.105	13.322		
	∞	1.307	0.975		
3	1.000	1.864	1.280	1.834	
	0.900	1.918	1.209	2.026	
	0.800	1.997	1.120	2.237	
	0.700	2.114	1.015	2.517	
	0.500	2.557	0.759	3.436	
	0.400	2.985	0.615	4.242	
	0.300	3.729	0.463	5.576	
	0.200	5.254	0.309	8.225	
	0.100	9.890	0.153	16.118	
	∞	1.572	1.518	0.932	
4	1.984	0.920	2.586	1.304	1.826
	2.000	0.845	2.720	1.238	1.985
	2.500	0.516	3.766	0.869	3.121
	3.333	0.344	5.120	0.621	4.480
	5.000	0.210	7.708	0.400	6.987
	10.000	0.098	15.352	0.194	14.262
	∞	1.436	1.889	1.521	0.913
n	R_L/R_S	L_1	C_2	L_3	C_4



Chebyshev Low-Pass Prototype Element Values for 0.5-dB Ripple



n	R_S/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	1.000	1.807	1.303	2.691	1.303	1.807		
	0.900	1.854	1.222	2.849	1.238	1.970		
	0.800	1.926	1.126	3.060	1.157	2.185		
	0.700	2.035	1.015	3.353	1.058	2.470		
	0.600	2.200	0.890	3.765	0.942	2.861		
	0.500	2.457	0.754	4.367	0.810	3.414		
	0.400	2.870	0.609	5.296	0.664	4.245		
	0.300	3.588	0.459	6.871	0.508	5.625		
	0.200	5.064	0.306	10.054	0.343	8.367		
	0.100	9.556	0.153	19.647	0.173	16.574		
	∞	1.630	1.740	1.922	1.514	0.903		
6	1.984	0.905	2.577	1.368	2.713	1.299	1.796	
	2.000	0.830	2.704	1.291	2.872	1.237	1.956	
	2.500	0.506	3.722	0.890	4.109	0.881	3.103	
	3.333	0.337	5.055	0.632	5.699	0.635	4.481	
	5.000	0.206	7.615	0.406	8.732	0.412	7.031	
	10.000	0.096	15.186	0.197	17.681	0.202	14.433	
7	1.000	1.790	1.296	2.718	1.385	2.718	1.296	1.790
	0.900	1.835	1.215	2.869	1.308	2.883	1.234	1.953
	0.800	1.905	1.118	3.076	1.215	3.107	1.155	2.188
	0.700	2.011	1.007	3.364	1.105	3.416	1.058	2.455
	0.600	2.174	0.882	3.772	0.979	3.852	0.944	2.848
	0.500	2.428	0.747	4.370	0.838	4.289	0.814	3.405
	0.400	2.835	0.604	5.295	0.685	5.470	0.669	4.243
	0.300	3.546	0.455	6.867	0.522	7.134	0.513	5.635
	0.200	5.007	0.303	10.049	0.352	10.496	0.348	8.404
	0.100	9.456	0.151	19.649	0.178	20.631	0.176	16.665
	∞	1.646	1.777	2.031	1.789	1.924	1.503	0.895
n	R_L/R_S	L_1	C_2	L_3	C_4	L_5	C_6	L_7



Model answer to Q 1(a): Calculation

An LNB has the following measured electrical specifications:

Frequency Band:	10.95 to 11.70 GHz
Input V.S.W.R.:	2.5 : 1
Conversion Gain:	55 dB
IMD3:	-40 dBc (at -15 dBm IF Output)
Noise Figure (To = +25 C):	0.7 dB
Local Oscillator Leakage Levels:	-50 dBm
Output Frequency:	0.95 to 1.70 GHz
Output V.S.W.R.:	2.0 : 1
Output Impedance:	75 Ohm

Using the above specifications and stating any assumptions, calculate the following:

-3 dB fractional bandwidths and loaded quality factors for both the input and output BPFs. What low cost resonator technologies can be employed to realise the input and output BPFs?

Input band centre frequency = 11.325 GHz
-3 dB bandwidth = 0.75 GHz
-3 dB fractional bandwidth = 6.6%
-3 dB loaded Q-factor = 15.1
Coupled microstrip or stripline resonators can be used.

Output band centre frequency = 1.325 GHz
-3 dB bandwidth = 0.75 GHz
-3 dB fractional bandwidth = 57 %
-3 dB loaded Q-factor = 1.8
Discrete lumped-element LC components can be used

[3]

Model answer to Q 1(b): Calculation

Calculate both the input and output return losses. Discuss the practical significances of these measured values.

Input return loss = -7.4 dB
Output return loss = -9.5 dB

The recommended minimum measured return loss should be -10 dB, which corresponds to 10% of the incident power being reflected back. At the output, the return loss is approximately -10%. At the input the return loss is higher than the recommended value, but this is not a problem because there is no risk of instability or insertion loss ripples.

[3]

Model answer to Q 1(c): Calculation

With an output 1 dB compression point of -15 dBm, calculate the input power, IP3 and 3rd order intermodulation power. What is the corresponding 3rd order intermodulation output voltage?

Input power = -15 dBm – 55 dB = -70 dBm = 100 pW

IMD3 = 2{IP3 [dBm] – C [dBm]} [dBc]

IMD3 = 40 dBc with C = -15 dBm
I3 = -15 dBm - 40 dBc = -55 dBm = 3.16 nW
RMS 3rd order intermodulation output voltage = SQRT(I3 x 75) = 0.487 mV

[3]

Model answer to Q 1(d): Calculation

At the 1 dB compression given by 1(c), calculate both the input and output signal-to-noise (S/N) ratios, assuming the antenna noise temperature is equal to the ambient temperature of +25 C. What is the significance of the input S/N to output S/N ratio?

Input signal power = - 70 dBm = 100 pW
Bandwidth = 750 MHz
Absolute temperature at +25 C, To = 273 +25 = 298 K
Input noise power = kToB = 3.08 pW = -85.1 dBm
Input S/N = 15.1 dB

Output signal power = -15 dBm = 31.6 uW
Bandwidth = 750 MHz
Absolute temperature at +25 C, To = 273 +25 = 298 K
Noise factor = 1.175
LNB equivalent noise temperature Tlnb = To (1.175 -1) = 52.1 K
System equivalent noise temperature, Ts = 298 + 52 = 350 K
Gain = 55 dB = 316,228
Output noise power = Gain x kTsB = 1.145 uW = -29.4 dBm
Output S/N = 14.4 dB

The Input S/N to Output S/N ratio is equal to the LNB noise figure when the antenna noise temperature is equal to the ambient temperature.

[6]

Model answer to Q 1(e): Calculation

Briefly explain why LO leakage is important for a military radar system. If the above LNB is used with an antenna having a gain of 35 dBi, calculate the EIRP after quoting a typical LO power level from the receiver.

Electronic counter measures include detecting the first local oscillator from a radar system; turning the radar into a target. As a result, the LO leakage levels must be kept very low indeed. The radar's EIRP = - 50 dBm + 35 dB = - 15 dBm.

[2]

Model answer to Q 1(f): Calculation

State the Friis Link equation. If both the radar and electronic counter measure (ECM) receiver have 35 dBi gain antennas, using the EIRP calculated in 1(e), determine the maximum distance at which the radar can be detected by an ECM having a minimum receiver signal level of -120 dBm.

Transmit power = - 50 dBm = 10 nW
Receiver power = -120 dBm = 1 fW
Antenna gain = 3162
Wavelength = 26.49 mm

Maximum range = 37 km or 23 miles

The Solutions for E4.18, 2013

[3]

Model answer to Q 2(a): Texbook

State the simple expression for differential-phase group delay, given the transfer function for a linear 2-port network.

Transfer function:

$$H(j\omega) = |H(j\omega)|\, e^{j\angle H(j\omega)}$$

Differential-phase group delay (also known as envelope delay):

$$\tau(\omega) = -\frac{\partial \angle H(\omega)}{\partial \omega}$$

Ideal delay element has the following transfer function:

$$H(j\omega) = e^{-j\omega T} \; where\; delay\; T \neq f(\omega)$$

[3]

Model answer to Q 2(b): Texbook

Briefly explain the importance of differential-phase group delay when designing RF circuits and briefly explain the related issue of causality.

The delay must be near-constant within the pass band of operation, so that the Fourier signal components having different frequencies experience the same delay and can thus re-construct the original time-domain envelope signal with minimal distortion. A negative differential-phase group delay cannot be the same as the transit time delay though the network, otherwise there would be a signal output before a signal entered the network.

[2]

Model answer to Q 2(c): New Derivation and Application of Textbook

The attenuation of a signal through a narrow-band BPF can be approximated by the expression given in (2.1):

$$\propto(\omega) \approx e^{-\left(\omega_o \tau(\omega) / \overline{Qu(\omega_o)}\right)} \quad [\mathrm{Np}] \qquad (2.1)$$

All variables have their usual meaning.

From (2.1), derive a simple expression for excess insertion loss (from the ideal), stating any assumptions. Given a frequency-independent average unloaded quality factor, sketch the frequency response for the excess insertion loss.

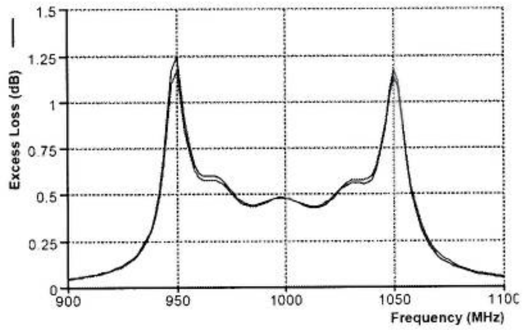
Insertion Loss, $\mathrm{L}(\omega) = 10\log_{10}\{\propto(\omega)\}^2 \approx -8.686\,\frac{\omega_o \tau(\omega)}{\overline{Qu(\omega_o)}}$ [dB]

The ideal insertion loss has and lossless components (i.e. with infinite unloaded quality factor):

$$\mathrm{Lo}(\omega) \rightarrow 0 \; when\; one\; assumes\; \overline{Qu(\omega_o)} \rightarrow \infty$$

Excess insertion loss:

$$\Delta\mathrm{L}(\omega) = \mathrm{Lo}(\omega) - \mathrm{L}(\omega) \approx 8.686\,\frac{\omega_o \tau(\omega)}{\overline{Qu(\omega_o)}} \;[\mathrm{dB}]$$



[10]

Figure 2 shows the frequency responses for a filter.

Model answer to Q 2(d): New Derivation and Application of Textbook

Figure 2 shows frequency responses for a filter.

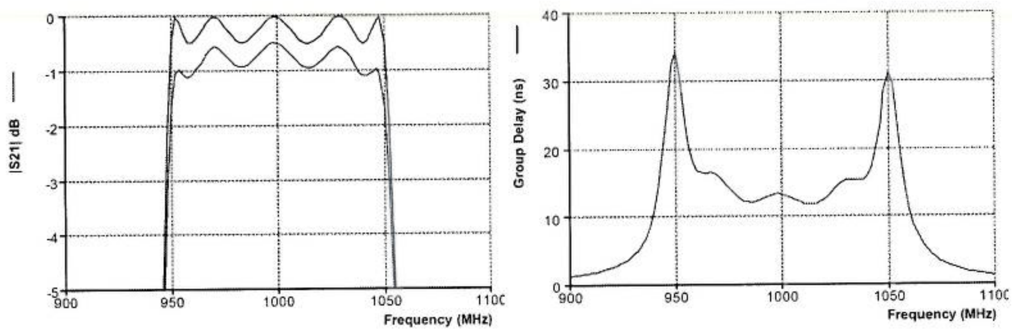


Figure 2: (Left) Insertion losses – ideal (top) and measured (bottom);

(Right) Measured differential-delay group delay

(i) By observation of the ideal insertion loss performance, state which family of filter approximations this filter belongs to and state its order. Also estimate the fractional bandwidth and loaded quality factor for this filter.

This is a 4th order Chebycheff band-pass filter. The fractional bandwidth is 100/1000 =10 % and loaded quality factor is 1000/100 = 10.

[2]

(ii) By observation from the measured results, and using the expression derived in 2(c), estimate the minimum unloaded quality factor for the filter's components.

$$\overline{Qu(\omega_o)} \approx 8.686\,\frac{\omega_o \tau(\omega)}{\Delta \mathrm{L}(\omega)}$$

From the measured results, at the centre frequency, the measured differential-phase group delay is ~13 ns and excess loss is ~0.5 dB. Therefore, the minimum unloaded quality factor for the filter's components is 1,419.

[3]

Model answer to Q 3(a): Textbook and Calculated Example

(i) For a lossless linear two-port network, state the simple equation that show the relationship between insertion loss and return loss.

$$Insertion\ loss = 10log_{10}|S_{21}|^2$$

$$Return\ Loss = 10log_{10}|S_{11}|^2$$

$$For\ a\ lossless\ linear\ 2-port\ network, 1 \equiv |S_{21}|^2 + |S_{11}|^2$$

[3]

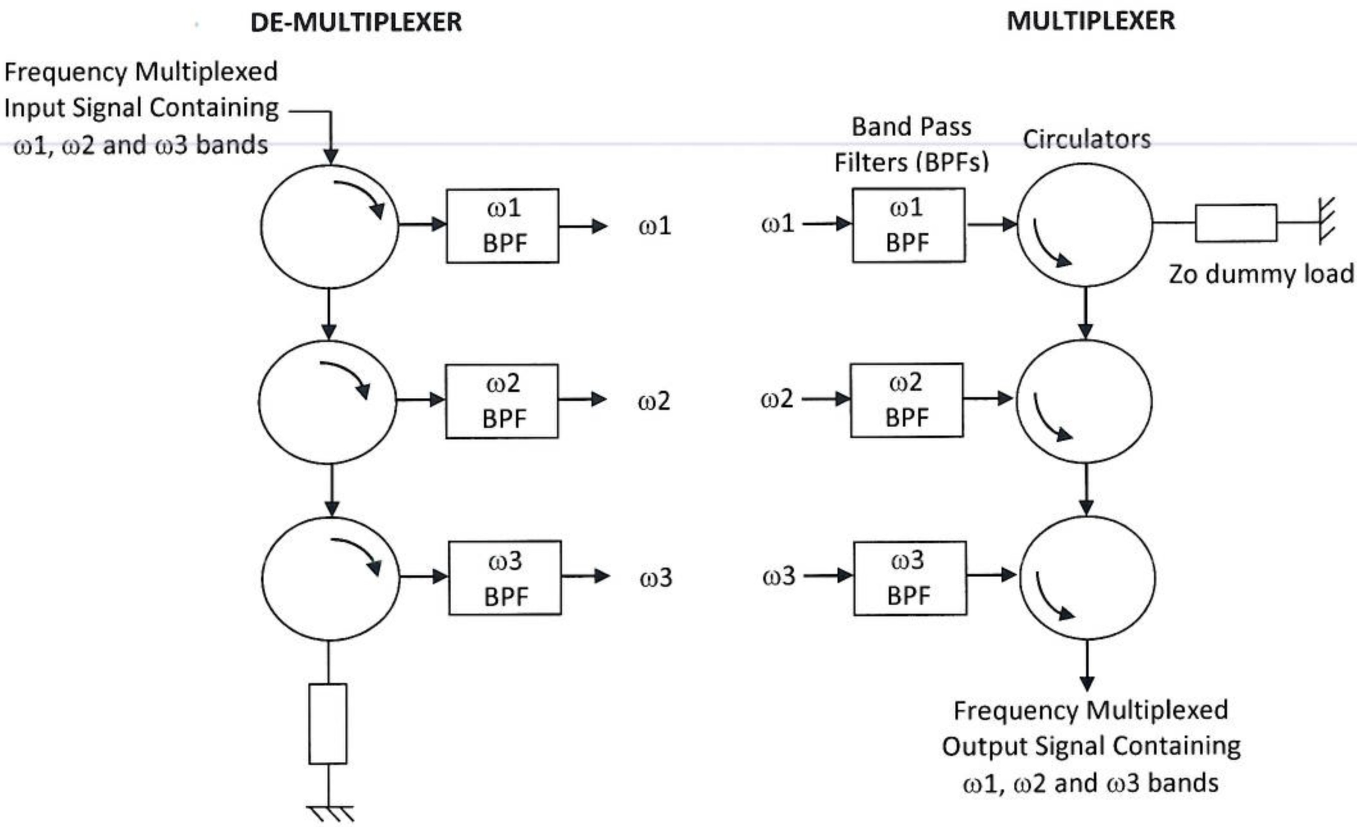
(ii) Using the equation stated in 3(a)(i), calculate the return loss when insertion loss is -1 dB.

$$|S_{21}|^2 = 0.794\ and\ |S_{11}|^2 = 0.206\ and\ Return\ Loss = -6.868\ dB$$

[2]

Model answer to Q 3(b): New Application

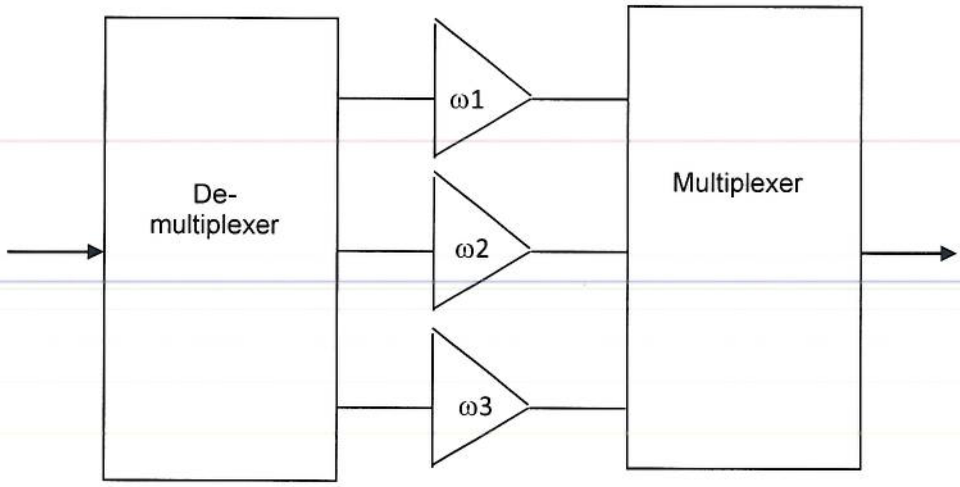
Draw a 3-channel frequency de-multiplexer and a 3-channel frequency multiplexer, employing circulators and band-pass filters.



[5]

Model answer to Q 3(c): New Application

Employing the topologies given in 3(b), draw a unilateral 3-channel amplifier. Assume that for each frequency band the associated filters and amplifiers have the same -1 dB band edge frequencies.



[3]

Model answer to Q 3(d): Calculated Example

Employing the topology from in 3(c), use simple power loss budget analysis to calculate the overall gain, given that the insertion loss of each circulator is - 0.1 dB, the mid-band insertion loss of the filters is 0 dB and the mid-band gain of the amplifiers is 10 dB. State any simplifying assumptions.

(i) Calculate the gain at mid-band, assuming that the transition frequency bandwidth is insignificant.

Total Insertion Loss = -0.1 – 0 +10 – 0 -0.1 -0.1 – 0 -0.1 -0.1 -0 -0.1 = +9.4 dB

Assuming perfectly matched circulators and no inter-stage reflections between the filters and the amplifier

[2]

(ii) Calculate the gain at the -1 dB frequency band edge, assuming that the ideal upper -1 dB band edge frequency of one channel is the same as the ideal lower -1 dB band edge frequency of the adjacent channel.

Total Insertion Loss = -0.1-1 +9 -1 -0.1 -0.1 – 6.868 -0.1 -0.1-0 -0.1 = -0.468 dB

Assuming perfectly matched circulators and no inter-stage reflections between the filters and the amplifier, but taking into account the -6.868 dB return loss at the output of the final filter seen by the circulator.

[3]

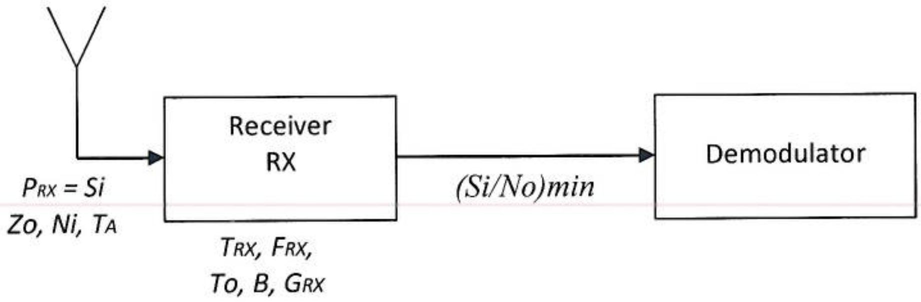
(iii) Using the results from 3(d)(i) and (ii), comment on the resulting frequency response over the entire bandwidth of the 3 channels.

The frequency response for one channel amplifier overlaps the other. However, in the region of the overlapping -1 dB band edge, rather than a large power gain there is a power loss. As a result, the roll-off for each channel will be much steeper and so the overall ripple across the entire bandwidth of the 3 channels will be severe.

[2]

Model answer to Q 4(a): Textbook

Draw the simple block diagram containing an antenna, linear receiver and demodulator. Clearly indicate the appropriate associated variables for signal power level, noise power level, power gain, bandwidth, input impedance, noise figure and noise temperature.



All variables have their usual meaning.

[2]

Model answer to Q 4(b): Textbook Derivation

Using the block diagram from 4(a), derive expressions for both the input and output noise powers.

The Available (i.e. with perfect antenna impedance matching to the receiver) Input Noise Power going into the receiver: $Ni = kT_A B$

$No = G_{RX}(kT_S B)$

System Equivalent Noise Temperature, $T_S = T_A + T_{RX}$

Antenna Noise Temperature $= T_A$

Reciever Equivalent Noise Temperarture, $T_{RX} = T_o(F_{RX} - 1)$

Ambient Temperature of the Receiver, $T_o = 273 + T\ ^oC \cong 290\ K\ at\ 17\ ^oC$

F_{RX} = Noise Factor of the Receiver

Noise Figure of the Receiver $= 10\log(\mathrm{F_{RX}})[\mathrm{dB}]$

B = Bandwidth of the Receiver, usually set by the final IF filter before the detector

$\therefore No = G_{RX}(Ni + kT_{RX}B) \quad where \quad Ni = kT_A B$

[6]

Model answer to Q 4(c): Textbook Derivation

From first principles, prove that the noise factor of the receiver is equal to the signal-to-noise power ratio at the input divided by the signal-to-noise power ratio at the output when the antenna noise temperature is equal to the ambient temperature.

Noise Factor of the Receiver, $F_{RX} = \dfrac{T_o + T_{RX}}{T_o} \Rightarrow \dfrac{Si/Ni}{So/No}$ $ONLY\ WHEN\ Ni = kT_o B$!!!

[2]

Model answer to Q 4(d): Textbook Derivation

Derive expressions for the minimum detectable signal (MDS) power in terms of the minimum output signal-to-noise ratio and also sensitivity. Briefly explain why MDS does not depend on the gain of the receiver.

$$So = G_{RX} Si$$

$$\text{Minimum Detectable Signal (MDS), } Si \,|\, \min = \frac{So \,|\, \min}{G_{RX}} = \left(\frac{No}{G_{RX}}\right) \cdot \left(\frac{So}{No}\right) | \min$$

$$\therefore Si \,|\, \min = kB\left[T_A + T_o\left(F_{RX} - 1\right)\right] \cdot \left(\frac{So}{No}\right) | \min$$

Note that the MDS does not depend on the gain of the receiver, since both the input signal and the input noise are amplified equally.

Receiver Voltage Sensitivity (or Receiver Sensitivity or just Sensitivity):

$$Vsi(peak) \,|\, \min = \sqrt{2ZoSi \,|\, \min}$$

$$Zo = \text{Antenna Input Impedance (e.g. 50 } \Omega)$$

[4]

Model answer to Q 4(e): Computed Example

The first generation analogue Advanced Mobile Phone System (AMPS) has a minimum output signal-to-noise ratio of 18 dB, 30 kHz channel bandwidth, and 6.2 dB noise figure. Assume that the antenna noise temperature is the same as the ambient temperature. Calculate the minimum detectable signal power and sensitivity for this receiver. Assume typical values for ambient temperature and antenna input impedance.

For the special case when $T_A = T_o$:

$$No = G_{RX} F_{RX}\left(kT_o B\right) \quad \therefore Si \,|\, \min = F_{RX}\left(kT_o B\right) \cdot \left(\frac{So}{No}\right) | \min$$

$$\therefore Si \,|\, \min[dBm] = F_{RX}[dB] + 10\log\left(kT_o\right) + 10\log B + \left(\frac{So}{No}\right) | \min[dB]$$

$$where,\ 10\log\left(kT_o\right) = -204\ dBW/Hz \equiv -174\ dBm/Hz \text{ at } 17\ ^\circ C$$

If we assume an ambient temperature of 17 C = 290 K

$$\therefore Si \,|\, \min = -105\ dBm = 31.6\, fW$$

If we assume an impedance of 50 Ohms at the antenna input port. Sensitivity is:

$$Vsi(peak) \,|\, \min = 1.8 \mu V$$

[6]

Model answer to Q 5(a): New Application of Theory

For a -0.1 dB worst-case pass band insertion loss, design a lumped-element *L-C* band stop filter (BSF) to meet the following specifications:

Lower pass band -3 dB cut-off frequency:	9.25 GHz
Upper pass band -3 dB cut-off frequency:	10.75 GHz
Band stop attenuation:	> 110 dB
Stop band bandwidth:	150 MHz
Source impedance, *Zs*:	25 Ω

Load impedance, Z_L: 50 Ω

Calculated the centre frequency, pass band bandwidth *Bp* and prototype *f/fc* ratio.

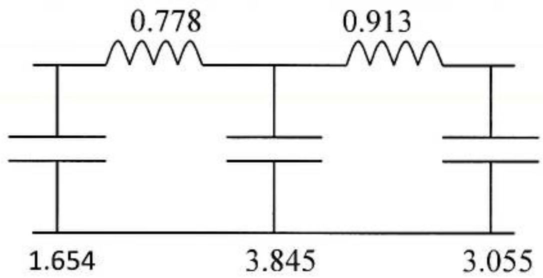
-3 dB cut-off frequencies are at f_{P1} = 9.25 GHz and f_{P2} = 10.75 GHz
Centre frequency, fo = $\sqrt{(f_{P1}\, f_{P2})}$ = 9.97 GHz
Pass band bandwidth, Bp = f_{P1}- f_{P2} = 1.5 GHz
Stop band bandwidth, Bs = 150 MHz
f/fc = Bp/Bs = 10

[3]

Model answer to Q 5(d): New Application of Theory

From the standard filter curves and tables supplied, determine the normalised component values for the low-pass prototype that meet the required specification. Justify your choice of curve and table.

From the attenuation curves, the 5th order 0.1 dB ripple Chebyshev filter with R_s/R_L = 0.5 meets the specification with a stop band attenuation of 113 dB (i.e. a margin of 3 dB). The normalised values for the low-pass prototype is given below:



[5]

Model answer to Q 5(c): New Application of Theory

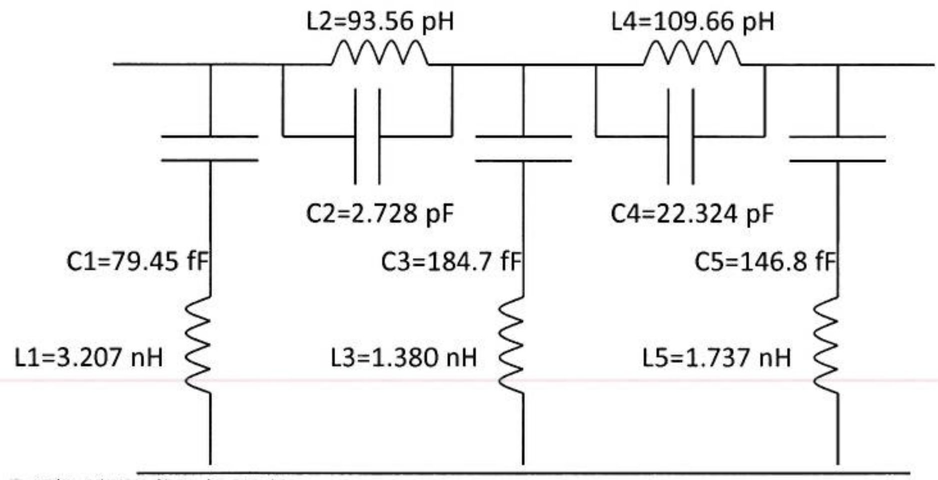
Draw the topology for the BFP and calculate the component values.

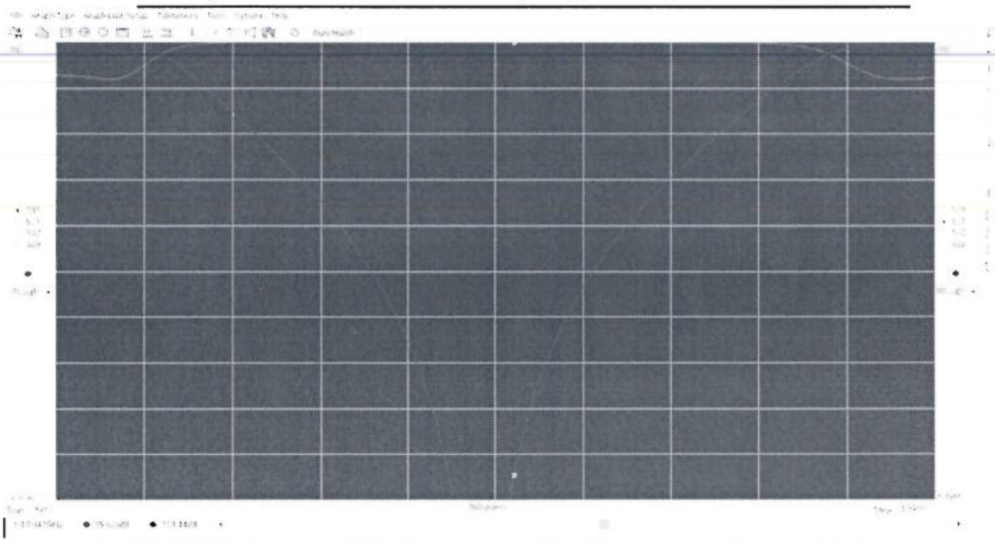
For a band stop filter, the capacitors are replaced by a series L-C resonators and the inductors are replaced by parallel L-C resonators.
The un-normalized shunt connected series tuned circuit element values are:

$$Cs = \frac{BpCn}{2\pi f_o^2 R_L} \quad and \quad Ls = \frac{R_L}{2\pi BpL_n}$$

The un-normalized series connected parallel tuned circuit element values are:

$$Cp = \frac{1}{2\pi BpCnR_L} \quad and \quad Lp = \frac{BpLnR_L}{2\pi f_o^2}$$





[10]

Model answer to Q 5(d): New Application of Theory

Comment on the range of component values and suggest more practical methods for implementing the filter.

The inductance values range from 94 pH to 3.2 nH, while the capacitors range from 79 fF to 2.7 pF, a ratio of 34:1 in both cases. This makes it very difficult to achieve such a large range with the same technology. Moreover, the precision to 3 decimal places is also impractical.

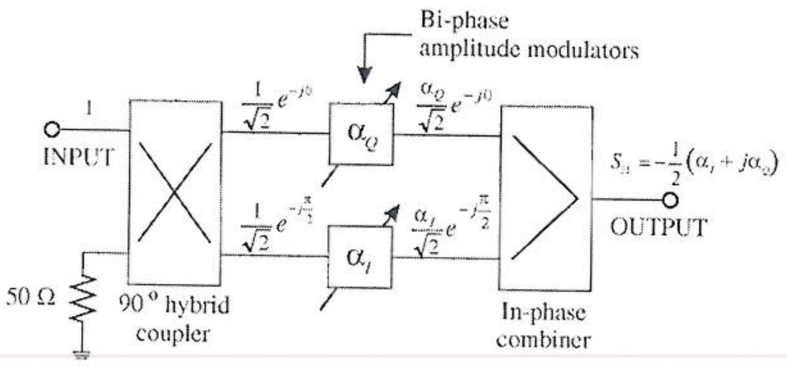
To solve the first problem, impedance/admittance inverters can be employed. While distributed-element components can be employed to replace the more sensitive lumped-element components.

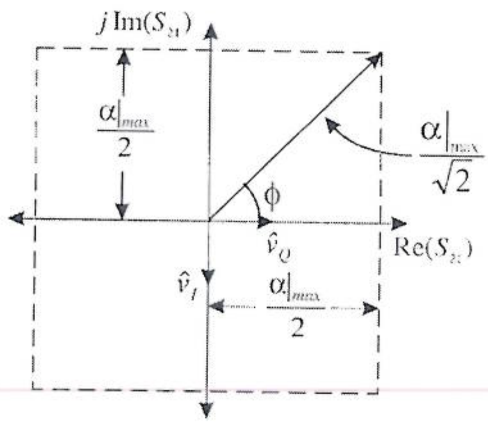
[2]

Model answer to Q 6(a): Presented in Lecture

Draw the block diagram of a simple 2-channel I-Q vector modulator and explain the basic principle of operation. Also, give two examples of applications for this circuit.

The basic 2-channel I-Q vector modulator is shown below. The input signal is split into 2 quadrature channels, using a quadrature power coupler. Each signals in each channel than then be modulated by independent bi-phase amplitude modulators. The two resulting signals are then power combined using an in-phase power combiner.





This circuit can be used as direct-carrier digital modulators and can also be found in phase array antenna applications, where each radiating element has its own vector control.

[3]

Model answer to Q 6(b): Extension of lecture presentation

Using simple S-parameter analysis, derive equations for all the S-parameters for the simple I-Q vector modulator in 6(a). HINT: assume that directional couplers are lossless and reciprocal. Also, treat the bi-phase amplitude modulators as simple S-parameter blocks.

The following superscript notations L, I, Q, W represent the quadrature directional coupler, In-phase modulator, quadrature phase modulator and in-phase power coupler, respectively.

$$S_{21} = S_{21}^L S_{21}^I S_{12}^W + S_{41}^L S_{21}^Q S_{13}^W$$

$$S_{21}^L = S_{12}^L = \frac{1}{\sqrt{2}} \quad and \quad S_{12}^W = S_{41}^L = S_{14}^L = S_{13}^W = \frac{-j}{\sqrt{2}}$$

$$\therefore S_{21} = \frac{-1}{2}\left(S_{21}^Q + jS_{21}^I\right) = S_{12}$$

$$S_{11} = S_{21}^L S_{11}^I S_{12}^L + S_{41}^L S_{11}^Q S_{14}^L$$

$$\therefore S_{11} = \frac{1}{2}\left(S_{11}^I - S_{11}^Q\right)$$

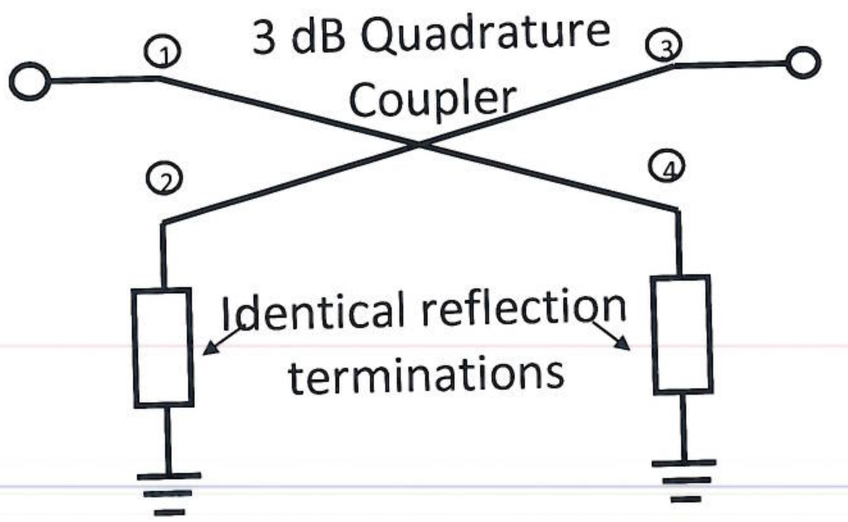
$$S_{22} = S_{21}^W S_{22}^I S_{12}^W + S_{31}^W S_{22}^Q S_{13}^W$$

$$\therefore S_{11} = \frac{-1}{2}\left(S_{22}^I + S_{22}^Q\right)$$

[5]

Model answer to Q 6(c): Extension of lecture presentation

Draw the block diagram for a simple bi-phase reflection-type amplitude modulator.



[3]

Model answer to Q 6(d): Extension of lecture presentation

Using simple S-parameter analysis, derive equations for all the S-parameters for the simple bi-phase amplitude modulator in 6(c). HINT: assume that directional couplers are lossless and reciprocal.

The following superscript notations C represent the quadrature power coupler and the subscript T represents the reflection termination.

$$S_{21} = S_{21}^{C}\rho_T S_{32}^{C} + S_{41}^{C}\rho_T S_{34}^{C}$$

$$S_{21}^{C} = S_{12}^{C} = S_{34}^{C} = \frac{1}{\sqrt{2}} \quad and \quad S_{32}^{C} = S_{41}^{C} = S_{14}^{C} = \frac{-j}{\sqrt{2}}$$

$$\therefore S_{21} = -j\rho_T = S_{12}$$

$$S_{11} = S_{21}^{C}\rho_T S_{12}^{C} + S_{41}^{C}\rho_T S_{14}^{C}$$

$$\therefore S_{11} = 0 = S_{22}$$

[5]

Model answer to Q 6(e): Computed example

Calculate the power insertion loss for the complete 2-channel I-Q vector modulator having the following conditions:

i) All reflection terminations are short circuits

$$\rho_T^I = \rho_T^Q = -1$$
$$\therefore S_{21}^I = S_{21}^Q = +j$$

$$S_{21} = \frac{-j}{2}(+j-1) \quad \therefore |S_{21}|^2 = \frac{1}{2}$$
$$\therefore Power\ Insertion\ Loss = -3dB$$

[2]

ii) The in-phase reflection terminations are a short circuit and the quadrature-phase reflection terminations are impedance matched to the coupler.

$$\rho_T^I = -1 \quad \rho_T^Q = 0$$
$$\therefore S_{21}^I = +j \quad S_{21}^Q = 0$$

$$S_{21} = \frac{1}{2} \quad \therefore |S_{21}|^2 = \frac{1}{4}$$
$$\therefore Power\ Insertion\ Loss = -6dB$$

[2]