Design of "PI" and "T" Network Attenuators for Inter-Stage Buffering

The NBB and NDA-series matched amplifiers may be cascaded in a driver chain or used adjacent to other components such as mixers, oscillators, or filters. In all such instances, it is desirable to provide isolation between adjacent components to minimize ripple due to any impedance mismatch. "PI" and "T" Network Attenuators (also known as PAD attenuators) are simple networks to insert between an amplifier chain (see Figure 1) or between an amplifier and adjacent component to minimize ripple over frequency.

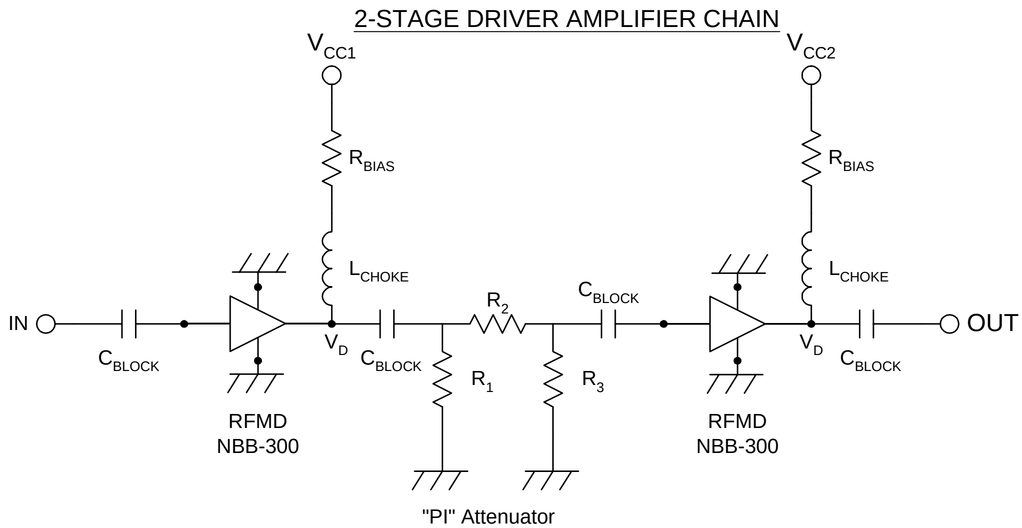
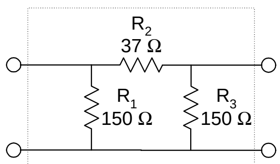


Figure 1. Two-stage driver amplifier chain using two NBB-300 amplifiers, along with a "PI" buffer network, used to minimize ripple in the amplifier chain's response. The "PI" network is symmetric and consists of two resistor values, R1 and R2.

The following example illustrates a circuit technique to analyze the "PI" network configuration.



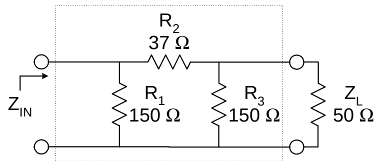
Example 1. S-Parameters for a 6dB Pi-Pad Attenuator.

Derive the four s-parameters from the 6dB Pi-Pad attenuator shown.

Solution:

Notice the "PI" attenuator shown above is a symmetrical circuit, and therefore the knowledge learned from one port may be applied to the other port.

(i) S_{11}:



$$S_{11} \overset{\Delta}{=} \Gamma_{in}\Big|_{Z_L = Z_o} = \frac{\zeta - 1}{\zeta + 1}$$ where $\zeta = \frac{Z_{in}}{Z_o}$ and is called the normalized input impedance.

Solving for Z_{in}:

$$Z_{in} = R_1 \parallel (R_2 + (R_3 \parallel R_L)) = 49.78\Omega$$

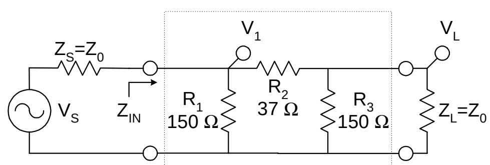
Calculating Γ_{in}:

$$\Gamma_{in} = \frac{0.996 - 1}{0.996 + 1} = 0.00203$$

Now S_{11} may be expressed in dB:

$$S_{11} = 20 \times LOG(\Gamma_{in}) = -53dB$$ (matched in a 50Ω system)

(ii) S_{21}:



$$S_{21} = 2 \times \frac{V_L}{V_S}$$

where:

$$\frac{V_L}{V_s} = \frac{V_L}{V_1} \times \frac{V_1}{V_S}\left(\frac{R_3 \parallel Z_L}{(R_3 \parallel Z_L) + R_2}\right)\left(\frac{Z_{in}}{Z_{in} + Z_s}\right) = \frac{37.5}{37.5 + 37} \times \frac{49.78}{49.78 + 50} = \frac{1}{4}$$

Therefore, S_{21} may be expressed in dBs:

$$S_{21} = 20 \times LOG\left(2 \times \frac{V_L}{V_S}\right) = 20 \times LOG\left(\frac{1}{2}\right) = -6dB$$

(iii) S_{12}:

From Symmetry arguments:

$$S_{12} = S_{21} = -6dB$$

(iv) S_{22}:

From Symmetry arguments:

$$S_{22} = S_{11} = -53dB$$ (matched in a 50Ω system).

Generally speaking the same arguments and techniques apply to a “T” configured network. The general representation of each network is shown in Figure 2.

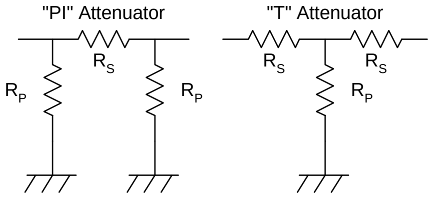


Figure 2. General representation of “PI” and “T” network with parallel (Rp) and series (Rs) resistors.

The values for a 50Ω matched “T” attenuator network are given in Table 1. The complete values for a 50Ω matched “PI” attenuator network are given in Table 2. The attenuation value (S_{21}) usually determines which network is more realistic to construct.

Table 1. Tabular Summary of Values for “T” Attenuator Matched in a 50Ω System

T Pad Attenuator Values			
R_S (Ω)	R_P (Ω)	S_{21} (dB)	R_{IN} (Ω)
2	624.0	-0.7	50
4	310.5	-1.4	50
6	205.3	-2.1	50
8	152.3	-2.8	50
10	120.0	-3.5	50
12	98.2	-4.3	50
14	82.3	-5.0	50
16	70.1	-5.8	50
18	60.4	-6.5	50
20	52.5	-7.4	50
22	45.8	-8.2	50
24	40.1	-9.1	50
26	35.1	-10.0	50
28	30.6	-11.0	50
30	26.7	12.0	50
32	23.1	-13.2	50
34	19.8	-14.4	50
36	16.7	-15.8	50
38	13.9	-17.3	50
40	11.3	-19.1	50
42	8.8	-21.2	50
44	6.4	-23.9	50
46	4.2	-27.6	50
48	2.0	-33.8	50

Table 2. Tabular Summary of Series and Parallel Values Required to Construct a "PI" Attenuator Matched to a 50Ω System.

PI Pad Attenuator Values								
R_P (Ω)	R_S (Ω)	S_{21} (dB)	R_{IN} (Ω)		R_P (Ω)	R_S (Ω)	S_{21} (dB)	R_{IN} (Ω)
60	272.73	-20.83	50		530	9.52	-1.64	50
70	145.83	-15.56	50		540	9.34	-1.61	50
80	102.56	-12.74	50		550	9.17	-1.58	50
90	80.36	-10.88	50		560	9.00	-1.56	50
100	66.67	-9.54	50		570	8.84	-1.53	50
110	57.29	-8.52	50		580	8.69	-1.50	50
120	50.42	-7.71	50		590	8.54	-1.48	50
130	45.14	-7.04	50		600	8.39	1.45	50
140	40.94	-6.49	50		610	8.25	-1.43	50
150	37.50	-6.02	50		620	8.12	-1.40	50
160	34.63	-5.62	50		630	7.99	-1.38	50
170	32.20	-5.26	50		640	7.86	-1.36	50
180	30.10	-4.96	50		650	7.74	-1.34	50
190	28.27	-4.68	50		660	7.62	-1.32	50
200	26.67	-4.44	50		670	7.50	-1.30	50
210	25.24	-4.22	50		680	7.39	-1.28	50
220	23.97	-4.02	50		690	7.28	-1.26	50
230	22.82	-3.84	50		700	7.18	-1.24	50
240	21.78	-3.67	50		710	7.08	-1.23	50
250	20.83	-3.52	50		720	6.98	-1.21	50
260	19.97	-3.38	50		730	6.88	-1.19	50
270	19.18	-3.25	50		740	6.79	-1.18	50
280	18.45	-3.14	50		750	6.70	-1.16	50
290	17.77	-3.03	50		760	6.61	-1.14	50
300	17.14	-2.92	50		770	6.52	-1.13	50
310	16.56	-2.83	50		780	6.44	-1.12	50
320	16.02	-2.74	50		790	6.35	-1.10	50
330	15.51	-2.65	50		800	6.27	-1.09	50
340	15.03	-2.57	50		810	6.20	-1.07	50
350	14.58	-2.50	50		820	6.12	-1.06	50
360	14.16	-2.43	50		830	6.05	-1.05	50
370	13.76	-2.36	50		840	5.97	-1.04	50
380	13.39	-2.30	50		850	5.90	-1.02	50
390	13.03	-2.24	50		860	5.83	-1.01	50
400	12.70	-2.18	50		870	5.77	-1.00	50
410	12.38	-2.13	50		880	5.70	-0.99	50
420	12.08	-2.08	50		890	5.64	-0.98	50
430	11.79	-2.03	50		900	5.57	-0.97	50
440	11.51	-1.98	50		910	5.51	-0.96	50
450	11.25	-1.94	50		920	5.45	-0.95	50
460	11.00	-1.90	50		930	5.39	-0.93	50
470	10.76	-1.86	50		940	5.33	-0.92	50
480	10.53	-1.82	50		950	5.28	-0.92	50
490	10.31	-1.78	50		960	5.22	-0.91	50
500	10.10	-1.74	50		970	5.17	-0.90	50
510	9.90	-1.71	50		980	5.12	-0.89	50
520	9.71	-1.68	50		990	5.06	-0.88	50