Chapter Four

ALTERNATIVE ALIGNMENTS

NOW THAT YOU ARE experts in vented loudspeaker system design, construction, and adjustment, it's time to examine some additional alignment possibilities. You may have the impression that once you've selected the drivers you are locked into the unique design spelled out by the tables in my first article (*SB* 4/80, p. 7). But in loudspeaker design as in life, things are not that simple. In fact, there are many reasonable alternatives. I will discuss some of the unequalized possibilities here and go into equalized alignments in a later article.

OLD AND NEW ALIGNMENTS

Recall that the tables in my first article list what are called fourth order quasi-Butterworth (QB3) and fourth order Chebyshev (C4) alignments which yield QB3 and C4 responses. If you visualize each point in the rectangle in *Fig. 1* as corresponding to a possible fourth order response, then the QB3 and C4 responses will all lie on the curves indicated. Many other points in the rectangle represent good loudspeaker responses; the problem is to distinguish them mathematically from the bad ones. I have chosen several alternatives for which alignment tables are relatively easy to construct, and will show you a representative response curve for each alternative alignment type, comparing them so you can decide which alignments are acceptable by your criteria.

Two new response types can be obtained by extending the QB3 and C4 alignments to other Q_T values. The extension of the C4 is called a sub-Chebyshev (SC4), and Small mentions it[1] as a possibly attractive alternative. The QB3 extension has not been mentioned in the literature; so I will call it a super-quasi-Butterworth (SQB3) because it covers higher Q_T values. These

FIG. 1

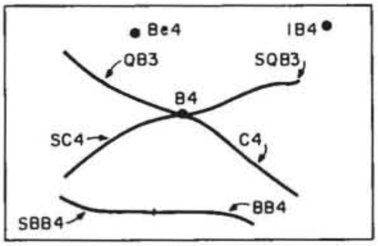

Fig. 1. The universe of possible fourth order responses.

FIG. 2

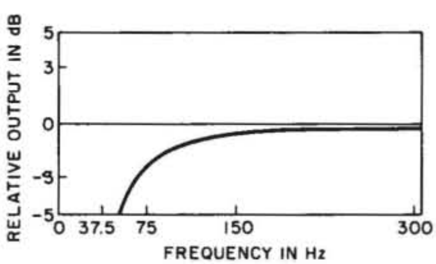

Fig. 2. Simulated response of a SBB4 alignment with f_s=35 Hz., Q_L=7 and Q_T=.30.

FIG. 3

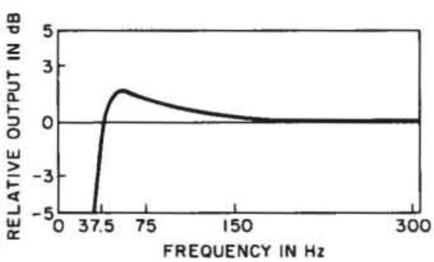

Fig. 3. Simulated response of a BB4 alignment with f_s=35 Hz., Q_L=7 and Q_t=.50.

TABLE I
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS:
Q_L = 3

Q_t	H	Alpha	F_3/F_s	PK(dB)
.20	1.0000	5.4444	3.5401	
.21	1.0000	4.9031	3.3255	
.22	1.0000	4.4355	3.1280	
.23	1.0000	4.0290	2.9454	
.24	1.0000	3.6736	2.7761	
.25	1.0000	3.3611	2.6186	
.26	1.0000	3.0850	2.4718	
.27	1.0000	2.8399	2.3347	
.28	1.0000	2.6213	2.2068	
.29	1.0000	2.4257	2.0873	
.30	1.0000	2.2500	1.9759	
.31	1.0000	2.0916	1.8724	
.32	1.0000	1.9484	1.7763	
.33	1.0000	1.8114	1.6876	
.34	1.0000	1.7002	1.6060	
.35	1.0000	1.5924	1.5313	
.36	1.0000	1.4938	1.4632	
.37	1.0000	1.4035	1.4014	
.38	1.0000	1.3205	1.3456	
.39	1.0000	1.2441	1.2952	
.40	1.0000	1.1736	1.2499	
.41	1.0000	1.1085	1.2091	.01
.42	1.0000	1.0482	1.1724	.05
.43	1.0000	.9923	1.1394	.12
.44	1.0000	.9403	1.1096	.20
.45	1.0000	.8920	1.0828	.30
.46	1.0000	.8469	1.0585	.41
.47	1.0000	.8049	1.0365	.53
.48	1.0000	.7656	1.0165	.66
.49	1.0000	.7289	.9982	.79
.50	1.0000	.6944	.9815	.93
.51	1.0000	.6621	.9663	1.08
.52	1.0000	.6318	.9523	1.23
.53	1.0000	.6033	.9394	1.38
.54	1.0000	.5765	.9275	1.54
.55	1.0000	.5512	.9165	1.70
.56	1.0000	.5274	.9063	1.86
.57	1.0000	.5048	.8968	2.02
.58	1.0000	.4836	.8880	2.18
.59	1.0000	.4635	.8797	2.34
.60	1.0000	.4444	.8720	2.50
.61	1.0000	.4264	.8649	2.66
.62	1.0000	.4093	.8581	2.82
.63	1.0000	.3931	.8518	2.98
.64	1.0000	.3777	.8458	3.14
.65	1.0000	.3631	.8402	3.30
.66	1.0000	.3492	.8349	3.46
.67	1.0000	.3359	.8299	3.61
.68	1.0000	.3233	.8252	3.77
.69	1.0000	.3113	.8207	3.92
.70	1.0000	.2999	.8165	4.08

two new response series appear in *Fig. 1* as extensions of the QB3 and C4 curves.

As an example of a completely different series I picked Hoge's[2] fourth order boom box responses which cover the high Q_T range and are abbreviated BB4. This series also has an extension to lower Q_T's which I will call a sub-boom box and denote SBB4. These two series are represented by the third curve in *Fig. 1*.

As well as response series, there are discrete responses corresponding to a single point in *Fig. 1*. A discrete response can be realized for only one value of Q_T once Q_L is fixed. Probably the best known is the fourth order But-

FIG. 4

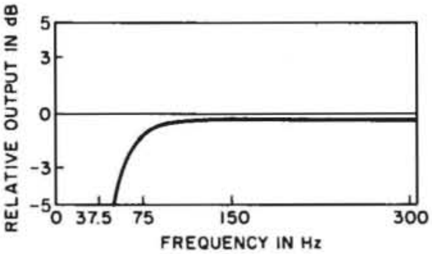

Fig. 4. Simulated response of a QB3 alignment with f_S=35 Hz., Q_L=7 and Q_T=.30.

FIG. 5

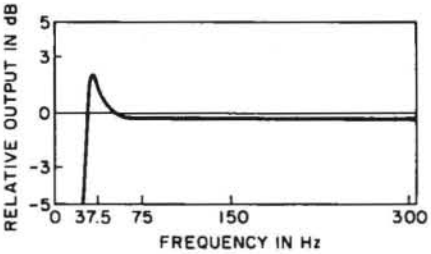

Fig. 5. Simulated response of a SQB3 alignment with f_S=35 Hz., Q_L=7 and Q_T=.50.

FIG. 6

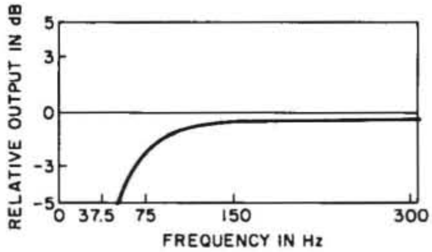

Fig. 6. Simulated response of a SC4 alignment with f_S=35 Hz., Q_L=7 and Q_T=.30.

TABLE II
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS: Q_L = 5

Q_T	H	Alpha	F_3/F_S	PK(dB)
.20	1.0000	5.7600	3.4202	
.21	1.0000	5.2027	3.2041	
.22	1.0000	4.7207	3.0051	
.23	1.0000	4.3011	2.8210	
.24	1.0000	3.9336	2.6502	
.25	1.0000	3.4100	2.4914	
.26	1.0000	3.3236	2.3435	
.27	1.0000	3.0690	2.2057	
.28	1.0000	2.8416	2.0774	
.29	1.0000	2.6378	1.9582	
.30	1.0000	2.4544	1.8476	
.31	1.0000	2.2889	1.7456	
.32	1.0000	2.1389	1.6519	
.33	1.0000	2.0027	1.5664	
.34	1.0000	1.8785	1.4887	
.35	1.0000	1.7651	1.4185	
.36	1.0000	1.6612	1.3555	
.37	1.0000	1.5659	1.2991	
.38	1.0000	1.4781	1.2487	
.39	1.0000	1.3972	1.2037	.02
.40	1.0000	1.3225	1.1637	.07
.41	1.0000	1.2533	1.1280	.15
.42	1.0000	1.1891	1.0961	.25
.43	1.0000	1.1295	1.0676	.36
.44	1.0000	1.0741	1.0420	.50
.45	1.0000	1.0223	1.0189	.64
.46	1.0000	.9741	.9981	.79
.47	1.0000	.9290	.9793	.96
.48	1.0000	.8867	.9622	1.12
.49	1.0000	.8472	.9467	1.30
.50	1.0000	.8100	.9324	1.47
.51	1.0000	.7751	.9194	1.65
.52	1.0000	.7422	.9075	1.84
.53	1.0000	.7113	.8965	2.02
.54	1.0000	.6822	.8863	2.21
.55	1.0000	.6546	.0770	2.39
.56	1.0000	.6286	.8683	2.58
.57	1.0000	.6040	.8602	2.77
.58	1.0000	.5807	.8526	2.96
.59	1.0000	.5587	.8436	3.15
.60	1.0000	.5378	.8390	3.33
.61	1.0000	.5179	.8329	3.52
.62	1.0000	.4991	.8271	3.70
.63	1.0000	.4812	.8217	3.89
.64	1.0000	.4641	.8166	4.07
.65	1.0000	.4479	.8118	4.25
.66	1.0000	.4324	.8073	4.43
.67	1.0000	.4177	.8030	4.61
.68	1.0000	.4036	.7989	4.79
.69	1.0000	.3902	.7951	4.97
.70	1.0000	.3773	.7915	5.14

TABLE III
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS: Q_L = 7

Q_T	H	Alpha	F_3/F_S	PK(dB)
.20	1.0000	5.8980	3.3686	
.21	1.0000	5.3339	3.1518	
.22	1.0000	4.8457	2.9521	
.23	1.0000	4.4204	2.7674	
.24	1.0000	4.0478	2.5960	
.25	1.0000	3.7114	2.4366	
.26	1.0000	3.4286	2.2883	
.27	1.0000	3.1699	2.1503	
.28	1.0000	2.9388	2.0220	
.29	1.0000	2.7315	1.9031	
.30	1.0000	2.5448	1.7932	
.31	1.0000	2.3761	1.6922	
.32	1.0000	2.2233	1.6000	
.33	1.0000	2.0843	1.5162	
.34	1.0000	1.9576	1.4406	
.35	1.0000	1.8419	1.3728	
.36	1.0000	1.7357	1.3122	
.37	1.0000	1.6392	1.2583	
.38	1.0000	1.5484	1.2104	.01
.39	1.0000	1.4656	1.1679	.06
.40	1.0000	1.3890	1.1302	.14
.41	1.0000	1.3181	1.0966	.24
.42	1.0000	1.2523	1.0667	.37
.43	1.0000	1.1911	1.0399	.51
.44	1.0000	1.1341	1.0160	.66
.45	1.0000	1.0809	.9944	.82
.46	1.0000	1.0313	.9750	1.00
.47	1.0000	.9849	.9574	1.17
.48	1.0000	.9414	.9415	1.36
.49	1.0000	.9006	.9270	1.55
.50	1.0000	.8622	.9137	1.74
.51	1.0000	.8262	.9015	1.93
.52	1.0000	.7923	.8904	2.13
.53	1.0000	.7603	.8801	2.33
.54	1.0000	.7302	.8706	2.53
.55	1.0000	.7017	.8619	2.73
.56	1.0000	.6747	.8537	2.93
.57	1.0000	.6493	.8462	3.13
.58	1.0000	.6251	.8391	3.33
.59	1.0000	.6022	.8325	3.53
.60	1.0000	.5805	.8264	3.73
.61	1.0000	.5599	.8206	3.93
.62	1.0000	.5403	.8152	4.12
.63	1.0000	.5216	.8102	4.32
.64	1.0000	.5038	.8054	4.51
.65	1.0000	.4869	.8009	4.70
.66	1.0000	.4708	.7967	4.90
.67	1.0000	.4554	.7926	5.09
.68	1.0000	.4407	.7889	5.27
.69	1.0000	.4267	.7853	5.46
.70	1.0000	.4133	.7819	5.65

TABLE IV
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS: Q_L = 10

Q_T	H	Alpha	F_3/F_S	PK(dB)
.20	1.0000	6.0025	3.3290	
.21	1.0000	5.4333	3.1125	
.22	1.0000	4.9405	2.9122	
.23	1.0000	4.5110	2.7270	
.24	1.0000	4.1344	2.5551	
.25	1.0000	3.8025	2.3954	
.26	1.0000	3.5094	2.2469	
.27	1.0000	3.2467	2.1087	
.28	1.0000	3.0127	1.9805	
.29	1.0000	2.8027	1.8619	
.30	1.0000	2.6136	1.7527	
.31	1.0000	2.4427	1.6527	
.32	1.0000	2.2877	1.5617	
.33	1.0000	2.1467	1.4794	
.34	1.0000	2.0181	1.4056	
.35	1.0000	1.9005	1.3397	
.36	1.0000	1.7926	1.2810	
.37	1.0000	1.6935	1.2291	.00
.38	1.0000	1.6022	1.1831	.04
.39	1.0000	1.5180	1.1424	.11
.40	1.0000	1.4400	1.1063	.21
.41	1.0000	1.3678	1.0743	.33
.42	1.0000	1.3007	1.0458	.47
.43	1.0000	1.2383	1.0204	.63
.44	1.0000	1.1802	.9976	.80
.45	1.0000	1.1260	.9771	.98
.46	1.0000	1.0753	.9587	1.16
.47	1.0000	1.0279	.9420	1.35
.48	1.0000	.9834	.9268	1.55
.49	1.0000	.9417	.9130	1.75
.50	1.0000	.9025	.9004	1.95
.51	1.0000	.8656	.8889	2.16
.52	1.0000	.8309	.8783	2.37
.53	1.0000	.7982	.8685	2.58
.54	1.0000	.7672	.8595	2.79
.55	1.0000	.7380	.8512	3.00
.56	1.0000	.7104	.8434	3.21
.57	1.0000	.6842	.8362	3.41
.58	1.0000	.6595	.8295	3.62
.59	1.0000	.6359	.8233	3.83
.60	1.0000	.6136	.8174	4.04
.61	1.0000	.5924	.8120	4.25
.62	1.0000	.5722	.8068	4.45
.63	1.0000	.5530	.8020	4.66
.64	1.0000	.5347	.7975	4.86
.65	1.0000	.5173	.7932	5.06
.66	1.0000	.5007	.7891	5.26
.67	1.0000	.4848	.7853	5.46
.68	1.0000	.4696	.7817	5.65
.69	1.0000	.4551	.7783	5.85
.70	1.0000	.4413	.7751	6.04

terworth (B4). From its position in *Fig. 1* you can see it may be considered as a transition between quasi-Butterworth and Chebyshev responses. As such it marks the change from QB3 to C4 in the first article's alignment tables. The fourth order Bessel response (Be4) is said to have superior time delay behavior; however, this is not necessarily true since the time delay property is attributable to a low pass Bessel filter, not to the high pass filter used to model loudspeaker response. The inter-order Butterworth (IB4) is a discrete response used by Thiele.

FIG. 7

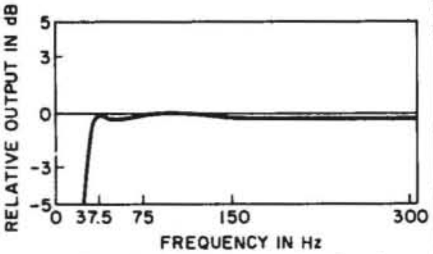

Fig. 7. Simulated response of a C4 alignment with f_S=35 Hz., Q_L=7 and Q_T=.50.

FIG. 8

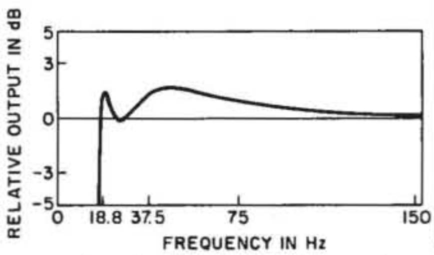

Fig. 8. Simulated response of a C4 alignment with f_S=35 Hz., Q_L=7 and Q_T=.80.

FIG.9

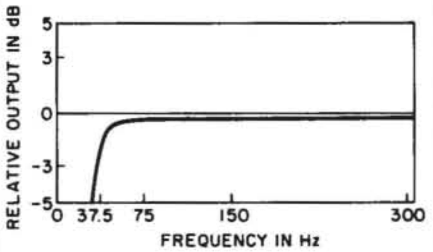

Fig. 9. Simulated response of a B4 alignment with f_S=35 Hz.

TABLE V
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS:
Q_L = 15

Q_T	H	Alpha	F_3/F_S	PK(dB)
.20	1.0000	6.0844	3.2996	
.21	1.0000	5.5113	3.0818	
.22	1.0000	5.0149	2.8811	
.23	1.0000	4.5821	2.6955	
.24	1.0000	4.2025	2.5233	
.25	1.0000	3.8678	2.3633	
.26	1.0000	3.5711	2.2146	
.27	1.0000	3.3070	2.0764	
.28	1.0000	3.0708	1.9483	
.29	1.0000	2.8588	1.8301	
.30	1.0000	2.6678	1.7214	
.31	1.0000	2.4950	1.6222	
.32	1.0000	2.3384	1.5323	
.33	1.0000	2.1958	1.4514	
.34	1.0000	2.0657	1.3790	
.35	1.0000	1.9467	1.3146	
.36	1.0000	1.8375	1.2576	
.37	1.0000	1.7372	1.2071	.01
.38	1.0000	1.6447	1.1626	.07
.39	1.0000	1.5593	1.1233	.16
.40	1.0000	1.4803	1.0886	.27
.41	1.0000	1.4070	1.0577	.41
.42	1.0000	1.3390	1.0303	.57
.43	1.0000	1.2757	1.0059	.73
.44	1.0000	1.2167	.9840	.91
.45	1.0000	1.1616	.9643	1.10
.46	1.0000	1.1101	.9466	1.30
.47	1.0000	1.0619	.9305	1.50
.48	1.0000	1.0167	.9160	1.71
.49	1.0000	.9743	.9027	1.91
.50	1.0000	.9344	.8906	2.13
.51	1.0000	.8969	.8795	2.34
.52	1.0000	.8616	.8693	2.56
.53	1.0000	.8282	.8599	2.78
.54	1.0000	.7967	.8513	2.99
.55	1.0000	.7670	.8432	3.21
.56	1.0000	.7388	.8358	3.43
.57	1.0000	.7121	.8289	3.65
.58	1.0000	.6868	.8224	3.86
.59	1.0000	.6628	.8164	4.08
.60	1.0000	.6400	.8108	4.29
.61	1.0000	.6183	.8055	4.51
.62	1.0000	.5977	.8006	4.72
.63	1.0000	.5781	.7959	4.93
.64	1.0000	.5594	.7916	5.14
.65	1.0000	.5415	.7874	5.35
.66	1.0000	.5245	.7836	5.55
.67	1.0000	.5083	.7799	5.76
.68	1.0000	.4927	.7764	5.96
.69	1.0000	.4779	.7731	6.16
.70	1.0000	.4637	.7700	6.36

TABLE VI
FOURTH ORDER SBB4 AND BB4 ALIGNMENTS:
Q_L = 20

Q_T	H	Alpha	F_3/F_S	PK(dB)
.20	1.0000	6.1256	3.2844	
.21	1.0000	5.5505	3.0665	
.22	1.0000	5.0523	2.8656	
.23	1.0000	4.6178	2.6797	
.24	1.0000	4.2367	2.5074	
.25	1.0000	3.9006	2.3472	
.26	1.0000	3.6027	2.1984	
.27	1.0000	3.3374	2.0602	
.28	1.0000	3.1001	1.9323	
.29	1.0000	2.8871	1.8142	
.30	1.0000	2.6951	1.7059	
.31	1.0000	2.5214	1.6072	
.32	1.0000	2.3639	1.5178	
.33	1.0000	2.2206	1.4375	
.34	1.0000	2.0897	1.3659	
.35	1.0000	1.9700	1.3023	
.36	1.0000	1.8602	1.2461	.00
.37	1.0000	1.7592	1.1964	.02
.38	1.0000	1.6661	1.1527	.09
.39	1.0000	1.5802	1.1141	.19
.40	1.0000	1.5006	1.0799	.31
.41	1.0000	1.4269	1.0497	.45
.42	1.0000	1.3583	1.0228	.61
.43	1.0000	1.2946	.9988	.79
.44	1.0000	1.2351	.9773	.97
.45	1.0000	1.1796	.9581	1.17
.46	1.0000	1.1278	.9407	1.37
.47	1.0000	1.0792	.9250	1.57
.48	1.0000	1.0336	.9107	1.79
.49	1.0000	.9908	.8977	2.00
.50	1.0000	.9506	.8858	2.22
.51	1.0000	.9128	.8749	2.44
.52	1.0000	.8771	.8650	2.66
.53	1.0000	.8435	.8558	2.88
.54	1.0000	.8117	.8473	3.10
.55	1.0000	.7816	.8394	3.32
.56	1.0000	.7532	.8321	3.54
.57	1.0000	.7262	.8253	3.76
.58	1.0000	.7007	.8190	3.98
.59	1.0000	.6764	.8131	4.20
.60	1.0000	.6534	.8076	4.42
.61	1.0000	.6315	.8024	4.64
.62	1.0000	.6107	.7975	4.85
.63	1.0000	.5908	.7930	5.07
.64	1.0000	.5719	.7887	5.28
.65	1.0000	.5539	.7847	5.49
.66	1.0000	.5367	.7808	5.70
.67	1.0000	.5202	.7772	5.91
.68	1.0000	.5045	.7738	6.12
.69	1.0000	.4895	.7706	6.32
.70	1.0000	.4751	.7675	6.52

TABLE VII
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS:
Q_L = 3

Q_T	H	Alpha	F_3/F_S	PK(dB)
.1000	4.3303	31.2904	5.6709	
.1100	3.9371	25.6824	5.1456	
.1200	3.6096	21.4169	4.7069	
.1300	3.3325	18.0974	4.3348	
.1400	3.0950	15.4635	4.0150	
.1500	2.8892	13.3386	3.7371	
.1600	2.7092	11.5994	3.4932	
.1700	2.5504	10.1581	3.2772	
.1800	2.4092	8.9502	3.0844	
.1900	2.2830	7.9280	2.9113	
.2000	2.1694	7.0552	2.7548	
.2100	2.0666	6.3041	2.6125	
.2200	1.9733	5.6531	2.4824	
.2300	1.8881	5.0851	2.3630	
.2400	1.8100	4.5866	2.2528	
.2500	1.7381	4.1467	2.1508	
.2600	1.6719	3.7566	2.0559	
.2700	1.6105	3.4090	1.9674	
.2800	1.5536	3.0980	1.8845	
.2900	1.5006	2.8186	1.8065	
.3000	1.4512	2.5666	1.7331	
.3100	1.4050	2.3386	1.6636	
.3200	1.3617	2.1317	1.5978	
.3300	1.3210	1.9432	1.5351	
.3400	1.2828	1.7712	1.4754	
.3500	1.2467	1.6136	1.4183	
.3600	1.2127	1.4690	1.3636	
.3700	1.1806	1.3360	1.3110	
.3800	1.1501	1.2133	1.2605	
.3900	1.1213	1.0999	1.2118	
.4000	1.0939	.9949	1.1649	
.4100	1.0679	.8974	1.1198	
.4200	1.0431	.8069	1.0763	
.4300	1.0195	.7225	1.0346	
.4400	.9970	.6439	.9947	.00
.4500	.9755	.5704	.9568	.00
.4600	.9550	.5016	.9210	.02
.4700	.9354	.4372	.8875	.06
.4800	.9166	.3767	.8563	.14
.4900	.8986	.3199	.8276	.27
.5000	.8813	.2665	.8014	.45
.5100	.8647	.2161	.7775	.70
.5200	.8488	.1686	.7558	1.00
.5300	.8336	.1238	.7363	1.36
.5400	.8189	.0814	.7186	1.77
.5500	.8047	.0413	.7027	2.25
.5600	.7911	.0033	.6883	2.78

TABLES AND SHAPES

I have generated alignment tables for each of the responses described above using the Q_L values 3, 5, 7, 10, 15, 20, which should cover any box loss encountered in practice.

Table I through *VI* cover the SBB4-BB4 series. The alignment is a BB4 if there is an entry in the peak column; otherwise it is a SBB4. The representative response curves are given in *Fig.* 2 (SBB4) and *Fig.* 3 (BB4). All of the BB4 responses have a peak whose height is in the peak column.

The QB3-SQB3 alignments are given in *Tables VII* through *XII*. If the peak column is empty the alignment is a

FIG. 10

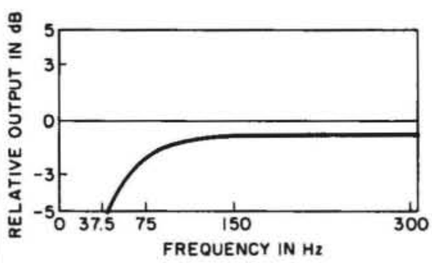

Fig. 10. Simulated response of a Be4 alignment with f_s=35 Hz. and Q_L=7.

FIG. 11

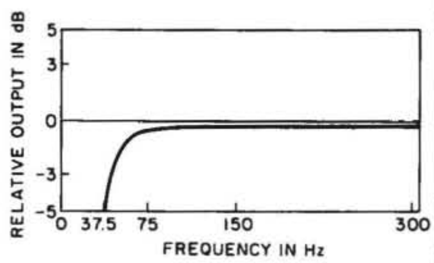

Fig. 11. Simulated response of an IB4 alignment with f_s=35 Hz. and Q_L=7.

FIG. 12

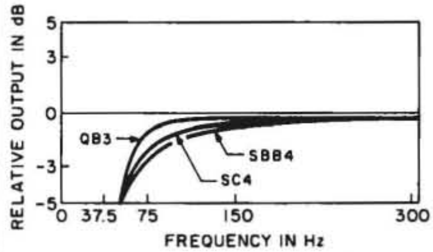

Fig. 12. Comparison of QB3, SC4 and SBB4 for f_s=35 Hz., Q_L=7 and Q_T=.30.

TABLE VIII
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS: Q_L = 5

Q_T	H	Alpha	F_3/F_s	PK(dB)
.1000	3.9737	33.5256	5.3464	
.1100	3.6143	27.5207	4.8505	
.1200	3.3149	22.9534	4.4364	
.1300	3.0618	19.3989	4.0851	
.1400	2.8449	16.5786	3.7831	
.1500	2.6571	14.3032	3.5205	
.1600	2.4929	12.4409	3.2900	
.1700	2.3482	10.8975	3.0858	
.1800	2.2196	9.6040	2.9035	
.1900	2.1047	8.5093	2.7397	
.2000	2.0014	7.5746	2.5914	
.2100	1.9080	6.7702	2.4566	
.2200	1.8232	6.0730	2.3332	
.2300	1.7459	5.4646	2.2198	
.2400	1.6751	4.9306	2.1151	
.2500	1.6101	4.4594	2.0180	
.2600	1.5502	4.0415	1.9276	
.2700	1.4948	3.6691	1.8430	
.2800	1.4434	3.3358	1.7637	
.2900	1.3957	3.0364	1.6889	
.3000	1.3512	2.7663	1.6183	
.3100	1.3097	2.5220	1.5514	
.3200	1.2708	3.3001	1.4877	
.3300	1.2344	2.0980	1.4269	
.3400	1.2003	1.9134	1.3687	
.3500	1.1681	1.7444	1.3129	
.3600	1.1378	1.5893	1.2592	
.3700	1.1093	1.4464	1.2074	
.3800	1.0823	1.3147	1.1576	
.3900	1.0568	1.1929	1.1095	
.4000	1.0326	1.0801	1.0632	
.4100	1.0097	.9753	1.0189	
.4200	.9880	.8779	.9766	.00
.4300	.9673	.7872	.9366	.01
.4400	.9477	.7025	.8992	.04
.4500	.9290	.6233	.8646	.13
.4600	.9113	.5492	.8329	.27
.4700	.8943	.4796	.8043	.49
.4800	.8782	.4144	.7785	.79
.4900	.8628	.3530	.7555	1.16
.5000	.8481	.2951	.7351	1.62
.5100	.8341	.2406	.7170	2.16
.5200	.8207	.1891	.7010	2.79
.5300	.8078	.1404	.6868	3.50
.5400	.7956	.0944	.6742	4.32
.5500	.7839	.0507	.6631	5.25
.5600	.7727	.0092	.6533	6.31

TABLE IX
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS: Q_L = 7

Q_T	H	Alpha	F_3/F_s	PK(dB)
.1000	3.8416	34.3925	5.2233	
.1100	3.4947	28.2341	4.7386	
.1200	3.2058	23.5499	4.3337	
.1300	2.9615	19.9046	3.9902	
.1400	2.7524	17.0120	3.6949	
.1500	2.5712	14.6784	3.4381	
.1600	2.4129	12.7685	3.2126	
.1700	2.2743	11.1855	3.0128	
.1800	2.1495	9.8589	2.8345	
.1900	2.0388	8.7361	2.6741	
.2000	1.9393	7.7775	2.5289	
.2100	1.8494	6.9524	2.3968	
.2200	1.7678	6.2372	2.2759	
.2300	1.6935	5.6132	2.1647	
.2400	1.6254	5.0655	2.0620	
.2500	1.5629	4.5822	1.9667	
.2600	1.5054	4.1535	1.8778	
.2700	1.4522	3.7714	1.7946	
.2800	1.4029	3.4295	1.7165	
.2900	1.3571	3.1223	1.6429	
.3000	1.3145	3.1223	1.5732	
.3100	1.2748	2.5944	1.5070	
.3200	1.2376	2.3667	1.4439	
.3300	1.2028	2.1594	1.3836	
.3400	1.1702	1.9699	1.3258	
.3500	1.1395	1.7964	1.2702	
.3600	1.1106	1.6371	1.2167	
.3700	1.0834	1.4905	1.1651	
.3800	1.0578	1.3552	1.1153	
.3900	1.0335	1.2300	1.0674	
.4000	1.0106	1.1141	1.0214	
.4100	.9889	1.0065	.9776	.00
.4200	.9683	.9064	.9362	.01
.4300	.9488	.8131	.8975	.05
.4400	.9303	.7260	.8618	.14
.4500	.9128	.6445	.8294	.31
.4600	.8961	.5682	.8001	.56
.4700	.8802	.4966	.7741	.90
.4800	.8651	.4294	.7510	1.32
.4900	.8507	.3661	.7307	1.85
.5000	.8370	.3065	.7129	2.46
.5100	.8240	.2503	.6972	3.18
.5200	.8116	.1971	.6835	4.01
.5300	.7998	.1468	.6715	4.97
.5400	.7886	.0992	.6610	6.08
.5500	.7779	.0540	.6518	7.36
.5600	.7677	.0111	.6438	8.87

TABLE X
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS: Q_L = 10

Q_T	H	Alpha	F_3/F_s	PK(dB)
.1000	3.7493	35.0129	5.1363	
.1100	3.4111	28.7446	4.6594	
.1200	3.1296	23.9771	4.2611	
.1300	2.8915	20.2667	3.9231	
.1400	2.6877	17.3226	3.6325	
.1500	2.5113	14.9474	3.3798	
.1600	2.3570	13.0033	3.1578	
.1700	2.2212	11.3921	2.9611	
.1800	2.1006	10.0418	2.7855	
.1900	1.9928	8.8990	2.6275	
.2000	1.8960	7.9232	2.4845	
.2100	1.8085	7.0834	2.3543	
.2200	1.7292	6.3554	2.2351	
.2300	1.6569	5.7202	2.1255	
.2400	1.5908	5.1627	2.0241	
.2500	1.5301	4.6706	1.9299	
.2600	1.4742	4.2342	1.8421	
.2700	1.4225	3.8452	1.7599	
.2800	1.3747	3.4971	1.6826	
.2900	1.3303	3.1843	1.6097	
.3000	1.2890	2.9022	1.5406	
.3100	1.2505	2.6469	1.4748	
.3200	1.2146	2.4150	1.4121	
.3300	1.1809	2.2038	1.3521	
.3400	1.1413	2.0109	1.2945	
.3500	1.1197	1.8342	1.2390	
.3600	1.0918	1.6719	1.1855	
.3700	1.0656	1.5225	1.1339	
.3800	1.0409	1.3846	1.0841	
.3900	1.0175	1.2571	1.0363	
.4000	.9955	1.1389	.9906	.00
.4100	.9747	1.0292	.9474	.00
.4200	.9549	.9271	.9069	.03
.4300	.9363	.8320	.8695	.12
.4400	.9186	.7431	.8355	.28
.4500	.9018	.6600	.8049	.53
.4600	.8859	.5821	.7778	.87
.4700	.8707	.5091	.7538	1.31
.4800	.8564	.4404	.7329	1.86
.4900	.8428	.3757	.7146	2.51
.5000	.8299	.3148	.6986	3.27
.5100	.8176	.2572	.6848	4.16
.5200	.8059	.2028	.6727	5.20
.5300	.7949	.1513	.6623	6.40
.5400	.7844	.1025	.6532	7.82
.5500	.7744	.0562	.6454	9.52
.5600	.7650	.0121	.6387	11.60

QB3; otherwise it is an SQB3. *Figure 4* shows a typical QB3 response and *Fig. 5* an SQB3.

The SC4-C4 series is covered by *Tables XIII* through *XVIII*. Here the alignment is SC4 when the ripple column is empty and C4 otherwise. *Figure 6* is an SC4 and *Fig. 7* a C4. The ripple is not very apparent in this figure, so I have also included a high Q_T C4 as *Fig. 8*.

The discrete response alignment data is in *Table XIX*; *Fig. 9, 10* and *11* give the relevant response curves.

I have included several other figures with multiple response plots on the same axes for purposes of comparison. In *Fig. 13* one graph is a natural QB3 and the other is the response obtained with the vent blocked. This will give you an idea of the low frequency extension achievable by venting. *Figure 14* compares an extremely low Q_T alignment with a more moderate one. You can see that even though the low Q_T driver has a much lower resonance than the other, the latter will give a wider bandwidth in a vented box. Finally, *Fig. 15* compares a B4 response with an IB4.

RESPONSE COMPARISONS

With more than one alignment possible, it is important to find out how they differ so you can make the best choice for your circumstances. The tables show explicity that box size, box resonance, response "flatness," and cut-off frequency distinguish the alignments from one another. Generally, the alignment choice with the best combination of these four characteristics is found in the composite QB3-C4 tables of my first article. The new tables do allow us to extend the usable Q_T range up to .80 and down to .10.

Alignments also differ in their transient response, which deteriorates with increasing Q_T. Even more, equal Q_T alignments will not necessarily exhibit the same transient behavior. I will make specific comparisons below. According to Thiele[3], the ringing in a vented box alignment should be imperceptible except in the case of very high Q_T alignments. Now for some specific comparisons.

RESPONSE FLATNESS

Responses are either flat (SBB4, QB3, SC4, B4, Be4, IB4) and correspond to low Q_T values, or nonflat (BB4, SQB3, C4) and call for a large Q_T value. Because of this the driver you use will almost always determine whether your system will have a flat or nonflat response. Consider this point carefully before selecting drivers, and keep in mind also that the flat alignments will have better transient response. Having compared flat and nonflat, we are now

TABLE XI
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS: Q_L = 3

Q_T	H	Alpha	F_3/F_S	PK(dB)
.1000	3.6841	35.4793	5.0715	
.1100	3.3494	29.1286	4.6004	
.1200	3.0732	24.2984	4.2069	
.1300	2.8398	20.5392	3.8730	
.1400	2.6400	17.5563	3.5859	
.1500	2.4670	15.1498	3.3362	
.1600	2.3158	13.1802	3.1169	
.1700	2.1826	11.5478	2.9225	
.1800	2.0644	10.1797	2.7488	
.1900	1.9589	9.0218	2.5926	
.2000	1.8640	8.0331	2.4512	
.2100	1.7784	7.1822	2.3225	
.2200	1.7007	6.4446	2.2045	
.2300	1.6299	5.8010	2.0960	
.2400	1.5652	5.2361	1.9956	
.2500	1.5058	4.7375	1.9023	
.2600	1.4512	4.2952	1.8153	
.2700	1.4007	3.9011	1.7338	
.2800	1.3540	3.5484	1.6571	
.2900	1.3106	3.2314	1.5846	
.3000	1.2703	2.9455	1.5159	
.3100	1.2327	2.6867	1.4504	
.3200	1.1976	2.4517	1.3880	
.3300	1.1648	2.2376	1.3281	
.3400	1.1341	2.0420	1.2705	
.3500	1.1052	1.8629	1.2151	
.3600	1.0781	1.6983	1.1615	
.3700	1.0526	1.5468	1.1099	
.3800	1.0286	1.4070	1.0602	
.3900	1.0059	1.2777	1.0125	
.4000	.9845	1.1579	.9672	.00
.4100	.9643	1.0466	.9245	.02
.4200	.9452	.9430	.8849	.08
.4300	.9272	.8464	.8488	.21
.4400	.9101	.7562	.8162	.43
.4500	.8939	.6719	.7872	.76
.4600	.8786	.5928	.7618	1.18
.4700	.8641	.5185	.7395	1.72
.4800	.8503	.4488	.7202	2.36
.4900	.8373	.3830	.7034	3.13
.5000	.8249	.3211	.6889	4.04
.5100	.8132	.2625	.6764	5.09
.5200	.8021	.2072	.6656	6.33
.5300	.7916	.1547	.6563	7.79
.5400	.7817	.1050	.6483	9.56
.5500	.7723	.0577	.6416	11.80
.5600	.7635	.0128	.6359	14.70

TABLE XII
FOURTH ORDER QB3 AND SQB3 ALIGNMENTS: Q_L = 20

Q_T	H	Alpha	F_3/F_S	PK(dB)
.1000	3.6482	35.7075	5.0399	
.1100	3.3196	29.3166	4.5717	
.1200	3.0460	24.4556	4.1806	
.1300	2.8148	20.6726	3.8487	
.1400	2.6169	17.6708	3.5632	
.1500	2.4455	15.2490	3.3150	
.1600	2.2959	13.2669	3.0969	
.1700	2.1640	11.6240	2.9036	
.1800	2.0470	10.2473	2.7310	
.1900	1.9425	9.0820	2.5757	
.2000	1.8486	8.0970	2.4350	
.2100	1.7638	7.2307	2.3069	
.2200	1.6869	6.4884	2.1896	
.2300	1.6169	5.8407	2.0816	
.2400	1.5529	5.2721	1.9817	
.2500	1.4941	4.7703	1.8888	
.2600	1.4401	4.3252	1.8022	
.2700	1.3902	3.9286	1.7210	
.2800	1.3440	3.5735	1.6445	
.2900	1.3011	3.2545	1.5722	
.3000	1.2613	2.9667	1.5037	
.3100	1.2241	2.7063	1.4384	
.3200	1.1895	2.4697	1.3760	
.3300	1.1571	2.2542	1.3162	
.3400	1.1267	2.0574	1.2587	
.3500	1.0982	1.8770	1.2032	
.3600	1.0715	1.7114	1.1496	
.3700	1.0463	1.5589	1.0980	
.3800	1.0226	1.4181	1.0483	
.3900	1.0003	1.2879	1.0007	
.4000	.9793	1.1672	.9556	.00
.4100	.9594	1.0552	.9153	.03
.4200	.9406	.9508	.8742	.11
.4300	.9228	.8536	.8387	.27
.4400	.9061	.7627	.8069	.53
.4500	.8902	.6777	.7788	.89
.4600	.8751	.5980	.7542	1.36
.4700	.8609	.5232	.7328	1.95
.4800	.8474	.4529	.7143	2.65
.4900	.8347	.3867	.6983	3.49
.5000	.8226	.3242	.6845	4.47
.5100	.8112	.2651	.6726	5.62
.5200	.8004	.2093	.6624	6.98
.5300	.7902	.1564	.6537	8.61
.5400	.7806	.1062	.6463	10.62
.5500	.7715	.0585	.6401	13.20
.5600	.7629	.0131	.6348	16.80

TABLE XIII
FOURTH ORDER SC4 AND C4 ALIGNMENTS: Q_L = 3

Q_T	H	Alpha	F_3/F_S	Ripple (dB)
.2500	1.0093	3.4080	2.6083	
.2600	1.0322	3.2301	2.4391	
.2700	1.0529	3.0516	2.2860	
.2800	1.0703	2.8731	2.1473	
.2900	1.0871	2.6952	2.0217	
.3000	1.1004	2.5188	1.9078	
.3100	1.1109	2.3447	1.8042	
.3200	1.1187	2.1738	1.7097	
.3300	1.1236	2.0068	1.6232	
.3400	1.1255	1.8448	1.5437	
.3500	1.1244	1.6885	1.4703	
.3600	1.1203	1.5387	1.4023	
.3700	1.1133	1.3961	1.3390	
.3800	1.1034	1.2616	1.2798	
.3900	1.0909	1.1356	1.2244	
.4000	1.0758	1.0187	1.1724	
.4100	1.0586	.9110	1.1236	
.4200	1.0394	.8128	1.0778	
.4300	1.0188	.7238	1.0348	
.4400	.9770	.6439	.9947	.00
.4500	.9744	.5726	.9572	.00
.4600	.9515	.5093	.9222	.00
.4700	.9286	.4533	.8898	.00
.4800	.9059	.4040	.8597	.00
.4900	.8837	.3605	.8318	.00
.5000	.8621	.3223	.8060	.01
.5100	.8412	.2885	.7822	.02
.5200	.8212	.2586	.7601	.02
.5300	.8021	.2321	.7397	.03
.5400	.7838	.2084	.7208	.05
.5500	.7664	.1872	.7033	.06
.5600	.7499	.1681	.6871	.08
.5700	.7341	.1508	.6720	.10
.5800	.7192	.1350	.6579	.12
.5900	.7049	.1205	.6447	.14
.6000	.6913	.1072	.6324	.17
.6100	.6784	.0948	.6209	.20
.6200	.6661	.0832	.6101	.23
.6300	.6543	.0723	.5999	.26
.6400	.6430	.0621	.5903	.29
.6500	.6322	.0524	.5812	.32
.6600	.6218	.0431	.5726	.35
.6700	.6118	.0343	.5644	.39
.6800	.6022	.0258	.5567	.42
.6900	.5929	.0175	.5493	.46
.7000	.5840	.0096	.5423	.50
.7100	.5754	.0019	.5355	.53

FIG. 13

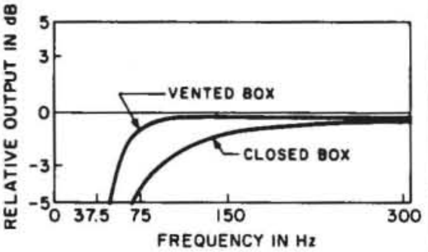

Fig. 13. Simulated response of a QB3 compared with the closed box response obtained by blocking the vent.

FIG. 14

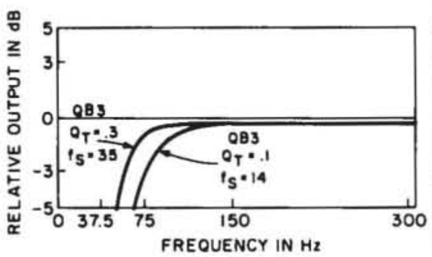

Fig. 14. A very low Q_T alignment compared with a more moderate one. Note that even though the driver resonant frequency of the low Q driver is less than half that of the other, the cut off frequency of the low Q system is higher.

FIG. 15

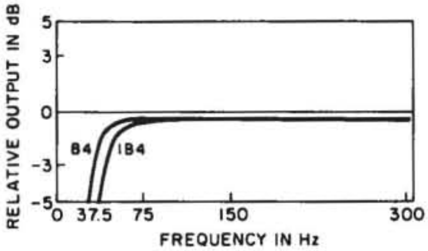

Fig. 15. A comparison of the B4 and IB4 responses plotted separately in Figs. 9 and 11.

TABLE XIV
FOURTH ORDER SC4 AND C4 ALIGNMENTS:
$Q_L = 5$

Q_T	H	Alpha	F_3/F_S	Ripple PK(dB)
.2500	1.0271	3.7503	2.4589	
.2600	1.0478	3.5430	2.2912	
.2700	1.0658	3.3356	2.1402	
.2800	1.0812	3.1290	2.0042	
.2900	1.0936	2.9242	1.8816	
.3000	1.1031	2.7223	1.7708	
.3100	1.1095	2.5242	1.6705	
.3200	1.1127	2.3311	1.5791	
.3300	1.1120	2.1441	1.4957	
.3400	1.1096	1.9641	1.4191	
.3500	1.1033	1.7923	1.3485	
.3600	1.0939	1.6296	1.2831	
.3700	1.0817	1.4769	1.2225	
.3800	1.0667	1.3347	1.1660	
.3900	1.0495	1.2036	1.1134	
.4000	1.0303	1.0840	1.0645	
.4100	1.0095	.9757	1.0190	.00
.4200	.9877	.8785	.9767	.00
.4300	.9652	.7920	.9377	.00
.4400	.9425	.7154	.9016	.00
.4500	.9200	.6480	.8684	.00
.4600	.8979	.5889	.8379	.01
.4700	.8766	.5370	.8100	.01
.4800	.8560	.4915	.7844	.02
.4900	.8364	.4516	.7609	.03
.5000	.8178	.4166	.7395	.04
.5100	.8002	.3857	.7198	.06
.5200	.7836	.3583	.7017	.08
.5300	.7680	.3340	.6852	.11
.5400	.7533	.3122	.6699	.13
.5500	.7394	.2927	.6558	.16
.5600	.7263	.2752	.6428	.20
.5700	.7140	.2592	.6307	.23
.5800	.7024	.2447	.6195	.27
.5900	.6915	.2314	.6091	.31
.6000	.6811	.2192	.5994	.35
.6100	.6713	.2080	.5903	.40
.6200	.6620	.1975	.5818	.44
.6300	.6531	.1878	.5738	.49
.6400	.6447	.1787	.5663	.54
.6500	.6367	.1701	.5592	.59
.6600	.6290	.1621	.5525	.64
.6700	.6217	.1544	.5462	.70
.6800	.6147	.1472	.5402	.75
.6900	.6079	.1403	.5346	.80
.7000	.6015	.1337	.5292	.86
.7100	.5953	.1274	.5240	.91
.7200	.5893	.1213	.5192	.96
.7300	.5835	.1155	.5145	1.02
.7400	.5780	.1098	.5100	1.08
.7500	.5726	.1044	.5057	1.13
.7600	.5674	.0991	.5016	1.19
.7700	.5623	.0939	.4977	1.24
.7800	.5575	.0889	.4939	1.30
.7900	.5527	.0840	.4903	1.35
.8000	.5481	.0792	.4867	1.41

TABLE XV
FOURTH ORDER SC4 AND C4 ALIGNMENTS:
$Q_L = 7$

Q_T	H	Alpha	F_3/F_S	Ripple (dB)
.2500	1.0338	3.8961	2.3949	
.2600	1.0534	3.6755	2.2282	
.2700	1.0703	3.4551	2.0784	
.2800	1.0842	3.2360	1.9439	
.2900	1.0951	3.0193	1.8229	
.3000	1.1028	2.8062	1.7137	
.3100	1.1073	2.5977	1.6149	
.3200	1.1086	2.3952	1.5251	
.3300	1.1065	2.1997	1.4431	
.3400	1.1012	2.0125	1.3679	
.3500	1.0926	1.8347	1.2986	
.3600	1.0810	1.6672	1.2345	
.3700	1.0667	1.5109	1.1751	
.3800	1.0498	1.3665	1.1200	
.3900	1.0309	1.2343	1.0689	
.4000	1.0103	1.1146	1.0215	
.4100	.9886	1.0070	.9777	.00
.4200	.9662	.9113	.9373	.00
.4300	.9436	.8266	.9001	.00
.4400	.9212	.7521	.8660	.00
.4500	.8992	.6868	.8348	.01
.4600	.8780	.6297	.8064	.01
.4700	.8578	.5798	.7804	.02
.4800	.8385	.5361	.7567	.03
.4900	.8203	.4978	.7351	.05
.5000	.8031	.4642	.7155	.07
.5100	.7870	.4345	.6975	.09
.5200	.7719	.4083	.6810	.12
.5300	.7578	.3849	.6659	.15
.5400	.7445	.3640	.6520	.19
.5500	.7321	.3453	.6393	.23
.5600	.7205	.3284	.6275	.27
.5700	.7096	.3131	.6166	.31
.5800	.6993	.2992	.6065	.36
.5900	.6896	.2865	.5971	.41
.6000	.6805	.2749	.5883	.46
.6100	.6719	.2641	.5802	.51
.6200	.6638	.2542	.5726	.57
.6300	.6561	.2449	.5654	.63
.6400	.6488	.2363	.5587	.68
.6500	.6418	.2283	.5524	.74
.6600	.6352	.2208	.5465	.80
.6700	.6289	.2136	.5409	.86
.6800	.6229	.2069	.5355	.92
.6900	.6171	.2006	.5305	.98
.7000	.6116	.1946	.5258	1.05
.7100	.6064	.1888	.5212	1.11
.7200	.6013	.1833	.5169	1.17
.7300	.5964	.1781	.5128	1.24
.7400	.5917	.1731	.5089	1.30
.7500	.5872	.1682	.5051	1.36
.7600	.5829	.1636	.5016	1.43
.7700	.5787	.1591	.4981	1.49
.7800	.5746	.1547	.4948	1.55
.7900	.5707	.1505	.4917	1.62
.8000	.5669	.1465	.4886	1.68

TABLE XVI
FOURTH ORDER SC4 AND C4 ALIGNMENTS:
$Q_L = 10$

Q_T	H	Alpha	F_3/F_S	Ripple (dB)
.2500	1.0385	4.0048	2.3469	
.2600	1.0573	3.7740	2.1811	
.2700	1.0731	3.5437	2.0325	
.2800	1.0860	3.3150	1.8992	
.2900	1.0965	3.0893	1.7794	
.3000	1.1020	2.8677	1.6715	
.3100	1.1051	2.6515	1.5739	
.3200	1.1048	2.4419	1.4853	
.3300	1.1012	2.2403	1.4044	
.3400	1.0942	2.0479	1.3303	
.3500	1.0840	1.8658	1.2620	
.3600	1.0708	1.6950	1.1990	
.3700	1.0550	1.5366	1.1407	
.3800	1.0368	1.3909	1.0867	
.3900	1.0168	1.2584	1.0368	
.4000	.9954	1.1390	.9907	.00
.4100	.9732	1.0325	.9482	.00
.4200	.9507	.9381	.9092	.00
.4300	.9282	.8550	.8736	.00
.4400	.9062	.7822	.8410	.01
.4500	.8848	.7187	.8114	.01
.4600	.8644	.6632	.7844	.02
.4700	.8451	.6148	.7600	.03
.4800	.8269	.5725	.7377	.05
.4900	.8097	.5355	.7175	.07
.5000	.7937	.5029	.6991	.10
.5100	.7787	.4742	.6823	.13
.5200	.7648	.4487	.6670	.16
.5300	.7517	.4261	.6529	.20
.5400	.7396	.4059	.6401	.24
.5500	.7282	.3877	.6282	.29
.5600	.7176	.3714	.6173	.34
.5700	.7077	.3565	.6072	.39
.5800	.6983	.3431	.5979	.44
.5900	.6896	.3308	.5892	.50
.6000	.6814	.3195	.5812	.55
.6100	.6736	.3092	.5737	.61
.6200	.6663	.2996	.5667	.68
.6300	.6594	.2907	.5601	.74
.6400	.6529	.2825	.5540	.80
.6500	.6467	.2748	.5482	.87
.6600	.6409	.2677	.5428	.93
.6700	.6353	.2609	.5376	1.00
.6800	.6300	.2546	.5328	1.07
.6900	.6249	.2487	.5282	1.14
.7000	.6201	.2430	.5239	1.20
.7100	.6155	.2377	.5198	1.27
.7200	.6111	.2326	.5159	1.34
.7300	.6068	.2278	.5122	1.41
.7400	.6028	.2232	.5086	1.48
.7500	.5988	.2188	.5052	1.55
.7600	.5951	.2146	.5020	1.62
.7700	.5915	.2105	.4989	1.69
.7800	.5880	.2066	.4960	1.76
.7900	.5846	.2029	.4932	1.83
.8000	.5814	.1993	.4905	1.90

ready to compare alignments within these two groups.

NONFLAT ALIGNMENTS

The C4 is the standard in this group. The principal advantage of the BB4 alternative is that a smaller box and higher tuning can be used for a given Q_T, although the cut-off frequency will be higher and the response variation greater. The SQB3 is quite similar to the BB4, but available Q_T values are lower and it requires a much larger box. However, the SQB3 cut-off frequency is lower than the corresponding C4 for Q_T's below .50. In terms of transient response the BB4 is best, the SQB3 is worst, and the C4 occupies the middle ground. Both the BB4 and SQB3 alignments should be appropriate for electric bass loudspeakers, since a large bass emphasis is usually designed into such units.

I used a BB4 alignment to design a system for my parents. They wanted it built into their enclosures, which fixed the V_B parameter. I ordered woofers with Q_{TS} = .33 and had in mind a QB3 alignment. But the samples I received showed a measurement of Q_{TS} = .50. This eliminated my original plan, since the customary C4 alignment would have required a much larger V_B than my parents' boxes provided.

Luckily, the box-driver combination fitted a BB4 alignment almost exactly. The 2dB peak in the upper bass response is very noticeable in my opinion, but the overall sound is comparable to commercial units I have heard costing $300 apiece. My parents are extremely pleased with the results of their $80 investment. (Of course, their opinion had nothing to do with the fact that their son built the system.)

FLAT ALIGNMENTS (SBB4, SC4, QB3)

The QB3 is the standard alignment in this group, but both the SC4 and SBB4 will give better transient response; the SBB4 is best. For a given Q_T the SBB4 requires the largest box and the QB3 the smallest. For very low resonance drivers the SBB4 may call for an exceptionally long vent since the box tuning is so low. The vent constraints of the SC4 are a little less stringent and the cut-off frequency is lower. In my opinion any of these alignments should give an excellent sounding system, but as yet I have used only the QB3. If you use one of the other two I would appreciate your impressions of performance.

DISCRETE ALIGNMENTS

These alignments (B4, Be4, IB4) are all flat. On the basis of Q_T values the Be4 will have the best transient response and the B4 the worst. I recommend you not use any of these alignments, because the target is fixed once Q_L is known and what may appear to be a

TABLE XVII
FOURTH ORDER SC4 AND C4 ALIGNMENTS:
Q_L = 15

Q_T	H	Alpha	F_3/F_S	Ripple (dB)
.2500	1.0420	4.0890	2.3097	
.2600	1.0601	3.8500	2.1477	
.2700	1.0751	3.6119	1.9970	
.2800	1.0871	3.3757	1.8647	
.2900	1.0958	3.1429	1.7460	
.3000	1.1011	2.9147	1.6391	
.3100	1.1031	2.6924	1.5426	
.3200	1.1016	2.4774	1.4549	
.3300	1.0966	2.2711	1.3749	
.3400	1.0884	2.0748	1.3016	
.3500	1.0769	1.8896	1.2342	
.3600	1.0626	1.7166	1.1720	
.3700	1.0456	1.5567	1.1146	
.3800	1.0265	1.4104	1.0615	
.3900	1.0058	1.2779	1.0125	
.4000	.9840	1.1591	.9675	.00
4100	.9615	1.0535	.9262	.00
.4200	.9390	.9604	.8884	.00
.4300	.9167	.8787	.8539	.00
.4400	.8951	8074	.8226	.01
.4500	.8744	.7453	.7942	.02
.4600	.8547	6911	.7684	.03
.4700	.8361	.6439	.7451	.05
.4800	.8187	.6027	.7239	.07
.4900	.8025	.5666	.7047	.09
.5000	.7873	.5348	.6873	.12
.5100	.7732	.5068	.6714	.16
.5200	.7601	.4820	.6569	.20
.5300	.7479	.4599	.6437	.24
.5400	.7366	.4402	.6315	.29
.5500	.7260	.4225	.6204	.34
.5600	.7162	.4065	.6101	.39
.5700	.7070	.3921	.6006	.45
.5800	.6984	.3789	.5919	.51
.5900	.6903	.3670	.5838	.57
.6000	.6828	.3560	.5762	.63
.6100	.6757	.3459	.5692	.70
.6200	.6690	.3366	.5626	.77
.6300	.6627	.3281	.5565	.83
.6400	.6567	.3201	.5508	.90
.6500	.6511	.3127	.5454	.97
.6600	.6458	.3058	.5403	1.04
.6700	.6408	.2994	.5355	1.12
.6800	.6360	.2933	.5311	1.19
.6900	.6314	.2876	.5268	1.26
.7000	.6271	.2823	.5228	1.33
.7100	.6230	.2772	.5190	1.41
.7200	.6190	.2724	.5154	1.48
.7300	.6152	.2679	.5120	1.56
.7400	.6116	.2636	.5087	1.63
.7500	.6082	.2595	.5056	1.70
.7600	6049	.2556	.5026	1.78
.7700	.6017	2519	.4998	1.85
.7800	.5986	.2483	.4971	1.93
.7900	.5957	.2449	.4946	2.00
.8000	.5929	.2416	.4921	2.07

TABLE XVIII
FOURTH ORDER SC4 AND C4 ALIGNMENTS:
Q_L = 20

Q_T	H	Alpha	F_3/F_S	Ripple (dB)
.2500	1.0436	4.1309	2.2912	
.2600	1.0614	3.8879	2.1266	
.2700	1.0760	3.6458	1.9793	
.2800	1.0875	3.4058	1.8476	
.2900	1.0957	3.1694	1.7294	
.3000	1.1006	2.9379	1.6231	
.3100	1.1019	2.7126	1.5270	
.3200	1.0998	2.4949	1.4398	
.3300	1.0942	2.2863	1.3603	
.3400	1.0853	2.0881	1.2875	
.3500	1.0753	1.9014	1.2205	
.3600	1.0583	1.7274	1.1587	
.3700	1.0409	1.5668	1.1017	
.3800	1.0214	1.4203	1.0491	
.3900	1.0003	1.2879	1.0007	
.4000	.9783	1.1695	.9562	.01
.4100	.9557	1.0645	.9154	.01
.4200	.9332	.9721	.8782	.01
.4300	.9111	.8912	.8444	.01
.4400	.8898	.8206	.8137	.01
.4500	.8694	.7592	.7859	.02
.4600	.8501	.7057	.7607	.03
.4700	.8319	.6591	.7379	.05
.4800	.8149	.6184	.7173	.08
.4900	.7991	.5827	.6986	.11
.5000	.7844	.5514	.6816	.14
.5100	.7708	.5238	.6662	.18
.5200	.7581	.4993	.6521	.22
.5300	.7463	.4774	.6393	.27
.5400	.7354	.4579	.6275	.32
.5500	.7252	.4404	.6167	.37
.5600	.7157	.4247	.6067	.43
.5700	.7069	.4104	.5976	.49
.5800	.6986	.3974	.5891	.55
.5900	.6909	.3856	.5812	.61
.6000	.6837	.3748	.5739	.68
.6100	.6769	.3649	.5671	.74
.6200	.6705	.3557	.5608	.81
.6300	.6645	.3473	.5549	.88
.6400	.6588	.3395	.5493	.96
.6500	.6535	.3322	.5441	1.03
.6600	.6484	.3254	.5392	1.10
.6700	.6437	.3191	.5346	1.18
.6800	.6391	.3132	.5303	1.25
.6900	.6348	.3076	.5262	1.33
.7000	.6307	.3024	.5224	1.40
.7100	.6268	.2975	.5187	1.48
.7200	.6231	.2929	.5152	1.56
.7300	.6196	.2885	.5120	1.63
.7400	.6162	.2843	.5088	1.71
.7500	.6129	.2804	.5059	1.79
.7600	.6098	.2766	.5030	1.86
.7700	.6069	.2730	.5003	1.94
.7800	.6040	.2696	.4978	2.01
.7900	.6013	.2663	.4953	2.09
.8000	.5987	.2632	.4929	2.17

TABLE XIX
UNIQUE FOURTH ORDER ALIGNMENTS

Q_L	Q_T	h	alpha	f_3/f_s
Butterworth:				
3	.4386	1.0000	.6543	1.0000
5	.4144	1.0000	.9316	1.0000
7	.4048	1.0000	1.0613	1.0000
10	.3979	1.0000	1.1629	1.0000
15	.3927	1.0000	1.2444	1.0000
20	.3901	1.0000	1.2861	1.0000
50	.3856	1.0000	1.3624	1.0000
Bessel:				
3	.3535	.9696	1.4036	1.4911
5	.3376	.9725	1.7488	1.4933
7	.3312	.9735	1.9076	1.4941
10	.3266	.9743	2.0311	1.4947
15	.3230	.9749	2.1296	1.4951
20	.3213	.9751	2.1797	1.4953
50	.3182	.9756	2.2713	1.4957
Butterworth Inter-order (3½)				
3	.3835	1.1397	1.1722	1.2432
5	.3647	1.1241	1.5206	1.2347
7	.3572	1.1184	1.6802	1.2315
10	.3513	1.1145	1.7998	1.2294
15	.3477	1.1117	1.9030	1.2278
20	.3457	1.1103	1.9533	1.2270
50	.3421	1.1079	2.0450	1.2257

correct driver initially may be incorrect in the final system. This is not a problem with the alignment series because you can always shift to a new target in the series.

MAKING THE CHOICE

In summary, you must consider several trade-offs in choosing an alignment. By selecting a low Q_T driver you can attain a flat alignment and the best transient response. On the other hand, a high Q_T driver may allow you to realize a system with a very low cut-off frequency.

If you must still pick an alignment after choosing the driver, you must consider the trade-offs among box size, box resonance, cut-off frequency, and transient response, according to your criteria.

EXTREME Q_T ALIGNMENTS

Extreme Q_T alignments present special problems. It can sometimes be difficult or impossible to design a satisfactory vent for a very low Q_T alignment, since the box volume may be too small to permit using a vent of adequate cross-section and reasonable length. This problem is most likely to occur with a small diameter, low resonance driver.

At the other extreme, a large Q_T alignment can call for a box size many times larger than the driver V_{AS}. Usually this leads to an enclosure which would be obtrusively large in most listening rooms. A recent experience underscores the problem. A student asked my advise on designing a system using a pair of Radio Shack 12" woofers. The woofer parameters were Q_{TS} = .70 and V_{AS} = 18 cu. ft. A standard C4 alignment would have required a 92 cu. ft. enclosure, assuming Q_l = 7. A cubic enclosure of this volume would have to be 4½ feet on a side! Even a BB4 alignment would call for a 43 cu. ft. box, still much too large to fit comfortably in a typical dormitory room. I finally advised him to use a closed box of as large a volume as possible. He seemed to think 6 cu. ft. would be tolerable, which would give a response with a 3.5dB peak in the upper bass, or about half that which would result from using a BB4 alignment.

Considering all factors it is my opinion that the best results will be obtained by starting with a driver whose Q_{TS} is in the range from .20 to .50. This will give a reasonable box size in most instances and avoid excessive peak or ripple in the response. Personally, I usually try to choose a driver with Q_T no higher than .40 so I can use a flat alignment, and no lower than .20 so that the advantages of venting are still significant.

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