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DESIGN OF A HIGH POWER ACTIVE CONTROL ROOM MONITOR

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Abstract

This report describes the design of an active control room monitor for SPLs in excess of 130 dB(lin). To ensure good sound quality a new direct radiating midrange system was developed with an acoustic loading technique which allows 103 dB/W sensitivity and 1 kW peak power handling. Power amplifiers and driver unit protection logic are also presented.

1. INTRODUCTION

Traditionally large control room monitors have been designed around two large woofers and a horn-loaded mid/treble unit. The main problems in horn-loaded systems are distortion due to air nonlinearity in the throat, problematic reproduction of lower midrange and rapid changes of directivity.

Direct radiating drivers are today preferred due to sound quality reasons. Several designs known as "soft dome monitors" have recently emerged towards more accurate reproduction. However, they suffer from output power limitations or reliability problems at levels commonly used in rock studios. Also they are omnidirectional at low midrange and thus prone to response aberrations due to control room.

It would be useful to find a solution which could combine the direct-radiating driver sound quality and mild but constant directivity. This would yield in flat frequency response, flat power response and thus better immunity to listening environment inconsistencies. High amplifier powers are, however, needed and thus certain protective features are necessary in system electronics to ensure safe operation.

2. PRACTICAL DESIGN REQUIREMENTS

2.1. Monitoring environment

The volume of a typical large control room is around 200 m^3. Reverberation time depends on designer but in most cases 0.2 s is a typical value in the midband and 0.4 s around 80 Hz. At lowest octaves separate standing wave modes dominate and it is better to look how the modes decay. Typical decay times are 0.4 to 0.6 s. Reverberation radius is 1...2 m which means that the listening position is always in reverberant field. This fact has led the designers to look more closely the sound field build-up in time domain to keep early reflections away from the listener's ears.

The monitoring speakers should be (and they usually are) flush mounted into an acoustically hard wall. The radiation space is thus always 2π or smaller, depending of frequency. At lowest frequencies the speaker is radiating to π or even $\pi/2$ space which has beneficial effect on sound power output due to increased radiation resistance, but tends to spoil the frequency response if not corrected. Ballagh [1] has described the boundary effects in speaker power output; well known is also Allison's work on the subject [2]. When correctly applied this can be used to relax the woofer displacement requirements at extremely low frequencies.

Table 2-1 below shows the required volume displacement in litres for constant 130 dB SPL at 2 m reverberation radius and the speaker radiating in π space.

f/Hz	$V_{d\ peak}$/l for 130 dB at 2 m reverberation radius into π space	$V_{d\ peak}$/l from 4 x 385 mm drivers in 4 x 200 l f_b=28 Hz cabinet, ± 9 mm excursion
30	9,3	16,1
40	5,2	4,9
50	3,3	3,6
60	2,3	3,3
100	0,84	2,8

Table 2-1 Volume Displacement

2.2 Sound pressure level

In most industrialized countries the noise levels in work have been limited to around 85 dB(A) for an 8 hour noise exposure time to reduce risks of hearing damages. Some broadcasting companies have tried to recommend the same in control rooms [3]. However, the levels found around the musicians in an orchestra can exceed 120 dB(A) for symphonic music. In rock music the levels are still higher and at 2 meters from a drum set levels of 115 dB(fast), 118 dB(imp) and 129 dB(peak) have been recorded. At the drummer's position the corresponding levels are 123 dB(fast), 128 dB(imp) and 139 dB(peak). High listening levels are thus occasionally necessary during track laying and specially when the musicians want to listen their recorded performance. Thus the short term SPL design target for the monitoring system shall be 130 dB(lin) at 1m in 2π space. Peak values with wideband program material will then be around 136 dB.

2.3. Frequency response

As mentioned earlier, systems of this category are flush mounted. More important than free field frequency response is then the performance in the room. For design purposes the frequency response requirements were set to 30 Hz...20 kHz +/- 2 dB in 2π field. In control room the f_3 will then be around 25 Hz.

2.4. Distortion and coloration

Again some broadcasting companies have tried to specify the loudspeaker distortion performance [4]. For music recording industry no such specification is known to the authors. In [5] the frequency response was found to be the most significant single factor affecting the perceived sound quality. However, the frequency response can be flat and still the system suffers from severe colorations, for example in a form of delayed resonances. The Hi-Fi industry has been active in minimizing different forms colorations although exact definitions, audible limits and measuring methods are missing. It should therefore be natural that monitoring speakers which are used to control recordings, which will later be listened with very good domestic speakers, should, at comparable level, be better in any respect than the end user's system.

3. LOUDSPEAKER DESIGN

The acoustical design was made using a three way system principle. The cabinet was designed primarily for flush mounting although a free standing situation shall also be possible.

3.1 Low frequency reproduction

To reach the target SPL figures both sensitivity and utilization of the available displacement capacity shall be maximized. In these terms the basic B6 alignment is very good. One advantage is the 2nd order term which is usually made electrically and is thus easy to make variable.

In this case f_3 was set to 28 Hz. With the variable 2nd order term the cutoff can be raised to 40 Hz to compensate LF boost which is often present in control rooms.

The V_D requirements of table 2-1 can be met best with multiple drivers. Two 385 mm drivers were chosen with V_D of 0.8 l each. Another criteria for this choice is limited enclosure front panel area and necessary performance at crossover frequency. With larger cone diameters reproduction of 400 Hz may be problematic.

The low frequency enclosure consists of two 200 l vented and mutually isolated cabinets. Tuning frequency is 28 Hz and sensitivity 98 dB/W.

3.2 Mid and high frequency system

High frequency driver

Direct radiating high frequency dome drivers normally offer a sensitivity 90...95 dB/W at 1m. Maximum long term power input is, due to the small motor system, limited to 10...20 W. The maximum long term acoustical output is thus 100...108 dB at 1 m distance. 1 kW amplifier power would result in short term RMS output of 120...125 dB, provided that no power compression occurs. 130 dB short term output would thus require an amplifier power of at least 3 kW.

Large ribbon-type drivers are also available and their sensitivity and power handling are better than dome tweeters. However, due to their large dimensions their radiation pattern is very narrow at high frequencies.

Using a compression driver with 25 mm throat and only moderate horn loading a sensitivity of approximately 105 dB/W is available (see fig. 3.1) from 1,5 to 8,5 kHz above which the response tilts smoothly down to 101 dB/W at 15 kHz. Using a 300 W amplifier and a long term power limitation to

12 W RMS short and long term outputs of 130 dB and 116 dB are obtained, respectively. The higher sensitivity is, of course, the benefit of compression drivers as well as good control of the radiation pattern. The penalty is higher distortion and to minimize that penalty, crossover frequency should be high.

Midrange driver

Midrange drivers currently found in large monitoring systems fall into the following categories:

- a compression driver in a two-way system with crossover frequency at 450 Hz...1.5 kHz.

- a 200 mm...315 mm cone driver in a 3- or 4-way system with crossover frequencies at 150 Hz...300 Hz and 800 Hz...2 kHz. Above this a compression driver or a direct radiator is used.

- a 75 mm...100 mm soft dome unit covering the range from 250 Hz...500 Hz to 2.5 kHz...3.5 kHz.

- two 100 mm direct radiating soft cone drivers covering the frequency range from 200 Hz...400 Hz to 2.5 kHz...3 kHz.

Since a compression driver was selected for high frequencies, the upper cutoff frequency was to be kept high enough to avoid 2nd order harmonic distortion occurring at midband. The upper crossover frequency was selected to 3.5 kHz and thus the midrange driver passband will be 400 Hz ... 3.5 kHz. Conventional 200 mm ... 315 mm midrange drivers (developed from woofers), although showing an acceptable sensitivity of 98...102 dB/W and a continuous power handling of 75..150 W, cannot cope with the high crossover frequency without considerable colouration and non-uniform directivity because of their large cone diameter. Soft dome and small diameter cone units offer better freedom from colouration but their sensitivity is at maximum 90...94 dB/W and continuous power handling 50...120 W. See the comparison in table 3-1.

Since the only driver type capable of producing the required SPL falls short in bandwidth, and the driver with sufficient bandwidth cannot handle the power, a new type of cone midrange had to be developed.

Small diaphgram is necessary to avoid breakups at passband and non-uniform directivity at higher frequencies. Because of high SPL, the moving system must also be able to handle acceleration forces up to 200 N without mechanical breakdown. High temperature voice coil materials are needed to allow sufficient power handling. Lightweight motor and diaphragm are necessary for maximum sensitivity and for reduced need of mechanical damping for breakup modes.

Driver	200 mm cone midrange driver	315 mm cone midrange driver	3" soft dome
P_e	100 W	150 W	120 W
Sensitivity	97 dB/W	100 dB/W	92 dB/W
Maximum continuous SPL	117 dB	121 dB	113 dB
Voice coil volume	500 mm^3	750 mm^3	260 mm^3
Voice coil thermal time constant	5 s	6 s	5 s
Amplifier power for 130 dB short term output	2.0 kW	1.0 kW	6.3 kW
Usable bandwidth	200...1 kHz	150...600 Hz	450...3,5 kHz

Table 3-1 Midrange Driver Comparison 1

A smaller diameter voice coil offers better high frequency behaviour and, due to less thermal expansion, can work with tighter air gap tolerances than larger diameter coils with equivalent conductor volume. Thus the heat conductivity can be kept high [6]. In fact, the short peak power input is limited by the coil mass, not the diameter. The extreme input limit is the fusing current of the wire.

The designed driver is a 130 mm cone transducer operating in a 0,40 l sealed enclosure which forms the unit's chassis (see fig 3.2). The chassis works also as an effective heat conductor for the voice coil power dissipation. The laminated hard Kevlar cone is integrated with a self centering and field replaceable assembly. The one-layer voice coil diameter is 40 mm and it is wound from aluminium ribbon wire on a Kapton former and supported by a lightweight and stiff spider. A center phase plug is used. The other data is shown in table 3-2.

Nominal diameter	130 mm
Effective piston diameter	105 mm
Voice coil diameter	40 mm
Air gap height	6 mm
Voice coil length	7 mm
Voice coil volume	280 mm^3
Voice coil resistance	5,7 ohm
Voice coil thermal resistance	$3^oK/W$
Maximum voice coil temperature	250^oC
Maximum short term temperature	350^oC
Thermal time constant	5,5 s
P_e	70 W
Program power handling	1000 W
Flux density	1,5 T
Resonance frequency	370 Hz
Q_t	0.64
Sensitivity	99 dB/W @ 1 m
Usable bandwidth	370...4,5 kHz
Nominal impedance	8 ohm

Table 3-2 Midrange Driver Data

Two midrange drivers were connected in parallel in close vertical array to obtain the desired sensitivity and power handling and to increase the vertical directivity for less floor and mixing console reflections.

Directivity Control Waveguide

Direct radiators have their directional characteristics mainly dependent on their physical size, or when using parallel drivers, the distance of the radiators relative to wavelength. When two 385 mm drivers are crossed over to two 120 mm midrange drivers at 400 Hz, system's power response will have a peak above the crossover point because of the lower directivity of the smaller drivers. In order to increase the directivity of the midrange system under 1 kHz a special large area curved plate (Directivity Control Waveguide) was constructed to the front of the drivers. It has also a moderate loading effect under 1 kHz increasing the sensitivity up to 3 dB at the range 350...800 Hz (see fig. 3.3). The midrange average sensitivity becomes thus 103 dB/W and the total P_e is 140 W. The comparison to a 315 mm cone midrange driver and a 75 mm soft dome is shown in table 3-3 in the next page.

The Directivity Control Waveguide was made from die-cast aluminium alloy. It works also as a large heat sink for the midrange and tweeter drivers. The short and rapid flare-rate tweeter horn was integrated into the plate allowing the closest possible driver placement. The DCW plate dimensions are 645 x 645 mm, which allows it to be rotated in either horizontal or vertical position (see fig. 3.4). Ribs were included in the casting to prevent vibration and extra damping was laid on the inner edges to terminate higher order resonances.

Driver	2 x 120 mm development units on the DCW-plate	315 mm cone midrange driver	75 mm soft dome
Pe	140 W	150 W	120 W
Thermal time constant	5,5 s	6 s	5 s
Sensitivity	103 dB/W	100 dB/W	92 dB/W
Maximum continuous SPL	124 dB	121 dB	113 dB
Maximum displacement volume	± 17 cm^3	± 100 cm^3	± 9 cm^3
Amplifier power for 130 dB short term output	500 W	1.0 kW	6,3 kW
Usable bandwidth	370...4,5 kHz	150...600 Hz	450...3,5 kHz

Table 3-3 Midrange Driver Comparison 2

Distortion

The following distortion figures were measured for the midrange system at 110 dB continuous SPL at 1 m distance:

f/Hz	d_2/%	d_3/%
500	0,2	< 0,1
1 k	0,25	< 0,1
2 k	0,3	< 0,1
4 k	0,4	< 0,1

Table 3-4 Distortion Figures

3.3 Loudspeaker enclosure

The enclosure front panel dimensions are 1105 x 820 mm. Walls are made of a two layer material laminated with a vibration absorbing compound. Internal bracing is used and the front plate rigidity is assisted by the internal partitioning wall between the two isolated bass enclosures. The DCW-plate is acoustically isolated from the bass section. A display panel with overload and failure indicators is included in the DCW-plate.

4. ELECTRICAL DESIGN

4.1 Block Diagram

A simplified block diagram of the system designed is shown in Fig 4.1. The circuitry is divided to three functionally different sections, which are: Audio Processing Unit (APU), Power Amplifiers and Speaker Enclosure. The APU is further split to Crossover Section and Control Section.

The input signal is taken via active balanced amplifier, attenuator and a buffer amplifier to the active crossover filter. The signal is divided in the filter into the bass, midrange and treble channels and finally amplified with separate power amplifiers.

The loudspeaker driver units are protected against excessive power levels by a special Driver Unit Protection Processor (DPP) located in the control section of the APU-unit. This protection circuit also takes care of the protection of the loudspeaker drivers against a power amplifier failure.

4.2 Crossover Network

The crossover section of the APU consists of a balanced input amplifier and three parallel band pass filters. The input sensitivity of the whole amplifier can be varied 20 dB with input attenuator switch and input sensitivity control. The acoustic response in the control room can to a certain extent be balanced with five tone control switches: TREBLE-LEVEL, MIDDLE-LEVEL, BASS-LEVEL (1 dB/step), and BASS-TILT and BASS-ROLL-OFF (2 dB/step). Fig. 4.2 shows the effect of the control switches to the speaker free field response.

Crossover filters are aligned for equal acoustical phase and delay over the crossover region taking into account the drive elements' own transfer functions including phase and group delay responses. This ensures the acoustical axis to remain constant regardless of frequency.

4.3 Protection Circuits

The Control Logic section of the APU-unit contains several protection and safety functions for the amplifier and the driver units. The self diagnostics/starting sequencer controls the operating status of the entire system during the start-up as well as during normal operation. The system status is displayed on APU front panel. For the operator, the summary of the real time status display of the APU is monitored with the loudspeaker enclosure status display.

The Driver Unit Protection Processor (DPP) monitors continuously the safe operation area of the tweeter and midrange drivers. As stated in section 3. the design values for the long term and short term power limits of the treble driver are 12 W and 300 W. The thermal time constant of the treble driver is 2 s. The corresponding values for the midrange are 100 W (long term) and 600 W (short term), and thermal time constant is 5.5 s. The system tracks the voice coil temperature from the present signal and its previous history.

If safe limits are exceeded, the DPP gives a warning to the user. If the overload continues, the gain of the whole channel is reduced to safe level and a red warning light is flashed on the status panels of the APU-unit and the speaker enclosure. The essential factor in overload is total energy and the system should react correctly to signals having different duty cycles. Figure 4.3 shows the maximum continuous power supplied to the midrange and tweeter drivers while varying the burst ratio of the overloading signal from 5 to 100 %.

The control logic of the APU also senses the temperature of the power amplifier modules and the DC-voltage at their outputs. All driver units including the speaker interconnection cable are tested when the system is switched on and the user is alerted if any fault is detected. The muting operation in the starting sequence eliminates all undesired tone bursts in the speaker during power-on/power off conditions.

4.4 Power Amplifiers

Use of separate amplifiers for each frequency band will give benefits for example in terms of output current requirements [7],[8], equalization, wideband output level and driver unit damping [9]. Calculating from the achieved sensitivity figures the necessary amplifier powers are 2000 W for bass, 500 W for midrange and 300 W for treble. The bass section is naturally wise to divide into two 1000 W channels.

The power amplifier system has three identical modules, each consisting of two separate amplifiers. Two modules are used in bridged mode for bass channels and the output power is 2x1000 W. One module is used for mid and treble channels in single ended configuration. The modules are connected to the system back wiring board through 30 pin connectors at the rear of each module.

The power amplifier module can be divided into three functionally different parts: Driver stage, Power stage and Power supply. The input and voltage amplification stages of each power amplifier channel are located on two separate plug-in circuit boards. These boards are made using surface mount technology (SMT) and they are fully discrete design without operational amplifiers. The complete board can easily be changed if any service is needed.

For high output current capacity the power circuit for each module consists of 12 pcs of 200W/17A 35 MHz fast power transistors and of 8 driver transistors. The power supply capacitor size for each module is 60000 uF and the DC-current from the capacitors is supplied to the power transistors through 10X40 mm^2 aluminium bars which also act as mounting site for the transistors. The voltage amplification stages are powered from separate regulated power supplies. All components are visible after withdrawing the power module from the rack frame.

The main power supply consists of 3.5 kVA continuous duty shielded toroidal transformer with separate windings for each power amplifier module. A special delaying circuit driven by APU control logic is used for suppressing a huge starting current of the transformer. The power transformer has a built in thermal switch which is sensed by the APU control logic. A thermal-magnetic circuit breaker with its handle on the front panel functions as ON/OFF switch and also acts as power mains protector.

4.5 Mechanics

For the mechanics the key parameters for design were ease of maintenance and general rigidity because of heavy mass of some components. For example the 3.5 kVA power transformer only weights 30 kg. The amplifier is built into a 19" welded iron rack frame. The power amplifier modules and the APU module are plug-in units, and can be removed by only removing two screws and pulling the module out of the rack. The power amplifier electronics is integrated together with a massive aluminium heat sink which also acts as the module frame. Four low noise fans are used for cooling the amplifier.

5. PERFORMANCE

5.1 Frequency response

Free field frequency response is shown in fig. 5.1. Active equalisation allows the low frequency response to be set for flat free field or flat half space responses with the aid of the bass tilt adjustment. Overall passband tolerance of +/- 2 dB from 29 Hz to 17 kHz is achieved. Frequency response in a control room is shown in figure 5.3. Measuring distance was 3.2 meters (engineer's chair) and 1/3 octave warble signal was used.

5.2 Directivity

Curves in figure 5.2 show the frequency response of the system in different horizontal angles. The advantage of the DCW-plate can be seen at the range of 200...2 kHz where the directivity is very uniform and free from cabinet edge diffraction.

5.3 Maximum sound pressure level

Peak level of 136 dB per pair was recorded in control room conditions at 2.2 m from the speakers. Material was Madonna: True blue, track 1. The following SPL readings were obtained in free field conditions at 1 meter:

IEC weighted pink noise	123 dB continuous RMS, 135 dB peak
IEC weighted pink noise bursted	138 dB peak
sine burst f=500 Hz	135 dB peak

Table 5-1 SPL readings

5.4 Thermal compression

The following measurements were made with continuous sinusoidal signal. The drive elements had sufficient time to reach stable voice coil temperature. Measuring distance was 1 m in free field.

	SPL theoretical/dB	SPL out/dB	Compression/dB
f=100 Hz	100,0	100,0	0,0
	105,0	105,0	0,0
	110,0	109,9	0,1
	115,0	114,5	0,5
	120,0	119,0	1,0
	125,0	121,5	3,5
f=1 kHz	100,0	100,0	0,0
	105,0	105,0	0,0
	110,0	109,6	0,4
	115,0	114,0	1,0
	120,0	116,8	3,2
f=10 kHz	100,0	100,0	0,0
	105,0	104,9	0,1
	110,0	109,5	0,5

Table 5-2 Thermal Compression

6. CONCLUSION

A high power active control room monitor was designed. The key for necessary SPLs and low coloration was a new midrange driver and its loading. On amplifier side the most important development was the driver unit protection logic, because powerful amplifiers can also easily destroy the drivers. In addition to sound engineers the system has satisfied in listening tests also discerning hifi listeners.

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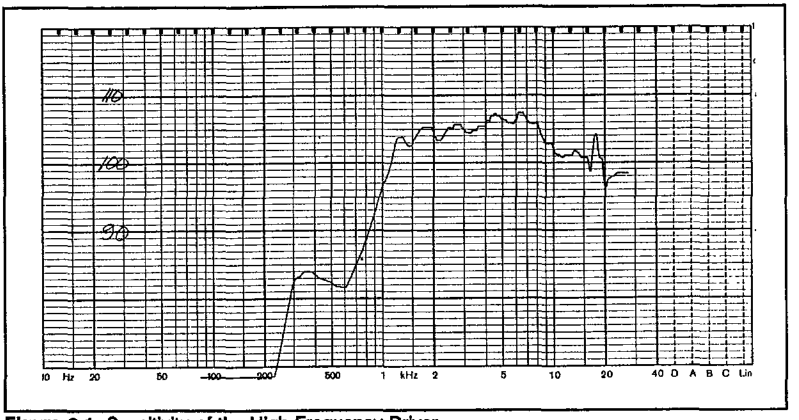

Figure 3.1 Sensitivity of the High Frequency Driver

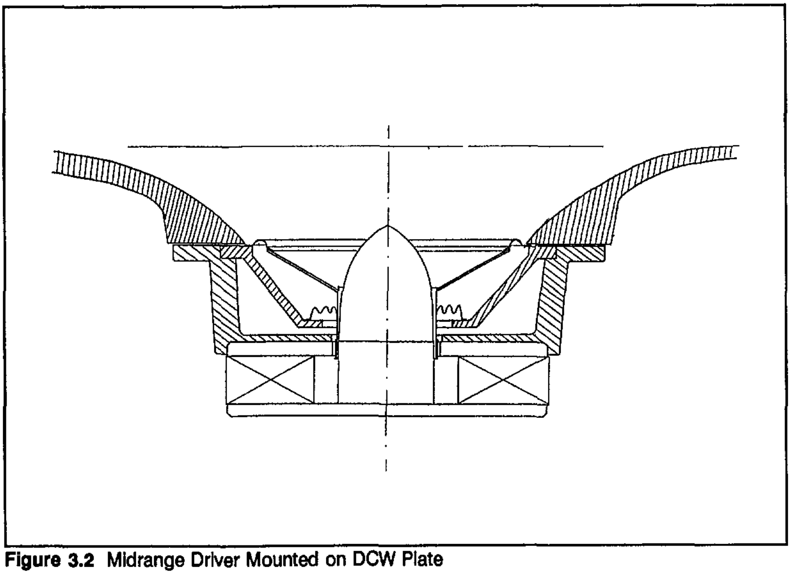

Figure 3.2 Midrange Driver Mounted on DCW Plate

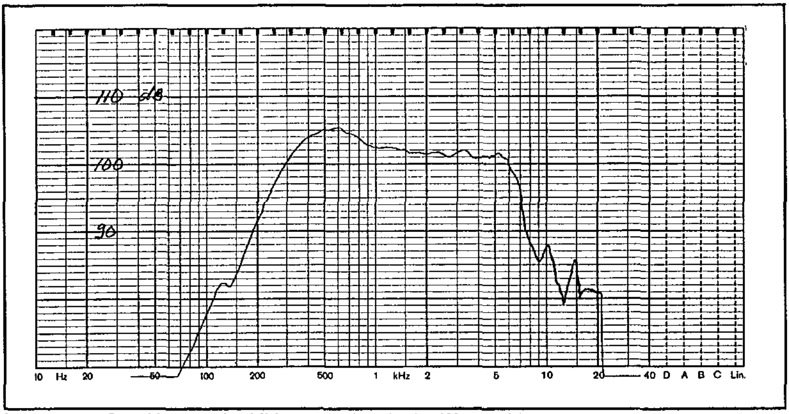

Figure 3.3 Sensitivity of the Midrange Driver in the Waveguide

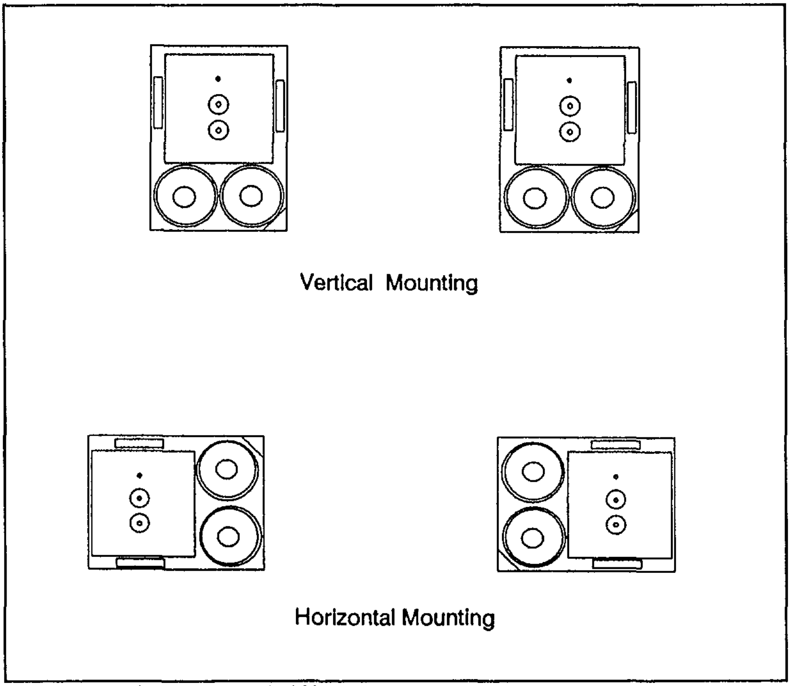

Figure 3.4 Horizontal and Vertical Mounting

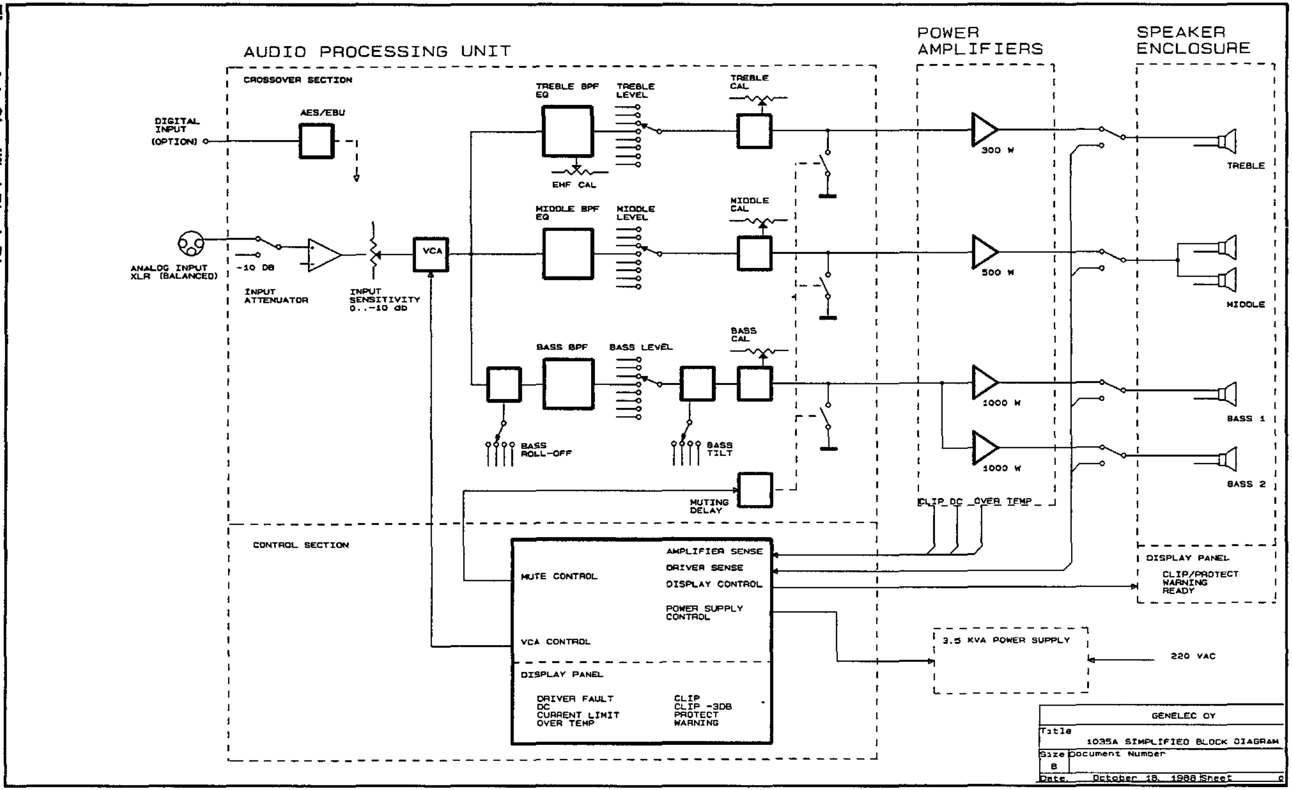

Figure 4.1 Simplified Block Diagram

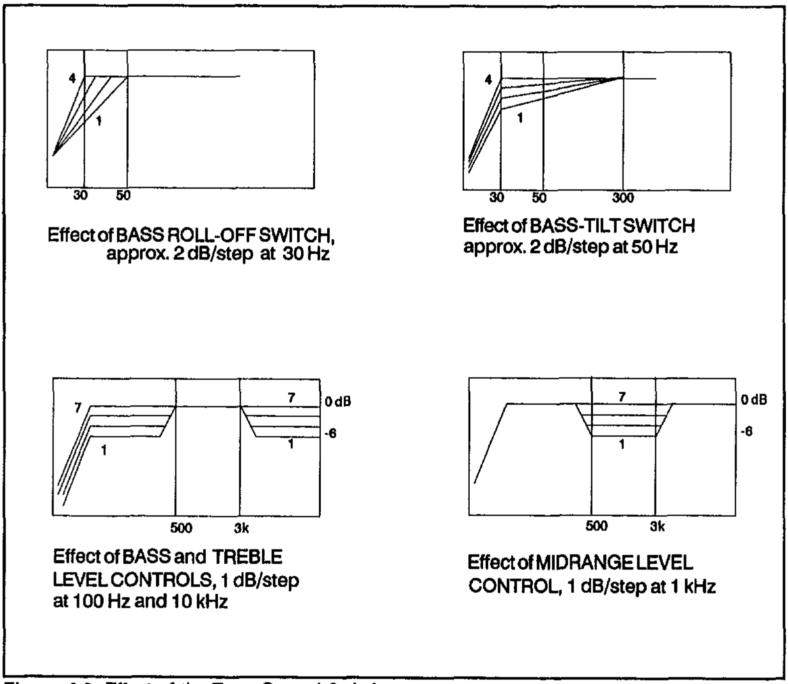

Figure 4.2 Effect of the Tone Control Switches

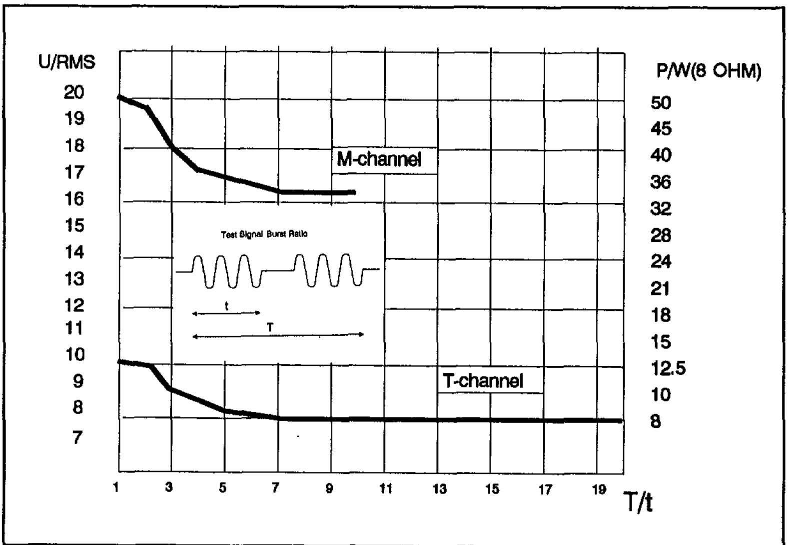

Figure 4.3 Maximum Continuous Power vs. Signal Burst Ratio

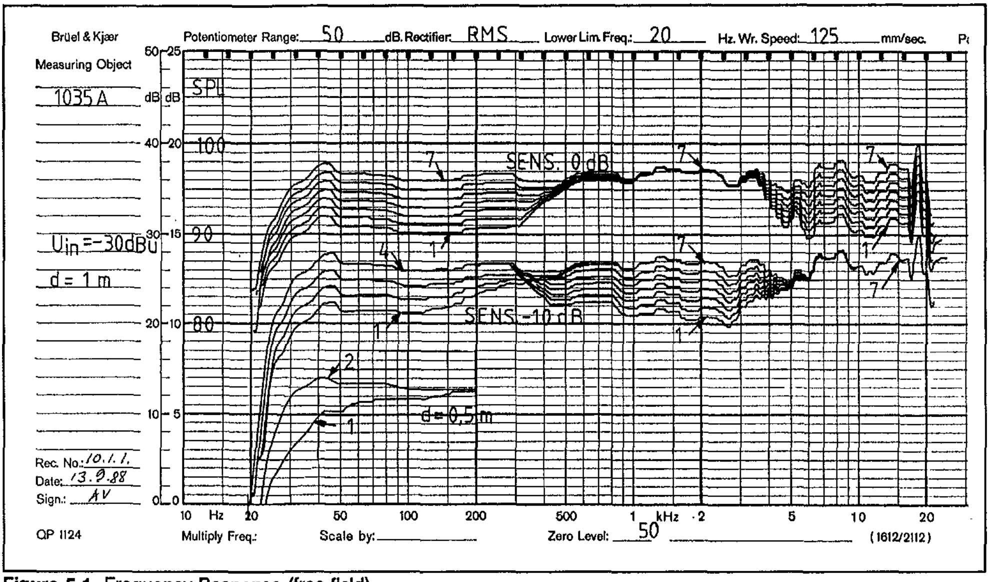

Figure 5.1 Frequency Response (free field)

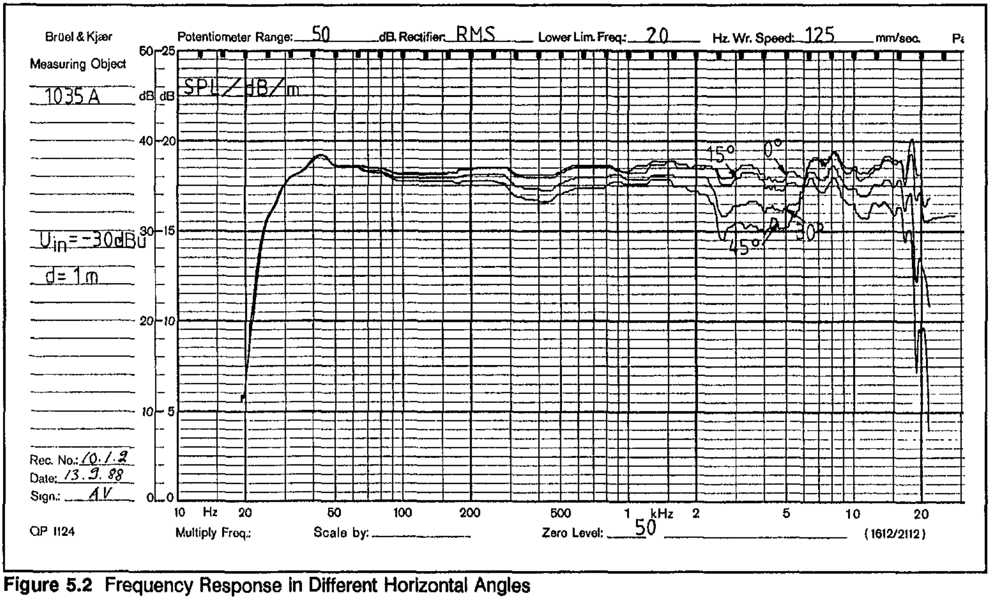

Figure 5.2 Frequency Response in Different Horizontal Angles

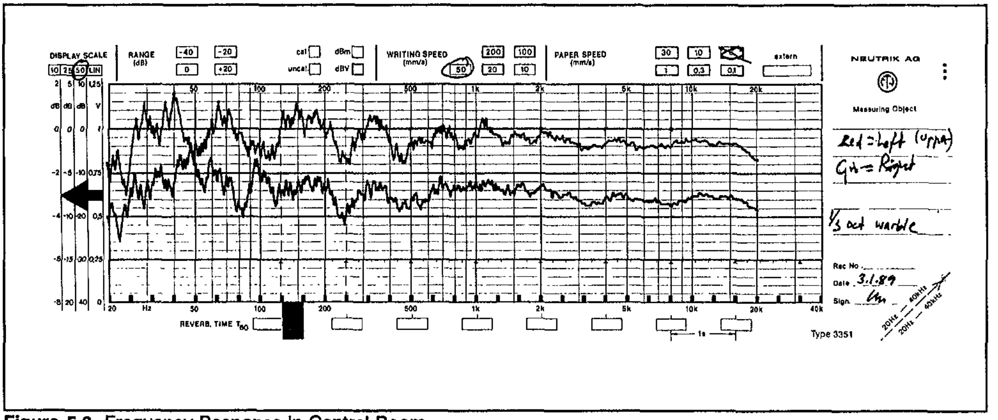

Figure 5.3 Frequency Response In Control Room