ENGINEERING THE AR-9

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Bass Response

Regardless of the principle employed in its design, a loudspeaker system's bass response is controlled by the same laws of physics:

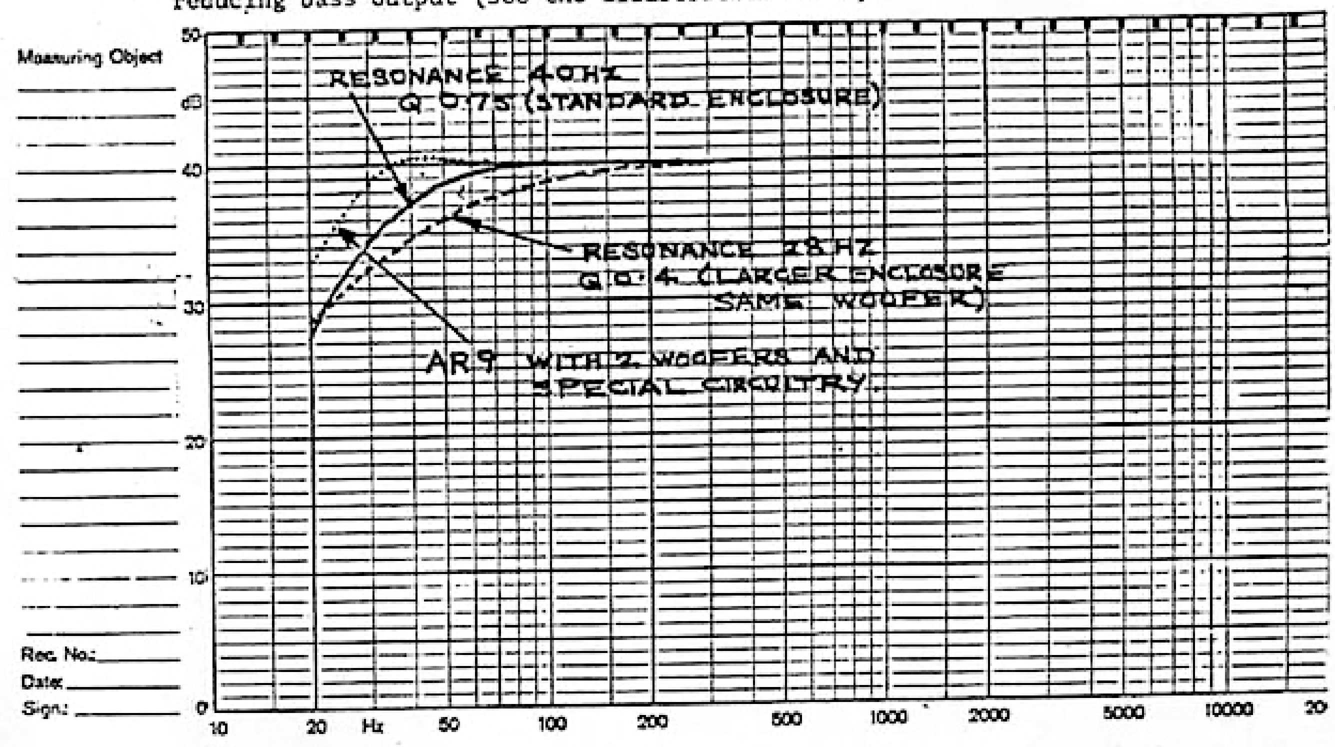
1. Bass response can normally be extended by use of a heavier cone, because this lowers the resonance frequency of the system (all other things being equal). However, the increased cone weight requires greater amplifier power to move it, so that efficiency decreases.
2. Making the cabinet larger also lowers the system resonance frequency, if the speaker remains unchanged. However, the frequency response will gradually drop at low frequencies because the stiffness of the air in the cabinet has been reduced. Engineers say that the "Q" has decreased.
3. Increasing the size of the magnet in the loudspeaker, when possible, is one way of increasing efficiency. However, such a change also increases damping, lowering the "Q" and therefore suppressing bass response at the lowest frequencies.

The AR-11 woofer and cabinet combination represent an optimum design. Examination of this system shows some of the problems of creating a superior system.

Suppose we were to take two AR-11's and connect them in series; we would get the same frequency response, sound pressure level and "Q" at a given setting of the volume control as we get with one AR-11 at that setting. However, the two systems would draw only half as much power from the amplifier as the single AR-11. (This is because of the changing values of acoustic and electrical impedances involved.) Exactly the same effect would be observed if we put both woofers in a single cabinet twice the size of an AR-11. There would appear to be no advantage to such a system, in actual use, over a single AR-11.

If the two woofers were to be connected in parallel, instead of in series, conditions would change. We would have the same "Q" and frequency response curve, but now the sound pressure level will have doubled over a single speaker at the same volume control setting. Twice as much power will also be taken from the amplifier. The main problem is that the impedance of the two woofers in parallel will be dangerously low for most amplifiers.

By making the volume of the two-woofer cabinet larger, we can lower the resonance frequency, but we will also lower the "Q", actually reducing bass output (see the illustration below).

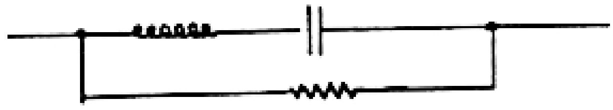


Clearly, achieving extended bass response, even with AR's exceptional low-frequency driver design, requires a new approach. In the AR-9, the method chosen was to control the "Q" electrically as follows:

1. If a resistor is placed in series with the woofer, the "Q" is raised, while the acoustic output is reduced.
2. A woofer has its highest impedance at the system resonance frequency. Two woofers in parallel could safely be used in the frequency range near resonance, but not at other frequencies.
3. If a way can be found to put a resistor in series above and below the resonance frequency, but out of the circuit at and near resonance, the impedance, "Q" and output level might be adjusted to give an ideal system combination.

This is exactly what has been done in the AR-9. At the resonance frequency, the two woofers are in parallel, doubling sound pressure level in that region. As the previous illustration shows, adding 6 dB to the dashed curve in the vicinity of 28 Hz will take it 3 dB higher than the solid line representing a standard enclosure. Fine. But as we move up in frequency, we would like the level to drop gradually to match the solid line curve. We also would like to make the impedance stay as high as possible in this range.

Using the network shown below, we can have both of these things.



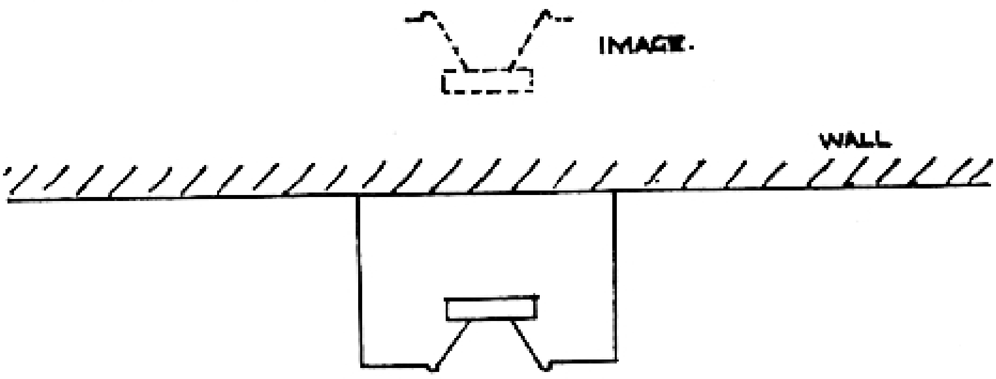
At and near the system resonance frequency, the choke and capacitor are essentially a short-circuit; the presence of the resistor is irrelevant. As the signal frequency increases, the impedance of the resonant circuit also goes up--and the speaker system output goes down! By selecting precise values for the components, and using a choke coil with low internal resistance, "Q" and impedance are smoothly controlled to yield extended bass response with full amplifier protection.

Interaction With Room Reflections

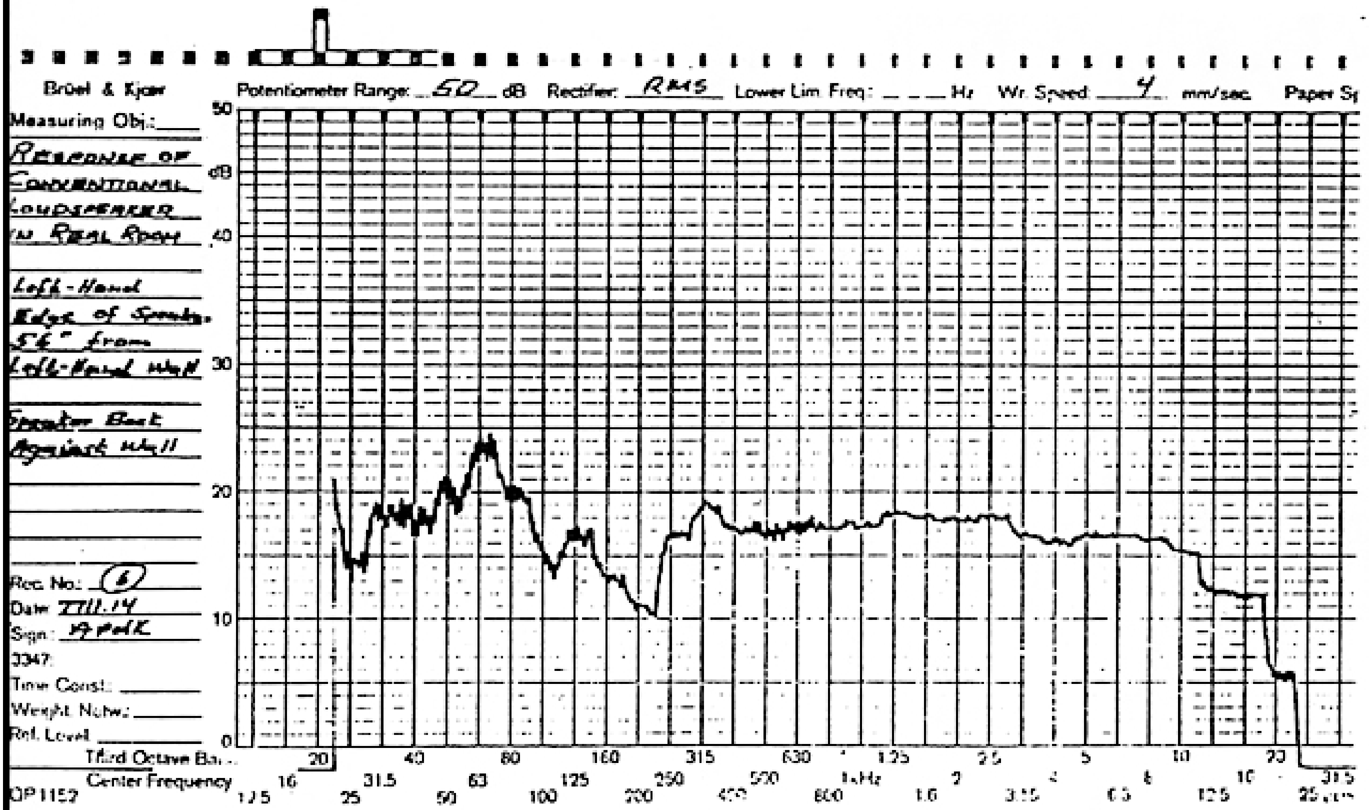
The walls of a room are excellent mirrors for low-frequency sound waves. In fact, if we could see with such waves as we do with light waves, we would notice images of our loudspeakers in the walls, floor and ceiling just as we would in a hall of mirrors.

These images of loudspeakers behave almost exactly like real loudspeakers. Their radiation, when combined with the sound waves coming directly from the "real" loudspeakers, can produce interference patterns that make bass response uneven. The most serious problem is that caused by the image in the wall immediately behind the speaker system, because this image is usually one of the closest--and loudest--to the listener.

Looking at the drawing below, it can be seen that sound waves, moving across the front and then toward the back of the speaker cabinet, will bounce off the wall and go out toward the listener a short time after the direct sound from the loudspeaker. Because of this time difference, the peaks and dips of sound pressure in the wave--like the peaks and dips in a wave on the surface of water--will coincide at some frequencies and cancel at others.



If the distance from the speaker, around the cabinet to the wall, and back to the front of the cabinet again, is exactly one-half the distance between wave peaks (one-half wave length), there will be severe cancellation. This means a substantial drop in bass output at that frequency. The result can be measured, and is visible in the frequency response curve below, measured in a relatively typical listening room. Although the dip in response varies somewhat with system placement and exact cabinet dimensions, it is never absent.



How to remove this effect?

As it happens, when the distance between the loudspeaker driver unit and the wall is reduced, the frequency at which the dip occurs goes up. In the AR-9, the two woofers used for extended bass response were carefully mounted so as to be as close to the floor and rear wall as possible, the best position for reduction of image interference. The reason is that the woofers in the AR-9 operate only up to about 200 Hz. One-half wave length at this frequency is about 3 feet (1 meter). Since the sound path from the woofer to the wall and back again is only a little more than one foot in the AR-9 (corresponding to a dip frequency of about 600 Hz), the problem does not arise.

There is, however, an 8-inch driver unit mounted directly on the front of the AR-9 cabinet. How is the same effect prevented in its range? By using the opposite solution (which actually pretty much takes care of itself). The distance around the cabinet to the wall and back, in this case, is so long that the corresponding frequency is too low to be in the range of the 8-inch driver.

The resulting frequency response, shown in the accompanying set of room curves, is exceptionally smooth and free of excessive variation. Moreover, the system frequency response is essentially the same almost anywhere along the wall. Placement as close as 2 inches from a side wall causes only a moderate and gradual rise below 200 Hz, to a maximum of about 6 dB.

Cabinet Damping

In a cabinet as tall as the AR-9 enclosure, made necessary by the vertical array design, conventional acoustic absorbent material (such as glass fiber wool) cannot prevent the occurrence of strong standing waves. Normally, this would result in a loss in output over most of the frequency range from 30 to 80 Hz. This effect has been suppressed by an unconventional technique. The upper 32 inches of the cabinet are filled with fairly dense polyester fiber wadding to absorb frequencies which would otherwise be reflected up and down inside the enclosure, as in an organ pipe. In order to keep the system "Q" from being lowered by excess wadding, the bottom 18 inches of the cabinet are left unfilled. Because the woofers at the bottom of the cabinet operate only at low frequencies (long wavelengths), the side-to-side dimensions of the cabinet do not introduce a comparable effect.

The Lower Midrange Unit

This is an 8-inch driver mounted in its own acoustic suspension enclosure, attached to the front panel of the AR-9 from behind. The crossover frequency used is 200 Hz at the lower end of its range, and 1200 Hz at the high end. The choice of low-frequency crossover relieves the woofers of any need to reproduce very low and relatively high frequencies simultaneously; this could cause Doppler or intermodulation distortion. The problem arises because the low frequencies cause the woofer cone to move up and back over substantial distances, at the same time as higher frequencies are being radiated from the cone. The result is a constant fluctuation in the apparent frequency of the higher tone, caused by the same physical interaction that makes the horn of a passing automobile seem to change pitch. Restricting the range of frequencies over which the woofers operate prevents any such effect, which might be noticed due to the extended bass response in the AR-9.

The Upper Midrange Unit

This is a fully sealed 1½-inch diameter dome unit with special energy-absorbent diaphragm. The frequency range covered is from 1200 to 7000 Hz; the upper portion of the frequency range is maintained in level by use of a "semi-horn" surrounding the dome, providing better acoustic loading. Below 3000 Hz the semi-horn has no effect, and the unit is essentially a simple dome radiator.

To increase its power-handling capacity, the coil is surrounded by (and completely immersed in) a specially-developed high-temperature magnetic fluid. This was made necessary because conventional magnetic fluid, as used in units designed to operate at lower power levels, literally boiled away at the levels at which the AR-9 is designed to work. In addition, heavy tinsel lead-out wire and high-temperature adhesives are used in this unit.

The Tweeter

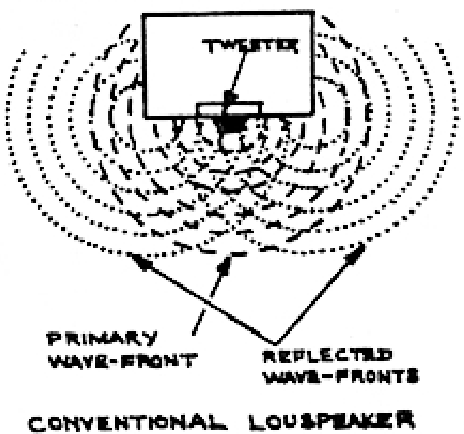
This unit is a fully-sealed 3/4-inch unit with energy-absorbent dome. It covers the frequency range from 7000 to beyond 20,000 Hz. Like the upper midrange, the voice coil of the tweeter is surrounded by magnetic fluid. It is constructed with cyano-methacrylate adhesives for high-temperature, high power handling operation.

Acoustic "Blanket"

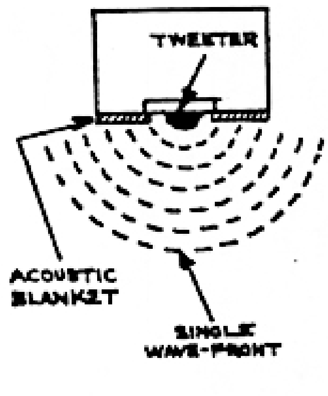
On a conventional loudspeaker cabinet, sound waves from the tweeter and mid-range units move across the front panel and are reflected from obstructions such as mounting screws, moldings, decorative parts, and even from the cavities formed by other driver units. When the sound waves reach the cabinet edges, they are reflected again.

The direct and reflected sound waves interfere with each other in a way that varies with frequency, blurring the stereo image and making frequency response uneven.

These effects are suppressed in the AR-9 by an acoustic "blanket", a layer of absorbent material on the front panel surrounding the mid- and high-frequency drivers (patent applied for). The "blanket" keeps sound from spreading to, and being reflected by the cabinet edges and the cavity formed by the 8-inch driver. The absence of the usual interference effects caused by such reflections,when coupled with the vertical drive unit placement described in the next paragraph, gives the AR-9 exceptional stereo localization and very smooth frequency response.



CONVENTIONAL LOUSPEAKER SYSTEM SHOWING REFLECTED WAVES FROM CABINET EDGES.



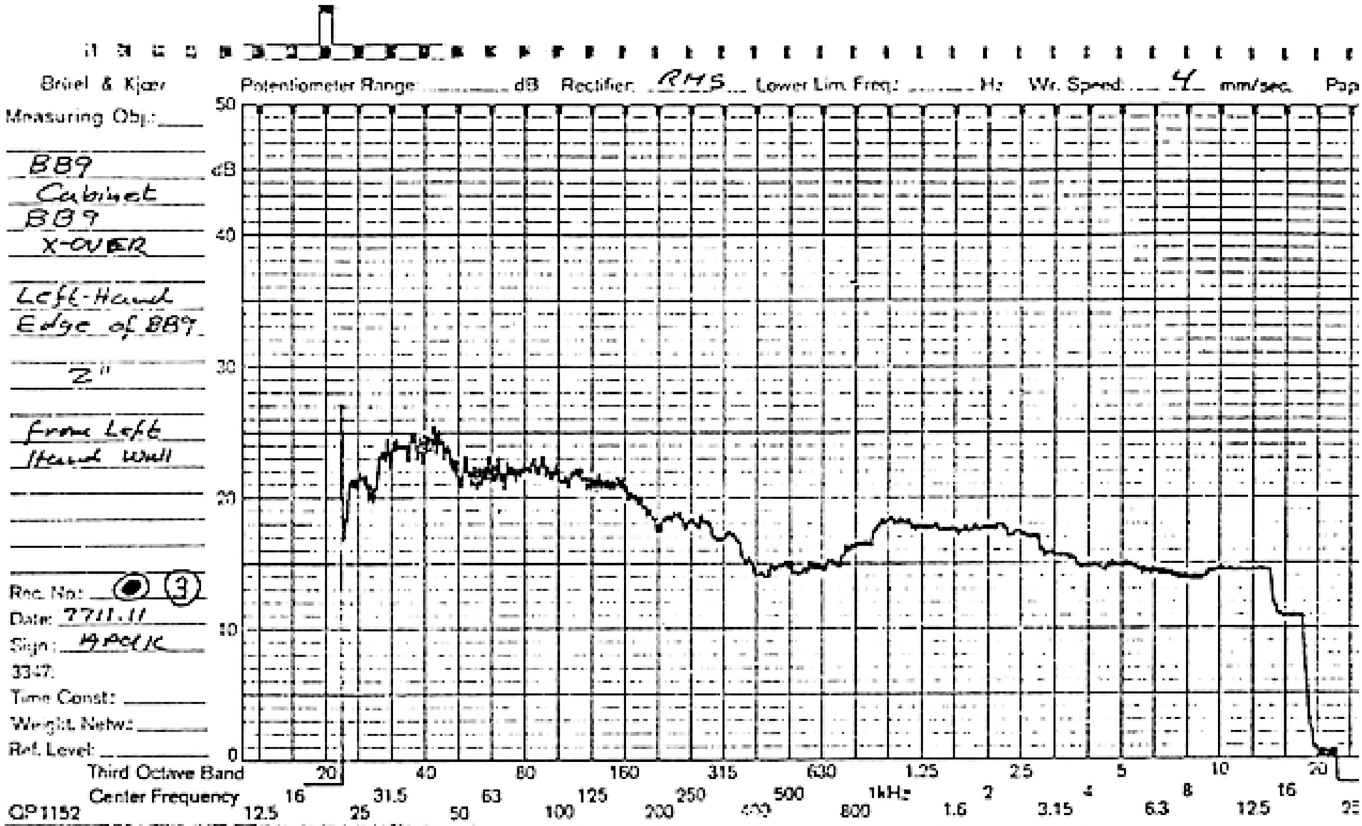
LOUDSPEAKER SYSTEM WITH "ACOUSTIC BLANKET" SHOWING ABSENCE OF REFLECTED WAVES.

Drive Unit Placement

Whenever two driver units operate in the same frequency range, as is the case just above and below the crossover frequencies of a system, there is danger of interference patterns affecting frequency response and stereo placement at the listener's position. If the drivers are mounted side by side, the usual result is that the sound in the crossover region is radiated as a series of beams spread out horizontally. Even small head movements can shift the listener's ears in and out of the beams, changing the level for each ear at various frequencies in a quite unpredictable way. When this happens--and it is not at all uncommon--the musical instruments in the program seem to jump and slide across the room as the notes go up and down the scale.

In a stereo pair,the effect is a complete blurring of image,as the horizontal beams produced by each system will not be the same as each other at the listening position.Unfortunately,regardless of how much effort has gone into designing mid-range and tweeter units with perfect dispersion,incorrect mounting can largely negate such effort.

The best solution, chosen for the AR-9, is to mount the mid-range and high-frequency drivers in a single vertical array. This makes horizontal distribution of sound much more uniform at all frequencies, matching the horizontal alignment of the ears of the human listener. In addition,both speaker systems of a stereo pair are now also automatically aligned with each other,providing an extremely precise stereo image.


Brüel & Kjær
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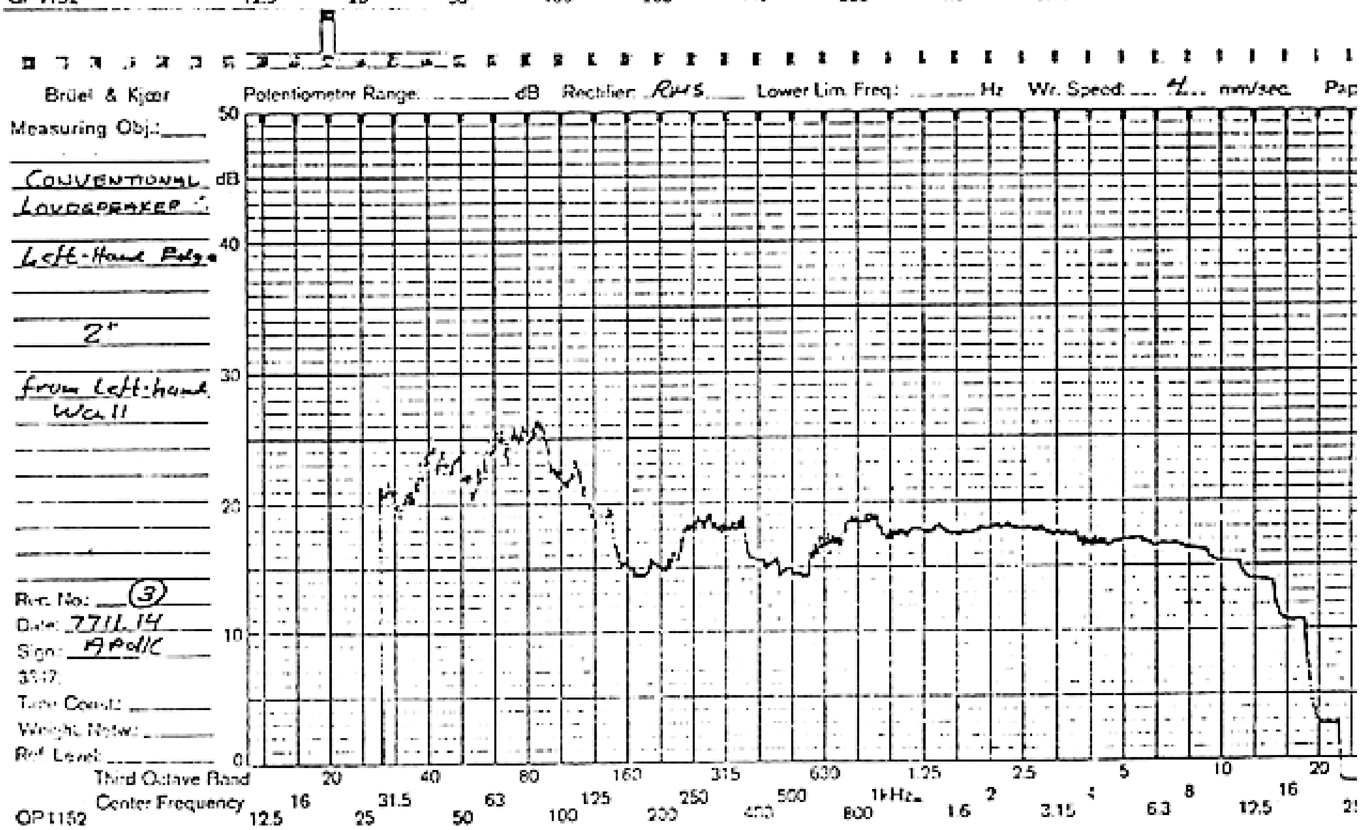
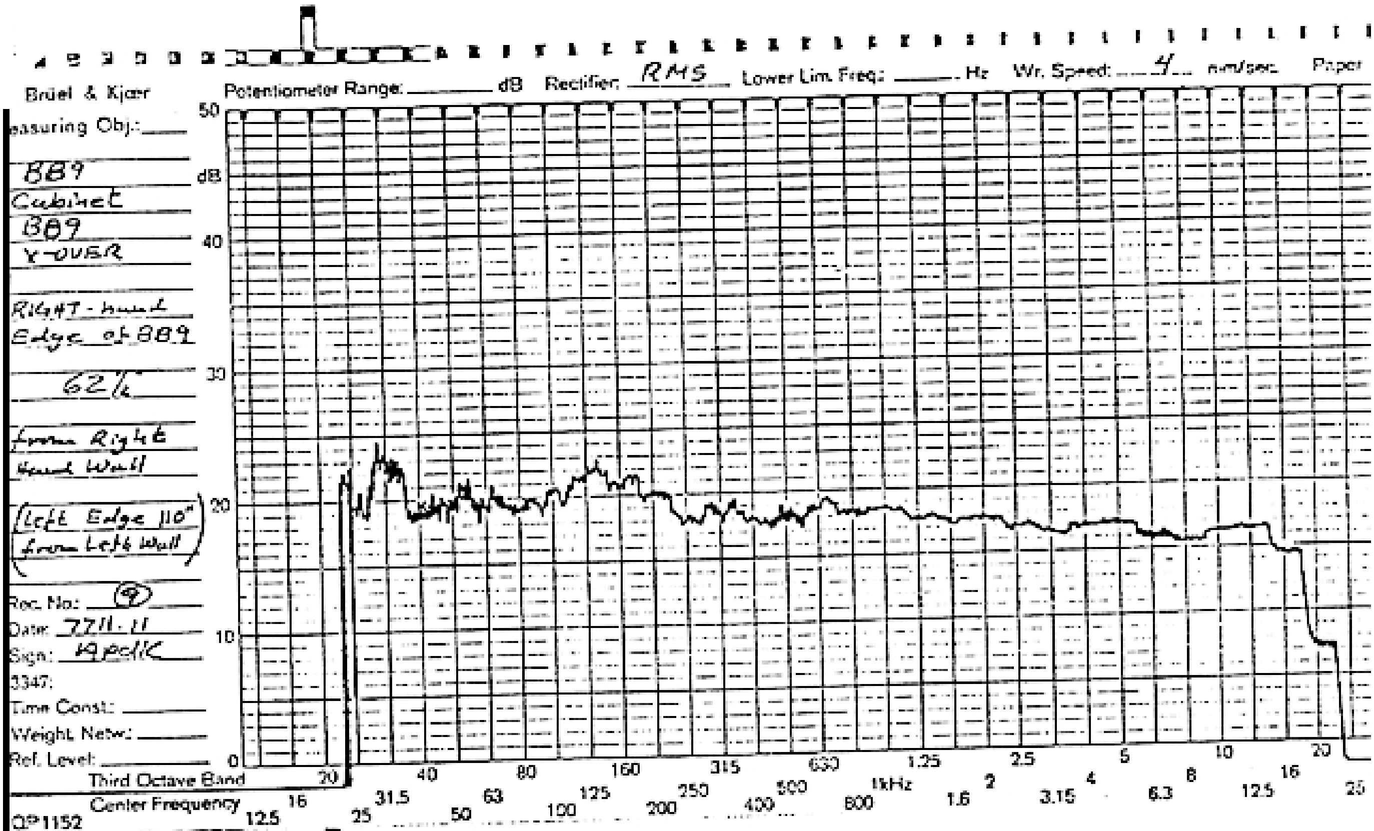
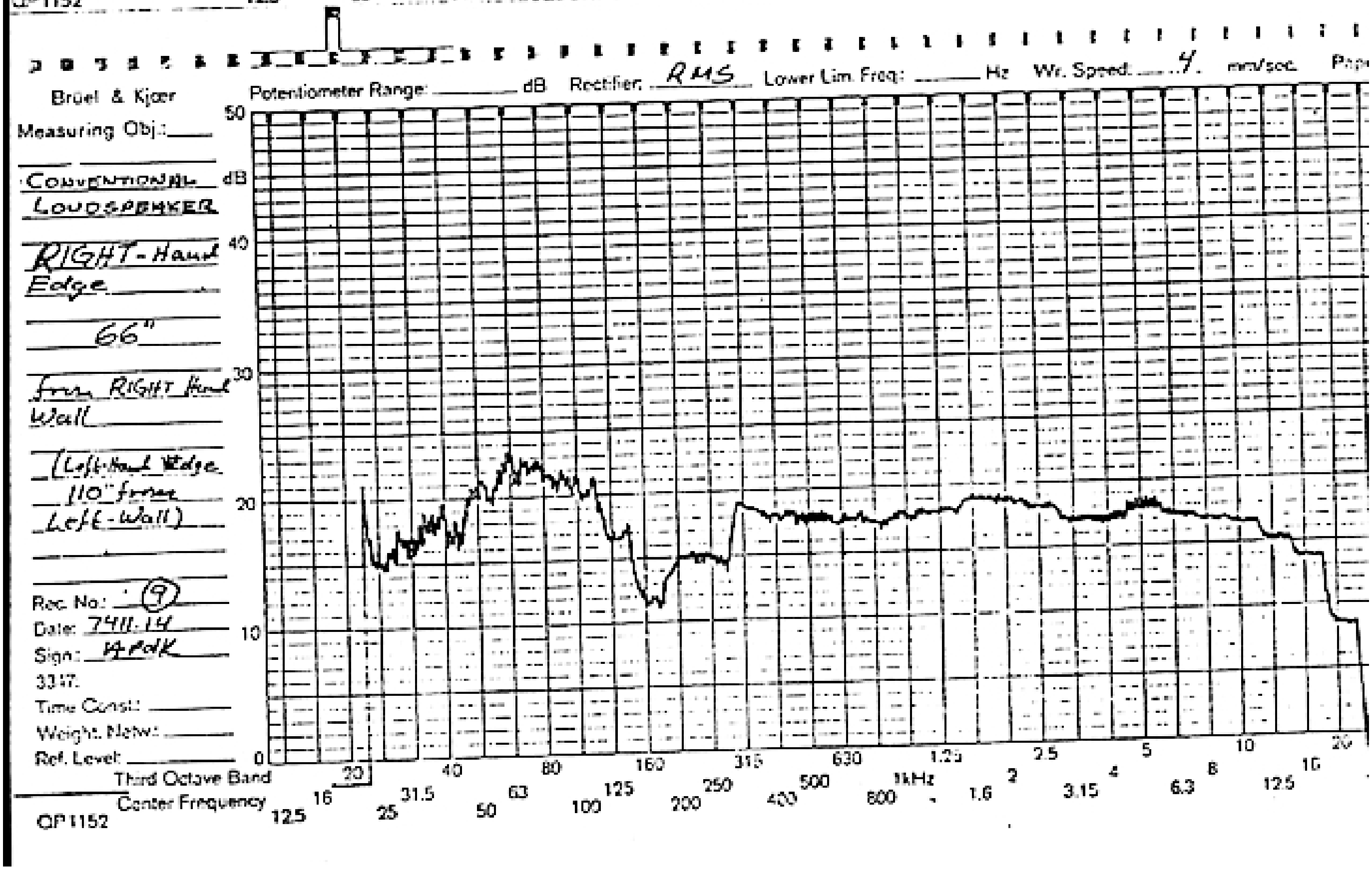
Measuring Obj.:
BB9
Cabinet
BB9
X-OVER
Left-Hand
Edge of BB9
2"
from Left
Hand Wall
Rec. No.: 3
Date: 7711.11
Sign.: HPolK
3347
Time Const.:
Weight. Netw.:
Ref. Level:
Third Octave Band
Center Frequency
QP1152
dB
50
40
30
20
10
0
12.5 16 20 25 31.5 40 50 63 80 100 125 160 200 250 315 400 500 630 800 1kHz 1.25 1.6 2 2.5 3.15 4 5 6.3 8 10 12.5 16 20


Brüel & Kjær
Potentiometer Range: .... dB Rectifier: RMS Lower Lim. Freq.: .... Hz Wr. Speed: 4 mm/sec.
Measuring Obj.:
CONVENTIONAL
LOUDSPEAKER
Left-Hand Edge
2"
from Left-hand
Wall
Rec. No.: 3
Date: 7711.14
Sign.: HPolK
3347
Time Const.:
Weight. Netw.:
Ref. Level:
Third Octave Band
Center Frequency
QP1152
dB
50
40
30
20
10
0
12.5 16 20 25 31.5 40 50 63 80 100 125 160 200 250 315 400 500 630 800 1kHz 1.25 1.6 2 2.5 3.15 4 5 6.3 8 10 12.5 16 20


Brüel & Kjær
Potentiometer Range: dB
Rectifier: RMS
Lower Lim. Freq.: Hz
Wr. Speed: 4 mm/sec.
Paper
Measuring Obj.:
BB9
Cabinet
BB9
X-OVER
RIGHT-hand
Edge of BB9
62"
from Right
Hand Wall
(Left Edge 110"
from Left Wall)
Rec. No.: 9
Sign:
3347:
Time Const.:
Weight. Netw.:
Ref. Level:
Third Octave Band
Center Frequency
QP 1152
dB
50
40
30
20
10
0
12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1kHz
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
25


Brüel & Kjær
Potentiometer Range: dB
Rectifier: RMS
Lower Lim. Freq.: Hz
Wr. Speed: 4. mm/sec.
Measuring Obj.:
CONVENTIONAL
LOUDSPEAKER
RIGHT-Hand
Edge
66"
from RIGHT Hand
Wall
(Left-Hand Edge
110" from
Left-Wall)
Rec. No.: 9
Date: 7411.14
Sign:
3347.
Time Const.:
Weight. Netw.:
Ref. Level:
Third Octave Band
Center Frequency
QP 1152
dB
50
40
30
20
10
0
12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1kHz
1.25
1.6
2
2.5
3.15
4
5
6.3
8
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12.5
16
20