Rectilinear X

A MINIMUM-DISTORTION BOOKSHELF SPEAKER SYSTEM

Design Goals

The Rectilinear X was designed to provide the critical listener with a loudspeaker of more accurate response and significantly lower distortion (in particular, lower *time delay distortion*) than the most sophisticated systems previously available. This was to be accomplished without exceeding the dimensions of full-size bookshelf speakers and without resorting to exotic driving systems of prohibitive cost. Other than that, cost was not in itself a design consideration.

Basic Configuration

The Rectilinear X is a three-way speaker system utilizing a woofer, a midrange driver and a tweeter, all of the moving-coil principle but of somewhat unconventional design. In addition, the woofer is crossed over to the midrange at an unconventionally low frequency, the midrange to the tweeter at an unconventionally high one. The completely enclosed cabinet incorporates an airtight internal shelf that isolates the woofer from the midrange and tweeter. A specially designed grill cloth acts as a wide-dispersion acoustic lens.

Woofer

An entirely new woofer was developed especially for this speaker system. Its diameter is 10 inches, which is considered by Rectilinear engineers to be optimum size for a modern bass driver. It has faster transient response than 12-inch or 15-inch units and, despite its smaller cone, can move sufficient air to produce unusually high power at low distortion even in the bottom octave of the audio spectrum. This is possible because of a completely linear excursion capability of ½ inch from rest, i.e. one full inch from peak to peak. The rubber surround, the spider and the voice coil all incorporate novel design techniques to achieve this specification.

Above 100 Hz, the response of the woofer is rolled off at the rate of 12dB per octave, so that its operating range is strictly within the lower bass frequencies. Not allowing the woofer to contribute to the midrange response is one of the most important design characteristics of the Rectilinear X, being largely responsible for its freedom from time delay distortion and its lack of midrange coloration.

Voice coil diameter of the woofer is 1½ inches; total magnet weight is 10 lbs.

Midrange Driver

This is a 5-inch unit with a 2-inch "whizzer" cone. The entire dual cone structure moves as a rigid piston at the lower midfrequencies; at the higher frequencies a gradual decoupling takes place and only the whizzer cone moves. Thanks to a unique European paper used in fabricating the cone structure, plus an unusually light self-supporting voice coil, transient response is exceptional throughout the driver's operating range and beyond.

Below 100 and above 8000 Hz, the crossover network of the Rectilinear X rolls off the response of the midrange driver. This leaves more than six octaves to be covered by this unit, the widest range ever assigned to the middle channel of a three-way system. The range covers nearly all the fundamentals and overtones of instrumental and vocal music, so that they are reproduced by a single, coherent source, uninterrupted by phase-shifting networks. Thus the Rectilinear X has the same benefits as certain widely touted "no-crossover" speakers, without suffering from the inevitable distortions produced when all ten octaves of the audio spectrum are fed to a single voice coil and diaphragm.

Voice coil diameter of the midrange driver is ¾ in.; total magnet weight is ¾ lb.

Tweeter

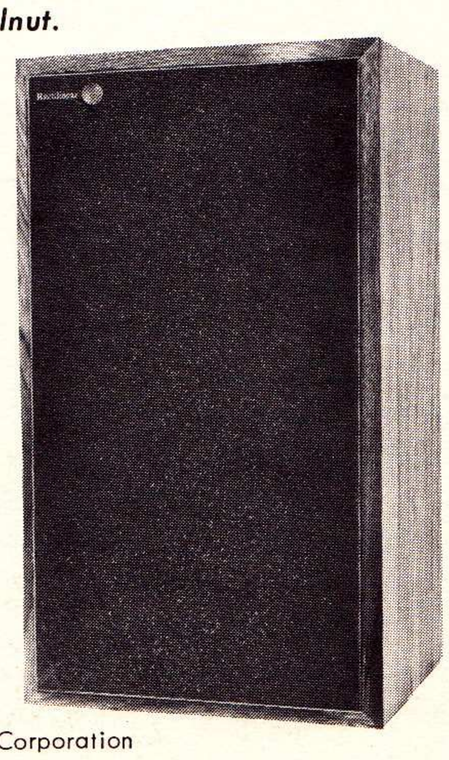
A 2½-inch unit covers the range from 8000 Hz up. It is of simple, straightforward design, with an extremely light cone and voice coil structure, and it reproduces the 1¼ octaves assigned to it with exceptional smoothness and virtually unmeasurable distortion. In fact, as used in the Rectilinear X, for the highest frequencies only, it is the top-performing moving-coil tweeter ever tested by Rectilinear engineers, regardless of cost or complexity.

Voice coil diameter is ½ in.; total magnet weight is 1 oz.

Crossover Network

The unconventional crossover frequencies of the Rectilinear X necessitate an unconventional network. To cut off the woofer response at

FIGURE 1:
Rectilinear X in oiled walnut.



Rectilinear X bookshelf speaker

100 Hz with an electrical attenuation slope of 12 dB per octave requires a huge series inductance as one of the network elements. The normal air-core coil of the correct value would be ludicrously large and heavy. Rectilinear solves the problem with a 5-lb., air-gapped iron-core choke of special design, proving, among other things, that inevitable distortion in iron cores is just another popular superstition.

At 8000 Hz, the crossover between the midrange and the tweeter is much less critical than it would be at a lower frequency. Thus a simple quarter-section network with an attenuation slope of 6 dB per octave in each direction is the preferred choice. The tweeter just begins to fill in where the whizzer cone response starts falling off.

The midrange and treble channels are each provided with a level control, accessible on a recessed panel in back of the speaker, so that a judicious amount of deviation from flat response may be applied to suit the acoustic environment.

Cabinet

The outside dimensions of the Rectilinear X cabinet are 25" by 14" by 10¾" deep. It is of unalterably rigid one-piece construction, in ¾" stock. Once the cabinet is completed and filled with sound-absorbent material, it is never again opened, the drivers being mounted from the front with silicone rubber (the same as used in the window seals of the Apollo capsule). The internal shelf completely isolates the back radiation of the woofer from the midrange, in further implementation of the speaker's basic design concept. The finish is oiled walnut.

The spacing of the drivers on the front panel is the result of careful study and has nothing to do with production convenience or aesthetics. To minimize phase interference problems, the drivers must be separated by a distance equal to a specified fraction of the wavelength at the crossover frequency. The separation of the midrange driver from the woofer is particularly critical. Many speaker systems neglect this elementary principle, with dire consequences.

Grill Cloth

In all other speaker systems the grill cloth is acoustically transparent, allowing sound waves of all frequencies to pass through unaffected. The grill cloth of the Rectilinear X is different. It is specially designed to be slightly nontransparent above 5000 Hz in varying degrees across its area. Thus it presents a graduated acoustic impedance to the midrange and tweeter units, increasing their acoustic load and modifying their dispersion pattern. In much the same way as an optical lens bends light because of the continuously varying thickness of the glass, this grill cloth acts as an acoustic lens and bends the sound. The result is an almost perfect cardioid sound pressure pattern at the higher frequencies.

FIGURE 2:
Rectilinear X with grill cloth removed.

The frame supporting the grill cloth is slightly raised and open at the sides, so that the acoustic lens effect works right out to the edges of the speaker, without any diffraction. It is literally impossible to hear any directionality on the Rectilinear X.

Impedance and Efficiency

The nominal impedance of the Rectilinear X is 4 ohms. It is a low-efficiency system requiring a considerable amount of clean amplifier power. Amplifiers with less than 35 watts rms power capability per channel are not recommended, and in large rooms 50 to 100 watts rms per channel will be preferred by the critical listener for the reproduction of heavy program material at high levels.

Frequency Response

Although it is far from the most important speaker specification, the pressure amplitude response of the Rectilinear X (the conventionally cited "frequency response") has been made as linear as the state of the art permits. Unfortunately, this subject has never been treated with complete candor by the high-fidelity industry, and most manufacturers' published frequency response measurements seem to be impossible to duplicate, or even to approximate, by impartial outside testers.

The amplitude response curve shown in Figure 3 may not be the most impressive ever printed in loudspeaker literature. It is, however, the flattest, smoothest curve ever recorded in the Rectilinear laboratories, where both Rectilinear and competitive speakers are constantly being measured and evaluated. Furthermore, it is a curve that can be recognizably approximated under outdoor conditions by anyone with access to well-calibrated measuring equipment,

FIGURE 3:
Rectilinear X frequency response on axis; outdoor conditions. Midrange and tweeter controls in flat position.

FIGURE 4: Harmonic Distortion in %

Frequency of fundamental	50 Hz			100 Hz			500 Hz			5000 Hz		
Power input	1W	5W	10W	1W	5W	10W	1W	5W	10W	1W	5W	10W
2nd harmonic distortion	1.0	1.8	1.8	1.0	1.0	0.9	1.0	1.0	0.7	0.8	1.9	2.2
3rd harmonic distortion	0.5	1.8	1.9	0.4	0.6	0.5	0.4	0.5	0.4	*	0.5	1.0
4th harmonic distortion	*	*	*	*	*	*	*	*	*	*	*	1.1
higher harmonics	*	*	*	*	*	*	*	*	*	*	*	*

*negligible

as it is a single uninterrupted run taken from a single microphone position, not a reconstructed composite of the separate response curves of the drivers.

As will be seen, the most unusual thing about the amplitude response of the Rectilinear X is the way the bass holds up right down to the bottom octave of audible frequencies. The speaker is literally flat down to 40 Hz and puts out useful power down to 25 Hz.

Harmonic Distortion

The chart in Figure 4 gives a complete harmonic analysis of spurious response with fundamental inputs of increasing power at key frequencies. This is a much more revealing specification than total harmonic distortion expressed in a single figure. No other speaker system measured by Rectilinear engineers has yielded equally low percentages.

Intermodulation Distortion

Since the woofer is cut off at 100 Hz, the most powerful bass tones cannot possibly modulate the higher frequencies, so that the most disturbing type of IM distortion is automatically eliminated. Within the midrange channel, with 200 and 2000 Hz mixed 4:1, first-order IM distortion is 3% at 5 watts input. This is an unusually good figure for such a severe test.

Rectilinear X bookshelf speaker

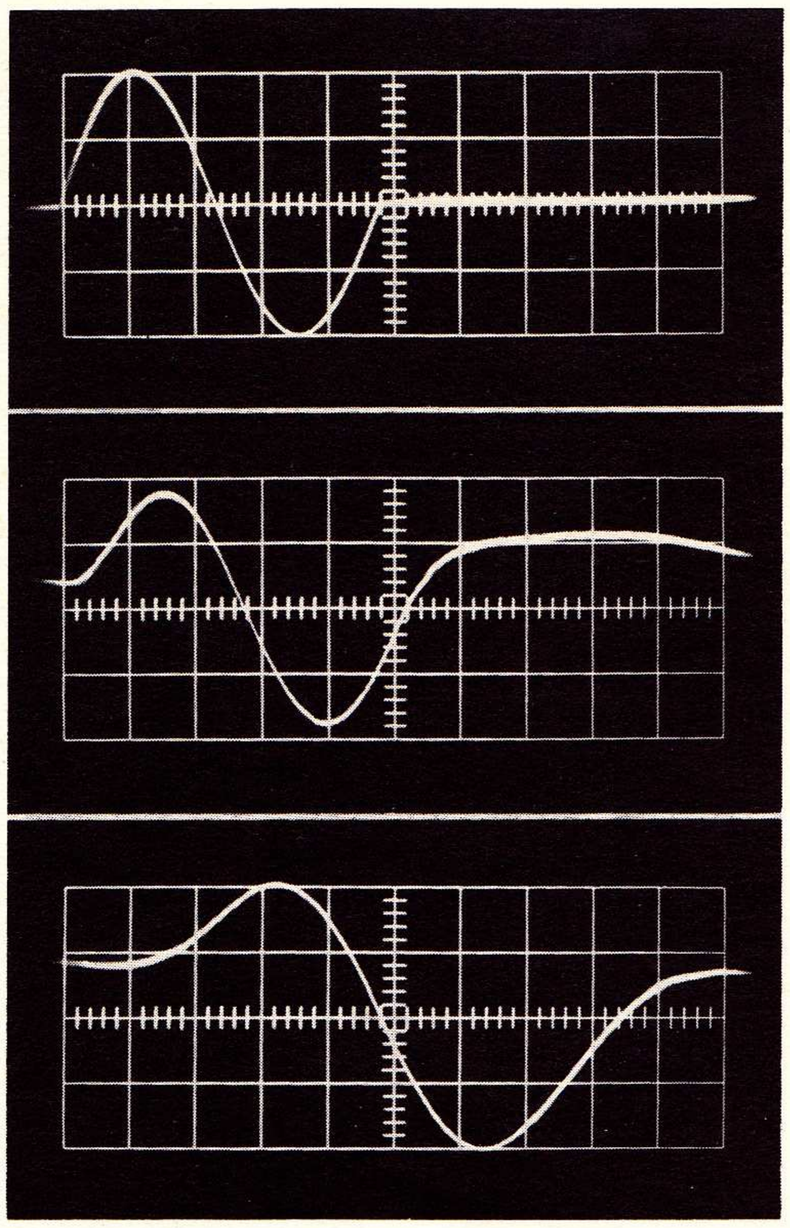


FIGURE 5:
Time delay distortion of a single-cycle tone burst at 500 Hz. Time base 0.4 millisecond per major division; microphone distance from speakers negligible. (Top) Amplifier output. (Middle) Rectilinear X output. Time delay less than 0.2 millisecond. (Bottom) Output of top-of-the-line model of famous bookshelf speaker brand, with 575 Hz crossover. Time delay approximately 0.8 millisecond. Note stretching of wave form; it is no longer a 500 Hz tone.

Time Delay Distortion

This, in the light of recent research at the Rectilinear laboratories, is what separates the best loudspeakers from the merely good ones.

It has always been a great frustration to speaker designers that, once a certain level of excellence is attained in terms of frequency response and distortion percentages, further improvements along those lines no longer correlate with listening quality. In fact, it is impossible to predict the sound of a reasonably advanced speaker system from its frequency response or distortion data. Time delay measurements, on the other hand, promise to develop into a completely objective criterion of speaker quality.

A loudspeaker produces time delay distortion when, counting from the instant that an amplifier signal is applied to the speaker terminals, the resulting pressure wave does not reach the listener's ear (or a measuring microphone) at the speed of sound. There is a time lag, due to a delay within the speaker between the entry of the electrical signal and the exit of sound. This delay appears on an oscilloscope as a no-output condition, an actual moment of dead silence.

All speakers produce *some* time delay distortion. Woofers and their associated networks have inherently greater delay than smaller drivers with their lower mass, and in general the amount of delay is frequency-dependent. This, of course, changes the phase relationship of signals passing through the speaker, with considerable effect on the phase response (as distinct from the amplitude response). There is steadily increasing evidence that phase response, which is the phase angle plotted against frequency, is the key to the difference between natural and "canned" speaker sound.

A detailed analysis of loudspeaker phase characteristics and time delay distortion in the reproduction of music or speech would involve the network theory concept of envelope delay, since actual program material consists of complex, aperiodic signals rather than sine waves. However, Rectilinear engineers have found that time delay measurements of sine-wave tone bursts are thoroughly meaningful as a simple, practical speaker test. (Not to be confused with conventional tone-burst tests for transient response and ringing.)

There seems to be a close correspondence between shortness of tone-burst delay and naturalness of sound. This is less apparent at the lowest frequencies but becomes more and more obvious going up into the midrange. It appears that a delayed midrange will actually mask the "faster" high frequencies and create a loss of clarity. The superior clarity of the Rectilinear X is due not so much to the inherently low time delay distortion of each driver but to the reproduction of all frequencies above 100 Hz by the midrange unit, which is considerably faster than any woofer. Figure 5 dramatically illustrates the difference this uniquely low crossover can make.

Summary of Specifications

Size:	25" by 14" by 10¾" deep
Drivers:	10" woofer, 5" midrange, 2½" tweeter
Crossover Frequencies:	100 Hz and 8000 Hz
Nominal impedance:	4 ohms
Minimum Power Requirement:	35 watts rms
Frequency Response:	30 to 20,000 Hz, ±4 dB
Time Delay:	woofer 2.0 millisec., midrange 0.2 millisec., tweeter 0.06 millisec.
Controls:	midrange level, tweeter level
Connection to Amplifier:	choice of binding posts or banana jacks
Cabinet:	oiled walnut
Shipping Weight:	65 lbs.
Price:	$199.00

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