



Compact Ribbon Emulator: An Introduction

*By Christopher Barrow, Product Manager
Community Professional Loudspeakers*

Abstract

The need for a high-frequency device with physical driver spacing suitable to behave as a line source beyond 16 kHz is well understood. A new method has been developed for creating such a device using closely spaced individual elements uniformly coupled to a single ribbon-like diaphragm. Certain unique challenges had to be overcome for this device to be suitable for use in professional audio applications; these are discussed within. The finished device and system are lightweight and small, with uniform dispersion characteristics and very low distortion.

Introduction

Community's new **Compact Ribbon Emulator™ (CRE)** uses an array of ceramic transducers coupled to a linear polyester ribbon to produce a lightweight and rugged high-frequency driver with performance and sound quality that rivals a traditional ribbon driver. The patent-pending CRE device is a series of devices, the first embodiment of which will be discussed in this paper as it is applied within Community's **ENTASYS™ Column Line Array Loudspeaker System**.

At the heart of each CRE is a drive device that has often been used in audio applications of every kind. As often as it has been used, it has been maligned, shunned and disavowed by the professional audio community as not being of desirable quality for use in professional applications. Much of this reputation has been well deserved. The device has commonly been misapplied, used poorly and its characteristics not studied closely enough to allow designers to understand how to take advantage of its most beneficial characteristics. The device being discussed is, of course, the bimorphic polycrystalline lattice structure of lead, zirconium and titanium on a ceramic substrate known as a PZT, or more commonly, a Piezoelectric Driver¹.

The Piezoelectric Driver (PZT) has earned its poor reputation, unfairly, from repeated misuse of the device in poorly designed, low cost loudspeakers since its

introduction. However, PZT devices have also been used correctly and successfully for years in both pro audio and high-end home audio by companies like Community, Meyer Sound, Apogee Sound, JBL, Klipsch, Altec, Dahlquist, Polk Audio and others². Terms like "harsh," "high distortion" and "sibilant" are often used to describe the sound quality of PZTs. However, these descriptions of "piezo sound" only apply when the devices are applied poorly. A PZT device in actuality has very low inherent distortion³, and can be made to sound smooth, pleasing and musical if the proper design guidelines are followed; as they have been in the application of the CRE in Community's ENTASYS Column Line Array Loudspeaker.

Why Not Just Use A Traditional Ribbon Driver?

Before discussing the advantages and challenges of applying CRE technology, it is appropriate to discuss the engineering consideration for not using a traditional ribbon driver.

A traditional ribbon driver consists of an aluminized strip in a magnetic field. Audio current through the ribbon causes it to move in the magnetic field producing sound. Ribbon drivers are primarily used as high-frequency devices and are known for their smooth sound quality and extended frequency response.

However, traditional ribbon drivers have at least four disadvantages:

1. They need powerful magnetic fields from large, heavy magnets. Their overall size (width and depth) and weight do not allow them to be used in a compact, lightweight column line array loudspeaker design like Community's ENTASYS. Their wide magnet and frame structure ensure that they can only be coaxially mounted in front of large drivers while still allowing a reasonable crossover point to be reached between the low frequency drivers and the ribbons. If used in front of compact drivers, as the CRE is used in ENTASYS, too much of the upper midrange energy from the low frequency drivers would be blocked and an appropriate

-

There are three fallacies that must be immediately addressed and corrected before discussing the use of piezoelectric drivers any further:

-

$$C_i = \text{Input Capacitance} = \frac{\epsilon_0 \epsilon_r A}{t}$$

$\epsilon_0 = 8.85 \times 10^{-12}$ farads/meter
 $A =$ Electrode Area
 $t =$ Dielectric Thickness

C_M = Mechanical Compliance = $1 / \text{Spring Rate (M / N)}$

Figure 1: Simplified Piezoelectric Equivalent Circuit

As can clearly be seen in these measurements, the impedance of the piezo devices in a single CRE are purely capacitive only from about 6 kHz to 20 kHz and then again below resonance starting at about 4 kHz (Figure 2a). Directly associated with the resonance in the impedance is a very large resonant spike in frequency response magnitude (about 12 dB), over a

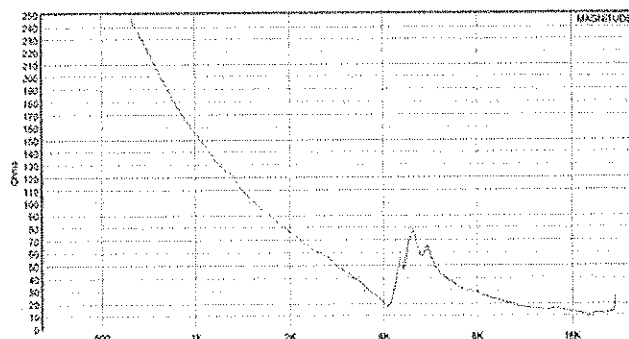


Figure 2a: Impedance of a Single CRE

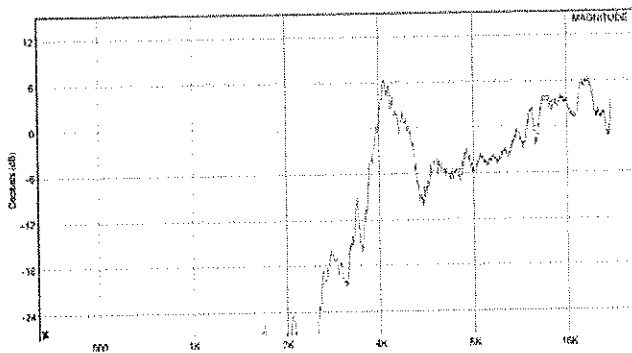


Figure 2b: Magnitude of a Single CRE

very narrow range of frequencies (Figure 2b). This behavior is identical for a single piezo device or group of devices, like in a CRE.

2. Piezoelectric drivers can be used without a crossover. Technically, this is true. However, referring to the frequency response in Figure 2, one can easily come to the conclusion that while a piezoelectric device *can* be used without a crossover it is clearly not desirable nor acceptable to use one without a crossover in any professional application (and it is entirely questionable whether or not they should *ever* be used without a crossover in any application).

This is the first, and most obvious, misapplication of piezoelectric drivers. From the beginning, designers of low cost equipment have looked at the capacitive-like impedance of the piezoelectric driver and realized that it is extremely easy to build a very low cost loudspeaker using a piezo HF driver. After all, they would avoid paying for the expensive crossover components typically found in a high quality loudspeaker *and* the driver itself is relatively inexpensive. But the performance price to be paid for such designs is a very "peaky" frequency response, often right in the middle of the voice band where it can be extremely harsh⁶ and irritating, and a very audible resonance and "ringing" due to the electromechanical properties of the piezo device itself.

To make matters worse, while a piezoelectric driver does have very low distortion within its intended pass band, the distortion increases greatly just below resonance. Without a crossover helping to remove it, this distortion can be clearly audible.

In review, without a crossover, a piezoelectric high-frequency driver will sound harsh, resonant and appear to have high distortion. This is the exact description a typical audio professional would attribute, unfairly, to *all* piezoelectric drivers. This kind of sound quality is entirely predictable by just looking at the raw frequency response and impedance graphs of these devices without proper filtering.

3. Piezoelectric HF drivers always have high distortion. This is false. In fact, it is one of the most

misunderstood characteristics of piezoelectric high-frequency drivers. As a direct radiating device, a piezoelectric driver typically has distortion of only 0.5% over most of its range³. *This is far lower than most dome radiators and most horn loaded compression drivers*, especially when the latter is coupled to elaborate plane wave generating pattern control horn devices as are common on many large line array systems. Additionally, since the piezoelectric device has a lower moving mass it responds to transients better than a moving coil-type device⁷. When used properly, a piezoelectric driver has lower distortion and very fast transient response⁸, better than just about any other device available, comparable with some of the better push-pull electrostatic loudspeakers⁹.

Below (Figure 3) is a graph of the manufacturer's datasheet for the Motorola KSN1016A wide dispersion piezo-driven horn loaded high-frequency driver. The impedance/distortion graph is being included here as a second means of illustrating the inherently low distortion present in a piezo driver. This particular model was chosen due to the similarities in radiation pattern to that of a CRE. Due to horn throat distortion, the overall distortion level of the device is slightly higher than that of a direct radiating piezo, but still respectable at only 1% THD at the stated drive level.

Note the same resonance peak in both the impedance and frequency response that are present in the CRE measurement of Figure 2. Also note that the resonance present does not directly relate to "distortion." While a resonance can sometimes clearly be heard by our ears, it does not necessarily have to contribute to the actual distortion of the device. This is a quantitatively elusive value to quantify in some cases and illustrates some of the deficiencies in our easy-to-capture, but nonetheless flawed, data measurement and gathering techniques typically employed. In the next section, other hard-to-capture resonances (that

Impedance, and Distortion Ratings

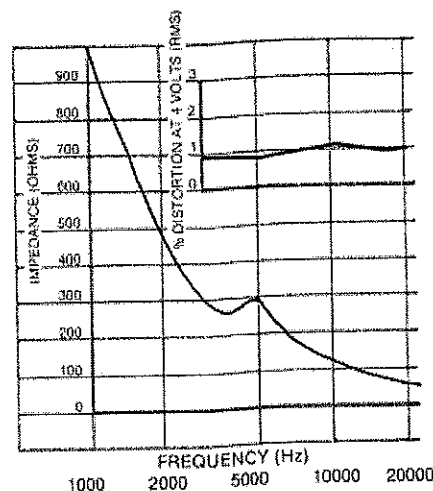


Figure 3a: Motorola KSN1016A Impedance/Distortion

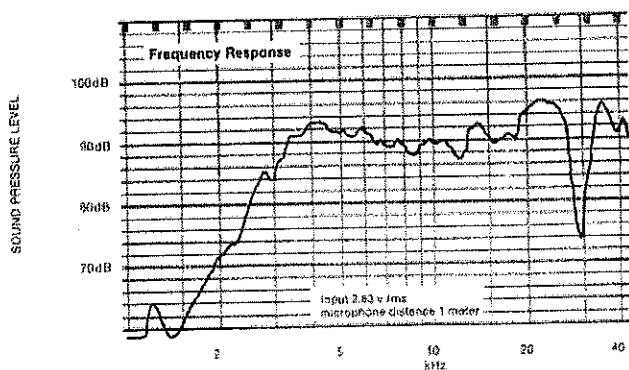


Figure 3b: Motorola KSN1016A Frequency Response

are equally difficult to quantify using simple measurement techniques) related to piezoelectric devices will be explored.

Lastly, not only can piezoelectric drivers sound fairly harsh in their lower regions due to their inherent resonance properties; but due to their very low, capacitive, impedances at high frequencies they can sometimes make amplifiers unstable, causing everything connected to the amp to sound bad¹⁰. Consider that a typical "stress-test" for a Class A/B amplifier is to connect it to a 2uF load and see if it remains stable at reasonable levels. The capacitive nature of the piezo is causing the amplifier to be under a "stress-test" at high frequencies at all times. The distortion attributed to the piezoelectric driver may sometimes not be inherent in the driver at all. Often it is the amplifier that is actually causing the distortion; the piezo is just reproducing it.

With these three fallacies about piezoelectric drivers explored and corrected, the discussion can focus on how to use a piezo driver correctly in a professional audio application and the challenges of designing the requisite crossover for it. However, before that, a proper description of the Compact Ribbon Emulator is in order.

A Compact Ribbon Emulator

The typical piezoelectric high-frequency device consists of a piezoelectric disk connected to a small cone driver within a small plastic housing. This assembly is then, typically, attached to a small plastic horn. These horns come in many varieties, from single device "bullet" tweeters featuring a 3-inch square frame and the characteristic "bullet" phase plug, to multi-driver units on pattern control horns, and everything in between. Some of these devices work well, some do not. The phase plugs and horns attached to many of these devices are questionable. These horn loaded piezo devices have been misapplied for years in low-cost DJ equipment. It is not uncommon to see three, four or five of these devices all lined up in a row across the face of a low cost loudspeaker. Not only do the designers not use crossovers on these devices, they apparently do not understand the destructive interference and comb filtering that can occur in the high-frequency regions due to

spatial misalignment of the devices. Two high-frequency devices three inches or more apart will have a terrible on-axis frequency response and a very poor off-axis response with heavy comb filtering in most cases. Often, the uneven, peaky frequency response attributed to piezos is, once again, a result of their application and not inherent in the devices. No high quality compression driver or dome driver would sound good in this arrangement either.

Community has taken an entirely different approach to using multiple piezoelectric transducers in a single device to take advantage of their small size and the beneficial interference needed to create a high-frequency line array device. Now, as diagrammed in Figure 4, Community has updated this piezo-ceramic transducer technology and coupled a vertical line of seven optimized ceramic transducers to a single, ribbon-like polyester diaphragm. The result is a unique patent-pending Compact Ribbon Emulator (CRE). The piezoelectric transducers, coupled with a well-designed crossover network, give the CRE a smooth and extended frequency response. The slender, ribbon-style diaphragm gives the CRE a ribbon-like dispersion pattern (narrow vertical, wide horizontal) and helps average out minor variations in the individual transducers. The resulting CRE driver has a smooth, sweet sound quality, very much like a traditional ribbon driver, and has the additional advantages of low weight, high impedance, ruggedness and moderate cost.

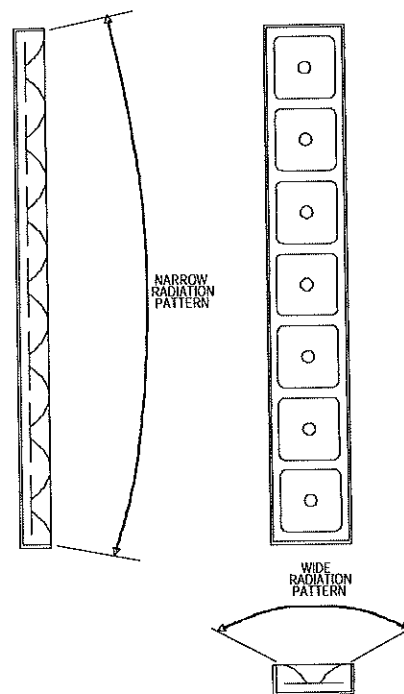


Figure 4: Compact Ribbon Emulator (CRE)

Overall, the CRE is only 1.1-inch wide, 7-inches tall and less than 0.75-inch thick. The individual piezoelectric driver elements coupled to the 7-inch long ribbon are spaced only 0.985-inch apart vertically, center to center. The narrow horizontal radiating surface allows the CRE to maintain a

very wide horizontal dispersion up to 14 kHz before beginning to narrow. The extremely close vertical spacing of the individual elements, combined with the singular diaphragm of the CRE coupled to all seven devices, allows the CRE to maintain vertical line array control up to 16 kHz before the first vertical off-axis lobes are radiated. The space between two CRE devices in Community's ENTASYS Line Array is less than 3/32-inch, assuring better than a 98% ARF (Active Radiating Factor) within the loudspeaker for the high-frequency devices at the highest frequencies.

Designing and creating the CRE device, once seen, appears to be a relatively simple endeavor but learning how to apply the CRE properly in a way that will sound good and be acceptable to the professional sound community and its customers was an entirely different challenge.

Applying the CRE and Designing a Professional Crossover

There was little prior art on the subject of developing a driver like the CRE. The design of the driver and fabrication process had to be developed from scratch. Tooling had to be created and a trial and error process used to determine how to best construct the CRE to perform as desired and be rugged and reliable. The same was true when it came to designing the CRE crossover network. There has been little written on how to design a crossover network for a piezoelectric driver. After all, the piezo device acts more like a capacitive load than it does like the resistive/reactive load we are used to dealing with when designing a crossover network for a typical driver. All of the typical rules of thumb are turned upside down when designing a circuit to crossover a capacitor instead of an inductor.

The one crossover design rule that remains constant, even with a piezoelectric device, is that if you want the device to sound good, you must only use it within the region where its performance is linear and repeatable. It has already been shown that a piezo device has a low frequency resonance and that there is an associated peak in the frequency response at the same frequency, making that region of the frequency response undesirable for use without corrections from a crossover. The remaining questions were: *Is that region stable? Even if a crossover is used to dampen the resonance, would it be suitable for use in a professional application?*

What Should the Crossover Point Be?

The following graph (Figure 5) shows the results of directly measuring the voltage drop across a representative sample of each of the seven piezo devices, wired in series, within a CRE. A direct voltage drop measurement was chosen because it would isolate the performance and stability of the driver while not being dependent upon microphone placement or the output of adjacent drivers bleeding into the measurement.

The results of this measurement correlate very well with the

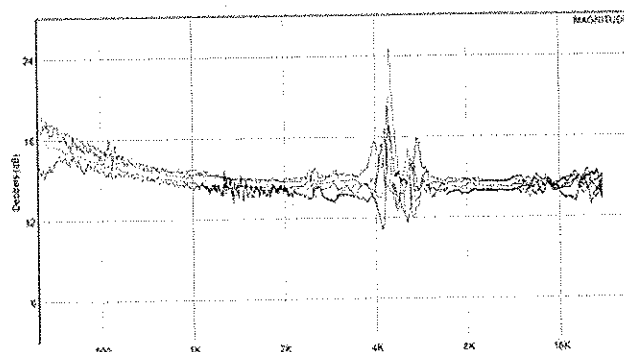


Figure 5: Direct Voltage Drop Measurements across Individual Piezo Elements within a CRE Driver

frequency response and impedance measurements of this device. It clearly shows that is the region where the piezo elements exhibit a purely capacitive impedance, from 6 kHz to 20 kHz and again below 4 kHz, the drivers are perfectly stable, linear and repeatable – all of the criteria needed to make a good sounding driver. It also shows that near their primary resonance the devices appear to be unstable, non-linear and individual. In order to use these piezo devices in a professional, high quality sound reinforcement loudspeaker the crossover point needs to be placed above 6 kHz, where the response is uniform. Placing the crossover this high in frequency eliminates the resonance problems inherent in the audible piezo frequency response and also ensures that the piezo elements are being used well within their low-distortion operating range.

Crossovers and Piezoelectric Drivers

All of the published prior art for developing crossovers for use with piezoelectric drivers appears to have been derived from a 10-page technical paper written by the engineers at CTS Electronics Corporation many years ago¹¹. A handful of AES papers and pre-prints on the use of piezoelectric drivers have also been written over the years¹² but none of those cite any different methods for piezo crossovers than the original CTS paper. The recommended crossover for a piezoelectric device in these papers consists of nothing more than placing one or two resistors in series and/or in parallel with the piezo or adding a series capacitor for attenuation of the output and some of the primary resonance¹³. However, neither of these methods addresses modification of the high pass crossover point for a piezoelectric driver when crossing over to a midrange or low frequency driver. The methods suggest modifying the low pass crossover point of the other driver, not the piezo¹⁴. For a professional loudspeaker application, this arrangement will not be sufficient. As has already been shown, for professional audio applications the crossover point must be moved up to around 6 kHz or the inherently detrimental response problems of the piezo will be included in the sound of the final product.

Simple Improvements

Adding a series resistor, or resistors, to a piezo crossover has merit and can be useful to both help smooth the high-

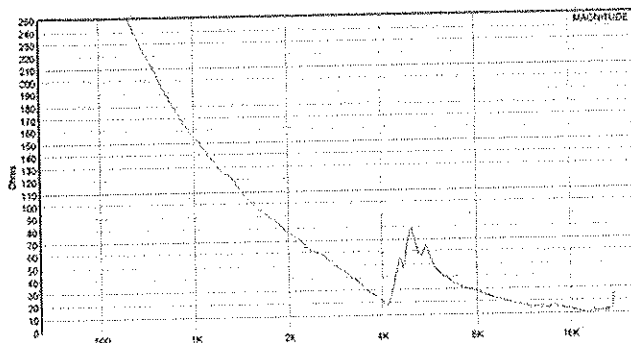


Figure 6a: Impedance of a Single CRE

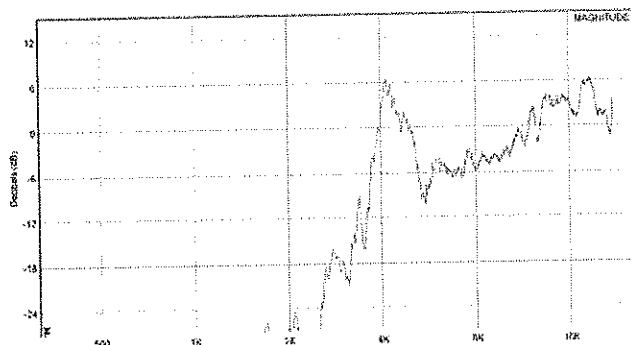


Figure 6b: Magnitude of a Single CRE

end frequency response and isolate any amplifier from the purely capacitive load presented by the piezo devices. Figure 6 shows the response and impedance of the raw CRE. Figure 7 shows the same device with just a 25 ohm resistor in series with it.

The simple addition of a series resistor has made dramatic improvements in both the impedance and frequency response of the CRE. While the shape of the impedance curve remains unchanged, the magnitude has risen from 10 ohms at 20 kHz to 30 ohms at 20 kHz. Since six CREs are used in each ENTASYS Column Line Array, this simple change ensures that the combined impedance at 20 kHz has risen from 1.667 ohms up to a manageable 5 ohms. Some amplifiers may exhibit a tendency to become unstable with a 1.667 ohm load at such a high-frequency, but nearly all amplifiers will operate quite happily with a 5 ohm impedance at 20 kHz. In the final ENTASYS crossover, the impedance is actually 12 ohms at 20 kHz, ensuring that multiple columns of CREs can easily be run from one amplifier.

The frequency response has also been dramatically improved. The highest frequencies (above approximately 12 kHz) are down by 3 to 4 dB and the frequency response between 6 to 12 kHz has completely flattened out, right in the range where we want to use it.

The improvement to the frequency response and impedance are good things, but the 25 ohm resistor alone does not help cross over the piezoelectric drivers in the desired range of 6 kHz or above.

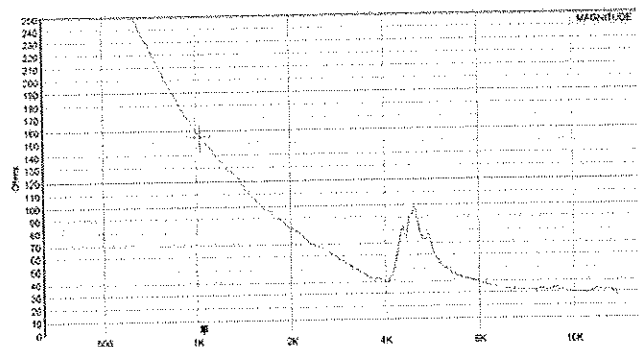


Figure 7a: Impedance of a Single CRE with 25 Ohm Series Resistor

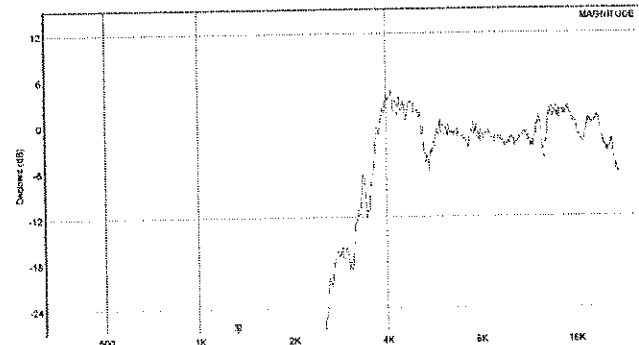


Figure 7a: Magnitude of a Single CRE with 25 Ohm Series Resistor

Crossover Interaction with Piezoelectric Elements

When adding a crossover to a piezoelectric element, it is important to remember that, primarily, the piezo device acts like a capacitor. Adding a single capacitor to a moving coil driver will produce a 6 dB/Oct high pass at the frequency determined by the reactance of the capacitor and the impedance of the driver. The moving coil driver is a mostly resistive and inductive device and most of the standard calculations assume that resistive and/or resistive + inductive devices are being employed. Placing a capacitor in series with a capacitive-like piezoelectric driver creates nothing more than a voltage divider and induces very little high-pass action, if any¹⁵. Any first-year electronics student would recognize this relationship: $V_{out} = V_{in} \cdot C1 / (C1 + C2)$. The smaller the series capacitor is, the greater the attenuation.

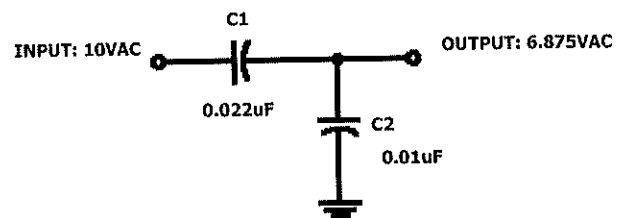


Figure 8: Capacitive Voltage Divider

This capacitive voltage divider relationship is very different from what is typically seen in a moving coil crossover. In a

6 dB/Oct moving coil crossover, great care must be used to take into account the interaction present between the series capacitor, the electromechanical resonance of the driver and the motor-coil inductance. Unexpected errors and deviations from predicted response due to simple calculations are common. See Figure 9¹⁶.

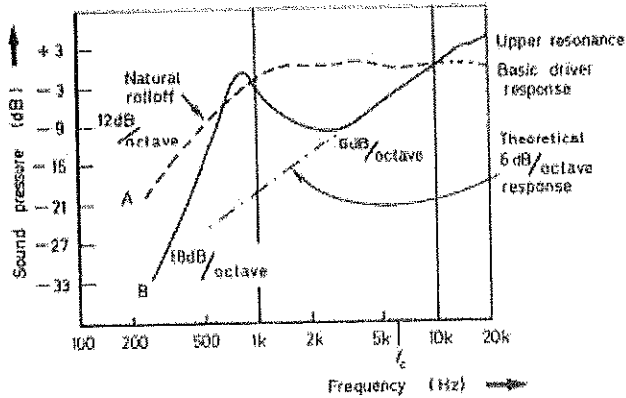


Figure 9: Moving Coil Driver Response, high pass; A, alone; B, with first order series capacitor, $f_c = 7$ kHz

Luckily, most of this resonant interaction can be suppressed by the use of higher order (12dB/Oct or higher) crossovers. The crossover inductor, in parallel with the inductive voice coil, swamps out the inductive contribution from the driver voice coil and most of its electromechanical resonances.

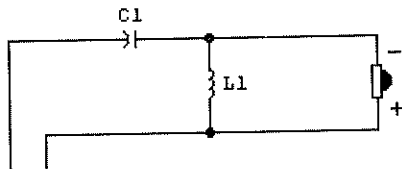


Figure 10: Second Order High Pass Crossover

For a second order high pass crossover connected to a piezoelectric element, just the opposite problem occurs. The parallel inductor in the high pass circuit (L1 in Figure 10), is now in parallel with the mostly capacitive piezoelectric device. Instead of forming a series resonant circuit, like the first order high pass moving coil crossover, it forms a parallel resonant circuit (sometimes called a "tank circuit"). See Figure 11. Both types of resonant circuit have the same effect; they can cause very sharp resonances in the impedance.

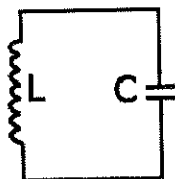


Figure 11: Parallel ("Tank") Resonant Circuit

Figure 12 shows an impedance (a) and frequency response (b) measurement of a CRE with a second order high pass crossover in front of it:

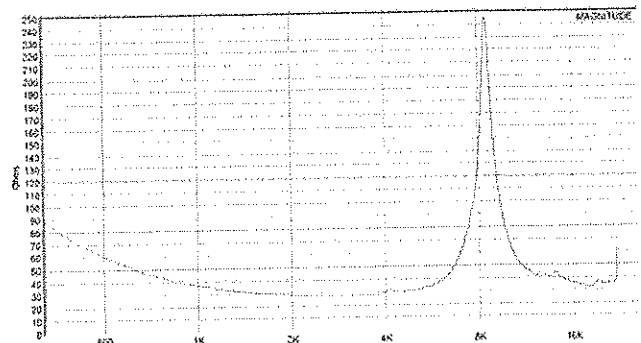


Figure 12a: Impedance of a Single CRE with a 12 dB/Oct High Pass Filter

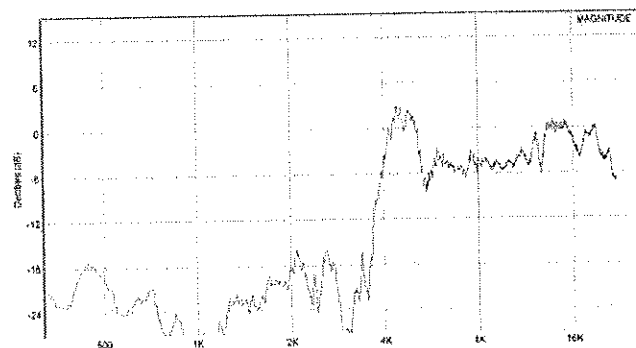


Figure 12b: Magnitude of a Single CRE with a 12 dB/Oct High Pass Filter

The first problem that should be immediately apparent from this second order crossover measurement is the 245 ohm resonant peak centered at 10 kHz in the impedance measurement (Figure 12a). The parallel inductor has completely swamped out the inherent resonance of the piezo devices but in doing so has caused a much worse resonance in its place. Interestingly though, the frequency response (Figure 12b) still shows the resonance around 5 kHz from the piezo electromechanical resonance but shows absolutely no sign of the purely electrical resonance at 10 kHz. Since the 10 kHz resonance in the frequency response trace is not visible, one could easily conclude that it is not audible. That assumption would be incorrect. While the FFT pink noise measurement does not show a peak in amplitude at 10 kHz, a clearly audible "sibilance" can be heard at 10 kHz while playing either pink noise or music. This has the characteristic piezo sound of "one note cymbal" while playing a music track. The drum cymbals jump out of the mix with a hissy dissonance at seemingly only one frequency. Unfortunately this experience is, admittedly, subjective. Measuring this type of response appears to be elusive using standard, easily acquired measurements using either FFT or a swept sine wave but it is nonetheless present.

In the frequency response of Figure 12b, there are a few other interesting points to note. As predicted by the

capacitive voltage divider rule, the overall magnitude of the response has been reduced by about 6 dB (compare to Figures 6b & 7b) due to the series capacitor present in the second order high pass circuit. Secondly, there is a small amount of high pass response taking place in this measurement. There is less energy present just above and below 4 kHz (compared to Figures 6b & 7b). Lastly, as with the series 25 ohm resistor frequency response (Figure 7b), the high pass circuit has smoothed the frequency response somewhat as compared to the raw CRE response (Figure 6b) but not quite as well as the 25 ohm resistor. Surely combining the 25 ohm series resistor and high pass circuit together will give even better results.

There is no doubt that some well-meaning manufacturers in the past have applied this type of crossover to a piezoelectric driver without realizing that they were probably doing more harm than good with this resonant circuit design. Make no mistake, this circuit sounds bad but it measures well. The sound of the "one note cymbal" is often associated with piezo drivers. But once again, the culprit is probably not the piezo device; it is more likely the poor engineering and poorly designed electronics driving the piezo device.

Amplitude Matching

Both the series resistor and high pass circuits bring needed improvements to the frequency response of the piezoelectric drivers in the CRE. However, both means of improvement also reduce the output level of the driver in different portions of the frequency response. By the time a proper professional high pass crossover is designed to operate the CRE at 6 kHz and above, the amplitude of the CRE will be lower than intended by the original design. A flat frequency response that is 3 to 6 dB lower than required is not acceptable either. A new method must be developed to raise the output level of the CRE back up to the intended amplitude after a crossover has been developed.

That method is, of course, some type of step-up voltage transformation device or, as it is usually referred to, a transformer. Using a transformer on a piezoelectric high-frequency device must be done with care. It is well known that a piezo device will cease to work after its maximum rated voltage is exceeded, even if it is only one time¹⁷. Since the piezoelectric elements in the CRE will always be protected by Community's exclusive PowerSense™ protection circuitry, designed explicitly for the protection of piezoelectric devices, stepping up the voltage should not be a problem. Rated for 35 volts each, the seven series elements in an ENTASYS Compact Ribbon Emulator device can handle an astounding 245 volts before any damage could occur anyway.

While a transformer technically has resistive, inductive and capacitive properties that create its complex response, its simple response is dominated by the inductance of the large primary and secondary windings (see Figure 13)¹⁸. Placing a transformer in parallel with piezoelectric devices will form the same type of parallel resonant circuit as the second order high pass crossover did (see Figure 11). Since the CRE is only being asked to work above 6 kHz, a small transformer with a relatively small primary and

secondary inductance can be used. The low frequency response of a transformer is largely a function of its inductance. Higher inductances in the transformer windings result in lower f_c values for the low frequency roll-off. The relationship can be seen in the formula of Figure 14¹⁹. The first experimental measurement with a small transformer is shown in Figure 15.

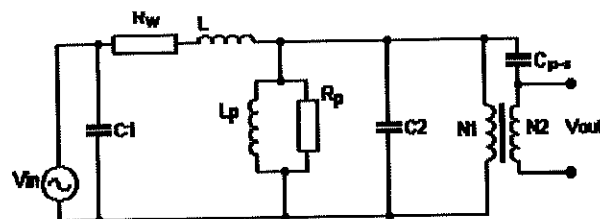


Figure 13: Transformer Simplified Equivalent Schematic

$$L_p = \frac{R}{4\pi f_3 \text{ dB}}$$

Figure 14: Mathematical Relationship between Transformer Inductance and Low Frequency Roll-Off

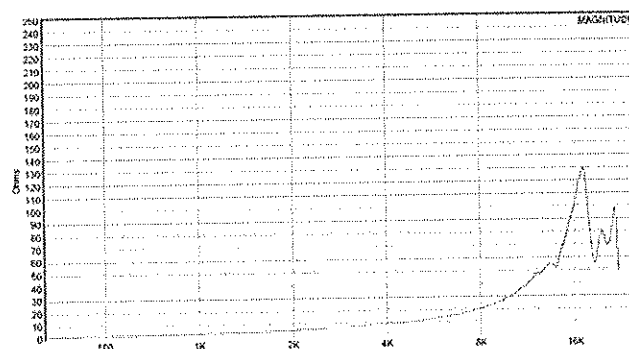


Figure 15a: Impedance of a Single CRE with a Step-Up Transformer

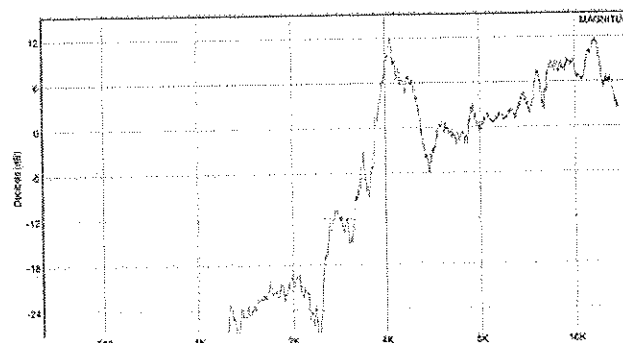


Figure 15b: Magnitude of a Single CRE with a Step-Up Transformer

Not surprisingly, the results of the impedance measurement using a transformer with very low inductance windings (Figure 15a) shows the same type of resonance as the second order high pass filter due to the parallel resonance of the inductive transformer's secondary output windings and the capacitive piezoelectric elements. In this case, the resonance is even higher in frequency than before, indicating that if this transformer and the second order high pass were used at the same time a dual resonance would likely occur in the system. The frequency response (Figure 15b) appears to be almost identical to the original raw CRE frequency response (Figure 6b), except that it is 6dB higher in amplitude. It should be noted that, as with the second order high pass circuit, the purely electrical resonance is not reflected in the frequency response but the results of this resonance can clearly be heard using pink noise or music.

Putting the Pieces Together

Up to this point, it has been demonstrated that piezoelectric high-frequency devices have a number of positive, attractive attributes but that they also have a number of downsides as well. The attractive attributes include small size, low weight, good high-frequency extension, low distortion, fast transient attack and relatively low cost. The downsides include inherent resonance at lower frequencies, quickly rising distortion below resonance and low impedance at high frequencies. Moreover, it is difficult to design a professional crossover for them.

Of the negative attributes, all but one has been addressed and a solution has been proposed. The inherent resonance and high distortion below resonance will be avoided by applying a crossover at 6 kHz or above where the drivers are stable and repeatable. Low impedance at high frequencies can be easily solved by adding series resistance between the amplifier and piezo elements. The only remaining question is, *How can a crossover be created for the piezoelectric elements without also creating annoying, audible resonances throughout the usable frequency range?*

Zero Resonance Crossover

The finer details and schematics of the Zero Resonance Crossover cannot be presented here, for obvious reasons. They are the result of many hundreds of hours of hard development work and are proprietary. However, measurements of the crossover, impedance and combined response of the crossover and CRE driver will be presented here to show the working solution without revealing proprietary details of the crossover arrangement.

The task of designing a PZT crossover is already hard enough, but for use in Community's ENTASYS Column Line Array the task was made even more difficult. In order to allow users to parallel multiple ENTASYS columns on one amplifier, a design goal was set to achieve a nominal 12 ohm impedance for the system, with impedance dips not to be lower than 8.5 ohms. This design requirement meant that a simple 8 ohm resistor could not be placed in parallel with the CRE's at the output of the crossover to make them appear to be a resistive load²⁰. If this could be done,

designing a normal crossover would be no problem, the load would appear mostly resistive to the crossover; but doing so would reduce the impedance too much to meet the 12 ohm design criteria. Even if that approach would have worked a second problem existed; with the ability to withstand 245 volts, an 8 ohm resistor would need to be capable of dissipating about 7500 watts (Not a typo! Power = $(V^2 / R) = 245^2 / 8 = 7500$ watts). Too much to consider even if 1/8 music power was considered; that would still be over 900 watts of dissipation.

The problem was solved in a number of steps.

1. *Add series resistance between the amplifier and the crossover.* This series resistance was adjusted to keep the minimum impedance above the design goals while not being made so large that it attenuated high-frequency energy more than desired.
2. *Implement a second order high pass crossover early in the circuit, and then isolate it from interaction with the piezo devices.* This was accomplished in a number of ways. It was placed directly after the amplifier isolation resistors in the circuit and was followed by series and parallel wired resonant circuits to isolate it from the piezo devices further. Additionally, critically tuned capacitors were used in the circuit to offset parallel resonances. These were followed by a secondary isolation resistor at the end of the circuit to isolate the high pass from the capacitive reactance of the piezos to an even greater extent.
3. *Implement multiple notch filters to increase the roll-off rate and frequency of the high pass circuit from 12 dB/Oct to over 36 dB/Oct with a final crossover point at 7 kHz while also severely dampening the inherent electromechanical primary resonance of the piezo elements.*
4. *Use a secondary set of isolation resistors in the circuit to isolate the inductive crossover components from the capacitive piezo elements.*
5. *Use a custom designed transformer with a properly tuned primary and secondary inductance for minimal interaction with the piezo elements and the rest of the crossover circuit.*

The result of this arrangement was a very flat crossover with a steep high pass slope at 7 kHz with just the right amount of high-frequency roll-off to prevent the CRE drivers from sounding fatiguing to the listener. The resultant impedance curve had no more resonance in it than that of any typical compression driver, dome driver or any other driver. In fact, the high-frequency portion of the ENTASYS impedance curve is much flatter than any other part of the system impedance. The curves are shown in Figures 16 through 19.

These graphs represent the response of a single CRE element from the Community ENTASYS three-way column line array loudspeaker. The response on these graphs appears to have a sharp frequency response peak around 14 kHz but once combined with the other five CRE

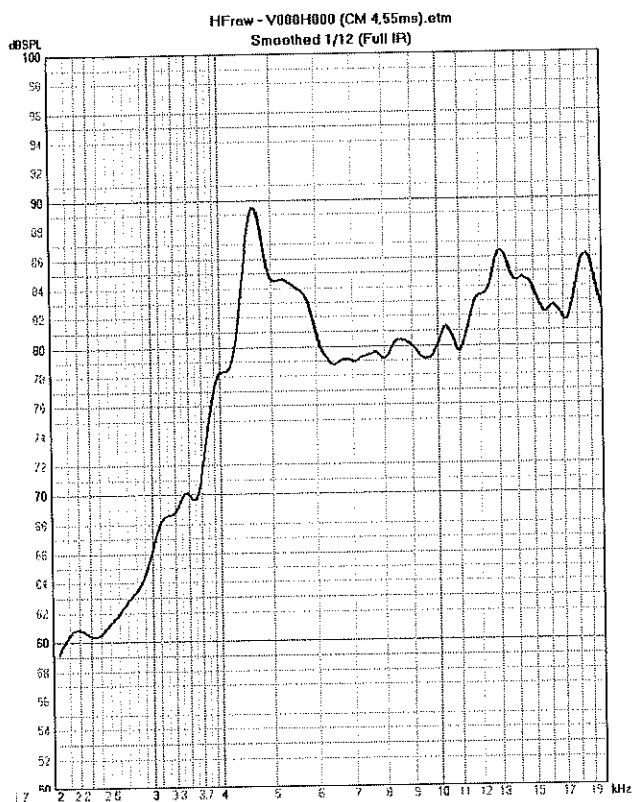


Figure 16: Raw CRE Driver Measurement

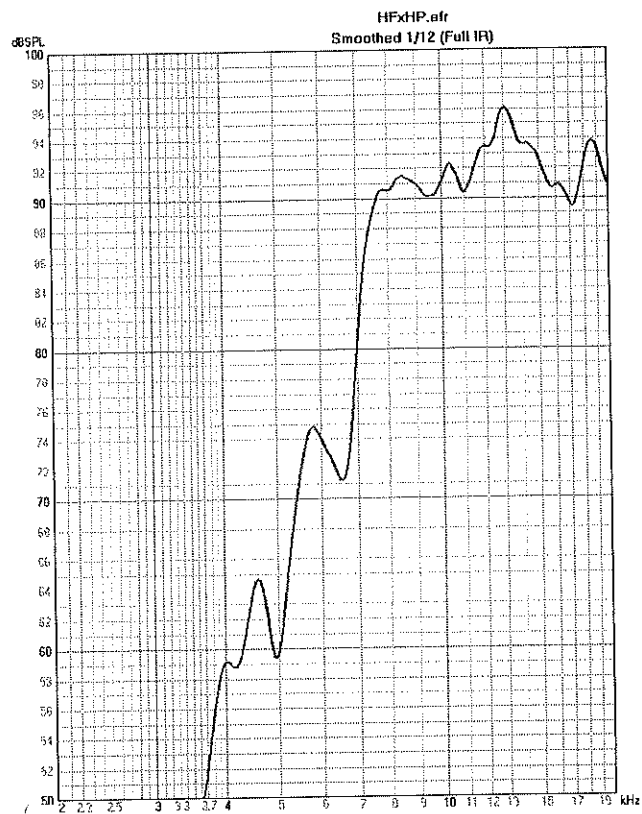


Figure 18: CRE Single Element Frequency Response with Crossover

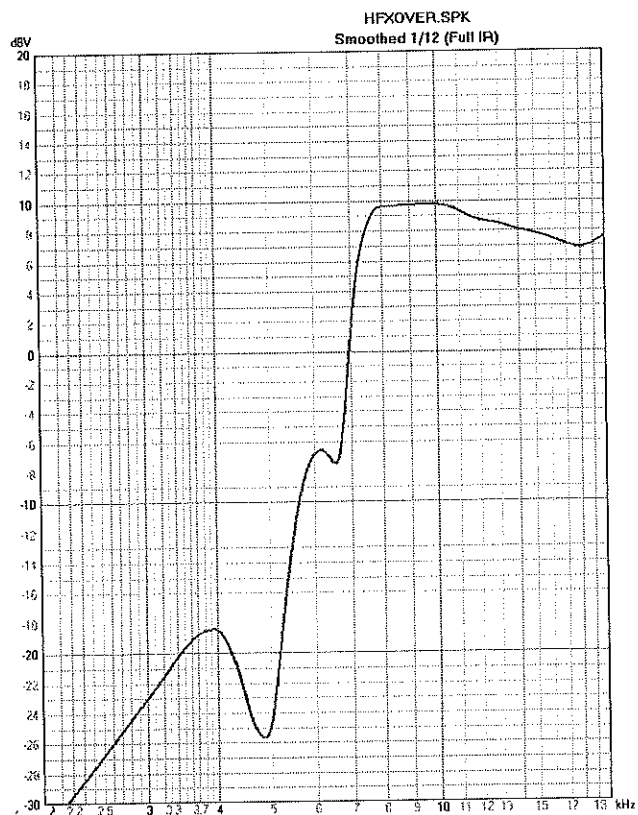


Figure 17: Measured CRE Passive Crossover Transfer Function

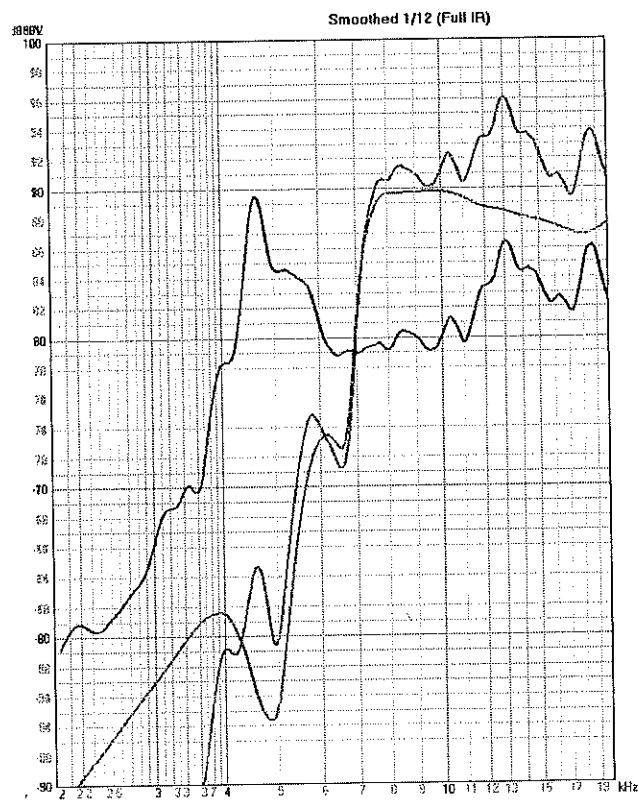


Figure 19: Overlay of Figures 17, 18 & 19

elements in the ENTASYS column and curved to the designed 10 degree arc, this response peak becomes indistinguishable. The full column flat frequency response and low resonance impedance response show this for themselves:

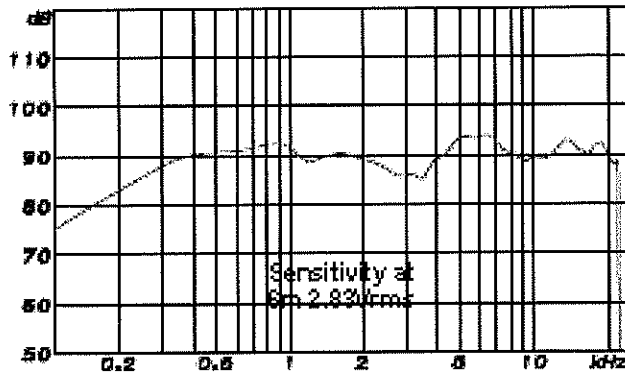


Figure 20: Community ENTASYS Three-Way Column Line Array Frequency Response (taken on-axis at a distance of 8 meters)

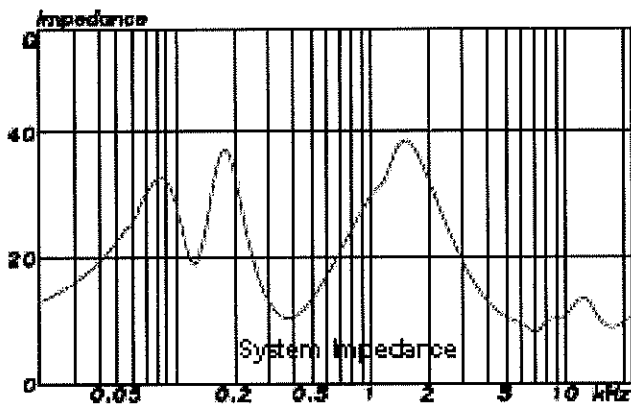


Figure 21: Community ENTASYS Three-Way Column Line Array Impedance Response

The key in designing a good, professional crossover for piezo drivers lies in knowing where resonances are occurring, why they are occurring and how to counteract them. Just like the inductor in parallel with the moving coil of the high-frequency driver swamped the effects of the series resonant circuit caused by the first order crossover capacitor in series with that coil, so can the opposite approach be used to swamp resonances created in a piezoelectric driver crossover. Parallel capacitors of just the right value placed at the right position in the circuit can counteract and swamp any other resonances developed in the circuit by the interaction of other components. Judicious use of isolation resistors to isolate one portion of the circuit from another also helps resolve resonance interactions within the crossover/driver circuit.

ENTASYS Column Line Array Systems

As shown in Figure 22, Community's CRE creates a uniform narrow vertical beamwidth up to 16 kHz before any lobing begins. Like a traditional ribbon driver, this dispersion pattern makes the CRE ideal for use in a line array. For this reason, Community has chosen the CRE for the HF section of its ENTASYS three-way column line array system.

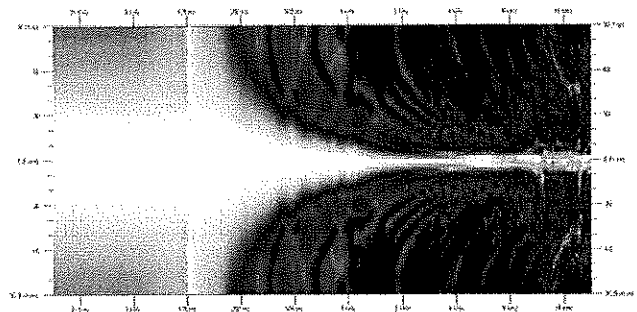


Figure 22: Community ENTASYS Three-Way Column Line Array Vertical Dispersion (1/24 Octave Resolution, Single Column with 10 Degree Vertical Curvature)

ENTASYS uses six CREs. In the ENTASYS column, as illustrated in Figure 23, Community has joined the CREs together, end-to-end, and curved the resulting array slightly outwards (convex) by 10 degrees to increase the vertical dispersion in the mid to upper frequencies. This helps the ENTASYS column maintain a very consistent vertical dispersion pattern of 12 degrees over its entire usable frequency range. Straightening the column results in 6 degrees of vertical dispersion over the same frequency range and even better coupling above 16 kHz.

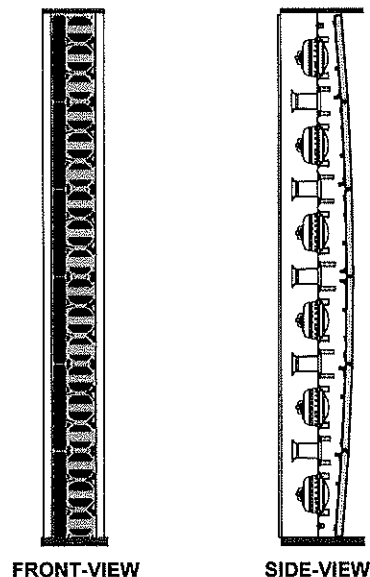


Figure 23: ENTASYS Three-Way Column Front-View and Side-View Showing 10 Degree Arc

Conclusion

Community's Compact Ribbon Emulator™ (CRE) is a high-performance, ribbon-style high-frequency driver with a smooth, sweet sound quality similar to that of a traditional ribbon driver. Although it is suitable for a wide variety of loudspeaker systems, the CRE's ribbon-like dispersion makes it especially useful in line array loudspeakers such as Community's ENTASYS Column Line Array System.

The challenges in designing the CRE driver and the crossover for the CRE drivers in ENTASYS is only outweighed by the challenge of overcoming years of misconceptions, bad press, misuse, abuse and poor understanding of the true potential of piezoelectric drivers to create a smooth, musical, low distortion driver that is suitable for the most demanding professional audio applications. Community has created a very good device and applied it in the proper methods, as has never been accomplished previously.

References

- [1] Piezo Tweeter Application Note. CTS Electronics Corporation. 1. 11 Jan. 2008 <<http://www.pulsardevelopments.com/products/detail/piezoan.html>>.
- [2] Klasco, Mike. "Eulogy for the Piezo Ceramic Tweeter." Voice Coil Feb. 2008: 18-22.
- [3] Capel, Vivian. Audio & Hi-Fi Engineer's Pocket Book. 3rd ed. Oxford: Newnes, 1994. 249.
- [4] Griffin, James R. Design Guidelines for Practical NearField Line-arrays. 2003. 10-15. 7 Nov. 2005 <<http://www.audioundtable.com/misc/nflawp.pdf>>.
- [5] Phillips, James R. Piezoelectric Technology Primer. CTS Electronics Corporation. Albuquerque, NM. 9. 11 June 2008 <http://www.ctscorp.com/components/pzt/downloads/Piezoelectric_Technology.pdf>.
- [6] Piezo Tweeter Application Note. CTS Electronics Corporation. 5. 11 Jan. 2008 <<http://www.pulsardevelopments.com/products/detail/piezoan.html>>.
- [7] Capel, Vivian. Audio & Hi-Fi Engineer's Pocket Book. 3rd ed. Oxford: Newnes, 1994. 255.
- [8] Piezo Tweeter Application Note. CTS Electronics Corporation. 4. 11 Jan. 2008 <<http://www.pulsardevelopments.com/products/detail/piezoan.html>>.
- [9] Schmetter, Ronald M. The Piezoelectric Loudspeaker: Its Use in Audio Systems. 2. 43rd Convention of the Audio Engineering Society, 12 Sept. 1972, Motorola, Inc. Audio Engineering Society, 1972.
- [10] "Piezo Tweeter XOs." Planet 10 HiFi. 11 June 2008 <<http://www.planet10-hifi.com/piezo-XO.html>>.
- [11] Piezo Tweeter Application Note. CTS Electronics Corporation. 1-10. 11 Jan. 2008 <<http://www.pulsardevelopments.com/products/detail/piezoan.html>>.
- [12] Google. AES. 11 June 2008 <<http://www.google.com/search?hl=en&q=piezo+site%3Aaes.org&btnG=Search>>.
- [13] Piezo Tweeter Application Note. CTS Electronics Corporation. 5-9. 11 Jan. 2008 <<http://www.pulsardevelopments.com/products/detail/piezoan.html>>.
- [14] Schmetter, Ronald M. The Piezoelectric Loudspeaker: Its Use in Audio Systems. 3. 43rd Convention of the Audio Engineering Society, 12 Sept. 1972, Motorola, Inc. Audio Engineering Society, 1972.
- [15] Piezo Tweeter Application Note. CTS Electronics Corporation. 6. 11 Jan. 2008 <<http://www.pulsardevelopments.com/products/detail/piezoan.html>>.
- [16] Colloms, Martin, and Paul Darlington. High Performance Loudspeakers. Sixth ed. Chichester: Wiley & Sons, Ltd., 2005. 284-285.
- [17] Piezo Tweeter Application Note. CTS Electronics Corporation. 1. 11 Jan. 2008 <<http://www.pulsardevelopments.com/products/detail/piezoan.html>>.
- [18] Elliott, Rod. "Transformers - the Details Section 2." Elliott Sound Products - the Audio Pages. 3 Apr. 2001. 28 Nov. 2005 <<http://sound.westhost.com/xlrm2.htm>>.
- [19] Purdie, Ian C. "Audio Transformers." Electronics-Tutorials.Com. 15 May 2005. 22 Nov. 2005 <<http://www.electronics-tutorials.com/basics/audio-transformers.htm>>.
- [20] Piezo Tweeter Application Note. CTS Electronics Corporation. 5. 11 Jan. 2008 <<http://www.pulsardevelopments.com/products/detail/piezoan.html>>.