db theory&practice

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● The theory of a crossover is that at its design frequency both units will receive precisely 3 dB less signal than they receive in their pass range, so that each delivers exactly half the power at that frequency. As we have been saying, that theory is based on the assumption that the loudspeaker has an impedance that looks like a pure resistance, to receive that half of the power.

Whatever may be the situation with the unit that receives the high-pass ouput, the one that receives the low-pass output usually has an inductive impedance at this frequency. In the August issue, I showed that a low frequency (woofer) unit has an impedance that can be approximated as a combination of resistance and inductance. So you count the inductance as part of the crossover filter you design. That is the idea.

WOOFER INDUCTANCE

But to do that, you need to know the equivalent inductance of the woofer unit. How do you arrive at that? I have heard engineers argue that the value is the voice coil inductance of the unit. So they clamp the voice coil to stop it from moving and measure its inductance.

That might work out, if that was the way you operated your loudspeaker. But the speaker doesn't radiate very much sound with its voice coil clamped! You need to know the inductance component when the unit is working, in exactly the situation it will be when the whole system is operating.

As I said before, part of the equivalent inductance is due to the actual voice coil inductance and part of it is due to mass effects of the moving cone, and of air that the cone pushes around. Radiated energy appears principally as resistance, which adds to the voice coil resistance.

So how do you measure the effective inductive and resistive components, and at what frequency do you take them? The answer to the last part of that question should be obvious: at crossover. But a surprising number of people will use an a.c. bridge, which has its own built-in frequency, meaning that they measure it at that frequency, thus assuming that the values are constant, which they seldom are.

Anyway, you probably do not need a value as precise as one that a bridge can give you. So using a bridge to measure the unit's inductance will give you a value that is unnecessarily precise and, more importantly, wrong for the purpose you have in mind, unless the bridge measurement frequency just happens to be the same as the crossover you plan to use.

With a little care in calibration, those same ellipses I introduced to you in the last column can tell you what you want to know in order to design an appropriate crossover filter.

TESTING

First, you should make the test with the unit in position and, if possible, with the unit that takes high pass drive also connected. Be careful to measure only the impedance of the low-pass fed unit (FIGURE 1). This will produce a loading on the low-pass unit equivalent to what will exist when your design is complete. You may want to try reversing connections to the high-frequency unit to make sure the phasing is correct at crossover frequency.

To take your readings on the 'scope, use as small a resistor as possible in series, to measure current, that will give you an adequate horizontal deflection—not more than 1 ohm. You want the electrical damping of the unit to be as near operating value as possible.

You calibrate the vertical and horizontal scales in a conventional way so you know what they mean in voltage

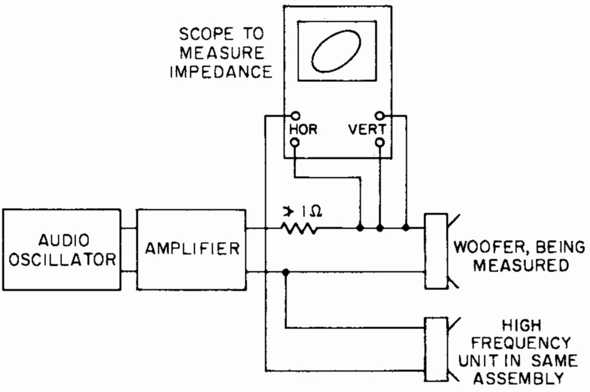


Fig. 1. Schematic for oscilloscope set-up for measuring impedance of low-frequency unit of a crossover pair, with both units being driven in frequencies within range of crossover frequency to be chosen.

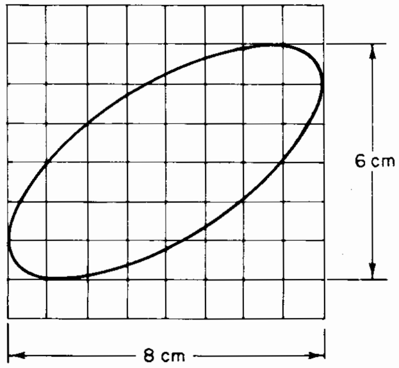


Fig. 2. Typical ellipse obtained to use as measure of magnitude of impedance, showing relevant measures for this purpose.

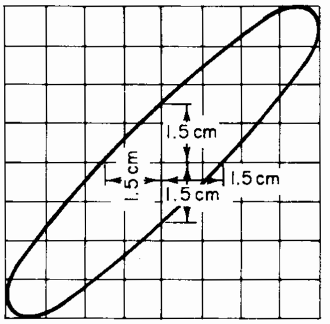


Fig. 3. Typical measurement of phase on a relatively narrow ellipse.

and current, respectively. Then the width and height of the ellipse will give you the impedance magnitude and the shape of the ellipse will tell you its phase.

This is how you do it. Suppose, with the gain of both defections calibrated, the width is 8 cm. and the height is 6 cm. The horizontal gain is set at 10 millivolts per centimeter, and your series resistance is 1 ohm.

8 cm. represents 80 millivolts across the 1 ohm, or 80 milliamps. If the vertical gain is set for 0.5 volt per centimeter, 6 cm. represents 3 volts. Both those values are peak-to-peak, by the way, so you do not need to convert them to rms because the ratios will be the same.

The impedance represented by this trace is one that will pass 80 milliamps with 3 volts across it, which figures to $3 \div 0.08 = 37.5$ ohms. Now, to measure phase, you will find it easier to set the gain so height equals width. This will lose your calibration for impedance magnitude, but you already have that.

If the ellipse is skinny, the easiest way to figure phase is to take the intercepts on the axes (FIGURE 3). If you have set both height and width to 8 cm., and the average intercept on the axes is 1.5 cm. from the center of the grid, the sine of the phase angle is $1.5 \div 4 = 0.375$. A table, or your pocket computer, will give the angle at 22 degrees.

Now, the resistance component is 37.5 ohms, times cos 22 degrees, which figures to 34.77 ohms. The reactance component is 37.5 ohms, times sine 22 degrees, which figures to about 5.27 ohms. Now, what you want is inductance, so you apply the formula $X_L = \omega L$, or $L = X_L \div \omega$, where ω is $2\pi f$.

With a frequency of 800 hertz, ω is $6.28 \times 800 = 5024$. And 5.27 ohms divided by 5,024 makes about 1.05 millihenries.

If the ellipse is broad, the easier way is to see how far from the axes the ellipse makes a tangent with the top, bottom and sides (FIGURE 4). This will give the cosine of the angle. If it is 1.5 cm. again, the cosine is 0.375, leading to the 68 degree angle, from which point the method will be the same, although the values will be different.

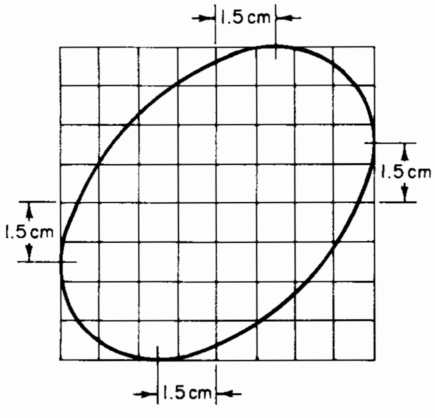
That method will enable you to compute resistance and inductance at just one frequency at a time. If you compute it at a number of frequencies, all near to crossover frequency since that is where you are concerned with the value, you may find the value varies a little. This is because the equivalent circuit is not quite as simple as just one resistance and inductance combined.

PLOTTING ON GRAPH PAPER

Perhaps an even easier way, and one that is accurate enough for most purposes, is to plot the impedance on logarithmic graph paper (FIGURE 5.) I have shown a probable impedance curve in solid line against which I have drawn a dashed line that could represent a simple resistance and inductance combination, showing the construction.

You will want to operate your low frequency unit with a cut off below

Fig. 4. Typical measurement of phase on a relatively broad ellipse.



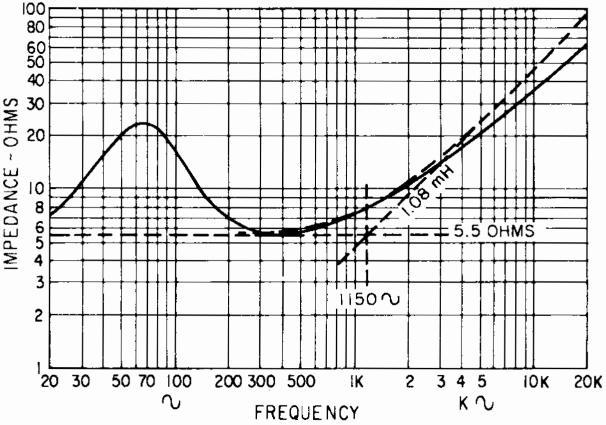


Fig. 5. An example of how to estimate resistance and inductance directly from a plot of impedance against frequency, using log-log paper. Note the idealization necessary to make the computation.

the point where its impedance, thus approximated by an ideal representation, is 1.414 times the resistance component. You can figure a workable value for the equivalent inductance from the frequency at which this 1.414 point occurs.

Suppose the best approximation of resistance is 5.5 ohms, and the frequency where the idealized impedance curve is 1.414 times 5.5, or 7.8 ohms (as nearly as you can read the graph), is 1,150∿. The value for ω is 6.28 times this, or 7,222. Dividing 7.8 ohms by 7,222 gives 1.08 millihenries as the equivalent inductance.

A suitable crossover frequency would be anything below 1,000 hertz, although not too far below.

Now, to complete a crossover design, you need to pick a configuration that has an inductance in the output lead of the low-pass section so that tht loudspeaker's equivalent inductance can be part of it. Suppose the crossover design, for the impedance and frequency chosen, calls for 1.6 millihenries. Then you will use an actual value that makes it up, with whatever you figure the loudspeaker's inductance to be. If it was 1.08 millihenries, your inductor in the network needs to be 1.6 − 1.08 = 0.52 millihenries, or 520 microhenries.

You should design your network for the resistive impedance of the loudspeaker. If this is 5.5 ohms, then design your network for that value, for best results. It may be nominally an 8-ohm loudspeaker, and perhaps has values that straddle that nominal value throughout its pass range. The amplifier should use an 8-ohm output, that is, one designed to feed an 8-ohm speaker. Except near crossover, the network will pass the actual loudspeaker's impedance back to the amplifier, unchanged in value.

The amplifier may be a little mismatched at crossover frequency, but the filter will assure the correct shape of roll-off for the design chosen, that is, how many dB per octave you choose to use. ■