The problem with powering field coils with AC signals in field coil loudspeakers *

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More often than not I receive the following question: "Have you tried powering the field coil with AC(music) signal?". While I do understand why we might think of this being an option, I will try to explain in this article the reason why I will never do it.

1 Analytical Study

The proposal to use the audio signal, that normally feeds into the voice coil, to power the field coil as well comes usually in two ways. Either to connect the field coil in series with the voice coil or to connect them in parallel. The reason behind it can be either to use the field coil as a low pass filter component, useful maybe for Open Baffle type of applications of LF drivers or simply remembering that in the old days of tube amplifiers, the field coil was used as a chocke in the power supply.

Regardless of the reason or the exact proposal on usage, lets first take an analytical look at how the field coil plays its role in the loudspeaker system. There is a small amount of math involved in this section so if you're not interested in this you can skip to the next section.

We should start with describing the force that acts upon the cone when we send current throught the voice coil. The famous force equation is as below,

$$F = BLi_{vc} \tag{1}$$

where,
F - is the force acting on the cone,
B - is the magnetic flux density in the gap,
i_{vc} - is the current through the voice coil.

Equation 1 is the general form and we can use it to represent force as a function of time and represent i as a period sine wave signal. A sine wave signal can be described as follows:

$$i_{vc}(t) = I_{vc}sin(\omega t + \phi) \tag{2}$$

where,
I_{vc} - is the amplitude of the signal,
ω - is the angular frequency,
ϕ - is the initial phase.

For our purposes we can consider $\phi = 0$. Describing voice coil current i_{vc} as equation 2 will result in the following force equation:

$$F(t) = BLI_{vc}sin(\omega t) \tag{3}$$

With a permanent magnet or with DC current powering the field coil, in equation 3, we can consider that BL term is a constant and do not change in time. While this is not exactly true and this term depends slightly on the current i, it is actually an undesired effect and small enough to be negligible.

Now if we are to feed the same signal that drives the voice coil to the field coil, B value is no longer a constant. The field coil's purpose is to create a magnetic field around the voice coil. If the current passing through the field coil varies with time, so will the magnetic field. We can approximate B value as follows:

$$B = \mu N i_{fc} \tag{4}$$

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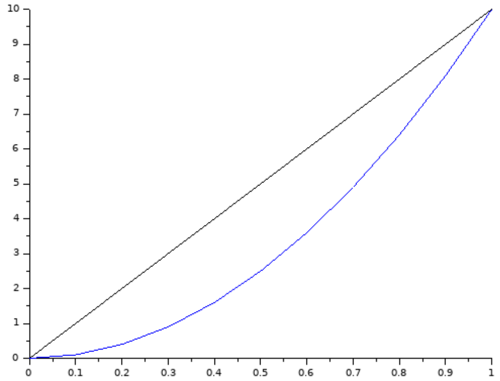

Figure 1: *Force output. Black - Linear dependency on I_{vc}; Blue - Non-linear dependency on I_{vc}^2*

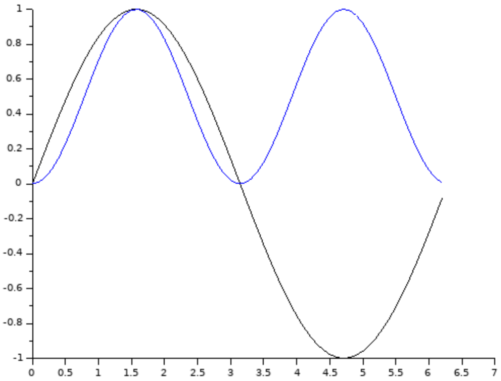

Figure 2: *Force output. Black - input signal; Blue - force output signal caused by powering field coil with the input signal*

where,
μ - is the magnetic permeability of the core,
N - is the number of turns in the field coil,
i_{fc} - is the current through the field coil.

As stated this is an approximation but it is enough for the purpose of this article. Replacing i_{fc} with $i_{vc}(t)$ results in:

$$B(t) = \mu N I_{vc} sin(\omega t) \tag{5}$$

In reality, depending on ω and connection, there will be some phase shift between the signal at voice coil and the signal at field coil. To keep things simpler and easier to understand lets assume this phase shift is 0. Then we can rewrite equation 3 as below:

$$F(t) = (\mu N I_{vc} sin(\omega t)) L I_{vc} sin(\omega t) \tag{6}$$

$$F(t) = \mu N L I_{vc}^2 sin^2(\omega t) \tag{7}$$

$$F(t) = \mu N L I_{vc}^2 \frac{1 - sin(2\omega t + \pi/2)}{2} \tag{8}$$

Now, equation 8 shows us a very good picture of what happens with the force driving the cone and thus, what happens with the cone movement and sound that radiates from it. We can see two major problems:

- The I_{vc}^2 term shows a non-linear dependency on the audio signal current illustrated in Figure 1
- The $sin(2\omega t + \pi/2)$ term shows the output frequency is no longer the same as the input frequency shown in Figure 2

As mentioned, we only considered the case in which the signals that feed the voice coil and field coil are the same. Of course, in practice for a series connection the signal goes through a voltage divider formed by the coils' impedances.

2 Experimental Study

To further analyze this, we will make an experimental setup to try the two connection methods. In total there needs to be 4 setups to account for coil connected in "phase" or not. We need to establish some test parameters and calculate signal levels. Obviously the audio amplifier will need to drive both coils so we need to start by looking at the field coil DC resistance. This puts a limit on field coils with a DC resistance between 4 - 16 Ω depending on the amplifier used. My test loudspeaker will be a 15" LF driver with a 7.5Ω DC resistance and an 6.4Ω voice coil DC resistance. These values should be suitable for power amplifier.

- 7.5 Ω field coil DC resistance
- 6.4 Ω voice coil DC resistance
- 100mH field coil inductange at 1kHz, 315mH at 100Hz
- 1.81mH voice coil inductance at 1kHz, 2mH at 100Hz
- 900 turns in field coil $N = 900$
- 1404 core relative permeability

Introducing this data in equation 4, we get:

$$B = 1404 \times \mu_0 \times 900 \times i_{fc} \tag{9}$$

$$i_{fc} = \frac{B}{1404 \times 4 \times \pi \times 10^-7 \times 900} \tag{10}$$

$$i_{fc} = \frac{B \times 10^7}{15870816} \tag{11}$$

Equation 11 shows us that for a field of amplitude of 1T we will need about a current of amplitude of 0.7A through the field coil. This is an aproximate value as equation 4 is expressed in its simplest form.

2.1 Parallel Connection, Same polarity

The output was quite low and needed to raise the output of the power amplifier to about 8V amplitude. The connection diagram is shown in figure 3 and result in figure 4. As predicted by our analysis we can see a

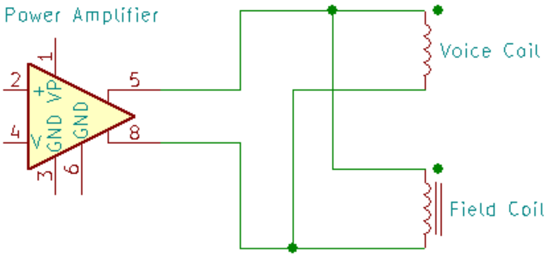

Figure 3: *Parallel connection, same polarity*

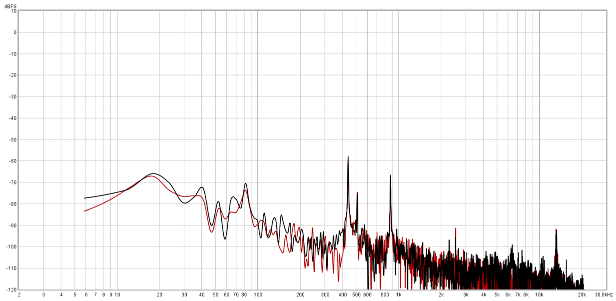

Figure 4: *Result for parallel connection, same polarity*

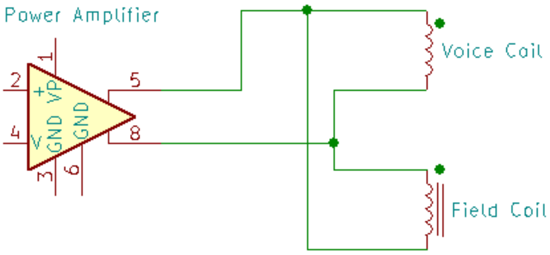

Figure 5: *Parallel connection, opposite polarity*

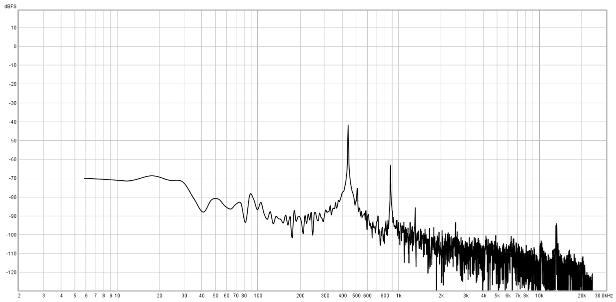

Figure 6: *Result for parallel connection, opposite polarity*

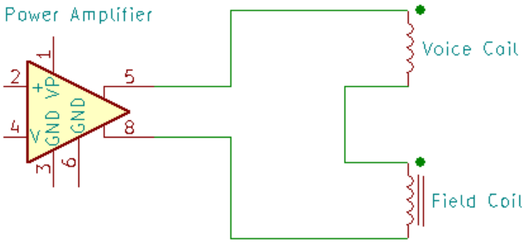

Figure 7: *Series connection, same polarity*

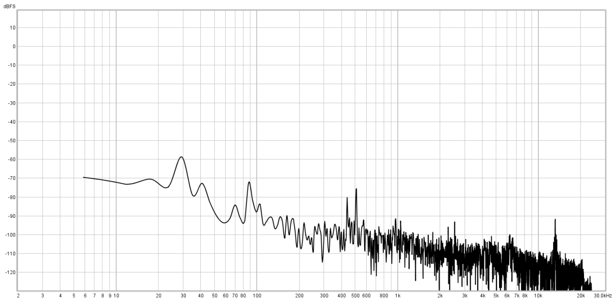

Figure 8: *Result for series connection, same polarity*

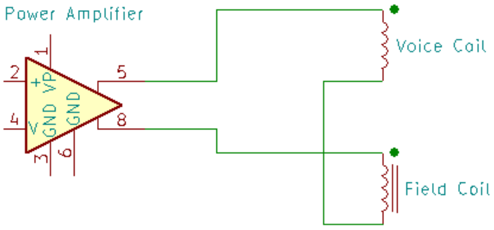

Figure 9: *Series connection, opposite polarity*

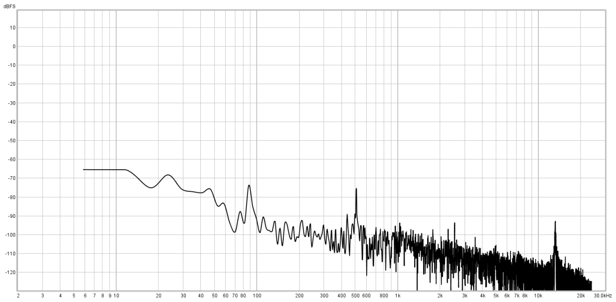

Figure 10: *Result for series connection, opposite polarity*

component that is double in frequency at an amplitude close to the fundamental. This means a high degree of distortion.

2.2 Parallel Connection, Opposite polarity

The amplitude of the fundamental component is higher to due to better vector alignment for magnetic field and voice coil current. Still the double frequency component is present and clearly visible. Connection shown in figure 5 and result in figure 6

2.3 Series Connection, Same polarity

In this connection the inductance of the field coil dominates, it is 2 orders of magnitude higher than the voice coil and thus most of the signal is across its terminals leaving very little to drive the voice coil. The output is very low and even with 12V amplitude from power amplifier still burried in noise. Connection shown in figure 7 and result in figure 8

2.4 Series Connection, Opposite polarity

Not surprisingly, the results do not differ much from previous case. With high inductance field coils, series connections are not very useful. Connection shown in figure 9 and result in figure 10

3 Conclusion

It is hard to see a reason why one would pass audio signal through the field coil and as shown above this will result in adding distortion and ruining dynamics. A clean DC power will ensure linearity of output which is always desirable.