ISCE

The Institute of Sound and Communications Engineers

Engineering Note 32.1

Don't put a sock in it!

or: Impairment of loudspeaker performance due to acoustic impedance added at the sound exit

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Don't put a sock in it!

This Engineering Note was prompted by examining a loudspeaker at a surface Underground station, and two previous experiences during consultation projects.

So what's it about?

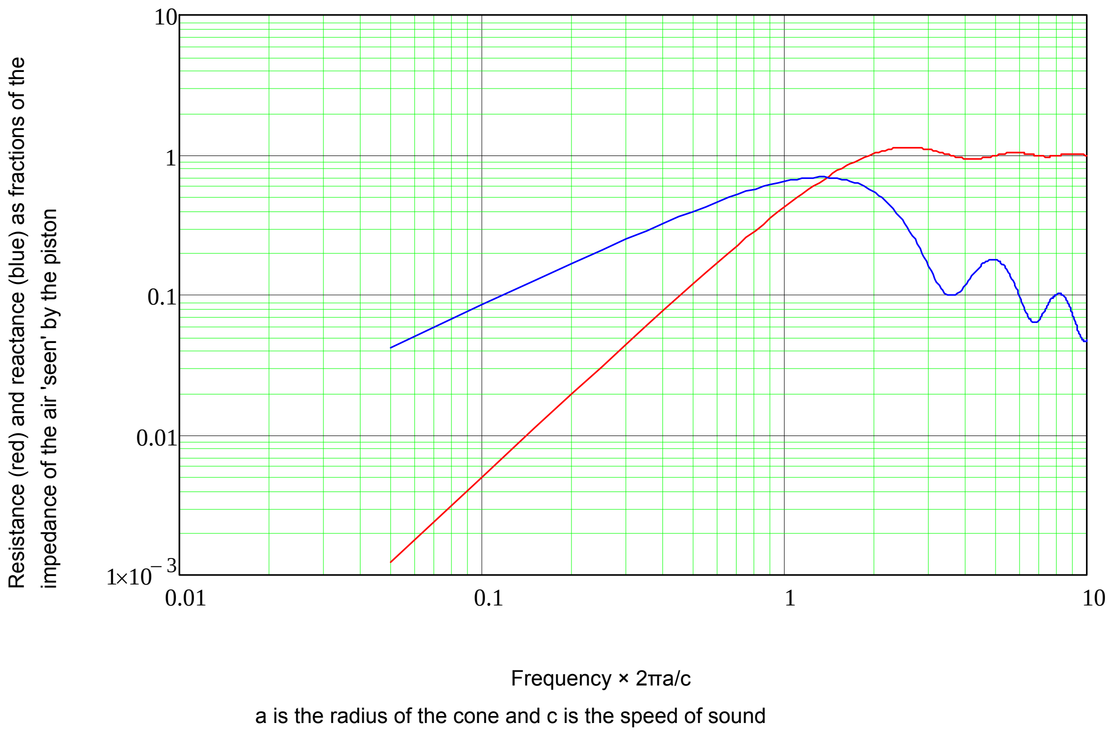
One of the first things I learned when I started working on loudspeaker drive units was that it matters what you put in front of them. If you don't do frequency response measurements and/or comparative listening tests, with and without the front piece, you may not notice this, and it appears that many people are in that position.

For some, now would be the time to develop a model - an equivalent electrical circuit of a drive unit with something in front of it, and simulate the behaviour over frequency using SPICE. But it appears that, at high audio frequencies anyway, the model would need to be extremely complicated. However, the idea of an electrical model still helps to explain in words what is going on.

We start with a voltage generator, representing the acoustic pressure generated by the cone movement. This generator has a source impedance, and that's where the mathematical trouble starts. It's a frequency-dependent resistor in series with a frequency-dependent inductor. Without the mathematics, we can just press on, but we will briefly come back to that later.

Note that this is NOT the electrical impedance of the drive unit, but the electrical equivalent of its *acoustic output source impedance.* The mathematics of a 'first approximation' model is, in modern terms, not that hard, but it involves a rather obscure function, the Struve function, which neither Excel nor Mathcad understand. However, the maths web resource Wolfram does, and one can teach it to Mathcad, so you can have a pretty picture of the resistance and reactance as functions of frequency, *assuming* that the cone behaves as a rigid piston, which it had better not, because it would become excessively directional at high frequencies. Instead, benign cone 'break-up' in a practical drive unit makes the effective diameter shrink as the frequency increases, thus complicating the mathematics even more.

Figure 1 Radiation resistance and air-load reactance on a rigid piston



The acoustic pressure produces a *volume velocity* in the air, which is the sound wave. Volume velocity looks very unfamiliar, but not when you realise that it is how the flow rate through a pipe or over a waterfall is expressed - so many litres per second or cubic kilometres per year. The only difference is that while flow through pipes is normally 'DC' (unless you have water hammer or a hydraulic ram), the acoustic volume velocity is very definitely AC.

Sock effect

If there is nothing in front of the drive unit, the volume velocity of the sound wave causes it to spread out as a spherical wavefront into the room. But what happens if there IS something, often called a grille, in the way? The air trapped between the cone and the 'something' acts as a spring - an acoustic compliance, just like the air trapped behind the drive unit in an enclosure. The grille is usually a fabric or a metal sheet with holes in it, or maybe a sandwich of both. Whatever it is, it represents an acoustic resistance (easy to see that - try blowing through it!) in series with an acoustic mass (not so easy to see!). It can be shown, as they say when the maths is too difficult, that a hole in a sheet of rigid material does act as a mass, and, counter-intuitively, the smaller the hole, the greater the mass. However, in the thickness dimension, intuition works; the thicker the sheet, the greater the mass.

Note that you may have met this 'long, narrow tube has a high acoustic mass' before, in the design of ports for vented enclosures.

So we get a series circuit; generator, source impedance consisting of frequency dependent resistance and inductance in series, compliance represented by a capacitor and the acoustic mass/resistance layer represented by an inductor and a resistor in series. What we have is a series-tuned circuit, but we have resistive losses as well, so we may not be able to see any resonant behaviour. In any case, the resonance frequency may be outside the audio frequency range. If there is any resonant behaviour, it would show up as a peaked increase in volume velocity over a restricted frequency range.

You may ask where the sound comes from in that circuit. It 'comes' from the source resistance, which may alternatively be called the radiation resistance, rather like the light comes from an LED. The sound power emitted is equal to the resistance multiplied by the square of the volume velocity, and it is the latter that is reduced by the presence of the grille in front of the cone.

What actually happens?

If the added acoustic resistance is high enough at low frequencies, its effect shows up in the impedance curve, lowering and broadening the peak at the bass resonance frequency. The reactive elements may also shift the frequency, usually upwards but in some cases, slightly downwards. The same effect may modify impedance peaks caused by crossover networks and the resonances of mid-range and tweeter drive units. Over most of the frequency range, however, the added acoustic impedance has no perceptible effect on the electrical impedance. This is actually another way of saying that the conversion efficiency from electrical input power to acoustical output power is very low!

But the added impedance does affect the frequency response. If the bass resonance is damped, the response around that frequency is reduced. The mass/resistance impedance usually has more effect at high frequencies, producing a roll-off from possibly as low as 1 kHz. This is, after all, what you would expect from adding a lossy inductor in a series circuit.

Digital rules (the digit being the thumb)

Fabrics

Anything 'woolly' or 'fuzzy' is likely to be bad news. Hard threads with an open weave are a good sign. Traditional fabrics are 'Tygan' and Vynair'. See http://www.vintage-radio.com/trg/ The 'Tygan' offered is called 'reproduction', so it may not be exactly as the original. 'Vynair' came in two ranges, and range 2 was much cheaper and much worse. Another material, not usually meant to be seen, is scrim. This comes in a huge number of varieties, but the 'hard threads, open wave' principle still applies.

Expanded and perforated metal

Expanded is usually better than perforated, but there are 'expanded' products that have microscopic holes, and they are thus very unsuited. In principle, the diameter of the holes must be greater than the thickness of the material in order to minimise acoustic mass, but this does not apply to highly-expanded material, where the metal 'ribs' are actually nearly parallel to the sound path.

Moulded plastic

There are so many possible configurations that even a rule of thumb is difficult. However, the rules for perforated materials provide a guide. For perforated mouldings, the holes should not be less than 3 mm in diameter, and slots, regardless of length, should not be less than 3 mm wide. The worst designs have narrow zig-zag paths through the thickness of the material.

Splash-resistant

It isn't widely recognised that the drive unit cone can be protected from splashes by means of a 'slack membrane'. Peter Walker (the one of QUAD fame) used to demonstrate the acoustic transparency of such a membrane. The material needs to be as thin and light as possible, while having adequate mechanical strength. Film from Tesco 'free' vegetable bags (one layer) is suitable for small drive units! The membrane needs to have space to move back and forth: 3 mm clearance each side is usually adequate for drive units up to 200 mm and speech signals. Large woofers and sub-woofers obviously need more clearance. Don't try to make an airtight seal as that would result in inflation and deflation in sympathy with atmospheric pressure changes. If you really want a tight seal, pierce an 'anti-aneroid' hole in the membrane with a pin. The hole has a huge acoustic mass (remember?), but passes 'DC' (bulk air flow) quite well.

Examples

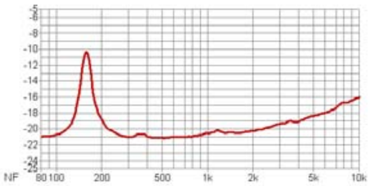
The drive unit was a modest 125 mm unit with a main resonance at 160 Hz, typical of this size and type of drive unit. It was mounted in a stout closed cabinet 280 mm by 220 mm by 560 mm high. The various grilles were tightly fixed in place by a rigid clamping ring, leaving the whole cone plan area unobstructed except by the grille material.

The electrical impedance curves were measured with a quasi-constant current drive (1000 Ω source) so are quite accurate. The reference frequency response was measured at 1 m in an ordinary room, so is not accurate but the difference effects shown are real. The materials used were:

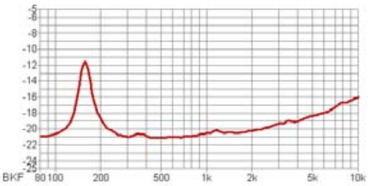
1. Black fabric with hard threads and a fairly open weave;
2. Brown scrim with hard threads and holes about 1 mm square;
3. White textured fabric with soft threads and fairly dense weave;
4. Expanded metal with high expansion factor and holes approximately 4 mm by 2 mm;
5. Perforated metal 0.3 mm thick with holes approximately 1.2 mm diameter;
6. Polyurethane foam approximately 10 mm thick.

Impedance curves

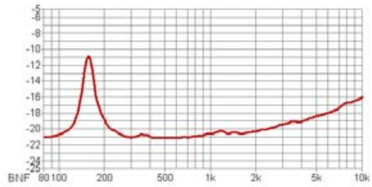
All 'decibel' scales are relative. I do not like expressing impedance ratios in 'decibels', because there is a philosophical difficulty. In this case, 10 dB represents a ratio of 3.162.



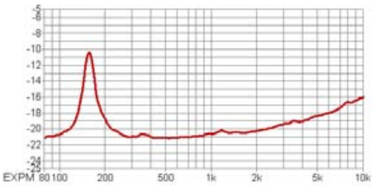
No grille
(reference)



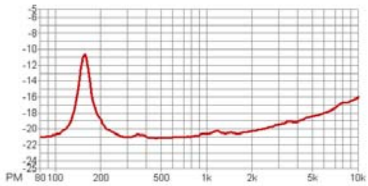
Black fabric
reduces and broadens peak



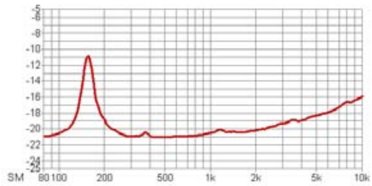
Brown fabric
almost no effect



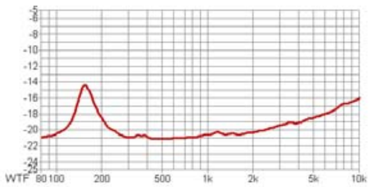
Expanded metal
almost no effect



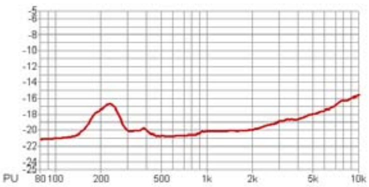
Perforated metal
almost no effect



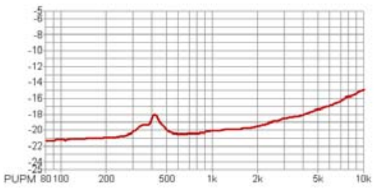
Slack membrane
almost no effect



White fabric
reduces and broadens peak a lot



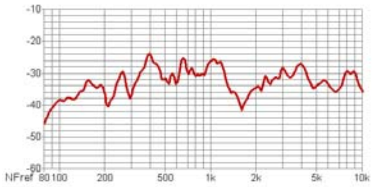
Polyurethane foam
greatly reduces and broadens peak and increases frequency



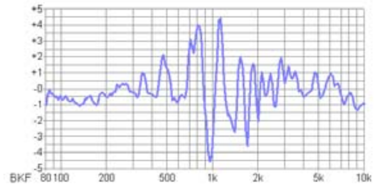
PU foam and perforated metal
almost eliminates peak and increases frequency a lot

Frequency response differences

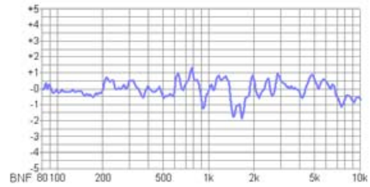
All decibel scales are relative



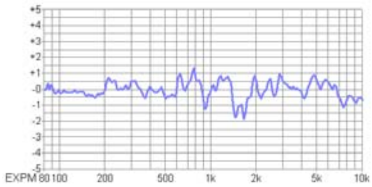
No grille (reference)
The dip around 1.5 kHz is due to reflection from the cabinet back



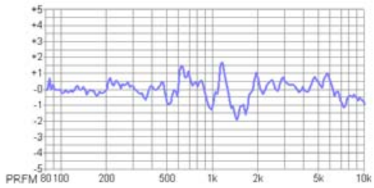
Black fabric
Large but narrow peaks and dips are not very audible



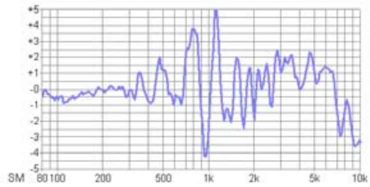
Brown fabric
Not much effect



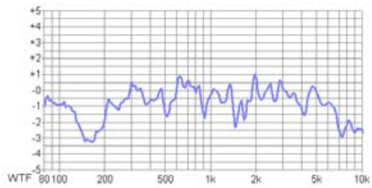
Expanded metal
Not much effect



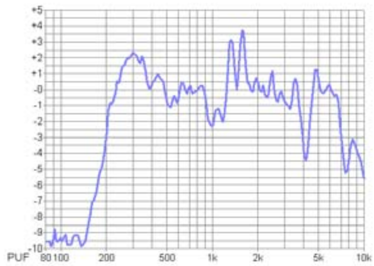
Perforated metal
Not much effect



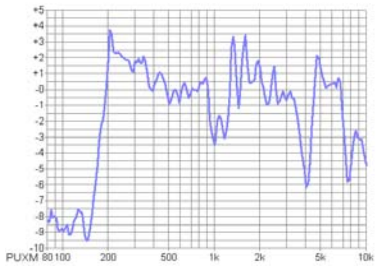
Slack membrane
Large but narrow peaks and dips are not very audible



White fabric
Typical 'sock' effects at low and high frequencies



Polyurethane foam
Large losses at low and high frequencies



PU foam and perforated metal
Even larger unwanted effects