Speaker impedance

The following article is based on news articles posted to rec.audio.tech newsgroup by Richard Pierce, Dan Marshall and John Woodgate at 1998 and 1999- The article is compiled and edited by Tomi Engdahl at 1999. The following things have effect on speaker impedance:

- Voice coil's electrical impedance (resistance, inductance, stray capacitance)
- Driver's mechanical impedance (stiffness, mass, damping)
- Driver's acoustic radiation impedance (resistance, reactance)

SPEAKER NOMINAL IMPEDANCE:

There is a convention to the use of the term "nominal impedance", and if the impedance over the majority of the bandwidth, specifically covering the range in spectrum where majority of the musical spectral power occurs, it's 8 ohms. A single number cannot tell all there is to tell about impedance that varies with frequency.

You must keep in mind that 'nominal impedance' is not defined in IEC. Indeed, the electronics industry was advised when the Trade Descriptions Act was introduced, that the word 'nominal' should no longer be used in specifications. That is why the IEC concept of 'rated value' is so useful. There is a very detailed definition and explanation of this term in IEC60268-2.

The IEC standard (IEC60268-3) allows any "increase" above the rated value, but limits the "decrease". The standard does not allow the impedance to fall below the 80 % of the nominal value at any frequency, including DC.

PRACTICAL CASE:

In practice all loudspeakers are a compromise, the designer is therefore free to allow the speaker to suck more power from the amp in order to optimise other parameters. Most high-quality loudspeakers do dip well below 80% of their nominal impedance at one or more points in the audio band. Speakers which attempt to present a flat impedance load using conjugate techniques have sometimes been described as 'flat and boring', which may or may not be connected to their excessively complex crossovers. Speaker design is non-trivial!

Remember that a specification is only of relevance when a product is claimed to meet it. A specification is only of value when it lays down a minimum standard which is of relevance to the intended purpose of the product. A high-quality speaker may reasonably be assumed to be intended to be driven by a high quality amplifier; hence minimum impedance is not an important criterion in establishing sonic performance.

MEASURING SPEAKER NOMINAL IMPEDANCE:

If you just want to find out the nominal impedance of the speaker e.g. ist it 4, 8 or 15 ohms then there is a rough & ready way. Just use your multimeter to measure the DC resistance of the voice coil i.e. across the speaker terminals (with nothing else connected) and multiply the answer by 1.3. So if the DC resistance is say 6 ohms then the speaker is nominally 8 ohm impedance.

More complete analysis with minimal equipments:

a) Measure the DC resistance across the voice coil with the driver disconnected. The ohm value you get is the lower impedance bound of the driver. Add an ohm or two to this value, and you should be at the nominal (rated) impedance of the driver.
b) Connect a pot in series with the driver voice coil and then to the amp.
c) Connect frequency generator or CD player with suitable test CD in it to the amp input, and start walking up the frequency scale in steps. For each step, measure the voltage across the voice coil terminals and then across the pot. Adjust the pot until both voltages match. Now shut down the amp. and measure the resistance across the pot. This is the driver impedance for the current drive frequency.

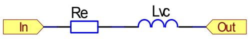
This approach is not the most accurate, but it needs minimal set of measuring equipments: multimeter, signal generator and a potentiometer of 50 ohms 5-10 watts. The clear advantage of this approach is that the accuracy of the measurement is not affected by the multimeter frequency response (their AC range is designed to show right values at around 50 Hz range and at higher frequencies the accuracy can drop noticeably depending on the meter construction, but this does not affect in this measurement because the absolutely correct AC voltage values are not needed). Warning, KEEP DRIVE LEVELS TO SPEAKER VERY LOW. High levels of sustained sine wave can up the driver voice coil.

SPEAKER MODEL:

The single most dominant branch of the model is the voice coil DC resistance, re. It's going to be in series with everything else we will look at (you mentioned "stray capacitance". Yes, there is some, but its magnitude is absolutely miniscule compared to all other components so it can be ignored).

Next we have the voice coil inductance (we'll call it L_{vc}). Now, it, too, is in series with everything else, but it's no simple inductance.

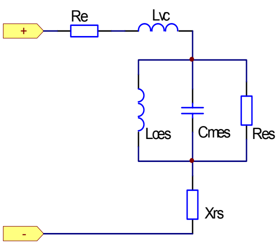
So far, we have the two real electrical components, and they look like:



Now, the next major set of components are the electrical equivalents of the major mechanical components of suspension compliance, cone mass and suspension losses. The suspension compliance is modelled as an inductor, L_{ces}. The cone mass is modelled as a capacitance, C_{mes}, and the suspension losses are modelled as a resistor, R_{es}. These three are in parallel and form a damped, parallel resonant branch called the driver mechanical branch.

Finally, in series with that is the radiation impedance. No single lumped-parameter synthesis comes close to approximating this. Also the magnitude of the impedance of this branch is small compared to the others, so for simulating the ELECTRICAL characteristics, it can be safely eliminated.

The driver electrical model, then, looks like this:



Now, the relative values of these components depends upon the magnitudes of the physical values times a transformation factor. That transformation factor is the electromagnetic transduction factor, proportional to the Bl product (the product of the length of the wire l immersed in the magnetic field B), measured in N/A (or T/M, if you will). So, IF we know the magnitudes of the physical components, we can easily calculate their electrical equivalents:

R_e Don't calculate it, just measure it with a good ohmmeter!

L_{vc} Measure it, but see below!

L_{ces} Depends upon the suspension compliance: $Lces = Cms * (Bl)^2$
Where C_{ms} is the mechanical compliance in m/N, and the resulting Inductance is in Henries.

C_{mes} depends upon the cone mass: $Cmes = \frac{Mms}{(Bl)^2}$
Where Mms is the mechanical compliance in kg, and the resulting Capacitance is in farads

R_{es} depends upon the suspension losses: $\mathrm{Re}\, s = \frac{(Bl)^2}{Rms}$
Where R_{ms} is the mechanical losses in 1/s, and the resulting Resistance is in ohms.

X_{rs} Depends upon the air, the driver diameter, the baffle dimensions, position of the driver on the baffle, etc., but has little effect on the electrical impedance.

TYPICAL CHARACTERISTICS:

For example, a typical 8" woofer with F_s=30 Hz, V_{as}=60L, Q_{ms}=2.40, Q_{es}=0.42, Q_{ts}=0.36, R_e=6.25 ohms, might have the following mechanical parameters:

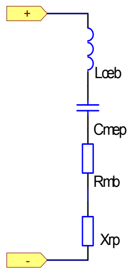
$$Cms = 1.01 * 10^{-3}\, m/N$$
$$Mms = 27.9 * 10^{-3}\, kg$$
$$Rms = 2.19\, kg/s$$
$$Bl = 8.84\, N/A$$

Then, the electrical equivalents would be:

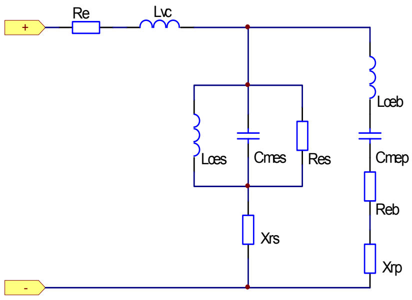
$$Lces = 78.9mH$$
$$Cmes = 356uF$$
$$\mathrm{Re}\, s = 35.7\Omega$$
$$\mathrm{Re} = 6.25\Omega$$

EFFECT OF ENCLOSURE:

One can construct a similar branch for the enclosure, using the lumped parameters of a capacitive equivalent C_{mep} for the port mass M_{mp}, and inductive equivalent L_{ceb} for the enclosure compliance C_{mb} a resistive equivalent R_{eb} for the system losses R_{mb} and the port radiation impedance X_{rp} (which is, again, small). That branch looks like:



The complete driver + enclosure + electrical model look like:



Now there are some other complicating elements that would make for a complete mechanical and acoustical model, such as the mutual coupling of the driver and port, etc., but for the electrical model the above suffices quite well for predicting reality.

TYPICAL IMPEDANCE CHARACTERISTICS OF SPEAKER ELEMENT AT DIFFERENT FREQUENCIES:

Let's look at the impedance of a very typical driver. It has the following characteristics:

- At DC, the impedance is completely dominated by the DC resistance of the voice coil.
- As you increase in frequency towards the fundamental mechanical resonance, the reflected motional impedance begins to dominate and is inductive in nature. However, the total phase angle of the impedance RARELY exceeds 45 degrees and thus the resistive and reactive (inductive) parts of the impedance are just about equal.
- At fundamental resonance, the impedance is purely resistive, its phase angle is 0, and is determined by the effective series combination of the voice coil DC resistance and the reflected mechanical losses of (primarily) the suspension (R_e + R_{es} in standard Thiele/Small notation).
- Above fundamental resonance, the impedances drops, has a negative phase angle (rarely exceeding 45 degrees) and is, surprise, capacitive in nature. The impedance drops until...
- In the midrange, it approaches the DC resistance of the voice coil it is SLIGHTLY higher than that DC resistance for a variety of reasons, typically about 10-20% (and THIS is the region that is used by MOST reasonably responsible manufacturers for specifying the nominal

impedance). The impedance at these frequencies is predominantly resistive in nature and is dominated by the DC resistance of the voice coil.

- Above this region, the inductance of the voice coil begins to influence the impedance. However, it NEVER becomes purely inductive, or even remotely close. First, over the majority of the range of operation, the voice coil resistance still dominates. Second, eddy current losses in the pole piece (see Vaderkooy, et al) dominate quickly, such that the phase angle of the impedance asymptotically approaches about 45 degrees, and NEVER 90 degrees, which would be necessary if your assertion that the impedance was almost a pure inductance were true.

Impedance of a speaker IS NOT ALMOST A PURE INDUCTANCE. It is NOWHERE NEAR a pure inductance. The impedance of a speaker is only a rough average of the impedance and that the voice coil dc resistance of most normal cone type dynamic speaker is roughly 75% of its "rated" impedance as the industry rates impedance. Most 8 ohm speakers will measure somewhere around 6+ ohms dc give or take a bit. (When horn loaded, the impedance increases).

IMPEDANCE AND EFFIENCY:

Let's look at the following situation: Take an 8 ohm speaker and wind twice the length of wire onto the voice coil. The resistance would go up, for sure, but because there is no more wire in the gap, the electromagnetic coupling coefficient, the B_l product, would also go up. And you would have, as a result, a 16 ohm speaker with essentially the same efficiency as the 8 ohm speaker, all other things being equal.

Or you could design a speaker with both a higher impedance (longer wire in the voice coil) AND a larger magnet assembly with higher flux density in the gap and get a higher impedance driver with higher electro-acoustic efficiency.

Or you could design a higher impedance driver with a stronger magnet and a lighter cone and get even more efficiency.

The point is, the rated impedance IS NOT the same as the efficiency, nor is there any direct correlation between the two. Efficiency of a given direct radiator driver is determined by the following relationship:

$$N0 = K * \frac{B^2 * L^2}{R_e * S_d^2 * MAS^2}$$

where:

- k is a constant determined by the properties of air.
- B is the magnetic flux density in the gap.
- l is the length of wire in the magnetic field.
- R_e is the DC resistance.
- S_d is the radiating area of the cone.
- M_{as} is the effective total moving acoustical mass of the driver.

So, we can see that by doubling the length of the wire that's in the gap (doubling l) will, by itself, increase the efficiency by a factor of 4, but since Re also doubles, it drops it by half, meaning that, all other things being equal, lengthening the voice coil winding in the gap increases BOTH impedance AND efficiency. Now, there ARE tradeoffs, and everything CAN'T be equal. Lengthening the wire ALSO increases the mass, though the voice coil is only part of a larger mass (it includes the voice coil former, the cone, and so on) so there is not a direct relation. Also, the gap may need to be widened to accommodate the greater winding diameter of the voice coil, and that may reduce B.

Add resistance certainly reduces efficiency all by itself. You could, for example, just simply solder a resistor in series and, lo and behold, the impedance goes up and the efficiency goes down. But we already have a case where the efficiency goes up as the impedance goes up.

You could wind the voice coil with the same length of finer gauge wire. The result would be the impedance goes up, and so does the resistance, but since l remains about the same, l^2, remains the same and the efficiency goes down. But wait!, finer wire means less mass, so we can gain some efficiency back from that and the finer wire means a smaller thickness to the voice coil, and the designer may be able to close up the gap and increase B.

Or, the designer may just design a TOTALLY difference driver with a different B, a different l, a different cone diameter (changes S_d), a different moving mass and a different resistance and get something totally different efficiency wise.

The point being is that a statement like "The higher the impedance, the lower then efficiency," as a generalization has NO basis in physical fact.