Loudspeaker

. . . A hifi hassle

On paper, the impedance rating of a loudspeaker system looks all very tidy and official: 4 ohms, 8 ohms, 15 ohms, etc. But don't take it too seriously; don't count on it. At best it's a rough guide; at worst, it can add up to a variety of hifi problems that have been around for the past 50 years.

by NEVILLE WILLIAMS

It is for this reason that engineers generally tend to avoid reference to loudspeaker "resistance", preferring the more factual term "impedance" or even "nominal impedance".

Virtually by definition, the impedance of a loudspeaker will not be a single, constant figure but will vary with frequency. It is something that loudspeaker (and amplifier) designers are stuck with, no matter how much they might wish it otherwise!

Back in the early '30s, "wireless" technicians were aware of these facts in a vague sort of way, assuming that the impedance of a loudspeaker would always be 20% or so higher than the measured resistance of the voice coil, by reason of its inductance. In fact, they relied on this "rule of thumb" to classify loudspeakers that had lost their identification marks.

A practical reminder that there could be more to it than that came with the widespread introduction of pentode output valves. Even though they offered considerably more power output, with comparable distortion ratings, there were numerous complaints that they lacked the "sweetness" of the old-fashioned triodes, sounding shrill and harsh by comparison. (Shades of "transistor tone", 30 years later!)

Could it be that, with their intrinsically high output resistance, pentodes performed badly into a typical reactive loudspeaker load — published ratings notwithstanding? Initially, however, the "quick fix" was to wire a $0.02\mu F$ capacitor across the primary of the output transformer, as a brute force restraint on both treble response and distortion.

A more salutory lesson came with the release by RCA of their state-of-the-art all-metal 6L6 beam power tetrode. Used in conventional circuitry, it showed a marked tendency to self-destruct at high signal levels, by arcing across a glass bead insulator separating the plate lead from the metal shell.

A crack and a fizz, and another 6L6 had ceased to be!

While the problem should, perhaps, have been forseen by RCA, it did underline the fact that the load impedance presented by a typical loudspeaker was likely to exceed its measured DC resistance, not just by a few percent, but several 100%! Across such a load, a high-power, high-impedance driver — in this case a 6L6 beam tetrode — could generate a destructively large peak voltage.

In technical terms, a loudspeaker or loudspeaker system can be described as the "load", to which an amplifier delivers audio power ranging, typically, from a few tenths of a watt for a small portable radio, to a 100 watts or more for a large hifi system.

Logically, a loudspeaker should be capable of coping with the audio drive power available from the associated amplifier but there is more to it than merely ensuring a sensible balance between the power handling capability of one, and the rated power output of the other.

It is also necessary to ensure that a loudspeaker presents to the amplifier that order of (load) resistance into which the amplifier can most effectively deliver its output power. If, for example, the design of an amplifier is such that it calls for an 8 ohm load, complications can arise if it is used instead with, say, a 4 ohm or 16 ohm loudspeaker or system. More about that later.

Unfortunately, it is virtually impossible to design practical loudspeakers which will present to the amplifier a pure resistance load of a desired value. To start with, the ubiquitous "dynamic" loudspeaker depends for its very operation on a "voice" coil, exhibiting not only DC resistance but also inductance and distributed capacitance. Inevitably, inductive and capacitive reactance will be present, along with the DC resistance.

No less to the point, loudspeakers normally involve moving parts, which exhibit mass, momentum, inertia, stiffness, springiness and a tendency to mechanical resonance. In the ultimate, all of these mechanical properties reflect back into the load, as seen by the amplifier, as electrical analogs: equivalent resistance, inductance and capacitance, adding to the electrical quantities already present.

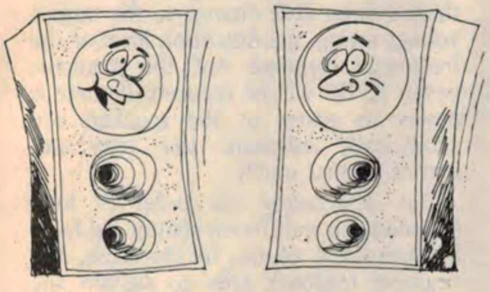
In April, 1938, the late Fritz Langford-Smith, Editor of the "Radiotron Designer's Handbook", presented a definitive paper on the general subject to the World Radio Convention in Sydney, organised by the IREE. It was entitled: "The Relationship Between the Power Output Stage and Loudspeaker". Although it related, at the time, to valve technology, it set out many broad principles equally applicable to modern solid-state devices.

I happened to be his assistant at the time and prepared the original diagrams from which Figs. 1, 2 and 3 have been redrawn.

Fig. 1 shows the impedance curve of a then-current 25cm loudspeaker (probably an AWA/Amplion model) with a nominal impedance of 12 ohms. It conforms to this figure, at most, over the range 100-700Hz. Below 100Hz, the impedance rises to a peak of 80 ohms at 70Hz (the main cone resonance) falling to reference again at 50Hz. Above about 700Hz, it rises progressively through 80 ohms at 10kHz — an increment of 6.5 times, or 650%!

It was no wonder that pentodes and tetrodes failed to perform as into a resistive load.

impedance that won't go away



"They're asking awkward questions about our impedance."
"Ah!"
"Not just R; I wish it were."
"I see . . ."
"It's not just C, either."
"Oh 'ell!"
"They know about L as well."
"You really do mean impedance . . ."
"That's what I Z!"

Fig. 2, from the same source, shows the nature of the impedance: inductive up to about 70Hz, changing to capacitive from just above 70Hz to about 190Hz, and then reverting to inductive for all frequencies above 200Hz. Only across a narrow band, centred on 200Hz, could the particular loudspeaker be said to present its rated load: 12 ohms, resistive.

Fig. 3 shows the combination of electrical components necessary to duplicate the impedance and phase characteristics of Figs. 1 and 2, up to 400Hz. Considerable elaboration would be necessary to simulate the curves above that frequency but, at least, the diagram conveys some idea of how even a simple loudspeaker appears to the drive amplifier. More importantly, it emphasises the fact that loudspeaker "resistance" is a mythical quantity.

In his paper, Langford-Smith pointed out that, for a given level of drive signal, a low impedance output stage tended to produce a constant voltage across the load, irrespective of variations in the load impedance. For this reason, triode output stages tended not to exaggerate the bass resonance (71Hz in Fig. 2) or the rising treble response above 1kHz. High impedance stages, on the other hand, (eg pentodes and tetrodes) exaggerated both effects, because their output voltage tended to rise and fall with load impedance.

He drew attention also to loudspeaker damping. When a loudspeaker cone tended to "overshoot" by reason of its mass and momentum, or to oscillate freely at a natural resonance, its surplus mechanical energy could be absorbed ("damped") much more rapidly in a low impedance output stage than in one with higher impedance.

These were the facts behind the then-preference for triodes, and the criticism of pentodes and tetrodes — facts which had at least as much to do with the limitations of the load, as with any vagaries of the valves!

Although the behaviour of a high impedance output stage could be modified by the use of a top-cut filter, Langford-Smith maintained that the use of (voltage) negative feedback was much to be preferred. He went on to show that, with negative feedback of the order of 8-11dB, a typical receiver type output pentode or tetrode could offer essentially the same performance as a power triode, but with improved efficiency in terms of the power supply.

In fact, the next generation of domestic receivers and amplifiers followed this general design philosophy, using pentode or tetrode output stages, with 10-12dB of negative feedback in a modestly configured circuit and with distortion figures hopefully below 3% at rated output. Peace reigned!

But then followed the call for ever lower figures of distortion, adding up to more complex circuit arrangements using a greater amount of feedback over more stages. In a roundabout way, that stirred up the problem of loudspeaker impedance all over again.

When the amount and the extent of negative feedback is increased, in the interests of reduced distortion, lower output impedance and flatter frequency response, it becomes progressively more important to ensure that the feedback does indeed remain "negative" — a requirement that applies no less to modern solid-state amplifiers than to classical valve designs such as the "Williamson" (ref. "Wireless World") or our own ultra-linear "Playmasters".

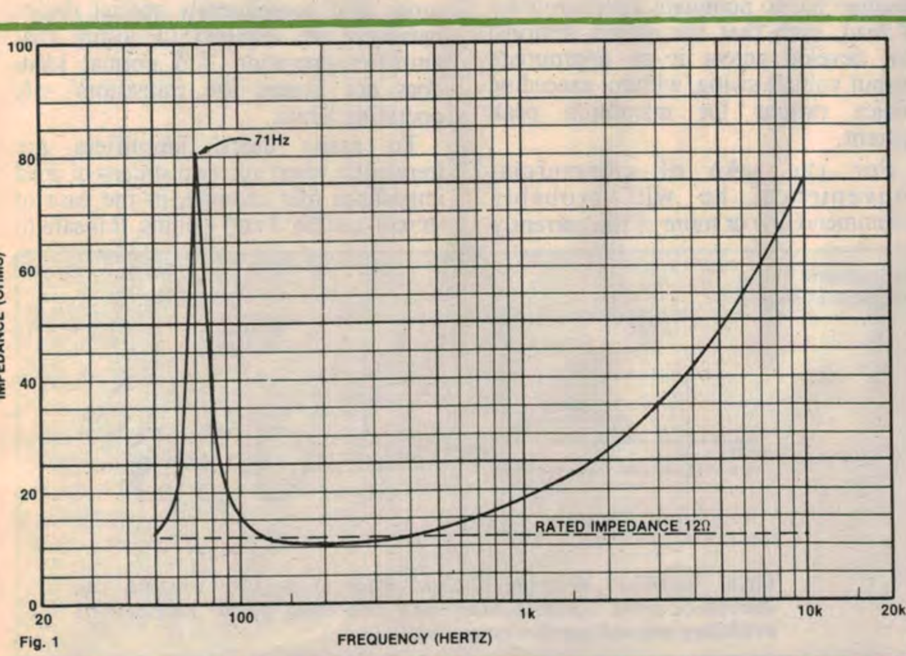


Fig.1: The impedance curve of a traditional receiver-type 10in (25cm) loudspeaker, with a nominal impedance rating of 12 ohms. It was probably mounted on an open baffle.

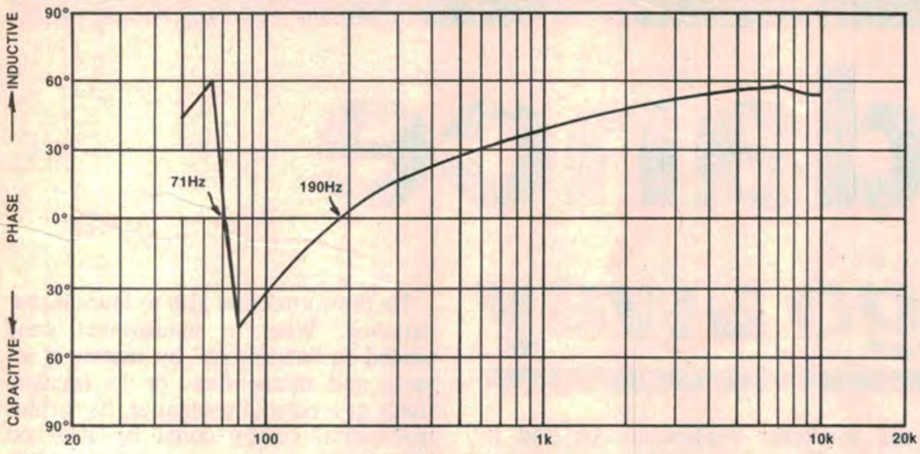


Fig. 2 FREQUENCY (HERTZ)

Fig.2: The phase characteristics of the same loudspeaker as for Fig.1. The impedance approximates 12 ohms resistive only within a narrow band centered on 200Hz.

Loudspeaker Impedance

The problem is that reactive effects are present in any amplifier, which modify its phase response in the supersonic (and perhaps subsonic) region. Thus, even though the feedback may be strictly negative over the entire audible range, phase rotation effects can still cause the feedback to become positive somewhere within the overall passband, and therefore apt to promote instability. The problem multiplies with greater amounts of feedback and with the number of stages/components included within the feedback loop.

In an elementary way, Fig. 4 illustrates the problem which faces the designer of a high-gain high-quality amplifier, whether valve or solid-state. He can manipulate the internal design to ensure that it is stable at all frequencies, when looking into a resistive load of a certain order, or even into an open circuit. But how will the amplifier behave when it is terminated by a predominantly capactitive or inductive load instead or by a particular combination of L, C & R found in somebody's loudspeaker system? Will some unforseen combination of components cause enough phase rotation in the load, at some frequency, to promote instability?

In an extreme case, amplifiers have even been known to "take off" when provoked, not so much by a particular loudspeaker system, but by connecting leads having (for the amplifier) an unfortunate order or combination of inductance and capacitance.

Fortunately, the matter is well enough understood, these days, for actual or incipient instability not to be a problem for most amplifiers, most loudspeaker systems and most connecting leads. Indeed, some amplifier manufacturers are sufficiently confident to specify their product as "unconditionally stable".

But enough of phase and stability; let's get back to loudspeaker impedance and to the load values specified for typical domestic amplifiers.

In developing a new amplifier, the designer has to nominate a certain order of load, such that the output device(s) can develop across it an appropriate output voltage swing, without exceeding device ratings for maximum peak current.

For the sake of commercial convenience, he will probably recommend one or more of the currently popular values — 4 or 8 ohms — and list the corresponding power output, distortion level, frequency response, and so on. As far as possible, these recommended operating conditions should be observed.

Normally, however, no special difficulty will result if an amplifier is operated into a load higher than specified; eg into 16 ohms instead of 8 ohms. Because of the negative feedback, there will be little change to the output voltage swing, the distortion level or the frequency response but the available power (E^2/R) will be reduced. If there is power to spare, or the speakers are acoustically efficient, this may not matter all that much.

But descreasing the order of load impedance is a different matter, eg from 8 ohms to 4 ohms. In this case, the negative feedback tries to sustain the signal output voltage, resulting in higher output current through the load. This, in turn, may yield higher power output but with more stress on the output stage devices — conceivably sufficient to endanger them at peak signal levels.

A valve output stage will generally take such abuse without getting more than "hot under the collar" and suffering a possible reduction in overall life span but solid-state devices could blow a fuse or, more seriously, blow themselves by reason of excessive current or by exceeding their "safe area of operation". By way of explanation most power transistors have reduced power handling at higher voltages within their rated range and consequently special design measures are required to ensure that amplifier operation into normal loads does not exceed the transistors' safe operating limits.

To assist users, amplifiers are frequently rated for two orders of load impedance (per channel, in the case of stereo). usually 8 and 4 ohms. It is safe to

Fig.3: To an output stage, a loudspeaker appears like a complicated electrical network. This much simulates Figs 1 and 2 only below 400Hz.

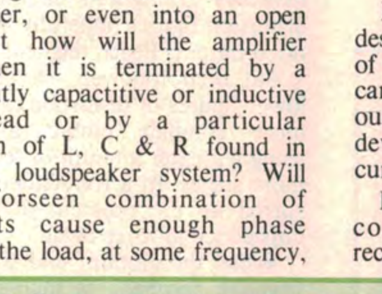


Fig. 3

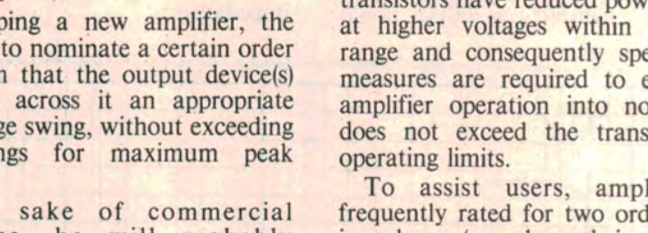


Fig. 4

Fig.4: Amplifiers involving a large order of negative feedback can sometimes prove unstable when used with leads and/or loudspeakers exhibiting unusual reactive properties.

Loudspeaker Impedance

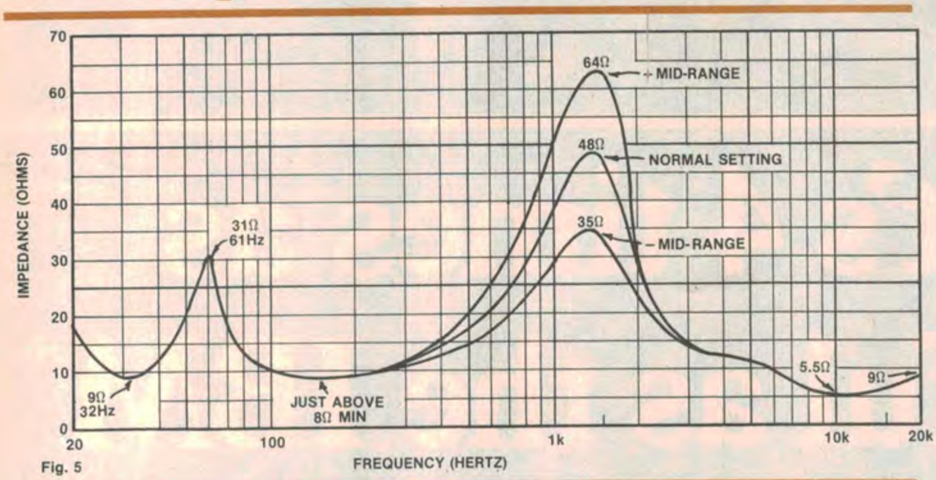


Fig.5: The impedance curve of a popular medium-priced hifi 8-ohm loudspeaker system, using the bass reflex principle and fitted with a 3-position "presence" switch. Note the dip in impedance at 10kHz.

use an amplifier with a nett load impedance equal to, between, or larger than the specified values — but not substantially less than.

Where an amplifier has provision for multiple loudspeaker systems (typically "Main" and "remote") the impedance presented by the two systems, operating simultaneously, should not be less than minimum figure for which the amplifier is rated. Two 8 ohms systems would be the obvious choice for an amplifier with a minimum rating of 4 ohms. In fact some amplifier designers go so far as to have the main and remote loudspeakers connected in series when both are selected. This ensures that excessively low values of load are unlikely but it does nothing for the damping of each individual loudspeaker system!

And that brings us to consideration of Fig. 5, based on the published impedance curve for a medium-priced, bass reflex hifi system, (actually the original Kef 104) with a nominal impedance rating of 8 ohms. It is much more typical of present day systems than Fig. 1.

The impedance is just under 20 ohms at 20Hz, dipping to 9 ohms between the two bass reflex peaks. At the upper bass peak, the impedance rises to 31 ohms, falling to just above the rated 8 ohms between 100 and 300Hz. From there it rises to peaks of 35, 48 or 64 ohms, depending on the setting of the mid-range "presence" switch. At around 3kHz, the impedance falls to below 15 ohms and then, with a slight plateau at 5kHz, passes through a dip to 5.5 ohms at 10kHz and back to 9 ohms at 20kHz.

In looking at Fig. 5, it is important to remember that it is a curve depicting impedance, **not** frequency response. If such a system were driven by an amplifier having a high output impedance (eg non-feedback pentodes or bipolar transistors) the frequency response might indeed take on something of the same shape. However, when driven, as normal, by a low-impedance (constant-voltage) amplifier, variations in the load have only a very secondary effect; in fact, the particular loudspeaker is credited with a frequency response flat within a very few dB from 50Hz to 20kHz.

While, for the most part, the impedance approximates, or remains safely above 8 ohms, it does dip to 5.5 ohms at 10kHz — raising the question as to whether it would pose any hazard to an 8 ohms amplifier.

The answer, in this case is "probably no", if only because the risk of encountering sustained high-level drive in the 8-15kHz region is not very great under ordinary listening conditions. But one could be more concerned with profound dips that occur further down in the range, as with some loudspeaker systems.

The general answer has to be that, although not uncommon, dips in the impedance curve below the nominal rated value are undesirable, in principle, especially if they fall below, say, 75% of the nominal value; ie below 6 and 3 ohms respectively for 8 and 4 ohms systems. They would certainly add to the risk of using Main and Remote loudspeakers or less than the appropriate nominal impedance.

The presence of dips in the impedance curve also has a bearing on the choice of cable connecting the loudspeaker system to an amplifier.

Taken together, the resistance of the contacts and of the cable itself should be as small as possible relative to the impedance of the load — the loudspeaker system. Certainly, it should not amount to more than 5% of the load impedance, representing a maximum resistance of 0.4 ohms for an 8 ohms system, as in Fig. 5. Ostensibly, this would introduce a loss of less than 0.5dB and make no discernable difference to the sound, as heard.

If it was purely a question of signal level, the matter could possibly rest there but the variation in impedance with frequency introduces another consideration:

In those sections of the curve in Fig. 5, where the impedance approximates 8 ohms, the cable loss might indeed be just under 0.5dB, as predicted. However, at 60Hz, where the system impedance is much higher, the cable loss would be a mere 0.1dB, and less again in the region 1-2kHz. But, at the impedance minima, around 10kHz, it would range around 0.6 to 0.7dB.

From this flows the contention that, with practical loudspeaker loads, contact and cable resistance causes not just a loss in level (which might pass unnoticed) but a variation in frequency response or a "colouration", which might be more apparent.

The counter argument is that the frequency response of a practical loudspeaker system in a practical listening room is already so peaky that it is fantasy to worry about plus-and-minus an extra quarter-decibel!

However, human nature being what it is, the impedance "ogre" still has the last laugh, when he sees even the counter-arguers doubling and trebling the gauge of their cables "just in case".

But he must really fall about at the sight of ultra-purists "wiring" up their loudspeaker systems with lead pipe!