Hi-Fi Power Meter

Build this inexpensive power meter for your audio systems

By Paul Chappell

When faced with the task of designing a power amplifier, the variety of different approaches that can be taken is almost overwhelming.

If the load to the amplifier is known, the power can be derived from the voltage alone. The very simplest method is to assume that the load is a pure resistance, to rectify the output voltage and apply it to a single quadrant square-law circuit, (since power is proportional to the square of the voltage for a given resistive load) and then to smooth the output and use it to drive a meter.

If the meter movement is sensitive enough, the entire circuit can be made from passive components and will divert very little power from the loudspeakers.

This approach relies for its accuracy on two factors. First of all it assumes the loudspeaker impedance is close enough to a pure, fixed resistance for the assumption to be valid. The second assumption is that a reasonably accurate square-law circuit can be made. In practise, reasonable results can be achieved, and this type of design has the advantages of being simple, cheap and reliable. A practical circuit along these lines will be given later on.

This is all very well for PAs, music centres and the like but for top flight hi-fi or for accurate power monitoring, something considerably better is called for. If the current is measured as well as the voltage, there is no need to make any assumptions about the loudspeakers. The circuit can take into account the characteristics of the load. But how?

What do we do with the current and voltage signals when we've got them? Multiply them? Find the RMS values and multiply? Find the average and multiply? It depends on exactly what we're trying to measure — which is not as silly a question as it sounds.

Power To People

For a resistive load there's no doubt about what we want to measure. However, for a load with a reactive component the case is not so clear cut. Fig. 1a shows the voltage, current and instantaneous power waveforms for a resistive load with a sinusoidal voltage applied. The power (p) varies from a peak when v and i are both at peak positive or negative values down to zero when v and i are both zero. However, it is always positive.

The average power delivered to the load is shown by the dotted line. This is the mean value of the instantaneous power curve. It can be calculated by taking the product of the instantaneous current and voltage over a whole number of half cycles and averaging the result, or by multiplying together the RMS voltage and current, or from the mean squared value of the voltage divided by the load resistance, and so on. All these methods give exactly the same result.

Fig. 1b shows the situation where the load is a pure reactance — it can be a capacitor or inductor depending on which of the waveforms you take to represent v and which to be i.

In either case the instantaneous power varies symmetrically about zero. On the positive parts of the curve, energy is being stored by the load. On the negative part it's being returned to the source. The load does not dissipate any energy and the mean value of the power curve is zero.

However, if we multiply the RMS voltage and current in this case we get exactly the same result as for the resistive load. One way of calculating power gives the answer zero another gives a positive value. Which is correct?

The answer is that it depends on exactly what you are trying to measure. If you want to know the average power delivered to the load (the 'real' power, measured in watts) the answer is zero. On the other hand, suppose you were to connect a capacitor directly across an AC transformer. The current flow in the windings would have just the same heating effect as for a resistive load. There is a limit to the size of capacitor you can connect directly across a transformer before it burns out! Clearly the 'real' power is not the whole story.

The effect on the transformer is measured by the product of RMS voltage and current. It is called the 'apparent' power and is measured in volt-amperes (VA) – a unit you'll no doubt have come across in transformer specifications.

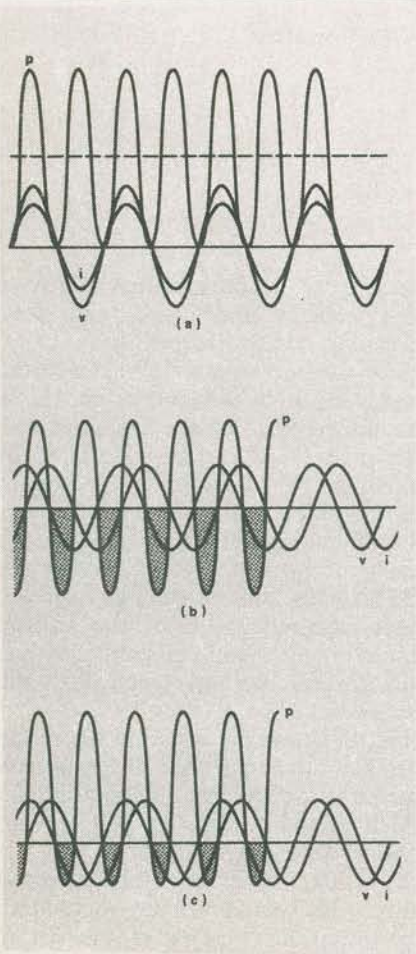


Fig. 1 Voltage, current and power waveforms for (a) a resistive load (b) a pure reactance load (c) a load with both resistive and reactive components.

Fig. 1c shows the more general situation where the load has resistive and reactive components, as in the case of a hi-fi loudspeaker. Here, the power situation is even worse – we can distinguish three different kinds.

The product of RMS voltage and current still gives the apparent power (VA), the mean of the power waveform will give the real power (watts). Now the difference between the two gives yet another power reading – the 'reactive' power, measured in 'volt-amperes reactive' (VAR).

The apparent power, then, is made up of two components: the real power delivered to the load and the reactive power which shunts backwards and forwards between load and source. So, what should a power meter measure?

The Old Bill

If we asked the electric utility, we'd get an answer without hesitation – apparent power is the one to go for. It's bigger than either of the other two and the choice can be justified by saying that even if the energy transferred from the generators to the customer's load is less than the meter reading, the 'extra' power shunted back and forth means that heavier gauge wires and bulkier transformers are needed.

The utility does indeed charge for apparent power. As a slight digression, factories are perfectly well aware that they can be charged for energy they haven't used and go to great lengths to apply power factor correction to their supplies.

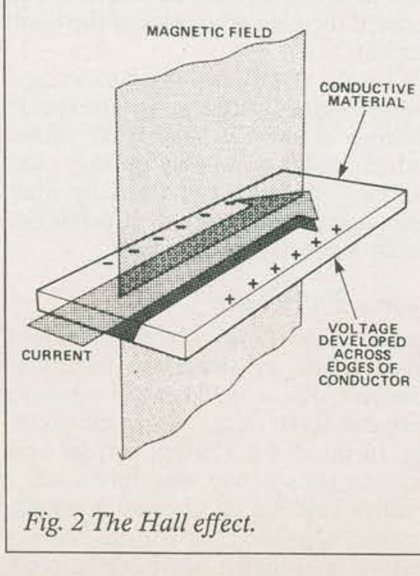


Fig. 2 The Hall effect.

The most common cause of trouble is large electric motors which have a high inductive component and the solution is to connect a whopping great capacitor across the AC – just like an amplifier's Zobel network but on a much, much larger scale.

The result is that the factory appears more like a pure resistance to the power supply and the reactive power circulates between the capacitor and the motors.

Unlikely as it sounds, this measure will often give a considerable reduction in the electricity bills.

I should point out that the capacitors used are not the type you buy from your corner shop. They have to withstand continuous AC voltage and huge currents and are therefore very costly and bulky. Four household supplies it just isn't worth the time and effort. Also, since different gadgets are being turned on and off at various times, there's no sensible way to compensate for them.

To return to the hi-fi power meter, the most sensible thing to measure seems to be the power that is actually used by your loudspeakers – the real power. It may not be quite so flattering to your amplifier as apparent power but it's a realistic indication of the power used by the loudspeakers. How much of this actually gets converted to sound rather than heat is a matter between you and the hi-fi manufacturer.

The method for calculating real power applies to any old waveform, and this is:

The voltage and current signals are continuously multiplied to give the instantaneous power, then the resulting power waveform is average over a number of cycles to give the mean power.

The four quadrant multiplier is needed because the areas below zero on the power waveform represent energy returned to the amplifier to be dissipated in the output transistors. This must be subtracted from the area above zero which represents the total energy supplied (some of which is returned). This will all be taken care of by a four quadrant multiplier and suitable averaging circuit.

Acceptability

Having decided what we want to measure and how to go about it, the next question is acceptability. What will make hi-fi enthusiasts feel happy to connect to their amplifiers? My modest aim has been to produce a circuit which will introduce no distortion whatsoever into top-flight hi-fi equipment. Anybody who will be happy with this approach should be more than satisfied with the circuit.

Tapping a voltage reading from the amplifier output presents no particular problem. The main question is how to derive a suitable current signal. Introducing a resistor into one of the speaker leads is the usual solution. However, although the disturbance caused by a 0.1 ohm resistor would be negligible in all but the very finest equipment, a better approach should be sought if possible.

My first thought on the subject was to use a Hall effect device to measure the current. If you are not familiar with the Hall effect, Fig. 2 shows the general idea. The rectangle is a strip of some kind of conductive material. A magnetic field at right angles to the strip will produce a voltage at the edges.

The effect is exhibited by any conductor whatsoever, even the track on a PCB but is generally so small as to be unmeasurable. Some semiconductor materials produce relatively high voltages for fairly modest flux densities and can be obtained in IC form, often with internal amplifiers.

One of the loudspeaker leads running alongside such an IC would have been the ideal way to derive a current signal without disturbing the audio signal. Unfortunately, the devices I tried were all far too noisy and insensitive to obtain clean signal, so it was back to the drawing board.

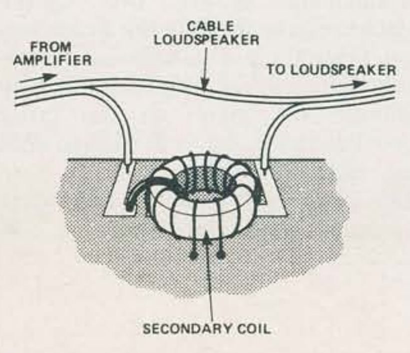


Fig. 3 The current transformer approach.

The Long And Winding Road

The solution that eventually produced excellent results was a current transformer (Fig. 3). One of the speaker leads is broken and forms a half turn around a suitable toroid via a single hoop of wire. The secondary coil is wound around the toroid giving a step-down in current of about 200:1.

For best performance (and to avoid reflecting the slightest suspension of anything unwanted back into the primary circuit) the transformer must be terminated with a very small resistance – a fraction of an ohm if possible. Since high performance current buffers don't exist in IC form, this approach leads to some interesting problems, but space won't allow me to elaborate at this time.

Budget Power Meter

The circuit of the budget power meter is shown in Fig. 4. It depends entirely on the voltage for the readings, and draws a small current from the amplifier output to drive the meter. The rectifiers are used to produce an approximation to a square law, and also to rectify the signal for the meter. Two different speaker impedances can be selected by SW1 and two different power ranges (0-10W and 0-100W) by SW2.

The component overlay for the project is shown in Fig. 5. There is so little on the PCB that it should be almost impossible to make a mistake. If you use the specified meters, the PCBs can be mounted on the back. Otherwise, they can be fixed to the case by means of the screw holes.

The meters can be back-lit, but this means giving the meter a power supply it would not otherwise need, so it's up to you whether or not you think it worthwhile. Incandescent bulbs will give better result than LEDs. You can probably get away with using a small transformer driving a few bulbs in series.

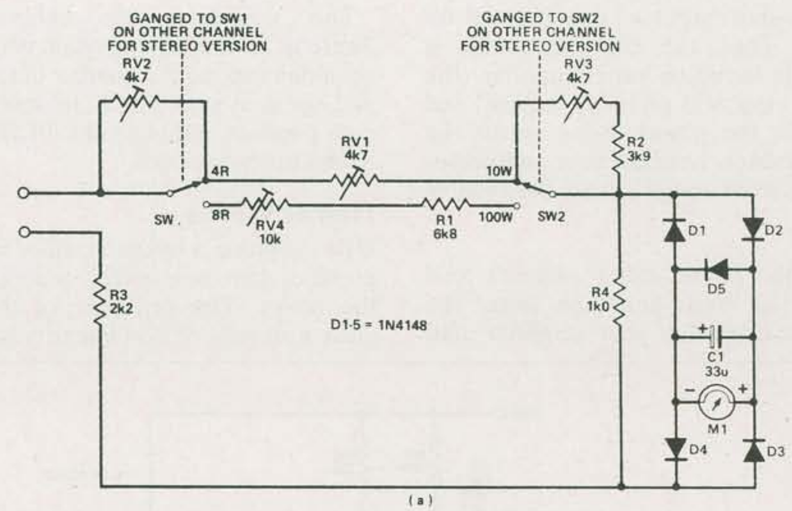
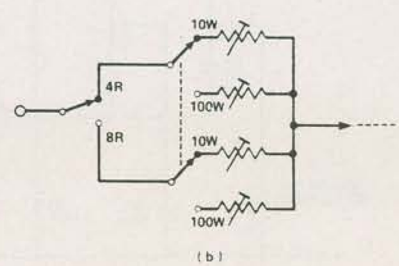


Fig 4. (a) the circuit diagram of the budget power meter



(b) alternative switching arrangement for totally independent range adjustment.

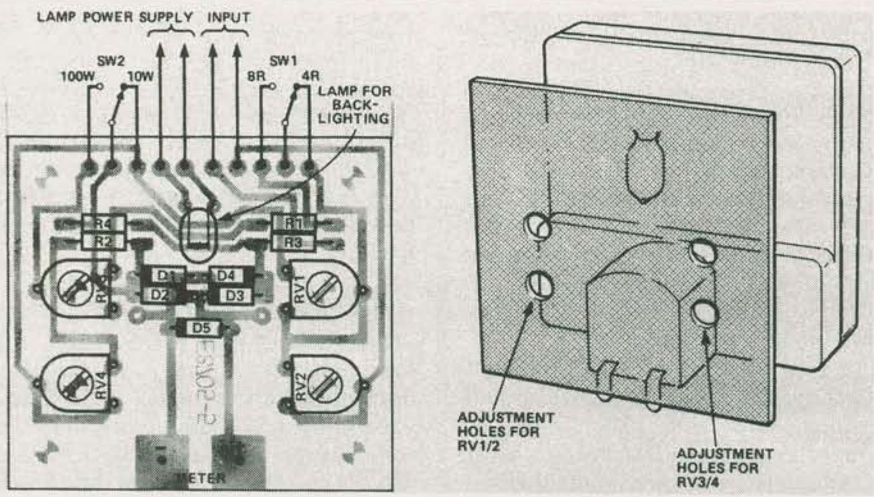


Fig. 5 The component overlay for the budget power meter.

Parts List

Resistors

R1	6k8
R2	3k9
R3	2k2
R4	1k0
RV1,2,3	4k7
RV4	10k

Capacitors

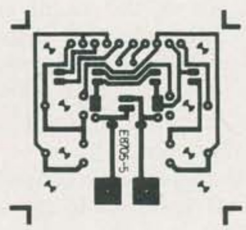
C1	33uF 16V elect.

Semiconductors

D1-D5	1N4148

Miscellaneous

PCB; any fairly sensitive current meter movement, scaled 0 - 10; optional components for backlighting: bulbs, transformer; and case.



The PCB pattern for the power meter

Calibration

You will need a sine wave generator and a multimeter. If you haven't got a signal generator, the circuit of Fig. 6 will do the trick. If you haven't got a multimeter, go out and buy one! (How on earth do you manage to test your circuits without it?).

Disconnect the speakers from your amplifier and connect a 1K0 resistor across the output of one channel instead. Feed the sine wave into a suitable input on your amplifier (the AUX input will probably be best) and connect the power meter across the 1K0 resistor. Connect your multimeter on AC volts range across the resistor too.

Set the power meter switches to 4 ohms, 10 Watts and then adjust the volume control of your amplifier until the meter reads 6.3V. Adjust RV1 until the power meter reads 10W exactly.

Set the power meter to 8 ohms, and adjust the amplifier volume control until the meter reads 8.9V. Adjust RV2 until the meter reads 10W.

For 4 ohms, 100W, set the multimeter to 28.3V and the power meter to a reading of 10 (which once again represents 100W).

This completes the calibration. There is, of course, no reason why you shouldn't expand the number of ranges and speaker impedances to suit your own purpose, although the PCB only allows for two of each.

How It Works

D1 to D4 form a bridge rectifier which provides drive of a suitable polarity for the meter. The presence of diodes gives a degree of non-linearity to the current to voltage relationship with a little imagination we can pretend it's something like a square law relationship.

To make the best of the diode characteristics, the more sensitive the meter movement the better. If you choose a more sensitive type, you should reduce the value of R4 and leave all other components values the same.

The network of resistors around SW1 and SW2 simply pad the voltage divided to cope with different input ranges. The arrangement looks unnecessarily complicated but was devised to avoid the need for a double gang switch in each channel. With the arrangement shown, two DPDT switches can be used for the stereo version. Since the pot settings are not entirely independent, it's important to calibrate the meter in the order described in the text – RV1 first, RV2 next, and so on.

D5 gives protection to the meter movement against the overload. ■

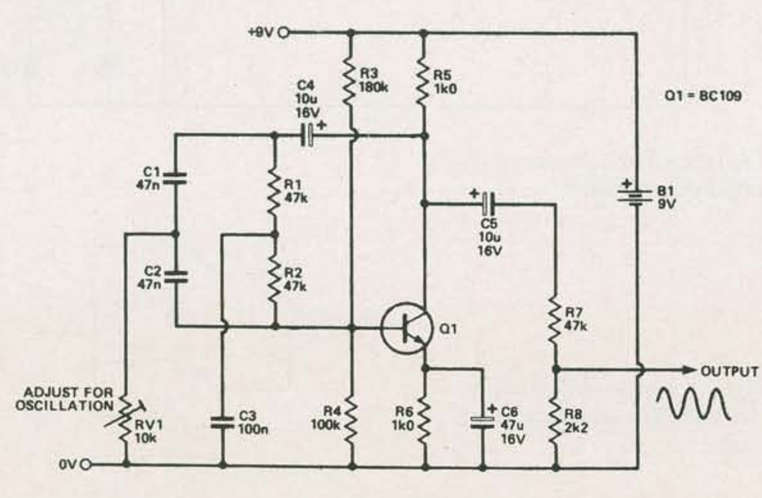
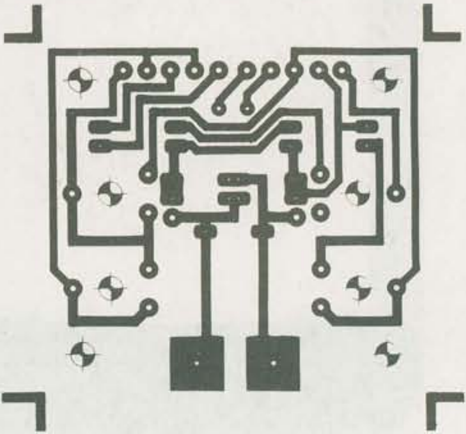


Fig. 6 A simple signal generator circuit for calibrating the power meter.

Oops!



The PCB artwork for the Power Meter project in our February issue was supplied at 50% full size. The full size artwork is given above.

Oops, the second. In Fig. 1 of the Car Alarm project from the same issue, Q7 is not numbered and its emitter is shown unconnected. This should connect to ground. Also, the transistors in the parts list are numbered incorrectly. They should read Q2–6 2N5825 and Q7 is the TIP31.