

FIG 1.

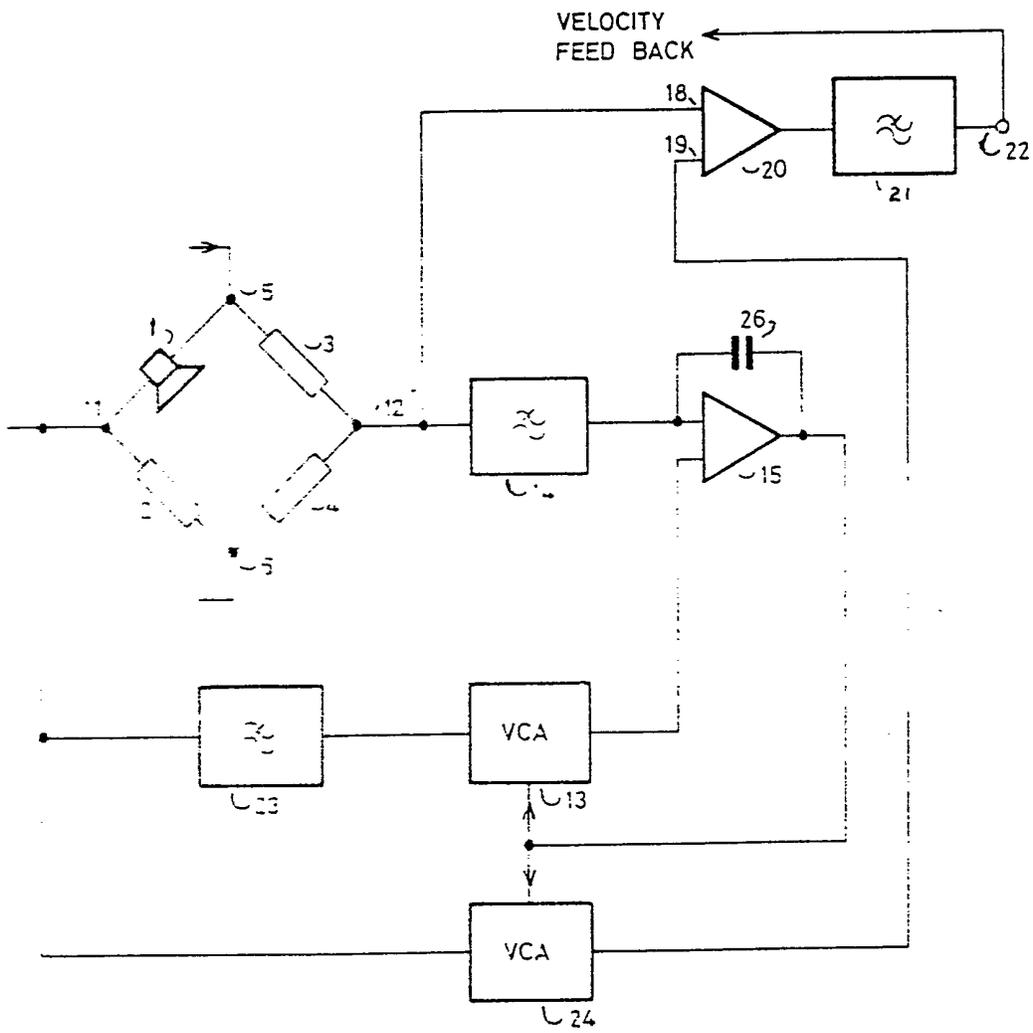


FIG 2

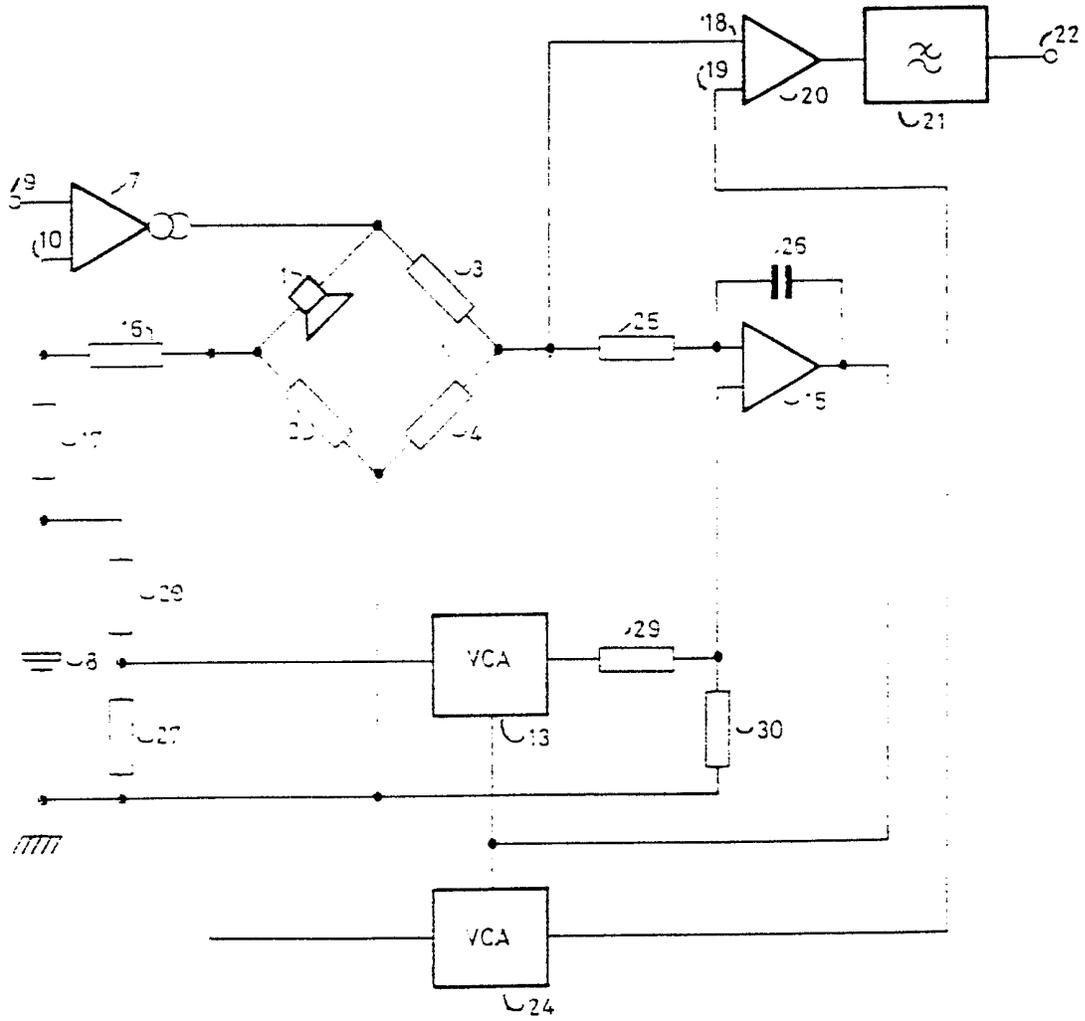


FIG 3.

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A METHOD OF CONTROLLING THE Q FACTOR OF
CURRENT-DRIVEN MOVING COIL LOUDSPEAKERS

The invention relates to audio frequency power amplifiers which are designed to current drive electro-dynamic transducers such as moving coil loudspeakers. It is particularly concerned with the amplifier-transducer interface, and discloses a means of deriving a velocity feedback signal which is independent of the transducer coil temperature, and does not require special construction of the transducer, or additional connections to it, over and above the existing two wires. Additionally, the transducer is protected against thermal damage.

Conventionally, moving coil loudspeakers are driven from a power amplifier having a low output impedance so as to facilitate electrical damping of the loudspeaker drive unit in combination with its enclosure. This implementation is referred to as voltage drive.

Current drive, wherein the power amplifier is designed to have very high output impedance, such as to constitute a current source, has certain potential advantages which are primarily that the system becomes:-

- 1) Insensitive to temperature-induced voice coil resistance changes.
- 2) Insensitive to voice coil inductance, moreover to changes in inductance with displacement of the cone. (Hence reduced intermodulation distortion)
- 3) Less sensitive to variations in force factor Bl.

A full technical discussion of these advantages of current drive is presented in a paper by Greiner and Sims "Loudspeaker Distortion Reduction" published in the Journal of the Audio Engineering Society (JAES) volume 32 pp956-963 (1984 December) and latterly in a further paper by Mills and Hawkesford "Distortion Reduction in Moving Coil Loudspeaker Systems using Current Drive Technology" JAES Vol.37 pp129-148 (1989 March).

It is implicit that current drive removes the electrical damping provided by conventional voltage drive, and so alternative means have to be found to control the Q of the system such as to achieve a desired uniform frequency response. Both Greiner and Sims, and Mills and Hawkesford have proposed velocity feedback to achieve this objective. In both papers the proposers have described the implementation of velocity feedback by special loudspeaker drive units having more than two connecting wires. Greiner and Sims propose the addition of an accelerometer to the voice coil/cone. Mills and

Hawkesford propose an extra feedback coil overwound over the main voice coil; together with electronic means for negating the undesired transformer coupling between the two coils. It is the object of the present invention to derive a velocity feedback signal from a standard loudspeaker without any additional attachments, and whilst maintaining two-wire connection.

It is well known that the voice coil back-emf can be extracted by means of a bridge circuit. It is also well known that the back-emf is a velocity analogue equal to Blv , where (Bl) is the product of the magnetic flux density B interacting with the coil; and the length of wire l (forming the voice coil) which is situated within the magnetic field. v is the velocity of motion of the voice coil. Seemingly, therefore, a bridge circuit at balance provides the required analogue of velocity to implement velocity feedback. In practice, the resistance of the loudspeaker voice coil (which forms one arm of the bridge) experiences substantial temperature-induced changes which occur in sympathy with the continually changing mean power of the programme which the loudspeaker is reproducing. Therefore a conventional bridge circuit does not stay balanced at normal listening levels, and so a proper velocity analogue cannot be recovered.

The present invention describes means for implementing a dynamically self-balancing bridge whereby a velocity analogue is obtained irrespective of the resistance of the voice coil. Additional warning and protection means may be provided so as to limit the temperature rise of the voice coil and prevent thermal damage of the loudspeaker.

UK Patent application GB 2,203,609A "Improvements in or relating to audio frequency power amplifiers" discloses the use of a self-balancing bridge circuit, interposed between the output terminals of the power amplifier and the loudspeaker; whereby the output resistance of the amplifier is rendered adaptive to the temperature-induced changes in voice coil resistance. The electrical damping and control of Q is, by such means, made independent of voice coil resistance changes. Such a system falls within the classification of voltage drive. In the present invention the self-balancing bridge disclosed in GB 2,203,609 is adapted to provide velocity feedback in a current drive class of operation, or at classifications intermediate between constant voltage and constant current drive.

Embodiments of the present invention will now be disclosed by way of example, with reference to the accompanying drawings in which:-

Fig.1 is a diagram showing a dc energised self-balancing bridge incorporating a loudspeaker and providing a velocity-dependent output signal.

Fig.2 is a variant of the circuit of Fig.1

Fig.3 is a variant of the circuit of Fig.2

Fig.1 shows a loudspeaker 1, incorporated in a Wheatstone bridge wherein the other three arms of the bridge are impedances 2,3 and 4. The bridge is energised at terminals 5, and 6 by a small current (eg 1-20mA) supplied by the power transconductance amplifier 7, which amplifier is in receipt at its input terminals 9,10 of a dc voltage provided by reference source 8.

The output terminals of the bridge 11, 12 are connected to the input terminals of integrating, balance-sensing, dc amplifier 15, via low pass filter 14, and voltage-controlled attenuator (VCA) 13. The output of balance-sensing error amplifier 15 is connected to the control terminal of VCA 13. Impedances 3 and 4 may be resistors. Impedance 2 may be the scaled electrical impedance of loudspeaker 1, representing its voice coil resistance, voice coil inductance, and a loss resistance to account for eddy current losses in its centre pole. At the lower frequencies at which it is desired to provide velocity feedback to control the Q of the loudspeaker bass resonance, impedance 2 may often be a resistor.

VCA 13, and amplifier 15 comprise a servo system according to known art (GB 2,203,609, Fig 4) such that the dc error at the input terminals of amplifier 15 is maintained at virtually zero, even though the resistance of the voice coil of loudspeaker 1 changes over a typical range of 2:1 (due to programme-induced temperature changes). The voltage at the control terminal of VCA 13 is a measure of voice coil temperature, and therefore said control terminal may be also connected to warning and/or protection means.

Considering next the path of the ac audio programme signal, this is fed in at terminal 9, and is amplified by amplifier 7, whose output current path includes loudspeaker 1, and impedance 2. Optionally, negative current feedback is derived across impedance 2 and fed back via resistor network 16, 17 to stabilise and linearise amplifier 7.

It will be noted that the Wheatstone bridge is also energised by the audio signal at terminals 5 and 6, but that low-pass filter 14 prevents audio frequencies from passing to the dc amplifier 15 with sufficient magnitude to disturb its operation.

Given that impedance 2 is a sufficiently accurate scaled version of the impedance of loudspeaker 1 in the "blocked" condition: ie the impedance when motion of its voice coil is prevented, then the behaviour of the bridge comprising impedances 1,2,3,4 will be substantially the same at low ac frequencies as it is at zero frequency or dc. It follows that if motion of the voice coil of loudspeaker 1 is temporally prevented, not only will there be zero dc voltage at the input terminals 18, 19 of amplifier 20, but also there will be zero ac audio signal. At auto-balance of the bridge, the input terminals of amplifier 20 are decoupled from the power amplifier 7.

If the situation is now considered when the voice coil of loudspeaker 1 is unblocked, and free motion is allowed; the moving voice coil interacting with the magnetic field surrounding it will produce an emf equal to Blv . Loading of the emf may be made negligible by making resistors 3 and 4 of high ohmic value: it being noted that the output impedance of transconductance amplifier 7 is by definition high.

It is evident that the back-emf (Blv), being applied at one arm of the bridge between terminals 11 and 5, will not be nulled out at self balance, and that a substantially constant fraction of emf (Blv) appears at the input terminals of amplifier 20. Amplifier 20 may have gain such as to establish a velocity-proportional emf at its output terminals equal to, or greater than (Blv); provided that amplifier 20 has sufficient output voltage capability.

Filtering means 21 may optionally curtail the velocity feedback taken from terminal 22 at high frequencies so as to relax the scaling complexity of impedance 2. This may allow impedance 2 to be a resistor, rather than a more complex network.

The velocity dependent signal (Blv) at terminal 22 is fed back, according to known art, to the input of the power amplifier 7 to control the damping of the loudspeaker such as to achieve a desired Q factor in respect of the loudspeaker/enclosure, and corresponding frequency response.

Variations of the circuit configuration of Fig. 1 may be employed. The requirements of linearity for the VCA may be relaxed by using two tracking VCAs for example, as shown in Fig 2 . A first VCA 13 intercepts one input line to amplifier 15 (as previously) but is preceded by a low-pass filter 23, so that it only handles dc. A second identical VCA 24 routes the bridge output at terminal 11 to one input 19, of amplifier 20. The two VCAs 13, and 24 share a common control terminal connection and track together.

The illustrative circuits of Fig 1 and Fig 2 do not impose a very stringent specification of dc offset stability in the power amplifier 7. The offset polarity must be correct, but variations of dc energising current do not effect the balance condition of the bridge. In the event that the power amplifier 7 has very stable dc characteristics such that the dc energising current supplied to the bridge is constant, then provided resistors 3 and 4 have ohmic values which are large compared with impedances 1 and 2 ,it is evident that that the dc voltage developed across impedance 2 in the bridge is a constant dependent only on reference source 8, and is independent of the resistance of loudspeaker 1. In this case, some simplification and reduction of filtering may be accomplished as outlined in Fig 3.

In Fig. 3 the dc input to VCA 13 has the same value as the product (energising current X impedance 2); but is derived from the reference potential 8 via a potential divider 27, 28. Since the input to VCA 13 is pure dc, the low pass filter (23 in Fig. 2) can be omitted. The potential divider 27, 28 may be augmented by a further potential divider 29, 30 to optimise the performance of the VCA, whilst maintaining the correct potential at the input of amplifier 15.

Large loudspeakers tend to have long thermal timeconstants defining the rate or change of voice coil resistance (temperature) with applied audio power. The thermal timeconstant may be tens of seconds, and so the response time of the bridge balancing servo does not have to be fast. Adequate filtering of the the audio signal may sometimes be provided by a simple integrator arrangement comprising resistor 25, and capacitor 26.

Many different types of tracking VCA may be used, including dual cadmium sulphide cells, or dual transconductance amplifiers such as the National Semiconductor 13700. Dual sampling switches, switched by a pulse waveform of duty-cycle responsive to the output of error amplifier 15 is a further possible technique. Voltage controlled amplifiers may be used in place of voltage controlled attenuators.

In principle, the functions of amplifiers 15 and 20 could be combined in a single amplifier, provided that intermodulation between ac and dc functions were to be kept to a low order. However the low cost of integrated amplifiers 15 and 20 does not give a strong incentive for simplifications of this kind.

Power amplifier 7 may be ac coupled to the bridge circuit, and a dc energising source for the bridge provided by a separate dc current source.

Multiple series connected loudspeakers could be used in place of the single unit depicted.

CLAIMS

1. A self-balancing bridge circuit, incorporating an electromagnetic transducer such as a moving coil loudspeaker as one arm of said bridge circuit which is disposed in the output current path of an audio power amplifier of high output impedance such as to establish current-mode driving of the loudspeaker; and providing a velocity dependent signal which is fed back to the input of said audio power amplifier to control the frequency response of the loudspeaker and its enclosure, independently of the loudspeaker voice coil resistance.
2. A self-balancing bridge circuit as in claim 1, in which the self-balancing action responsive to changes in voice coil resistance is achieved by a balance-sensing amplifier in cooperation with one or more voltage-controlled attenuators, or with one or more voltage-controlled amplifiers.
3. A self-balancing bridge circuit as in claim 2, wherein a first Voltage-Controlled Amplifier feeding one input of the balance-sensing amplifier is fed from a voltage reference common to the audio power amplifier, and a second, tracking Voltage-Controlled Amplifier having its input connected to a first output terminal of the bridge, operates to provide a velocity-dependent signal with respect to a second output terminal of the bridge.
4. A self-balancing bridge as in claims 2 and 3 including a differential amplifier providing at its output an unbalanced velocity-dependent feedback signal.
5. A system as in any of the preceding claims, using more than one loudspeaker.
6. A circuit as in any of the preceding claims, wherein additionally the output of the balance-sensing dc amplifier cooperates with warning means, or protection means; either or both of which are activated at or beyond a defined threshold level, which threshold level is indicative of a maximum safe voice coil temperature.
7. Apparatus containing circuit arrangements substantially as herein described.