# Distortion Reducer

## Added to audio power amplifiers reduces t.h.d. and i.d. without loss of gain

*by D. Bollen*

Many audio power amplifiers in general use today have harmonic distortion levels of more than 0.5% somewhere in their useful frequency range or at maximum rated output, the chief offenders being those in the low price, i.c., and high power "pop" categories. This article describes an active feedback system which can be added to such amplifiers to clean up their sound by reducing total harmonic and intermodulation distortion without loss of gain. The principle employed is similar to an error feedback loop in a servo system. Valve amplifiers, transformer transistor amplifiers, and amplifiers prone to instability may not function satisfactorily with the reducer circuit.

Modern transistor audio power amplifiers of the transformerless type can offer a very flat gain characteristic and unvarying phase relationship between input and output over a wide frequency range, and this makes possible a straightforward method of extracting a distortion feedback signal without recourse to frequency dependent filters. Briefly, operational amplifier techniques are used to subtract the input signal from an attenuated version of the power amplifier output signal, thus leaving a difference signal consisting of distortion and noise. This difference signal can be fed back in anti-phase to the power amplifier input to reduce the unwanted error, with an attendant lowering of hum and output impedance, a slight decrease in stability, and some modification of frequency response due to phase differences between the power amplifier and reducer circuit.

In a typical case, t.h.d. and i.d. at 1kHz can be reduced by ten, or down to 0.1%, whichever is greater, and by about five at 30Hz and 20kHz, with comparable increases in damping factor. Hum is reduced about seven times. The reducer circuit contributes its own distortion and wideband noise while, at the same time, working to lower power amplifier distortion and noise, with the result that final noise level is maintained at a level of about −70dB. Frequency response can be within 2dB of the original from 20Hz–40kHz.

With the above amount of distortion reduction, and a resistive amplifier load with 2μF in parallel, overshoot or ringing on a 10kHz square wave will be increased approximately by a factor of five.

In the block diagram of the reducer Fig. 1, op-amps *A*, *B*, and *C* form a distortion selective feedback loop shown by the thickened line. Each op-amp has unity gain inputs and is inverting (i.e. 180° phase difference between input and output, signified by a minus sign). The power amplifier also inverts and has a gain $-G$.

Distortion, in its several forms, is a complex function only loosely related to signal amplitude, and for this reason the description which follows is simplified for convenience. It is assumed, for example, that harmonic distortion can be considered as a constant equivalent input signal *D*—with a negative sign in the case of inverting power amplifiers—and that the measured distortion at the power amplifier output is *D* multiplied by amplifier gain *G*.

The operations performed upon signals by the circuit of Fig. 1 are as follows. Input *S* from the pre-amplifier is inverted by amplifier *A* and passed to the power amplifier as

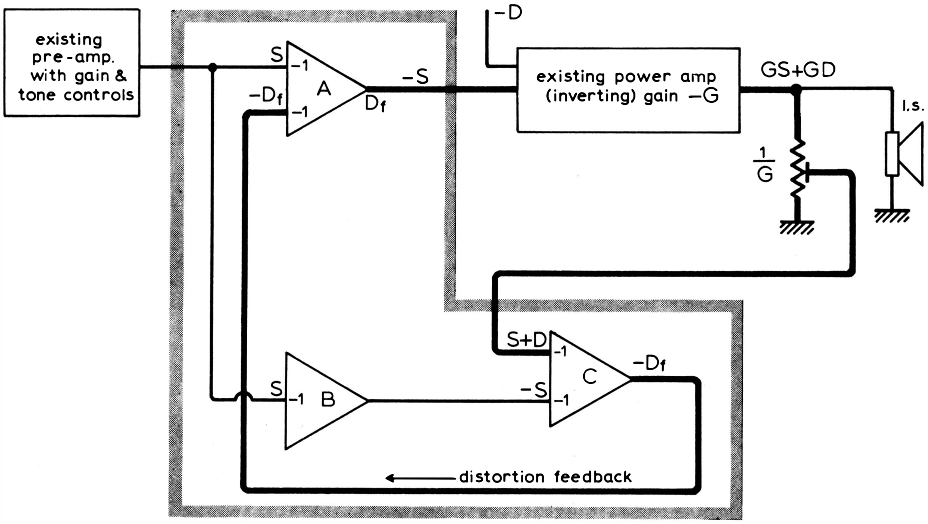


*Fig. 1. Distortion reducer with inverting power amplifier. D, equivalent amplifier input distortion; GD, distortion at amplifier output; $D_f$, distortion feedback signal.*

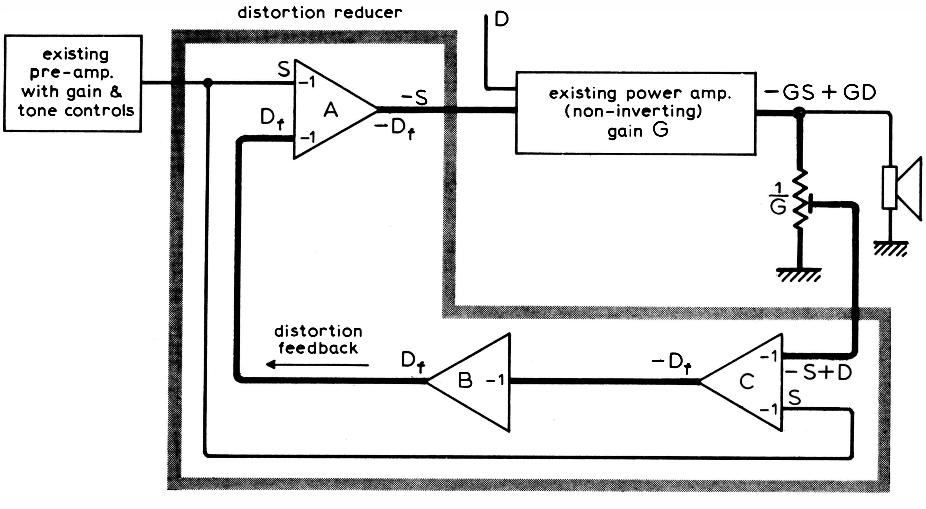


*Fig. 2. Distortion reducer with non-inverting power amplifier.*

$-S$. The power amplifier adds $-D$ to $-S$ and multiplies both terms by $-G$ to give an output $GS+GD$. A potentiometer set for a coefficient $1/G$ then cancels out $G$ to leave $S+D$ at one of the summing inputs of amplifier $C$. At the other amplifier $C$ input is $-S$, which has previously been taken from the pre-amplifier and inverted by amplifiers $B$. Functions $S+D$ and $-S$ are summed and inverted by amplifier $C$ to leave $-D_f$, the distortion feedback signal. Finally, after inversion by amplifier $A$ and summation with the original input signal, $D_f$ is presented to the power amplifier input, clearly in anti-phase with the equivalent input distortion signal $-D$.

The net effect of the unity gain distortion feedback loop in Fig. 1 is to halve distortion while leaving the amplitude of the output signal $GS$ unchanged. If now a gain $G_2$ is given to the $D_f$ input of amplifier $A$ the amount of distortion reduction obtained will be, ideally,

$$\frac{1}{1-\left(-G\times\frac{1}{G}\times G_2\right)}=\frac{1}{1+G_2}$$

but to this must be added any distortion contributed by the reducer circuit itself. Obviously, all forms of distortion and noise, in short anything which is not present in the input signal $S$, will tend to be reduced in the above manner.

In the case of a non-inverting power amplifier $A$, $B$, and $C$ amplifiers are rearranged as shown in Fig. 2, to feed an appropriate anti-phase error signal back to the input. Bridge output power amplifiers consist of two separate amplifiers fed by a phase splitter, so this application will demand two reducers, one for each output terminal, with error signals fed back to the power amplifier halves after the phase splitter, as in Fig. 3.

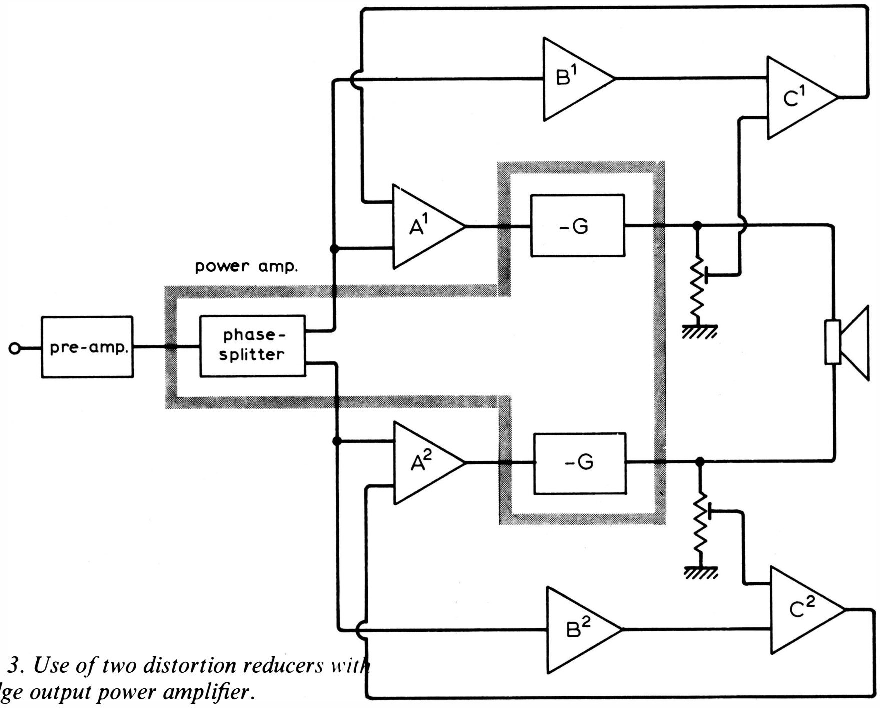


*Fig. 3. Use of two distortion reducers with bridge output power amplifier.*

## Circuit considerations

When compared with the cost of replacing or redesigning a power amplifier and its power supply for lower distortion, the price of the reducer circuit is negligible. Nevertheless it was considered desirable to aim for simplicity and economy consistent with a useful amount of distortion reduction and reasonable noise level.

The op-amps used in the reducer circuit could hardly be simpler, based as they are on single transistors of the BC109 type. Power amplifier sensitivities of 100mV to 1V can be accommodated without modification or loss of gain, and unlimited power outputs by adjustment of a single resistor value. The complete circuit of Fig. 4, for use with inverting power amplifiers, is optimized for distortion versus noise at around 500mV input r.m.s. At high power amplifier sensitivities noise becomes a problem which can be solved by accepting some gain loss, while at low sensitivities minimum attainable distortion can rise to 0.2%.

Op-amp $A$ in Fig. 4 has adder inputs $R_1$ and $R_2$, with $R_1$ handling the input signal at unity gain and $R_2$ adjusting distortion feedback loop gain starting at times three. Capacitor $C_2$ provides compensation to offset high frequency instability. Emitter

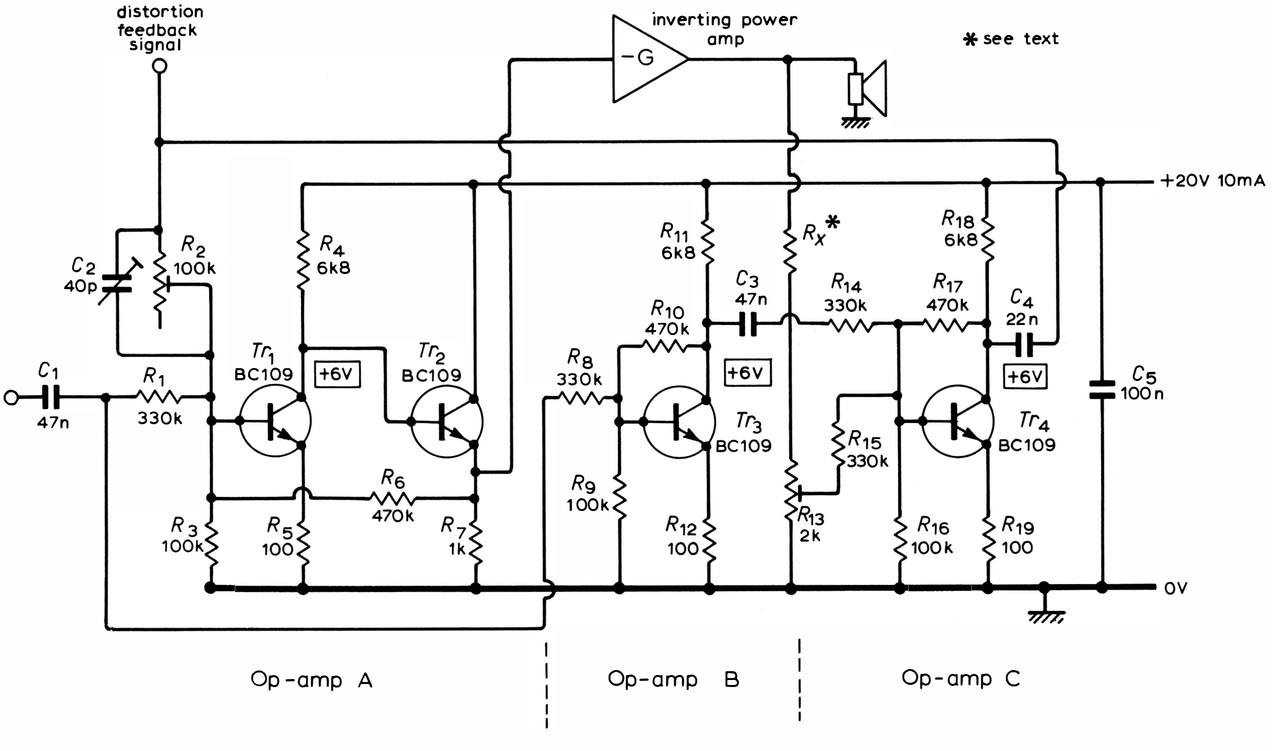


*Fig. 4. Circuit of distortion reducer, for use with inverting power amplifiers.*

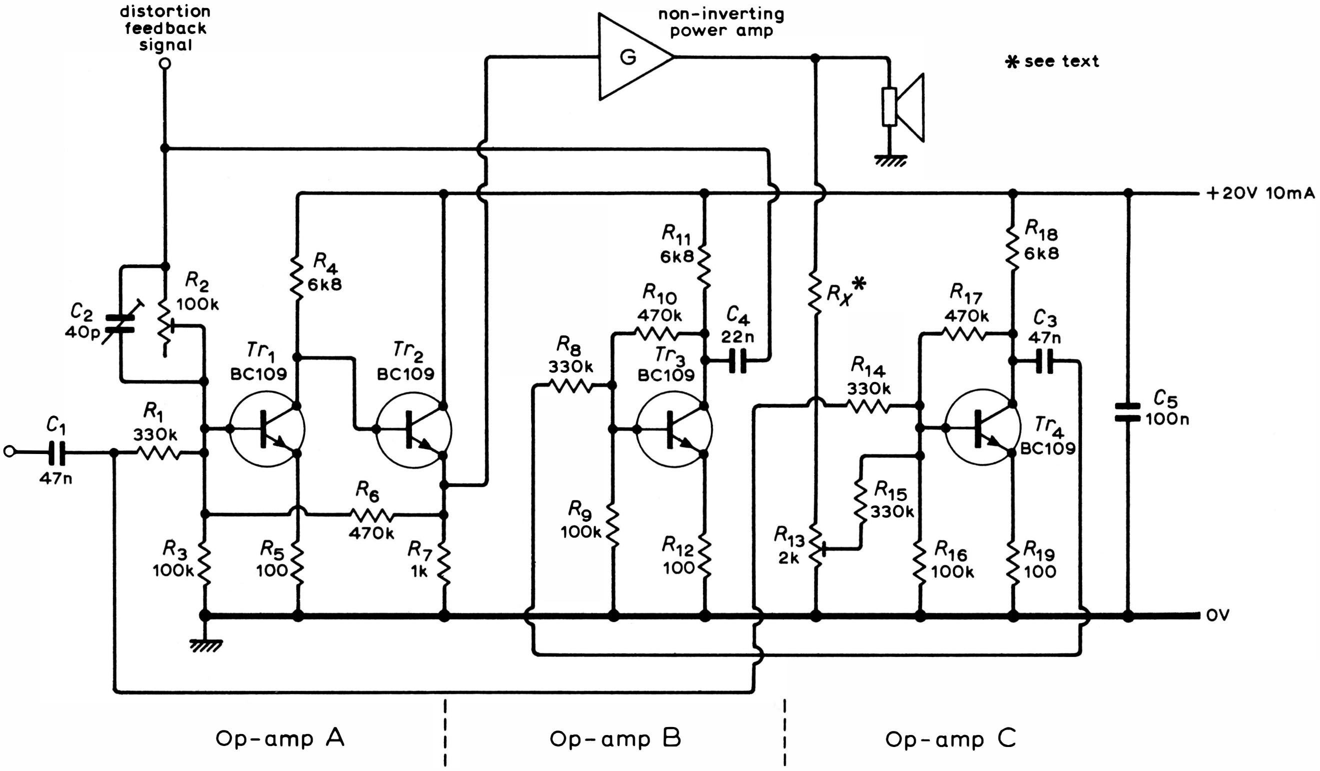


*Fig. 5. Circuit of distortion reducer, for use with non-inverting power amplifiers.*

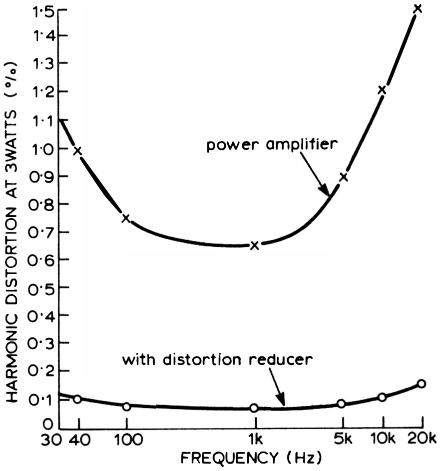


*Fig. 6. Distortion/frequency curves of test amplifier.*

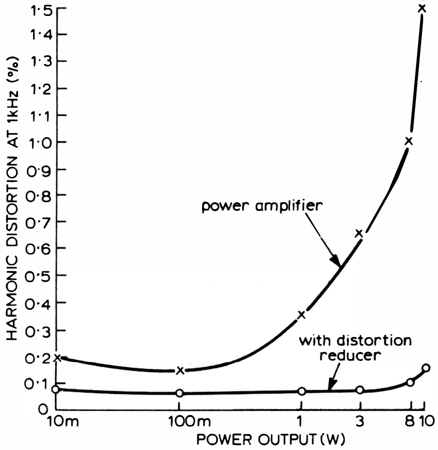


*Fig. 7. Distortion/power curves of test amplifier.*

follower $Tr_2$ is capable of driving power amplifier input impedances of down to 1kΩ at 500mV without increased distortion. Op-amp $B$ is a simple unity gain inverter which feeds op-amp $C$ input $R_{14}$. Resistors $R_2$ and $R_{13}$ are adjusted for a null at the distortion product terminal.

In Fig. 4, an output taken from across the loudspeaker load is passed via $R_X$ to $R_{13}$, and thence to op-amp $C$ input $R_{15}$. Resistor $R_X$ is selected on the following basis: $R_X = (\sqrt{WR/S})-2$, where $R_X$ is in kilohms, $W$ the power amplifier output in watts given by an input signal $S$ in volts r.m.s., and $R$ the loudspeaker impedance. There is sufficient latitude in the value of $R_X$ for the above calculation to be based on manufacturer's power amplifier data.

Capacitors $C_1$, $C_3$, and $C_4$ in Fig. 4 are chosen to give a steep cut below 20Hz, and this discourages low frequency instability. If desired, the l.f. roll-off can be modified by adjusting the value of $C_1$ (see Fig. 8).

A second version of the distortion reducer circuit, for use with non-inverting power amplifiers, is shown in Fig. 5. The only differences between Fig. 4 and Fig. 5 are connections to op-amp inputs and outputs and the positions of $C_3$ and $C_4$.

## Results

Apart from random checks with various amplifiers, a pair of low cost power amplifiers of 10 watt rating were built for detailed tests with the reducer, from an anonymous circuit which claimed "less than 1% distortion".

Alone, one power amplifier oscillated freely with a 2μF load, while the other showed one cycle of ringing on a 10kHz square wave. This disparity was thought to be due to gain variations in the transistors used, since the layouts were identical. Wideband noise, excluding hum, was −60dB for the unstable amplifier and a good −80dB for the other, which gave a "lop sided" hiss in stereo headphones. The distortion characteristics of the power amplifiers were similar, and not untypical, with claimed distortion being exceeded at 8 watts, and beyond the limits of 40Hz–8kHz at 3 watts. The lowest t.h.d. obtained was 0.15% at 100mW and 1kHz. With an unregulated power supply of generous 3A rating at 30V, and 10,000μF smoothing, power amplifier hum was an inaudible <0.5mV, but 3mV hum could be simulated by removing a smoothing capacitor. Apart from noise, listening tests with normal loads revealed no discernible difference between the two power amplifiers.

When a pair of distortion reducers was coupled to the power amplifiers noise was equalized at −70dB, giving "centre of the head" hiss in the stereo headphones, and the 3mV hum level was reduced to less than 0.5mV. With single loudspeaker and crossover network loads there was virtually no overshoot or ringing on a 10kHz square wave.

Distortion curves, with and without reducers, are shown in Fig. 6 and Fig. 7. A single spot check of intermodulation distortion indicated a similar reduction factor. In the frequency response curve of Fig. 8, there is a general loss of 1dB gain attributed to circuit tolerances, and slightly disconcerting, though small, kinks at 20–30Hz and 80–100kHz.

As might be expected from Fig. 6 and Fig. 7, the subjective improvement in power amplifier sound was most noticeable at low and high frequencies, and at maximum output. Over an extended period of use no

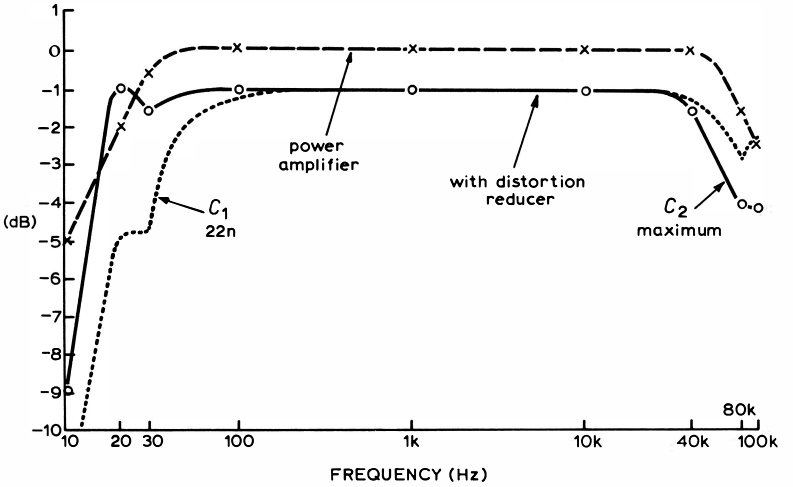


*Fig. 8. Frequency response of test amplifier.*

vices appeared, and the distortion reducer circuits remained in alignment.

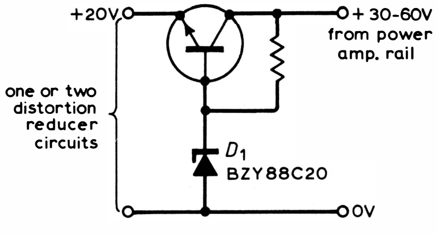
## Construction and alignment

Component layout is not particularly critical. A distortion reducer in breadboard form, coupled to a power amplifier by six feet of microphone cable, operated well at up to six times distortion reduction, but with slightly enhanced wideband noise and hum. A compact and screened layout, with the reducer situated close to the power amplifier will ensure optimum results, and a stereo pair of reducers can be assembled on a circuit board which is small enough to fit inside a 2oz tobacco tin.

The simple voltage regulator of Fig. 9 will serve to power a couple of reducers from a positive power amplifier supply rail of 30-60V. Alternatively, the reducer circuit of Fig. 4 or Fig. 5 could be modified for negative supply rail operation by substituting, say, BC159 p-n-p transistors for the n-p-n BC109, and an OC29 for the 2N3053 of Fig. 9, with the zener polarity reversed.

An oscilloscope of 10-30mV/cm sensitivity and an audio signal generator are needed to align the reducer circuit.

Remove the power amplifier load, set $R_2$ and $R_3$ to mid resistance, and $C_2$ to approximately half capacitance, connect the 'scope to the distortion product output terminal and switch on. Inject a 1kHz signal of sufficient amplitude to give a clear trace without overloading the power amplifier and adjust $R_3$ for a null. If there is any evidence of high frequency instability its source should be traced before connecting a load to the power amplifier.



*fitted with push fit 50°C/W heat sink

*Fig. 9. Simple regulator for power supply for distortion reducer.*

Next, with the usual loudspeaker load connected, trim $R_2$ and $R_3$ for minimum trace amplitude on the 'scope until high frequency blurring of the trace occurs just past the null position of $R_3$, then screw down $C_2$. There is some interdependence between the settings of $R_2$ and $R_3$. Also, a change of load impedance, say from 8 to 16 ohms, may require a re-trim of $R_3$.

Finally, connect the 'scope to the power amplifier output and check the frequency response. If there is excessive peaking at 20Hz, reduce the value of $C_1$.

It should perhaps be stressed that the distortion reducer's alignment will be upset if there is a subsequent change of power amplifier gain, and for this reason all gain and tone controls should be situated in front of the reducer, including stereo balance. If the reducer gives excessive noise with sensitive power amplifiers a pre-set pot of 5-25kΩ can be wired to the power amplifier input, and this should be adjusted for the required sensitivity prior to reducer alignment.

### Components

**Resistors** (all 5% hi-stab or oxide, unless shown otherwise)
1—330k
2—100k min. horizontal pre-set
3—100k
4—6.8k
5—100
6—470k
7—1k
8—330k
9—100k
10—100
11—6.8k
12—100
13—2k min. hor. pre-set
14—330k
15—330k
16—100k
17—470k
18—6.8k
19—100
$R_x$—see text

**Capacitors** (all 250V polyester, unless shown otherwise)
1—47n
2—40p mica compression trimmer
3—47n
4—22n
5—100n

**Transistors**
1,2,3,4—BC109
5—2N3053

**Diode**
1—BZY88C20 (400mW, 20V, 5%)

# Sixty Years Ago

This letter to the editor of *The Marconigraph* for February, 1913, was written by a thunderstruck wireless operator. Wireless telephony was, obviously, in its experimental phase, using arc transmitters and rotary r.f. generators for the production of continuous waves. Modulation was a problem (no valves) and was accomplished by the use of water-cooled microphones in the aerial circuit.

## A Strange Occurrence

SIR, — On December 17th, 1912, about 4 p.m., as the ss. "Keemun" was coming out of the harbour, Yokohama, I put on my receivers, and after "listening-in" for a few moments, I was very much surprised to hear, in place of the customary Morse buzz, a faint unusual sound of varying pitch, which on "tuning-in", I recognised to be a *human voice singing*! For a few minutes the tune was drowned by the sending of a neighbouring station, but between the breaks, however, the voice was faintly but distinctly audible. When this station ceased transmitting the tune and the words became easily distinguishable, and they proved to be those of the "Village Blacksmith".

Two verses were heard, and towards the end the voice became clearer — possibly due to some readjustment of the transmitter being used, and the final words *"Like chaff from a threshing floor"*, were as distinct as though from a gramophone.

Later in the evening I called up the Japanese Government station, Chosi, and asked him if he could suggest who was likely to have been experimenting in wireless telephony, and he replied probably the Department of Communications at their laboratory in Tokyo. My receiving set is of the ordinary ship type, and as detector I then had a piece of silicon in use.

Yours, etc.,
Herbert S. Peet.

# Correction

The B.B.C. has pointed out an error in the article **"High-standard Low-frequency Source"** (January issue) regarding the accuracy of frequency of the Radio 2 transmitter at Droitwich. The carrier frequency is in fact maintained to an accuracy of ± 2 parts in $10^{11}$ and not ± 5 parts in $10^{10}$ as stated.

### Binding of *Wireless World*

Readers may like to know that our publishers will undertake to bind their copies of *Wireless World*. The inclusive cost is £2.25 (plus VAT after April 1st). Copies should be sent to IPC Business Press Ltd, Binding Department, c/o 4 Iliffe Yard, Walworth, London S.E.17, with a note of the sender's name and address. A separate note, confirming despatch and enclosing the remittance, should be sent to IPC Business Press (Sales & Distribution), 40 Bowling Green Lane, London EC1P 1AN.

For those who wish to bind their own copies cloth binding cases are available from the latter address at an inclusive price of 50p (plus VAT after April 1st). Readers will have noticed that the index for volume 77 (1971) was included in the December issue. Copies of the index are available price 12½p.