Low Distortion Tone-control Circuit

Bipolar transistors used in a Baxandall configuration

*by P. M. Quilter**

Now that very high quality transistor power amplifiers are definitely with us, attention must be refocused on the pre-amplifier. The main source of distortion in the pre-amplifier is often the tone control circuitry as the power amplifier may require 1V r.m.s. or more to drive it fully, and it usually takes this directly from the output of the tone-control circuit.

The standard one-transistor circuit, as used by A. R. Bailey[1], gives a total harmonic distortion figure in the region 0.1% to 0.2%. The circuit, adopted by J. L. Linsley Hood[2] is an improvement but necessitates the use of an f.e.t. which is not yet as cheap as a bipolar transistor and, because of its high drain load, requires an output buffer. Ideally a distortion figure in the region of 0.01% at 1V output is desirable.

To achieve this using bipolar devices requires that either the inherent open-loop distortion in the amplifier be reduced, or the open-loop gain increased to give a higher feedback factor for the same closed-loop gain.

The distortion in a transistor with a very high ratio of collector-slope resistance to collector-load is very nearly a function of output current alone. Therefore if the collector load can be raised the output current required to produce a given voltage will be reduced with a consequent reduction in distortion (and an increase in open-loop gain). Unfortunately, the high value of collector load would ordinarily make a high value of supply voltage necessary, and might also make loading effects of the feedback network significant. These difficulties can be overcome simply with an emitter follower performing two functions—providing an output buffer for the high collector load, and giving a bootstrap voltage to raise the effective value of collector load.

The function of bootstrapping is to reduce the actual voltage swing across the collector load resistor for a given collector current required to produce this change, and hence raise the effective resistance of the collector load. This can be achieved by driving the top end of the collector resistor in step with the collector

*University of Sussex

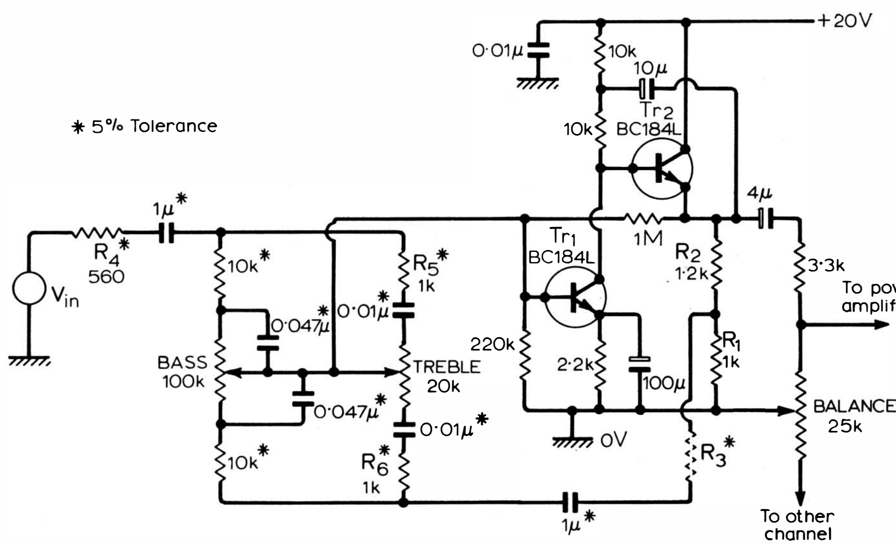

Fig. 1. The complete tone-control circuit built round two n-p-n silicon transistors.

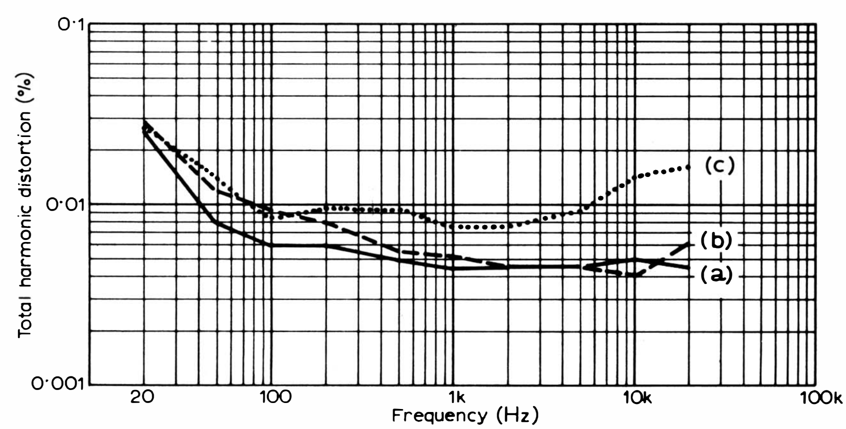

Fig. 2. Total harmonic distortion as measured at 2V output. (a) is the measured t.h.d. of the signal generator, (b) the distortion curve with the tone control flat, and (c) the distortion curve with maximum bass and treble boost.

voltage. The final arrangement is shown in Fig. 1.

The circuit as tested omitted R_3 giving R_4 equal to 560Ω with the values of R_1 and R_2 shown. The gain was 2.2:1 at centre frequency with a subsequent loss of about 1.2:1 with the balance control fitted as shown. The distortion figures for a constant output of 2V r.m.s. are shown plotted against frequency (Fig. 2). The distortion curves for the test oscillator used and the distortion measured at the output of the amplifier are substantially the same up to 2kHz but, with the treble control set for maximum boost, there is a slight rise at high frequencies. This may have been due to emphasis of the harmonics produced by the test oscillator itself because of the rising characteristic of the amplifier at high frequencies.

The output clips at 6V r.m.s. and with the controls set to the "flat" position, the total harmonic distortion from 40Hz to 20kHz was measured to be 0.01% or less at 5V r.m.s. output.

The signal-to-noise ratio measured with reference to 1V r.m.s. output over a 20kHz bandwidth was 104dB and the rise time to a step input, 0.1μs.

The circuit may be modified to suit personal taste as required. The relevant equations are as follows:

$$\text{gain} = \frac{R_1 + R_2}{R_2} \quad (1)$$

$$R_1 + R_2 \approx 2\text{k}\Omega \quad (2)$$

$$R_3 = R_4 - \frac{R_1 R_2}{R_1 + R_2} \quad (3)$$

Some increase in distortion may result if the gain of the circuit increases beyond 5 or 6 although this may be acceptable especially if the required output voltage is fairly low, as the distortion is a function of output voltage.

Balancing equation (3) is important in order to ensure the controls will be set at their electrical centre when the frequency response is flat. In fact a perfect square wave response cannot be achieved for any setting of the controls unless this equation is balanced.

It should also be noted that the output impedance of the stage driving the circuit is part of R_4 because R_4 is the total source resistance. If this is not taken into account equation (3) will be invalid.

If R_4 is greater than about 500Ω the two 1kΩ resistors R_5, R_6 can be omitted. They are included only to limit the ultrasonic gain to prevent instability. It is not advisable to increase R_4 above 2kΩ as the treble control range within the audio range will then be restricted.

The transistor type BC184L was used for this circuit in preference to the more common BC109 because, from experience, the latter type had a tendency to oscillate parasitically due to its collector connected metal can.

In conclusion, this circuit has the advantages of a high output voltage with very low output impedance, negligible distortion and good signal-to-noise ratio.

REFERENCES

1. A. R. Bailey, "High-Performance Transistor Amplifier", *Wireless World*, December 1966.
2. J. L. Linsley Hood, "Modular Pre-amplifier Design", *Wireless World*, July 1969.

Progress in Air Traffic Control

The first stage of the national air traffic control scheme—code name Mediator—has been introduced at the National Air Traffic Control Service centre at West Drayton, Middlesex. Civil and military radar units operating until recently at Heathrow and serving South-east England have now been closed. With 2,500 movements per day at peak times, increasing at about 10% per year, the new system is needed to increase capacity as well as safety. Work on Mediator was initiated by N.A.T.C.S. in 1962 when it was set up to organize a comprehensive air traffic control system for both civil and military use.

Mediator recognizes radar as the controlling agent whereas in the past radar has been a back-up to 'procedural' control. With it, a whole new range of radar, communications, and automatic data processing equipment is being brought into operation with its associated engineering control, maintenance, power station, and new traffic control techniques. Thinking behind the scheme is similar to that proposed in the early 1960s–see 'Electronics for Mediator' *Wireless World* vol.71, September 1965, pages 426-9–but there have been changes since then, partly as a result of difficulties with equipment.

Difficulties with the computer for flight plan processing have meant postponement of the full implementation of stage 1 but in the words of Michael Noble, Minister for Trade '. . . This was not a reason for delaying other improvements . . . not dependent on this particular development.' Improvements include completely new consoles–illustrated on page 181–with bright radar displays and a secondary radar facility, providing controllers with aircraft identification codes superposed on the primary radar display.

The secondary system, of course, works only with those aircraft installed with transponders, at present in the minority. They either have a 64-bit coded transponder–which enables a two-digit route code to be shown on the radar display–or 4096-bit coded transponder which allows aircraft to be identified with two additional decimal digits. Further, some aircraft are fitted with altimeter telemetry equipment, allowing flight level to be shown as well.

Facilities which make up stage 1 of Mediator fall into four main parts–radar outstations, communications links, processing and distribution, and display. The most interesting parts of the system are to do with processing and display, but of course the outstations and communications links are vital and much effort has been devoted to their reliability. Of the long-range primary radar stations at Ash, Ventnor, Lowther and St Annes using 50-cm radars–chosen in preference to the alternative 10-cm radar which would give more precisely defined blips but is susceptible to rain effects–three have dual aerial heads.

All the secondary radars, co-sited with the primary radars, have dual heads. The main heads have duplicated electronics to give a high degree of reliability and to facilitate maintenance without interruption to the service. . . .

Bright radar displays use a scan conversion technique in which primary video data is written into the storage surface of a conversion tube. This is read with a 1024-line scan many times a second reinforcing the 55-cm display and thus achieving television-screen brightness level. This system differs from other scan conversion systems in the way the secondary radar information is added to the primary. Use of two electron guns–with consequent registration problems–is avoided by sharing gun writing time between the two data. When secondary radar information is available, the normal 'square' scan (equal forward and 'flyback' trace time) for primary information is interrupted and the aircraft designation written on the 256-bit line using digital character generation.

With this system it had been possible to superpose primary and secondary displays to an accuracy of $\pm$ 1.5mm.

There is also a third kind of information on the display tube—a locally generated map together with range rings and other static information.

One problem found with this technique of digitally writing the secondary radar information relates to the equal forward and reverse scans. If a display's digit is not accurately matched in position on the forward and reverse scans a jagged sawtooth effect can be produced–an effect which did in fact occur. Attempts to right this by adjusting electrical lengths of cables between scan conversion unit display were unsuccessful and passive delay networks had to be introduced. This needed extra gain from the video amplifiers to maintain display brightness and consequently these are being replaced.

Flight plan processing for controlled airspace is now done with a 32,000-word store using a Ferranti Hermes computer. The system stores flight plans–aircraft identification and certain other information–wind speed and direction, airways structure, link routes, reporting points, and runways in use at Heathrow, verifies the flight plans, calculates an e.t.a. for each reporting point en-route, and prints-out flight progress strips.

For middle airspace a Marconi Myriad computer system will be brought into use by March 1972 at which time R.A.F. middle airspace controllers move to the new centre. This triplicated real-time system was originally planned to be operational by now but software problems led to its postponement. Although only one of the three computers is connected on-line at any time, the others contribute through a kind of self-checking voting