

New Approach to Class B Amplifier Design

by Peter Blomley*

The class B amplifier has established itself as the most versatile and lowest cost amplifier known. This is mainly due to the excellent work in the field of semiconductor circuit design by H. C. Lin¹, R. C. Bowes², R. Tobey and J. Dinsdale³, A. R. Bailey⁴ and P. J. Baxandall⁵. In this article it is hoped to complement the work of these designers by putting forward a new approach† which may solve some of the problems inherent in present designs.

Conventional approach

A definition of a class B amplifier could be 'one in which the operating point of each output device is set at the lower extreme of its transfer characteristic. Hence in a push-pull design, for any symmetrical input signal, each output device conducts only one half of the output waveform'. This method of operation gives the amplifier zero (or nearly zero) quiescent power consumption, high efficiency and excellent peak current drive capability. It is unfortunate that the sacrifice paid for these virtues is the problem of ensuring a linear transfer of signal drive from one output device to the other.

So that the class B system can be analysed it is useful to approach the output circuit as two separate amplifiers (labelled X and Y in Fig. 1 for convenience), the outputs of which combine to give the complete signal. This is shown in diagrammatic form in Fig. 1, where it is assumed that the blocks representing the amplifiers form the equivalent of a complementary output stage.

The transfer characteristic for one of these 'sub-amplifiers' is shown in Fig. 2, where above the bias point A the characteristic is extremely linear and below it becomes a combination of linear and exponential relationships. The designer's task is to define this last region so accurately that when it is combined with that of the other sub-amplifier, the overall gain will remain constant (i.e. as the gain of one sub-amplifier decreases, the other increases equally to compensate).

The workings of a class B output circuit can be clarified by the use of g_m diagrams, these being a plot of gain—or in this case

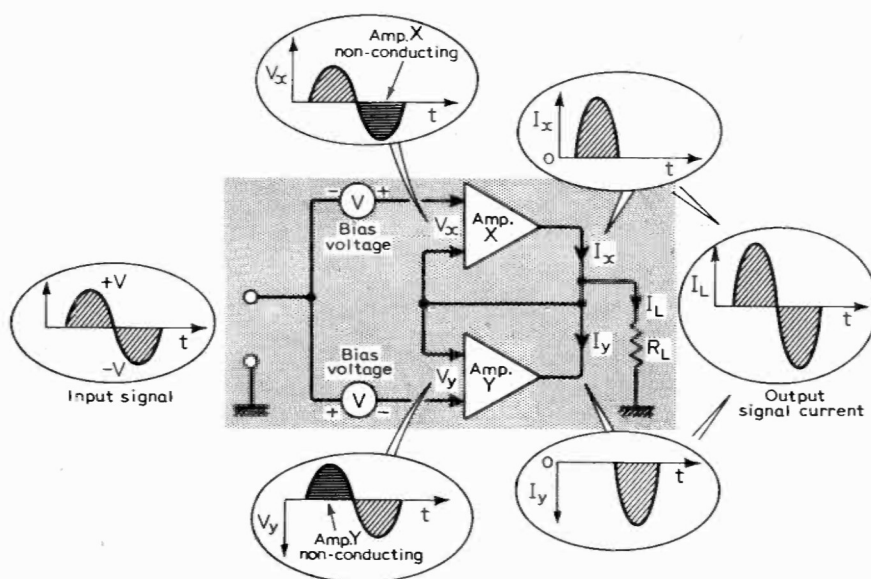


Fig. 1. Block diagram of conventional class B amplifier with the two halves of a complementary output stage represented by sub-amplifiers X and Y.

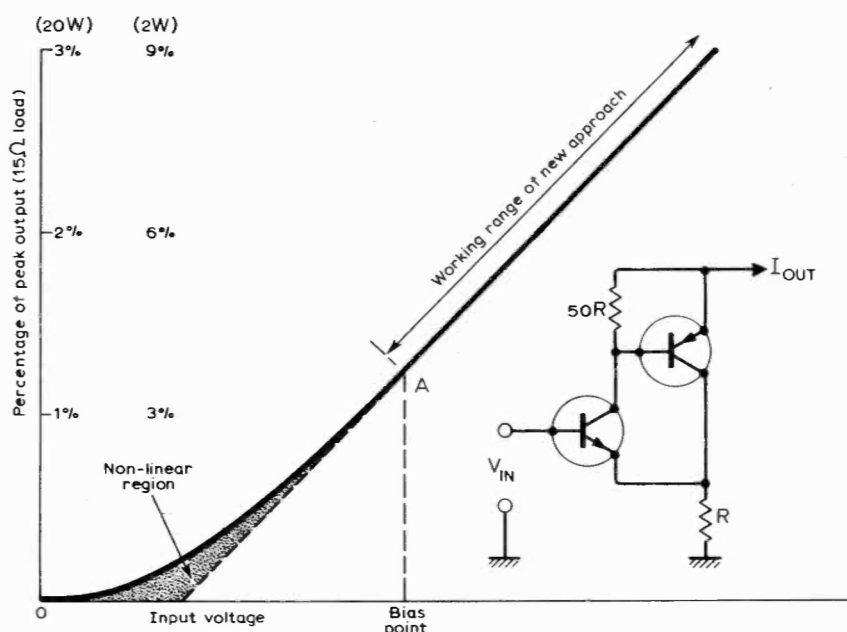


Fig. 2. Transfer characteristic of sub-amplifier X which is linear above bias point A and non-linear below. In conventional class B, non-linear regions of X and Y sub-amplifiers have to be accurately matched to give overall linearity.

*Allen Clark Research Centre (Plessey), Caswell, Northants.

†The subject of patent application 53916/69.

mutual conductance—of the complete output circuit against drive voltage. The ideal would, of course, be a straight line parallel to the input voltage axis (indicating there is no change of gain with input swing), but regrettably this is not the case with designs popular at the moment. To provide a comparison of the different types of output circuits, I have prepared gain plots showing the effects of different bias levels, these being illustrated in Figs. 3 and 4. From these it is now easy to see the characteristic change in gain which can occur during the transfer from one sub-amplifier to the other. Referring to Fig. 3 about a 10% gain change occurs during transfer, whatever the bias level is set at.

The output circuit in Fig. 4 is a quasi-complementary type giving most interesting results. The main conclusion is that it is impossible to bias this circuit for symmetrical gain change and in practice it proves very difficult to establish which biasing point would give the best results concerning the rate of gain change.

This method of describing a class B amplifier can give an insight into the problems involved with a conventional design. First, each sub-amplifier has to have two regions in its transfer characteristic:

- the constant gain region (above bias point A in Fig. 2)
- the non-linear region (below this point).

Second, the non-linear region of each sub-amplifier has to be complementary to its partner, otherwise the situation shown in the g_m diagrams (Figs. 3 & 4) will occur. An interesting point is that the only reason why the non-linear region of the transfer curve is important is because the input signal normally traverses this region as well as the linear portion. If this was not the case most

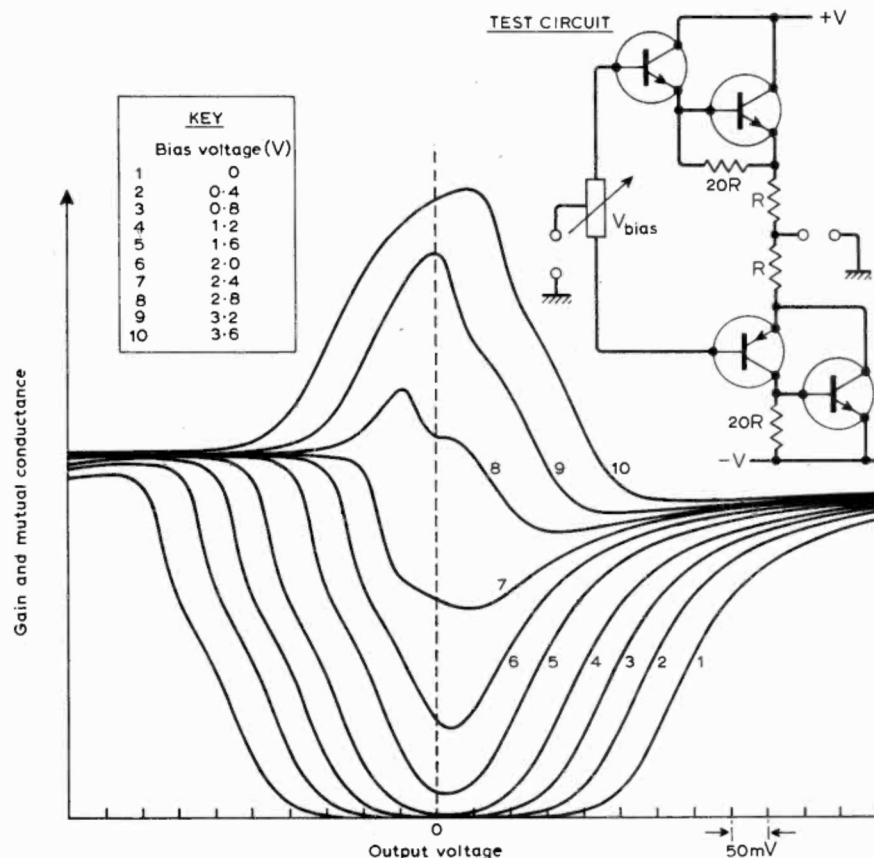


Fig.4. Curves for quasi-complementary output circuit show impossibility of biasing circuit for symmetrical gain change.

of the design problems in class B amplifiers would be solved.

It is difficult to realize at first that a class B amplifier has to have this non-linear region in the sub-amplifier characteristic so that the two halves of the waveform can

be separated. With conventional designs this is a built-in feature, but it need not be so. Assuming we define class A operation to include any amplifier where the input signal never traverses the non-linear region, the sub-amplifiers of a class B amplifier can operate in class A as long as the input signals are uni-directional. To accomplish this the required non-linear element is placed before the sub-amplifier inputs.

New approach

Now the key to the problem is in the proposition that each sub-amplifier should be considered as a separate class A design, hence distortion generated by each of these units can be held to an extremely low level as long as the input signal can be prevented from driving the amplifier into the cut-off region. In the new approach, the output sub-amplifiers are biased above the non-linear region and uni-directional signals are fed into the input. This arrangement is illustrated in Fig. 5, where the necessary circuit changes are shown by comparison with Fig. 1. The obvious difference is the addition of the two diodes at the input which produce the uni-directional signal to drive the output sub-amplifiers. The linear transfer of signal between the two amplifiers is now dominated by this signal splitter.

Signal splitter. As the name implies the task of the signal splitter in a class B amplifier is to segregate the top and bottom halves of the signal waveform. Normally this is achieved by using the non-linear characteristics of each half of the output stage, but as this particular approach leads to

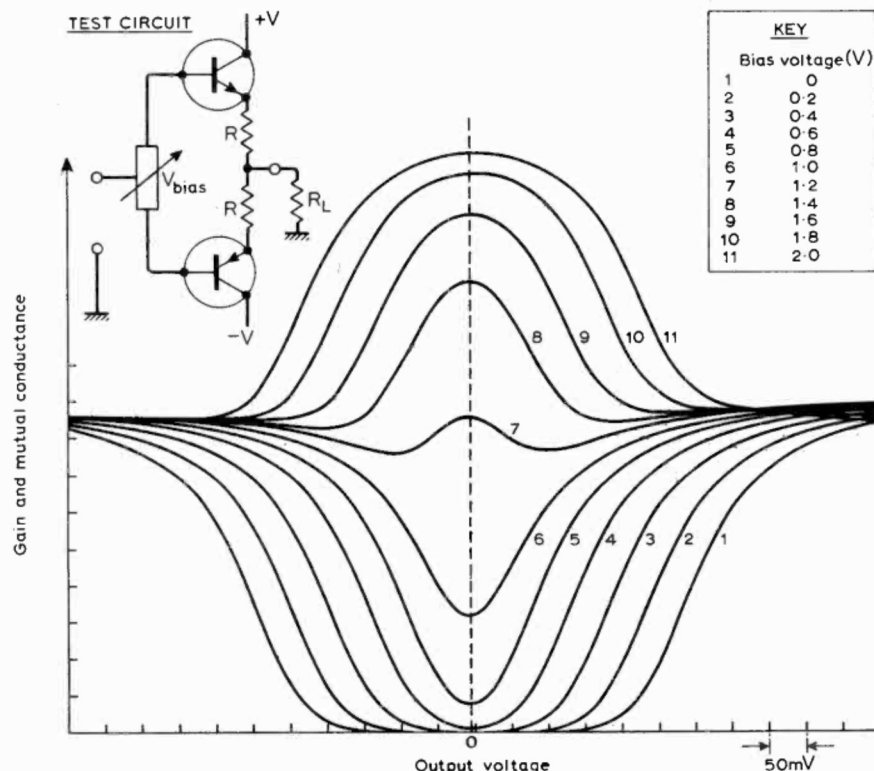


Fig.3. Gain—or mutual conductance—of simple symmetrical output circuit showing change in gain which can occur during transfer from one sub-amplifier to the other. Effect of different bias levels is shown.

problems, the new approach separates the two functions of amplifying and signal splitting completely.

To explain the problems involved with the design of a signal splitter it is usual to establish the ideal and see how this can be approached practically. As it happens there are two ideal 'half' characteristics which will give a linear cross-over when they are combined. The first, and obvious one, has a conduction path only in one direction and absolutely zero in the other. The other is more complicated and has three regions—linear region (large positive inputs), a non-linear region (transfer coefficient is proportional to signal) and a reverse region (transfer coefficient is zero).

The difficult region is the non-linear one. This will only give a linear crossover when it is combined with another conjugate characteristic. Not only this, but the relationship between the linear and non-linear portion has to be accurately defined. Normally this is achieved by altering the quiescent current in the signal splitter for minimum crossover distortion. Thus using this approach in the signal splitter means that the non-linear region has to be complementary to its partner and also that the linear and non-linear regions have to be accurately related. If additional constraints are imposed—due to device spreads and temperature changes—the situation can become very difficult unless a simple approach is used.

Returning to the first type of signal splitter, the immediate comparison which can be drawn is the simplicity of the characteristic. There are no interactions between each element and only one region has to be accurately defined. Ideally, therefore, this type of characteristic should be easy to control once a suitable device configuration is found.

Ideal element. The simple p-n diode fabricated in silicon can have a forward-to-reverse current ratio of 10^{10} ; thus it approaches the ideal almost within the boundaries of measurement. This is however only considering the forward characteristic under conditions of current drive. If a voltage source were used the forward transfer would revert to the familiar exponential relationship between input voltage and output current (Fig. 6a). If a signal splitter is now made of two of these diodes and a current of changing direction fed into the common point, then from Kirchhoff's second law the current must flow either in diode D_1 or diode D_2 depending on the direction of signal current flow. The transfer coefficient for the diode must be unity, as it is only a two-terminal device, hence this type of signal splitter is extremely linear under the conditions of current drive (Fig. 6b).

Transistor signal splitter. The use of a transistor as a signal splitter (Fig. 7) logically follows that of a p-n diode simply because the emitter-base junction has almost identical characteristics to that of a diode. Exactly where the transistor is superior to that of the diode depends on

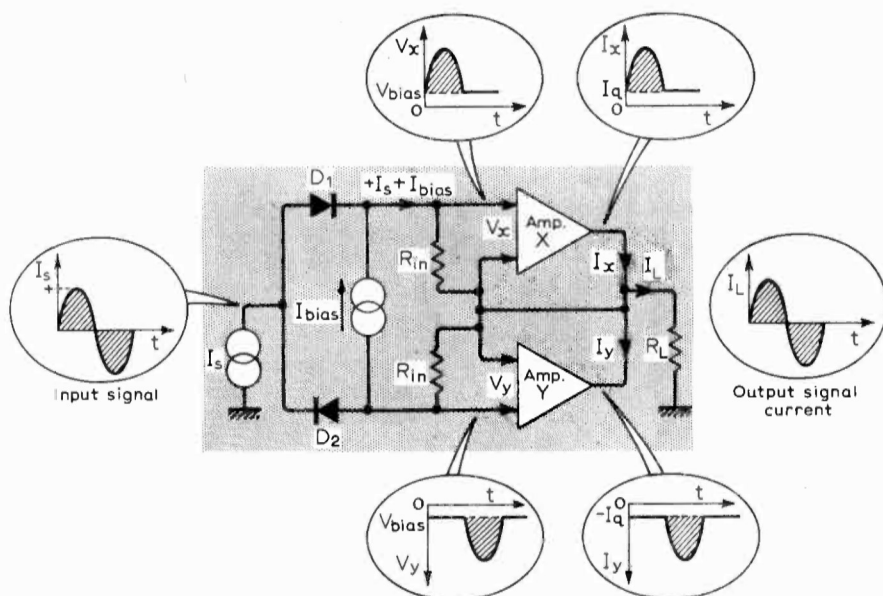


Fig. 5. New approach to class B amplifier in which sub-amplifiers are biased above non-linear region and fed with uni-directional signals produced by the diodes. This effectively transfers signal splitting from the sub-amplifiers to a separate part of the circuit.

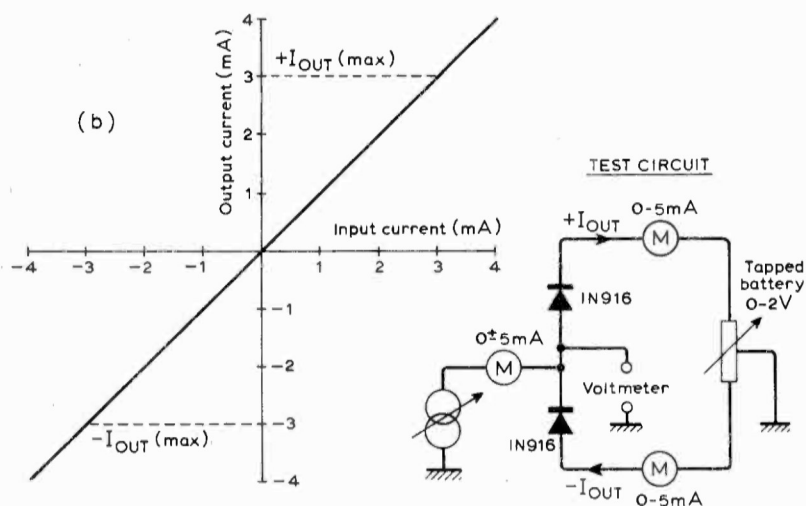
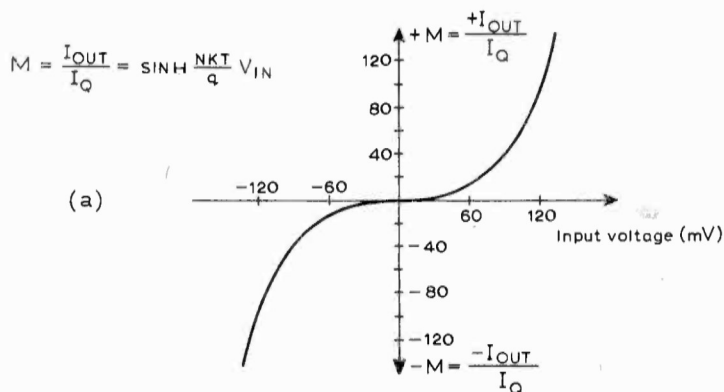


Fig. 6(a). Transfer characteristic of voltage driven diode signal splitter.

Fig. 6(b). Linear transfer characteristic of current driven diodes.

the design approach but in most cases the level-shifting property of a bipolar device is the main reason. This is very useful in a practical design but care has to be taken in the selection of the type of device. There is a problem with the use of transistors as signal splitters due to the emitter-base depletion capacitance. Under conditions of

low injection this can add an additional phase lag during the crossover period. The problem can be overcome by using silicon planar devices with very high transition frequency (f_T) or by selecting devices in which the f_T is dominated by the diffusion capacitance as f_T remains constant down to very low emitter currents.

Synchronous signal splitter. There is a limit to the speed at which the diode or transistor signal splitter will transfer the signal path between the sub-amplifiers. If a synchronous signal splitter is used the time taken can be reduced to a few nanoseconds. This makes true class B operation possible at frequencies far higher than the audio spectrum. The system diagram is shown in Fig. 8(a). Instead of using the characteristics of the devices, as in the signal splitter which separates the two halves of the waveform, switches Tr_1 and Tr_2 are turned on and off at the required time by another amplifier labelled

ST. This is a high-gain amplifier with a small amount of hysteresis, and as soon as the input exceeds a predetermined level the output from the trigger (amplifier ST) will change its polarity and turn on Tr_1 or Tr_2 , depending on the signal direction, Fig. 8(b). This therefore gives almost the ideal signal splitting characteristics but the added complication might spoil its commercial possibilities.

Performance of the new design

The transistor signal splitter and the output stage circuit have a combined charac-

teristic shown in Fig. 9 which demonstrates the excellent gain linearity. It is only when the bias of the sub-amplifiers is decreased below its optimum, allowing the output signal excursions to trace the non-linear region of the characteristic, that distortion begins to rise sharply. Further studies of these curves reveal that increasing the quiescent current through the output devices *does not* degrade, or for that matter improve, the crossover performance of the output circuit. Keeping this in mind it is therefore possible to design a class B amplifier *without any bias adjustment*. This assumes that the designer can guarantee that spreads in active devices and resistance values do not permit the quiescent current to fall below the level where the mutual conductance of the amplifier begins to decrease.

In this discussion about the performance of the design as a whole it would be fitting if the sub-amplifier design is mentioned. With conventional designs this two- or three-transistor element is fraught with compromises, one of the most serious being the decision on the inclusion of a base-emitter 'turn-off' resistance for the power transistor. Such a combination generates what can be called 'dead zone' distortion, mainly due to the change in slope of the transfer characteristic at zero crossing. One example of this is shown in Fig. 10 where, as predicted, the lower the value of resistance the more pronounced is the effect. It is very tempting to exclude this resistance altogether, especially if the current drive approach has been adopted, but the penalty would be a poor high-frequency performance coupled with overload recovery problems. This dilemma is aggravated if the designer decides to use homotaxial base powder devices (chosen for the robust nature of their construction and freedom from secondary breakdown) because the input diffusion and depletion capacitance is very high, hence the gain-bandwidth product of the device is relatively low (e.g. silicon planar $f_T \approx 90\text{MHz}$, homotaxial base $f_T \approx 1\text{MHz}$). In the latter case it is essential that the resistor is included. However, if the approach suggested in this article is adopted the sub-amplifier will never enter this non-linear region, thus the base-emitter turn off resistance can be included in the circuit to improve the performance without undue complications.

Once the decision has been taken to use the new approach the best circuit configuration has to be found and here again nature's swings and roundabouts create a difficult situation where compromise seems necessary. One of the criteria I used was that of thermal performance, following an initial consideration of the electrical properties of each configuration. The power transistor chip can change its temperature by tens of degrees centigrade during a power cycle, this being reflected by a corresponding change in the base-emitter voltage (V_{BE}) of the device. If the voltage bias to the sub-amplifier is applied directly to the power device (Fig. 11a), any change in the V_{BE} will cause a considerable change in quiescent current and in turn an

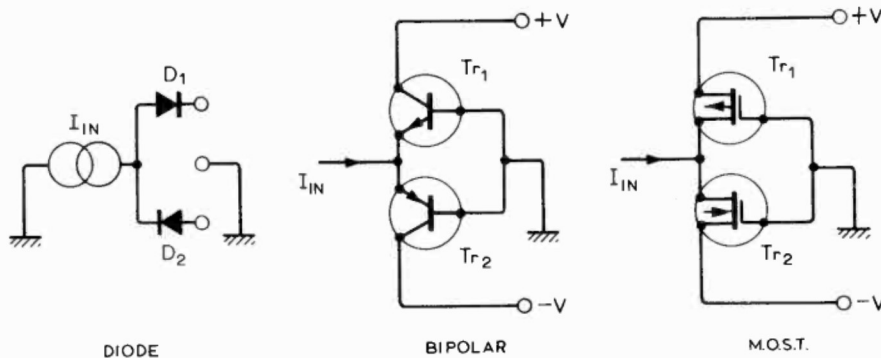


Fig. 7. Types of signal splitter. Transistor type has the advantage of level shifting.

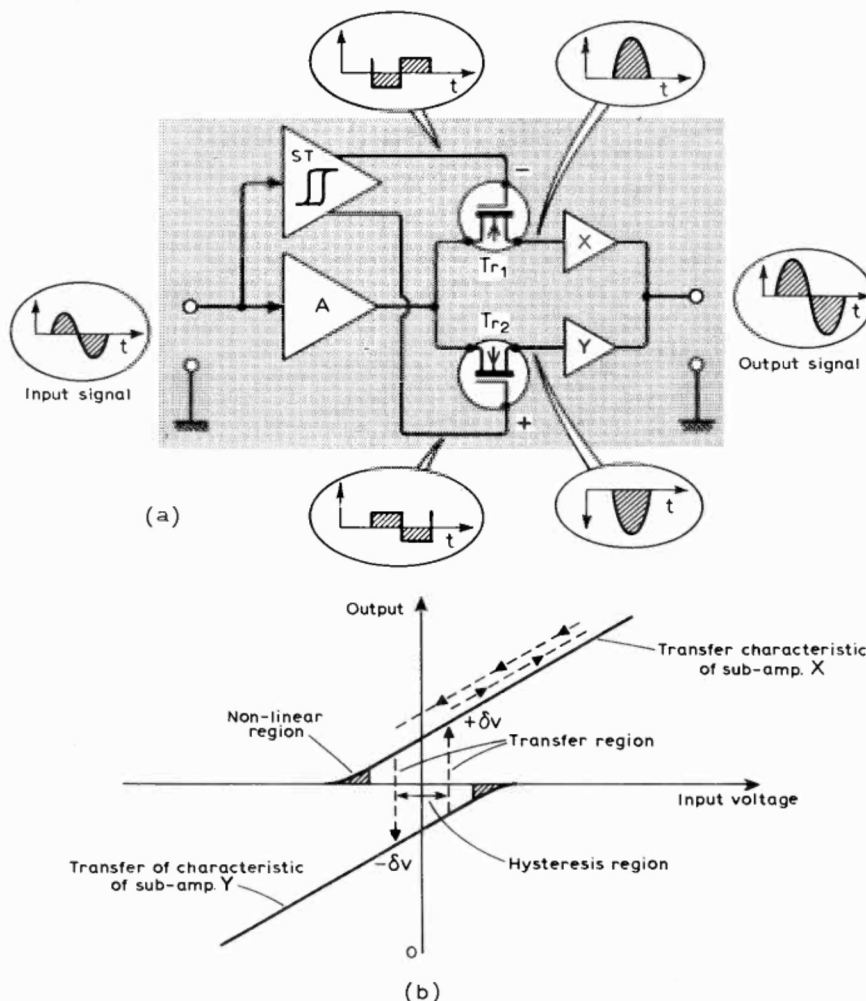


Fig. 8(a). Synchronous signal splitter, with fast switching time, allows new approach to be used at frequencies well above audible range.

Fig. 8(b). Operation of synchronous splitter of Fig. 8(a). When input level exceeds a pre-determined level, output changes polarity and turns on Tr_1 or Tr_2 .

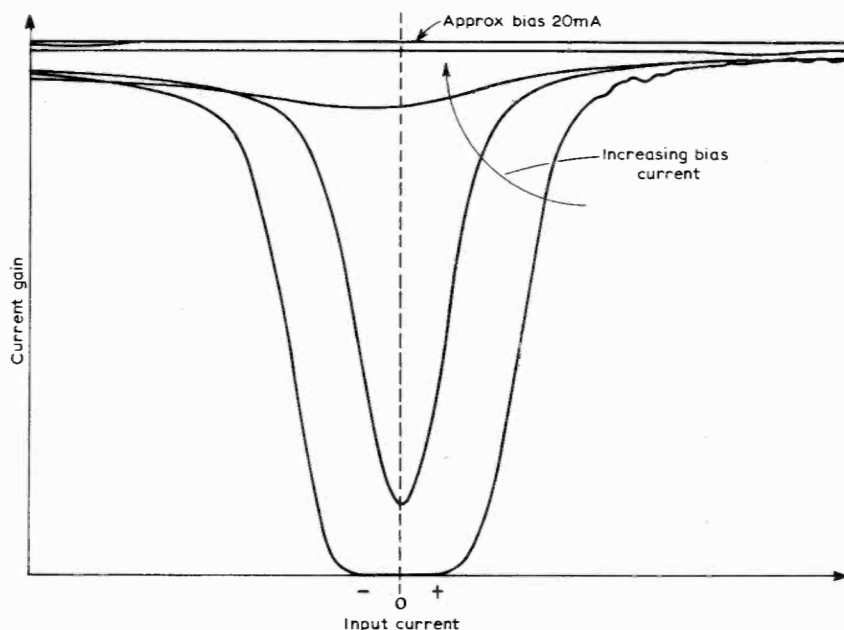


Fig.9. Combined characteristic of transistor splitter and output circuit shows excellent gain linearity.

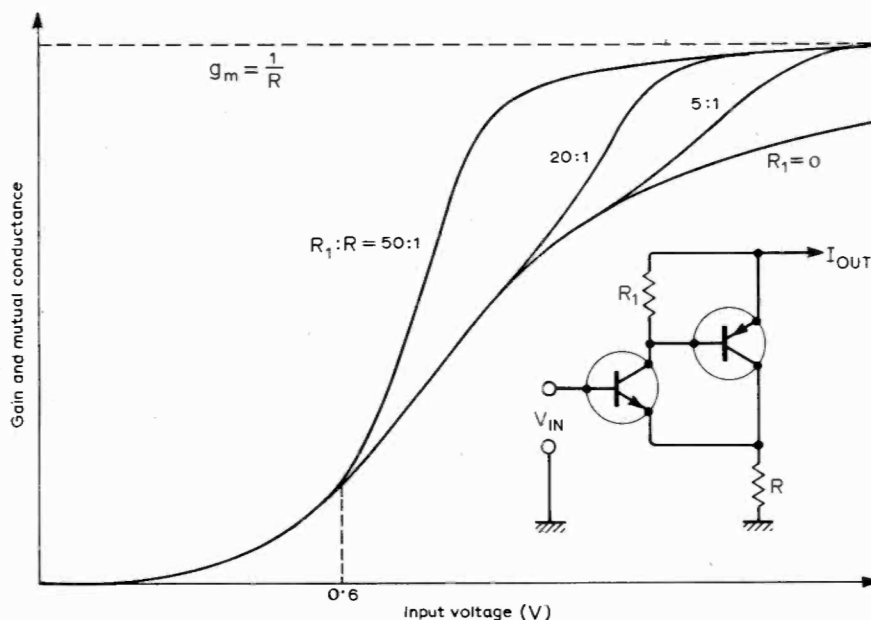


Fig.10. Transfer characteristic for conventional two-transistor sub-amplifier showing worsening effect of reducing the base-emitter 'turn-off' resistance of the power transistor. This normally generates 'dead zone' distortion due to the change in slope at zero crossing but is avoided in the new approach.

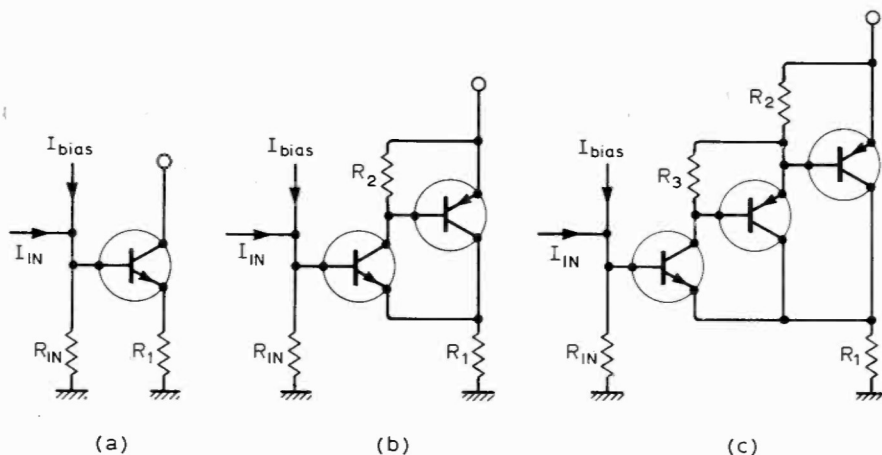


Fig.11. (a) Change in V_{BE} with temperature causes considerable change in bias current which could adversely affect intermodulation distortion. Circuits in (b) and (c) avoid this.

increase in distortion at low frequencies which could adversely affect the intermodulation performance of the amplifier as a whole. An improved design is shown in Fig. 11(b) and a more elegant version similar to that used in the Quad amplifier⁶, in Fig. 11(c). It is on this latter example that I have concentrated most design effort, mainly because the performance advantages tend to outweigh the increased cost of pre-driver devices.

Returning now to an examination of the performance of the whole amplifier—the total distortion through the audio range can readily be made less than 0.1% *before applying feedback*, this performance being repeatable at almost any level of quiescent current.

Future designs

The use of class B amplifiers is not, of course, confined to the field of audio and in fact the ideas set out in this article lend themselves to applications in the high-frequency (> 1MHz) spectrum. The poor cross-modulation performance of present designs is usually due to the presence of non-linearities in the crossover region, hence substantial improvements can be expected in this direction.

Other applications where an ultra-low distortion amplifier of low stand-by power and high output capability is needed can be seen, examples of such devices being portable standard oscillators and meter calibration amplifiers. In the next article a practical design for a 30-watt audio amplifier is discussed in detail and future proposals developed in diagrammatic form.

(To be concluded)

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5. Baxandall, P. J. 'Symmetry in class B' (letter), *Wireless World*, Vol.75, 1969, pp.416/7.
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Our 60th Birthday

The first issue of this journal, which for two years was entitled *The Marconigraph*, appeared in April 1911 and we therefore celebrate our 60th birthday this year. To mark the occasion we plan to have an enlarged April issue including several contributions reviewing the past 60 years in various fields. Further details will be given in our next issue.

News of the Month

Congratulations Glenrothes

The Glenrothes Development Corporation has embarked on an imaginative plan which was pioneered 100 years ago by Thomas Edison and forgotten. Edison provided work space and facilities for private inventors that they would otherwise not have had. The Corporation are building a £20,000 factory, due for completion in June, which will be divided into small units of something over 400 sq feet. These units will be let to inventors at a nominal rent. The exact rent will depend upon the means of the person involved and will not exceed 60s per week (a house in the area costs about 50s weekly to rent). On top of this the inventor will have to pay rates of around £30 per year.

Advice on setting up in business, business management, accountancy, marketing etc will be freely given by a committee. This committee, made up from prominent local business men, will vet each inventor who wishes to take advantage of the scheme, and will offer factory space to those, who in their opinion, are most likely to succeed.

An inventor, who has successfully developed his idea and has gone into production, would soon outgrow 400 sq.ft and would be offered a factory site in Glenrothes. However there are no strings attached to the offer at all and the successful inventor would be free to go where he chose. A bank has shown interest in the scheme and is willing to advance money for the purchase of plant to individuals who have successfully passed the committee's vetting and set up shop in the factory.

Individuals who would like to apply for factory space under the scheme should write to the Glenrothes Development Corporation, Glenrothes House, Glenrothes, Scotland.

European space consortium

Companies from eight of the ten member states of the European Space Research Organization have formed a consortium to respond to tenders issued by ESRO for both application and scientific satellites.

The new consortium has been named

STAR (Satellites for Telecommunications, Applications and Research). The member companies are British Aircraft Corporation; Contraves AG., (Switzerland); CGF-Fiar (Italy); Dornier System, (West Germany); Fokker VFW, (Netherlands); L. M. Ericsson AB., (Sweden); Mondetel, (Italy); SBICA, (Belgium) and Thomson CSF, (France).

The West German company AEG-Telefunken has also joined the STAR consortium but specifically for study and development of telecommunications satellites expected in the European programmes.

Naval trainer

A trainer system is to be designed and built for the Royal Navy by Ferranti Limited in collaboration with the Admiralty Surface Weapons Establishment at Portsmouth. The trainer will be commissioned at *H.M.S. Dryad*, the Royal Navy's School of Tactics, Navigation and Action Information Organization during 1975, at a cost approaching £5M.

The function of the new system will be to train staff in using automated action information and weapon control equipment. It will simulate the operations rooms and the weapon control systems of the *Leander* class frigates fitted with the various weapon systems as well as the new type-42 guided-missile destroyer.

The trainer will contain three FM.1600 and eight FM.1600B computers which will generate, process and distribute data to displays in the control and operation rooms of the trainer. The four simulated operations rooms are replicas of the ships' operations rooms they represent. Radar, sonar, electronic warfare and weapon control data are presented on the same displays and in the same form as under operational conditions. Many of the displays, themselves, will be supplied by Plessey Radar Ltd and by Decca Radar Ltd. Instead of live signals being used, the data will be synthetically generated. In general these synthetic signals will be programmed computer outputs, but for one of the more complex radars Marconi

Ltd are to supply special equipment.

Exercises will be controlled by the instructional staff in a central control room containing sixteen displays. Each of the simulated ships will be able to exercise independently or as a task force using radio and digital data-links for exchange of information. Communication with the computers is by means of keyboards.

Electronic typesetting

The latest method of high speed typesetting for printing forms the characters on a cathode-ray tube and the resulting images are recorded on photographic film, which is subsequently used for making lithographic plates. Characters are built up from closely spaced vertical or horizontal parallel lines traced by the c.r.t. spot, rather on the principle of television picture synthesis except that the spot intensity is not continuously variable—just full on or full off. The instants of turning on and off the beam current are determined by binary digital data held in magnetic-tape and disc stores under the control of a computer-like system. An interesting feature of the method is that it is not restricted to letters, numbers and other such characters but can also be used for composing diagrams, which can be directly interspersed with the text.

Wireless World's printing has not quite reached this advanced technique though much of the journal's text is composed by an earlier phototypesetting method (see "Electronics in Typesetting", March 1968). But our publishers have an associated printing company, Computaprint Ltd., which has just installed a machine of the fully electronic kind described above, the RCA Videocomp 70/800. This is capable of typesetting at the astonishing speed of 6000 characters (about two columns of this page) per second—which compares with up to 500 characters/second for non-c.r.t. photo-composition, 5 characters/second for conventional "hot metal" mechanical typesetters and 1 character/second for hand setting. Another commercial machine, the Mergenthaler Linotron, is claimed to work at up to 10,000 characters/second.

The Videocomp 70/800 is in fact a room-full of computer-like equipment: c.r.t./photographic unit, two magnetic tape stores, a random-access disc store, a data processor with a core store of its own, and an operator's console with a typewriter. The c.r.t. forms characters from vertical lines with a definition of up to 1800 lines/inch and diagrams up to 450 lines/inch. Type of various founts (styles) can be set with character sizes varying from 4 to 96 points (72 points = 1 inch), and characters can be altered electronically to form roman, oblique (quasi italic), expanded and condensed versions of the basic "face". A piece of