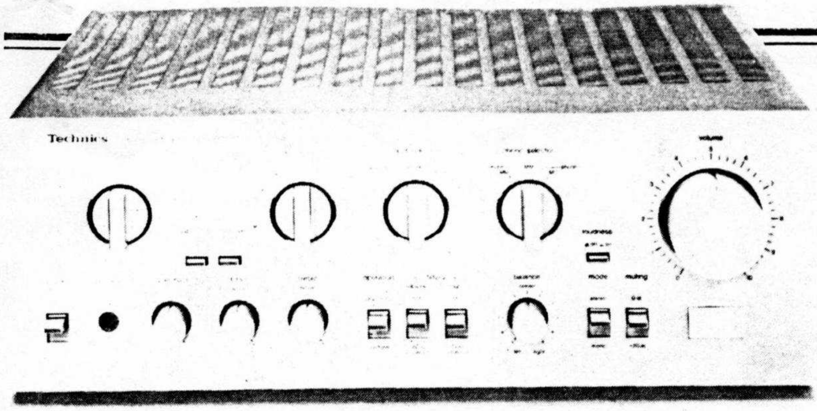
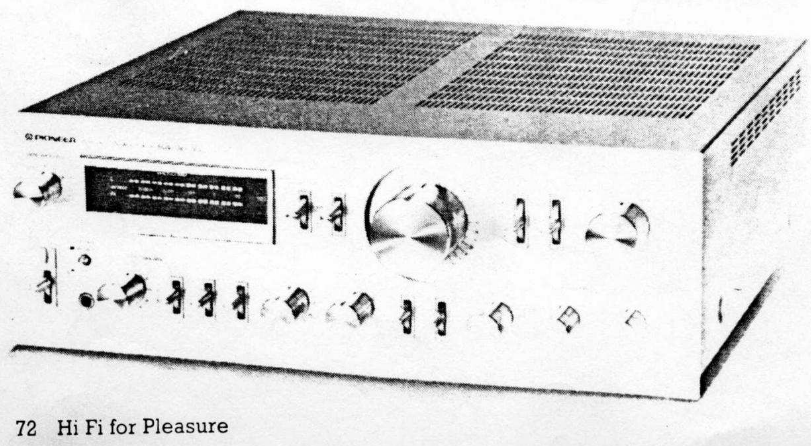


GET SWITCHED ON

The latest craze is Class A amplification — but with a difference. Do the new output stages really class as "A"? Stan Curtis investigates.



Way back in 1978, my very first *Short Circuit* was on the subject of Class A amplifiers; but, despite my ardent propaganda, most people continued to adopt an attitude of "desirable but the wife wouldn't like it". Suddenly, though, everybody is talking about Class A. Why? The answer is that the Japanese mass marketing bulldozer has discovered a new 'gimmick' and is about to brainwash us into believing that Class A is better. Ah well, not quite Class A but a better version of Class A called "...... ......" — but then it's all the same isn't it?

Well, this article will look a little deeper into the claims of the new designs, as well as undoubtedly spreading some more propaganda in favour of Class A. (Some people take to Class A amps and horn-loudspeakers like others take to religion.)

First of all, let us define what we mean by Class A. The straight-forward definition is that the output transistor(s) must always operate between the boundaries of collector cutoff and saturation. In other words it must always be operating in its linear region.

The Japanese companies have referred to a report of the Electro-Technical Commission which defines a Class A amplifier as "one in which the current in each active device supplying the load current is greater than zero throughout each cycle of the signal for all values of load current up to and including the value determined by the rated output power or voltage and the rated load impedance".

Now we know what Class A means; but what are its advantages? The most commonly known advantage is the avoidance of the switching or crossover distortion generated by Class AB and Class B stages. The origins of this distortion can be seen in Fig. 2 which shows that the transfer characteristic of the output stage, whilst nominally a straight and continuous line, is in fact made up of the characteristics of two transistors. The two lines join just where the transistor curves are non-linear near to the collector cut-off region. Thus there is a discontinuity in the characteristic which leads to the crossover distortion shown.

The effect is compounded at higher frequencies by the tendency of transistors to store a carrier charge on their bases which must be discharged before the transistor can switch-off. This time-lag causes further non-linearity at the crossover point. We will not dwell on the subject of crossover distortion as the effect is well known and is fully explained in Figs. 1 and 2.

Class A amplifiers avoid these problems by conducting a high current through the output stage regardless of the signal state. This makes for poor efficiency and a high thermal dissipation. In consequence Class A amplifiers need masses of heat-sinking and a large (expensive) power supply to provide the current. Despite these disadvantages, Class A has always been seen as the optimum for high quality audio amplification. As the output transistors are always 'on' they are always able to instantaneously respond to the input signal, instead of needing to turn-on first — a process which may take a microsecond or so. It may not sound very long but you could lose the first 2% of a 20kHz waveform in that time.

The low-output impedance and high-current sourcing and sinking capability of the amplifier makes for tight control of the loudspeaker during high current audio transients. Finally, the operation of the output stage continuously in the linear region of its transfer characteristic results in a minimum of distortion. Because the transfer characteristic can only deviate to a gentle curve (instead of the theoretical straight line), the distortion harmonics will be of a low order (usually 3rd harmonics) and so more musical in nature (remember musicality?) and less offensive to the ear. These harmonics will be very small in amplitude and will be reduced still further when the minimum of negative feedback is used.

By contrast, the Class B characteristic has a notch in the line which produces high order harmonics (5th, 7th etc) which are audibly offensive. These harmonics can be very difficult to reduce to low levels because the negative feedback process is not working whenever the output stage is off and so no current is flowing.

So much for conventional or 'true' Class A amplifiers (readers should refer to my previous article for a more thorough introduction to the subject).

The main purpose of this article is to look at the various attempts to get a litre out of a milli-litre pot, by building a Class A amplifier that doesn't get hot.

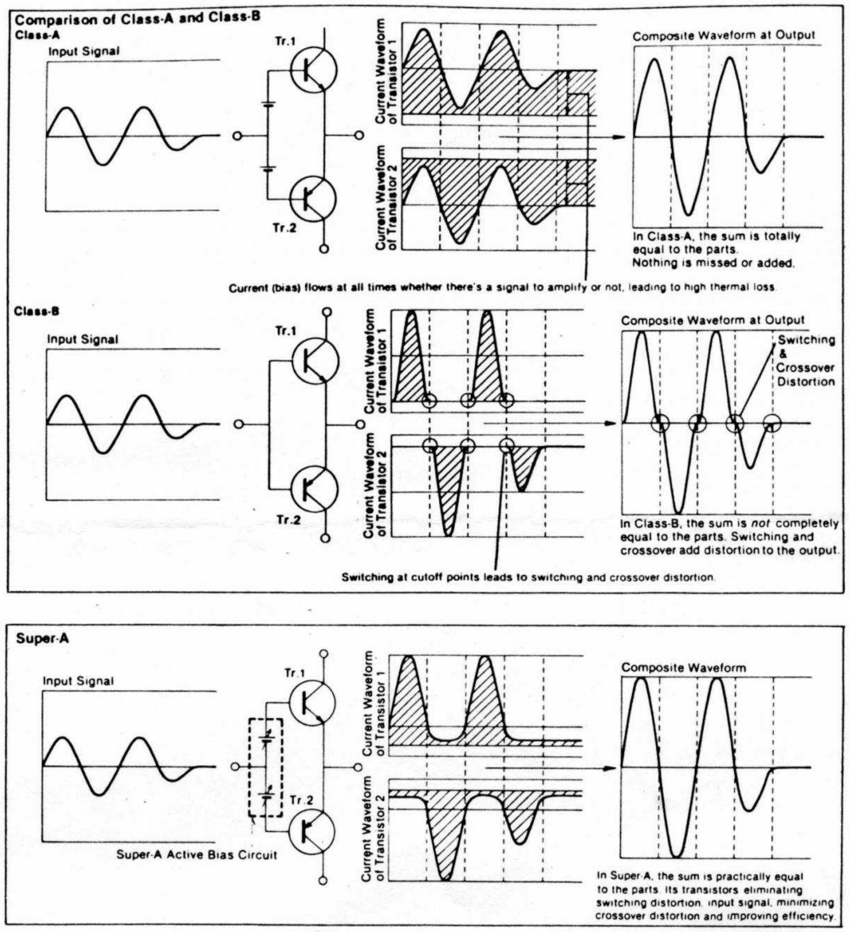


Fig. 1(a). The workings of a different class of output stage (courtesy JVC).

The company which really started up the current fashion for 'semi-Class A' amplifiers was the Threshold Corporation of California, USA. About five years ago they brought out their model 800A power amplifier which used a new active bias system. To quote from their literature: "The Threshold 800A overcomes these limitations through the utilisation of a new, patented active bias circuit that dynamically adjusts the bias in a push-pull circuit so as to constantly operate all transistors in the output stage in their linear collector region under all signal conditions".

The Threshold amplifier met with immediate success in the USA and was hailed as *the* audiophile power amp. It was a big, powerful amplifier and it got very hot despite fan cooling. Unlike the modern Japanese 'versions', this amplifier had quite a high idling current. The dissipation was about 200 watts per channel or almost equal to its power output rating for 8ohm loads. The quiescent current was about 1½ amps and so the 800A operated in true Class A for outputs up to about 8 watts, after which the active bias took over.

To put this high dissipation into perspective, it must be remembered that a true Class A amplifier (rated at 200 watts into 8ohms) would have to dissipate a minimum of 900 watts per channel — not far off 2kW for a stereo amplifier! The Threshold active bias system tracks the signal and adjusts the output stage current so that (up to a maximum peak current of 50 amps) the output stage current always equals or exceeds the load current. In this respect the 800A far more closely resembles a true Class A amplifier than the 'non-switching' amplifiers made by the Japanese companies.

Threshold have not released the full circuit diagram of the 800A but Fig. 3 shows the essential parts of one channel. The massive output stage uses 24 output transistors in a triple-Darlington, triple series, triple parallel configuration. Thus the output current flows through 18 power transistors, the other six being used as driver transistors. The drivers are driven from a true Class A stage whose operating current is approximately 50 times the ▷

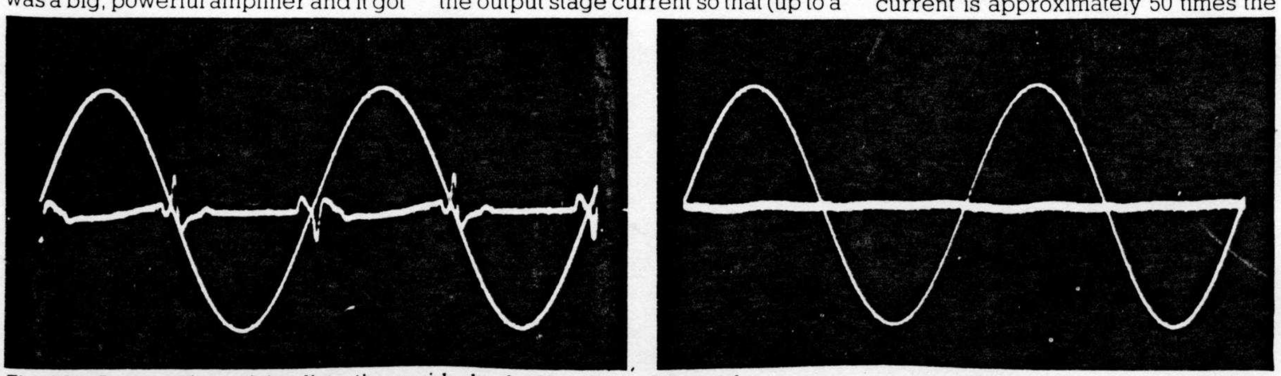


Fig. 1(b). A comparison of the distortion residuals of a Class B amplifier and a Technics "New Class A" amplifier (courtesy Technics).

drive current required to drive the output stage when it is delivering a peak current of 50 amps to the load (equivalent to 10 kilowatts into 4ohms). The bias circuitry is shown as two boxes as the exact circuit details are not known to me.

However, various circuit arrangements can be designed to fulfil this function. Such a circuit is shown in Fig. 4, but be warned that this particular circuit has some limitations so don't try it in an amplifier.

The Threshold active bias circuit adjusts the bias voltage at a speed faster than that of the output stage itself and enable the amplifier to deliver high currents at high output slew rates. To clarify this arrangement, let us consider the conditions that it must fulfil. If the amplifier is to deliver an output of 8 watts to an 8ohm load, it must deliver an output voltage of 8 volts RMS or about 11·2 volts peak. This voltage would generate a peak current in the load of 1·4 amps, and so an 8 watt Class A amplifier would need to have an idling current greater than this figure. Now, if the amplifier is to deliver 200 watts to an 8ohm load, it must deliver an output voltage of 40 volts RMS or about 56 volts peak. Hence the peak load current would be about 7 amps, and this would represent the minimum idle current of this Class A amplifier.

The current demands become even greater with lower impedance loads (remember that some loudspeakers have impedance dips down to below 2½ohms). The model 800A has a peak 'instantaneous' output current capability of 50 amps which suggests that the amplifier can drive 2ohm loads to full power in Class A but closer reading shows that the maximum 'continuous' current is only 6 amps — just sufficient for true Class A operation with 8ohm loads. Threshold's later model 400A (nominally 100 watts per channel) has a continuous output current of 5 amps. This rating permits true Class A operation into loads slightly lower than 8ohms, but it still means that 4ohm loads will be driven in the conventional Class AB mode albeit at peak currents in excess of 45 amps! It is this incredible output current capability that is the hallmark of the better Class A designs, and one of the reasons why they sound so loud despite their apparently low output power ratings.

Threshold put great emphasis on the speed of their active bias circuits. However, this speed is only of advantage in biasing 'on' the 'off' half of the output stage, thereby producing a 'non-switching' amplifier. But it is not possible for the bias circuit to change the current flowing through the output stage any faster than the signal can. By running their amplifier at a fairly high quiescent current, Threshold minimise the demands on the active bias circuitry, albeit with the disadvantage of what is still a very high standing dissipation.

The Japanese are ever quick to spot a trend and soon they saw that the audiophile 'thing' was to go Class A. ▷

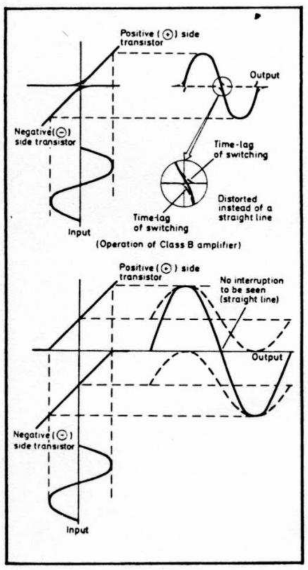


Fig. 2. How crossover distortion occurs in Class B — but not Class A — amplifiers.

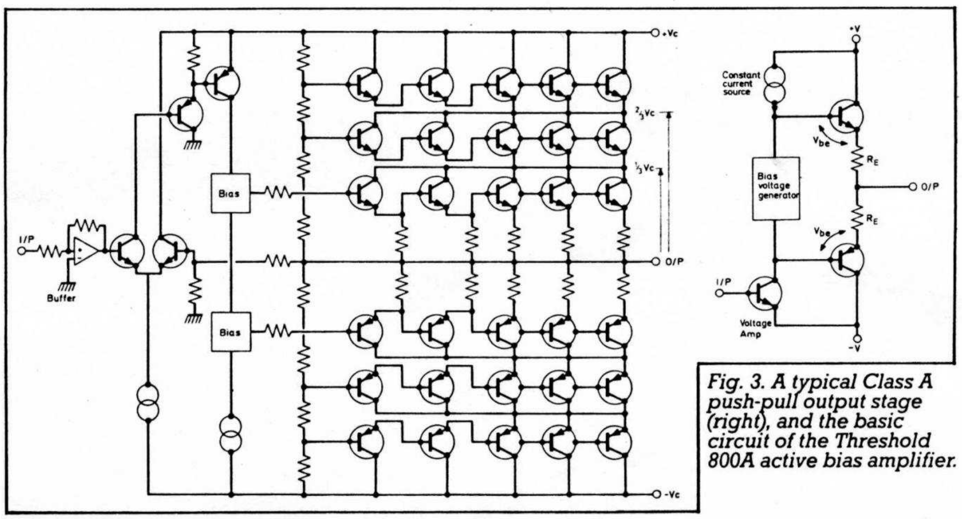


Fig. 3. A typical Class A push-pull output stage (right), and the basic circuit of the Threshold 800A active bias amplifier.

Fig. 5. The circuit schematic of the Pioneer SA-9800 power amplifier section using their NSA arrangement (courtesy Pioneer). ▶

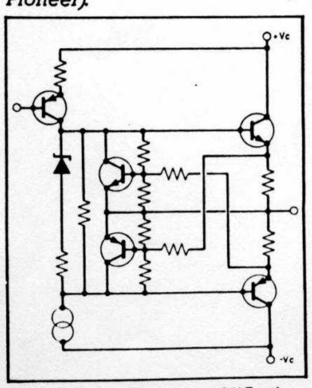
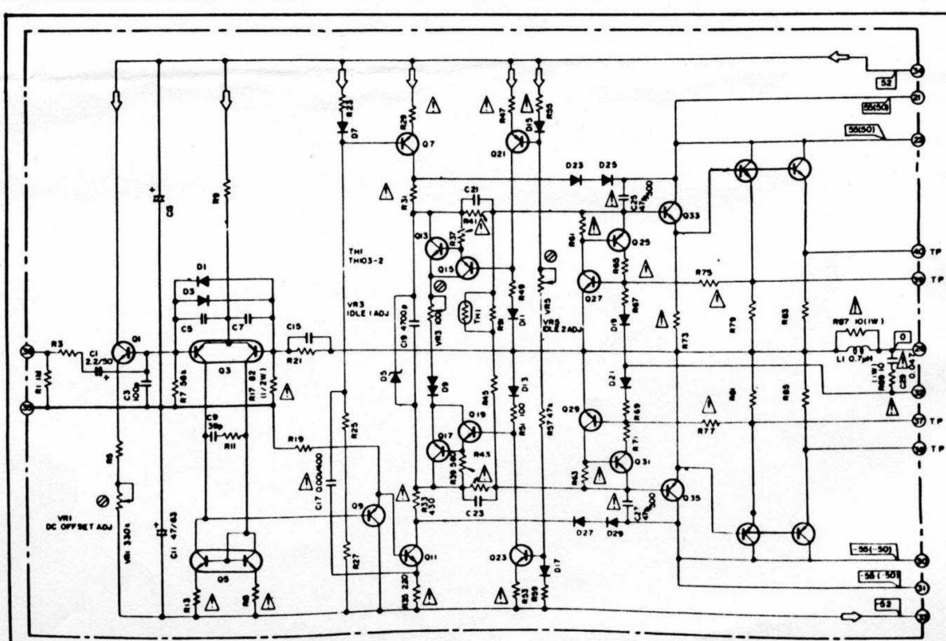


Fig. 4. A crude form of "Active Bias" circuitry.



One or two true Class A designs have appeared from Japan (notably the Technics Model SE-A1 monster weighing in at 51kg and 350 watts), but the Japanese much prefer to earn the big money by giving their products mass-appeal. And so came a whole new generation of amplifiers from Pioneer, Technics, JVC, Toshiba and Hitachi, all claiming to be "better than Class A" at a fraction of the cost and foot-warming capacity.

My first thought on seeing these amplifiers was: "how do they all manage to offer such similar products more or less simultaneously?" Just how do you keep a secret in Japan or do you indeed bother to try? Must be something to do with all those paper walls or those less than trustworthy giesha girls!

Whatever the reason, most of these amplifiers work in more or less the same way. They are all fairly conventional Class AB designs whose fixed bias networks have been replaced by new circuits which alter the bias conditions to prevent either half of the output stage ever getting into the collector cut-off regions. We will look at three designs, each of which achieves the same result with a completely different circuit. These are the designs of Pioneer, Technics and JVC who, as always, have been helpful with the supply of circuit schematics.

Pioneer "Non-Switching" amplifiers

The Pioneer version of semi-Class A is the Non-Switching Amplifier, and appears as their models SA-8800 and SA-9800. Both power amplifier sections are virtually identical except for their power output ratings.

The full circuit of the SA-9800 power amp is shown in Fig. 5 and is further broken down into functional parts in Fig. 6. The basic power amplifier is quite conventional except for the NSA biasing circuit wired across the bases of the complementary drivers transistors (Q33 and Q35). Again the biasing circuit is designed to prevent the non-operating half of the output stage being cut off. With a conventionally biased output stage (6(a)), the voltages between A and B and B and C will both be equal and will each be about 1·2 volts (in these examples we will keep all diode and transistor junction forward voltage drops at 0·6 volts for simplicity). Now, if the signal is applied and the output rises to, say, +6 volts, then the current through the upper power transistor will rise to 750mA (6/8 amps). This high collector current will cause a voltage drop in the emitter-resistor (Re) of almost 0·4 volts (V=IR=0·5×0·75). Thus the voltage between A and B rises from 1·2 volts (no signal) to 1·6 volts (6 volt peak signal). But the biasing voltage A-C must remain constant at 2·4 volts as it is determined by the current flowing through the series diodes D1-D4. This means that the voltage between B and C now reduces to 0·8 volts (2·4 less 1·6). But 1·2 volts is required to bias on Q35 and Q37 (2 times 0·6V), and so the PNP half of the output stage is turned off and no current flows through it. When the signal reverses to, say, —6 volts the same situation rises but in reverse with the NPN output stage now being cut off. Although this explanation is of necessity simplified, by keeping the junction voltage constant it does effectively summarise how a Class B output stage works and why such stages produce crossover distortion.

Now consider the Pioneer NSA biasing arrangement of Fig. 6(b). Again four junctions are used to establish the biasing voltages but now they consist of two diodes and two transistors (D9a, D9b, Q13 and Q17). Thus the voltage between the points A and C is again nominally 2·4 volts. Looking at the top half of the circuit it will be seen that transistor Q13 is coupled with a complementary transistor Q15 such that whatever voltage appears on the base of Q15 will also appear on the emitter of Q13. The base of Q15 is then connected to a diode D11 whose forward voltage drop is maintained at a fixed figure by holding its current constant (and similarly for the bottom half of Q17, Q19 and D13).

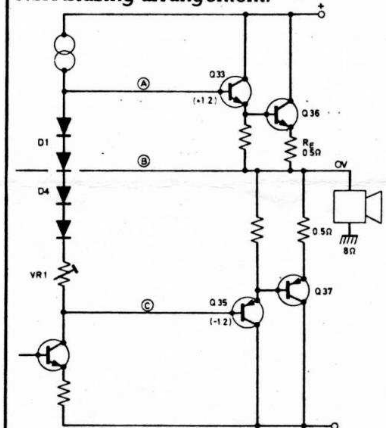
If the output signal again rises from zero to +6 volts the voltage between A and B will rise from 1·2 volts to 1·6 volts (as in the previous example), so the voltage at point A will be +7·6 volts. But the voltage at the emitter of Q13 will be 0·6 volts above the output (point B), this being determined by diode D11. Thus the voltage across Q13 has increased by 0·4 volts from 0·6 volts to 1·0 volts, and of course, this increase directly compensates for the voltage drop across resistor R_E.

Reference to Fig. 6(b) makes the process easier to understand and shows that, in the example given, the lower half (PNP) of the output stage remains 'on' and conducting current. The Pioneer NSA circuit could be much simplified as shown in Fig. 6(c) but, as the junction voltages of transistors and diodes are far from constant with temperature the whole set-up would drift and render the amplifier potentially unstable.

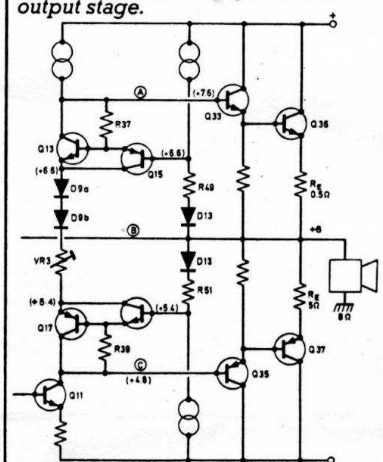
The quiescent output stage current is set in the normal way by adjusting VR3 and is set to a figure of 70mA. In the case of the model SA-9800, this computes to an output stage dissipation of under 15 watts under no signal conditions, compared to a maximum output power of about 125 watts. Thus to all intents and purposes the amplifier is a Class AB model as far as quiescent conditions are concerned. Reference to the full SA-9800 power-amp circuit in Fig. 5 shows that the current through diodes D11 and D13 (and hence their voltage drop) is set by trimming the current sources (Q21, Q23) using preset VR5. A Zener-diode (D5) is wired across the biasing chain to limit the voltage between A and B to a maximum of 6·1 volts to prevent the output stage current rising catastrophically in the event of a biasing fault.

The Pioneer NSA circuit works well, is simple and requires no exotic parts nor elaborate setting-up. It does exactly what Pioneer claim of it — it permits the amplifier to work without the output stage switching on and off, hence 'Non-Switching Amplifier'. They make no contrived claims (in their literature) of 'better than Class A performance' and indeed have been quite low key in their promotion.

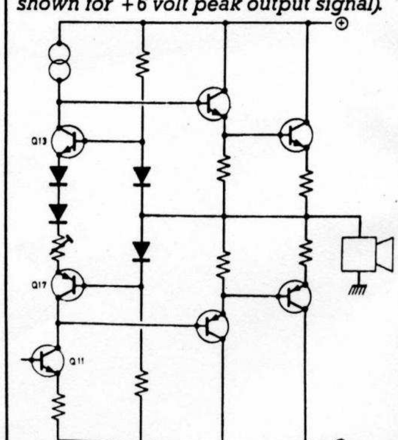
Fig. 6. Circuit details of the Pioneer NSA biasing arrangement.



a) Conventional biasing of a Class B output stage.



b) The Pioneer NSA biasing (voltages shown for +6 volt peak output signal).



c) The Pioneer NSA circuit in much simplified form.

Technics "New Class A" series of amplifiers

Meanwhile, just across the road, Technics are offering their contribution to the "Class A is better" campaign. With a total lack of modesty (and originality) they call their's 'New Class A'. But again the amplifier does not operate in Class A (except at very low signal levels) so it should be described as a 'non-switching amplifier' — except that Pioneer got there first. Technics' new circuit is called synchronous bias and is designed to achieve results very similar to the previously described Pioneer circuit.

Fig. 7 shows the basic operation of the synchronous bias arrangement used in the Technics SU-V8 power amplifier. The biasing circuit is composed of three distinct blocks. Of these, the one labelled 'bias 1' controls the quiescent operation. This biasing circuit is quite conventional and uses two transistors Q605, Q609) as 'active diodes' to maintain a constant voltage of approximately 4·8 volts between the bases of the pre-driver transistors (Q613, Q615). But with this simple bias circuit one half of the output stage would be cut-off whenever the other half was conducting current to the speaker load. This is where the 'bias 2' and 'bias 3' circuits come in. When the output signal goes positive the NPN power transistors (Q619, Q623) will be cut off so, to prevent this happening, the 'bias 3' network supplies a bias voltage sufficient to keep them conducting. Fig. 7(b) shows the operation of these circuits in more detail.

Again using our example of a +6 volt peak output, the relevant bias voltages can be worked out. First of all imagine that diodes D613 and D615 are disconnected. The voltage at point A can be found by working backwards from the output and is +8·8 volts. Now we know that the voltage between A and B is held constant at 4·8 volts, so the voltage at point B must be +4·0 volts. However we know that to bias the PNP stages 'on' we need the voltage at B to be below +3·6 volts (+6—(0·6+0·6+0·6+0·6)). So the PNP power stages will be cut off. Now let us solder diodes D613 and D615 back into the circuit and consider the 'bias 3' network around transistor Q611. Now this transistor acts as a fixed voltage source (rather than a floating one as with the 'bias 1' network) as its base is connected to a potential divider chain between the two power rails. The potential difference is sufficient to allow diode D615 to conduct and so bias 'on' the PNP output stage. Notice that when the output signal goes positive (on load) the diodes D611 and D613 *do not* conduct (whilst D609 and D615 *do* conduct), and when the output signal goes negative the diodes D609 and D615 *do not* conduct (whilst D611 and D613 *do* now conduct).

As the smooth operation of this arrangement depends upon these diodes, they have had to be selected for their very high speed. Without the ability of these diodes to switch on and off quickly, the changing bias conditions would always lag behind the signal changes. Technics claim that their switching diodes are fast enough to handle all signals in the audio band. But all switches — even fast ones — take a finite time to switch and so the operation of this circuit can never be as good, in theory, as true Class A arrangement. If the switching time is made small enough, then the slight delay in changing the output stage bias will not be noticed but it will still be there. That said, though, the Technics bias chain does operate very quickly indeed.

Again quite a simple circuit, although more complex than that of the Pioneer and again not really Class A. Under quiescent conditions the output transistor current is set at about 40mA and this computes to a dissipation of 10 watts for each amplifier (compared to a maximum output of about 130 watts).

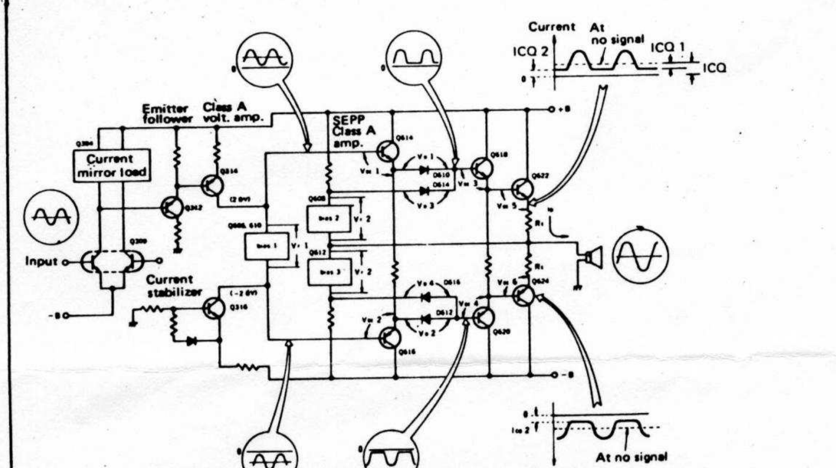


Fig. 7(a). The arrangement of the Technics synchronous bias circuit (courtesy Technics).

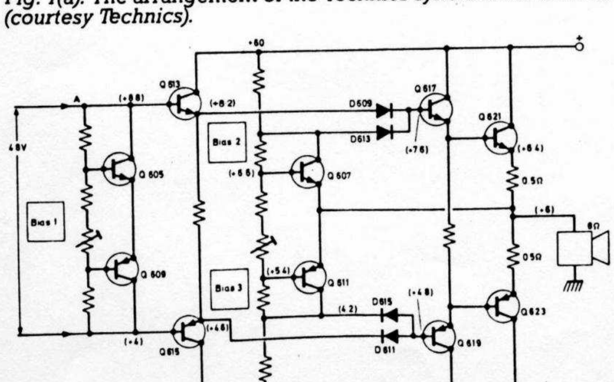


Fig. 7(b). The Technics "New Class A" biasing circuit. (Voltages shown for +6 volt peak output. Note that the values are simplified by making all junction drops 0·6 volts.)

JVC "Super A" amplifier bias system

It didn't take JVC long to put together their answer to the competition. And, of course, what could beat 'Super A'? JVC seem convinced that their circuits are the best for, to quote their literature: "our Active Bias Circuit uses no switching diodes, nor does it require a dual-voltage, high temperature constant current power supply. That it is so simple, and that no part of it switches on and off, makes Super A technically superior to similar non-switching type configurations".

Avid readers may already be able to name the 'inferior' competitive products!

So when I reached for the circuit schematics I was hoping to find a nice simple circuit that wouldn't tax the old brain too much (none of us is getting any younger). But no, the salesman must have been looking at a circuit of the mains cable when he wrote that piece. (And would he know the difference?) My circuit, in contrast, was one of those famous, wires-everywhere underground maps, all in different colours to make it 'easier' to follow. The key parts were eventually redrawn to make Fig. 8 which we will use as the basis of the circuit description. The block diagram construction of the JVC Model A-X9 (sounds like a sports car, doesn't it?) is shown in Fig. 9 and it will be seen that it is quite a complicated arrangement with 'Super- ▷

A' being just one of a series of design 'improvements'. Not least of the complications is the wiring of the tone controls and filters into the negative feedback loop of the power-amplifier.

The main part of the 'Super A' biasing circuit comprises six transistors, Q3 to Q8. The purpose of these transistors is made more clear by reference to the functional diagram in Fig. 8(b). Transistors Q3 and Q4 are both wired as diodes and steer the positive and negative halves of the signal to each half of the complementary output stage. These two diodes are biased 'on' by their respective current sources Q5 and Q6. Finally transistors Q7 and Q8 give a variable bias voltage between their emitters and collectors.

What is immediately apparent is that the bias chain is split halfway and tied to a point (A in Fig. 8(b)) which is always at the same potential as the output rail. This means that the bias voltage is no longer floating but is effectively a fixed voltage between the base of the driver-transistor (Q13) and the output rail. Thus the 'off' half of the output stage will always have a sufficient bias voltage to keep its output stage conducting regardless of what is happening to the other half. Thus the output stage is made non-switching. But if the bias voltage applied to each half were constant, we would get the effect shown in Fig. 10(a). Here transistor Q7 is arranged conventionally as a voltage source and an input signal of +8 volts has been applied. If the output is unloaded then it will also reach a voltage of +8 volts. Thus a potential of 9·6 volts is required at the base of Q13 to bias the output stage 'on'. This condition is met by the bias chain. If the output is now loaded by an 8ohm speaker (nominally), then a current of 1 Amp will flow and a voltage of 0·5 volts will be dropped across the emitter resistor R_E. This voltage drop cannot be balanced by starving the lower output stage (the normal Class B arrangement) so the output stage is current limited and unable to feed signal to the load.

JVC compensate for this requirement by making their bias voltage variable through feedback from the output (Fig. 10(b)). Whereas in the first example the potential difference across Q7 was 0·6 volts, now it will increase to compensate for the voltage drop across the emitter resistance. The result is that both halves of the output stage remain conducting whatever the signal polarity. This feedback also compensates for the small output DC offset voltage that would result from the quiescent current pre-set resistor only being in one half of the bias chain. The quiescent operation of the JVC amplifier is similar to that of the Pioneer and Technics models; the idle current being 50mA (ie a dissipation of 11 watts per channel).

We can now see that, in concept at least, the JVC 'Super A' arrangement is the simplest so far discussed. It requires no switching of bias by diodes and it works in a very linear manner. But (here we go again) the bias voltage is being controlled by the signal at the output stage and so it is essential that this 'servo' action be much faster than the signal itself. Otherwise there is a real danger that the output stage may suffer from momentary current limiting following a fast, large, transient signal. I've not yet been able to check this aspect on the JVC amplifier but it is a matter to be considered. However, for all its simplicity of concept, the practical realisation of the 'Super A' system is extremely complicated and was expensive to produce until the guts were put into a single integrated circuit.

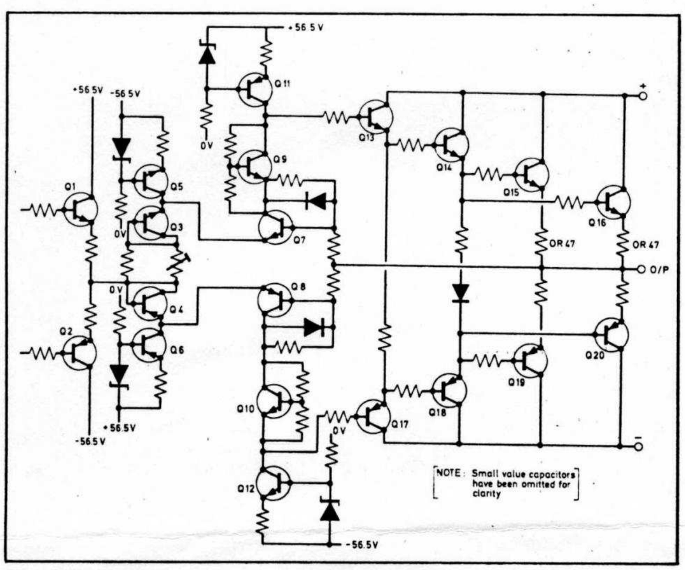


Fig. 8(a). Part of the power amplifier circuit of the JVC A-X9. (Note: small-value capacitors have been omitted for clarity.)

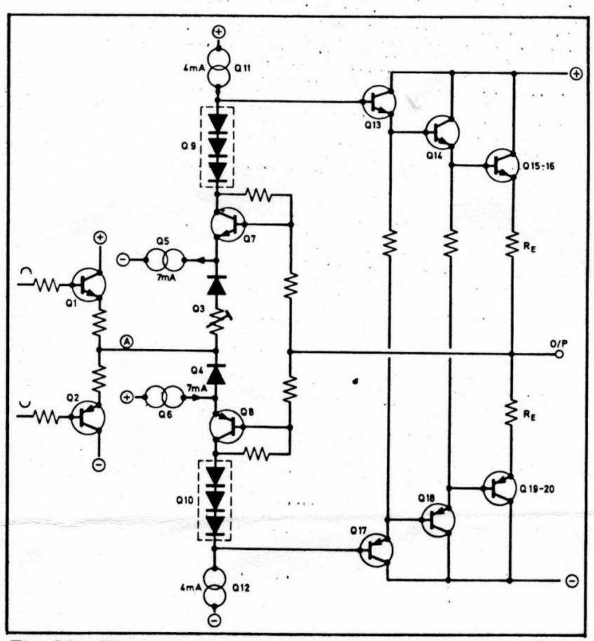


Fig. 8(b). The same circuit as Fig. 8(a) but in simplified form.

Fig. 9. Block-diagram layout of the JVC A-X9 power amplifier.

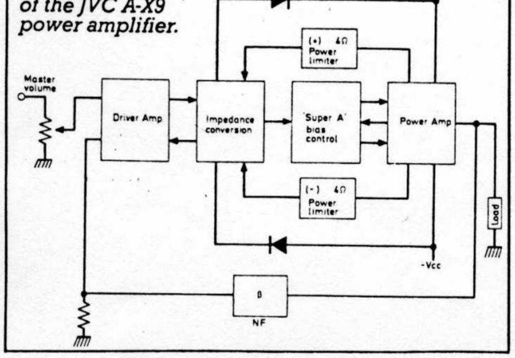
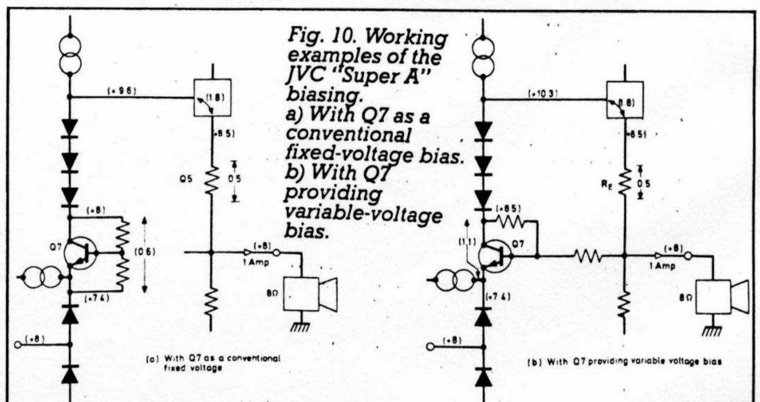


Fig. 10. Working examples of the JVC "Super A" biasing. a) With Q7 as a conventional fixed-voltage bias. b) With Q7 providing variable-voltage bias.



A new breed of Class A amplifiers

Well are these new amplifiers the genuine Class A product? In the strict application of the definition (operation between the boundaries of collector cut-off and saturation voltage) the answer must be yes. But I think in all honesty they should be referred to as Non-Switching Amplifiers although I wait with baited breath for reaction from the Japanese marketing man who defines them as a new class, perhaps Class ABC—1 — well it looks good on paper!

The conventional Class A amplifier has, of necessity, a very massive output stage and equally massive power supply. Such amplifiers can deliver substantial currents to the load and are, therefore, closer to the ideal of a voltage amplifier. They rarely need any form of protection circuits other than thermal cut-outs if the heat-sinking has been skimped. As a consequence of their design they have a very low open-loop (ie without negative feedback) output impedance which ensures good loudspeaker damping at all audio frequencies. A figure of 0·05ohms is quite typical compared to 0·5ohms for many conventional Class AB designs. The high quiescent current of all stages gives the true Class A amplifier a wider power-bandwidth and output slew-rate than the equivalent Class AB design (all other design aspects being equal).

I could go on but the fact is that there is far more to a Class A amplifier than the elimination of crossover distortion. The new generation of amplifiers goes a long way towards eliminating this distortion, although on some models the distortion residuals still show some low-level switching artefacts that would be completely absent in the results from a conventional Class A amplifier. If this new circuitry is fitted to a new generation of amplifiers with only a small price penalty, then everyone will benefit through a worthwhile purchase. But don't buy one thinking you've now got all the performance of an Electro-Research A75 at a tenth of the price.

For, on a side-by-side comparison, there is no doubt that "Class A still rules OK". And what if you've already got the real McCoy? Well, like me you'll be praying for a cold winter and a colder summer. Perhaps we could even have a special Electricity Board low tariff for Class A users. Well, perhaps!

CLASS A v. CLASS B

A comparison of ideal Class A and Class B push-pull output stages driving a resistive load.

	Class A	Class B
Maximum Output level	100W	100W
Power Dissipation of output stage under no-signal conditions	200W	NIL
Power Dissipation of output stage under full output conditions (sine-wave drive)	100W	27·4W