In your workshop

As usual, Christmas finds Dick and Smithy working furiously to clear an excessively large number of faulty radio and television sets. But they are fortunate this year and are able not only to repair all receivers by a reasonable hour but also to examine the intricacies of a transistor complementary pair a.f. amplifier that is very popular with set manufacturers

"HALLO, WHAT'S THIS?"

Smithy grunted the question to himself as his car turned the corner leading to the Workshop. It was the morning of Christmas Eve, and he had purposely started out from home early to make sure of clearing up all his outstanding work. The habitual phenomenon of the season had once more taken place, and he and Dick had been labouring mightily over the last week at an exceptionally large number of TV and radio receivers which had mysteriously chosen to break down just before Christmas, and which all had to be fixed in time for the Day.

But, early as Smithy was, someone had preceded him. The Workshop, ablaze with light streaming from its windows, stood out like a beacon in the surrounding gloom.

EMBELLISHMENTS

The bewildered Serviceman parked his car then walked the few yards to the door of the Workshop. He opened it and peered inside.

"Well," said a voice proudly, "what do you think of it?"

Smithy's eyes blinked as they became accustomed to the brightness of the Workshop lighting. Bemusedly, he looked around him.

The Workshop had been transformed. Two long brilliantly coloured paper chains were suspended diagonally across it, each passing from one corner to the corner opposite. A large red balloon marked their point of intersection, where they were raised to the ceiling so that they formed four gracefully dependent arcs. More embellishments were to be seen at the spares cupboard, where a veritable carillon of paper bells descended down both sides. At the windows, small pieces of cotton wool had been stuck in neat rows to the glass, giving the appearance of geometrically precise flurries of snow. Further paper chains were festooned along the wall surfaces, with more balloons at the points where they were suspended. The ricketty table near the sink on which were ranged the culinary effects of the Workshop had its legs covered in alternate stripes of green, orange and purple crepe paper, and the same colour scheme had been applied to the legs of both Dick's and Smithy's benches. Indeed, it was at that moment that Smithy's assistant, with a flourish, pushed in the last drawing-pin securing the paper at Smithy's bench. After this, Dick stood up and surveyed his handiwork with great satisfaction.

"Looks all right, doesn't it? he remarked.

"Er, yes," replied Smithy, a little uncertainly. "I suppose it does."

"Brightens the place up no end."

"Oh, definitely."

Gradually regaining his normal composure, Smithy took off his overcoat and hung it up behind the door, taking care not to disturb a cylindrical yellow balloon that hovered dangerously near its upper end. He donned his overall jacket.

"Well," he said briskly, "I *did* make a point of coming in early to clear up all the extra work, so I suppose I'd better get started on it right now."

"Fair enough," replied Dick. "I'll get stuck in, too. I've finished all the decorating."

Breathing a silent sigh of relief at this news, Smithy walked over to the 'For Repair' rack to pick up his first set for the day. Dick followed shortly afterwards and the multi-coloured Workshop was soon the scene of concentrated and dedicated activity. As time passed the pace became swifter, until Dick and Smithy were working like men possessed. The number of repaired sets rose slowly but steadily. Suddenly, Dick and Smithy found themselves both walking together to the 'For Repair' rack and reaching out in unison to pick up the same small transistor receiver. They looked at each other in wonderment, then turned back to the rack. That transistor radio was the only set left for repair.

"Gosh," said Dick in awestruck tones, "don't say we've actually cleared them all out!"

"We must have done," said Smithy.

He glanced at his watch.

"What's more," he resumed, "we've done the whole lot during the morning. It's only quarter to one now."

"Is it? Well then, all I can say is that either, unbeknown to ourselves, we've become super-skilled in our jobs, or the sets we've been working on today have all been easy ones."

"Seeing that it's Christmas," grinned Smithy, "I'll plump for your first explanation. Anyway, thank goodness we can ease off now. You see about making some tea, Dick, and I'll get started on this last little radio that's left."

COMPLEMENTARY OUTPUT STAGE

Dick walked over to the now gaily coloured table alongside the sink, filled the kettle and placed it on the electric ring. He then returned to Smithy's bench and watched the Serviceman as he experimentally adjusted the controls of the receiver. The sound from its speaker appeared to be badly distorted.

"This," announced Smithy, "should be a pretty easy one. I'll tune in a station and let you hear how it sounds, first at a low volume level and then at a high level."

Dick listened attentively as Smithy adjusted the volume control. At the low volume setting the sound from the radio was pleasant and acceptable, having the usual quality to be expected from a small transistor receiver. As Smithy increased the volume level the sound commenced to become harsh and distorted, the distortion increasing severely as volume level became greater. Smithy turned the volume control fully back, thereby switching off the set.

"The r.f. and i.f. sections of this receiver appear to be O.K.," he remarked cheerfully. "It looks as though we've just got a straightforward snag in the a.f. department."

"Here, hang on a minute," protested Dick. "You haven't even taken the back off that set yet, but you're already stating that whole sections of it are working properly."

"With good reason, too," retorted Smithy. "Here, let me show you."

The Serviceman switched the set on again with the volume control at a low level. He swung the tuning dial from one end to the other. The set was switched to the medium wave band, and some seven or eight stations were audible, all at more or less the same strength. Smithy switched the receiver to the long wave band, and tuned in the B.B.C. Radio 2 transmission on 1,500 metres. This also was reproduced at a similar level.

"Well," said Dick suspiciously, "what does that tell you?"

"It tells me," replied Smithy, "that there is enough i.f. getting to the diode detector to provide an adequate a.g.c. voltage. If there weren't, the set would either be obviously insensitive, or the local station or stations would come in at reasonable volume and the rest would be much weaker. The fact that the stations were all reproduced at about the same level indicates that the r.f. and i.f. stages are capable of producing an adequate a.g.c. voltage, and so they *must* be working at least reasonably well. Also, the set has the selectivity you expect from a receiver of this class, so all the i.f. tuned circuits are operating correctly. Having a quick run round the dial is, of course, a routine initial check which you should carry out with any a.m. radio set. It only takes a jiffy to do, but it can tell you a great deal about the condition of the receiver. Anyway, I'll satisfy you now by taking the back off."

Smithy removed the back of the receiver and carried out a visual check of its internal components.

"There's nothing obviously wrong," he pronounced. "No loose wires, connections adrift or anything like that. Let's check the battery voltage."

Smithy switched on the receiver and applied the prods of his testmeter to its internal PP9 battery.

"There's a full 9 volts there," remarked Dick, who had been watching the meter scale.

"Fair enough," grunted Smithy. "I might as well check battery current whilst I'm at it."

He switched his testmeter to read 100mA f.s.d., removed one of the

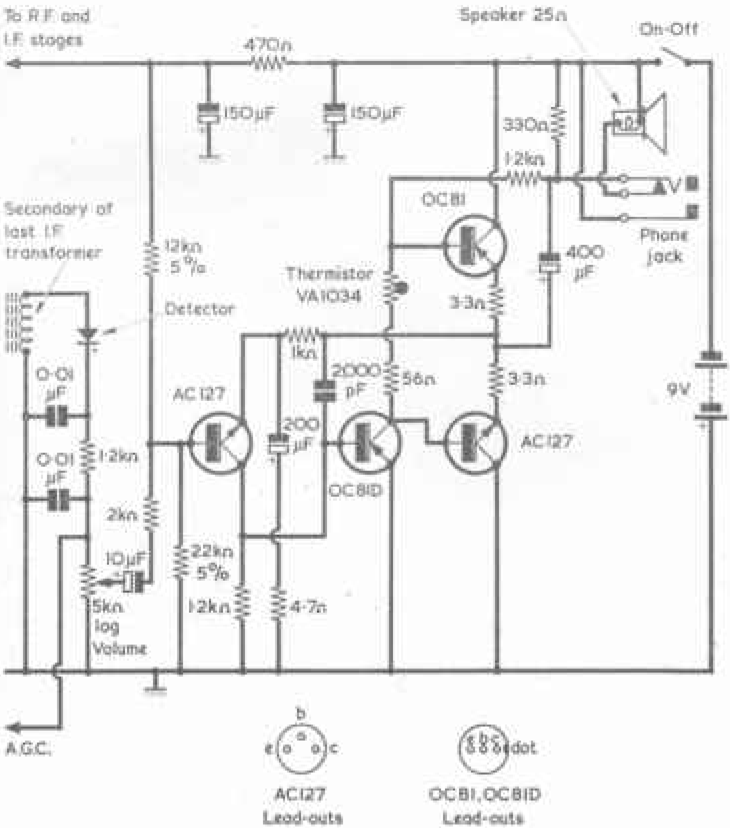

Fig. 1. The a.f. amplifier and output stages of the transistor radio serviced by Smithy. Nominal output power is 250mW. This basic circuit is employed in many transistor receivers

battery connectors and inserted the meter in series.

"The quiescent current," announced Dick from his station at the meter, "is about 7 or 8mA, which is pretty well what's to be expected. Try turning the wick up a bit, Smithy."

Smithy tuned in a station and adjusted the volume control. The receiver output increased in level, accompanied by its attendant distortion.

"The current," stated Dick, "is now hopping up to the 20 to 30mA mark on sound peaks."

"Right," pronounced Smithy. "Then the audio signal is getting to the Class B output stage. We'd better start being a bit technical now, Dick, so would you please get out the service sheet for this set?"

Dick walked over to the filing cabinet and, after a little searching, extracted the service manual in question. Returning, he opened it at the circuit diagram and laid it out on Smithy's bench. The latter, who had replaced the battery clip that had been disconnected for the current test, indicated the detector and a.f. amplifier section of the circuit. (Fig. 1).

"This is where the trouble will be," he stated assuredly. "Since the distortion only appears above a certain volume level it's pretty likely that the output stage is clipping."

"Clipping?"

"Clipping," repeated Smithy. "This set uses a complementary output stage and, for correct operation, the junction of the two output transistor emitters should be at approximately half the potential of the battery above chassis under quiescent conditions. This means that the potential at the junction of the two emitters can then swing both positive and negative by about the same voltage before clipping occurs. Incidentally, so far as this particular circuit is concerned, when I refer to the junction of the two emitters I really mean the junction of the two 3.3Ω resistors in series with those emitters. These resistors can be ignored in the present discussion."

"I'm not entirely clear," confessed Dick, "what exactly you mean by clipping."

Smithy took a pen from his pocket and sketched out a waveform on the margin of the service sheet.

"Now here," he remarked, "is what happens when the output transistor emitters are at the correct half-battery potential. They can, under this condition, swing positive and negative up to nearly half-battery potential on either side of zero without any distortion being introduced at all. (Fig. 2(a)). If the audio input to the output stage increases further, the negative and positive peaks at the emitters flatten off, because there isn't enough supply voltage to take them further. (Fig. 2(b)). That flattening off is known as 'clipping'. When the clipping is symmetrical on positive and negative peaks the output stage is working properly and it's possible

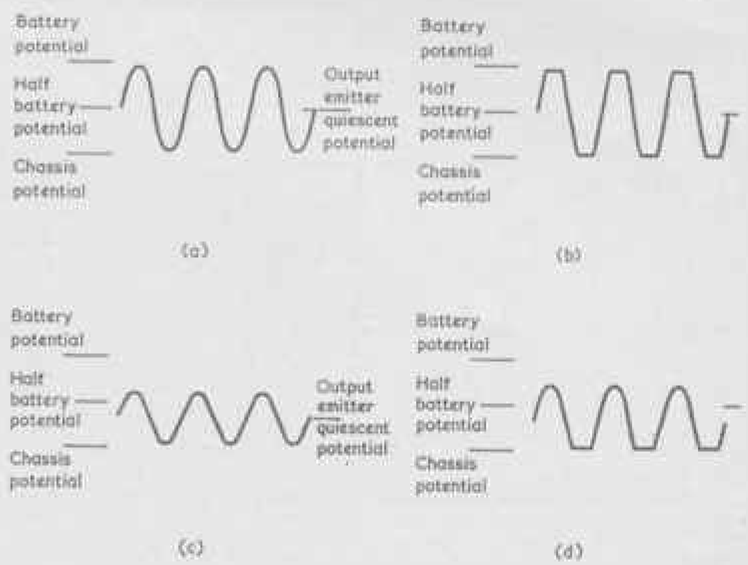

Fig. 2(a). The a.f. voltage output of a correctly set up complementary output stage
(b). Increasing the output causes symmetrical clipping
(c). An incorrectly set up output stage can still handle low level signals without distortion
(d). If the signal at (c) is increased in amplitude, asymmetric clipping occurs

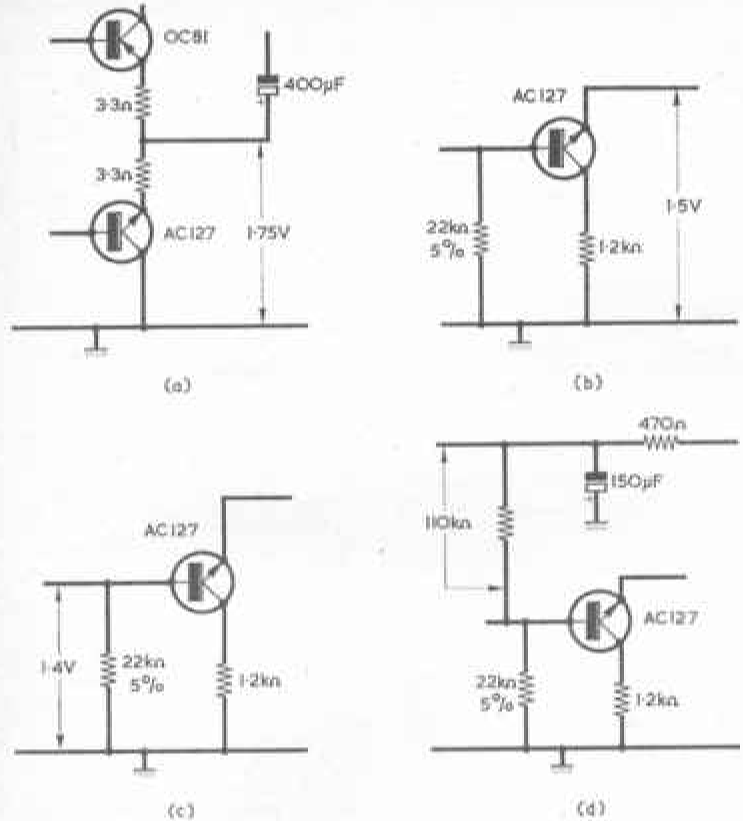

Fig. 3. Testmeter readings obtained with the circuit of Fig. 1. Output emitter voltage is shown at (a), and emitter and base voltages for the first AC127 in (b) and (c). The resistance reading in (d) located the faulty component

to get the maximum power from it of which it is capable before clipping, and hence distortion, takes place."

Smithy scribbled a further waveform on the margin of the service sheet. (Fig. 2(c)).

"This," he stated, " is what happens when, due to a fault condition or maladjustment, the output emitters are not at half-battery potential under quiescent conditions. I've shown their quiescent potential here as being displaced towards the supply rail which connects to chassis. The output stage can still handle low level signals without distortion, but clipping then starts as soon as the signal amplitude increases above that low level." (Fig. 2(d)).

"Oh, I see," said Dick brightly. "With a bit of luck it will be that quiescent voltage that's wrong with this set, then."

"I hope so," replied Smithy. "Seeing that it's Christmas Eve, we could do with a nice easy job to finish off with. Let's have a dig with the testmeter."

FAULT LOCATION

Smithy switched the receiver on again, set his testmeter to a low volts range, clipped its positive test lead to the receiver metalwork and, after having identified the point in the circuit board where the two 3.3Ω output emitter resistors connected together, applied the negative meter prod to their junction. The testmeter indicated a potential of 1.75 volts. (Fig. 3(a)).

"Blimey, Smithy," said Dick, impressed. "You've found the fault first go! The bottom output transistor must be partly short-circuit or something like that."

"I very much doubt it," returned Smithy. "What you have to remember is that the d.c. potentials in complementary output stages of the type we have here depend upon the balance of components further back in the amplifier. Let's see what we've got on the emitter of the first AC127, the one which immediately follows the detector diode. Ah, here it is!"

Smithy applied his test prods

carefully. (Fig. 3(b)).

"It's 1.5 volts this time," announced Dick, looking at the testmeter needle. "Just a wee bit less than the previous reading."

"Good show," said Smithy. "I'll try the base of that AC127 next."

"The voltage now," called out Dick, "is just a bit lower again. About 1.4 volts, I'd say." (Fig. 3(c)).

"Right," said Smithy, switching off the receiver and disconnecting the positive test clip from its chassis. "A simple resistance reading is called for next, I think."

He switched his testmeter to an ohms range, zeroed its needle, then applied the test prods to the upper base bias resistor for the AC127. The meter indicated 110kΩ. (Fig. 3(d)).

"That's it, then," he remarked, pleased. "That resistor I've just checked is *supposed* to be 12kΩ, but it's giving me a resistance reading that's a darned sight higher than that. We want a new 12kΩ 5% resistor here, Dick. The existing one's gone high."

"Okeydoke," said Dick, as he walked over to the spares cupboard. "Can I solder it in, Smithy? I'm getting a bit fed up with just standing here watching."

"As you like," replied Smithy. "Unless we're unlucky, that replacement resistor should clear up this fault, whereupon we're completely finished for the day."

At that instant the Workshop kettle produced an ear-splitting whistle and Smithy rose from his stool and walked over to make the tea. He returned with a cup for Dick and with his own tin mug full to the brim, then settled down alongside his assistant who was now busily soldering in the new resistor.

"By the way," said Dick. "I thought that it wasn't always advisable to check the value of a resistor when it's in circuit in a transistor radio. Aren't you liable to get false readings due to transistor junctions acting as diodes and causing other resistors to be effectively in parallel with the one you're checking?"

"That *can* happen," agreed Smithy. "When you're checking a resistor in a transistor circuit you should apply the testmeter prods to it one way round and then the other way round. If one reading is higher than the other it's the one that's more likely to be an accurate measure of the actual resistance. This is because any transistor junction which is acting as a diode and introducing extra resistance in parallel to give a false low reading will be non-conductive when the higher reading is obtained. Even then, though, you've got to be a wee bit careful, especially if the resistor connects between two separate transistors. In our case, fortunately, we got a reading which was *higher* than the nominal resistance of the resistor, so the resistor itself was obviously faulty."

Dick placed Smithy's soldering iron back on its rest.

"All done," he announced. "One new resistor soldered in!"

"Switch it on, then," replied Smithy. "We'll see how that set plays now."

Dick turned on the receiver and advanced its volume control. The previous distortion at high volume level was completely absent. Smithy leaned forward, turned the volume down and switched his testmeter back to the low volts range again. Once more he checked between chassis and the junction of the two 3.3Ω output emitter resistors.

The testmeter indicated 4.6 volts.

OUTPUT STAGE OPERATION

"Excellent," pronounced Smithy, rubbing his hands together. "Well, that's got our last pre-Christmas job buttoned up."

He gazed happily around the garishly decorated Workshop.

"I'm beginning," he continued exultantly, "to feel quite festive already. Just imagine – no more radio or TV to think about right up to the end of the Christmas holiday!"

"D'you know, Smithy," said Dick, breaking into Smithy's paean of joy at his release from matters electronic. "There's something in this circuit that's puzzling me."

Smithy's smile of pleasure ceased abruptly.

"I should have known," he commented bitterly, "that I'd have no escape, with *your* enquiring mind around the place. Okay then, tell me what it is that's puzzling you."

"It's the 200μF capacitor and 4.7Ω resistor in series," replied Dick promptly. "The components that connect from the emitter of the first AC127 down to the chassis line. I can't quite see what they're there for."

"That 200μF electrolytic," replied Smithy shortly, "is a d.c. blocking capacitor. And the resistor is a negative feedback limiter."

"A negative feedback limiter?" repeated Dick incredulously. "When it connects to chassis?"

"Dear, oh dear," sighed Smithy. "It's impossible to give you any further gen on those two components without going into the business of explaining how the whole amplifier works. So I suppose I'll have to do just that. Well now, let's start at the beginning. As you can see, the a.f. input from the volume control, which forms the diode detector load, passes to the base of the first AC127. Right?"

"Right."

"Good," said Smithy. "I'm glad you're not lost up to now. As you continue along the circuit you'll notice that the collector of the first AC127 drives the base of the OC81D. If, for the time being, you forget about the resistor and the thermistor between the two output transistor bases, you can see that the collector of the OC81D connects directly to the bases of those two output transistors. These transistors are nothing other than simple common-or-garden emitter followers. When the OC81D collector goes negative during negative half-cycles of a.f. so also do the base and emitter of the OC81. The AC127 at the bottom is then cut off. On the other hand, when the collector of the OC81D goes positive during positive half-cycles, so also do the base and emitter of the AC127. This time it's the OC81 that's cut off. What you've got, in consequence, is a basic transistor Class B arrangement, with one transistor handling negative half-cycles and the other transistor handling positive half-cycles."

"I see," said Dick, frowning at the circuit diagram. "I suppose the resistor and thermistor in series between the two output transistor bases will be the usual components you get in transistor output circuits. You know, the ones which allow the transistors to be slightly conductive under quiescent conditions."

"That's right," confirmed Smithy. "The output transistors need to pass a small current under quiescent conditions so that the change-over from one output transistor to the other on alternate half-cycles is smooth and doesn't introduce distortion. They provide the normal forward bias found in all Class B transistor output circuits. The next point to notice is that the two output emitters couple to the speaker via a 400μF electrolytic."

"There's a 1.2kΩ resistor coupled to that speaker as well," observed Dick. "Its other end goes to the base of the OC81."

"That resistor," stated Smithy, "is the collector load for the OC81D. Since the resistor is connected to the speaker, its speaker end goes positive and negative in sympathy with the a.f. voltage on the collector of the OC81D, so that there's virtually a constant voltage across it all the time. This is a useful feature because on large negative excursions it allows an adequate base current to flow into the OC81."

"Why, so it does," said Dick. "Gosh, Smithy, there are quite a lot of crafty ideas in this circuit, aren't there?"

"It *is* an ingenious arrangement," agreed Smithy. "Let's look next at those two 3.3Ω resistors in the output emitter circuit. These are usually referred to as emitter stabilising resistors. Alternatively, you can look upon them as current limiters which prevent the output transistors from passing excessively high currents. They function in conjunction with the resistance between the bases provided by the thermistor and the 56Ω resistor."

"What about that 200μF electrolytic and 4.7Ω resistor in series I asked you about at the beginning?"

NEGATIVE FEEDBACK

"I'll be getting to them shortly," promised Smithy. "But, before I do, take a look at the 1kΩ resistor coupling the junction of the two 3.3Ω resistors back to the emitter of the first AC127. One of the functions of this resistor is to allow the d.c. operating conditions to be stabilised. As we've just seen, it's necessary for the junction of the output emitters to be at half-battery voltage. Now, the potential at that junction is controlled by the potential on the base of the first AC127. Indeed, you've already seen how the output emitter potential drops when, due to a fault condition, the potential at the base of the first AC127 drops. In our circuit that base potential is controlled by the 12kΩ resistor which we replaced, and by the 22kΩ resistor below. The base potential, in its turn, controls the potential of the AC127 emitter. If, for any reason, the emitter of the first AC127 tends to go positive so also, by an amplified amount, does the collector. This causes a further-amplified excursion, but in the negative direction, at the collector of the OC81D, with a similar excursion at the output transistor emitters. Thus, the original positive change at the emitter of the first AC127 becomes cancelled out by an amplified negative excursion fed back to it via the 1kΩ resistor. The circuit similarly stabilises itself against negative changes at the emitter of the first AC127."

Smithy paused and drank deeply from his mug.

"As you can see, then, that 1kΩ resistor provides negative feedback at d.c. and stabilises the whole circuit so far as d.c. potentials are concerned. It also provides negative feedback at a.f. but, if the 1kΩ resistor were left in circuit on its own, the a.f. feedback would be so high that the circuit wouldn't give any useful amplification. That's where the 200μF electrolytic and 4.7Ω resistor you've been nagging me about come in. At a.f. these form what is effectively a potential divider with the 1kΩ resistor in the upper part and the 4.7Ω resistor below (Fig. 4), so that a.f. negative feedback, whilst still present, is considerably reduced. To be pedantic, it would be more correct to explain this process by saying that the 4.7Ω resistor passes feedback current which would otherwise flow in the emitter of the first AC127, because

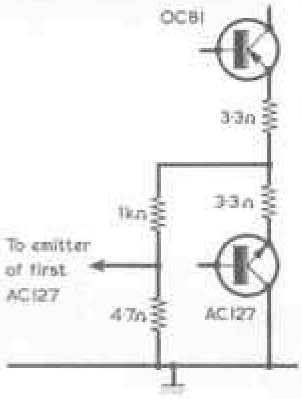

Fig. 4. At audio frequencies, negative feedback to the emitter of the first AC127 is effectively applied in the manner shown here

the effect is more in the nature of a current operation than a voltage operation. But the potential divider concept should enable you to initially grasp the idea more easily."

"Yes, it does help," agreed Dick. "You seem to have almost completely cleared up this circuit for me, Smithy. There's just a couple more questions I've got to put to you."

"Fire away!"

"What's that 2,000pF capacitor between the output emitters and the base of the OC81D for?"

"It provides top cut," explained Smithy. "Or, to use the more posh expression, 'tone correction'. The output emitters and the base of the OC81D are out of phase, and so the capacitor is in a frequency-selective negative feedback loop. It feeds back more signal at the higher frequencies, where its reactance is lower."

"Well, that's simple enough," remarked Dick. "Finally, what about that 330Ω resistor across the speaker?"

"That resistor is not just across the speaker," Smithy corrected him. "It's connected across the speaker and the closed-circuit phone jack that's in series with the speaker. Its purpose is to prevent excessively high a.f. voltages appearing at the output emitters if someone should plug in high resistance phones and then turn the wick up. You wouldn't need the resistor if the phone jack was omitted and the speaker connected directly to the 400μF electrolytic."

HOME CONSTRUCTOR VERSION

"Well, it's certainly a jolly useful audio amplifier circuit," remarked Dick.

"What I find mildly surprising is that you, as a service engineer, carry on as though you've never seen it before," stated Smithy. "It's an extremely popular circuit amongst set-makers and you'll find it used in a large number of portable transistor radios, as well as in more powerful mains-driven sets *and* car radios. Naturally, the transistors in these other applications are types chosen to suit the power output required. Also, different manufacturers use different makes of transistor and they play about with component values and minor circuit details as well. I should mention that there's a less frequently employed version which still has the complementary output transistors

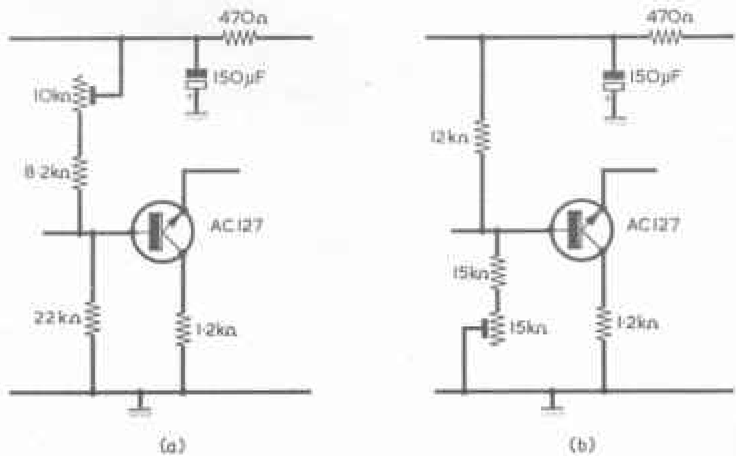

Fig. 5. If the circuit of Fig. 1 were used for a home-constructor project, it would be advisable to have the base bias for the first AC127 adjustable, using either the method of (a) or that of (b). All fixed resistors may be 10% tolerance

but which has feedback coupled back to the base of the driver transistor. With our circuit the driver is the OC81D. In the alternative circuit the first transistor is then just an ordinary a.f. amplifier and doesn't enter the feedback loop. Returning to the circuit in this service manual, I must point out that this has no adjustment for quiescent d.c. output potential. Such an adjustment is provided in a large proportion of sets using the circuit, and is given by replacing one or other of the base bias resistors for the first transistor by a preset potentiometer and smaller fixed series resistor. (Fig. 5). The preset pot is then adjusted to give half-battery voltage at the junction of the output emitters. If you were thinking of making up an amplifier like this as an amateur project, I'd definitely advise the inclusion of a preset pot for adjusting the d.c. potentials in the circuit. It would be difficult to guarantee that these would be correct using fixed resistors under home-constructor conditions. Also, you could replace the resistor and thermistor in series across the output bases with a 200Ω preset pot (Fig. 6), this being set up to give a current in the output transistors of some 5mA or so under quiescent conditions."

"What about matching the output transistors?"

"The beauty of this circuit," said Smithy in reply, "is that the output transistors don't have to be closely matched. That's because they both act simply as emitter followers. If you're unlucky enough to use two badly matched transistors, you can still guard against distortion by increasing their quiescent current a bit."

A TOUCH OF CHEER

"It's certainly an interesting circuit," said Dick. "Thank you very much, Smithy, for giving me all the gen on it."

Smithy looked suspiciously at his assistant.

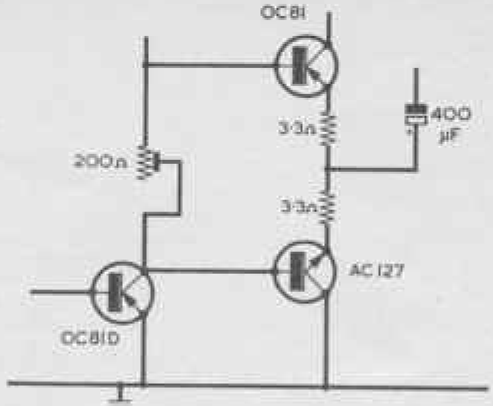

Fig. 6. The thermistor and 56Ω resistor of Fig. 1 can be replaced by a preset potentiometer

"You're getting very polite all of a sudden, aren't you?"

"That's because," replied Dick, "today is Christmas Eve and this is the Season of Goodwill to all men, mate."

"Well," chuckled Smithy, "I must admit that I'm beginning to feel all festive again myself now. Any more technical questions?"

"None at all."

"Hooray."

The Serviceman, freed at last from his technical responsibilities, gazed around the Workshop with eyes that were more ready to appreciate Dick's early-morning endeavours.

"You must," commented the Serviceman, "have put quite a lot of work into putting up those decorations."

Dick looked lovingly at the fruits of his labour.

"The worst part," he replied, "was blowing up those flaming balloons. It nearly creased me, mustering up all that puff first thing in the morning."

Smithy turned a further approving glance at the decorations, then stooped down and rummaged mysteriously in the cupboard under his bench. He straightened up, and there was the cheerful tinkle of bottle and glass.

"I think," he remarked as he carefully filled two glasses, "that a little something to celebrate the coming of Christmas and the end of work is now called for. Here you are, Dick my boy, and let me wish you a very Merry Christmas to go with it as well."

"Thanks, Smithy," said Dick warmly, as he sipped at his glass, "and the same to you."

"Thank you," replied Smithy. "Well now, let's be upstanding for our special annual toast."

The pair stood and held up their glasses.

"Let us," announced Smithy, "wish a really Happy Christmas to all the readers who've put up with our antics during this last twelve months. A truly Merry Christmas to you all."

They both drank deeply.

"And," added Dick. "Let us end, as we have done on so many previous Christmasses, by saying 'God Bless Us, Every One!'."

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