In your work-shop

As usual, Christmas Eve finds Smithy the Serviceman, aided by his able assistant, Dick, working hard on the inevitable rush of receivers which have to be made ready by Christmas Day. Nevertheless, the pair still manage to finish early enough to enable Smithy to conclude the discussion on microphones which he commenced last month

IT WAS THE DAY BEFORE Christmas. It was the time of Christmas cards, of Christmas decorations, of Christmas presents and of Goodwill to All Men. It was the time of office parties, unaccustomed cigars, snow, public house extensions and the entertainment of mothers-in-law. It was the time of preparation of vast quantities of turkey and of duff; whose consumption would be accompanied by unwonted draughts of sherry, gin or vodka; and it therefore heralded the period of testy lassitude, dyspepsia, throbbing heads and fizzing Alka-Seltzers which would inevitably follow.

Christmas: season of *schmaltz* and sallow slothfulness.

On this Christmas Eve both Smithy the Serviceman and his assistant Dick had decided to give the festivities a miss. On the previous year Dick had laboured extensively in providing and putting up decorations for the Workshop, and had then flatly refused to take them down again afterwards. Those decorations had been the cause of harsh words between the two, and they both looked back upon the incident with suppressed bitterness. By tacit consent Workshop business was, this year, carried on as usual: the benches were unsullied by Christmas cards or by any other concessions to the Yuletide spirit, and the whole place had the brisk and bustling atmosphere of an efficient servicing establishment, with no nonsense about it.

CARBON MICROPHONE

And the work *was* brisk, too. As happened every year at this time the pair were inundated with faulty TV sets, record-players and radios which had, for some strange unaccountable reason, all decided to cease operation in the few days preceding Christmas. It was not until the afternoon was half-way through that they were able to clear up the last set and to carry it proudly over to the heavily laden 'Repaired' racks.

"Phew," said Smithy, mopping his brow as he collapsed upon his stool. "These Christmas Eves get worse as the years go by."

"It was certainly a stinker today," agreed Dick. "Thank goodness there are no more sets to do until after Christmas."

"Thank goodness, indeed," echoed Smithy. "And thank goodness also that we haven't bothered to go all Christmassy this year. I'm certain that we'd never have been able to finish as early as we have done if we hadn't treated today just like any other working day."

"There's little doubt about *that*," confirmed Dick. "In any case, what's so special about today? It merely happens to be the 24th of December, that's all."

"True," agreed Smithy. "What's more, since we're treating today just the same as any other day, I'm going to finish it off by having a little gen-session with you."

Dick's jaw dropped open.

"You're *offering?*"

"I am," confirmed Smithy gravely. "You may recall that during our last little natter together we discussed microphones, and I said that I'd continue with that subject at a future date. This was because I wasn't able at that time, to cover all the microphone types that are available."

"Blimey, Smithy," said Dick appreciatively, "this really *is* unexpected. Well, the last time we talked about microphones you told me about the moving-coil, crystal and ribbon types. What other sorts of microphone are there?"

"Quite a few," replied Smithy. "To start off with, I'll deal with one of the commonest microphones that's going. This is the carbon microphone which is, of course, employed in telephone handsets. We don't use carbon microphones very often in normal electronic work but it's nice to know something about them nevertheless. You can sometimes obtain G.P.O. type carbon microphones in handsets sold by surplus stores and you can get quite a bit of fun playing around with these. I want to sketch out a few of the things I'm going to talk about, so would you please come over to my bench?"

Obediently, Dick picked up his stool, carried it over to Smithy's side and perched himself on it. Smithy had already pulled his note-pad towards him and was scribbling on the top sheet. (Fig. 1)

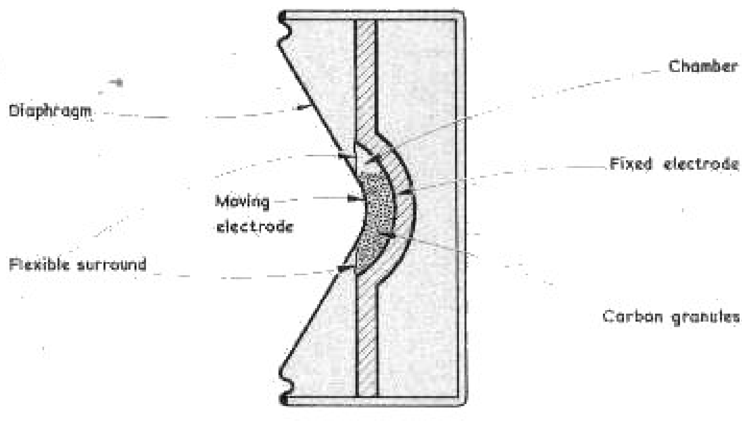


Fig. 1. The basic construction of the carbon microphone

"Here's the basic set-up for a carbon microphone," he announced. "There's a fixed electrode and a moving electrode, the latter being atttached to the diaphragm. Between the two electrodes is a space or 'chamber', this being nearly filled with fine particles of carbon, which are called 'granules'."

Smithy stopped for a moment and drew a further sketch. (Fig. 2)

"When you speak into the microphone," he continued, "the diaphragm moves in and out in sympathy with the sound waves, as also does the moving electrode. The resistance between the two electrodes, which is given by the contact resistance between the carbon granules, then varies. It goes down when the moving electrode moves inwards and causes the granules to be more tightly compressed, and it goes up when the moving electrode moves outwards and reduces the pressure on the granules. If the electrodes are connected in series with a battery and the primary of a transformer, the varying resistance causes the current in the primary to change at the audio frequency impressed upon the diaphragm. That audio frequency then becomes available, as an alternating voltage, from the secondary of the transformer."

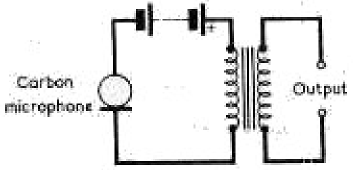


Fig. 2. Connecting the carbon microphone into a working circuit

"Yes, I see," said Dick. "There are one or two things that I'm not too sure about here, though. For instance, does the microphone always exhibit the same average resistance?"

"Oh no," replied Smithy. "Every time the microphone is moved in any way the granules flow into new positions and so the average resistance offered by the microphone can vary quite considerably whilst it is being used. Because of this random movement of granules a carbon microphone introduces a lot of background noise. Incidentally, modern telephone carbon microphones are designed to ensure that there is always a mass of granules between the two electrodes for all reasonable positions of the microphone. This is achieved by careful design of the shape of the chamber which holds them. Funnily enough, it is a good thing to move a telephone carbon microphone around a bit every now and again, as is given by lifting and replacing the handset when making a telephone call, because this keeps the granules mobile and prevents them packing."

"Packing?"

"Packing," confirmed Smithy. "If they aren't moved around occasionally they tend to pack, or settle down into a semi-solid mass, and the microphone then becomes very inefficient."

"How do they make the granules? Do they chop up bits of carbon?"

"Oh no," replied Smithy. "Ordinary carbon isn't hard enough to be used for microphone granules; it's much too crumbly and it tends to break up into dust. What they use nowadays, believe it or not, is powdered anthracite coal. This is crushed and ground and the subsequent granules are sorted out for size and given a special heat treatment. A typical granule, by the way, is of the order of seven or eight thousandths of an inch in diameter. And that's pretty well enough about carbon microphones. They have the disadvantage of introducing distortion and they offer a noisy background, and it is for these reasons that we don't normally employ them in electronic work."

"Why do the Post Office use them so much, then?"

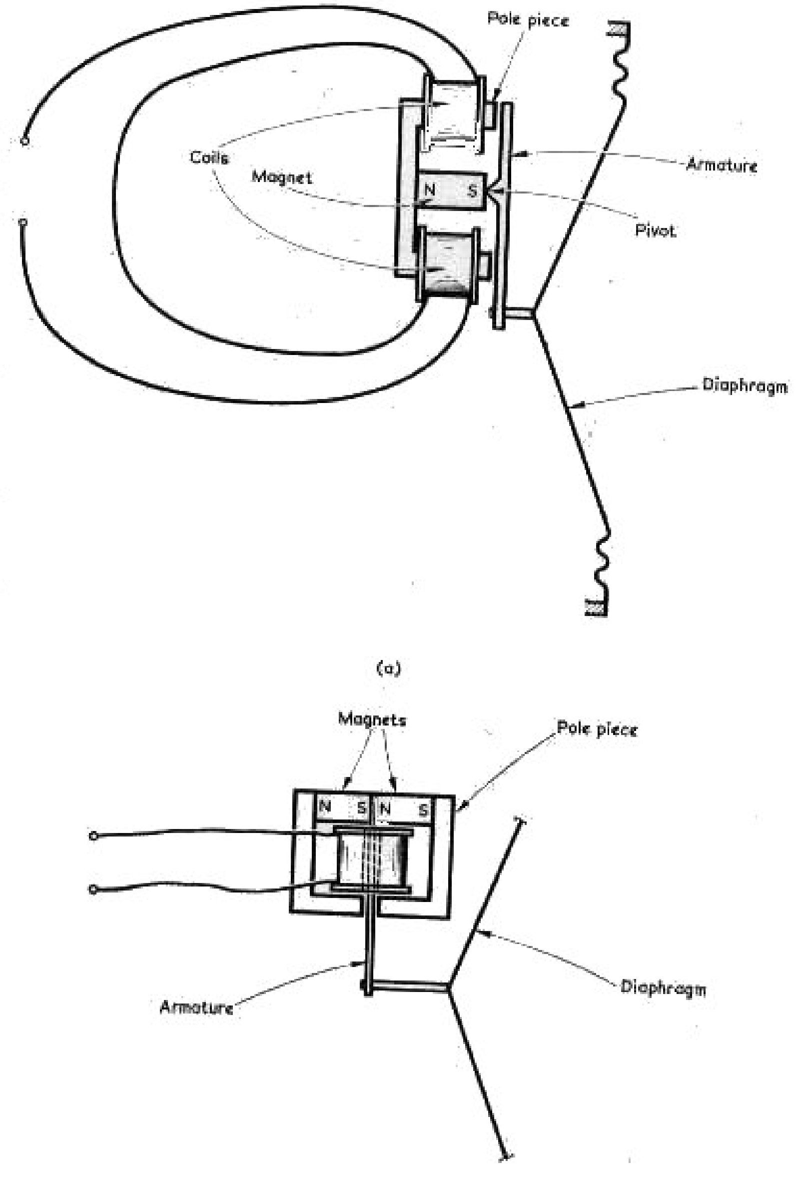
"Because they're inherently self-amplifying. The sound waves do not have to generate the corresponding electrical signal directly, as occurs with other microphones; they merely have to modulate a standing electric current. As a result, carbon microphones offer very much higher electrical outputs than other types of microphone, and it is this factor which makes them so useful for telephone applications."

ROCKING-ARMATURE MICROPHONE

Dick looked momentarily out of the window. It was already beginning to get dark and a few snowflakes were falling, forming an irregular outline at the lower part of the window-frame.

"Think of all those twits outside," he remarked scornfully. "All of them charging around getting last things in for Christmas. They should be like us and just ignore it."

"True, true," said Smithy, preoccupied. "But let's keep on with this microphone business. Now, I want to clear up a few other sorts of microphone next. These fall into the category of moving-iron microphone. Many of them are virtually the same in basic design as an ordinary magnetic headphone. Indeed, a headphone, particularly one of the large 2,000Ω types, makes quite a useful microphone if you're prepared to accept the low quality it offers. It can offer a surprisingly



(b)

Fig. 3(a). The method of operation of the rocking-armature microphone. (b). In balanced-armature microphones the armature is positioned centrally between opposite magnetic polarities, as in the typical example shown here. The coil is fitted around the armature but need not be mechanically secured to it

high a.f. output."

"I seem to have heard a lot recently," remarked Dick, "about rocking-armature headphones and microphones. Are these moving-iron types?"

"Oh, definitely," said Smithy. "Both the headphone and the microphone have the same basic construction, which consists of an armature which is free to rock between a central magnet and two pole pieces. Here's the general idea."

Smithy scribbled out a sketch illustrating the rocking-armature construction. (Fig. 3(a).)

"As you can see," he went on, "when the armature rocks in one direction it increases the flux density in one pole piece and decreases it in the other. The alterations in flux density then induce currents in the coils wound on the pole pieces. These coils are connected in series and the electrical a.f. signal corresponding to the sound which actuates the armature then appears at the two outside terminals. As with the other moving-iron microphones, the rocking-armature type does not feature very often in present-day electronic work. There are other types of moving-iron microphone, too, of which the balanced-armature type represents an example. A typical balanced-armature construction is like this."

Smithy scribbled another diagram. (Fig. 3(b).)

"And that's all the attention we need give to moving-iron microphones," he resumed. "So let's get on to the next type."

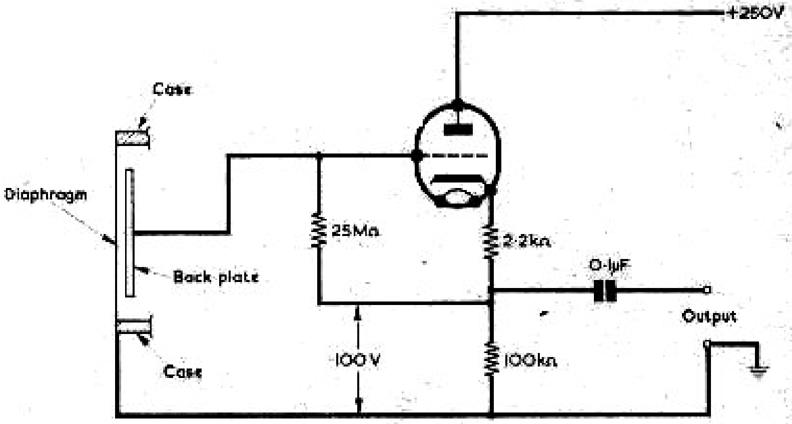


Fig. 4. The capacitor microphone consists essentially of a metal or metallised diaphragm positioned very close to a fixed back plate. This rather early valve head amplifier circuit serves to demonstrate the resistances and voltages required for successful operation

CAPACITOR MICROPHONE

"What type is that?"

"The capacitor microphone," replied Smithy, "or, as it is still quite frequently referred to, the condenser microphone. This consists fundamentally of a flat diaphragm made of a conducting material which is positioned very close to a flat metal back plate. The diaphragm and back plate are insulated from each other, and they constitute a capacitor."

"Oh, I see," interposed Dick. "I suppose that the diaphragm moves under the influence of sound, with the result that the capacitance changes in sympathy with that sound."

"That's the idea," confirmed Smithy. "Now, the average capacitance between the diaphragm and the back plate is small and the deviations in capacitance are even smaller, and so the leads connecting the diaphragm and the back plate to the subsequent amplifier need to be kept very short. In consequence, what is described as a head amplifier is built into the case of the microphone itself. In most instances, nowadays, the head amplifier incorporates a field-effect transistor, but let's start off by taking an example of the older type of microphone in which the head amplifier employed a valve. This is because the valve circuitry makes a good introduction to the basic principles involved."

Smithy pulled his pad towards him once more, and proceeded to sketch out a circuit diagram. (Fig. 4).

"As you so rightly said just now," he went on, "the capacitance in the capacitor microphone varies with the movement of the diaphragm. We want to convert these capacitance changes to voltage changes and the only way we can do that is to charge up the capacitor and do our best to see that it cannot discharge quickly. We have to ensure that it cannot discharge at a rate which is comparable with the time taken up by half a cycle at the lowest audio frequency we want the microphone to handle. If the capacitance is able to discharge too quickly, reproduction of the lower frequencies will be reduced."

"It would seem," said Dick "that whatever discharge takes place occurs by way of some sort of resistance. Would it be safe to say that it would be in order to reduce the value of this resistance if the value of the capacitance between the diaphragm and the back plate could be increased?"

"It would," agreed Smithy. "In fact that's quite a shrewd remark on your part."

"And," continued Dick, encouraged, "do we get a voltage change when the capacitance changes because of this business of a capacitive charge being equal to voltage multiplied by capacitance?"

"Blimey," said Smithy, impressed, "you *are* with it today. You're quite right, too; the situation is governed by the equation $Q = CV$, where Q is the charge in a capacitor in coulombs, C is the capacitance in farads and V is the voltage which caused the charge to be taken up. If the charge doesn't leak away, changing the capacitance *must* vary the voltage across the capacitor. Now let's get back to that circuit I drew out a few moments ago. If you look at this, you'll see that the capacitor microphone diaphragm and back plate connect between earth and the grid of a triode valve. The voltage which causes the diaphragm and back plate to acquire the charge is the 100 volts which appears across the resistor in the cathode circuit of the valve. This is known as the polarising voltage and it is applied to the diaphragm and back plate via a 25MΩ grid resistor. Thus, the capacitor microphone has a voltage of 100 volts across it. The capacitance between the diaphragm and back plate of a capacitor microphone is of the order of 50pF only, which corresponds to a reactance of about 30MΩ at 100Hz, and we might at first sight expect that the response at this frequency would be seriously down when the discharge resistor is only 25MΩ, as it is in my diagram. However, there is a form of boot-strapping at the cathode of the triode, and the lower end of the 25MΩ resistor follows the voltage changes across the diaphragm and back plate when the diaphragm moves. So, when the voltage across the diaphragm and back plate capacitor increases so also, by nearly the same amount, does the lower end of the 25MΩ resistor, and the discharge current due to the increased voltage becomes much lower than it would have been if the lower end of the resistor had stayed at a fixed potential. In other words, the discharge circuit presented to the capacitor is, effectively, considerably higher than the physical value of the grid resistor."

"That seems fair enough," said Dick brightly. "The only snag so far as I can see is that even if you do get the grid resistor value down to 25MΩ there are still liable to be troubles due to leakage resistance between valveholder tags, and so on."

"That's very true," confirmed

Smithy. "One of the difficulties with capacitor microphones employing valve head amplifiers has been the necessity of keeping valve and valveholder leakage resistances to as high a level as possible. Apart from attenuating the bass response, such leakage resistances are liable to introduce noise. At least one design overcame this problem by completely encapsulating the head amplifier, including the valve, in a block of resin. Another trouble resulting from the use of a valve as head amplifier is microphony in the valve. Yet a further snag is the necessity of supplying the valve with heater and anode currents."

"I suppose," remarked Dick, "that all these difficulties are removed if the valve is replaced by a field-effect transistor."

"They're certainly considerably eased," said Smithy. "But, before getting on to the f.e.t. head amplifier let me quickly show you a cunning circuit that was occasionally employed with valve head amplifiers when it was necessary to couple the microphone to the head amplifier by a short length of screened cable. The circuit isn't applicable to present-day capacitor microphone techniques but its basic method of operation lends itself to lots of other applications where it's necessary to screen a high impedance a.f. signal coupling lead, and where you don't want a high cable self-capacitance to be connected across the source of the signal."

Smithy tore the top sheet from his note-pad and drew out the circuit. (Fig. 5).

"Here you are," he announced. "This circuit is the same as the last one I sketched out, with the exception that the microphone is now coupled to the head amplifier via screened cable. Note that the cable isn't of the ordinary type. Instead, it's of the double-screened variety and consists of a central conductor and two concentric screens. The outside screen connects to earth, whilst the inside screen couples to the cathode of the head amplifier. We now have the same sort of effect as we had with the grid resistor. When the voltage from the capacitor microphone increases so, by very nearly the same amount, does the voltage on the inside screen. Because of this, charge and discharge currents into the self-capacitance between the centre conductor and the inside screen are very much smaller than would be given if the inside screen were at fixed potential, and the effective capacitance between the centre conductor and the inside screen is considerably reduced. There will, of course, still be a relatively high self-capacitance between the inside and outside screens, but this couples across the low output impedance of the cathode follower and, assuming reasonable component values, has little effect on the overall response."

F.E.T. HEAD AMPLIFIER

"Gosh, that's neat," said Dick enthusiastically. "You could use that approach in all sorts of circuits where you want to take a low-capacitance a.f. screened coupling from one point to another."

"You could, indeed," agreed Smithy. "And, of course, the valve cathode follower could be replaced by a transistor emitter follower or by an f.e.t. source follower."

He looked at the Workshop clock and gave a sigh a satisfaction.

"Only an hour to go before official packing-up time," he remarked

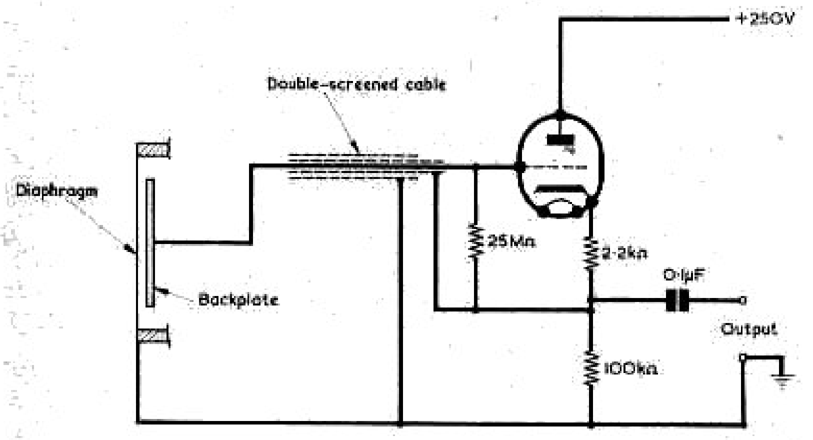


Fig. 5. A screened coupling to the microphone is permissable if double-screened cable is employed in the circuit shown here

contentedly. "After that we close down for the holiday."

"Good show," responded Dick. "I suppose we'll then have to fall in with everybody else and put up with all this Christmas business."

"I suppose so," said Smithy resignedly. "Still, it will soon be over, and everything will be back to normal again afterwards."

"I can hardly wait," commented Dick. "I've got really disenchanted over Christmas these days. It's just a period of commercial exploitation."

"Exactly," agreed Smithy. "For instance, just look at the price of Christmas cards. I bet somebody's making a bomb there."

"It's the same," grumbled Dick, "with all the other things people get at Christmas time. All those nuts and dates and figs and things."

"They only give you indigestion."

"Of course they do."

The pair fell silent for a moment as they pondered on the excesses of the Festive Season.

"Oh well," said Smithy eventually. "Let's get back to these capacitor microphones."

"Right-ho," replied Dick wearily. "Well, we've cleared up the capacitor microphones which use valve-head amplifiers. What about those with f.e.t. head amplifiers?"

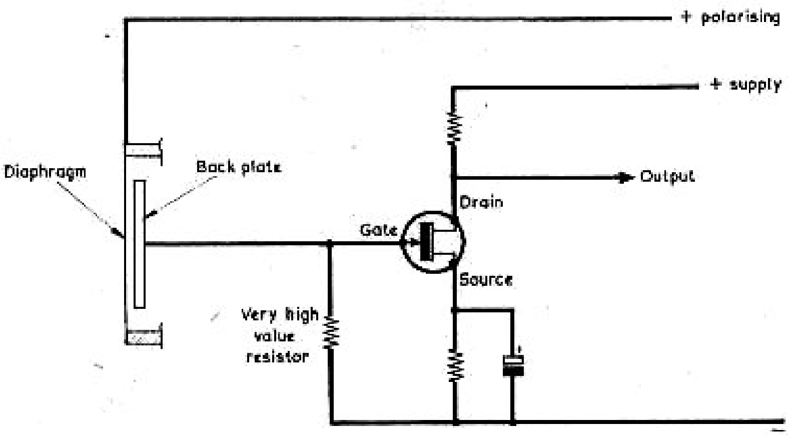
"Capacitor microphones with f.e.t. head amplifiers," stated Smithy, "represent a considerable improvement on those with valve head amplifiers. Indeed, one could hardly conceive of a device more suited for use with a capacitor microphone than the f.e.t. It has exceptionally high input impedance, it works at relatively low supply voltages and currents, it does not require a heater supply, it's small, and it is non-microphonic. With all these advantages, the f.e.t. is virtually custom-built for the job."

Smithy leaned over and scribbled out yet a further circuit. (Fig. 6(a).)

"Here's one method of coupling the diaphragm and back plate of the capacitor microphone to an f.e.t.," he resumed. "The polarising supply, which needn't now be much more than 50 volts or so, is simply applied via the microphone to the gate of the f.e.t., this being taken to the negative supply rail by way of a very high value of resistor. The f.e.t. has source bias, which is provided by a resistor and capacitor in the same way that cathode bias is applied to a valve. The signal can then be taken off from the drain."

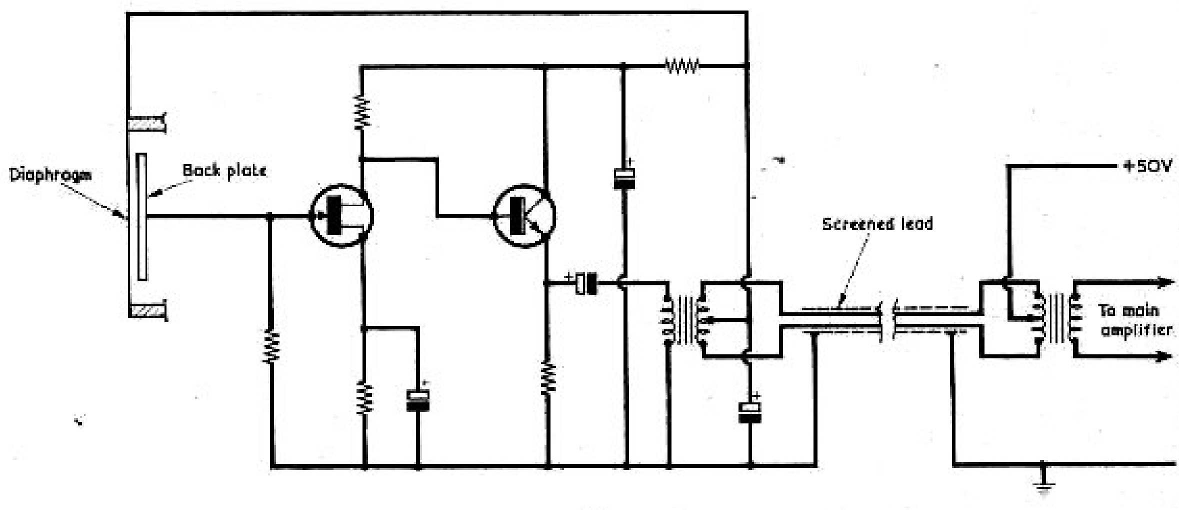
"How about supplying the polarising voltage?"

"That can be done by way of the output cable," said Smithy, sketching out another circuit. (Fig. 6(b).) "What I'm drawing now shows a typical f.e.t. head amplifier in its



(a)

Fig. 6(a). Coupling the capacitor microphone to a field-effect transistor. An n-channel f.e.t. is assumed



(b)

(b). A typical f.e.t. head amplifier with emitter follower transistor. Both the polarising voltage and the transistor supply current are applied via the screened lead coupling the microphone to the main amplifier

complete form. In this version I've included a transmitter emitter follower after the f.e.t. to provide a really low output impedance. The emitter follower is coupled to an output transformer which then feeds into a screened cable having two cores. The polarising voltage is fed by way of centre-taps in the secondary of the output transformer and the primary of an input transformer at the main amplifier end of the cable. This polarising voltage is also the supply for the two transistors, being dropped to a suitable value by a resistor in the head amplifier. The supply current flows in opposite directions in the two halves of the centre-tapped transformer windings so that the two fields cancel out in the transformer cores. The transformers can, therefore, be quite small components since their cores only have to handle the alternating a.f. currents."

"I see," said Dick thoughtfully. "Incidentally, there's something that's just occurred to me."

"What's that?"

"Well," continued Dick, "If the microphone works by changing sound waves to a varying capacitance, couldn't that varying capacitance be used to frequency modulate an oscillator by having it in the oscillator tuned circuit?"

"Certainly it could," confirmed Smithy. "Indeed, several designs of head amplifier, both for valves and transistors, have employed the frequency modulation idea, the f.m. signal frequently being demodulated in the head amplifier unit itself. This approach has the advantage that no polarising voltage is required. However, it is probable that, with the advent of the f.e.t. and the very simple a.f. circuitry with which it can be used, f.m. head amplifiers will be ousted by f.e.t. amplifiers of the type we've just discussed."

ELECTRET MICROPHONE

"The idea certainly seems to be simple enough," agreed Dick. "Let's get back to the diaphragm and back plate. What material is used for the diaphragm?"

"In the earlier days," said Smithy, "it used, in most cases, to be a thin sheet of aluminium alloy. At present, though, it is more common to use a thin sheet of plastic which has had a layer of gold or aluminium sputtered on to one of its surfaces. The plastic sheet is fitted to the microphone with the conducting surface away from the back plate, so that there is no risk of the two short-circuiting together. Since a volume of air is trapped between the diaphragm and the back plate, the latter may have slits or holes cut into its surface to reduce the damping effect on diaphragm movement which would otherwise be given. A more modern approach consists of employing a back plate made of a porous material."

"I should imagine," remarked Dick, "that the plastic used for the diaphragm has to be pretty tough."

"It has to be extremely tough," replied Smithy. "It is stretched very tightly when the microphone is assembled, and it must not lose its tension afterwards despite widely varying changes in the temperature around it. Also, great care has to be taken to ensure that it doesn't pick up electrostatic charges. If it picked up an electrostatic charge which, at the inside surface of the plastic, was of opposite polarity to the polarising voltage, the microphone wouldn't work properly. Electrostatic charges of this nature are known as 'electret' effects, which brings me to yet another type of microphone."

"Which one's that?"

"It's a relatively new type which purposely employs electrostatic charge principles," explained Smithy, "and it is in fact *called* the electret microphone. To be precise, I should tell you that an electret is the electrical version of a magnet, and that it consists of a material holding a continual charge and exhibiting opposite poles of electricity on two opposite ends or surfaces. It is possible to get certain plastics to act as electrets, and they hold their charge in just the same way as a magnet holds its magnetism. An electret microphone is built in the same way as a capacitor microphone, but it requires no polarising voltage since the diaphragm is an electret consisting of a sheet of plastic material exhibiting opposite polarities on its two surfaces. The outside surface of the plastic diaphragm is metallised, as with the capacitor microphone, and this metallising forms one of the microphone terminals. The other terminal is the back plate. In other words, the electret microphone is basically the same as a capacitor microphone with the exception that it has its polarising voltage built in, as it were."

"How do they get the plastic polarised?"

"The material is heated whilst being kept in a strong electrostatic field," replied Smithy. "For the thin films required for electret microphones, the plastic can be placed between two metal sheets, a high voltage then being connected across them."

CHANGE OF HEART

With a gesture of finality, Smithy pushed his note-pad away from him.

"And that," he announced, giving a sigh of relief, "is that. No more electronics till after Christmas!"

"Fair enough, "said Dick equably. "In any case I think I've picked up enough gen on microphones for the time being."

He sat quietly for several moments then, on a sudden impulse, walked over to the 'Repaired' rack, where he picked up a little transistor radio and switched it on. Inevitably, it reproduced Bing Crosby's rendering of 'I'm Dreaming of a White Christmas'. Dick irritably switched the radio off again and replaced it on the rack.

Silently, he walked back towards Smithy and sat down once more. The pair looked around the Workshop, which had suddenly acquired a bleak and desolate aspect.

"I'm beginning to wonder," said Dick morosely, "if we haven't been overdoing this anti-Christmas attitude a bit. It might be all right trying to ignore the Christmas spirit, but it doesn't half leave you feeling cheesed-off!"

"It does rather, doesn't it?" agreed Smithy. "I'm thinking that a change of heart wouldn't be a bad idea, too. So, let's start getting Christmassy now, even if it *is* a bit late in the day."

He got down from his stool and began to rummage mysteriously in the cupboard below his bench. There was the cheerful tinkle of glass and bottle.

"Why, Smithy, you old devil," exclaimed Dick. "You had the stuff hidden away there all the time!"

"I always believe in being prepared," chuckled Smithy, as he carefully filled the two glasses he had produced. "I had an idea that we wouldn't be able to keep up our stand against Christmas for too long. So here you are, Dick, and a very Merry Christmas to you as well."

"Thank you, Smithy, "responded Dick warmly, as he took the glass from Smithy, "and the same to you, too."

"Thanks, my boy," replied Smithy, "and, now, let us be upstanding for our annual toast."

They stood and raised their glasses.

"Let us wish the Compliments of the Season," pronounced Smithy, "to the readers who've put up with us through all of 1971. A truly Happy and Merry Christmas to you all."

They both drank deeply.

"And," said Dick, "it wouldn't be a proper Christmas if I didn't end, as I have done on so many previous years, by adding 'God Bless Us, Every One!'" ■

The cartoons appearing in this issue were based on ideas submitted by B. H. Baily.