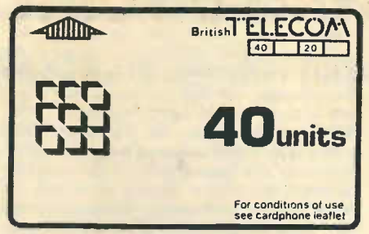
Cardphones — towards a cashless society?

Major London railway and tube stations are to have Cardphones installed in a trial for what British Telecom call "a step towards the cashless society." But before you get too excited, cashless does not mean broke – Cardphones eat Phonecards and that means purchasing either forty or two-hundred 5p units in advance.

A Phonecard is a piece of plastic similar to a credit card with 'holographically memorized' call units printed on it. As a unit is used up, so that unit is erased, but a warning is given twenty seconds before the last unit runs out to give you time to fumble for a new card, say goodbye or utter an expletive (Cardphones don't accept coins). Throughout a call, though, a readout tells the caller how many units are left without making a call by simply inserting the card in the slot – completely free of charge!

Long, consecutive and overseas calls to countries now on the direct dialling system are not hampered by the insertion (and availability) of coins, but if you make one call directly after another you still lose any remaining parts of a unit, as is the case with present domestic and public telephones.



Each card has one or two tracks, depending on its price, on which the call units and other information are printed. The extra information tells one of the two microprocessors used in the system whether or not the card is acceptable, i.e., whether British Telecom intended the card for making public calls and whether the card is indeed issued by them and not by any other authorities with similar systems. Belgium and Austria already have such systems and the French are making trials.

The call units are read by a configuration of infrared detectors that pick up reflected light from the coded patterns on the card. As a unit is used up it is erased thermally.

A second microprocessor looks after the normal routine of the dialling system and allows normally free calls such as '999' and directory enquiries to be made without the use of a card. The system was developed in Switzerland by Sodeco, a subsidiary of the Landis and Gyr Group who are now supplying the apparatus to British Telecom.

Initially around 120 Cardphones are being installed in London and another 80 or so will appear in Birmingham, Glasgow and Manchester. Phonecards will be available from post offices and some retail outlets including railway station bookstalls and fare counters.

Small wavelengths — large doubts

Over the years there has been much mild controversy in most western countries over the maximum safe level of microwave radiation. Recent news that an American body for workers' compensation defined the cause of death of a radio technician as chronic exposure to microwave radiation will hopefully invoke a closer look into the long term effects of these rays.

As in most Western countries, the maximum safe level in Britain for continuous exposure to microwave radiation is defined as 10mW/cm^2, a figure 1,000 times higher than that adopted by the Russians at 0.01mW/cm^2. Taking into account that the conditions associated with these figures are not exactly the same, the difference is still enormous.

Our maximum level is based on that determined by the Americans nearly 20 years ago. According to an International Electrotechnical Commission report† from 1979, the very large discrepancies between standards are due to differences in approach, namely that the USSR standards are based on the possibility of any noticeable biological effect, in contrast to thermal injury, and most western countries take the view that minor reversible effects are not necessarily hazardous to man. Also, say the IEC, the Russians have used very much larger safety factors than most other countries in defining their limit. As there is, even now, much doubt as to the long-term effects of microwave radiation, large safety factors seem a sensible precaution.

There are stumbling blocks in researching the effects of microwaves on humans, though, that could account for the uncertainty as to the 'safe level' of radiation. One problem appears to be the lack of a suitable guinea-pig; the position, size, density and material of every part of the body can be critical. Also, measurements made in the 'near field', i.e., the complex field close to the antenna which contains electric and magnetic components additional to those of the main propagation field, are difficult to interpret in terms of potential hazards.

According to the National Radiological Protection Board, frequency dependent limits have been proposed in the USA to bring down the maximum exposure figure to 1mW/cm^2 at frequencies where the radiation has the greatest effect on the human body. But only time will tell whether these new limits, if accepted, are safe, or indeed whether the old limits were on the safe side anyway.

● Research into electromagnetic coupling between a 'thin-wire' antenna and a biological body was reported in the IEEE's publication dealing with microwaves* last November. The research was carried out to assess the potential hazard of portable transmitters, especially those for c.b., and some interesting conclusions were drawn. According to the article, the power absorbed by a human adult standing 20cm away from an antenna with a 30W input at 90MHz or 140W at 27MHz is the same as would be absorbed from exposure to 10mW/cm^2 plane-wave irradiation. An average human adult standing 20cm away from a quarter-wave antenna operating at 20MHz will absorb about 8.5% of the antenna input power, but at 90MHz, over 50% of the input power will be absorbed as the average height of an adult is about a resonant length at this frequency. Electromagnetic coupling is increased considerably when the body is in contact with the ground, as opposed to being isolated, and the body may act as a director element when placed close to the antenna.

† IEC report number 657 'Non-ionizing radiation hazards in the frequency range from 10MHz to 300,000MHz.'

* IEEE transactions on Microwave Theory and Techniques, Volume MTT-28, Number 11 (part 1), 'Electromagnetic coupling between a thin-wire antenna and a neighbouring biological body', by K. Karimullah, K.-M. Chen and D. P. Nyquist.

Teletext goes commercial

You can now buy a page of text on Oracle, the six-year old ITCA teletext service, for a weekly rate of £400. That page would then be available to the 180,000 teletext-equipped sets throughout the UK, though the service will be available on a regional basis. First Scottish Television start their own input unit this autumn followed by Channel TV some time later, culminating in a fully regional service by 1984/5 that can offer local news as well as advertising – by which time the number of teletext sets is predicted to be 3,000,000. Oracle Television Ltd, formed last year by the ITV companies, will promote itself mainly through "filler" tv advertisements to the tune of £2 million-worth of tv "commercials" over a six-month period.

At about the same time – probably during the Department of Industry's teletext promotion in October – the number of Oracle lines will be increased from two to four. This allows the access time to be reduced typically from 45 to 20 seconds, which otherwise would become unacceptably long as the volume of text pages is increased. One feature of this new service is that certain advertising not permitted on television will be allowed on Oracle – from football pool promoters and bookmakers in particular.

Satellite on a string

Sounding rockets remain in the air for only a few minutes; low-altitude, non-propulsive satellites can gather data for a few hours before their orbits decay. A possible solution could be a low cost satellite tethered by a long (very long – up to 60 miles) super-strong cord to the NASA space shuttle.

Engineers from the Marshall Centre have been carrying out feasibility studies with space scientists from Italy for what could be the first US/Italian cooperative space project. The Italians could build the satellite and the Americans would supply the equipment necessary to handle it. The satellite, attached to the shuttle by the tether line, would be trolled through the Earth's upper atmosphere in a very low orbit, perhaps only 80 miles above the Earth, for an extended period. It would be used to gather data on the atmosphere, the magnetosphere and gravity. The system is likely to become operational by the mid 1980s.

Integrated circuit design

Understanding the nature of black boxes may make a significant contribution to circuit performance

by J. L. Linsley Hood

The starting point for this series of articles is the i.c. that perhaps has done most to encourage the application of op-amps as a simple, cost-effective solution to circuit problems.

Historically, the 741 device was introduced by Fairchild at the end of the 1960s, along with several other second-generation i.cs from rival manufacturers, as an internally-compensated improvement upon Bob Widlar's classic 709. In the Fairchild μA741, most of the minor operational problems of the 709 were reduced to an extent that they were no longer inconvenient in use, and the 741 then became a nearly ideal building block for low frequency applications.

Understandably, many of the internal circuit facilities such as output short-circuit protection were similar to, and inspired by the same requirements as, those being introduced in the discrete component audio amplifier designs current at the time. However, the standardization on the use of separate + and – supply lines, together with nearly identical inverting and non-inverting inputs and the use of circuitry which allowed a high degree of supply line isolation, presaged developments which the discrete component amplifier designs were not to adopt at all widely for many years.

I have shown the circuit, in very simplified form, in Fig.1, with the necessary apology that a simplification of this type inevitably takes liberties with the actual design, simply because a more accurate representation of its form would hardly be a simplification at all. For example, although I have shown the input transistors as a p-n-p long-tailed pair, because this is effectively how they operate, they are in reality a rather more complex arrangement to allow the use of a pair of n-p-n devices in the input stage – in a modified cascode connection – of a form which is identical to, and perhaps inspired by, a circuit proposed a couple of years earlier*.

The reason for this rearrangement, shown in Fig.2, is that it is very difficult in conventional bipolar technology to fabricate p-n-p transistors which have any respectable current gain h_{FE}, except in the case where the collector is electrically connected to the p-type substrate such as in the output device. Other p-n-p devices must be of the lateral type, as shown in Fig.3. These are robust, but generally have h_{FE} figures only in the range 5 to 25, depending on the skill of the manufacturer in defining small gaps in his diffusion masking.

In addition, great use is made in i.c. manufacture of current mirrors of one kind or another. These are circuit arrangements in which the output limb looks and behaves like a conventional high-impedance constant-current source, but with an output current controlled by an input current fed into its other limb from some external source. The output current then mimics or mirrors the input current. I have shown three of the more commonly used types in Fig.4†. The popularity of this type of circuit element in i.c. manufacture arises from the fact that resistors and capacitors are inconvenient to construct in any large values, whereas transistors and diodes are easy. Moreover, if a current mirror is used as a load, an improvement in gain can be won.

This allows, for example, better operation of an input long-tailed pair wherein the loss of gain due to the normal halving of the g_m of the input devices is recovered together with an improved equivalence of gain between the two inputs of the long-tailed pair.

The operation of this type of circuit, taking for example the simplest arrangement of Fig.4a, hinges on the fact that if a transistor is forward biased so that it passes a certain collector current, the voltage across its base-emitter junction will then be precisely that which is required to cause

*Linsley Hood, J. L., *Electronic Engineering*, March 1967. (Letters).

†Davidse., J., Integration of Analogue Electronic Circuits. Academic Press.

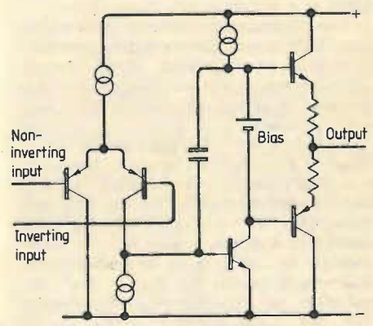
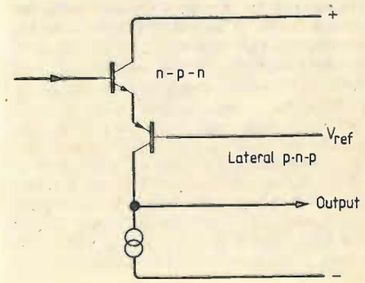


Fig. 1. Simplified input circuit operates as p-n-p long-tailed pair but in reality input devices are n.p.n.

Fig.2. Because of difficulty in fabricating high-gain p-n-p transistors input arrangement uses n-p-n types in modified cascode circuit.



Why look inside?

There are three ways in which a better understanding of the internal design of linear and quasi-linear integrated circuits can help the engineer: more satisfactory performance of circuits following from a greater appreciation of their strengths and limitations; possible use of accessible internal circuitry in unusual applications (a rich hunting ground in some of the more advanced units); and as an encyclopaedia of ingenious circuit design techniques, worked out by some of the most competent and resourceful design engineers.

Choice of the 741 as the starting point for this series stems mainly from a feeling that it was this i.c. more than any other which was responsible for the reconciliation of linear circuit engineers to the idea that most of the circuit functions they had implemented using discrete components could be done by integrated circuits, with improvements in simplicity and cost effectiveness.

In spite of all its limitations, in gain and phase-shift, slew rate and input bias current demand, there are many applications in which the 741 gives excellent service. This applies in audio and medium frequency applications so long as the associated circuitry is designed with an eye to its strengths and limitations. In addition there are a vast number of other circuit usages in which the very high d.c. and l.f. gain of this i.c., coupled with its good rejection of supply line voltage fluctuations and its ability to operate with input d.c. levels almost anywhere between the limits imposed by its supply voltage lines, make the life of the linear circuit engineer much simpler than it was some 15 years ago.

an identical transistor (such as one diffused at the same time on the same chip and having the same junction area) to pass the same current. This is not strictly true in practice because the input current will be greater by two lots of base current. However, if this was important, the mask used in the diffusion process could cause Tr_2 to be slightly larger than Tr_1. The circuits of Fig.4b and 4c minimize this error. My own shorthand symbol for the current mirror configuration is shown beneath, and I have used this in subsequent drawings.

In the full circuit of the input stage, shown in slightly simplified form in Fig.5, a three-transistor current mirror of the type shown in Fig.4b is used as the load for the input long-tailed pair, and an ingenious combination of two simpler (4a type) current mirrors, transistors 8 and 9 and 10 and 11, is used to stabilize the operating currents of the input devices. The way this works is by means of a d.c. negative feedback loop. If the total current of Tr_1 and Tr_2, which should not contain any signal components, tends to increase, then the current output of the mirror Tr_8, Tr_9 will also try to increase. However, this is effectively fed from a constant-current source (the output of the current mirror formed by Tr_{10} and Tr_{11}) so the only thing which can happen is for the base voltage on the p-n-p transistors Tr_3 and Tr_4 to become more positive, which reduces the throughput current of the input stage because it effectively reduces the forward bias on the input transistors at the same time.

The interaction of these current mirrors also operates to minimize the magnitude of any unbalance currents in the input stage, which improves its symmetry, while simultaneously acting to lessen the extent of any breakthrough of signal components from the supply lines.

The second class-A amplifier stage and output stage, as shown in Fig.1, is of conventional form – the traditional high-gain small-signal amplifier followed by unity-gain power output stage, as spelled out so many years ago in this journal by Tobey and Dinsdale. High-frequency loop stabilization is achieved by the simple and effective expedient so common in early "hi-fi" amplifier circuits of a capacitor between collector and base, as shown. This leads to a few avoidable limitations which are discussed later.

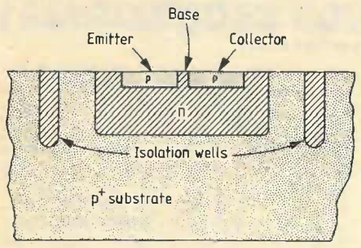


Fig.3. Lateral type of p-n-p transistor, though robust, has low value of h_{FE}, generally from 5 to 25.

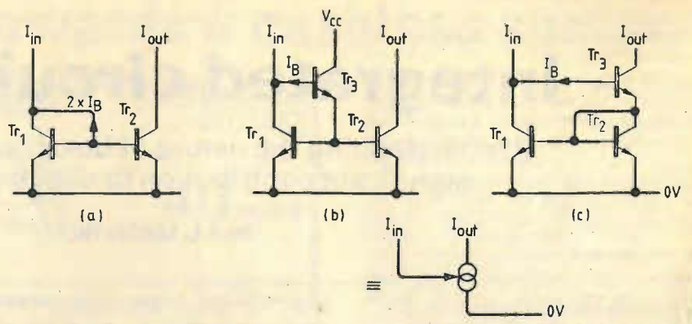


Fig. 4. Output current mimics input current in these current mirror variations, all much more easily integrated than resistors and capacitors.

As shown, the output stage would have no protection against damage due to output short circuits. This is accomplished by the use of a pair of n-p-n transistors (the preferred type), as shown in the more complete diagram of Fig.6, one of which is connected across the emitter resistor of Tr_{14}, and will take the current from the input to this if the voltage drop across this resistor exceeds its own base turn-on voltage, and the other (Tr_{22}) which acts in the same way in respect of the Darlington-pair class A amplifier stage Tr_{16}, Tr_{17}. The output stage forward bias is provided conventionally by an "amplified diode" Tr_{21} to give a quiescent current in class AB operation of about 1.5mA.

The final circuit of the complete i.c. is shown in Fig.7. I have actually shown that used by National Semiconductor, but all of the commercial 741s use a closely similar structure. In this, the only item not covered so far is the provision for offsetting inadvertent d.c. error at the output. This is done by putting a pair of resistors in the emitter leads of the current mirror used as the load for the input stage. If one or other of these is reduced relative to that in the other limb the current in that limb for balance will need to be greater; which calls for a change in input potential for that input device to maintain *status quo*. As this will not happen normally, the result of the adjustment will be to provide an output voltage shift equivalent to the stage gain multiplied by the required input offset. This provides a convenient means for obtaining a small shift in the output d.c. level, with minimal interference in the performance of the i.c. as a whole.

Performance

The d.c. and low-frequency voltage gain given by this circuit is very high – in excess of 50,000, with typical values of the order of 200,000. However, the presence of the h.f. stabilizing capacitor has a massive effect on the a.c. performance at frequencies higher than a few hertz, with the gain decreasing with frequency beyond some 5 to 10Hz at a rate of 6dB/octave.

A typical gain and phase-shift graph is shown in Fig.8.

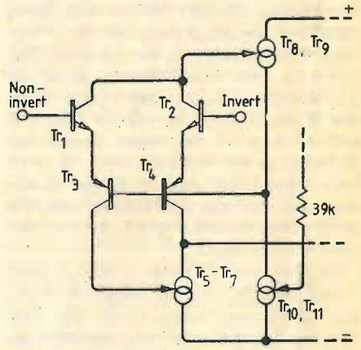
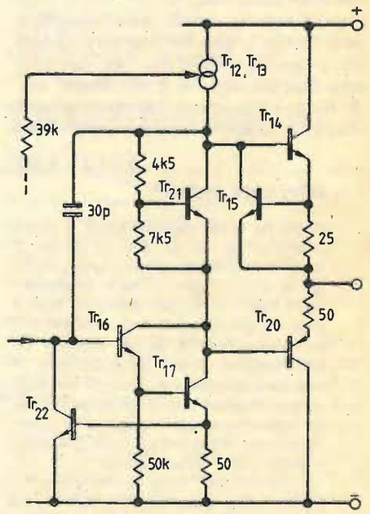


Fig.5. As well as a current mirror for the tail, type (b) in Fig.4, two (a)-types stabilize operating currents of the input transistors by d.c. negative feedback onto the base of Tr3, Tr4.

Fig.6. To provide short-circuit protection, Tr15 passes current from the input if the emitter resistor drop exceeds base turn-on voltage. Tr22 acts in a similar way for the Darlington pair.



An examination of this shows two important features. There is a significant additional phase error beyond 300kHz, which implies the presence of one or more

phase-lag inducing components within the i.c. having a pole at some few MHz. This is the reason why the unity-gain point for adequate unity-gain stability in a feedback configuration cannot be made much higher than 1MHz. And following upon this, the available open-loop gain at the upper end of the audio band, say 20kHz, is only of the order of 50.

Unless, therefore, the gain requirements of an audio amplifier stage using a 741 are kept deliberately low, neither the amplitude response and phase linearity, nor the harmonic distortion characteristics of the amplifier stage, are likely to be satisfactory in the context of contemporary expectations for "hi-fi" equipment. Fortunately there are now third-generation operational amplifiers, such as the Texas Instruments TL071 series, which offer substantial improvements over the performance of the 741-type i.c. in those regions which are of importance to the audio engineer, and I propose to examine this i.c. later in this series.

The other features inherent in the design of the 741 which must be borne in mind in its use if results are to be satisfactory are those which concern the input long-tailed pair of bipolar transistors and the effect of the h.f. compensation capacitor on the transient performance. Taking the first of these, the design of the input stage leads to a combined collector current for the long-tailed pair of around 25 microamperes. Assuming a current gain of 100 for the input devices, the necessary forward bias current for 25°C operation of the circuit will be 0.1 μA for each input, and this current must be supplied through any resistive circuit components in the input paths. While an output d.c. offset can be minimized by making sure that the total resistance value in each input circuit through which these bias currents must flow is the same (those components through which currents do not flow are unimportant in this calculation), it must be remembered that these currents increase significantly with temperature, and that the internal matching of the input devices may not hold over this range. For this reason, the total d.c. gain of the circuit and the amount of output d.c. offset which is tolerable must be considered when its circuit environment is being formulated, along with the temperature range over which it is to operate.

The second limitation of this i.c., that due to the nature of the internal h.f. compensation, is a rigid upper limit on the voltage slew rate which can be achieved at the output, around 0.5V/μs. If a composite signal is applied to the input which contains components calling for a greater rate of change in putput voltage than this, the total composite signal will be lost while the output moves from one instantaneous d.c. level to another, at the maximum rate possible. This self-evident fact applies to all amplifiers which are slew-rate limited, including some in the "hi-fi" field. It is, I think, a sad commentary on the state of our art that a fact which is so simple to comprehend and can be stated so simply, can be used as the basis for a whole series

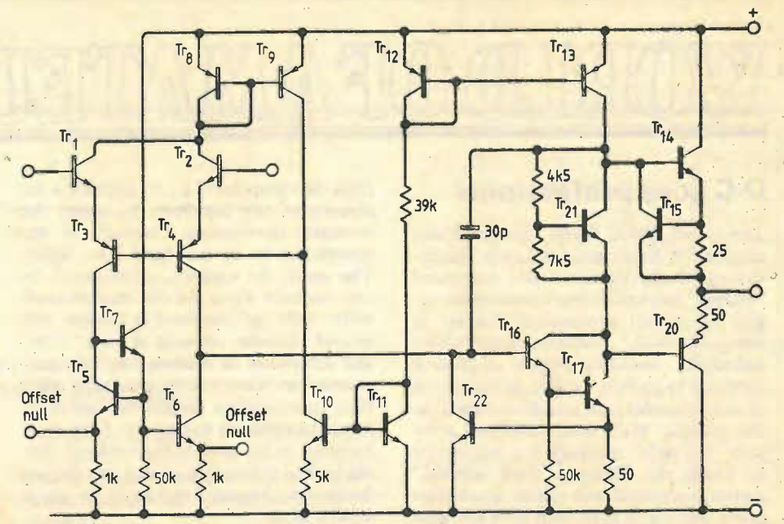


Fig.7. Complete circuit shows arrangement for offsetting d.c. error in the output. Reducing value of appropriate emmitter resistor in the input stage produces an output voltage shift equivalent to gain × input offset.

of technical papers aimed at proving the superiority of one or other commercial product.

To live within this limitation, it is necessary to ensure in all cases where slew-rate limited output saturation is important – and not all applications would be influenced by this – that the maximum rate of change of voltage in any input signal does not approach the output slew-rate divided by the effective a.c. gain.

There are now a large number of more recently designed and more expensive third generation operational amplifiers, in which both the small-signal bandwidth and slewing rate are much greater (by a factor of ten or more) than is the case for the 741. In some of these, such as the Ti TL071 and the RCA CA3140 types, the input bias requirements have been reduced to a level which is so low that the choice of input resistance values can be determined solely by other circuit requirements.

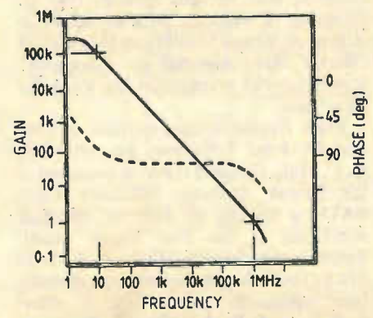


Fig.8. Frequency response shows phase error beyond 300kHz which limits unity-gain point to around 1MHz. Low open-loop gain at 20kHz limits usefulness in hi-fi applications.

FREE WITH THIS ISSUE

Extra-terrestrial relays

In October 1945 an article by a new author, a man named Arthur C. Clarke, appeared in *Wireless World*. At first glance, the subject of the article seemed to belong more to a science fiction periodical than to a technical journal like *Wireless World*; indeed, Mr Clarke subsequently became one of the best-known authors of science fiction. The second and succeeding readings, however, showed that what Mr Clarke had to say was sound sense. Here was nothing less than a scheme to use artificial geostationary earth satellites as broadcasting and communications platforms.

As everyone knows, space is now thick with satellites of all descriptions – there are 110 in geosynchronous orbit – but in 1945 it needed a great deal of thought to be sure that, by publishing such an article, *WW* would not be made to look foolish.

There is currently a crescendo of activity and speculation on the use of satellites for television and data communication, and readers might like to see how it all started. This month, therefore, we have included a reprint of the original article as an insert in those issues distributed in the UK. It was not possible to do this for overseas readers, but if anyone abroad would like a copy, they need only send a stamped, addressed envelope to Wireless World, Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS, whereupon it will be sent off immediately.