THIRD-GENERATION OP-AMPS

RCA CA3140 and TI TL071/2

John Linsley continues his series of articles on i.c. design with a look at the operational amplifiers which succeeded the versatile 741. The TL072 is the type used in the modular preamplifier, to be described in the next three issues.

by J. L. Linsley Hood

I made the comment in the first article of this series, last October, that I felt the advent of the 741 integrated-circuit operational amplifier was the turning point in the conversion of many linear circuit engineers to the use of i.cs. However, useful though the 741 and other similar contemporary i.c. op-amps were, they were relatively slow and their input impedance was low enough to make it necessary to consider the likely effects of the flow of the input bias current in the input circuitry.

CA3140

It is understandable, therefore, that the advent of the RCA 'mosfet-input' op-amp, the CA3140, with an input impedance of more than $10^{12}\Omega$ and a slew-rate of some 9V/μs in comparison with that of the 0.5V/μs typical of the 741 in the mid-1970s, should have been greeted with great enthusiasm by the industrial electronic-engineering fraternity, for whom a lot of rather awkward jobs now became very much easier to accomplish. Examination of the circuit, drawn in simplified form in Fig. 1, shows a very great similarity in general structure to that of the 741, except that the complementary-pair output stage emitter followers have been replaced by a single emitter-follower Darlington pair ($Tr_{17,18}$) with an active emitter load built up from $Tr_{15,16}$ and Tr_{21}.

The input stage is conventional, consisting of an input long-tailed pair of p-channel mosfets driving a current mirror ($Tr_{11,12}$) and a single class-A amplifier (Tr_{13}) with a constant-current source as its collector load. High-frequency compensation is again conventional in form, with a collector-base capacitor (C_c) connected across Tr_{13} to impose a dominant-lag type reduction in h.f. gain.

The major advantage of this circuit arrangement stems from the replacement of the relatively poor 'lateral' p-n-p transistors which would have to be used in a conventional, bipolar only type of i.c., with p.m.o.s. devices, which have an exceedingly high input impedance and very good h.f. characteristics. Unfortunately, in this circuit, there is an inevitable load mismatch so that, in spite of the current-mirror load, the gain of this input stage is only about 10×. Also, the need to protect the input gates from inadvertent breakdown due to electrostatic charges forces the use of internal Zener diodes, whose leakage currents effectively limit the input impedance to some 1.5×10^{12} ohms at 25°C.

In order, therefore, to get the gain up to the 100,000 mark expected from his type of device, some ingenuity has been applied to the design of the second class-A gain stage and the output circuitry, shown in full in Fig. 2. In this, the most obvious feature, apart from the four p.m.o.s. devices ($Tr_{8,9,10,21}$), is the most elaborate biassing circuitry, with its ladder of current-mirrors built up from D_1, Tr_1, Tr_6 and Tr_7, all fed from Tr_8, whose geometry is organized to make it act as a current source. This ladder of current-mirrors is used to control the cascade-connected current sources (Tr_2 and Tr_5) in the 'tail' of

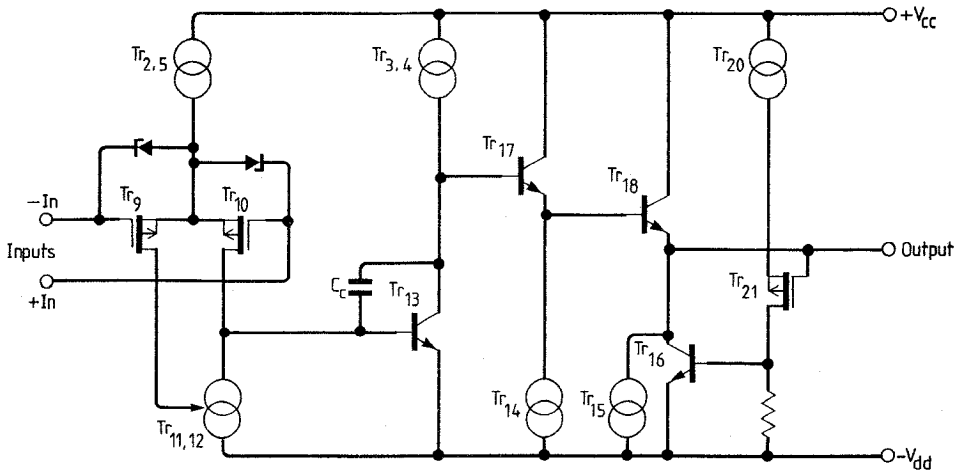


Fig. 1. Simplified CA3140 circuit, showing general similarity to 741 structure.

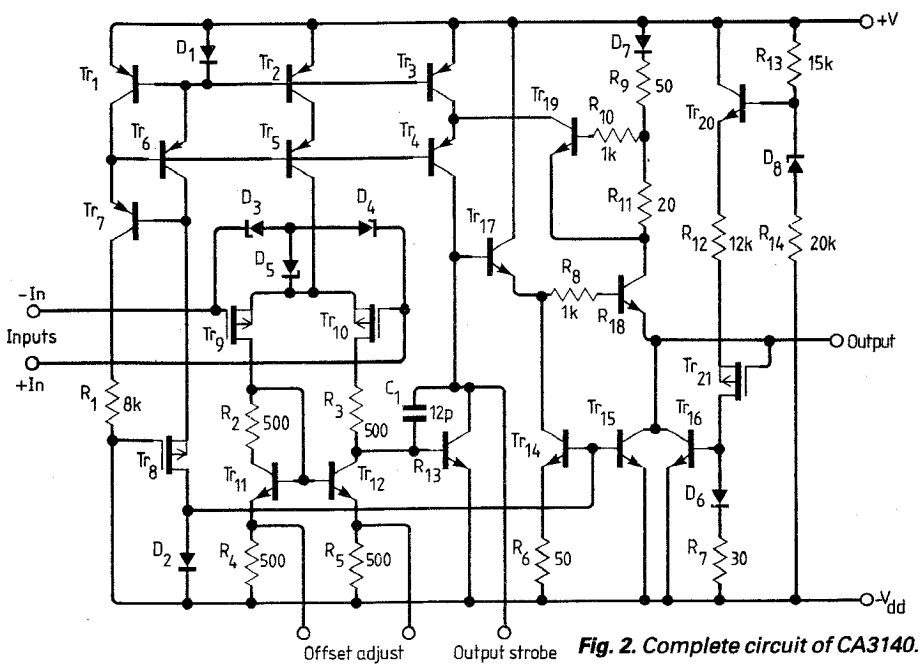


Fig. 2. Complete circuit of CA3140.

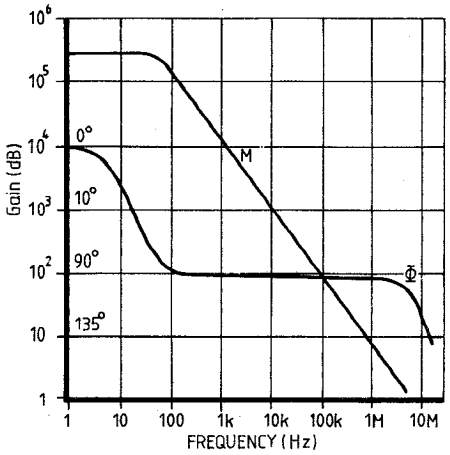


Fig. 3. Gain/frequency plot for CA3140.

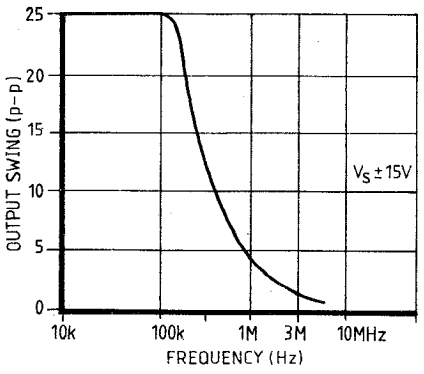


Fig. 4. Output swing plotted against frequency for CA3140.

the input long-tailed pair (Tr_9 and Tr_{10}) and in the load circuit (Tr_3 and Tr_4) of the class-A amplifier transistor (Tr_{13}). This second pair of cascade-connected current sources is used as an ingenious output overload protection device, in that if the current through the output transistor (Tr_{18}) exceeds some 30mA at 25°C (or less at higher temperatures), Tr_{19} will be turned on, and will steal the current from the driver stage.

The maximum current available from the lower half of the output stage ($Tr_{16,15}$) is already limited by the current fed into the two output current-mirrors ($Tr_{15}+D_2$, $Tr_{16}+D_6$ and R_7) from Tr_8 and R_{12}, which is itself fed from a semi-fixed voltage source arranged around the zener diode D_8 and Tr_{20}.

All in all, it is a rather elaborate circuit arrangement, which has always been somewhat expensive to produce and has demanded a relatively large chip size. Nevertheless, the performance of the i.c. is very satisfactory, and it has retained its place in instrumentation use, where its good high-frequency performance, its high input impedance, and its ability to operate over the supply voltage range ±2V – ±18V has made it a useful circuit component. Characteristic gain/frequency and output swing/frequency graphs are shown in Figs. 3 and 4.

TL071

From the point of view of the audio circuit engineer, the remaining requirements which remained to be satisfied in the field

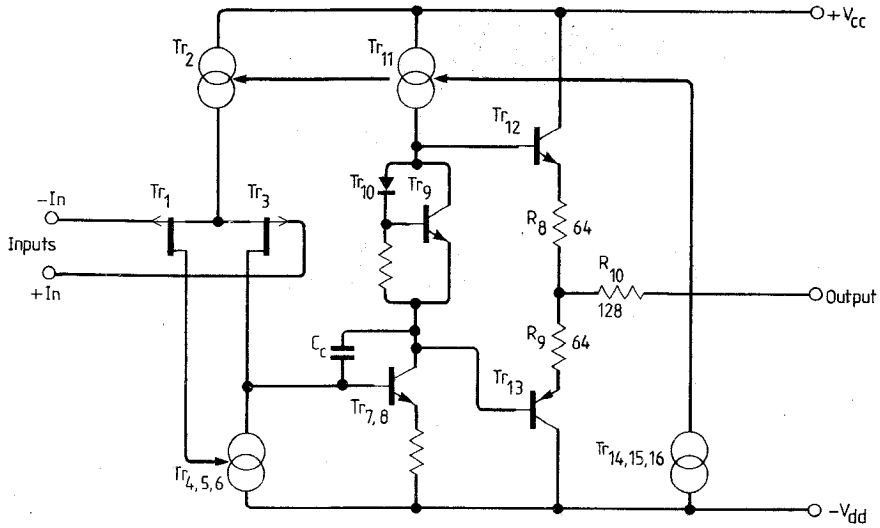


Fig. 5. TL071 in simplified form, showing return to complementary-pair output and apparently rudimentary short-circuit protection.

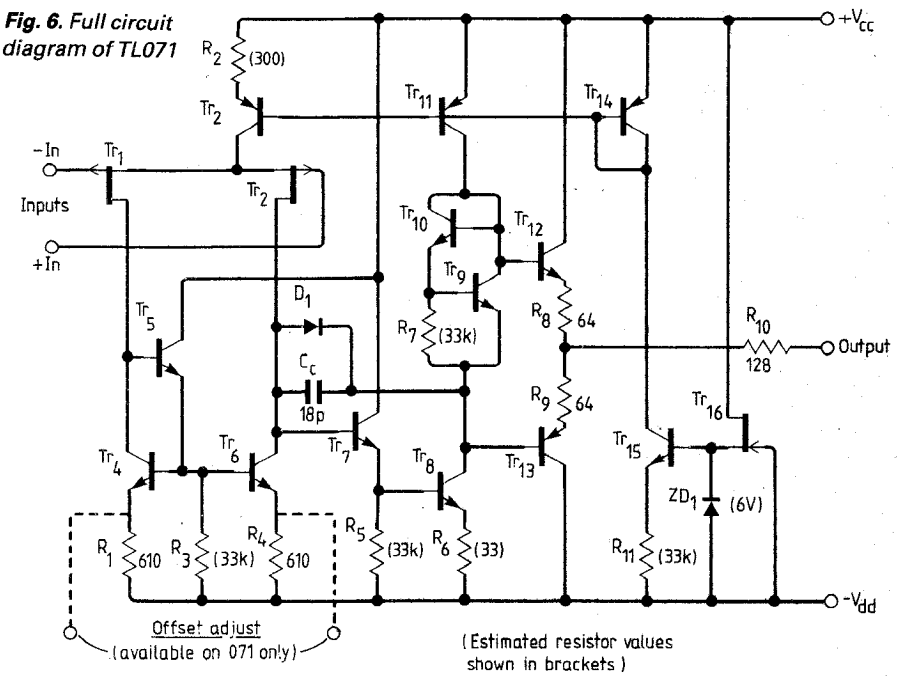
of i.c. operational amplifiers were guaranteed low noise and low distortion parameters. These residual requirements were amply met in mid-1977 when Texas Instruments introduced their TL0** series of 'BiFET' devices, based on a combination of bipolar and junction fet technologies, which were now capable of fabrication on the same chip.

Of these, for reasons of personal interests, the one which was most immediately attractive was the TL071, 072, 074 series of single, dual and quad op-amps which are characterized for use in audio circuitry, with a noise specification of 18nV/√Hz and a total harmonic distortion, just below clipping, of typically less than 0.01%. In addition, the typical input impedance was still of the order of 10^{12} ohms, and the unity-gain slew rate was typically 13V/μs. The use of junction fet input devices has also allowed a somewhat simpler circuit configuration, shown in its basic form in Fig. 5.

Once again, the circuit architecture is of familiar form, with an input long-tailed pair of p-channel junction fets driving a current mirror to add the signal components of both halves, a single class A amplifier stage (actually a Darlington-pair connected stage), and a complementary pair of n-p-n and p-n-p output transistors biased into class AB1 operation. The only curious feature to the professional op-amp watcher is the apparently complete absence of any formal positive-excursion output short-circuit protection, other than the use of an output resistor, R_{10}, and the adoption of relatively high-value emitter resistors for the output emitter-follower pair. However, the makers claim that such an output short-circuit can be sustained indefinitely.

I have shown the full circuit of the TL071 in Fig. 6, in which there are a few further details not apparent from the simplified diagram. It will be seen that the input circuit load is formed from a more highly developed form of current-mirror ($Tr_{4,5,6}$ and $R_{1,3,4}$) than the simple, two-

Fig. 6. Full circuit diagram of TL071



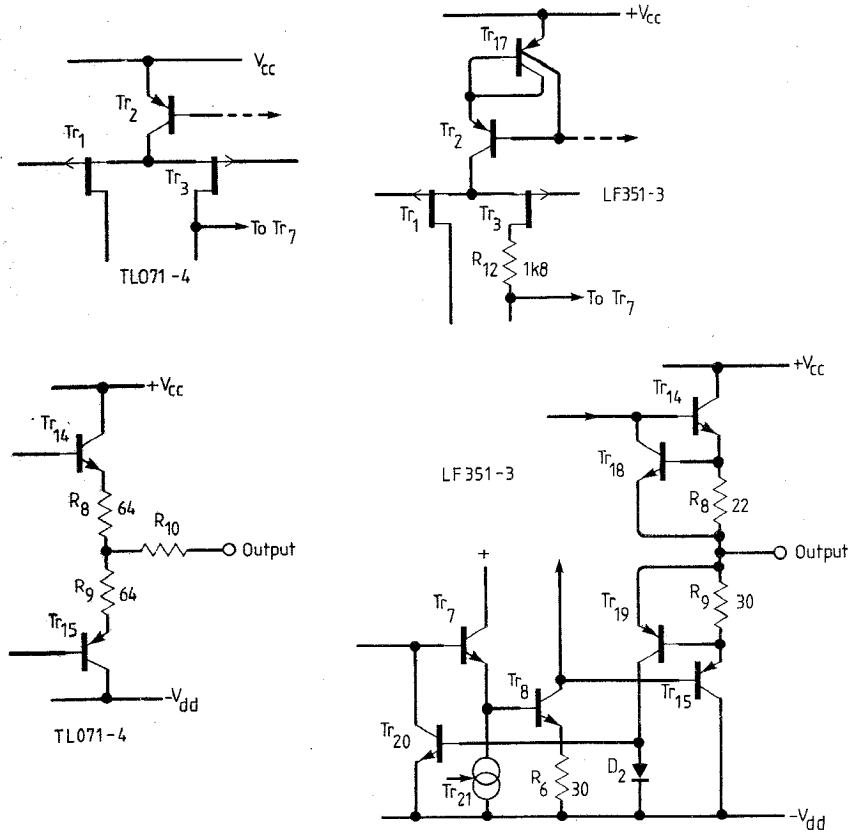


***Fig. 7.** Comparison between TL071 and LF351 from National Semiconductor, showing variations in input stage and overload protection.*

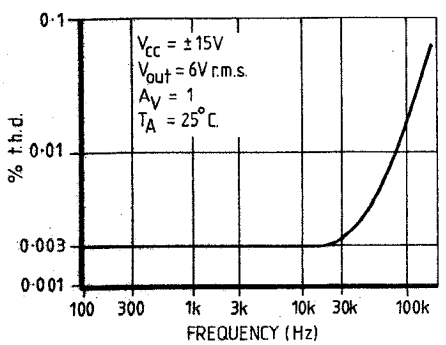


***Fig. 10.** Harmonic distortion plotted against frequency.*

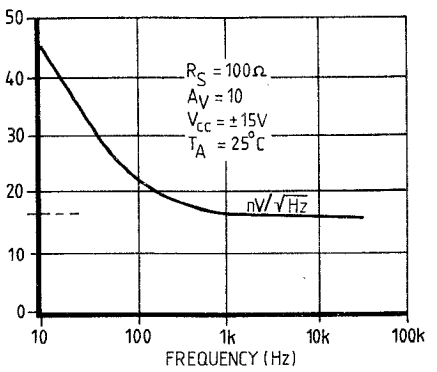
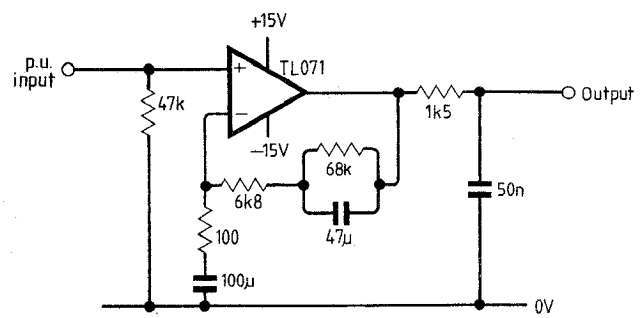
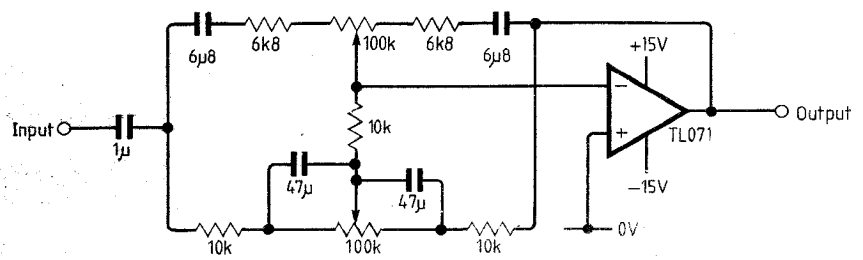


***Fig. 11.** Equivalent input noise voltage.*





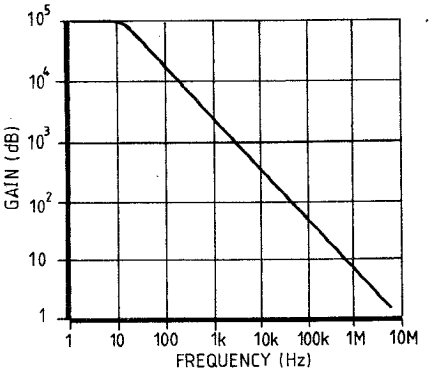


***Fig. 8.** Open-loop gain and phase characteristics of TL071-4.*

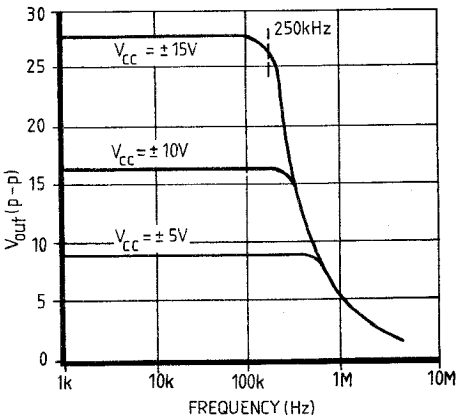


***Fig. 9.** Output voltage swing as function of supply voltage and frequency in TL071.*

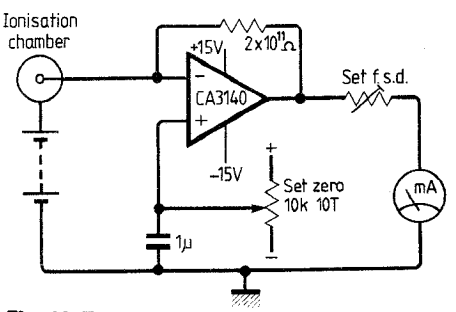


***Fig. 12.** Typical application of CA3140 is as ionization chamber amplifier at high impedance.*

transistor circuit employed in the 3140, and a catch-diode is connected across the compensation capacitor (D_1) to bypass the amplifier stages Tr_7 and Tr_8 if Tr_{13} is driven into saturation. This assists in output overload protection, and also speeds up recovery from any swing which drives the circuit into negative line clipping.

Transistors $Tr_{2,11,14}$ form a current-mirror group fed from the constant current source $Tr_{16,15}$,R_{11}, with transistors 2 and 11 acting as the input 'tail' and the class 'A' stage load, respectively. The transistor pair Tr_{10} and Tr_9, are merely a passive biassing network for the output emitter followers, in which Tr_{10} acts simply as a forward-biassed diode. Because of the relatively large proportion of the total (1.5-2mA) quiescent current consumption

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◀ ***Fig. 13.** Low noise and low distortion of TL071 make it very useful in small-signal audio circuitry.*