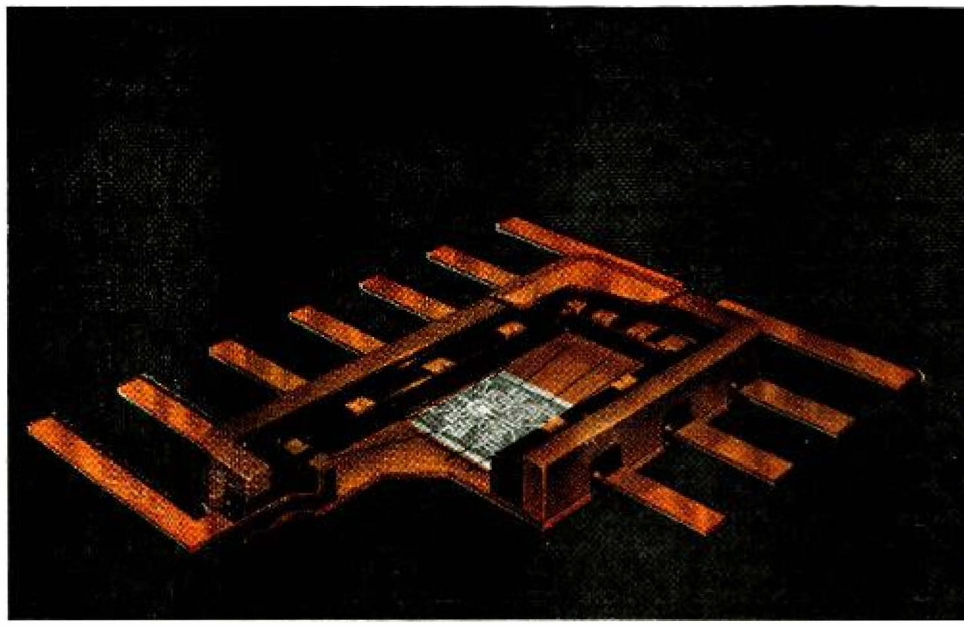
By DONALD E. LANCASTER



Cutaway view of integrated circuit mounted in 14-lead flat pack.

Linear Integrated Circuits: What's Available?

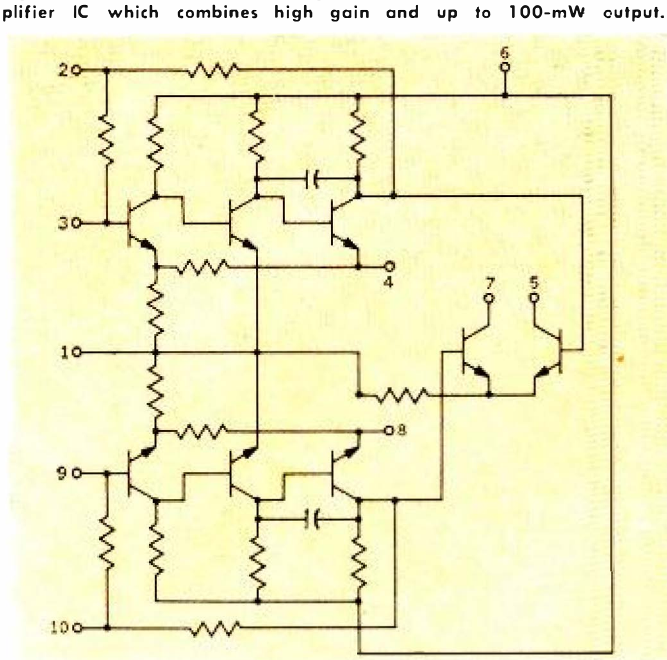
A survey of what the various manufacturers are now offering, arranged by circuit application. The article discusses where IC's can be used, their specs, what they cost, and how they are designed into circuits.

THE big breakthrough has arrived. Linear integrated circuits are finally distributor stock items, and they are available today in a wide variety of sizes, performance levels, and circuits from at least a half-dozen major manufacturers. Many linear IC's are now quite low in cost, with many devices in the $2 to $12 each price range.

For instance, a complete TO-5 can sized i.f. strip for a television set or FM receiver can be purchased for $2.65. A hearing-aid-sized audio amplifier can be obtained for $10.50. One r.f. amplifier costs $4.40, a second $4.50, and a third $4.80. Other linear integrated circuits are still very high-priced, but these frequently offer performance advantages unavailable in any other form of circuitry.

Let's take a closer look at some of the more noteworthy linear integrateds. Everything to be described is *now* distributor stock and available for immediate use. Prices in parentheses are approximate single-quantity cost at the time of publication. Sources of data sheets and distributor lists are indicated in Table 1.

Fig. 1. The circuit of the Westinghouse WC183, a class-B audio amplifier IC which combines high gain and up to 100-mW output.



Audio Amplifiers

The *Texas Instruments* SN1220 ($16.20) is a linear IC designed specifically for hearing aids but also useful for a wide variety of very-low-level, high-gain audio applications. The frequency response has been optimized for voice applications. Maximum output power is three milliwatts at a 5% distortion level, and total voltage gain is 16,000 (84 dB) when the device is powered by a single 1.5-volt, 4-milliampere cell. The ten-lead flat pack used has provision for an external gain control. Either an output transformer or a center-tapped earphone is normally required. The single-cell operation is a most important advantage for subminiature hearing aids as well as orbital satellite applications.

More audio power is offered by the *Westinghouse* WC183 ($10.50), the circuit of which is shown in Fig. 1. Available either in a ten-lead flat pack or a twelve-pin TO-5 style can, this linear IC is able to produce as much as 100 milliwatts of audio output with a voltage gain of over 30,000 (90 dB). Frequency response is flat from 50 Hz to beyond 20 kHz, and reasonable audio quality may be obtained at low output levels. Although 6 volts is required for maximum gain and output, the WC183 will also operate with a single 1.5-volt cell. In this mode, a voltage gain of 4000 (72 dB) is combined with a three-milliwatt output.

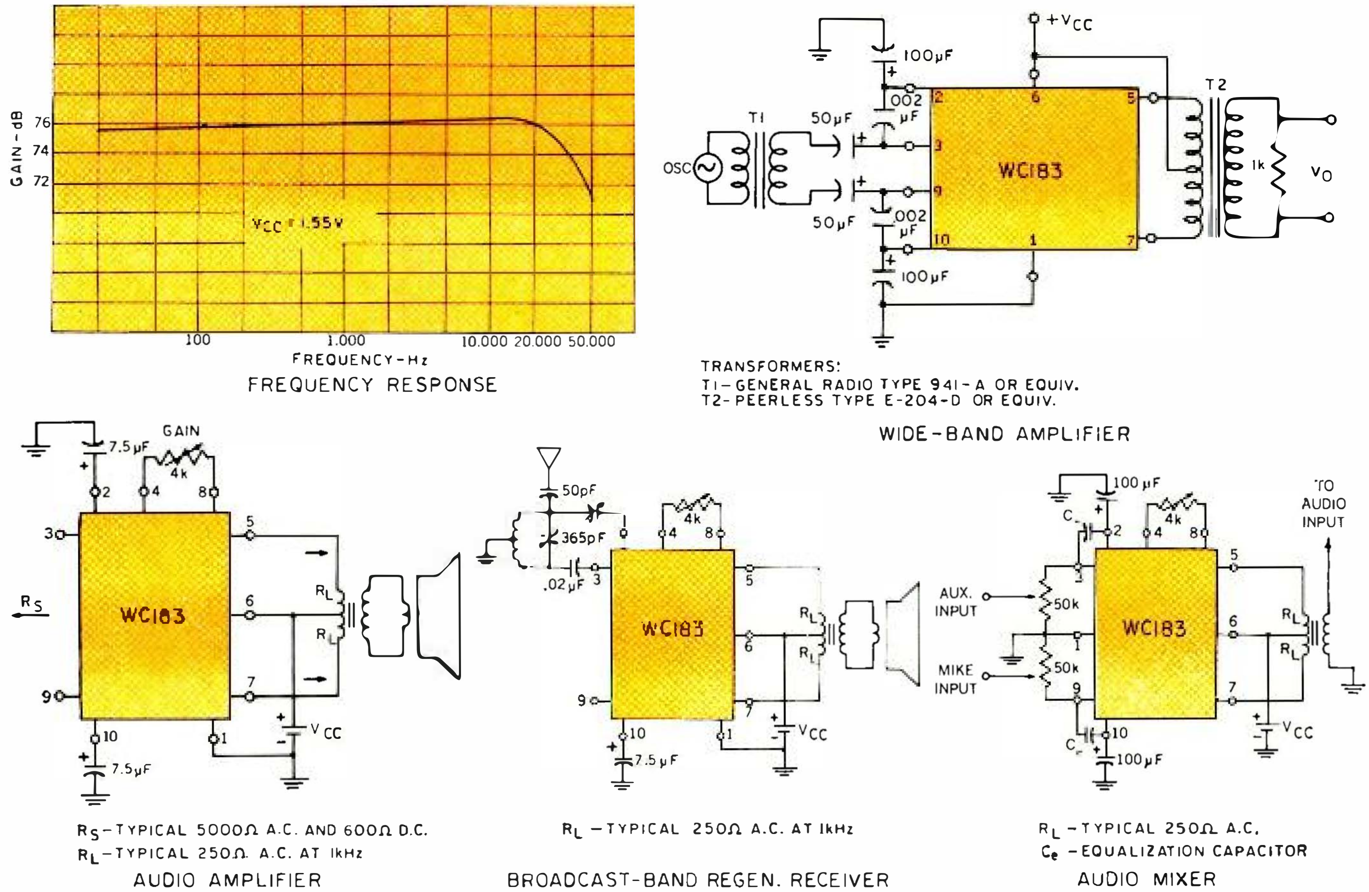


Fig. 2. Frequency response along with a number of typical circuit applications for the WC183 integrated circuit.

The WC183 is particularly suited to experimental uses, some of which are suggested in Fig. 2. Sufficient audio power is available for low-level recorder monitors, intercoms for low-noise areas, and similar applications.

Higher Power Audio IC's

The *RCA* CA3007 ($6.00) is an audio driver that may be combined with an output stage and transformer to produce 300 milliwatts or more of audio power. This twelve-pin TO-5 style package provides a power gain of 160 (22 dB) and is supplied with push-pull input and output. It serves nicely as a transformerless phase splitter and driver for class-B audio-output stages. Feedback is easily provided to automatically hold the output stage bias levels at optimum values.

Higher power audio IC's are still scarce and expensive, owing to the heat problems associated with substantial signal levels. *Motorola's* MC1524 is one 10-pin TO-5 style can linear IC that can supply one watt of audio-output power. It is oriented towards a military transceiver market and, as such, has a military reliability and a military price tag ($70). A hybrid construction technique is used in which the lower level circuitry is fully integrated, while the output stage consists of discrete transistors. A photo of the unit is shown on page 41.

Incidentally, for those with a military budget, this amplifier is strictly hi-fi. It has a voltage gain of 1000 (60 dB) and can provide 900 milliwatts of audio output with less than 0.6% harmonic distortion. Frequency response is flat from 20 Hz to over 300 kHz. Dual 6-volt supplies are required.

Low-cost, high-power audio integrateds are still well around the corner and will stay there until a better means of heatsinking IC's becomes practical or else until the switching-mode audio-amplifier schemes become more fully developed. NASA has recently demonstrated a one-watt switching-mode (class-D) audio amplifier that may readily be integrated. This is an important step towards solution of the high-power audio-IC problem.

R.F. and I.F. Amplifiers

R.f. and i.f. amplifiers form the application area where the majority of low-cost linear integrateds have recently been introduced. *Fairchild's* µA703 ($4.50) is an interesting entry. This 8-pin TO-5 style package functions as a self-limiting i.f. amplifier with up to 41 decibels (112:1) of voltage gain and may be operated either single-ended or

Table 1. Sources of linear IC's covered in the text.

FAIRCHILD SEMICONDUCTOR
313 Fairchild Drive
Mountain View, California

GENERAL INSTRUMENT SEMICONDUCTOR
600 West John Street
Hicksville, New York

GENERAL MICROELECTRONICS INC.
2920 San Ysidro Way
Santa Clara, California

MOTOROLA SEMICONDUCTOR
Box 955
Phoenix, Arizona 85001

RADIO CORPORATION OF AMERICA
Electronic Components and Devices
Harrison, New Jersey

TEXAS INSTRUMENTS
P.O. Box 5012
Dallas, Texas

WESTINGHOUSE MOLECULAR ELECTRONICS
Box 7737
Elkridge, Maryland 21227

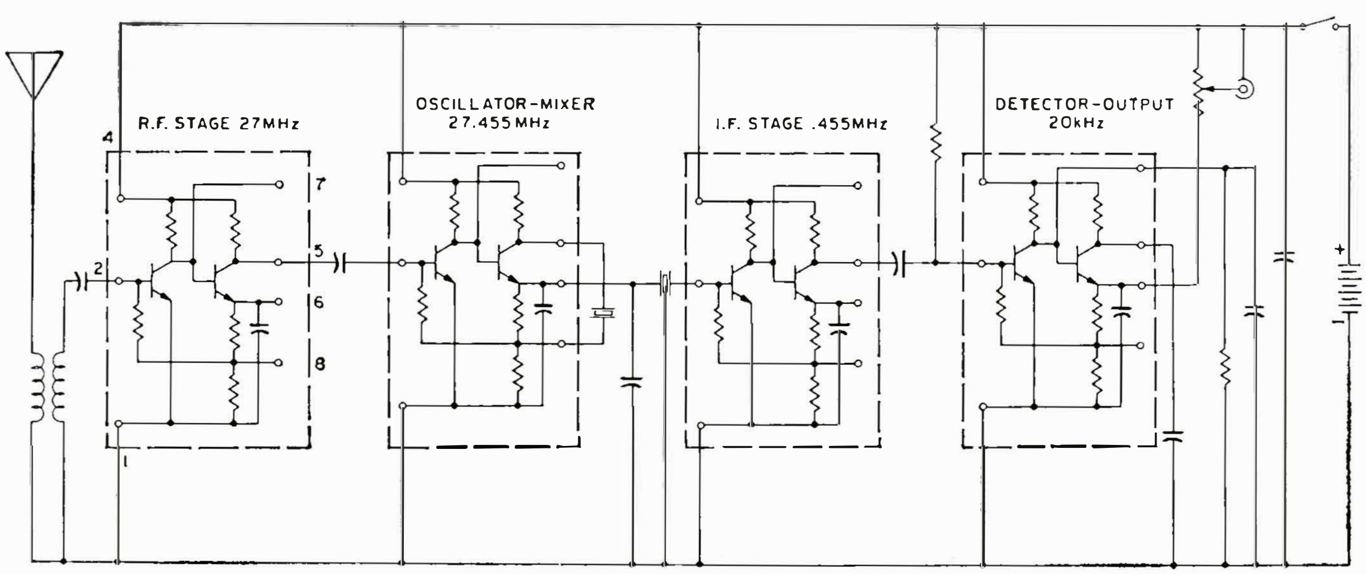


Fig. 3. A Citizens Band receiver using four WC1146 wide-band integrated-circuit amplifiers.

push-pull. The limiting action is symmetric and non-saturating, making the μA703 excellent for high-quality FM i.f. strips. *(See the article "An Integrated Circuit for Consumer Products" in our October issue.—Editors)* For non-i.f. applications, this IC also serves as a wide-band amplifier, a voltage-controlled oscillator, or an FM mixer useful above 100 MHz.

RCA's i.f. amplifier, the CA3002 ($4.40), is similar in purpose but has the added feature of a 10,000:1 (80 dB) electronic gain control (a.g.c.) range. A push-pull input is combined with a single-ended output, and an internal coupling capacitor is provided for direct interstage coupling in the 1- to 10-MHz range. Additional capacitance or transformer coupling may be used at lower frequencies. Voltage gain is typically 10:1 (20 dB). This same IC is also useful as a product detector, a Schmitt trigger, or a wide-band amplifier.

Westinghouse's candidate is the WC1146 ($10.50), a universal direct-coupled, two-stage negative-feedback amplifier that may be used for virtually any r.f. or i.f. application below 100 MHz. For instance, Fig. 3 shows a high-quality Citizens Band receiver which uses nothing but the WC1146's throughout. One serves as an r.f. stage, followed by an oscillator-mixer, an i.f. stage, and finally a detector and audio-output stage. An input antenna transformer, a ceramic filter, a crystal, and several capacitors complete the circuit. Each IC is capable of a high-frequency gain of 6:1 (16 dB), and automatic gain control is available.

Excellent high-frequency performance is obtainable in the *Motorola* MC1110 ($25), an emitter-coupled amplifier good to 300 MHz. The five-lead TO-5 style can IC offers a power gain of 400 (26 dB) at 100 MHz, with a typical noise figure of only 4 dB. The MC1110 operates over a —55 to +125°C range and is well suited for front-end, r.f., and i.f. applications in high-quality communications gear. Typical is the radar 60-MHz i.f. strip shown in Fig. 4 which offers a power gain of 80 dB with a 6-MHz bandwidth and a 6-dB noise figure. Four IC's are needed.

RCA's CA3004, CA3005, and CA3006 ($4.40, $4.80, and $6.80) round out the r.f. and i.f. linear-IC picture. These consist of a differential input stage and an internal controlled-current source. The amplifiers may be operated either in a differential or a cascode manner. No collector resistors are provided, as these IC's are normally used in transformer-coupled applications where interstage transformers determine the over-all frequency response. The three IC's differ in input offsets, gain, and linearity. All are potentially useful from d.c. to 100 MHz and have a very good a.g.c. capability. Important applications include use as detectors, mixers, limiters, modulators, and as cascode r.f. amplifiers.

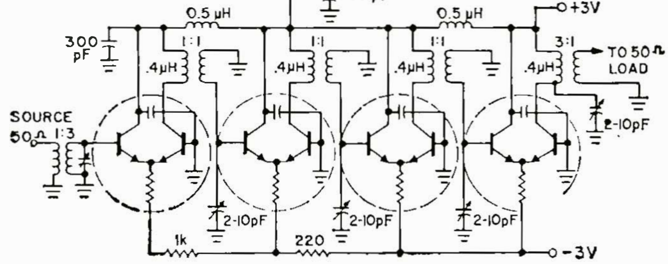
Differential Amplifiers

It is sometimes desirable to compare two input signals against each other and produce an output proportional to the *difference* between the two. This is often done in d.c. amplifying systems, servo loops, error detectors, and regulated power supplies.

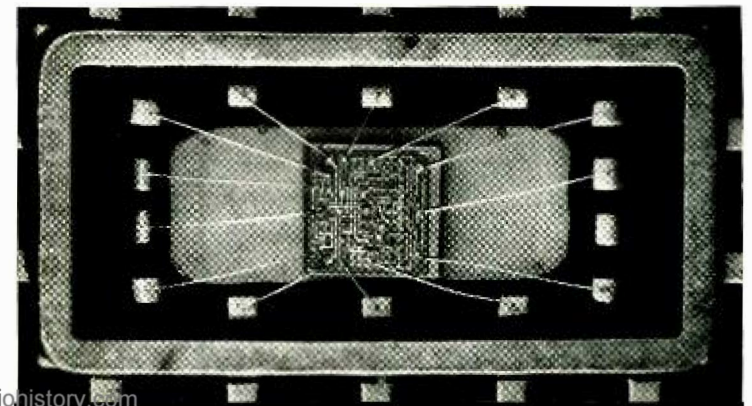
A differential amplifier is normally called on in these applications. Formerly, this meant expensive matched transistors, critical heatsinking, and perhaps external stabilization circuits to obtain good d.c. performance. Linear integrateds eliminate all of this. The transistors in an IC are practically identical in size and material. Due to their proximity, they must be at the same temperature, so the transistors track beautifully over wide temperature ranges.

Several companies manufacture linear-IC differential amplifiers. The *Westinghouse* WS115T ($10.50) offers some interesting performance features. It consists of four Darlington-connected differential emitter-followers combined with an internal controllable current source. Input impedance is typically half a megohm and the frequency response

Fig. 4. A 60-MHz radar i.f. amplifier using four MC1110 IC's.



Close-up of an integrated circuit in well of a flat pack.



is good from d.c. to 150 kHz. Drift is typically 10 microvolts per degree C, which means that over a 100° C operating range, an "extra" millivolt may appear at one input with respect to the other. For wide temperature operation, input signals as small as 10 millivolts may be processed with little error. Limited temperature range circuits will allow the d.c. processing of 100-microvolt input signals. The WC115T offers a voltage gain of 50 and comes in an eight-lead TO-5 style can.

Motorola has a whole family of integrated differential amplifiers. The most versatile is perhaps the MC1519 ($50), as *n-p-n* input transistors are combined with complementary matched *p-n-p* output transistors. This *n-p-n*/*p-n-p* configuration allows a variety of interconnections, all of which readily track over a wide temperature range. A gain of 4500 is combined with a 1-MHz bandwidth in the ten-lead TO-5 type package.

The *Motorola* MC1525 through MC1528 devices make up a family of medium-priced differential amplifiers, available either as all *p-n-p* or all *n-p-n*, with or without Darlington inputs. An *n-p-n* and *p-n-p* IC may be cascaded for extremely high gain and excellent temperature tracking.

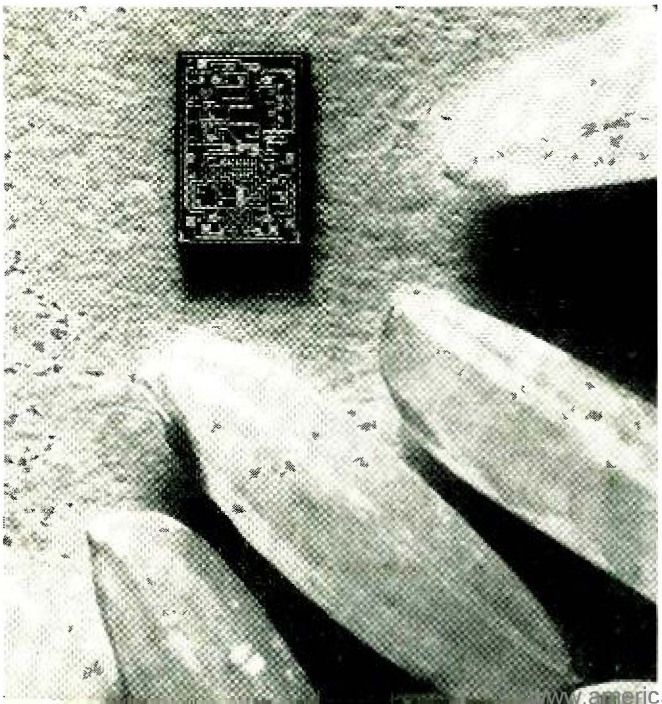
One of *Texas Instruments'* differential amplifier IC's is the SN723 ($27.60). Housed in a 14-lead flat pack, this particular IC offers a voltage gain of 1800 (65 dB), a 150-kHz bandwidth, and a 250-ohm output impedance. The SN723 normally uses dual 12-volt power supplies.

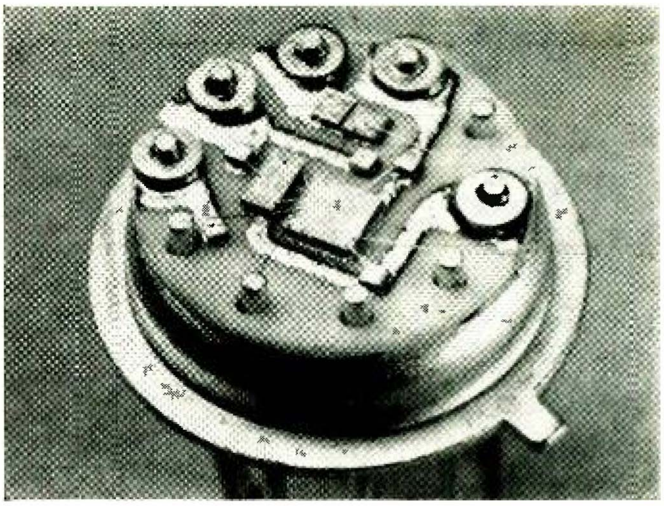
Operational Amplifiers

An operational amplifier is any high-gain d.c.-coupled bipolar amplifier with low offset. Its unique performance feature is that the gain may be precisely controlled by external resistors and capacitors. Operational amplifiers have long been used in analog computers, but because low-cost linear IC operational amplifiers are now available, this basic amplifier is beginning to find very wide use. Once again, linear IC's eliminate many of the temperature and tracking problems that formerly plagued the discrete tube and transistor circuits. External stabilization is now only very rarely required, thanks to the performance capabilities of today's linear IC's.

Important operational-amplifier applications are in precision waveform generation, controllable gain and bandwidth amplifiers, d.c.-coupled amplifiers, and active network synthesis. The latter is a new way of using resistors, capacitors, and operational amplifiers to simulate inductance and *LC* filters without using coils or transformers.

A complex IC shown here along with some grains of rice.





One-watt audio power amplifier using hybrid IC technique.

RCA's CA3010 ($12) is one of the lowest priced operational amplifiers available today. It offers a voltage gain of 1000 (60 dB), a 300-kHz bandwidth, and a peak-to-peak output swing of seven volts. The CA3010 is housed in a 12-lead TO-5 style case. A second IC, the CA3008, is the identical circuit in a flat package at a slightly higher cost.

Motorola offers four operational amplifiers, the MC1430, MC1431, MC1530, and MC1531 ($18 to $30), which differ mostly in input impedance and operating temperature ranges. Darlington inputs are supplied on the MC1431 and MC1531.

Texas Instruments produces one low-cost operational amplifier, the SN724 ($16.20), and several premium units which are primarily intended for military usage. All are in the ten-lead flat package.

The *Westinghouse* line consists of half a dozen IC's ranging in price from $20 to $70. One dual unit offers *two* independent operational amplifiers in a single TO-5 style package. Since operational amplifiers are often used in groups, such a configuration results in reduced space requirements and simplified wiring.

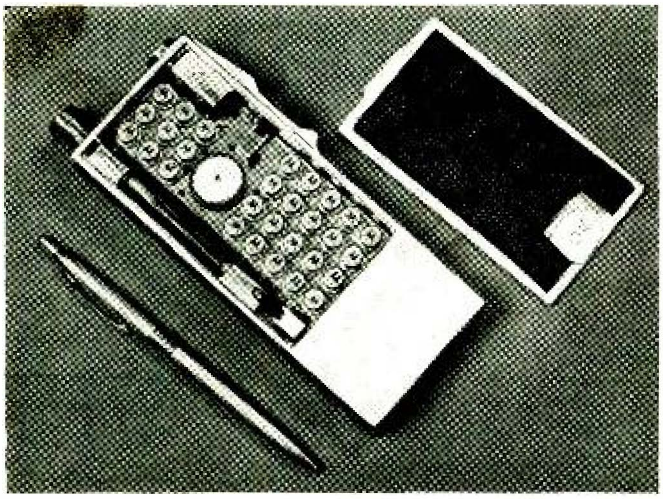
Fairchild supplies four distributor stock operational amplifier IC's, the μA702 and the μA709. Each has a commercial "C" version and a military "A" version as identified by a suffix ($14 to $22).

There are many other operational amplifiers on the market, but most of the ones we have not mentioned are premium units of limited availability. The choice of which operational-amplifier IC should be employed is highly dependent upon the specific application, and a careful study of the data sheets of likely candidates is in order before a particular device is selected.

Other Amplifiers

The CA3000 ($6.80) is an *RCA* ten-pin TO-5 style linear IC intended for d.c. amplifier use but also quite applicable to feedback amplifiers, crystal oscillators, modulators, and mixers. It consists of four transistors in a differential Darlington configuration and a controllable transistor and two-diode current source. A 200-ohm input impedance is combined with a voltage gain of 50 and a d.c. to 30-MHz frequency response.

A second *RCA* linear IC, the CA3001 ($6.40), is intended for video amplifiers and other wide-band amplifier applications. Circuitry is somewhat similar to the CA3000 except that emitter followers are added for low output impedance and internal coupling capacitors are provided. This IC has a push-pull input and output, a 9:1 voltage gain, and a 16-MHz frequency response. The circuit finds use in video amplifiers and other wide-band amplifiers



A complete 120-MHz transceiver built with linear IC's.

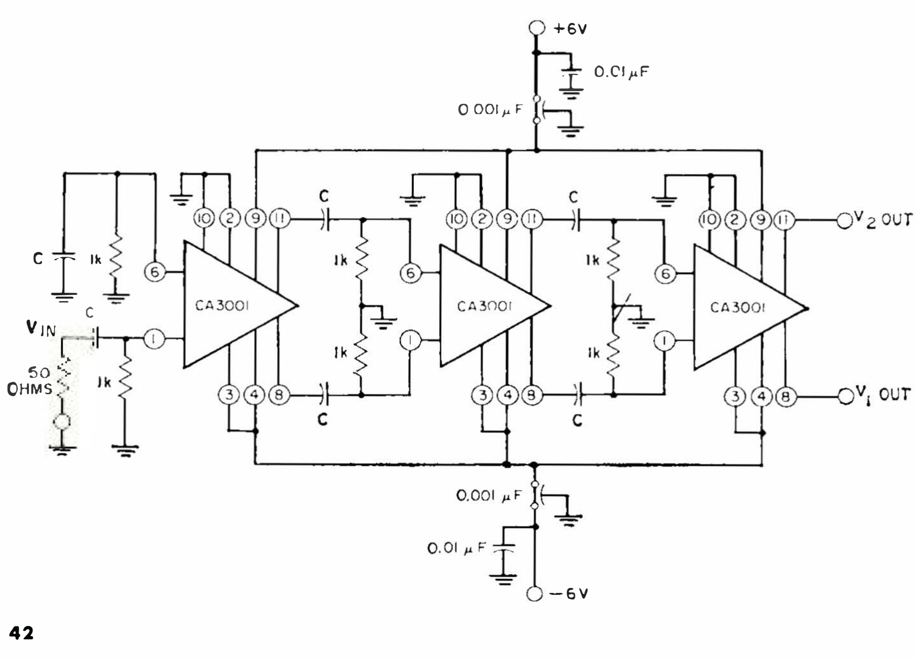
where the balanced, push-pull configuration serves to keep r.f. signals off the power-supply lines, allowing several stages to be cascaded with a minimum of supply decoupling and stability problems.

The internal coupling capacitors are useful from 1 to 20 MHz, enabling the IC's to be direct-coupled. A three-stage amplifier with a gain of more than 1000 from 10 kHz to 10 MHz is shown in Fig. 5. Here additional external capacitors have been used to obtain the better lower frequency response. Still larger capacitors would allow operation into the sub-audio region, making this particular circuit well suited for oscilloscope preamplifiers and other wide-band, low-level amplifiers.

Comparators

Comparators are used to answer the question, "Which one is bigger?" when two inputs are applied. One input is often a reference voltage. In this mode, a comparator serves as a limit detector, an alarm, an analog-to-digital converter, or a sense amplifier for a computer's core memory. By using the *output* of a comparator as its own reference, a Schmitt trigger with controllable threshold voltage and hysteresis, both of which may be made zero, positive, or negative, is obtained. This configuration is of value in level detectors, alarms, tachometers, and anywhere else a snap-action output is required the instant a slowly changing input voltage crosses a critical value.

Fig. 5. A wide-band amplifier employing three CA3001 video-amplifier integrated circuits. Larger capacitors may be added to extend response to sub-audio range.



Fairchild's μA710C ($7.75) offers a comparator with a 1-millivolt resolution and a 40-nanosecond response time to changing inputs. It then converts its response into a digital signal compatible with digital integrated circuits. The voltage gain of the eight-pin TO-5 style IC is 1200 (62 dB). Linear input signals up to 5 volts may be accommodated. Schmitt-trigger operation is obtained by cross-coupling output and input with two resistors.

Another *Fairchild* unit, the μA711, is a dual version of the 710 with an added feature called a "strobe," which allows the output of each comparator to be independently enabled or interrogated. One important application is in magnetic-core sense amplifiers, but this IC will find use anywhere several comparators would normally be employed in related circuits. As with other *Fairchild* units, both premium military versions and limited-temperature commercial versions are available.

Complete I.F. Amplifiers & Discriminators

Certainly, one of the most impressive low-cost linear integrateds available today is the *RCA* CA3013 ($2.65). This ten-pin TO-5 style IC is a *complete* i.f. and audio section for a television 4.5-MHz or a high-quality FM 10.7-MHz i.f. strip. Inside the can are three self-limiting i.f. stages, a discriminator, a dual audio stage, and a regulated power supply. The twelve transistors and twelve diodes add up to eleven cents per active device, a price totally unmatched by discrete circuitry. *(Refer to "TV Set Uses Integrated Circuit" in our June issue.—Editors)*

There are three other similar IC's in the *RCA* line, two without the discriminator and audio stage (CA3011 and CA3012) and one with a higher voltage capability, the CA3014. These range in price from $2.00 to $3.65 each and lend themselves to many non-FM applications as well. Typical would be wide-band limiters and amplifiers often found in industrial instrumentation circuitry.

MOS Analog Gates

We can conclude our survey with some remarkable IC's using MOS (metal oxide semiconductor) technology. Called commutators, analog gates, or multiplexers, these IC's are both linear and digital at the same time.

The units serve as high-speed selector switches of the single-pole, multiple-throw variety. The MOS technology offers several unique advantages. Analog or varying input signals up to ten volts in amplitude of *either polarity* are switched in a d.c.-coupled manner with *zero* offset, a feat that no ordinary transistor, IC, or vacuum tube can ever hope to perform. Further, there is only insignificant coupling between the signal voltages and the input switching waveforms. Practically no input switching power is required, as the input impedance on the switching inputs is typically several thousand *megohms*.

Being brand-new devices, they are still expensive, but the analog gates are already finding wide use in industrial telemetry and sampling circuitry as well as in radar-image-processing circuitry.

The *Fairchild* μM3700 ($62.50) is a representative sample of the dozen or so MOS analog gates now available. It may be used as a single-pole, five-position switch or as a single-pole, four-position switch with an all-channel blanking option. Any position can handle ±10 volts of analog signal. "On" resistance is around 150 ohms with

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Diode Meter Protectors

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fusing at *B* in Fig. 3B sidesteps fuse resistance problems and also protects the meter shunts. If the highest selectable current range is above the fuse rating, place the fuse at *A* as shown. Fusing at *A* requires that the fuse resistance be no larger than 1% of the meter resistance to avoid excessive decalibration.

For a v.o.m. using a 1-milliampere, 50-ohm meter, use a ¾- or even 1-ampere fuse at *A*, along with a diode having at least a six-ampere surge rating. Fuse resistance is no problem in Fig. 3C due to high meter resistance.

Diode Clipping

D.c. currents in pulse and multivibrator circuits, unfiltered battery chargers, and unfiltered d.c. SCR power supplies often have very high peak-to-average values. Typical d.c. meters respond to average values. By voltage-limiting action, the diode protector will clip the peaks, resulting in very large meter error, particularly near full scale.

Fig. 4 shows the voltage waveforms observed across the load current meter of an unfiltered half-wave battery charger in operation. Peak voltage (V_p) to average (V_{avg}) is 9 to 1 in this case. Upon connecting the diode, it clipped at voltage V1 and introduced a meter error of nearly 50%. (Compare V_{avg} in Fig. 4B with V_{avg} in Fig. 4A.)

To detect clipping, switch the v.o.m. to a higher current range and compare readings. A large difference indicates diode clipping, which can be reduced or eliminated by using a higher current range and restricting readings to the lower portions of the scale.

An effective remedy is to connect a capacitor across the meter terminals which will act like a filter for the a.c. components. Sizes may vary from .01-μF disc types to 50-μF transistor electrolytics, depending upon repetition frequencies and meter and circuit resistances. To be certain of obtaining the desired results, compare meter indications with the diode removed, diode attached, and with diode and capacitor connected. A capacitor permanently connected across the meter terminals has little or no effect on the v.o.m. a.c. ranges but this should be checked for the particular instrument being used.

Two diodes in series will double the meter's immunity to diode clipping. It will also reduce diode insertion error by more than one-half. However, it will double the overload factor by doubling the limiting voltage. But this is an acceptable compromise for meters having a low factor around 3× with one diode.

Diode Selection

The lower current rated diodes are preferred for use with the more sensitive high-resistance meters. This reduces diode insertion errors to a minimum. The higher rated diodes are preferred for the lower resistance meters because they have high current-handling ability.

Ordinary top-hat and epoxy diodes are often suitable for use as protectors but may introduce larger diode insertion errors than the commercial protectors. Select the most suitable by noting the meter error at full scale on the *lowest* current range. Use two diodes back-to-back for v.o.m.'s, as in Fig. 3A.

When the meter current range is not very small compared with the diode rating, the diode is less able to carry the major part of the short-circuit current. Higher rated diodes such as stud types can be used to effect an improvement. One exception is the circuit of Fig. 3C in which the diode always sees a fairly large resistance regardless of the range-switch setting. Higher current meters are adequately protected with fast-action fusing alone.

To conclude, v.o.m.'s should be safeguarded by a properly matched diode-fuse combination for maximum protection of the costly meter. ▲

Linear IC's: What's Available

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zero d.c. offset; the leakage when the gate is in another position is typically 1 nanoampere. The switch can safely pass 100 mA of current. Turn-on and turn-off times are 0.5 and 2 microseconds respectively.

Two other companies presently offer analog gates. These are *General Microelectronics* and *General Instrument Corp.* The latter provides an entire line of switches in its MEM5000 series, ranging from six-position single-throw through double-pole, double-throw. Prices are now in the $40 to $90 range, but the devices will inevitably become low-cost IC's once volume usage sets in and development costs have been returned. ▲

"That replaced Cosgrove . . . and I can't figure out what it does either."