Custom chip adds frequency to hand-held meter's repertoire

C-MOS measurement-acquisition chip controlled by a single-chip, 4-bit computer resolves frequency, voltage, and impedance to 4½ digits

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☐ Field service is constantly demanding greater measurement resolution and capability in easily portable form. Present data-processing equipment requires test instruments with not only greater accuracy, but a greater variety of test functions as well. In the 8060A, a 4½-digit multimeter has been combined with an autoranging frequency meter for the first time, and the combined system has been fit into a hand-held meter the same size as a 3½-digit hand-held digital multimeter.

To squeeze such capabilities into so small a package, a Sharp SM-4 microcomputer was used and a special chip was designed. Called the measurement acquisition chip, or MAC for short, the device is structured as a microcomputer peripheral that adds frequency and continuity measurement circuitry to the analog-to-digital converter that is basic to any digital multimeter.

As can be seen in Fig. 1, adding a microcomputer not only simplifies control of the measurement process, but also permits measurement manipulation so that results can be displayed in the most convenient form. Further, the computer performs a complete self-check of the a-d converter, letting an operator know if it is working correctly before he or she uses it.

The MAC (Fig. 2) contains an analog-to-digital converter, a counter, and measurement-continuity and power-control logic. It measures 145 by 155 mils and is packaged in a 40-pin dual in-line package. To accommodate analog as well as digital functions, the chip was designed in complementary-MOS circuitry. This also resulted in low power consumption, a must for battery-operated hand-held units.

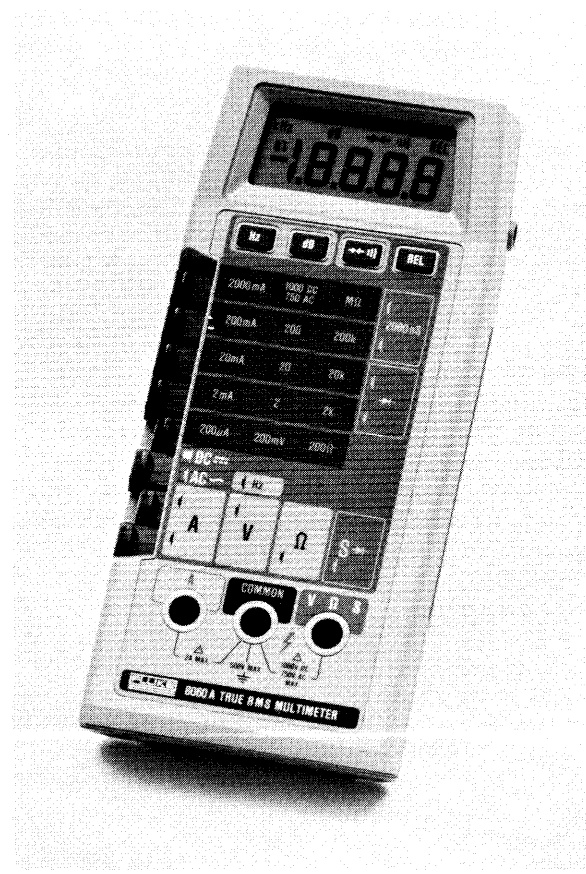
Like most modern DMMs, the 8060A uses a single-slope conversion technique, which has three major phases—autozero, integrate, and read. However, all the circuitry for conversion is now on a single chip and is configured for each phase through on-chip switches—actually C-MOS transmission gates—set by the microcomputer. Figure 3 shows the a-d section of the MAC and the gates used to switch the converter.

Resolution as low as 10 microvolts in the 200-millivolt range has not previously been achieved in monolithic C-MOS converters because of problems with noise and with linearity. Both limitations were overcome in the design of the 8060A.

Nose for noise

Noise problems were first minimized by careful attention to two areas: input noise (which arises in the buffer, integrator, and comparator) and thermal noise from the C-MOS switches. Large-scale integrated input transistors were instrumental in reducing noise from the buffer and integrator operational amplifiers. Low-resistance C-MOS switches were used at the most critical nodes to reduce their noise contribution.

To further reduce the noise to the level at which the display would be dead quiet, or flickerless, a digital filter was used. Implemented in software and stored in the SM-4 microcomputer's read-only memory, it is a recursive filter that averages four successive readings to generate a display. Unlike analog filters, the digital filter can still respond to step changes instantaneously; any input change greater than four counts is displayed imme-



8060A

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The 8060A meter in profile

Although Fluke is not the first to the marketplace with a 4½-digit hand-held multimeter, its 8060A is by no means a "me too" product. Its specifications and capabilities far surpass those of earlier units, such as the Keithley model 135 and the Data Precision model 945, but so does its price. Still, users may find it quite a bargain.

In the five dc voltage ranges—which run between 200 millvolts and 1,000 volts—the 8060A is roughly comparable to the 945. But the 8060A really outshines its competition when ac parameters have to be measured.

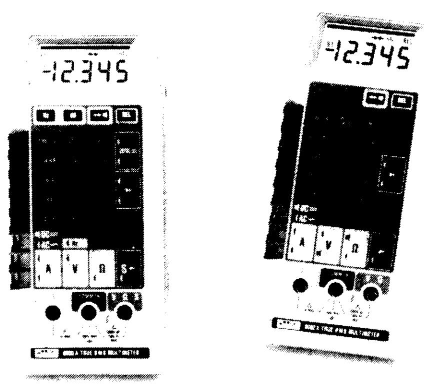
For one, the 8060A gives true root-mean-square readings and functions in a much broader frequency range than its competition. For example, while the 945 is aimed at applications below 1 kilohertz, whereas the 8060A covers the audio frequency range and then some: it is specified for frequencies from 20 hertz to 100 kHz and, according to Dave Taylor, the instrument's analog design engineer "that's a pretty conservative specification. The usable frequency response extends to 470 kHz." Basic accuracy up to 10 kHz on the 200-mV ac range is 0.2%, on the 2-, 20-, and 200-V ac ranges, 0.5%, and at 750 V ac, 1%—all plus 10 counts.

Further enhancing its ac capability is the fact that readings can be displayed either in volts, relative decibels, or dBm referenced to 600 ohms. Beyond even this, however, the 8060A is the only meter of the three able to measure frequency and can do so in autoranging mode.

The meter combines both reciprocal and direct measurement techniques to produce measurements with as fine a resolution as 0.01 Hz in just 1 second. There are four basic ranges—200 Hz, and 2, 20 and 200 kHz—and there is a range extension to 700 kHz that can be enabled at power-up. Measurement accuracy is 0.05% + 1 count, and sensitivity is 20 mV to 20 kHz; actual signal level can, of course, be checked using the ac voltage function.

Resistance measurements are made using a ratiometric technique and can go as high as 300 megohms. Basic accuracy is 0.07% + 2 counts to 200 kilohms, and resistance measurements can be made in circuit since the level of the ohms source (250 mV) will not turn on most semiconductors. "This greatly enhances the meter's use in field service, where most measurements are made in circuit," Taylor points out. In the high range, readings are made in a conductance range of 2,000 nanosiemens.

Other features include the ability to make relative measurements in all ranges, the continuity function at as little as 20 Ω, and the diode-test function. The unit is priced at $349, and if a user can do without decibel frequency, and conductance measurement capabilities, there is the model 8062 for $279. **-Richard W. Comerford**



diately and the averaging then starts from the new value.

To improve linearity, the a-d converter was designed to provide 80,000 counts internally for a full-scale, 20,000-count reading, reducing the digitizing error by a factor of four. The microcomputer divides the internal count by four before displaying the resultant reading.

To achieve wide measurement coverage, DMMs are built with dual-slope converters that have two operational ranges: 200 mV and 2 volts. Usually, this dual range capability is achieved by switching in an amplifier with a gain of 10 to obtain the 200-mV range. For the 8060A, however, this method was unacceptable; offsets would have increased by a factor of 10 unless an extra autozero loop was added on chip. As shown in the figure, the problem was overcome by using a precision resistor network to directly change the integrator's gain.

Using such a network results in an integrator gain of 20 for the 200-mV range and 2 for the 2-volt range. Thus the full-scale output of the integrator is ± 4 V, rather than ±2 V as in most such converters. This makes the resolution of the converter output 200 μV/count, reducing the noise performance requirement of the output comparator. Further, since the slope of the integrator output is thereby doubled, the speed and delay requirements for the comparator are halved.

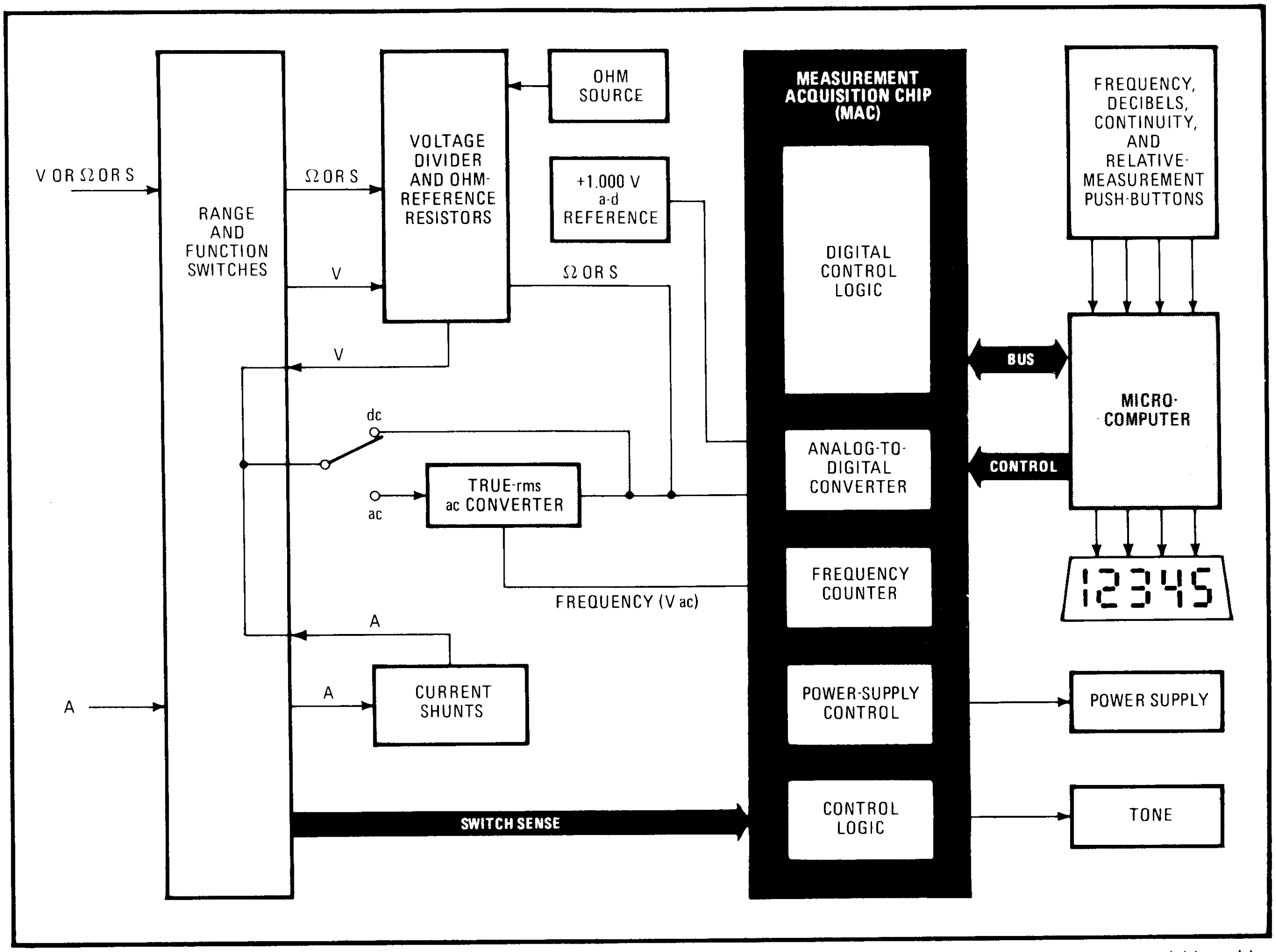
Even with these improvements, designing the comparator was a formidable challenge. As the single-comparator design seen in most converters would have resulted in an unacceptable penalty in stability, a dual-comparator scheme was used. The first comparator meets the noise and speed requirements, but does not provide enough gain, while the second comparator is used to make up the difference in gain. Since the second comparator does not need to be in the autozero loop, overall gain in the loop is reduced, making it more stable.

Central control

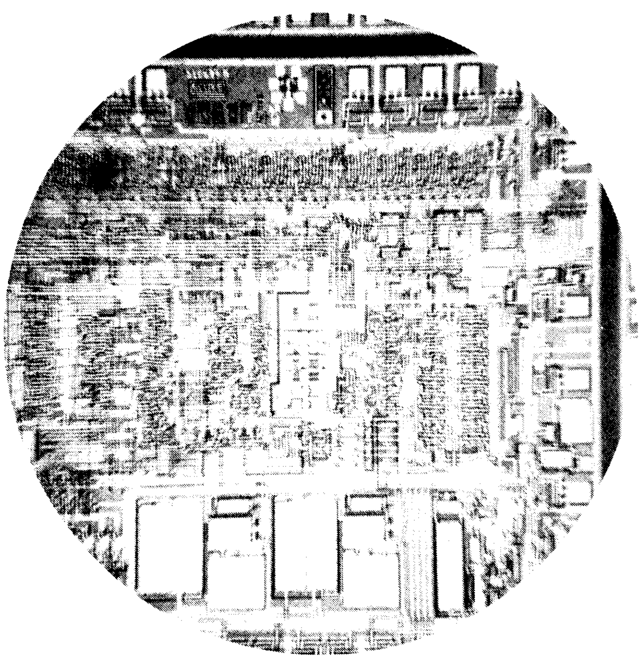
Certainly not the least significant feature of the multimeter is its single-chip 4-bit microcomputer, the Sharp SM-4. The C-MOS unit was chosen not only for its low power requirements—less than 50 microamperes at 3 V—but its duplexed drive circuitry, which can drive a 72-segment directly.

Choosing the microcomputer early in the design was essential, since its characteristics would directly determine the interfaces and requirements of peripheral circuits, such as the MAC. Further, the software that implemented such features as the decibel conversion and relative readings, as well as the self-test and operating system software, had to be written.

To create the software, an SM-4 assembler was first created to run on a Digital Equipment Corp. PDP-



1. Calculated choice. The major design difference between the 8060 and the 8020 is the use of the custom measurement acquisition chip, or MAC, and an SM-4 single-chip microcomputer. The combination lets the 4½-digit multimeter measure frequency, as well.



2. New way. The MAC is the first major chip designed and fabricated by Fluke in its own semiconductor facilities. Measuring only 145 by 155 mils, the chip performs most of the meter's analog measurement functions; the major analog circuits are seen at center.

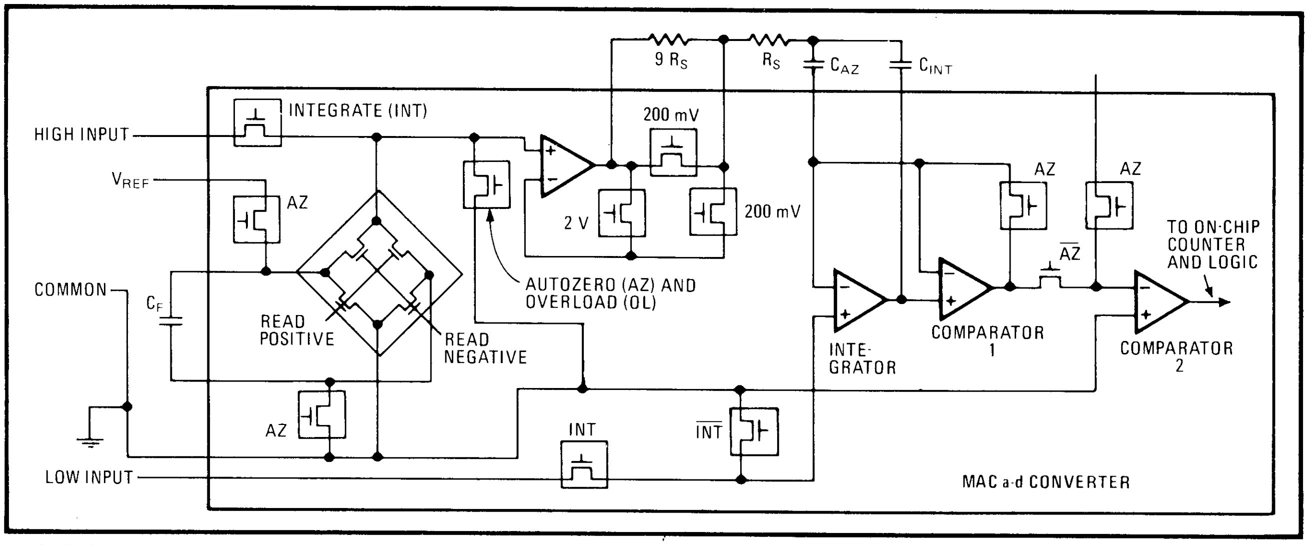
11/70. Not only did this permit rapid compilation, but it allowed the programmers to work in a structured manner and to document their work properly.

The a-d converter is controlled through a 4-bit, bidirectional bus by the SM-4 microcomputer, and the count that results from a measurement is read back through the same bus. This scheme greatly reduces the digital circuitry required in the MAC.

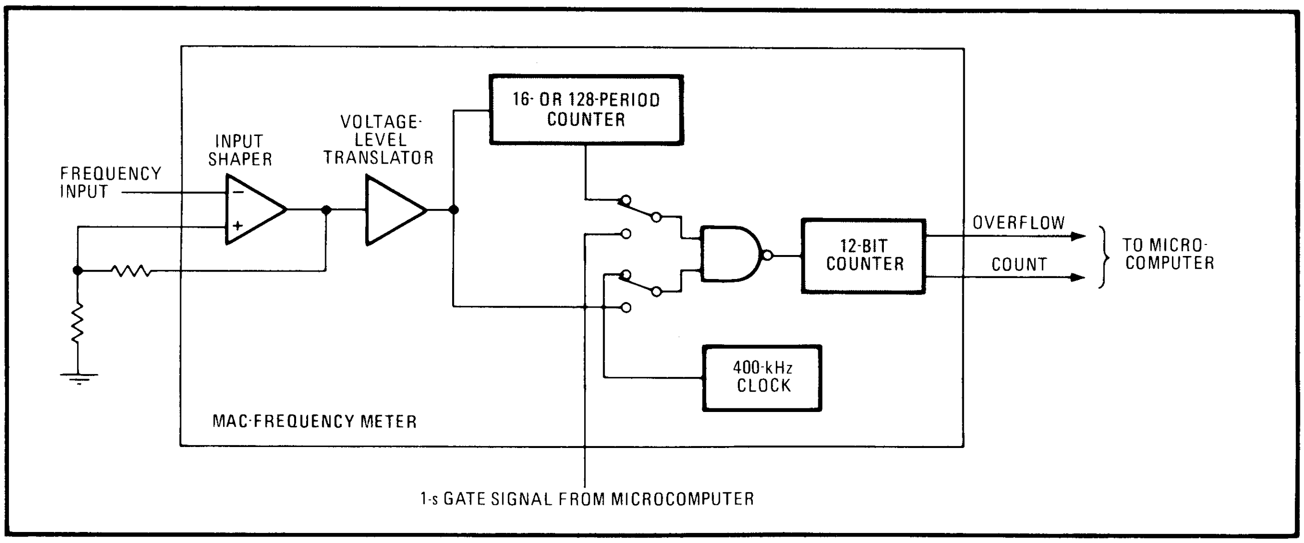
The MAC has only a 12-bit counter, rather than a 16-bit one. To complete a count, the microcomputer picks up the overflow carries from the counter. Nineteen overflows are generated in a full-scale count, and if a twentieth carry bit is generated, the microcomputer automatically knows an overrange condition has occurred and can act accordingly, displaying an OL (for overload) on the display and resetting the converter.

A further reduction in MAC digital circuitry results from this register-like structure. The need for an a-d–state machine and complex timing circuitry, usually found in single-chip a-d converters, is eliminated.

By having full control over the MAC's functions, the microcomputer can manipulate the a-d converter in unconventional ways. For example, modifying the conversion sequence performs a converter self-check. Called the ratio test, this user-initiated check uses the reference voltage for both the integrate and read phases. Since the



3. Switched dual-slope. The MAC's dual-slope converter is controlled by on-chip C-MOS gates, which are set by the microcomputer for three major conversion phases: autozero (AZ), integrate (INT), and read (RD). For overloads, the OL switch is used to quickly drain charge.



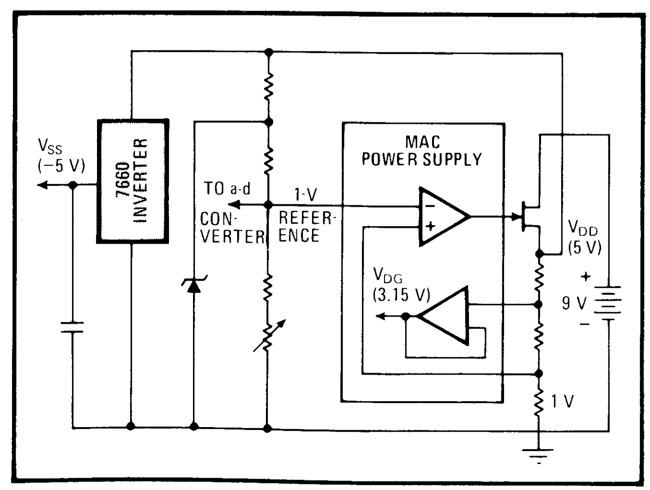
4. Reciprocal relationship. To get the best mileage out of the MAC's counters, the 8060 uses both direct and reciprocal counting techniques. Above 2 kilohertz, the actual number of cycles are counted for 1 second; for 2 kHz and below, the period is measured.

reference is used to reference itself, the resulting displayed count should be 10,000—a perfect ratio of 1:1. Further, by taking advantage of the integrator's gain change capability, a range equivalent of 20 mV full scale can be obtained. This strategy is used in the 300-megohm range, where the voltage across the reference resistor can be as little as 6 mV.

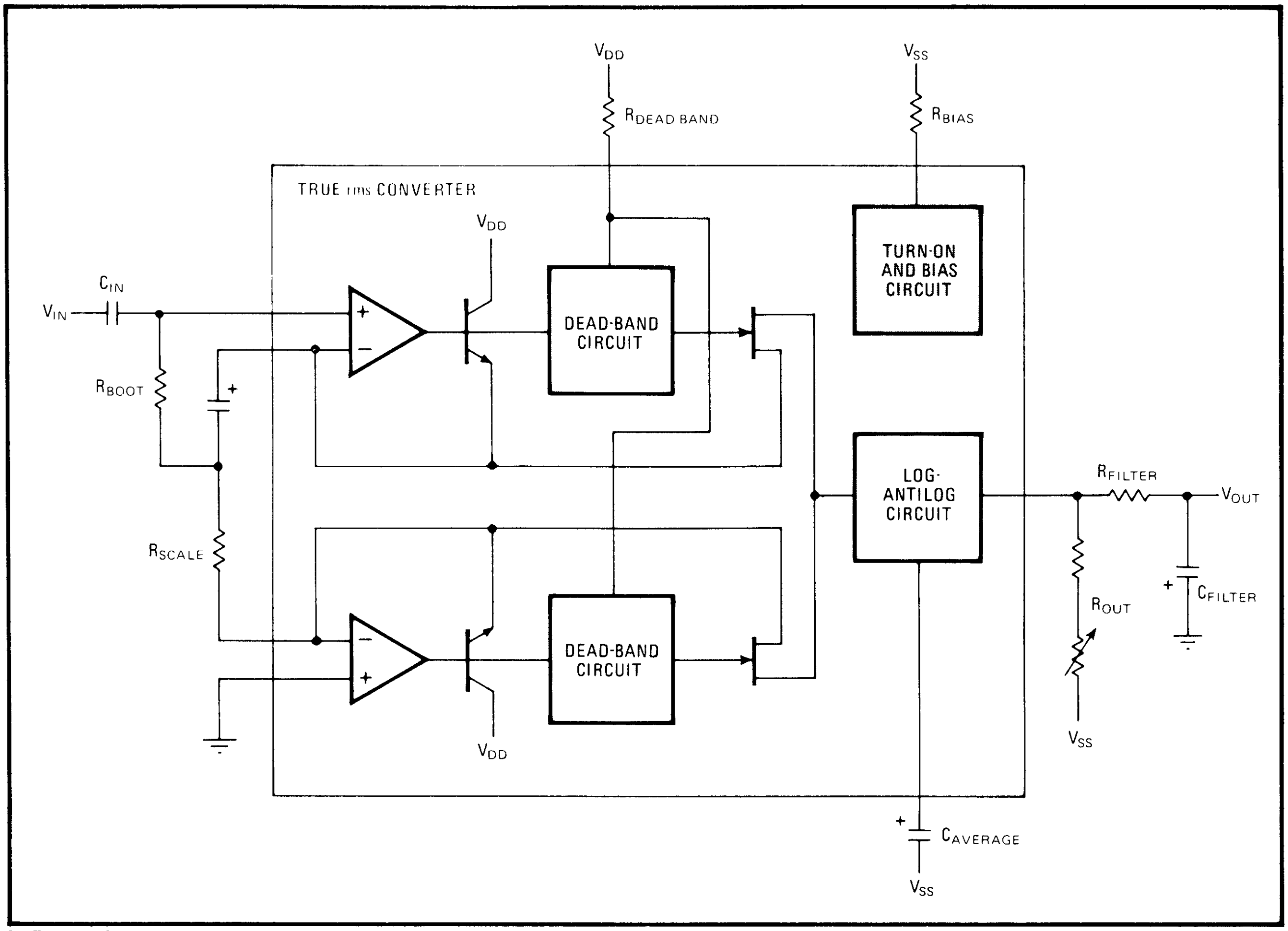
For measuring frequency, the same counter chain used with the conversion circuitry is employed, but the converter itself is not. Instead, the signal to be measured is fed to a comparator, shown in Fig. 4, whose hysteresis comparator serves to square up the input signal.

Reciprocal versus direct

Depending on its frequency, the input signal is handled in one of two ways—reciprocal or direct. For the lowest frequency ranges—200 hertz and 2 kilohertz—the input is used to gate the output of the 400-kHz system clock to the counter for a fixed number of cycles, 16 and 128, respectively. For the two highest ranges—20



5. Controlled power. To keep the numerous voltages needed accurate, the zener-derived 1-volt reference is used to check the power supply output and control a junction FET. The negative supply is derived from an Intersil 7660 used as an inverter.



6. Better than average. The rms converter shown above provides a highly accurate true-rms value for signals with crest factors on the order of 3:1 or less and frequencies to 100 kilohertz. R_{OUT} and R_{SCALE} scale the root of the squared input for conversion.

kHz and 200 kHz—the cycles of the input signal are counted directly for a fixed time period of 1 second under microcomputer control.

For low frequencies, reciprocal counting provides the advantage of high resolution and an accuracy limited only by the precision of the system clock. For a 20-Hz signal, for example, each cycle is in effect divided into 20,000 parts by the system clock and 16 cycles are averaged to obtain a reading. Thus, a high-resolution measurement of 0.01 Hz is easy.

Further, reciprocal counting allows averages to be taken much more quickly. Whereas the 8060 displays a 16-cycle-average reading in just 1 second, a conventional frequency meter would take as much as 100 s to achieve 10-millihertz resolution.

Above 2 kHz, however, no significant advantage in resolution is gained using the reciprocal technique with a 400-kHz clock. Thus, a direct frequency-counting technique is used, in which the positive-going transitions are counted for 1 s and the resulting binary number is read by the microcomputer to obtain the frequency.

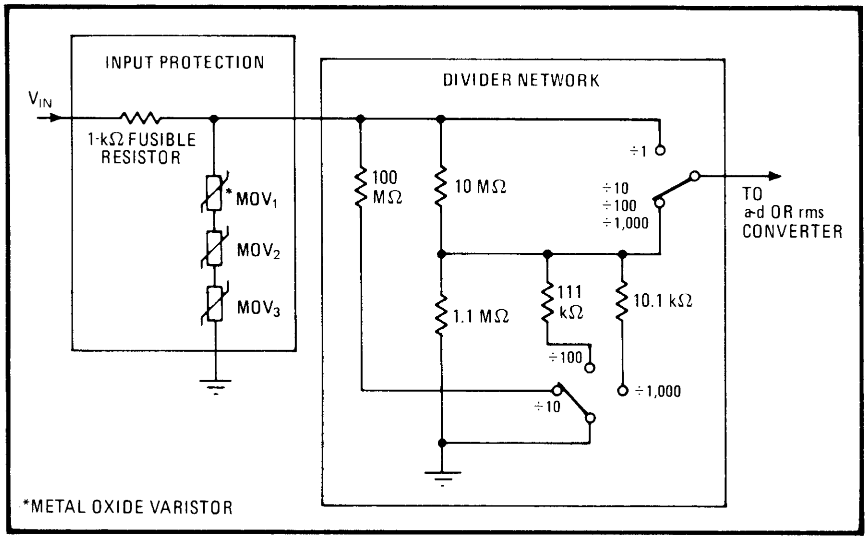
In actuality, the reciprocal readings could be accomplished in less than 1 s, but the display is always updated about once per second to keep the update uniform. The meter begins by making a 16-period measurement, and if this proceeds too quickly, it goes to a 128-period measurement and then a direct frequency count. Since the period measurement takes very little time at high frequencies, the direct count can be made for a second. Using this regimen permits the meter to be autoranging.

Just as the counter circuit does double duty—being used for a-d conversion as well as frequency measurements—so too is the comparator used to square up the input signal for frequency counting. For continuity checks, the comparator's threshold is changed off chip so that a signal level of approximately 20 mV will cause the comparator to trip.

When the comparator trips, it sets a latch that the microcomputer leaves on for 200 milliseconds. This allows pulses as short as 10 microseconds to be indicated on the display and, if the user desires, heard; a piezoelectric transducer is driven by dividing the system clock's output frequency by 150, down to 2.666 kHz, and gating this signal to the transducer for 200 ms.

Power play

Another task that the MAC was designed to perform was control of the DMM's power. The design was not a simple matter, for the constraints were numerous. For example, the meter had to work from a simple power source, a 9-V battery, for portability and ease of replacement. Yet, the microcomputer and LCD required 3.15 V so that they could operate with minimum temperature sensitivity, while the a-d converter's integrator required



7. Unified divider. As seen above, the 8060A's front end permits ratios of 1,000: 1, 100: 1 and 10: 1 to be selected. The monolithic 10: 1 divider is used only for the ac voltage range, where input impedance is maintained by switching in a 100-megohm resistor in parallel with the divider network.

±5 V to accommodate the large voltage swings desired. Further, ripples and spikes on the power supplies had to be carefully filtered to keep them from interfering with the frequency counter.

As shown in Fig. 5, the solution to these demands took relatively little extra circuitry thanks to careful planning. The zener-derived precision 1-V reference used for the a-d converter was enlisted to serve also as the regulator for the analog portion of the system supply. With a C-MOS operational amplifier as the battery output, the difference between the two is used to control the gate of a junction–field-effect transistor, ensuring the right current flow for the needed voltage levels.

Using J-FETs to control supply voltage is doubly beneficial. The battery voltage required to maintain regulation is only millivolts above the regulated output voltage, thus prolonging battery life. At the same time, the I_{DSS}-current –limiting action also prevents damage to the multimeter when the input is overloaded.

In addition to the MAC, other special circuits had to be created for the multifrequency meter. Since it was to have the capability for extensive ac measurement, the meter would also need a root-mean-square converter and an input divider capable of working at high frequencies.

Whereas some hand-held meters produce rms readings by rectifying the input signal and multiplying the measured dc value by a scaling factor, such a voltage measurement is valid only for pure sine waves. Thus, when ac measurements are taken on nonsinusoidal waveforms, the type most often encountered in field service, the readings can be misleading, particularly if the user is not familiar with the technology.

A true-rms converter, on the other hand, can measure the actual power of a signal with less constraint on its form and thus be more useful in the field. Two types of coupling, ac and dc, can be used to present the signal to the rms converter, and the former was chosen for the 8060A. While ac coupling will only measure the ac component of power supplied, it avoids the offset drift often associated with dc coupling, which degrades accuracy, and permits measurement of ripple on dc supplies.

What determines the design and accuracy of a true-rms converter are both the frequency and the crest factor of the signals that it will likely be used to measure. Crest factor is a measure of how rapidly the bulk of power is delivered during one cycle of a signal and is the ratio of the peak level to the rms voltage. Tied with the frequency, these values then determine how quickly the converter must be able to react to changes in signal level.

The converter design shown in Fig. 6 is able to handle signals with frequencies of 100 kHz and crest factors of 3:1 or more. Signals having crest factors of more than 3:1 seldom occur in common measurements, and even at crest factors of 5:1, measurement accuracy is degraded only by approximately 2% of input.

Grand design

While the design for the deadband, or crossover-distortion, and log-antilog circuits are proprietary, having been originated by Fluke and manufactured by Motorola, some aspects of the converter's operation can be discussed. The converter implemented in bipolar-FET technology, converts input signals into current proportional to the absolute value of the input voltage. Using matched logging transistors, an implicit rms calculation takes place. A current proportional to the input rms value is generated and converted into voltage by a scaling resistor. Additional filtering for low-frequency ripple is applied before the signal is routed to the a-d converter. The bias supply of the rms converter is brought out, allowing the microcomputer to turn off the true-rms converter when it is not needed, to save power.

The circuit topology usually employed in multimeter front-end design results in poor frequency response, due to stray capacitance; to make the frequency capability of the 8060A meaningful while retaining dc measurement accuracy, the input attenuator of the meter had to be specially designed. The thin-film resistor network actually employed (Fig. 7) uses a single tap to minimize stray capacitance created by multiple switches, and the circuit is carefully shielded as well. For accurate ac response, monolithic negative-positive zero (NPO) and ceramic capacitors and Teflon trim resistors are used. Voltage ranges are protected by metal oxide varistors and a fusible input resistor; the varistors clamp transients while the resistor protects against extended overloads. □

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