



## A 10 MC Scaler for Nuclear Counting and Frequency Measurement

IN recent years a new type of instrument—the scaler—has been increasingly used for pulse-counting and frequency measurement purposes. A scaler is basically a frequency-dividing instrument that is capable of dividing quantities of pulses by an arbitrary factor, usually  $10^n$  or  $2^n$ . Scaling circuits differ from conventional frequency divider circuits, however, in that scaling circuits must be aperiodic to be usable with pulses arriving at a random rate, whereas frequency dividers are usually periodic.

The major objective in the development of the scaler shown in Figure 1 was to design an instrument capable of operating at very high rates without sacrifice in reliability. In final design, the instrument is capable of scaling pulses arriving at uniform rates up to 10 million per second. It has a double-pulse resolving time of 0.1 microsecond and a triple-pulse resolving time of 0.2 microsec-

ond. The circuit consists of two decades, giving a scaling factor of one hundred, so that for every one hundred pulses applied to the scaler a single output pulse is generated. Residual counts are indicated by two panel meters having a combined capacity of one hundred counts. An important feature of the scaler is that it has no lower limit on pulse rate. The high speed and scaling factor allow the instrument to be used in front of the majority of existing scalers which are capable of operation into the region of  $10^5$  pulses per second.

The high speed of the scaler is not achieved at the expense of operational reliability. The circuit design is such that no adjustments of any sort are required, even for highest speed operation. Extensive tests of reliability have been made with favorable results. For example, from a group of 30 tubes selected at random and placed in the high-speed circuits, only one tube failed to allow the scaler to operate properly up to 10 mc. In temperature variation tests, the instrument operated properly over a range from  $-20^\circ\text{C}$  to  $+50^\circ\text{C}$ .

### SCALING METHODS

Since scalers must be usable with randomly-occurring pulses, scaling circuits must be aperiodic. This requirement has led to the use of Eccles-Jordan or bistable type multivibrators and to a binary system for counting purposes. A basic bistable multivibrator is shown in Figure 2. Such a circuit has two



Figure 1. -hp- Model 520A High-Speed Scaler operates up to 10 mc.

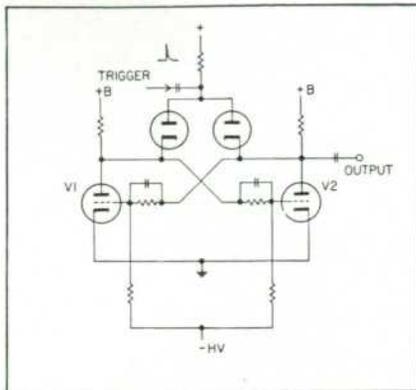


Figure 2. Basic bistable multivibrator circuit.

stable states—either one or the other of the two tubes conducts at any one time while the remaining tube is cut off by high grid bias. When triggered by a suitable incoming pulse, the conducting tube is cut off and the other tube conducts. The multivibrator remains in this condition until a second trigger causes the circuit to revert to its initial state, producing a pulse of given polarity at the output of V2. This type of circuit can be arranged to trigger from, say, only positive pulses and to produce a positive pulse at the output of V2 for every second trigger pulse applied. An arrangement such as this, then, divides the triggering pulses by a factor of two and is the fundamental principle used in most scalars.

For convenience of use, it is desirable that a scaling device scale by a factor much larger than two. Therefore, several bistable multivibrators are usually connected in cascade in a circuit such as that of Figure 3, which scales in a binary manner by a factor of 16. That is, every sixteenth pulse applied to the input multivibrator results in a single output pulse from the output multivibrator, as illustrated diagrammatically in Figure 4.

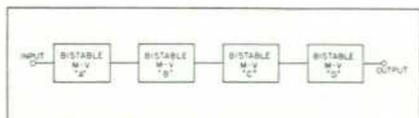


Figure 3. Multivibrator chain used in scale-of-16 circuit.

#### DECADE SCALAR

Because of wide preference for decimal rather than binary scaling, compounded binary systems such as that of Figure 3 are often modified by means of a feedback circuit so as to re-cycle after the tenth applied triggering pulse. Such an arrangement can be described by reference to Figure 5. In Figure 5(a) is shown the plate voltage on the output tube of each multivibrator in a scale-of-16 circuit. It will be seen that on the eighth applied pulse multivibrator "D" switches, giving a sharp voltage rise that can be used for triggering purposes. By a suitable circuit arrangement, this voltage rise can be fed back to multivibrators "C" and "D" as a triggering pulse to cause a rapid re-triggering. These opera-

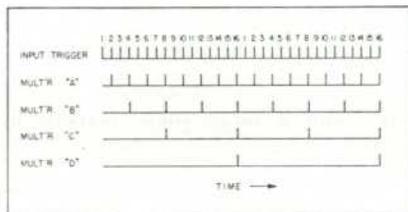


Figure 4. Schematic representation of operation of scale-of-16 circuit.

tions are illustrated in Figure 5(b), where it will be seen that after the tenth applied pulse all multivibrators are in the same condition as after the tenth pulse of the previous group. The circuit has thus completed a cycle after ten applied pulses. The output pulse is obtained by differentiating the voltage rise in multivibrator "D."

The limitation of such a feedback circuit at high speeds arises from the fact that the switching action in a multivibrator is not instantaneous. Rather, a short interval of time is required for the switching action to occur, resulting in a short delay before the next multivibrator in the chain can be triggered. At high pulse rates, these delays are such that the switching time becomes an appreciable fraction of the multivibrator half-cycle. As a result, the time interval required after the eighth applied

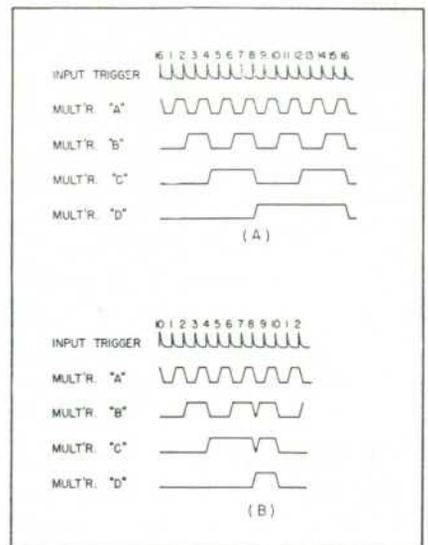


Figure 5. Waveforms in (a) binary and (b) decade scaler.

pulse for multivibrator "B" to be reset is the sum of the delays in each multivibrator as the trigger is passed through the chain and back to multivibrator "B" (Figure 6)—five separate delays. Instead of being re-triggered immediately, then, multivibrator "B" will not be re-triggered at the time of the last (tenth) pulse of the cycle, as indicated in Figure 6. In a straight binary system the delay between multivibrators "A" and "D" is relatively unimportant. In a decade scaler, however, this delay has been a limiting factor.

#### FAST DECADE SCALAR

To develop a scaler capable of operating at a 10-mc rate, it is apparent from the above that two important points must be accomplished. First, the multivibrators themselves must be designed to switch as rapidly as possible; second, the cumulative delay in the re-triggering circuit must be reduced substantially.

Figure 7 shows the basic high-speed multivibrator used in the Model 520A. Three important steps have been taken to increase the basic speed of this circuit over the fundamental circuit of Figure 2. First, the rise-time of each stage has been made short through the use of high  $G_{m1}$  6AH6 pentodes and by minimizing stray capacities. Second, the grid is

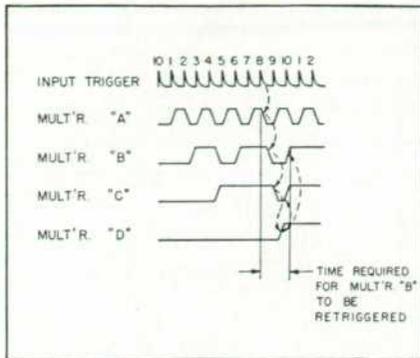


Figure 6. Delay in feedback circuit at high speeds.

clamped by diodes CR3 and CR4 so that it can not be driven below 2 volts. Instead of the need of the grid circuit's recovering from a value far below cut-off during the switching, then, the grid is required to change only about 2 volts.

In high-speed circuits, it is customary to use small plate resistors in order to minimize rise and decay times. However, this scheme also reduces the available output voltage. Other factors being fixed, the minimum usable plate resistor is thus limited by the voltage necessary to drive the following grid. In multivibrator applications, the use of a small load resistor tends to introduce unreliability, for a tube whose  $G_m$  becomes low will slow the effective rise time of the circuit and may not give the required amplitude of plate swing. This condition is illustrated in Figure 8(a).

In the -hp- Model 520A a plate clamping arrangement is used to overcome the disadvantages of the

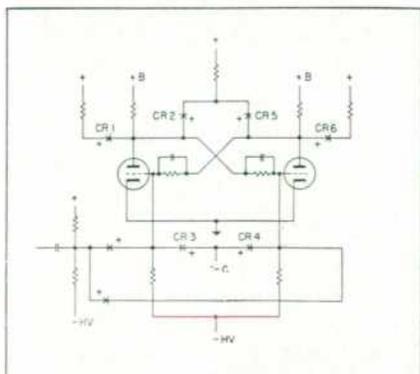


Figure 7. High-speed multivibrator circuit used in -hp- Model 520A.

use of small plate resistors. The plates of the tubes are clamped by diodes such as CR1 and CR2 in Figure 7 so that only a 20-volt plate swing is obtained between the conducting and non-conducting conditions. This arrangement offers a two-fold advantage. By clamping the plates, the operation of the multivibrator is made substantially independent of normal variations in tube characteristics, even at high pulse rates. This factor is largely responsible for the high percentage of usability of replacement tubes described before. In addition, plate clamping gives a more desirable rise and decay characteristic and allows a favorable portion of this characteristic to be used.

When the plate circuit is clamped, the situation is as illustrated in Figure 8(b). A relatively high value of B+ and a large plate resistor are used, thus giving a rise-time characteristic that is much longer than with a small plate resistor but that has the same initial slope. The plate clamps limit the operation to only a portion of the characteristic as shown. The rise-time of this portion can be shown to be somewhat faster than the total rise-time of a circuit that uses a small plate resistor.

The reliability of the clamped plate circuit is much better than in the case of the small plate resistor. This is illustrated by the dashed line in Figure 8(b). If a tube having low  $G_m$  is used, only a slight increase in rise-time is obtained. In addition, the required amplitude of plate swing will almost always be obtained.

It should be noted that for optimum resolving time the rise and decay times should be equal. Since the decay characteristic is the inverse of the rise characteristic shown in Figure 8(b), the clamped region must be placed midway between the limits of the unclamped plate excursions to give the necessary symmetry to the operation of the circuit.

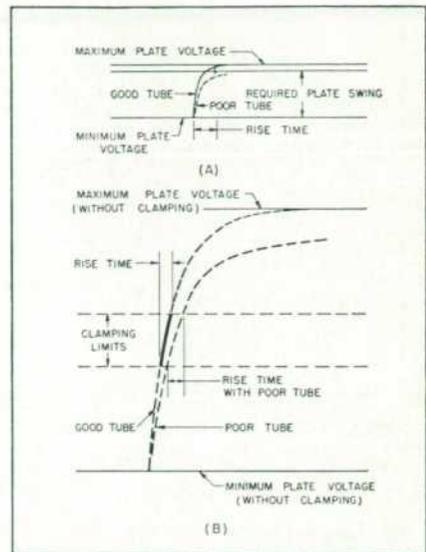


Figure 8. Comparison of rise and decay characteristic of (a) unclamped circuit using small plate resistors and (b) clamped plate circuit using large plate resistors.

#### HIGH-SPEED FEEDBACK CIRCUIT

A final factor in speeding up the scaler is the use of a high-speed feedback circuit that avoids the delays described before. The circuit used can be described with reference to Figure 9. In Figure 9(a), it will be seen that in the interval between the seventh and eighth applied pulses, multivibrators "A," "B" and "C" are all in the same sense. In addition, this interval is the only time at which the first three multivibrators are thus aligned. Through a special gating arrangement, then, the overall circuit would be susceptible to a feedback pulse at this time. To accomplish this, the multivibrators are coupled to a gating tube which can only be opened when multivibrators "B" and "C" are "up." The output of the gating tube is coupled to multivibrator "D." On the eighth applied pulse, the sharp negative voltage from multivibrator "A" triggers multivibrator "D" before the gate controlled by multivibrators "B" and "C" closes. Through a second feedback circuit, the sharp rise in multivibrator "D" is used to re-trigger multivibrator "C" and "B" as indicated in Figure 9(b). After being triggered by the ninth and tenth ap-

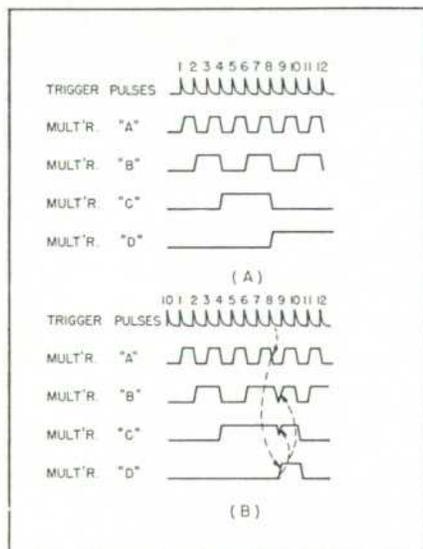


Figure 9. Operation of high-speed feedback circuit.

plied pulses, the multivibrators revert to the same sense as after the tenth pulse of the previous group, thus completing a cycle.

In effect, this arrangement has removed the major delays from former types of feedback circuits, because a pulse from multivibrator "A" re-triggers multivibrators "C" and "B" with only the delay in multivibrators "A" and "D." These delays have been minimized through the use of very fast switching circuits.

#### ONE MEGACYCLE SCALER

The output of the 10-megacycle

#### ACKNOWLEDGMENT

The *Hewlett-Packard Journal* wishes to acknowledge here the valuable contributions of Mr. Howard M. Zeidler toward the development of the Model 618A UHF Signal Generator described in last month's issue (Vol. 2, No. 1).

Mr. Zeidler envisioned the possibilities of the circuit with regard to straightforward suppression of undesired oscillations, and further performed much of the basic development work that led to the ultimate success of the project.

decade feeds into a 1-megacycle decade in order to obtain an overall scaling factor of one hundred. The 1-megacycle scaler is less elaborate than the high-speed circuit, since the significant time intervals are ten times as long.

The output of the 1-megacycle circuit is differentiated and applied to a two-stage shaping amplifier. The resulting pulse delivered to the output terminals has a 50-volt peak amplitude and a triangular shape. The rise-time of the output pulse is approximately 0.5 microsecond.

#### CRYSTAL DIODES

The design of the high-speed circuit requires a rather large number of diodes for clamping and gating purposes. If maximum speed is to be obtained, these diodes must necessarily be of the crystal type to minimize stray capacities.

Since crystal diodes are regarded by many as unreliable, considerable test work has been performed towards developing a reliable method for the selection of diodes to insure that diode replacement would not become troublesome. To date, the method used has given 97% reliability in 500-hour tests on finished instruments—a figure comparable if not better than the reliability of conventional tubes. Further refinements in the method of selection are expected to give even greater reliability.

#### RESIDUAL COUNTS

Two panel meters are provided to indicate residual counts. One meter is calibrated from 0 to 90 in multiples of 10 and the other from 0 to 9 in multiples of 1. The combination indicates residual counts from 0 to 99. Thus, if a discrete group of 4039 pulses is applied to the instrument, 40 output pulses will be delivered and the panel meters will show the residual count of 39.

#### INPUT CIRCUIT

The instrument operates from positive input voltages having a

maximum peak value of 30 volts and a minimum rate of rise of 10 volts per microsecond. For uniformly-spaced input voltages, a minimum peak value of 5 volts is required and the instrument will operate properly up to 10 mc on such voltages. If the input pulses are occurring randomly and if the highest resolution of 0.1 microsecond for double pulses or 0.2 microsecond for triple pulses is desired, it is recommended that the input pulses have a minimum peak value of 10 volts.

The input circuit consists of an input shaping amplifier with a dc restorer in the grid circuit to prevent blocking of the amplifier.

#### OTHER APPLICATIONS

It can be seen that a scaler such as the -hp- Model 520A is useful as a wide-range frequency divider. The basic circuit is also adaptable to measuring events occurring in limited time intervals and to measuring time intervals in terms of events occurring at uniform rates. Such circuits will be described in future issues.

—A. S. BAGLEY

#### MODEL 520A HIGH-SPEED DECIMAL SCALER SPECIFICATIONS

- REQUIRED INPUT POLARITY: Operates from positive pulses.
  - REQUIRED INPUT AMPLITUDE: See Resolving Time.
  - REQUIRED RATE OF RISE: 10 volts or more per microsecond.
  - INPUT IMPEDANCE: 5000 ohms.
  - RESOLVING TIME: For two 10-volt or more pulses, 0.10 microsecond; for three 10-volt or more pulses, 0.20 microsecond, first to third. Maximum continuous uniform rate, 10<sup>7</sup> counts per second on pulses of five volts peak. No lower limit on rate.
  - OUTPUT: Either positive or negative triangular pulse with approximately 0.5 microsecond rise time and approximately 3 microsecond wide at base. 50 volts peak amplitude.
  - OUTPUT IMPEDANCE: 5000 ohms.
  - AMBIENT TEMPERATURE RANGE: 0°C to +50°C.
  - INPUT AND OUTPUT CONNECTORS: UHF type jacks (Navy type-49194).
  - POWER SOURCE: Operates from nominal 115-volt, 50/60 cycle supply. Requires 200 watts.
  - DIMENSIONS: 10 1/2" high, 19" wide, 13" deep.
  - MOUNTING: Supplied in relay rack style
  - SHIPPING WEIGHT: Approximately 80 lbs.
  - PRICE: \$600.00 f.o.b. Palo Alto, California.
- Data subject to change without notice.