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To You . . . whom we think of as a friend and for whose pleasure and profit "The Capacitor" is dedicated, we sincerely wish a **New Year** of continued happiness and prosperity.

CORNELL-DUBILIER ELECTRIC CORPORATION.

FREQUENCY DIVIDER METHODS

The task of producing a submultiple frequency from an available standard or operating frequency seems simple enough on the surface. This attitude probably arises from reciprocal reasoning: Frequency multiplication is a simple, practical fact, so why not also frequency division? The practical realization of frequency division, however, is neither as simple or common as multiplication. The technician confronted with the problem often has perplexity as a companion.

The needs for frequency division are varied. Thus, submultiple frequencies may be required for purposes of instrumentation, calibration, control, operation of lower-frequency circuits or equipment, synchronization, timing, counting, comparison, etc. Because of the relative unfamiliarity of the subject, it is well to review here the state of the art with respect to frequency division.

Conventional Multivibrator

The conventional multivibrator is one of the better-known electronic frequency-dividing devices. Synchronized from the source of initial frequency, the multivibrator will divide that frequency by a factor depending upon the time constants of the multivibrator circuit components.

Figure 1 (A) illustrates the arrangement. The multivibrator is designed for operation at a natural frequency (f_2) equal to the desired submultiple of the signal-source frequency (f_1). Thus, in radio frequency standards, f_1 usually is derived from a precise 100-kc oscillator, and the frequency (f_2) of

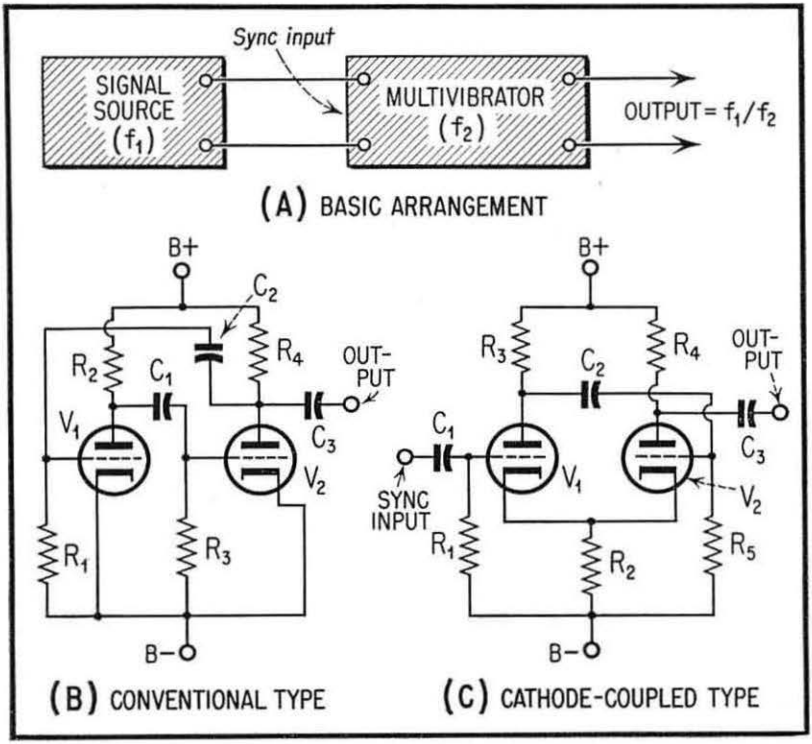

Fig. 1. Multivibrator Method.

the multivibrator may be 10 kc. Frequency division of 10 to 1 is common, although ratios as high as 100:1 have been achieved experimentally.

Also shown are two representative multivibrator circuits. The conventional multivibrator (Figure 1B) essentially is a 2-stage RC-coupled amplifier with output coupled back to input through capacitor C_2. This is a symmetrical circuit in which $C_1 = C_2$, $R_1 = R_3$, and $R_2 = R_4$. The circuit is unstable and is self-oscillating at a frequency equal approximately to $f/(500RC)$; where f is in kc, R (the resistance of either R_1 or R_2) is in ohms, and C (the capacitance of either C_1 or C_2) is in ufd.

A synchronizing voltage from the signal source, injected into the multivibrator circuit at either grid or plate, will lock the multivibrator into step and thereby stabilize its operation. The multivibrator then will not only divide f_1 but will have the same frequency stability and accuracy as that of the signal source. Signal injection at the grid of either V_1 or V_2 tends to favor odd values of frequency division, while injection at either plate favors even values.

Figure 1 (C) shows a **cathode-coupled** multivibrator. Here, V_1 is coupled to V_2 through capacitor C_2. But the feedback coupling occurs as a result of current flow through the common cathode resistor, R_2. In this circuit as in the preceding one, the natural frequency of oscillation is determined by the constants of the grid coupling capacitor (C_2), grid resistors (R_1 and R_5), and to some extent cathode resistor R_2.

The multivibrator signal-output voltage does not necessarily have the same waveform as that of the controlling signal. The multivibrator output is essentially rectangular in shape. The controlling signal may be a sine wave or pulse. When sinusoidal multivibrator output is desired, it may be obtained by passing the output signal through a suitable bandpass filter.

It is important to remember that normally a multivibrator is capable of operation with or without synchron-

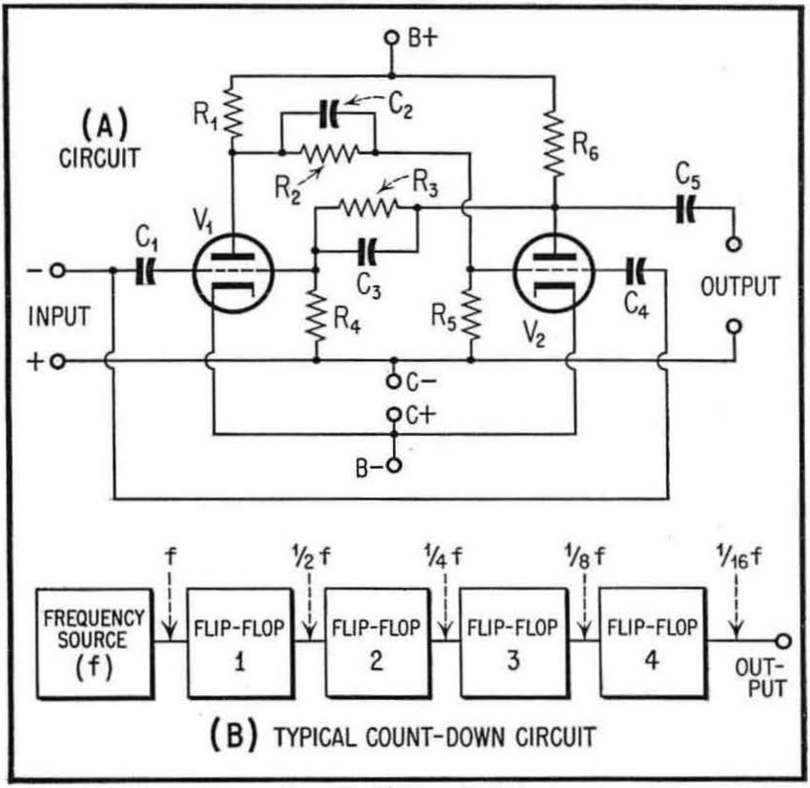

Fig. 2. Flip-flop Method.

ization but its output is unstable in the absence of synchronization. For this reason, signal-output voltage ordinarily will be present at the multivibrator output terminals whether the signal source is in operation or not. When the output is to be zero when the signal source is disabled, at least one tube in the multivibrator circuit must be biased to cutoff so that the circuit cannot operate in the absence of sync voltage.

Flip-Flop Circuit

Somewhat similiar in configuration to the multivibrator previously described is the Eccles-Jordan or **flip-flop** circuit. This is a symmetrical circuit which delivers an output pulse only in response to every second input-signal pulse. Thus, it is a frequency-halver or, as it often is termed, a "scale-of-2" counter.

Figure 2 (A) shows a typical flip-flop circuit. This is seen to be similiar to the conventional multivibrator except that the plates and grids are cross-coupled through resistors R_2 and R_3. In the flip-flop, as in other multivibrators, one tube conducts plate current during the interval that the other tube is cut off. When a suitable trigger pulse is applied to the cut-off tube, the latter is switched to the conducting state and the opposite tube is cut off.

A somewhat simplified explanation of flip-flop action takes the following sequence: When power is applied to the circuit, the plate current of one tube will, by chance, be somewhat higher than that of the other. This probably results from switching transients which drive one grid more positive than the other. Assuming that V_1 has the higher conduction, the plate-cathode voltage of V_1 then is lower than the supply voltage by the amount of the drop across R_1. This lowered plate voltage causes a less-positive voltage to be applied to the grid of V_2 through the voltage divider R_3-R_4. This more-negative potential increases the plate-cathode voltage of V_2, and this in turn makes the grid voltage of V_1 more positive through the voltage divider R_2-R_5. This action causes the plate current of V_1 to increase still further, and the grid voltage of V_2 to become even less positive. This action continues until V_1 is driven rapidly to high conduction, the final plate current of this tube being limited by the resistance of R_1. Concurrently, V_2 is driven rapidly to cutoff. This is one of the two stable states of the flip-flop.

Now, if a negative pulse of sufficient amplitude and short duration is applied to the INPUT terminals, this negative voltage at the grid of V_1 will reduce the plate current of that tube. This momentary reduction will reverse the sequence of events explained in the preceding paragraph; and, as a result, V_1 is driven rapidly to cutoff and V_2 to high conduction. This is the second stable state of the flip-flop. A subsequent negative pulse at the INPUT terminals can have no effect on V_1, since this tube already is cut off. But, being applied simultaneously to the grid of V_2 (through capacitor C_4), it will reduce the V_2 plate current momentarily and cause conduction to be flipped again to V_1. Consequently, a pulse appears at the OUTPUT terminals only when V_2 is cut off. Since this coincides with every other input pulse, the number of output pulses in any given time interval

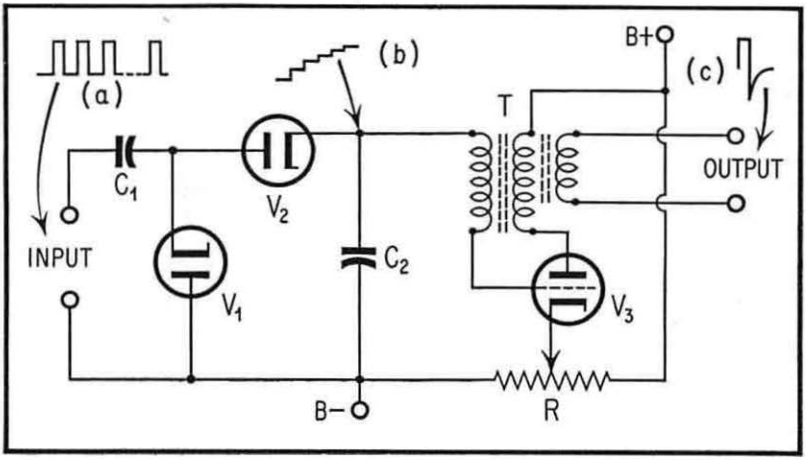

Fig. 3. Staircase Circuit.

is one-half the number of input pulses.

Flip-flops may be cascaded to obtain successive frequency halving. By proper selection of the number of stages, division of the input signal by 4, 8, 16, 32, 64, etc., may be accomplished. The final frequency division $= \frac{1}{2}^{n}$, where n is the number of stages. Thus, in the cascade shown in Figure 2 (B), flip-flop 1 divides the source frequency (f) by 2, flip-flop 2 divides the output of flip-flop 1 by 2, flip-flop 3 divides the output of flip-flop 2 by 2, etc. The output of flip-flop 1 accordingly is f/2; flip-flop 2, f/4; flip-flop 3, f/8; and flip-flop 4, f/16.

Efficient flip-flop action is obtained when the input signal is a series of pulses of short duration. If the frequency which is to be divided is sinusoidal or of long duration, the input signal may be converted into satisfactory, sharp pulses of the same repetition rate by means of suitable shaping circuitry before presentation to the flip-flops.

The waveform of the flip-flop output signal often bears no resemblance to that of the input signal. The reason for this is that the abrupt on-off switching operation of the flip-flop makes the output waveform essentially rectangular. However, when required, the input wave shape may be recovered by means of suitable filter circuitry.

Practical flip-flops have been designed around active components other than tubes. Such components include transistors, ferristors, magnistors, cryotrons, and neon lamps. Low-speed flip-flop action also may be obtained with relays. (See C-D CAPACITOR, November 1955, p. 10).

Staircase Circuit

In Figure 3, a pulse-type signal (a) of constant amplitude is applied to the INPUT terminals. During the positive rise of this signal, capacitor C_1 is charged with its diode side negative. The plate of diode V_2 now being positive, this tube conducts, charging capacitor C_2 (which is large with respect to C_1) by a small amount. During the negative half-cycle of signal voltage, V_2 cannot conduct because its plate is negative. However, V_1 is poled for conduction during this half-cycle and this tube passes current, discharging capacitor C_1. However, capacitor C_2 has no discharge path and accordingly retains its charge. During the next positive half-cycle, the voltage on C_2 is increased a small amount, in a step. This action continues, the voltage on C_2 increasing during subsequent positive half-cycles according to a staircase pattern, as shown at b. Note that successive steps decrease in height exponentially as the charge voltage increases.

Capacitor C_2 is connected, through the primary winding of transformer T, to the grid of triode V_3 in a single-swing blocking oscillator circuit. The grid-signal voltage of V_3 therefore is the staircase voltage developed across the capacitor, C_2. The operation of this circuit is set, by adjustment of potentiometer R, so that the oscillator will be triggered, delivering one output pulse (c) when a desired number of input-signal steps has been reached across C_2. This action discharges C_2, and the sequence of stepping up the staircase is repeated. Potentiometer R thus serves as a counting-rate control which permits adjustment of the circuit to divide the input frequency by a desired factor.

This method is employed with thyratron tubes as well as with blocking oscillators. Sometimes, a 1-shot multivibrator is used instead of a blocking oscillator. When a thyratron is employed, the circuit is adjusted so that the voltage across C_2 after a desired number of steps has been attained is equal to the firing potential of the tube.

In practical frequency dividers of the staircase type, the requirement that the input signal have constant amplitude is met by interposing an amplitude limiter between the INPUT terminals and diode circuit. While a rectangular input signal is shown at a in Figure 3, the circuit will operate with other wave shapes. However, the output signal will have the typical single-pulse shape (c) of the blocking oscillator and, in most instances, the

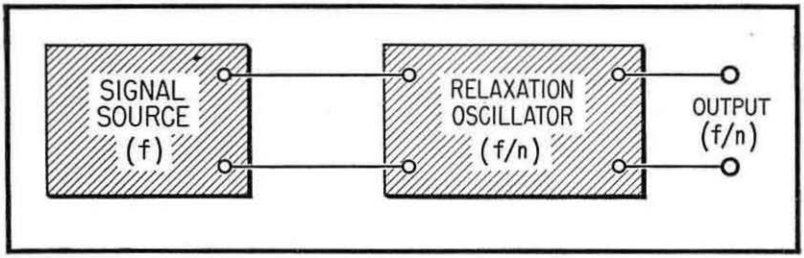

Fig. 4. Synchronized Relaxation Oscillator.

latter will bear no resemblance to the input-signal waveform. However, this output waveform may be modified, as desired, by means of suitable shaping circuitry.

Synchronized Relaxation Oscillator

Relaxation oscillators other than conventional multivibrators also may be synchronized from a signal source. Since the source frequency may be several times the natural frequency of the oscillator, the latter effectively divides the synchronizing frequency. Stable frequency divisions up to 1/10 are obtained in practice.

The basic arrangement is shown in Figure 4. Here, the relaxation oscillator may be any one of the well-known types: gaseous diode, gaseous triode, hard-tube, transistor, or ferristor. The oscillator circuit constants are chosen such that the natural frequency of the oscillator is near the desired submultiple of the signal-source frequency. The oscillator frequency must be an integral submultiple of the source frequency. Upon application of the signal, the oscillator frequency is pulled into step at an exact submultiple of the source frequency.

The output-signal waveform of a relaxation oscillator generally is sawtooth in shape. However, the oscillator may be synchronized with signal voltages having other waveforms. When the output signal must have the same waveform as that of the synchronizing signal, the sawtooth wave may be reshaped by means of wave filter action.

Normally, the relaxation oscillator delivers an output signal even in the absence of the synchronizing voltage. When it is desired that the output be zero when there is no signal input, the oscillator circuit must be suitably biased to cutoff and arranged for immediate triggering into operation upon application of the control signal.

Beam Switching Tube

The magnetron-type beam switching tube (e. g., Burroughs Type 6700) is by nature a fully-electronic distributor. It contains ten sets of special electrodes spaced axially about a common cathode. A series of input-signal pulses will switch the electron stream from the cathode successively to the various sets. The target output plate in each set delivers an output signal only when the electron stream enters that set.

As a result of this action, the output signal moves around the circle of plates in step with the input signal as the latter alternates or pulses. Thus, any single plate delivers output for only 1/10 of the time and the beam switching tube so used is essentially a 10:1 divider. It is possible also to interconnect the electrodes externally so that fewer than the full ten positions are utilized and the division reduced correspondingly to a figure less than 10. Similarly, two or more tubes may be operated in cascade so as to obtain divisors higher than 10.

The beam switching tube may be used to divide the frequency of sine-wave or pulse signals and may be operated at input frequencies up to several megacycles.