



A Precision Delayed-Pulse Generator For Measuring and Generating Short Time Intervals

DELAYED-PULSE generators, i.e., generators that produce a pulse at a known and selectable time following a trigger signal, give the laboratory and production engineer an excellent tool with which to measure and establish accurate time intervals in the microsecond to millisecond region. Checking radar, loran, DME and Tacan system range calibration, measuring resolution of fast circuits, measuring or simulating fast gates, and measuring delays in circuits and devices are typical of the measuring situations where such a generator is applicable.

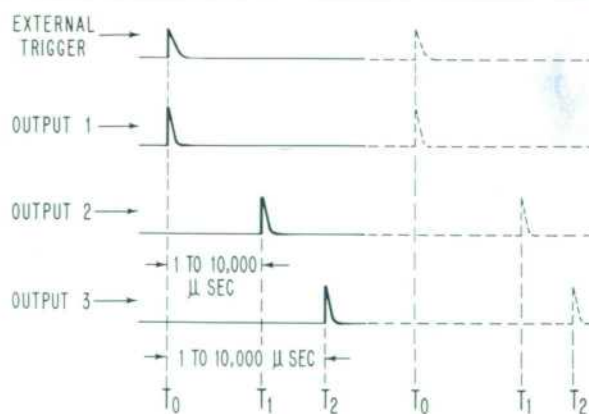
The new digital delay generator shown in Fig. 1 provides an initial time zero reference pulse and two positionable pulses (Fig. 2), all of which are accurately known in time with respect to an external trigger pulse. The two positionable pulses and thus the two time in-

tervals formed by the three pulses are each separately adjustable by calibrated panel controls over a range from 1 to 10,000 microseconds from time zero in digital steps of 1 microsecond and with continuous interpolation between steps. The pulses have less than ± 0.01 microsecond jitter, and their time of occurrence is accurate within ± 0.1 microsecond $\pm 0.001\%$ of the selected delay. Three plug-in type output circuits have also been designed to provide the pulses with optimum characteristics for a given application.

The generator is particularly distinguished by the fact that it is a direct slave to the external trigger, which can have a random rate, but at the same time generates selectable delays directly from a crystal-controlled oscillator. The instrument can also trigger from an internal rate circuit over a 10 cps to 10 kc range.



Fig. 1. New *hp* Model 218A Digital Delay Generator produces output pulses after digitally adjustable precision intervals of up to 10,000 microseconds on command of external signal to simplify calibrating and testing systems where time interval or delay time is important. Instrument can also count and produce outputs after any de-



sired number of external frequency cycles up to 10,000. Three plug-in type output units described in text make output available in various forms.

Fig. 2. (Above). Basic time-plan of Delay Generator operation. Also see Fig. 6 which shows various forms in which outputs are available.

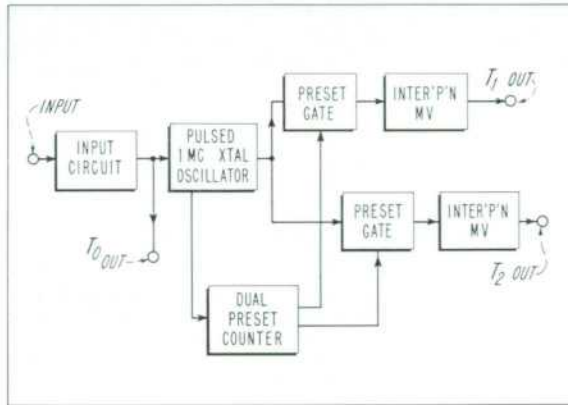


Fig. 3. Basic circuit arrangement of Digital Delay Generator.

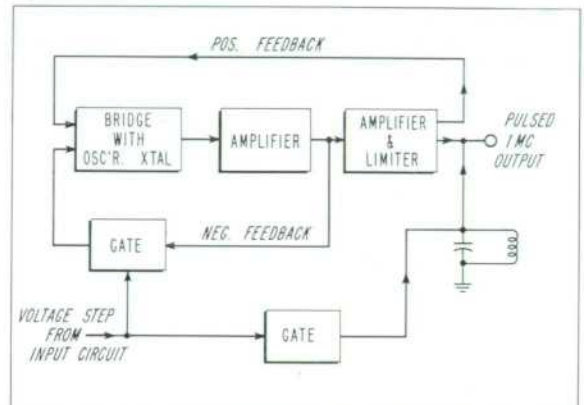


Fig. 4. Block diagram of pulsed crystal oscillator. Ringer is pulsed coincident with oscillator to insure accurate counting of first few cycles of oscillation where small starting transients may exist.

CRYSTAL-OSCILLATOR-DERIVED DELAY

The basic approach in the design of the instrument has been to take advantage of the present-day sophistication of digital techniques to gate-out from an internal crystal-controlled oscillator the particular oscillator pulse that forms the prescribed delay interval. Fig. 3 shows the circuit arrangement in elemental form. An external or internal signal turns on the crystal oscillator whose output is counted by a specially-developed dual preset counter until the first number preset on the panel controls is reached. The counter then opens a preset gate, allowing the gated-out pulse to trigger an interpolation multi-vibrator. The oscillator continues until

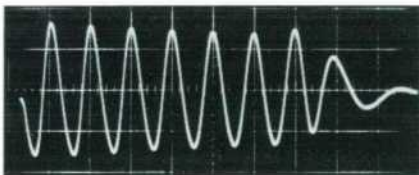


Fig. 5. Waveform of combined pulsed oscillator and ringer. Pulse width has been kept narrow (short delay) to show starting and stopping detail.

the second preset count has been reached and a second pulse gated out to a second multi-vibrator. By means of an arrangement described later, the preset counter gates out in each case the oscillator pulse that occurs between 1 and 2 microseconds before the ends of the prescribed delays. Those pulses then trigger the interpolation multi-vibrators which are arranged to have pulse widths that are continuously adjustable from about 1 to 2 microseconds and whose trailing edges thus coincide with the prescribed delays. At the end of the longer delay interval a reset circuit, not indicated in Fig. 3, turns off the oscillator and resets the counter to prepare the circuits for another trigger at

the input terminal. Until the reset circuit operates, a lockout circuit prevents any external triggers from re-starting the cycle.

The design approach used has the advantage that the delay period begins on command of an external signal and yet is generated by a crystal-controlled oscillator. This contrasts with arrangements wherein an oscillator can be operated continuously and wherein the generated delay is not time-locked to the external trigger.

PULSED CRYSTAL OSCILLATOR

To achieve a precision delay that is time-locked to an external trigger, it has been necessary to develop a special pulsed crystal oscillator that has constant starting phase in addition to constant starting amplitude. Special counter circuits capable of multiple presets have also been developed.

Basically, the pulsed crystal oscillator is a multi-stage circuit (Fig. 4) which also has a negative feedback loop controlled by a gate. During the time when no delay is being generated, the gate holds the negative feedback path in operation, thus preventing oscillation.

When an external trigger is received at the instrument input, it is amplified and applied as a command pulse to the oscillator gate. The gate then disables the negative feedback loop and simultaneously applies a voltage step to the network containing the quartz crystal. This network is arranged as a bridge so that the voltage step is suppressed to a large extent at the bridge output, yet the crystal itself becomes excited by that component of the step that coincides with the crystal's frequency. The arrangement thus provides a phase lock between the voltage step and the start of crystal vibration.

Although the reason for placing the crystal in a balanced bridge is to suppress at the bridge output the initial voltage step that excites the crystal, it is difficult to maintain perfect balance

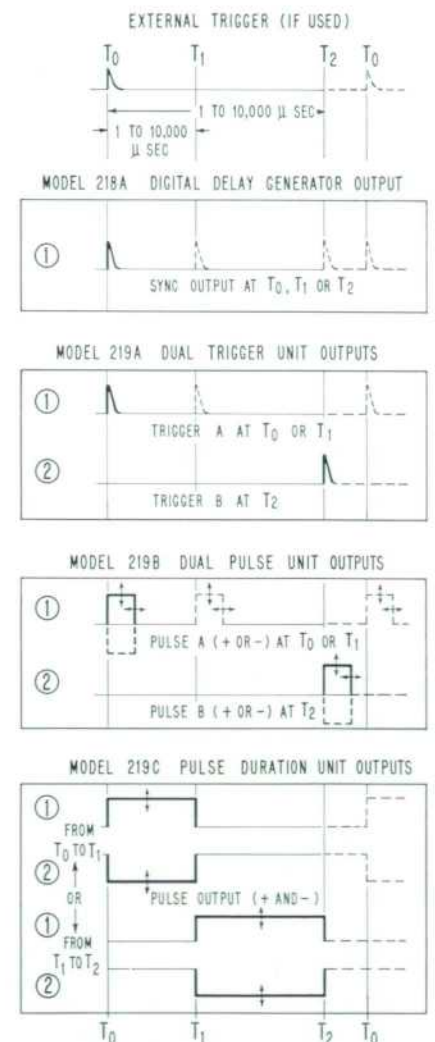


Fig. 6. Time, polarity and waveform characteristics of various outputs from the three plug-in output units.

for the bridge network. This fact may cause a small component from the voltage step to appear at the bridge output and this component will be at the same frequency as the crystal output. Further, depending on the nature of bridge unbalance, this component may be out of phase with the crystal output so that a substantial phase error would appear to exist. There is danger, therefore, that the first few cycles of oscillation might contain substantial phase error.

To counteract this situation, a ringer circuit is operated coincidentally with the oscillator. The ringer consists of an LC tank tuned to the 1-megacycle oscillator frequency. The ringer is operated by applying to it the same command pulse that operates the oscillator gate. Conditions are arranged so that the ringer is shocked into a decaying oscillation at the same time and in precisely the same phase as the crystal oscillation. The ringer output is then added to the oscillator output to produce a pulsed train of 1-megacycle oscillations that have constant starting phase and relatively constant amplitude (Fig. 5). The requirement for phase accuracy in this train can be demonstrated by noting that to maintain 0.1 microsecond delay accuracy the phase at the end of 10,000 cycles of oscillation must be within at least $\pm 36^\circ$.

OSCILLATOR SHUT-DOWN

At the end of the longer of the two delay periods prescribed by the settings of the panel controls, the oscillator is

turned off by applying to the bridge a voltage step that is so phased as to oppose almost exactly the vibration of the quartz crystal. This step causes a cancellation in a fraction of a cycle of most of the energy in the crystal. At the same time the negative feedback path in the oscillator is closed so that remaining crystal energy is quickly counteracted. The arrangement is such that after about 20 microseconds the crystal is capable of being again pulsed on.

PARALLEL-DRIVE DUAL-PRESET COUNTER CIRCUITS

A second major requirement for the circuitry of an instrument in which the output of the crystal oscillator forms directly the generated delay is substantial speed of operation for the preset counters. Basically, the requirement is that the counters must operate in a fraction of the period of the oscillator. Since the oscillator operates at 1 megacycle, this requirement demands that the counters operate and open the preset gate in a fraction of a microsecond. If conventional cascaded or serial-entry counters were to be used, the operating time of each of the (four) decades would add to that of its companions so that individual decade operating times would have to be very fast indeed. Alternatively, serial-entry counters could be reset to the complement of the desired delay, but this arrangement has the disadvantage that only one preset count can be obtained with one set of counters.

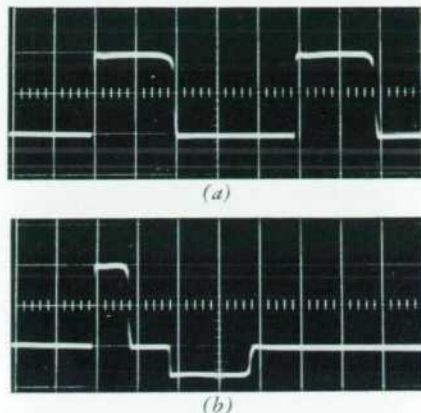


Fig. 7. (a) Oscillogram showing typical quality of output pulses from Model 219B Dual Pulse Unit (1 $\mu\text{sec}/\text{cm}$ sweep). Pulses can each be obtained from separate outputs or from common output as shown. Polarity, width, amplitude and spacing of pulses from 219B output unit are individually adjustable as indicated by (b).

To meet this problem in a more advantageous manner, a method has been developed for parallel entry into a set of counters. This method gives an operating time for four decade units that is the same as for one. The resulting counter has the additional advantage that it is theoretically capable of being preset to many different counts, although in this instrument it is used as a dual preset counter (gives an output at each of two preset counts). The instrument is thus provided with two sets of preset controls, but these operate in conjunction with only one set of four decades.

INTERPOLATION MULTIVIBRATOR

The proper pulse from the crystal oscillator could be gated directly to the output system to establish the desired delay to a resolution of 1 microsecond, but still higher resolution is achieved by using a one-shot multivibrator to form the last 1 microsecond or so of the prescribed delay. The time constant in the multivibrator is adjusted by a continuously-variable panel control calibrated in 0.1-microsecond increments between 0 and 1. The control thus interpolates the desired delay to an over-

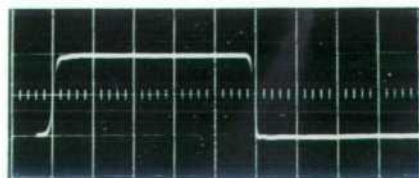


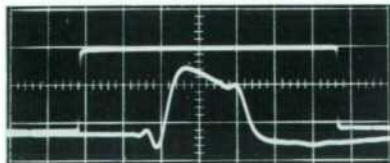
Fig. 8. Oscillogram showing typical quality of pulses from 90-ohm output of 219C Pulse Duration unit (0.1 $\mu\text{sec}/\text{cm}$ sweep). Pulse is available at either polarity and of duration T_0 to T_1 or T_1 to T_2 .

OTHER MEASUREMENTS WITH THE DELAYED-PULSE GENERATOR

Besides being designed to produce output pulses after a selectable number of cycles from its own internal precision oscillator, the delayed-pulse generator can alternatively count and operate from external periodic or aperiodic frequencies lying anywhere between 10 cycles and 1 megacycle. The instrument thus becomes valuable in measurements where other time bases may be used. In computers with internal clocks, for example, the delay generator can count any number of clock pulses up to 10,000 to permit looking at a desired section of the computer memory or at other delayed operations within the computer.

Using the Dual-Pulse output unit, the instrument can be used to synthesize pulse-code groups such as those used in some navigational systems. The output of the generator is of sufficient amplitude to modulate signal generators so that these groups can be obtained in r-f form if desired.

The instrument is also convenient for use as a precision go-no-go gage for such measurements as calibrating delay lines, especially those of long delay. In such work the Dual-Pulse or the Pulse-Duration output units can be used to generate a pulse whose width is equal to the time tolerance on the delay



Oscillogram showing simplicity of scope presentation obtainable when Delay Generator and Pulse Duration Unit are used to establish a visual go-no-go gage for rapid tests on delay devices. Illustration shows a delay line whose delay is within tolerance as marked by rectangular pulse. Sweep time is 1 $\mu\text{sec}/\text{cm}$ but delay preceding sweep start can be any amount up to 10,000 μsecs .

line and whose delay is equal to the line's minimum acceptable delay. If this pulse is applied to one input of a dual-trace oscilloscope and the delay line output to the other, alternate scope sweeps will directly show whether the line output is within tolerance. A single-trace oscilloscope can also be used by employing the delay generator pulse to intensity-modulate an appropriate section of the trace and noting whether the line output falls within the brightened section. Of these arrangements enables non-technical personnel to make precision delay measurements on a rapid, production basis.

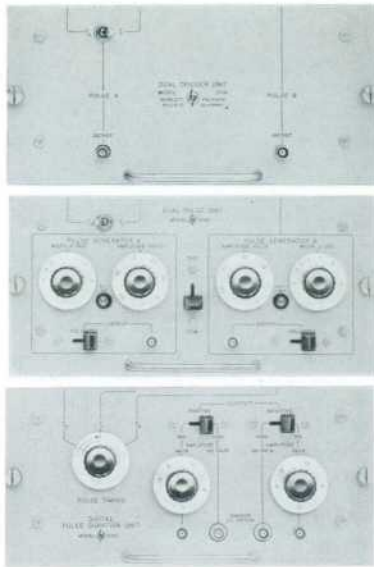


Fig. 9. Panel views of Model 219A Trigger Unit, 219B Dual Pulse Unit, and 219C Pulse Duration Unit, respectively.

all resolution of 0.1 microsecond. The multivibrator is designed with very low jitter commensurate with the overall performance of the instrument.

As used in the circuit, the interpolation multivibrators have a minimum duration of about 1 microsecond and the interpolation control adjusts the duration between about 1 and 2 microseconds. To avoid an error of 1 microsecond in the generated delay owing to this minimum 1 microsecond duration, the preset counters are arranged to count the pulse that comes from the oscillator at time zero, the beginning of the delay interval. When the counter reaches the preset number, then, the delay is about 1 microsecond short of the prescribed delay and this shortage is filled in by the minimum duration of the multivibrator pulse.

STARTING TIME

In a delay generator that, in effect, offers resolution to 0.1 microsecond, it is obviously of importance to know to better than 0.1 microsecond at what moment the delay interval begins. Such a specification unavoidably involves the nature of the external trigger pulse and it is desirable, of course, that the rise time of the external trigger be faster than 0.1 microsecond whenever possible. With an input trigger of 0.05 microsecond or faster rise time and of 2 volts minimum amplitude, the generated delay begins 0.25 microsecond ± 0.05 microsecond following the trigger. Start of the delay period is marked by the pulse T_0 so that operation is unambiguous when slower input triggers or sine waves are used.

OUTPUT UNITS

Any one of the output units completes the generator as an operating instrument. The simplest of the units provides two triggers, the first of which can occur at T_0 or T_1 as desired and the second at T_2 . Both pulses have a peak amplitude of 50 volts open circuit and are provided from a 50-ohm source at positive polarity with a rise time of 0.1 microsecond and a width of approximately 2 microseconds.

The second output unit is designed to enable the polarity, amplitude, and duration of any two of the three pulses to be selected to suit the application. The unit contains two 50-ohm pulse generators with two sets of controls for adjusting pulse width from 0.2 to 5 microseconds and pulse amplitude from 0 to 50 volts open circuit at either polarity. The two outputs are available separately or can be connected in common by a panel switch. In common operation the source impedance remains at 50 ohms. Rise time of the pulses is approximately 0.06 microsecond, while decay time is somewhat longer. Among other uses, this unit makes the instrument into a precision double-pulse generator. Typical pulse shape is illustrated in Fig. 7.

The third output unit produces a pulse which is equal to one or the other of the generated intervals. Thus, the pulse either begins at T_0 and ends at T_1 or begins at T_1 and ends at T_2 . The unit thus enables both delay and duration to be digitally controlled. The pulse is simultaneously available at both positive and negative polarity. In addition, two types of output circuits are provided. One output supplies from 0 to 18 volts open circuit from a 90-ohm source while the second provides a non-adjustable pulse value of 100 volts open circuit from a 500-ohm source. Shape of the pulses provided by the 90-ohm output is illustrated in Fig. 8.

Besides the above-described outputs, a trigger is also available at T_0 , T_1 , or T_2 from a main panel terminal.

DELAYED TRIGGERING OF OSCILLOSCOPES

The generator can also be used with an electronically-rearmable single-sweep oscilloscope such as the -hp-Model 150A to permit jitter-free examination of the individual pulses in trains that themselves have jitter. Elements of this arrangement are described in Vol. 7, No. 8 of this publication.

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and Marvin Willrodt

SPECIFICATIONS

-hp-

MODEL 218A

DIGITAL DELAY GENERATOR

Time Interval Range: (T_0 to T_1 and T_0 to T_2) 1 to 10,000 microseconds, accuracy ± 0.1 μ sec, $\pm 0.001\%$ of time interval selected.

Digital Adjustment: 1 to 10,000 microseconds in 1 μ sec steps.

Interpolation: Continuously adjustable control adds 0 to 1 microsecond to digital setting.

Input Trigger: Internal—10 cps to 10 kc in 3 decade ranges.
External—0 to 10 kc. Positive or negative pulses 2 to 40 volts peak rise time of 0.05 μ sec or less. Sine waves from 10 cps to 10 kc.

Delay between external input trigger and T_0 : 0.25 μ sec, ± 0.05 μ sec.

Jitter: 0.02 μ sec or less.

Recovery Time: 50 μ sec or 10% of selected interval, whichever is larger.

Sync Output: 50 volt positive pulse, rise time 0.1 μ sec from 50 ohm source. Available at T_0 , T_1 , or T_2 as selected by a switch.

1 Mc Output: When counting internal 1 mc crystal oscillator, pulses from crystal oscillator are available from front panel connector for duration of longer time interval. 2 volts from 500 ohm source.

External Counting: External sinusoidal frequencies between 10 cps and 1 mc or external pulses below 1 mc can be counted in place of internal standard; 5 volts peak minimum required across nominal 1 meg-ohm input Z.

Power: 115/230 volts $\pm 10\%$, 50 to 60 cps. 525 watts.

Weight: Net 75 lbs.

Dimensions: 14" high, 19" wide, 24" deep. Depth behind panel 21 $\frac{3}{4}$ ".

Price: -hp- Model 218A Digital Delay Generator, Rack Mount \$2,000.00 f.o.b. Palo Alto, California. Requires -hp- 219A/B/C series plug-in unit.

MODEL 219A

DUAL TRIGGER UNIT

(When plugged in Model 218A)

Output: Two trigger pulses, A and B, 50 volts, 0.1 μ sec rise time from 50 ohm source.

Timing: Trigger A at T_0 or T_1 as selected by a switch, Trigger B at T_2 .

Polarity: Positive.

Power: Supplied by 218A.

Weight: Net 10 lbs.

Price: -hp- Model 219A Dual Trigger Unit \$100.00 f.o.b. Palo Alto, California.

MODEL 219B

DUAL PULSE UNIT

(When plugged in Model 218A)

Output: Two pulses, pulse A and pulse B.

Timing: Pulse A—At T_0 or T_1 as selected by a switch.
Pulse B—At T_2 .

Amplitude: Individually adjustable, 0 to 50 volts peak, positive or negative polarity, available separately or from common jacks.

Output Impedance: 50 ohms, for both separate or common connection.

Width: Individually adjustable 0.2 to 5 μ sec.

Rise Time: 0.06 μ sec.

Power: Supplied by 218A.

Weight: Net 15 lbs.

Price: -hp- Model 219B Dual Pulse Unit \$450.00 f.o.b. Palo Alto, California.

MODEL 219C

DIGITAL PULSE-DURATION UNIT

(When plugged into Model 218A)

Output: Starts at T_0 ends at T_1 , or starts at T_1 ends at T_2 as selected by a switch

Polarity: Positive and negative pulses available simultaneously.

Amplitude: Adjustable, 0 to 18 volts peak into an open circuit from 50 ohms source impedance or 100 volt peak into an open circuit from 500 ohm source impedance.

Rise and Decay Time: 0.03 μ sec for 90 ohm output.

Power: Supplied by 218A.

Weight: Net 15 lbs.

Price: -hp- Model 219C Digital Pulse-Duration Unit \$350.00 f.o.b. Palo Alto, California. Data subject to change without notice.