PRECISION
INSTRUMENTATION
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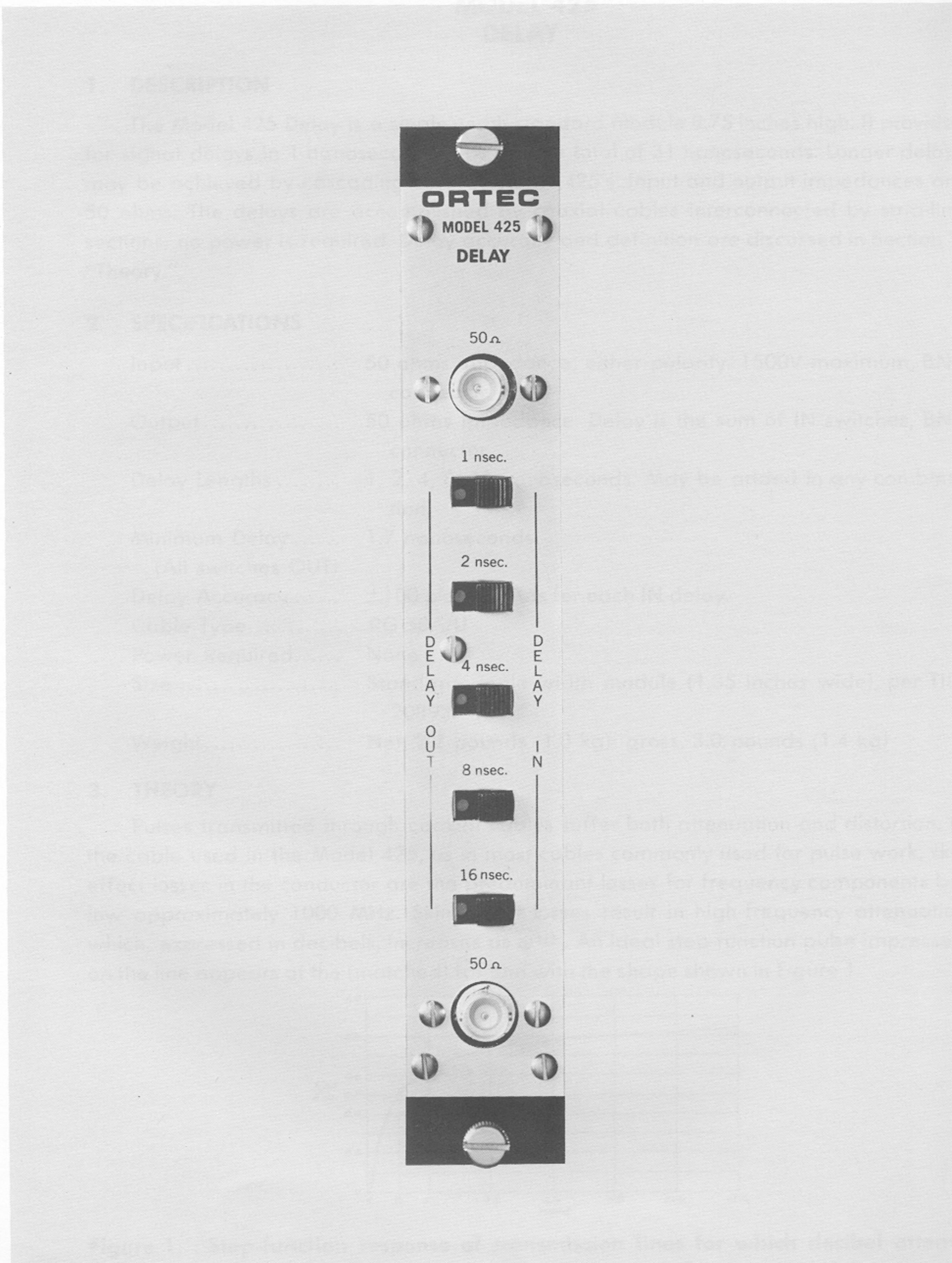
Oak Ridge Technical Enterprises Corporation

OAK RIDGE, TENNESSEE

ORTEC

INSTRUCTION MANUAL
MODEL 425
DELAY

TABLE OF CONTENTS



MODEL 425 DELAY

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1. DESCRIPTION

The Model 425 Delay is a single width standard module 8.75 inches high. It provides for signal delays in 1-nanosecond steps up to a total of 31 nanoseconds. Longer delays may be achieved by cascading several Model 425's. Input and output impedances are 50 ohms. The delays are accomplished by coaxial cables interconnected by strip-line sections; no power is required. Delay accuracy and definition are discussed in Section 3, "Theory."

2. SPECIFICATIONS

Input	50 ohms impedance, either polarity. 1500V maximum, BNC connector.
Output	50 ohms impedance. Delay is the sum of IN switches, BNC connector.
Delay Lengths	1, 2, 4, 8, 16 nanoseconds. May be added in any combination.
Minimum Delay (All switches OUT)	1.7 nanoseconds.
Delay Accuracy	±100 picoseconds for each IN delay.
Cable Type	RG-58A/U
Power Required	None
Size	Standard single width module (1.35 inches wide), per TID-20893.
Weight	Net, 2.2 pounds (1.0 kg); gross, 3.0 pounds (1.4 kg)

3. THEORY

Pulses transmitted through coaxial cables suffer both attenuation and distortion. In the cable used in the Model 425, as in most cables commonly used for pulse work, skin effect losses in the conductor are the predominant losses for frequency components below approximately 1000 MHz. Skin effect losses result in high-frequency attenuation which, expressed in decibels, increases as $\omega^{1/2}$. An ideal step-function pulse impressed on the line appears at the (matched) far end with the shape shown in Figure 1.

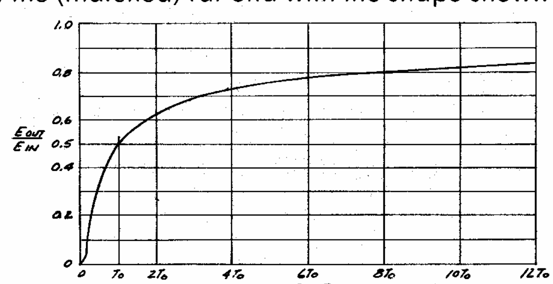

Figure 1. Step-function response of transmission lines for which decibel attenuation varies as the square root of frequency. The time T_0 is defined as the interval measured from the start of the output pulse to the point at which $E_{out} = 0.5\ E_{in}$.

The rise time from 0 to X percent can be expressed as multiples of T_0, where T_0 is the 0 to 50 percent rise time. Table 1 presents some rise time conversion factors.

TABLE 1. RISE TIME CONVERSION FACTORS

Percent of Pulse Height	0 to X% rise time
10	T_0 0.17
20	0.28
50	1.0
70	3.1
80	7.3
90	29.0
95	110.0

10% to 90% rise time $= (29.0 - 0.17)T_0 = 28.83T_0$

In Figure 2, T_0 is plotted against the delay length in nanoseconds.

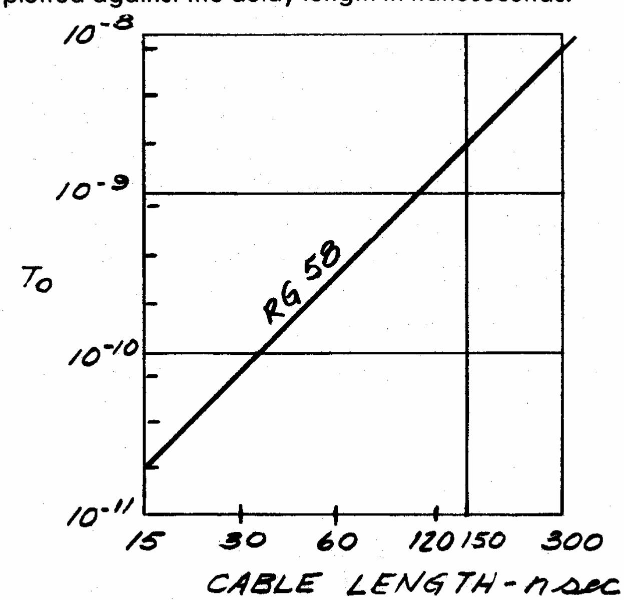

Figure 2. Calculated variation of T_0 with cable length for RG-58A/U.

For RG-58A/U cable whose decibel attenuation varies as $\omega^{1/2}$ for frequencies between about 100 MHz and 1000 MHz, it is convenient to calculate T_0 by:

$$T_0 = 3.0 \times 10^{-16} A^2 l^2 \text{ seconds}$$

where A is the commonly tabulated attenuation at 1000 MHz expressed in db/100 feet (20 to 24 for RG-58A/U), and l is the length in nanoseconds.

Since the rise time is proportional to the square of length, if two equal lengths of a given type of cable are cascaded, the rise time of the combination is four times the rise time of either length alone. This is in contrast to the familiar case of amplifiers of Gaussian frequency response, in which the rise time varies as the square root of the number of identical sections. For this reason, and also because the characteristic step-function responses of cables and of Gaussian devices are so different, the over-all rise time of combinations cannot be calculated from the square root of the sum of squares of individual rise times, either with cables alone or where cables are combined with Gaussian elements. Instead, the over-all response of a system with cables and other elements may be obtained graphically or with convolution integrals[3] using either step or impulse (obtained from the derivative of the function plotted in Fig. 1) function responses.

The above discussion makes it clear that the delay of a cable cannot be specified unless the point on the response function is specified. For the Model 425 Delay, an operational definition is chosen. **When the required delay has been selected by any one of the IN switches, the 50 percent amplitude point will be delayed by an amount equal to the delay which would be effected by a lossless delay line.** One example will serve to explain the sense in which this definition is operational. Two counters (scintillation) detect prompt coincidence γ rays from a radioactive source. The source is moved 120 centimeters away from one counter and 120 centimeters closer to the other. If the cable delay from one counter is changed by 8 nanoseconds by use of the Model 425, the two counters will be properly time-realigned if the discriminators associated with each counter are operated at 50 percent amplitude. In practice, the experimenter cannot readily operate at 50 percent amplitude just to have the cable calibrations meaningful, but, using Equation (1), it can be seen that the timing difference between 0 percent and 50 percent amplitude is less than 20 picoseconds for a 10-nanosecond length of RG-58A/U, and it is in this range of operation that discriminators are usually used. If the discriminator is to be used at a large percentage of full amplitude, or if long delays are to be achieved at discriminator settings other than 50 percent, corrections can be made using Figure 1 or Table 1 as a reference. For the above example, a delay error of 0.26 nanoseconds would result if the discriminator were operated at the 90 percent level.

Figure 3 shows the block diagram of the apparatus used in testing the delay cables of the Model 425.

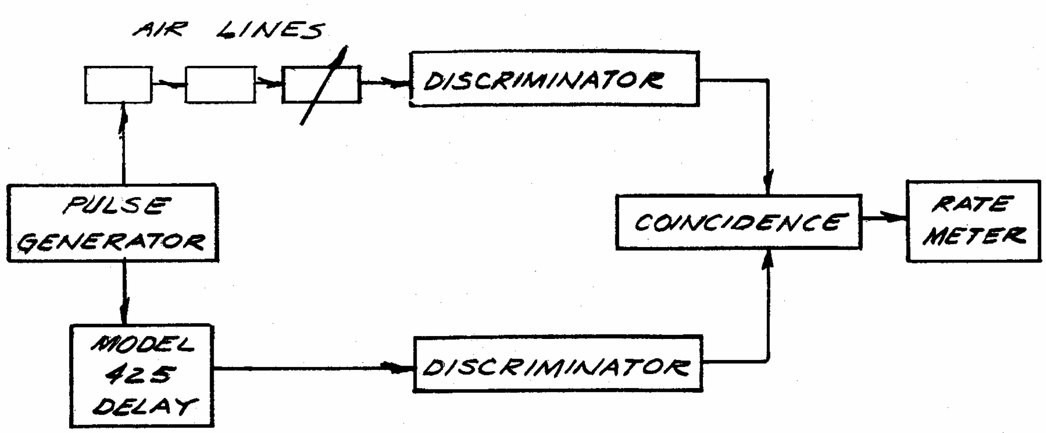

Figure 3. Block diagram of apparatus used in production testing.

A fast rising pulse is split into two branches, one of which is the Model 425 Delay, and the other which consists of sections of high quality rigid air lines with one adjustable section. The delays between the discriminators and the coincidence circuit are adjusted to the middle of the edge of the delay curve, i.e., 50 percent count rate. The width of this edge is about 20 picoseconds; that is, changing the adjustable air line by 20 picoseconds can change the output counting rate from 100 percent to 0 percent. When a delay is switched into the Model 425 branch, the equivalent length of air line is introduced into the other branch. If the delay cable has the correct length, the count rate will again be 50 percent; if not, the amount of required readjustment of the variable air line gives the error directly. Both discriminators operate at 50 percent amplitude for this test.

The termination of the cable at any realizable discriminator input is not exactly 50 ohms. Commonly used circuits include the shunt capacity of a tunnel diode or the base of a fast transistor plus stray inductances and capacitances. This slight deviation from perfect termination does not affect the delay definition appreciably because it is the same in both branches. Finite test pulse rise time ($\sim$1 nanosecond) also affects both branches equally, and so it introduces only second-order errors. Also, the air cables are not exactly lossless, but the T_0 is almost two orders of magnitude shorter than for RG-58A/U, so it can be neglected.

If a transmission line system were to introduce no reflections, it would have to have a uniform impedance throughout. Since $Z_0 = \sqrt{L/C}$, the ratio of inductance to capacitance at each point would have to be a constant. This cannot be achieved even for the cable itself, and further deviations occur where cables must be interconnected and the pulses routed through switches. At points of interconnection where excess inductance is encountered, some small capacitance has been purposely added, so that the ratio of L/C averaged over the connection is correct. Likewise, the switches have been mounted so that $\sqrt{L/C}$ averaged over the switch gives 50 ohms, even though from point to point there are deviations. Thus, reflections occur when the magnitude of the deviations and the distance over which they extend become appreciable when compared to the distance traversed by a pulse during its rise time.[8] For most pulses used in data acquisition systems in the physics laboratory where rise time is equal to or greater than one nanosecond, the reflection introduced at each end of each delay cable will be comparable in size to that incurred when two cables are connected together by BNC connectors and a BNC union.

The temperature coefficient of the delay of the cables used in the Model 425 is about $+1\frac{1}{2} \times 10^{-4}$ per degree centrigrade for temperatures within twenty degrees of room temperature.

4. MAINTENANCE

The assembly procedures peculiar to the Model 425 Delay are considered virtually irreversible; therefore, any warranty problems will be resolved by replacement of the module.