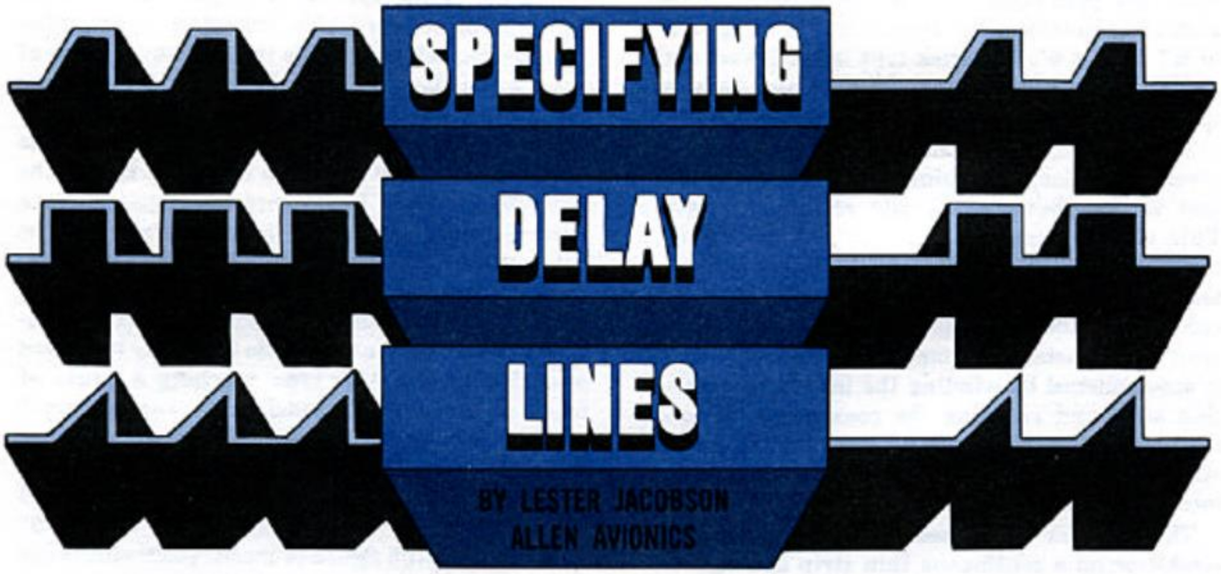
SPECIFYING DELAY LINES



THERE HAS BEEN a tremendous growth in the computer, television and radar fields. As a result, the demand for components that give time control over pulse information has led to the development of a great variety of delay lines; delay lines that find use in systems that relate electrical information to time. Computers, television studios, telemetering systems, guided missiles, navigation systems, identification coders and decoders, radar systems and video tape recorders are typical systems that use delay lines.

The selection of the proper delay device for a given application is not only important from an economic standpoint, but it can also contribute to the ultimate success or failure of a system. In order to understand and compare the different types of delay lines, it is first necessary to define certain parameters. These definitions, with pulse diagrams, are shown in the box on p 6.

Basically, there are two types of delay lines: electromagnetic lines and sonic delay lines. There are important differences between these two types. The electromagnetic line is limited in its time delay to rise time ratio to 250:1. This limits the upper frequency response but the passband starts at d-c and extends to its 3 db cut-off point. For long delays, or where the required frequency response is in the Megahertz range, this 3 db cut-off point imposes a severe limitation and makes the choice of a sonic line mandatory at these higher frequencies.

The sonic delay lines can be broken down into two basic types: magnetostrictive and solid (ultrasonic) lines (glass and quartz). Both types feature very high frequency response and excellent temperature stability. However, their attenuation (40 to 70 db), narrow bandwidth, and poor pulse fidelity has lead to the popularity of electromagnetic delay lines.

Electromagnetic lines

The electromagnetic lines are divided into two groups: distributed and the lumped constant delay lines. The distributed delay line is further broken down into two categories, the stick type and the Spiradel, manufactured by Allen Avionics. A list of electromagnetic delay lines and parameters are shown in Chart 1.

The stick line closely approximates a transmission line. It is fabricated by winding a coil (either a solenoid or a multilayer) on a rod (glass, ceramic or phenolic) that has been covered with a silver or copper coating. This conductive coating is the ground conductor. Between the coil and the ground plane is a thin dielectric layer. The coil provides a continuous and uniform inductance along the rod. The coil of wire and the ground plane act as a capacitor. The higher the dielectric constant of the dielectric layer, the greater the capacity. Figure 1 shows the construction of a stick line and the schematic representation of a distributed delay (both stick and Spiradel).

The delay of the line, T_d, is a function of the total inductance and capacitance ($T_d = \sqrt{LC}$), as is the impedance ($Z = \sqrt{L/C}$). The stick lines generally do not exceed 2 μsec of delay and are limited in their figure of merit, rarely exceeding a value of 10, which requires a rod six inches long. Not all impedances are possible for every delay, due to a limit on obtainable capacity. The attenuation of the small delays is generally very low since these are wound with heavy wire. When the delays

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approach 2 μsec, however, the attenuation increases greatly and reaches a maximum of about 3 db. The temperature coefficient is generally about 150 ppm from −55° to 105°C. Sizes of the stick lines usually range from about ⅜" x ⅜" x 2" to ½" x ½" x 6". The stick type is the lowest cost delay line available if its electrical and physical specifications are adequate.

The Spiradel line consists of an inductor up to several feet long, combined with a capacitance that is distributed uniformly along its length. This can be compared to a length of coaxial cable, where the inductance along the center conductor has been increased and sufficient capacitance added per unit length to provide the desired characteristic impedance. Size reduction is accomplished by winding the inductor on a flat thin strip and reducing the coaxial sheath to a multiple flat strip conductor, placed parallel to the strip inductor. These long lengths are then wound into a spiral and encapsulated.

The inductor is formed by winding a copper conductor on a continuous thin strip of magnetically permeable material. This inductor is designed to give a fixed inductance per unit of length. The distributed capacitance component is fabricated by placing conductive foil strips between two pieces of dielectric sheathing. The thickness of the dielectric strip is determined by the amount of capacitance per unit length required. This insulated conductive screen (ground plane) provides one plate of the distributed capacitance, while the individual turns of the strip inductor form the other. The ground plane, when combined with the inductor, also provides shielding between successive turns of the spiral when wound as shown in Fig. 2. Due to the uniform values of inductance and capacitance, a predetermined length of inductor strip may be cut to provide a given delay before fabrication. As a result of being able to use extremely long inductive and capacitance components in the Spiradel, the delay to rise time ratio is greatly improved over that of the stick type, reaching a figure of merit of up to 30. Spiradel delays range from 2 nsec to 6 μsec and impedance ranges from 50 ohms to 1000 ohms. The temperature coefficient from −55° to 105°C is less than 150 ppm. The Spiradel runs from ¼" to 7⁄16" high and from 0.7" to 3.75" in diameter. High figure of merit, small size, large delay range, and low cost make it popular.

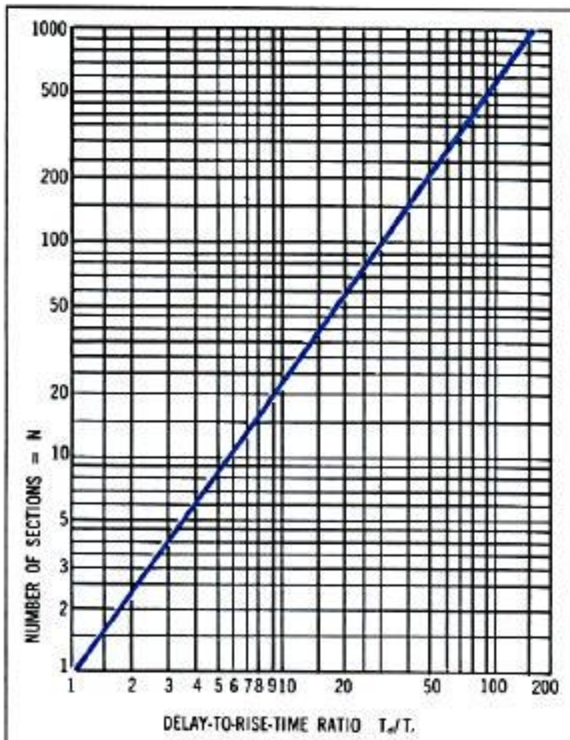

Fig. 4. The relationship between figure of merit, T_d/T_r = R, and the number of sections of a lumped constant delay line needed to achieve it, $N = R^{1.36}$, as plotted on log paper.

Lumped constant delay lines

The lumped constant line is the most widely used type. Like the stick and Spiradel types, its passband extends from d-c to its 3 db cut-off frequency and phase linearity over this range is good. The lumped constant line consists of a number of inductors and capacitors similar in value. The inductors are connected in series and the capacitors are connected from the junctions between inductors to the ground lead. Schematically, the circuit is shown in Fig. 3. The total inductance and capacitance is determined by the following equations: $L_t = T_d \times Z$, $C_t = T_d/Z$. The number of "lumps" (coils and capacitors) required for a given delay line can be determined, directly, from the time delay to rise time ratio: $N = R^{1.36}$ (with N = number of sections, $R = T_d/T_r$), see Fig. 4. Since the basic cost of a lumped line is related to the number of sections used, it is apparent that over-specification of time delay to rise time ratio results in a higher cost.

Once the number of sections has been determined, the inductance and capacitance of each cell or lump can be found by dividing the total inductance and total capacitance by the number of lumps required. When the total delay is small and the ratio relatively high, the values of the individual inductors and capacitors become so diminutive that the stray values of circuit capacitance and inductance become significant. This can prevent the realization of a delay line design. Another problem is the expense of high Q inductors. This is

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CHART 1 — ELECTROMAGNETIC DELAY LINES			
	DISTRIBUTED DELAY LINES		LUMPED CONSTANT DELAY LINE
	Stick Lines	Spiradel	
Delay range	up to 2 μsec	up to 6 μsec	up to 200 msec
Time delay / Rise time (Ratio)	up to 10:1	up to 30:1	up to 250:1
Impedance range (ohms)	100 to 2000	50 to 1000	50 to 10,000
Attenuation	up to 3 db	up to 4 db	Generally less than 3 db High ratios or long delays can be up to 20 db
Distortion (Step function having 10 nsec rise time)	2% to 10%	2% to 10%	Generally about 8% Range 2% to 15%
Temp. coefficient in ppm/°C (over a range of −55° to 105°C	150	150	Under 50 ppm to over 200 ppm
Size range	¼" x ¼" x ¾" to ½" x ½" x 6"	0.3" high x 0.8" dia. to 7/16" high x 3.75" dia.	From dual-inline package to 2' x 1' x 1'

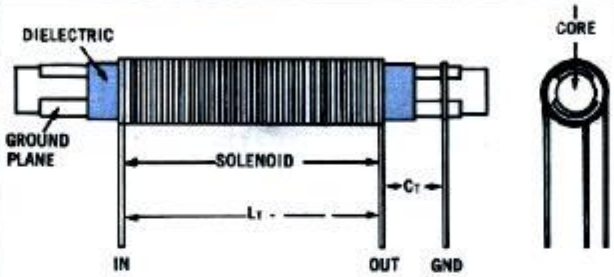

Fig. 1a. Typical configuration of a stick delay line.

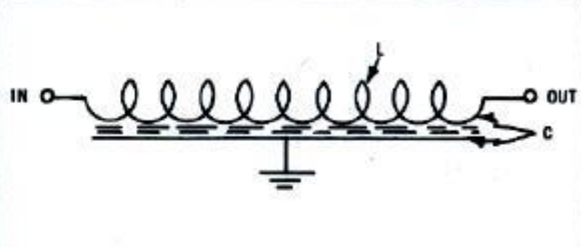

Fig. 1b. Schematic representation of both stick and Spiradel distributed delay lines. The marked similarity to a coaxial cable is obvious.

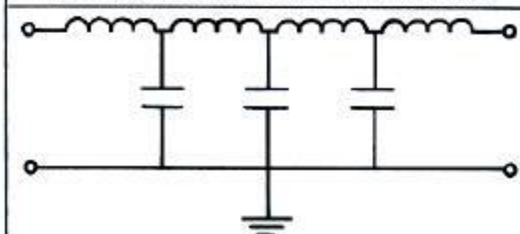

Fig. 3. Schematic representation of a lumped constant delay line.

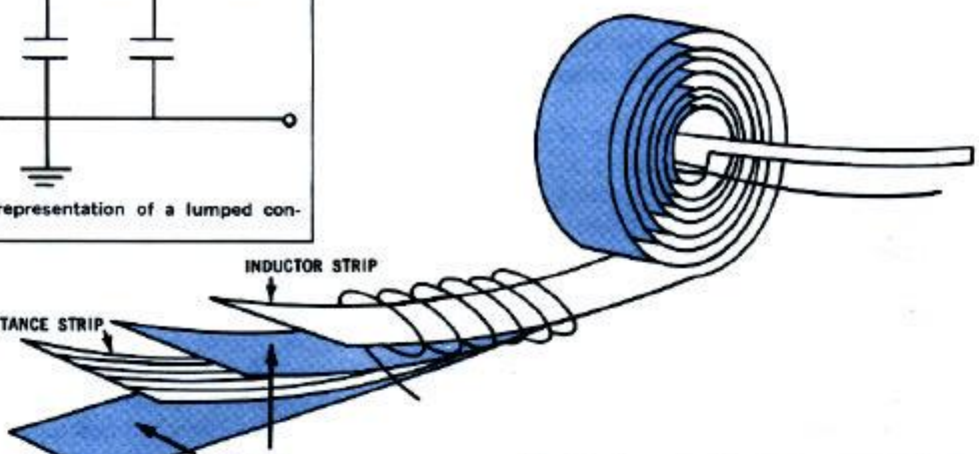

Fig. 2. Basic construction features of the Spiradel.

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DEFINITIONS

An electromagnetic delay line is a specially-designed transmission line or an electrical-network approximation of one, which delays a signal, from input to output, by a time interval determined by the electrical length of the line.

Delay time (T_d) = Elapsed time between specified amplitude points (usually 50%) on the leading edges of the input pulse and the output pulse.

Rise time = elapsed time required for the pulse amplitude to increase from one specified level to another (usually from 10% to 90%), as measured on the leading edge of the pulse:

T_R = delay line network rise time

T_{R_I} = input pulse rise time

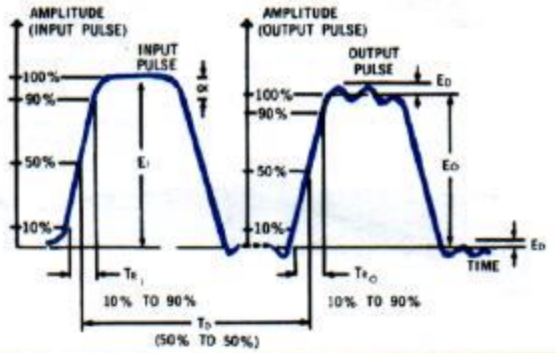
T_{R_O} = output pulse rise time

Time delay to rise time ratios (T_D/T_R) = The figure of merit or measure of quality of a delay line.

Bandwidth = Delay line performance is usually expressed in terms of bandwidth for applications involving transmission of sinusoidal information. Network bandwidth is related to rise time as follows:

$$3 \text{ db BW (MHz)} = 0.36/T_R\ (\mu\text{sec})$$

The relationship is valid as long as the delay line has a near linear phase shift characteristic.



especially important when a large number of sections is necessary. Powdered iron bobbins, toroidal cores, universal winds on magnetic and nonmagnetic forms, as well as ferrite pot cores, are all employed (where applicable) to achieve the highest possible inductor Q at the right frequency. Very seldom is a problem encountered in the Q of the capacitor.

When a step function, consisting of many different frequencies, is introduced to a lumped line, the phase shift should be a constant independent of frequency. When a delayed pulse is distorted, it is the result of poor phase linearity. With present coupling techniques, however, it is usual for lumped lines to display excellent phase linearity over all the frequencies within its passband. For most lumped delay lines, a ±2% phase variation can be readily maintained.

The impedance of a lumped constant delay line ($Z = \sqrt{L/C}$) and the time delay ($T_d = \sqrt{LC}$) determine the total values of inductance and capacitance. These values determine the type of components from which the line must be made and, therefore, are important in determining the realizability, as well as the size and cost. Therefore, the system designer should, if possible, specify an impedance range to permit the manufacturer to take advantage of this specification. The result could be a smaller, less costly delay line.

The attenuation of a lumped delay line is related to the resistance of the inductors and the impedance of the delay line. Attenuation of a delay line decreases with both an increase in size and a decrease in time delay to rise time ratio. Generally, the attenuation of a lumped line does not present a severe problem, unless size is extremely limited or time delay to rise time ratios are very high. Most lumped lines will exhibit about 0.5 db to 3 db attenuation. Even time delay to rise time ratios of 100:1 rarely attenuate more than 8 db. When this ratio reaches 250:1, however, one can expect an attenuation of about 20 db.

Temperature stability in most lumped lines is generally good; typically 50 ppm/°C to 100 ppm/°C over a −55° to 105°C range. Tighter temperature coefficient requirements can be manufactured with an increase in cost. Lumped lines having an operating voltage range of from 0 to 50 volts d-c are always available, and can be supplied to handle up to 300 working volts d-c.

Lumped lines are available in many packages. Epoxy encapsulated shells are becoming more universally used. Larger units, in hermetically sealed cans, have the delay line foamed in place. For ease of electrical connections to test equipment cable, BNC connectors are now commonly used. With the advent of the active and data processing components, delay lines have become available in dual-inline (DIP) packages that allow them to be used by high-speed automatic insertion equipment.

Are there any rules of thumb for choosing delay lines? Ultrasonic lines are limited by their narrow bandwidth and poor pulse fidelity and are rarely used. Of the electromagnetic lines, the stick is the cheapest but has the smallest figure of merit and shortest maximum delay time. The Spiradel, for a slight increase in cost, obtains a higher figure of merit and a greater maximum delay time. Lumped constant lines can achieve marked improvements in both figure of merit and delay time. However, this can be accompanied by a significant increase in cost. Since cost increases with performance, choose the least expensive delay line that supplies adequate performance. — *H/G* ⊕