The Delay Line and the Delay Line Amplifiers

In any digital computer system there must be some means of data storage. There are several types of storage systems in use, and each one has its own advantages and disadvantages. The storage medium chosen for the EC/130 is the magnetostrictive sonic delay line. The name sounds forboding, but the principle is quite easily understood.

If a torque is exerted upon a length of wire (piano wire, for example), the torsional wave will travel down the length of the wire, and will be felt at the opposite end of the wire at some later point in time. Figure 1 (a through f) graphically portrays this. 1(a) shows a length of wire before any torque has been applied. At 1(b) the end of the wire has been twisted by an amount "t". Note that although the end of the wire has been twisted, the rest of the wire remains untwisted, so a small area of stress is introduced into the wire. As the end of the wire is returned to its original position (Figure 1(c) the torsional stress begins travelling down the wire to the other end (Figure 1(d), 1(e)). The only thing remaining in the delay line concept is to realize that it isn't necessary to wait until the mechanical stress or "pulse" reaches the other end of the wire before beginning another pulse. Figure 1(f) shows several pulses on the line at once.

The next item of concern is how to "write" a mechanical pulse onto the line electrically. If a pair of ribbons is connected

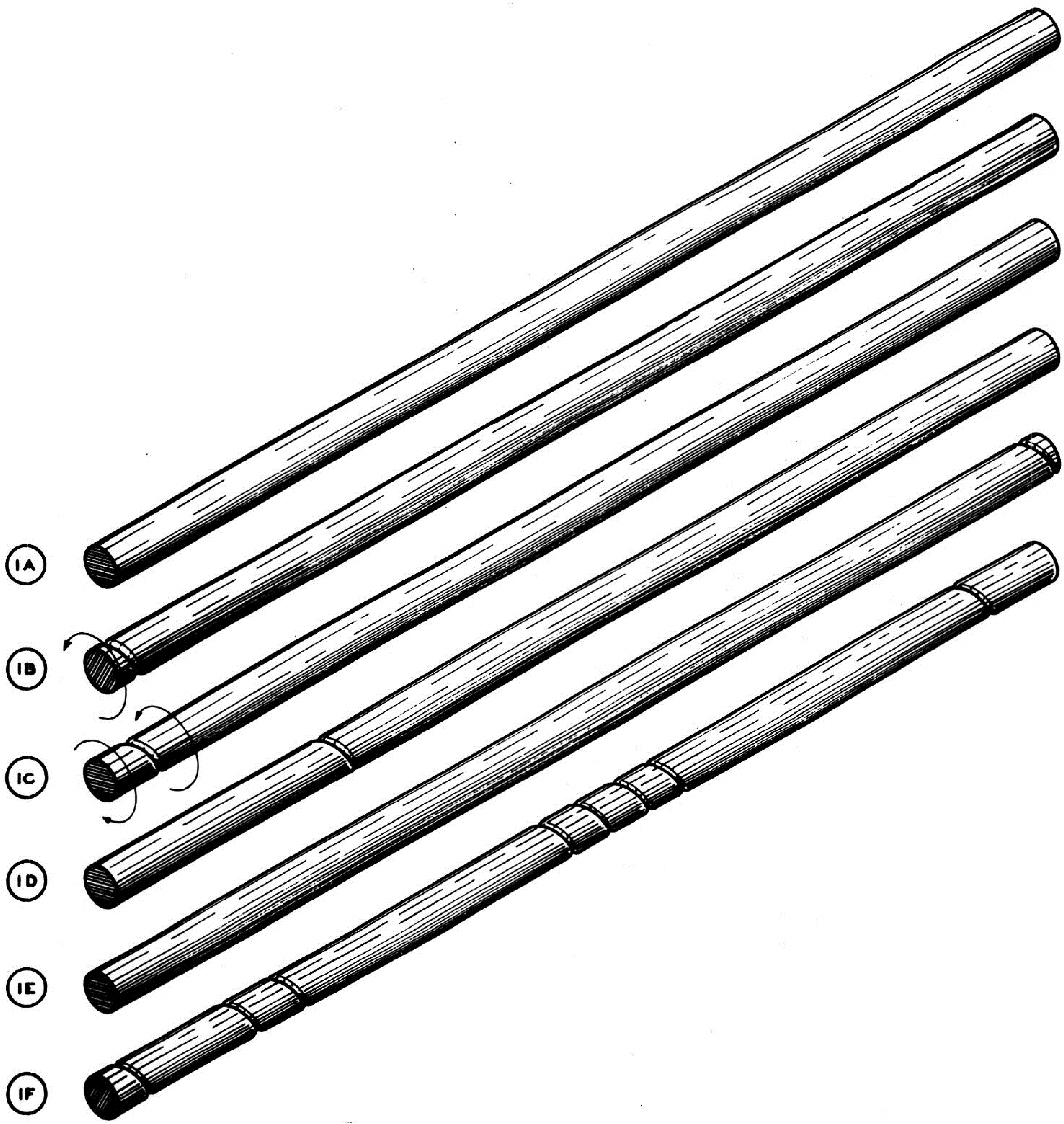


Figure 1

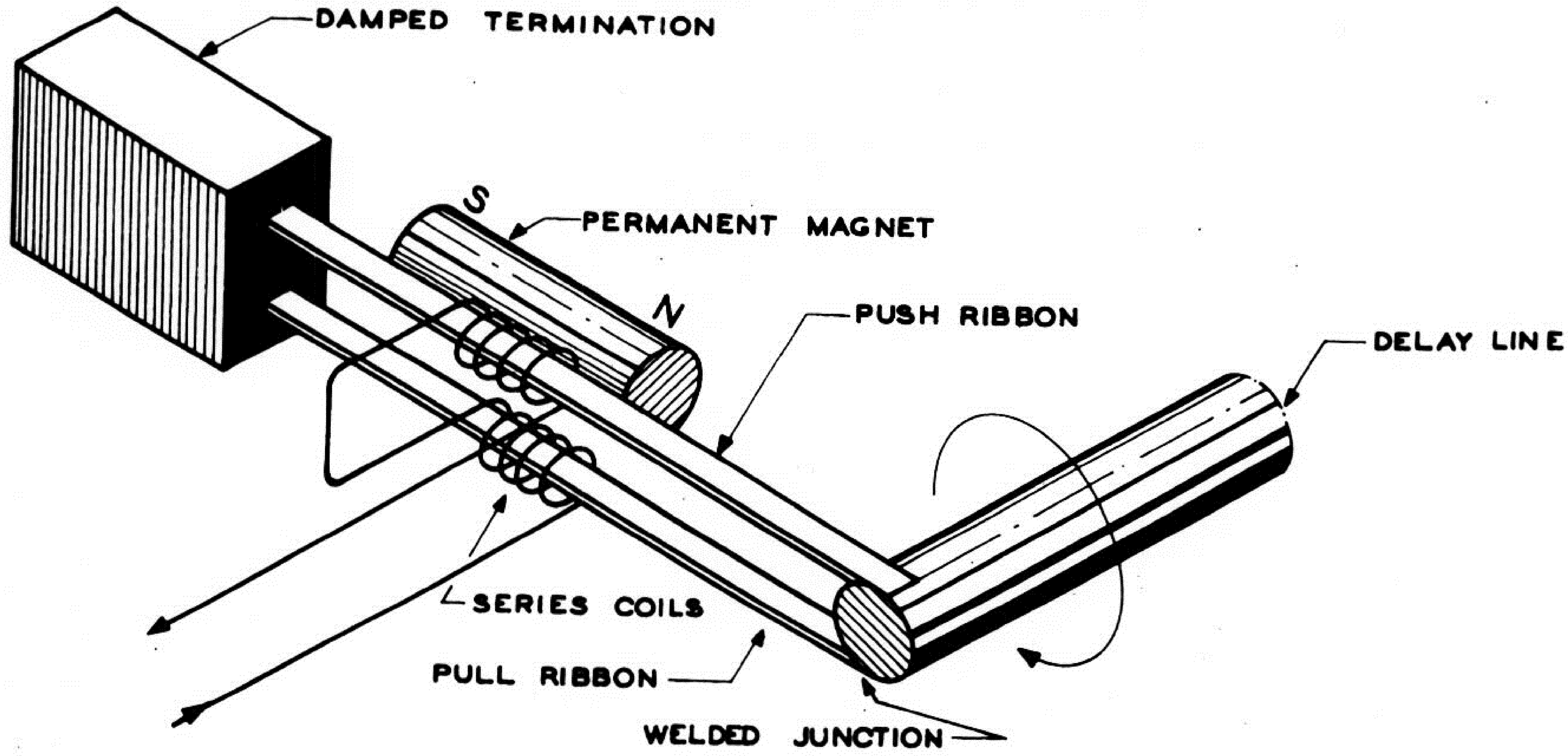


Figure 2

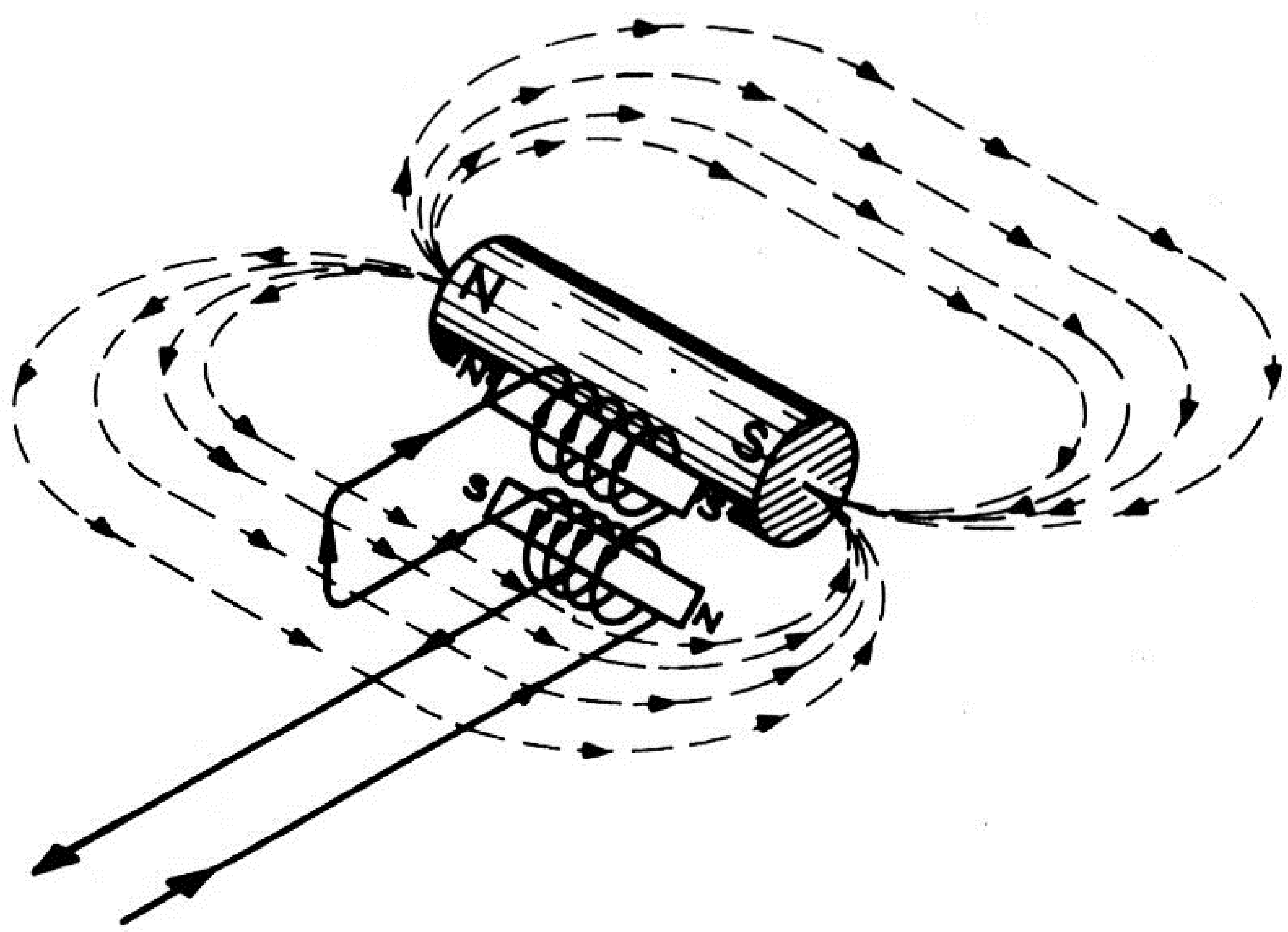


Figure 3

to the end of the delay line, and the ends of the ribbons damped mechanically as shown in Figure 2, then the delay line can be twisted, or pulsed, IF the ribbons can be made to shrink and expand. That is, if the upper ribbon shrinks and the lower ribbon expands, then the line will be torqued. Since nickel shrinks when subjected to a magnetic field, nickel seems the logical choice for the ribbon material. Nickel, however, only SHRINKS with the increase of a magnetic field. Application of a stronger magnetic field cannot make a nickel ribbon expand. In order to attain "push-pull" operation, one ribbon must be caused to shrink, and the other caused to expand. The solution is to subject both ribbons to a PERMANENT magnetic field. This will cause both ribbons to shrink some specific amount. By placing a coil around each ribbon, the coils can be connected in series in such a way that when a DC current flows, the magnetic field induced by one coil will aid the permanent magnetic field, and the field of the other coil will oppose the permanent magnetic field. (See Figure 3) The net result is that the ribbon through the aiding coil will shrink still further, and the ribbon through the opposing coil will shrink less, or in effect, will expand (because there is less magnetic field to act upon the nickel). This mechanical action of the ribbons causes a mechanical torque to be applied to the delay line.

Putting a mechanical torque, or pulse, onto the delay line is now reduced to a matter of switching current through the "launch" coils. A 2N1305 is connected in series with the coils in a common base configuration. It serves as a current switch, and is driven by an emitter-follower in its emitter circuit. Figure 4 shows the Write Amplifier and the connection of the launch coils. The input is via a negative AND gate. The AND gate drives an inverter (Q1). When the inverter is off, the

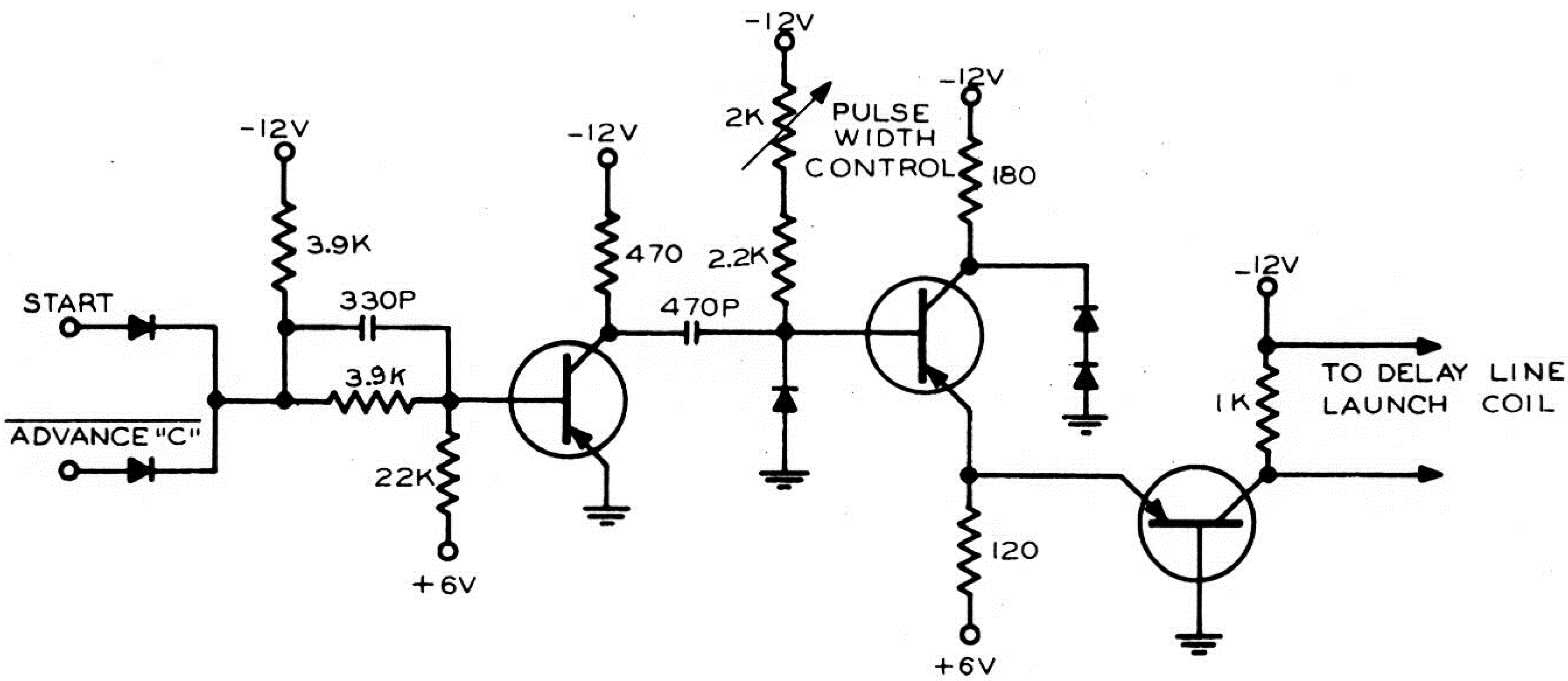


Figure 4

470pf capacitor is charged to -12 volts on the left side, and -.7 volts on the right side. When Q1 turns on, the right side of the 470pf capacitor is pulled to about +11.3 volts. This turns the emitter follower (Q2) off, and Q2 will stay off as long as its base is more positive than 0 volts. (Just why Q2 will turn off at 0 volts rather than +6 volts on its base may be a little obscure now, but it should clear up soon.) With +11.3 volts on the capacitor, it begins to charge (or discharge, as you will) toward -12 volts through a 2.2K resistor and a 2K pot. When the charge on the capacitor reaches 0 volts, Q2 will turn back on. This means that the off time of Q2 is dependent upon the time constant of the RC circuit. If the pot is set near the center (for a total of 3K, for convenience) the capacitor will discharge to 0 volts in about 980 nanoseconds. This is very convenient because 960 nano-seconds is the optimum pulse width (and the off time of Q2 IS the pulse width) so with just a little tweaking, the pulse width can be adjusted correctly and the pot is very nearly centered. The diode to ground on the base of Q2 shorts out the -12 volt pulse that must appear when Q1 turns off, and establishes a maximum negative level of about -.75 volts on the base of Q2. This diode, together with the two diodes on the collector of Q2, insures that Q2 never saturates. The two diodes on the collector of Q2 are there to cut down the amount of power Q2 must dissipate. They assure that most of the collector supply voltage is dropped across the 180 ohm resistor. If these diodes opened up, Q2 would probably be damaged by over heating.

The emitter of Q2 is returned to 6 volts through a 120 ohm resistor. The emitter of the common-base current switch (Q3) is tied to the emitter of Q2. When Q2 is on, its emitter is slightly negative. This back biases the emitter-base junction of Q3 and keeps it off. When Q2 turns off, the emitter starts to go positive. This forward biases the emitter-base junction of Q3 and Q3 turns on, switching current through the launch coils. When Q3 is on, its emitter is clamped to +.2 volts. This is why 0 volts on the base of Q2 turns it off. Q3 will stay on as long as Q2 is off; that is why the length of time Q2 is off determines the width of the current pulse written onto the line. The 1K resistor shunting the launch coils in the collector of Q3 is there to damp out ringing and to limit the voltage excursion on the collector of Q3 when Q3 is turned off.

In summing up, the Write Amplifier is a three-transistor current switch which has an adjustable output pulse width independent of the input pulse width. It works with high signal levels so it is relatively insensitive to noise.

Now that electrical pulses have been changed to mechanical pulses and have been written onto the delay line by the Write AMP, these mechanical pulses must be changed back into electrical pulses, amplified and shaped so that they can be used as data. These are the purposes of the receiver coils and the Read Amplifier.

It is a matter of historical fact that if a coil is wound around a nickel ribbon and the assembly placed in a magnetic field, a current will be induced in the coil if the physical demensions of the nickel ribbon are changed. Figure 5 shows the delay line assembly at the receive end. Note the similiarity

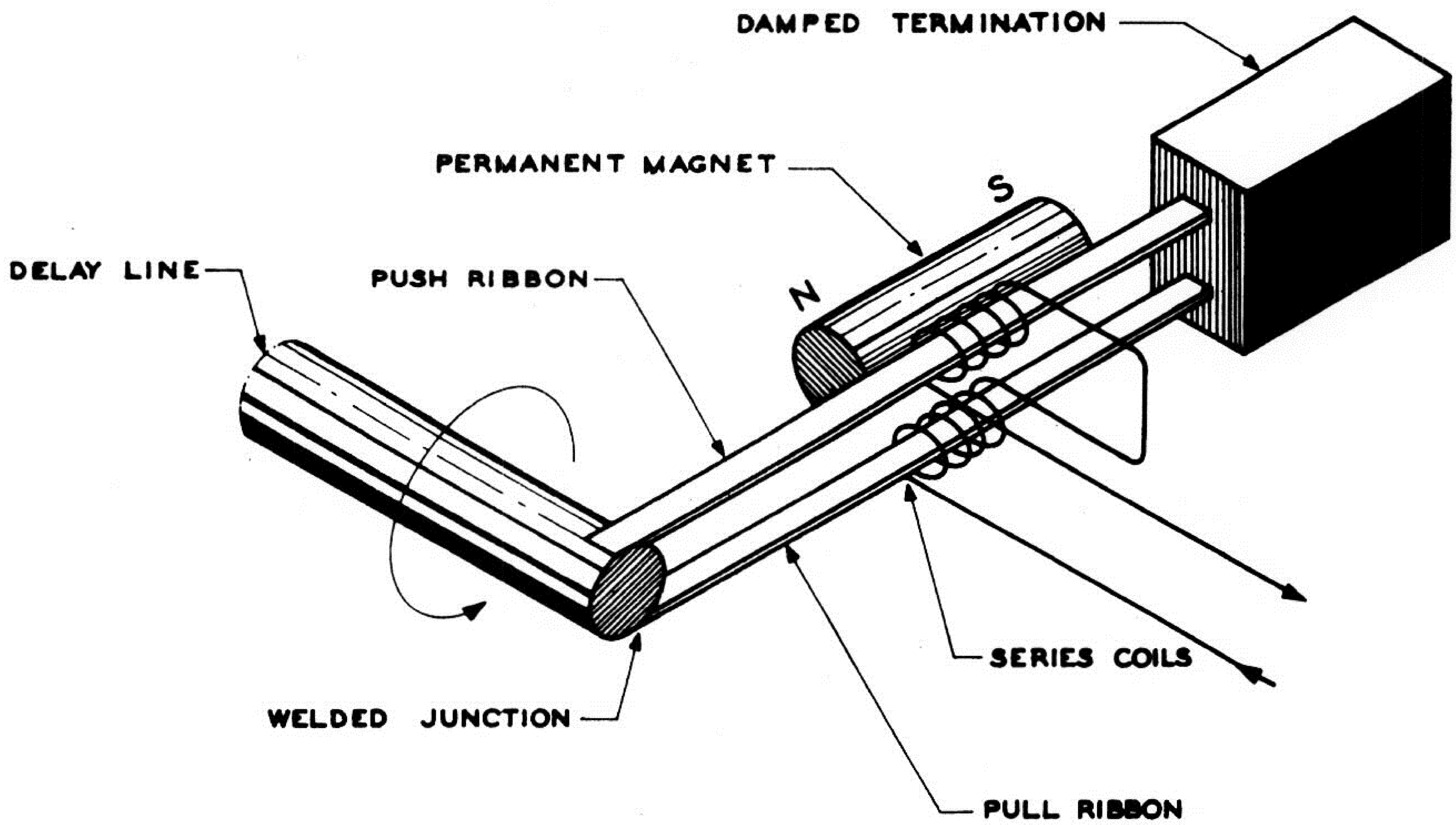
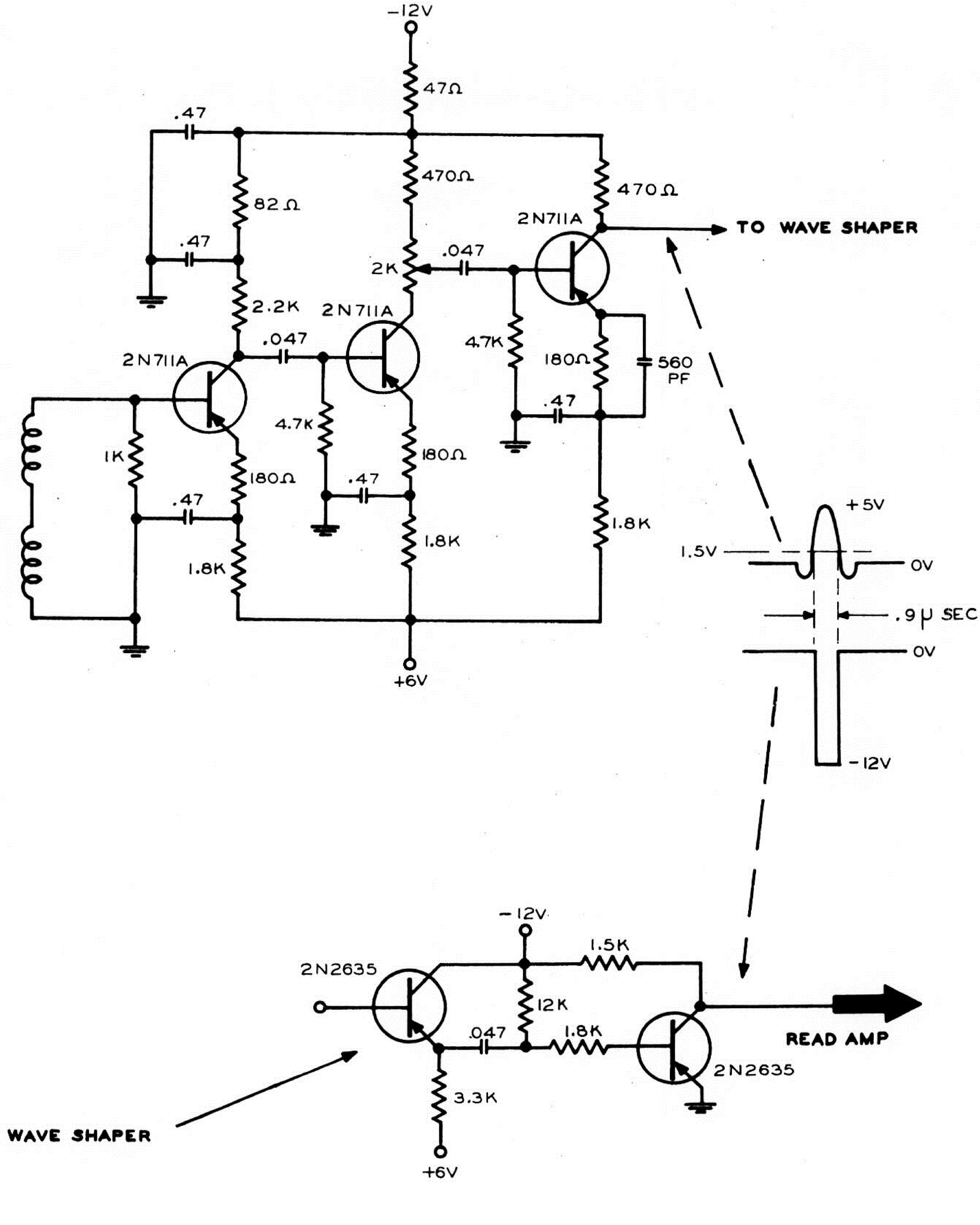


Figure 5

to Figure 2. The difference is in operation. When a mechanical torque (pulse) arrives at the end of the delay line, it causes one of the ribbons to be stretched and the other to be shrunk. This change in the physical demensions of the ribbons results in a change of the flux density through the coils which induces a voltage into the receive coils. The amplitude of this voltage is of the order of 25 millivolts. This is obviously too small to drive an AND gate, so the pulse is amplified by the Read Amplifier.

The Read Amplifier is a 3 stage class A amplifier connected cascade. For design purposes, it is desirable to have a 5 volt pulse as an input into the pulse shaper, so the amplifier needs a voltage gain of at least 200. The Read Amplifier designed for the EC/130 (Figure 6) has a gain of about 400. There is a gain adjustment between the second and third stages so that the voltage output may be adjusted properly. The three stages look similiar, however, the circuit configuration of the first stage is such that its gain is about 4. The second and third stages each have a gain of about 10. The abundance of .47 uf bypass capacitors help keep the amplifier noise level down. There is some degeneration (the 180 ohm resistor in the emitter circuit) in each stage for stability, but note that the 180 ohm feedback resistor in the third stage is bypassed by a 560 pf capacitor to increase the high frequency response.

Figure 6 shows the output of the Read Amplifier, and the output of the wave shaper. The wave shaper must take the amplifier output, and slice or clip it as shown, and amplify the usable portion. This is done to provide a pulse with all the desirable characteristics of a digital pulse. The output of the amplifier is applied to the base of an emitter follower. The output of the emitter follower is coupled to an inverter circuit through a .047 uf coupling capacitor. With 0 volts



-12V
47Ω
.47
470Ω
470Ω
82Ω
2N711A
TO WAVE SHAPER
.47
.047
2K
2.2K
2N711A
4.7K
.047
2N711A
180Ω
560 PF
.47
4.7K
1K
180Ω
180Ω
.47
.47
+5V
1.8K
1.5V
0V
1.8K
1.8K
.9 μ SEC
0V
+6V
-12V
-12V
1.5K
2N2635
12K
.047
1.8K
READ AMP
2N2635
3.3K
WAVE SHAPER
+6V

Figure 6

output from the emitter follower, the right side of the capacitor is at about -1.5 volts and the inverter is on. When the output of the emitter follower goes negative, this negative pulse is coupled to the base, but the inverter is already on, so nothing happens. Hence, the negative portion of the wave form is lost. When the output of the emitter follower goes more positive than +1.5 volts, the base of the inverter will see this as 0 volts, and the inverter will turn off. Any part of the waveform more positive than +1.5 volts merely keeps the inverter off, so that portion of the waveform more positive than +1.5 volts is lost. The only part of the output of the emitter follower that is used is that portion between 0 volts and +1.5 volts. The output of the waveshaping circuit is a -12 volt pulse about 900 nanoseconds wide, with good rise and fall times.

The net effect of the Write Amplifier, Delay Line, and Read Amplifier is to write a pulse in, and read the pulse out delayed 5 milliseconds or so.

By itself, the delay line and the delay line amplifiers do little for the digital system. It doesn't help a great deal to store data for only 5.2 milliseconds. If, however, the delay line is part of a closed loop system in which data can be kept circulating ready for use, then the delay line plays a key function. Data can now be stored for long periods of time by merely keeping it circulating, much like water in an

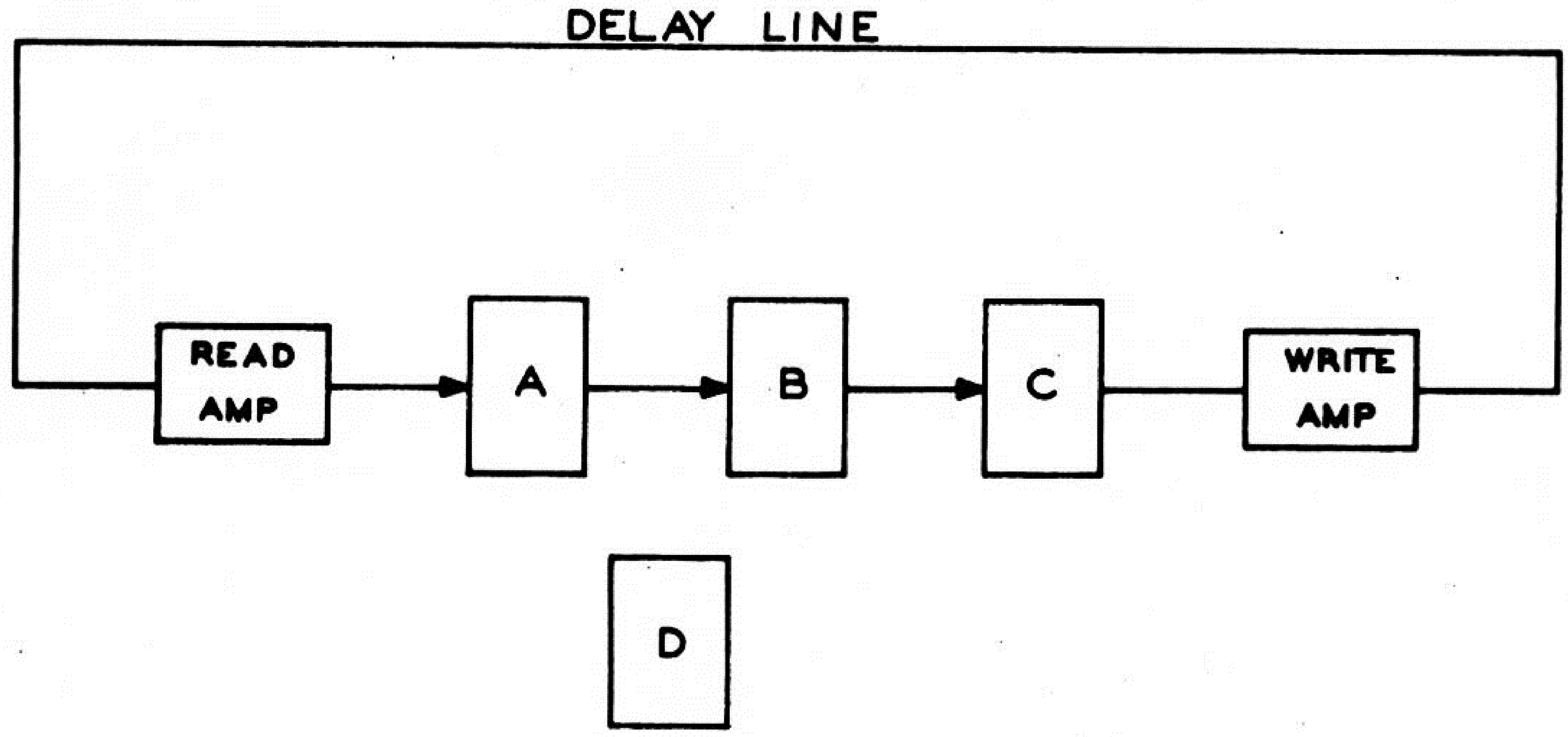


Figure 7

automobile cooling system is recirculated and used over and over. Figure 7 shows the closed loop system used in the EC/130. In this system, data is written onto the line, and read off the line 5.2 milliseconds later and counted into the A counter. From there, it is shifted to B, shifted to C, and written back onto the delay line from the C counter. In this way, no information is lost, and data may be kept in the machine as long as the machine is on.