

# 5345 ELECTRONIC COUNTER

HEWLETT  PACKARD

## MEASURING ELECTRICAL LENGTH (DELAY) OF CABLES

A precise knowledge of the delay (electrical length) of cables is particularly important in the design of balanced networks, matching stubs, cable systems, and antenna feeds. For example, antenna feed systems require many cable assemblies that are trimmed to specific electrical lengths. This application note describes a calculator based HP Interface Bus system using the HP 5345A Electronic Counter to measure either the length (in cm and feet) and delay (sec) or dielectric constant of cables. The technique requires access to only one end of the cable which is useful in trimming cables to specified lengths or matching the delay of one cable to another. The 5345A's unique time interval capability permits repeatability in the measurements of  $\pm .05$  centimeters ( $\pm .02$  inches). Since the measurements are fast and completely automatic, the system is well suited to application areas such as production and quality control. Use of the HP Interface Bus ensures that the instruments need not be dedicated to this particular configuration. The bus allows instruments to be quickly and easily reconfigured to solve a variety of measurement problems.

APPLICATION  
NOTE 174-10



## INTRODUCTION

The velocity of propagation of an electrical signal through a medium is dependent upon two specific properties of the medium: the permeability  $\mu$  and the permittivity  $\epsilon$ , and is given by

$$v_p = \frac{1}{\sqrt{\mu \epsilon}}$$

The velocity of propagation in free space (or air),  $v_o$ , is given by

$$v_o = \frac{1}{\sqrt{\mu_o \epsilon_o}} = 3.00 \times 10^8 \text{ meters/sec}$$

where  $\mu_o = 4\pi \times 10^{-7}$  henries/m and  $\epsilon_o = 1/36\pi \times 10^{-9}$  farads/m. The velocity of propagation in any medium may be expressed as

$$v_p = \frac{v_o}{\sqrt{\mu_r \epsilon_r}}$$

where  $\mu_r$  = relative permeability =  $\mu/\mu_o$  and  $\epsilon_r$  = relative permittivity (dielectric constant) =  $\epsilon/\epsilon_o$ . For most cases of interest,  $\mu = \mu_o$  and the velocity of propagation becomes

$$v_p = \frac{v_o}{\sqrt{\epsilon_r}} = \frac{3.00 \times 10^8 \text{ meters/sec}}{\sqrt{\epsilon_r}}$$

This expression is valid also when loss in the medium is present.

In this application note, the capability of the 5345A counter to precisely measure the time interval between a start signal (at the A input) and a stop signal (at the B input) is used to determine the length of the cable. In principle, a fast rise time pulse is simultaneously applied to the cable and the channel A input (start) of the counter. The reflected pulse from the open cable end triggers the channel B input (stop). The time interval ( $\Delta t$ ) measured by the counter is twice the one-way cable delay. The length of the cable is computed, when the dielectric constant of the material ( $\epsilon_r$ ) is known, from the equation,

$$\text{Length (cm)} = \frac{3.00 \times 10^{10}}{\sqrt{\epsilon_r}} \cdot \frac{\Delta t}{2}$$

Table 1

Dielectric Material	$\epsilon_r$ (1 MHz)
air	1.0
*Teflon beads	1.02
Teflon helix	1.23
foam polyethylene	1.5
solid Teflon	2.04—2.1
solid polyethylene	2.25—2.34
solid polypropylene	2.25
*Teflon is Dupont's trade name for polytetrafluoroethylene.	

Table 1† is a tabulation of dielectric constants for the dielectric materials most often used in coaxial cables. Even though the values were determined at 1 MHz,  $\epsilon_r$  is relatively independent of frequency for non-polar dielectrics (such as polyethylene and teflon).

## MEASUREMENT SET-UP AND THEORY OF OPERATION

The measurement system consists of the 5345A Electronic Counter (opt. 011), the 59307A VHF Switch, the 59405A opt. 020/021A HP-IB Calculator Interface, the 11221A Math ROM block, and the 9820/21A Calculator. The instruments are connected to the calculator as shown in Figure 1.

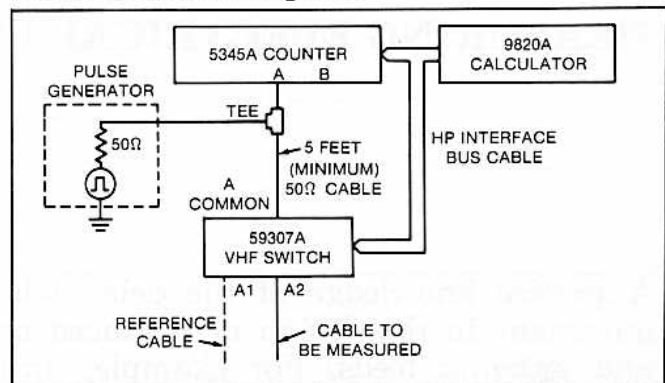


Figure 1

The measurement system shown in Figure 1 is set up to measure cable length on a differential basis. This means that to find the time interval corresponding to a length of cable, a reference and an "unknown" time interval are measured and the difference is taken. The advantage to this method is the fact that systematic errors are cancelled and the overall accuracy of the measurement is improved as compared to a single time interval measurement. The reference measurement is made with the A1 input of the VHF Switch connected to A common. The unknown measurement is made with A2 of the VHF Switch connected to A common. Figure 2 shows the waveforms which are simultaneously applied to the A and B

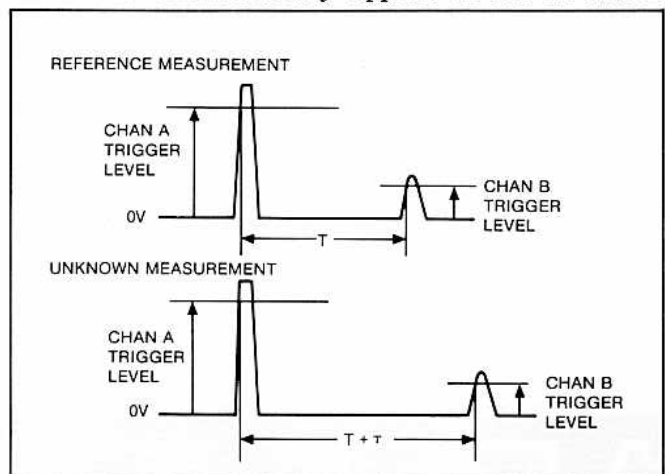


Figure 2

channels of the 5345A counter for the reference and unknown measurements. The result of subtracting the reference measurement from the unknown measurement is  $\tau$ . One-half of  $\tau$  corresponds to the unknown cable length.

Set the Talk/Listen address switches on the 5345A counter and the 59307A VHF switch as specified in Table 2. These switches are located on the rear panels of the instruments and must be set as specified so as to agree with the addresses used in the program.

Table 2

	Talk/Listen	Mode Switch	A5	A4	A3	A2	A1
5345A Counter	J/*	addressable	0	1	0	1	**
59307A VHF Switch	/>	addressable	1	1	1	1	0

\*\*not used

Place the Math and PCII ROM blocks into ROM slots 1 and 3 respectively of the 9820A Calculator. To interface the instruments to the calculator, perform the following: plug the ASCII Bus Interface Card into any of the four slots on the rear panel of the 9820A Calculator. Connect ASCII Interface cables (10631A, B, or C) from the interface card of the calculator to the rear panel plugs of the 5345A counter and the 59307A VHF switch (choose cable lengths such that the total length of ASCII cable does not exceed 18 feet).

Set the following 5345A controls: impedance (channel A and B) to  $50\Omega$ , slope (channel A and B) to +, attenuation (channel A and B) to X1, coupling (channel A and B) to DC, and the SEP/COM switch to common. The adjustment of the channel A and channel B trigger levels is critical to proper operation of the system. The following procedure should be followed: with an oscilloscope set the pulse generator (an HP 1900 series pulse generator with the 350 psec 1920A pulse output plug-in is recommended) for a 0 to 1 volt pulse less than 10 nsec wide at a repetition rate of approximately 500 kHz; set the counter to **FREQ** and a 10  $\mu$ sec **GATE** time; turn channel A trigger level control full clockwise and decrease until a stable reading of the input frequency is obtained (as decrease further, a reading twice the input frequency will be obtained because the counter will trigger on both the input and reflected signals); set the counter to **TIME INTERVAL** and the VHF switch to A2; turn channel B trigger level control full clockwise and decrease until a stable reading is obtained which is less than the period of the input signal (the first stable reading obtained is the period of the input signal-decrease to the next stable reading which occurs when channel B is triggering on the reflected pulse). Since the calculator remotely controls all other front panel controls of the counter and all the controls of the VHF switch, there is no need to set these controls to any particular position.

## PROGRAM OPERATION

Key into the calculator the program listed on the back of this application note. The program will require the user to respond to the following;

“CABLE LENGTH?1=Y” — enter 1 if the length of the cable connected to A2 of the VHF Switch is to be measured; enter 0 if the dielectric constant of the cable is to be measured.

“DIELECTRIC K?” — for cable length measurements, enter the  $\epsilon_r$  of the dielectric material in the cable.

“LENGTH (CM)?” — for dielectric constant measurements, enter the measured physical length (in centimeters) of the cable.

The VHF switch switches to A1 and makes a reference time interval average measurement. The switch then switches to A2 and the unknown time interval average measurement is made. The difference in the two measurements divided by two is the delay due to the cable connected to the A2 terminal of the switch.

Figure 3. Program Flow Diagram

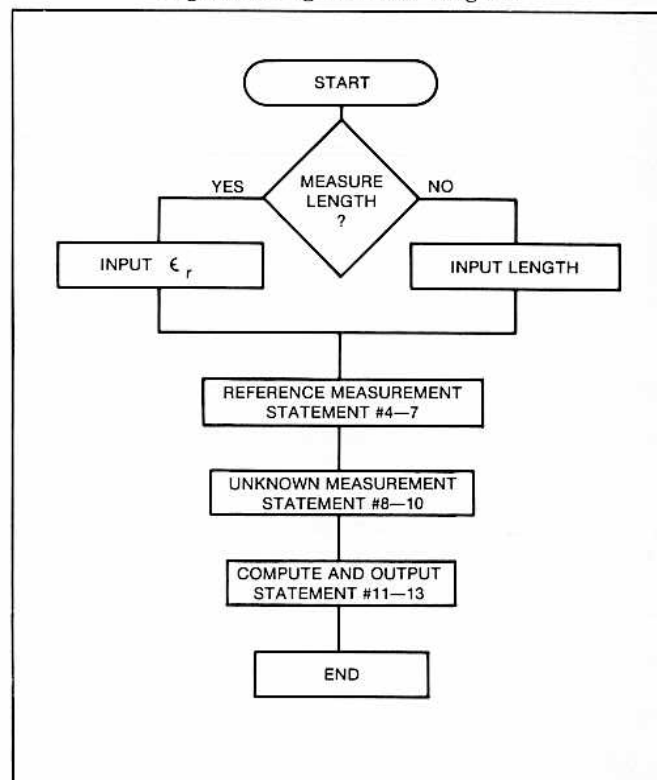


Figure 3. Program Flow Diagram

## MEASUREMENT CONSIDERATIONS

a. Although measurements are repeatable to  $\pm 0.05$  centimeter (on the order of  $\pm 2$  picoseconds), the absolute accuracy of the measurements depends upon the rise time of the pulse generator and the length and loss of the cable. If the rise time of the reflected pulse which triggers the B channel of the counter is degraded by 1 nsec with respect to the reference measurement, then the error in the length measurement could be on the order of 30 centimeters ( $\sim 1$  foot). To obtain the best possible absolute accuracy, the length of cable to be measured should be significantly less than the length of cable connecting A common of the VHF Switch to the A channel of the 5345A Counter. If this is true, the difference in the rise times of the reflected pulse for the two measurements will be small (nearly equal degradation in both paths) and the length error will be correspondingly small. The rise time at the end of the cable is proportional to the square of the length of the cable. Hence, if 1 foot of cable were to be measured and the length of cable from A common of the VHF switch to channel A of the counter were 10 feet, the reflected pulse rise time in the measurement path would be approximately 80% ( $=100 * (2 \times 10)^2 / (2 \times 11)^2$ ) of the reflected pulse rise time in the reference path. For a 350 psec rise time from the pulse generator, this would result in a worst case error of 70 psec or approximately 2 centimeters ( $\sim 1$  inch).

- b. Since only one end of a cable need be connected to make a length measurement, the system is well suited to trimming applications where it is desired to match the delay of one cable to another cable. To do this, connect the reference cable to terminal A1 of the VHF Switch and the cable to be trimmed to terminal A2. Trim the cable until the delay difference is zero. Since the two measurement paths are trimmed to be equal, the accuracy of this measurement is on the order of  $\pm 0.05$  cm ( $\pm 0.02$  in.).
- c. There is a worst case mismatch between legs of the VHF Switch of 10 psec. This can be measured for A1 and A2 by simply running the program without any cable connected to either A1 or A2. The resultant delay indicates how much greater the delay from A common to A2 is than the delay from A common to A1. This difference can be subtracted from program results to improve accuracy.
- d. The maximum allowable total length of cable in a system depends upon the loss characteristics of the cable. The reflected signal must be of sufficient amplitude to trigger channel B of the counter. For cables which are not specifically designated as high loss cables, cable lengths in excess of 200 feet are probably allowable.

†C.A. Harper, Editor, *Handbook of Wiring, Cabling, and Interconnecting for Electronics*, McGraw Hill, 1972, page 4-13.

### 9820/21A Program Listing

```

0:          6:          2: PRT "LENGTH (C
ENT "CABLE LENGT  CMD "?U*", "J1", "  M)=", Z*3.E10/FCF
H?1=Y", AF      ?J5" F      12:
1:          7:          IF A=1: FXD 3:
FMT Y3, Z: WRT 13F  FMT #: RED 13, YF  PRT "LENGTH (FT)
2:          8:          =", Z*9.84252E8/FCF
IF A=1: ENT "DIEL  CMD "?U>", "A2":
ECTRIC K?", CF    DSP " " F
3:          9:          13:
IF A#1: ENT "LENG  CMD "?U*", "J1", "  IF A#1: FXD 3:
TH (CM)", BF     ?J5" F      PRT "DIELECTRIC
4:          10:         K=", (Z*3.E10/B)†
CMD "?U>", "A1":  FMT #: RED 13, XF  2: GTO 0F
DSP " " F        11:
5:          (X-Y)/2+Z: IF A=1  END F
CMD "?U*", "I2F3G  #FLT 3: PRT "DELA  R371
>E89: I1", "?J":  Y (SEC)=", Z: FXD
DSP " " F

```

## USING THE 9830A CALCULATOR

The 9830A Calculator may be used in place of the 9820/21A Calculator with system operation remaining essentially unchanged. The following sections list the necessary equipment for operation with the 9830A Calculator, discuss any differences in program operation, and present the complete program listing of the 9830A software.

## MEASUREMENT SET-UP

The 9830A measurement system consists of the 5345A Electronic Counter (opt. 011), the 59307A VHF Switch, the 59405A opt. 030 HP-IB Calculator Interface, the 9830A Calculator, the 11274B String Variables ROM, and the 9866A Calculator Printer. A fast rise time pulse generator is required and the HP 1900 series pulse generator with the 350 psec 1920A pulse output plug-in is recommended. Place the Extended I/O ROM and the String Variables ROM in any of the calculator ROM slots. The instruments are configured in precisely the same manner as in the case when the 9820A Calculator is the controller.

## SYSTEM OPERATION

The system with the 9830A Calculator as the controller operates in the same manner as the system with the 9820A Calculator as the controller. The program requests the user to respond to the following:

"MEASURE CABLE LENGTH—YES OR NO?".  
Enter YES if the length of cable is to be measured. Enter NO to measure dielectric constant.

"DIELECTRIC CONSTANT?". For cable length measurements, enter the  $\epsilon_r$  of the dielectric material in the cable.

"LENGTH (CM)?". For dielectric constant measurements, enter the measured physical length (in centimeters) of the cable.

Figure 4 is a flow diagram of the 9830A program.

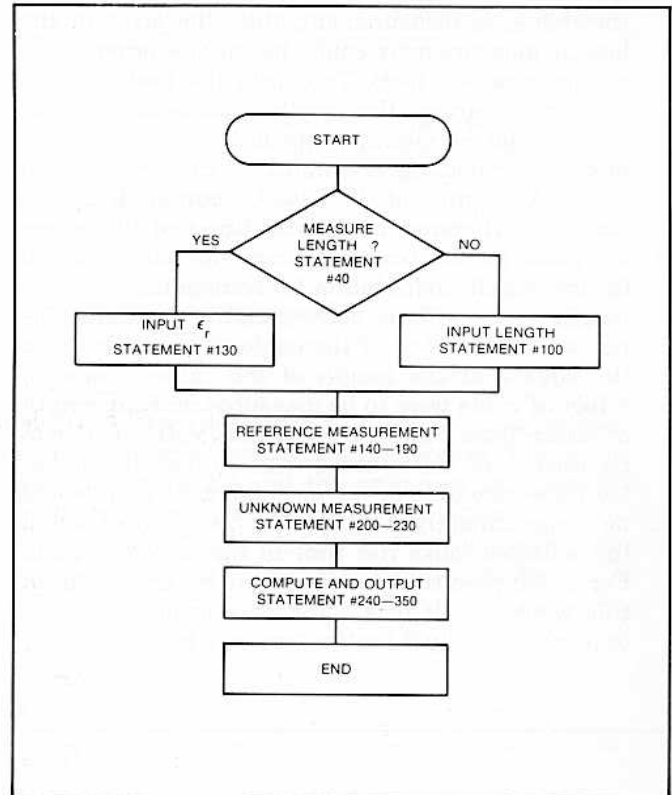


Figure 4

## 9830A Program Listing

```
10 DIM B#[4]
20 DISP "AM174-10: CABLE LENGTH"
30 WAIT 1000
40 DISP "MEASURE CABLE LENGTH-YES OR NO";
50 INPUT B#
60 IF B#[1,1]="Y" THEN 120
70 DISP "DIELECTRIC CONSTANT MEASUREMENT"
80 WAIT 500
90 DISP "LENGTH (CM)";
100 INPUT B
110 GOTO 140
120 DISP "DIELECTRIC CONSTANT";
130 INPUT C
140 CMD "?U>","A1"
150 WAIT 50
160 CMD "?U*","I2F3G>E89:I1","?J"
170 WAIT 50
180 CMD "?U*","J1","?J5"
190 ENTER (13,*)Y
```

9830A Program Listing

```

200 CMD "?U>","A2"
210 WAIT 50
220 CMD "?U*","J1","?J5"
230 ENTER (13;*)X
240 Z=(X-Y)/2
250 IF B#[1,1]="Y" THEN 290
260 FIXED 3
270 PRINT "DIELECTRIC K=",((Z*3E+10/B)+2
280 GOTO 10
290 FLOAT 3
300 PRINT "DELAY(SEC)=",Z
310 FIXED 2
320 PRINT "LENGTH(CM)=",Z*3E+10/SQR(C)
330 FIXED 3
340 PRINT "LENGTH(FT)=",Z*9.84252E+03/SQR(C)
350 PRINT
360 GOTO 10
370 END

```