Locating bus cable break point in a local area network

CHI-KIN LEUNG† and FUET-KIT LAM‡

A measuring system which can accurately locate an inaccessible break point over a local area network bus cable is described. The system utilizes sinusoidal signals instead of conventional narrow pulses as input test signals. It is shown that the variation of the amplitude with frequency in the resultant sinusoidal wave established over the cable length is periodic and that the periodicity is related to the break point distance. Thus the distance to the break point can be determined by measuring this period. Practical tests on a number of cable segments confirmed the viability of the approach. On account of its accuracy and modest equipment requirement, the method is valuable for break point location measurement over an Ethernet environment.

1. Introduction

With increasing office automation, local area networks (LANs) are becoming commonplace. Among the various types of LAN systems available in the market, the Ethernet (or the IEEE802.3 standard) system is perhaps the most widely adopted in the office environment, mainly due to its low cost and simplicity. The Ethernet LAN employs a linear bus topology with a coaxial cable as its medium (I.E.E.E. 1985). While being convenient and cost-effective, the linear bus topology cannot tolerate a single break along the cable medium, otherwise the whole LAN will be inoperative. For the original Ethernet (IEEE802.3 10Base5) system in which access to the cable is via a transceiver, the occurrence of cable breaks is quite rare, being limited to situations where actual faulty cables are present. However, for the cheaper version of the Ethernet system—the so-called thin-wire Ethernet or IEEE802.3 10Base 2 (I.E.E.E. 1988)—in which access to the cable is via a T-connector, the cable segment can easily be broken due to careless handling by operators, and cable breaks are no longer uncommon. For the everyday management of such systems, a means of locating the cable break is highly desirable (Rhodes 1991). A straightforward way to detect the break point is based on the common time domain reflectometry approach. In this measurement, a narrow pulse is sent into the cable and the time delay of the reflected pulse is recorded. From the time delay, the break point location can then be estimated. Such an approach suffers from the drawback that for good resolution, the interrogating pulse should be very narrow with an inherently broad spectral bandwidth. Owing to the band-limiting effect of the cable, the reflected pulse at the receiver will be widened and the resolution will deteriorate. Furthermore, with a very narrow pulse, the small amount of energy contained in it gives rise to a very poor signal-to-noise ratio for the measuring set-up. The approach proposed in this paper is to employ continuous sinusoidal signals instead of single pulses to overcome these difficulties.

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†Department of Electronic Engineering, Hong Kong Polytechnic, Hung Hom, Kowloon, Hong Kong.
‡Department of Electrical and Electronic Engineering, University of Hong Kong, Pokfulam Road, Hong Kong.
2. Theory of operation

In the proposed set-up (Fig. 1), a signal generator is connected to one of the end point of the cable under test. A sinusoidal signal is launched into the cable at the end point. The incident sinusoidal wave will travel down the cable and if it encounters a cable break, it will be reflected towards the incident end. The incident and reflected components will coexist along the cable, reinforcing or cancelling each other. At some other convenient location, a level detector monitors the amplitude of the resultant sinusoidal wave.

From transmission line theory (Collin 1966, Connor 1972, Dworsky 1979, Liboff and Dalman 1985), the propagation coefficient $\gamma$ is given in terms of the primary constants of the transmission line, i.e.

$$\gamma = \alpha + j\beta = [(R + j\omega L)(G + j\omega C)]^{1/2}$$

where the symbols have their usual meanings in transmission line terminology. Assuming that the wave at the input of the transmission line is given by

$$v(t, x) = v(t, 0) = e^{j\omega t}$$

After travelling for a distance of $l$ within the cable, the wave will be given by

$$v(t, l) = e^{j\omega t} \times e^{-\gamma l} = e^{j\omega t} \times e^{-(\alpha + j\beta)l}$$

$$= e^{j\omega t} \times e^{-\alpha l} \times e^{-j\beta l} = e^{-\alpha l} \times e^{j(\omega t - \beta l)}$$

hence the term $e^{-\alpha l}$ accounts for the attenuation and the term $-\beta l$ accounts for the phase shift.

For special classes of transmission lines such as loss-free or low-loss transmission lines, the attenuation coefficient $\alpha$ is a constant independent of frequency, while the phase shift coefficient $\beta$ is linearly related to the frequency given by (Collin 1966, Connor 1972, Dworsky 1979, Liboff and Dalman 1985)

$$\beta = \omega (LC)^{1/2}$$

Therefore the velocity of the wave within the cable is a constant independent of frequency is given by:

$$v' = \frac{\omega}{\beta} = \frac{1}{(LC)^{1/2}}$$

![Figure 1](image)  

Figure 1  Model for break point measurement.
LAN bus cable break point location

By referencing to the velocity of a TEM wave in free space, which is usually denoted as

\[ c \approx 3 \times 10^8 \text{ ms}^{-1} \]

the velocity of the wave within the cable is sometimes written as

\[ v' = v_f \times c \]

where the term \( v_f \) is called velocity factor which is a property of the cable and its value must fall within a certain range in order to satisfy the requirement of the corresponding LAN standard (I.E.E.E. 1985).

Referring back to Fig. 1, at the reference position along the cable where level monitoring is to be made, the incident component is given by

\[ v_i(t) = e^{j\omega t} \]

At the break point, the wave, denoted as \( v_i^+(t) \), will be given by

\[ v_i^+(t) = e^{j\omega t} \times e^{-\alpha l} \times e^{j\beta l} \]

\[ = e^{-\alpha l} \times e^{j\beta l} \]

\[ = e^{-\alpha l} \times e^{j(\alpha t - \beta n)} \]  \hspace{1cm} (7)

At the break point, because there is a discontinuity in the transmission line, the electromagnetic wave will be reflected back towards the source with the reflection coefficient (Connor 1972)

\[ \rho = |\rho|e^{j\phi} \]

so that the reflected wave is given by

\[ v_r(t) = e^{j\omega t} \]  \hspace{1cm} (6)

At the break point, the wave, denoted as \( v_i^-(t) \), will be given by

\[ v_i^-(t) = e^{j\omega t} \times e^{-\alpha l} \times e^{j\beta l} \]

\[ = e^{-\alpha l} \times e^{j\beta l} \]

\[ = e^{-\alpha l} \times e^{j(\alpha t - \beta n)} \]  \hspace{1cm} (7)

At this break point, because there is a discontinuity in the transmission line, the electromagnetic wave will be reflected back towards the source with the reflection coefficient (Connor 1972)

\[ \rho = |\rho|e^{j\phi} \]

so that the reflected wave is given by

\[ v_-\_l(t) = e^{-\alpha l} \times e^{j(\alpha t - \beta n)} \times |\rho|e^{j\phi} \]

After travelling back to the reference position, the reflected wave becomes

\[ v_{r(t)} = e^{-\alpha l} \times e^{j(\alpha t - \beta n)} \times |\rho|e^{j\phi} \times e^{-\alpha l} \times e^{-j\beta l} \]

\[ = |\rho|e^{-2\alpha l} \times e^{j(\alpha t - 2\beta l + \phi)} \]

\[ |\rho|e^{-2\alpha l} \times e^{j(\alpha t - 2\beta l + \phi)} \]  \hspace{1cm} (9)
In summary, when the reflected wave travels back to the reference point, it will have experienced a phase shift of $\Phi$, an attenuation of $k = |\rho|e^{-2\phi}$, and a time delay of $\tau = 2l/c'$ where $l$ is the distance of the break point from the reference position.

Therefore, the reflected wave can be written as

$$v_f(t) = ke^{j(\omega(t-\tau)+\phi)}$$

The resultant wave at the reference position will be

$$v(t) = v_i(t) + v_f(t) = e^{j\omega t + ke^{j(\omega(t-\tau)+\phi)}}$$

$$= [1 + ke^{-j(\omega\tau-\phi)}]e^{j\omega t}$$

(11)

The amplitude of this resultant wave is:

$$v_A = \left\{ \frac{1 + k \cos \left( \frac{\omega 2l}{c'} - \phi \right)}{2} + k^2 \sin^2 \left( \frac{\omega 2l}{c'} - \phi \right) \right\}^{1/2}$$

$$= \left\{ \frac{1 + k \cos \left( \frac{4\pi f l}{c'} - \phi \right)}{2} + k^2 \sin^2 \left( \frac{4\pi f l}{c'} - \phi \right) \right\}^{1/2}$$

It is evident that if the parameters $k$ and $c'$ can be assumed to be independent of frequency, as in the cases for loss-free or low-loss transmission lines, and if the amplitude $v_A$ is plotted against $\omega$ (or $f$), that plot will be a periodic function in $\omega$ (or $f$). An example of such a plot is shown in Fig. 2.

The period $\Delta f$ of the plot is simply given by

$$\Delta f = \frac{c'}{2l} \text{ (Hz)}$$

![Figure 2. Amplitude versus frequency plot-calculated results for (9) with $k=0.5$, $\Phi = 180^\circ$, $4\pi fl/c' = \Delta f$.](image-url)
If the velocity of the EM wave, $v'$, within the cable is known, then the distance from
the reference to the cable break point can be obtained as

$$l = \frac{v'}{2\Delta f} \quad \text{(14)}$$

It should be noted that the velocity of the EM wave, $v'$, within the cable can be
accurately determined. By substituting a cable of known length $l_4$ into the measurement
set-up, $v'$ will be given as $v' = \Delta f / 2l_4$.

3. Measurement

Based on the previous theoretical development, a procedure for locating cable
break points can be stated as follows.

Step 1. Determine $v'$ for the cable for measuring $\Delta f$ for a cable segment with known
length. This can be done before setting up the cabling system. The results are
documented for later reference.

Step 2 With $v'$ known, the amplitude versus frequency plot is obtained. For an
accurate result, a plot with several maxima and minima should be obtained
and an average value for the period $\Delta f$ can then be found.

Step 3. With $v'$ and $\Delta f$ known, the break point distance can then be determined.

4. Experimental set-up

To investigate the actual performance, an experimental set-up as shown in Fig. 3
was assembled. A sweep generator (Texscan VS-60B) with marker facility was used
to launch the signal into the cable. A frequency synthesizer (HP8656B) with digital
read-out generated the marker signal for the sweep generator. A diode detector was
used to detect the amplitude of the resultant wave. It is to be noted here that whether
the diode detector detects the true amplitude or the square of the amplitude is
unimportant because only the periodic feature of the plot will be of interest. With
the use of a sweep generator, the periodic plot can be displayed on the oscilloscope
in real time.

The cable under test was an RG58 A/U type 50 $\Omega$ coaxial cable manufactured by
Belden Co. The cable is delivered in a 305 m reel (1000 feet). Since there is no

![Figure 3. Experimental set-up.](image-url)
information available from the manufacturer about the velocity factor $v_f$, $v'$ has to be determined experimentally.

With an exact 3 m length of cable inserted in the set-up, the sweep generator is adjusted to give 10 periods on the oscilloscope. Through the use of the marker, the frequency range covering the 10 periods is accurately found (Fig. 4). As illustrated, the frequency range extends over 330 MHz for 10 periods, giving a period $\Delta f$ of 33 MHz; thus the velocity factor of the cable is evaluated to be 0.66.

A cable segment of 1 m in length is inserted into the set-up and the measurement is made once again. This time the sweep generator is adjusted to give 9 periods on the oscilloscope (Fig. 5). The frequency range extends over 891 MHz for 9 periods,
giving a period $\Delta f$ of 99 MHz. With a known velocity factor of 0.66, the cable length can be evaluated as 1 m, confirming the viability of the approach.

To ascertain the accuracy of this approach, cable segments with different lengths have been tested according to the previous procedure. The results are tabulated as in the Table. It can be seen that the method gives reasonable accuracy in measuring the cable break distance.

5. Discussion

In the above set-up, a sweep generator was employed. In fact, the use of such rather expensive equipment can be avoided. If time is not the crucial factor, the plot can be obtained in discrete steps with the help of a simple signal generator. The frequencies are now manually adjusted and the detected amplitudes recorded. It will be seen that since the period is inversely proportional to the distance to be measured, for a cable break point near the source, the sweep range will be quite large and this calls for the use of wide range signal generator. Such a requirement on the signal generator can be relieved by simply extending the distance of the break point with the addition of an extra cable segment to the cable under test. For example, with a standard segment of 10 m, the highest frequency required of the signal generator for one period of measurement is 10 MHz, assuming a velocity factor of 0.66. Similarly if a standard segment of 50 m is used, the highest frequency required of the signal generator is only 2 MHz. This frequency range is comfortably covered by most off-the-shelf low-cost signal generators.

6. Conclusion

A measurement method is described that is capable of determining velocity factor and break point location over a coaxial cable. The method makes use of sinusoidal signals instead of pulses as the excitation. The theory behind the approach is outlined. A measurement system consisting of a sweep generator, a frequency synthesizer, a level detector and an oscilloscope is assembled and tests on a number of cable segments are undertaken. On the basis of its accuracy and simplicity, the approach is to be recommended.

<table>
<thead>
<tr>
<th>Measured cable length (m)</th>
<th>Measured, $\Delta f$ (MHz)</th>
<th>Calculated velocity factor</th>
<th>Calculated cable length (m)</th>
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<tr>
<td>$3^\dagger$</td>
<td>33</td>
<td>0.66</td>
<td>1.0</td>
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</tr>
<tr>
<td>20</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
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$^\dagger$Standard segment for calibration.

Measurement results for different cable lengths.
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References