4 种测量馈线阻抗的方法

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1、Mesuring the Impedance of a Coax Using an SWR Analyser

使用驻波表测量同轴线缆的阻抗

- Calculate the required frequency (F in MHz), which is related to the cable length L in feet :
F = 185 / L (This is approximately the quarter wavelength frequency)
根据被测线缆的长度计算测试频率，目的是使被测线缆的长度接近测试频率的 1/4λ。公式中 L 的单位是**英尺**，F 的单位是**兆赫兹。**

- Connect the cable to the SWR analyzer and terminate the other end with a 50 ohms load.
被测线缆的一段接驻波表，另一端接 50Ω假负载。

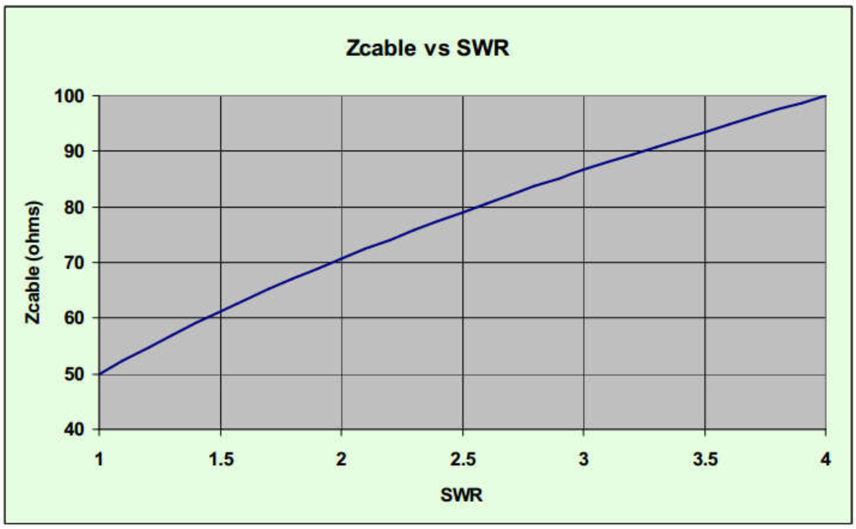
- Measure the SWR. If you get 1:1, then the cable impedance is 50 ohms.
If the SWR is above 1:1, change the frequency to **maximize** the SWR reading.
测量驻波。如果你得到的驻波比为 1，被测线缆的特性阻抗即为 50Ω；
如果驻波比大于 1，**调节测试频率，使驻波比读数最大**。

- Calculate Zcable at the frequency where the SWR is maximum, or use the graph below:
根据能测到的最大驻波比读数,按如下公式计算出被测线缆的特性阻抗,或者按曲线图查找对应结果。

$$Zcable = 50 * \sqrt{SWR}$$

Exemple: SWR = 2.25 gives Zcable = 75 ohms
例：SWR=2.25，得 线缆特性阻抗=75Ω

- NOTE: This technique is valid for Zcable >= 50 ohms.
注意：此方法只能用于被测电缆特性阻抗≥50Ω的情况。



2、Computing the cable impedance Zo with an L-C meter:

根据 L-C 电桥的测量结果计算出线缆阻抗

$$\mathbf{Zo} = 31.62 * \sqrt{\frac{\mathbf{L}_{(nH)\ short}}{\mathbf{C}_{(pF)\ open}}}$$

L is measured with the line end shorted
C is measured with the line end open

L (nH) short 被测线缆末端短路的情况下测得的电感，单位为 nH；
C (pF) open 被测线缆末端开路的情况下测得的电容，单位为 pF；
Zo 被测线缆的特性阻抗；

The cable length should be less than 1 % of the wavelength at the test frequency.
So, if using the AADE L-C meter, the cable length should be under 12 feet.
If measuring at 100 KHz, the cable length should be under 80 feet.

被测线缆的长度需要小于 L-C 电桥测试频率对应波长的 1% ；
所以，如果测试频率为 100kHz，则被测线缆的长度应小于 80 英尺。

3、Computing the cable impedance Zo with a VNA:

根据矢网的测量结果计算出线缆阻抗

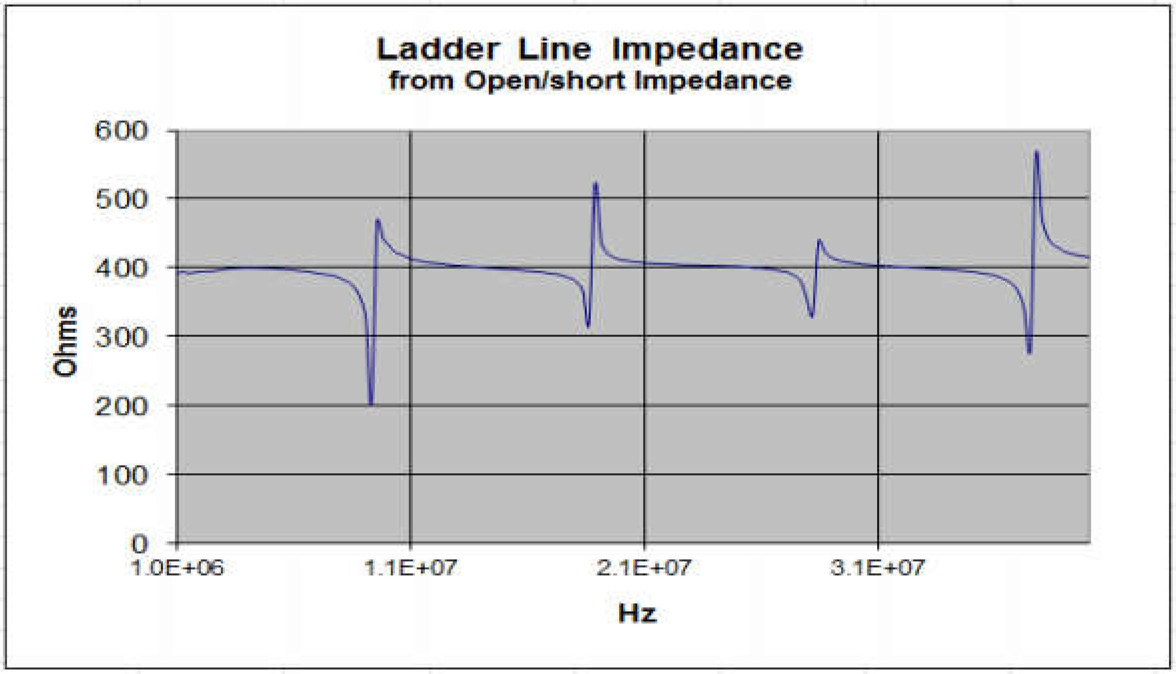
Computing the cable impedance as:
根据下式计算出线缆阻抗

$$Zo = \sqrt{Zopen \times Zshort}$$

-Measure the complex impedances Zopen and Zshort with a VNA.
使用矢网分别测量被测线缆末端开路、短路时的复数阻抗；

Perform the calculation. 根据上面的公式计算出线缆阻抗；

-Contact me for an Excel spreadsheet that does these calculations.
The best frequency to use is around 45 degrees line length.
See: http://ve2azx.net/technical/Degrees-Length.pdf
电长度 45°时的对应频率进行读数为优。原文作者 VE2AZX 整理了一份表格供下载对照（点上面的链接） 本文末尾的附录中也有收录。
-Zo calculated will have a complex value, ie a small amount of negative reactance. This is normal.
计算结果通常会含有少许负电抗，这都是正常的。



Example of Zo magnitude measurement on a ladder line.
例：在梯形（平行）馈线上测得的阻抗大小。

A 4:1 balun was used to improve the accuracy of
impedance measurements (derived from S11).
测量中使用了一个 4:1 巴伦来提高测试精度（由 S11 推导而来）
The peaks occur at line lenghts which are multiples of 90 degrees. These errors are caused by inaccuracies in measuring extreme values of impedance.
峰值出现在 90°的整数倍处，这些误差是由测量阻抗极值时的不准确性所导致的。
译注：所以要取 45°位置进行读数，计算结果会比较准确。

4、Computing the cable impedance Zo with a TDR:

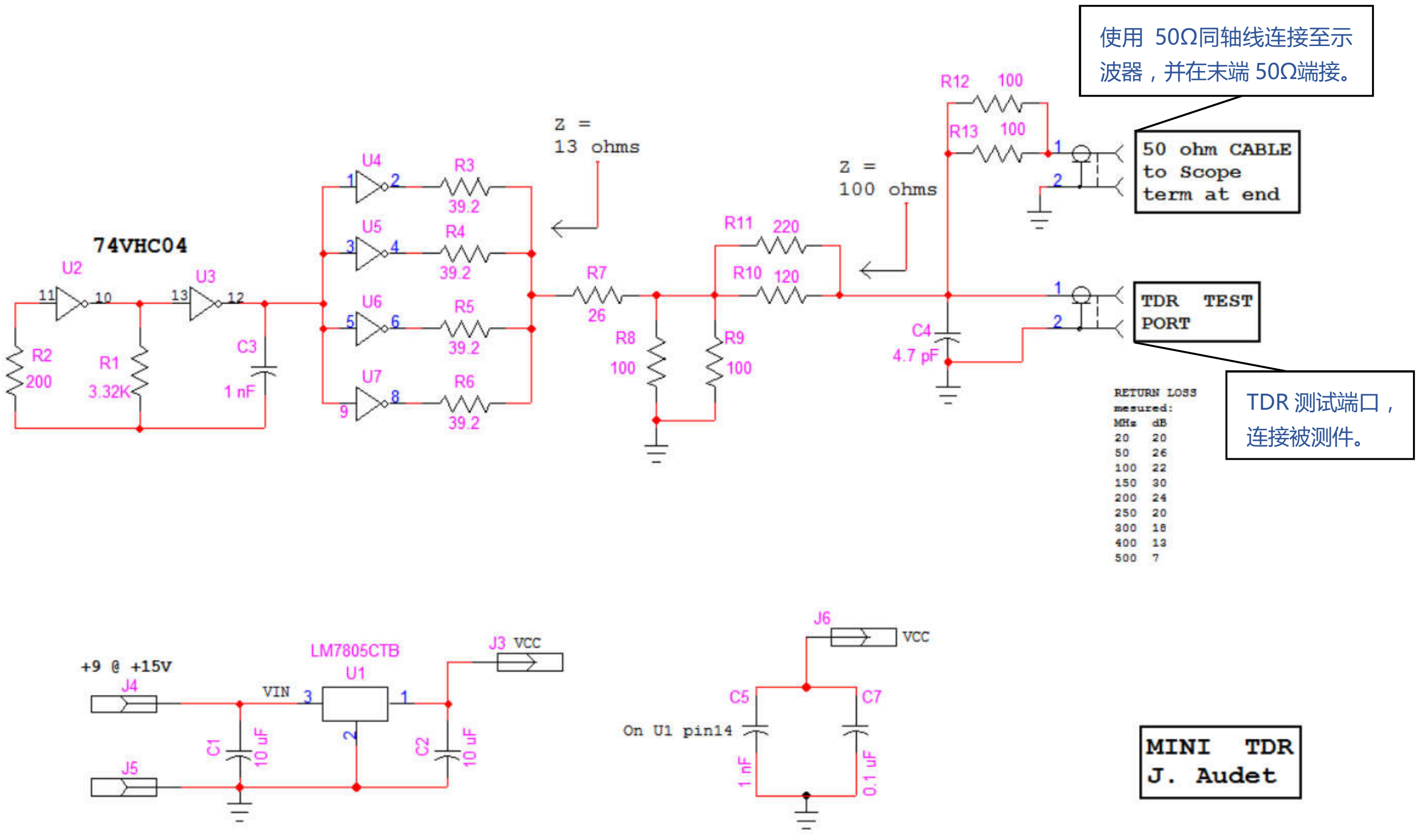
根据 TDR 的测量结果计算出线缆阻抗

译注：TDR——Time-Domain Reflectometer　时域反射计

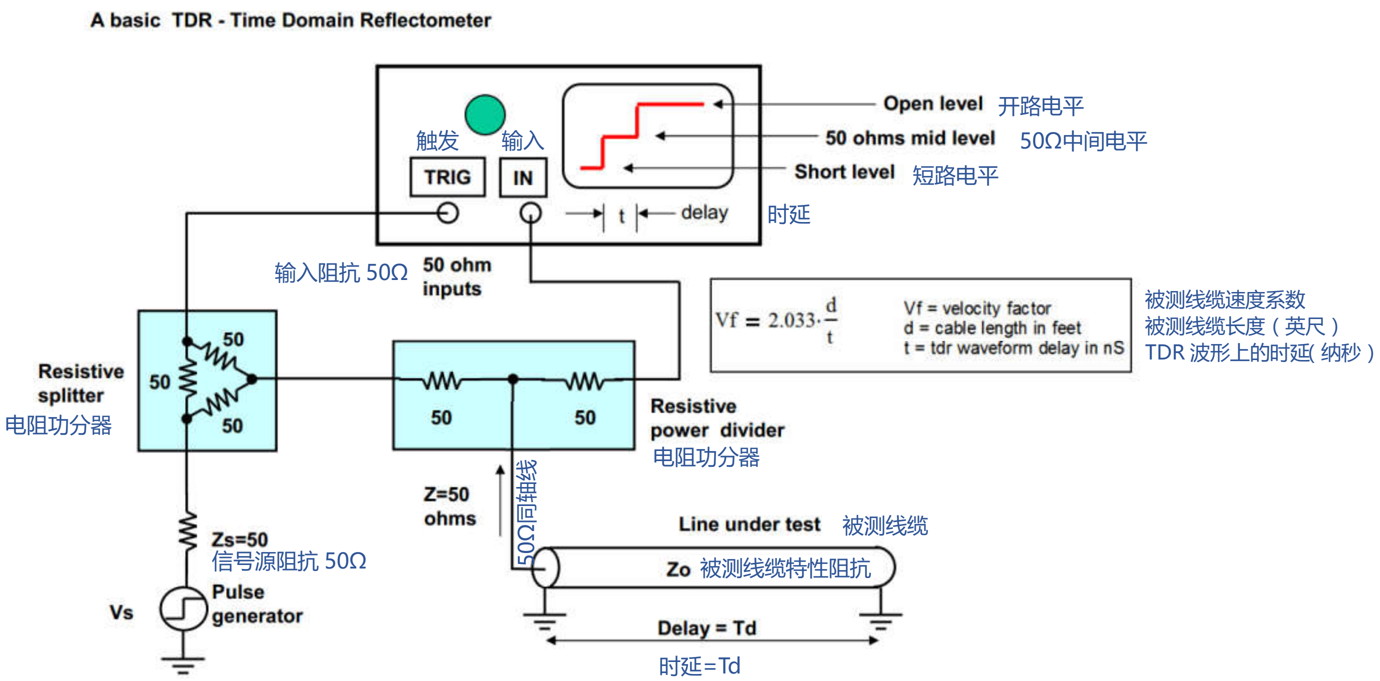
TDR 的具体原理请自行搜索学习，此处仅介绍用方法。

-Use your pulse generator to make your TDR

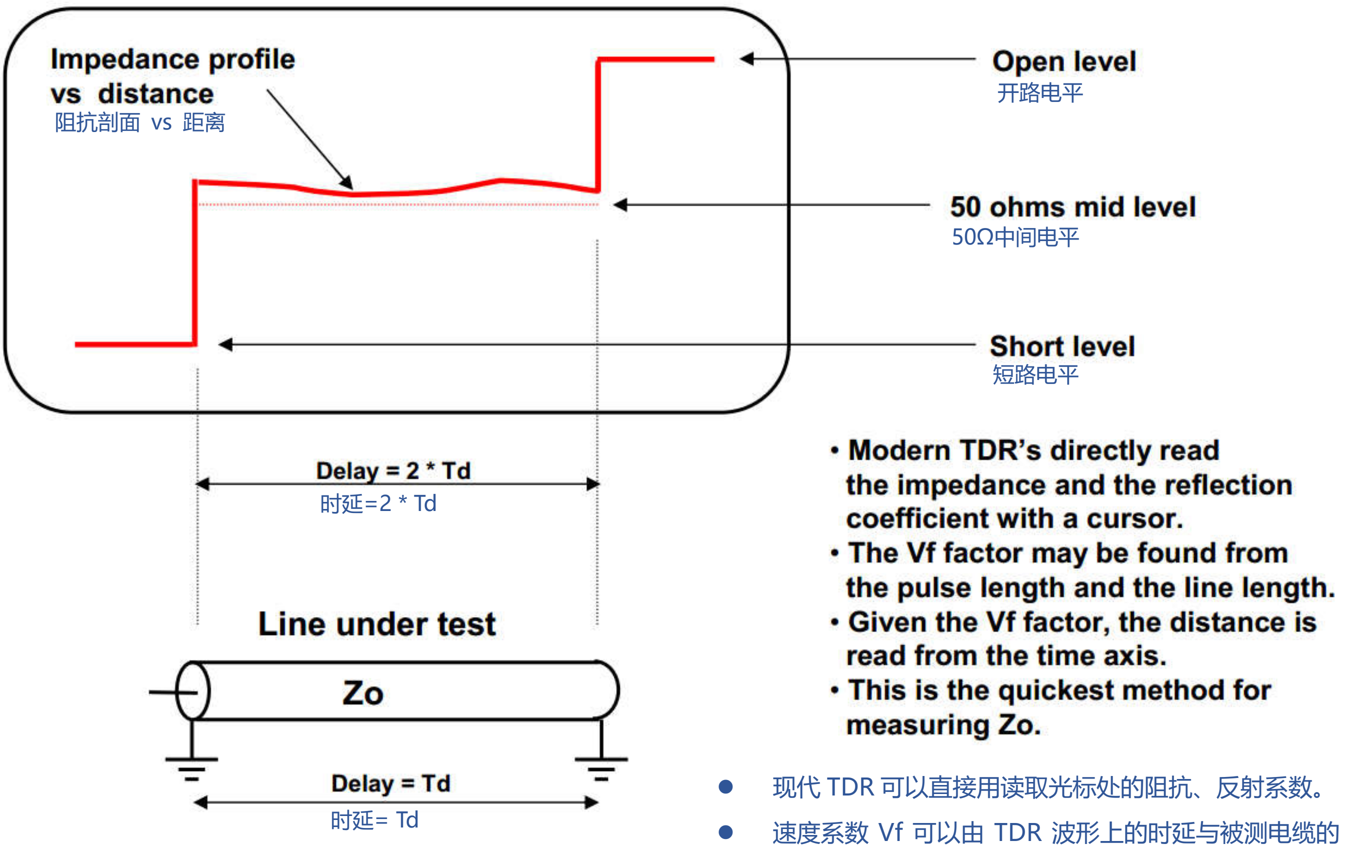
使用一个脉冲发生器来搭建你自己的 TDR。下图是一个典型的脉冲发生器：



下图是一个基础的 TDR 测试装置连接图：

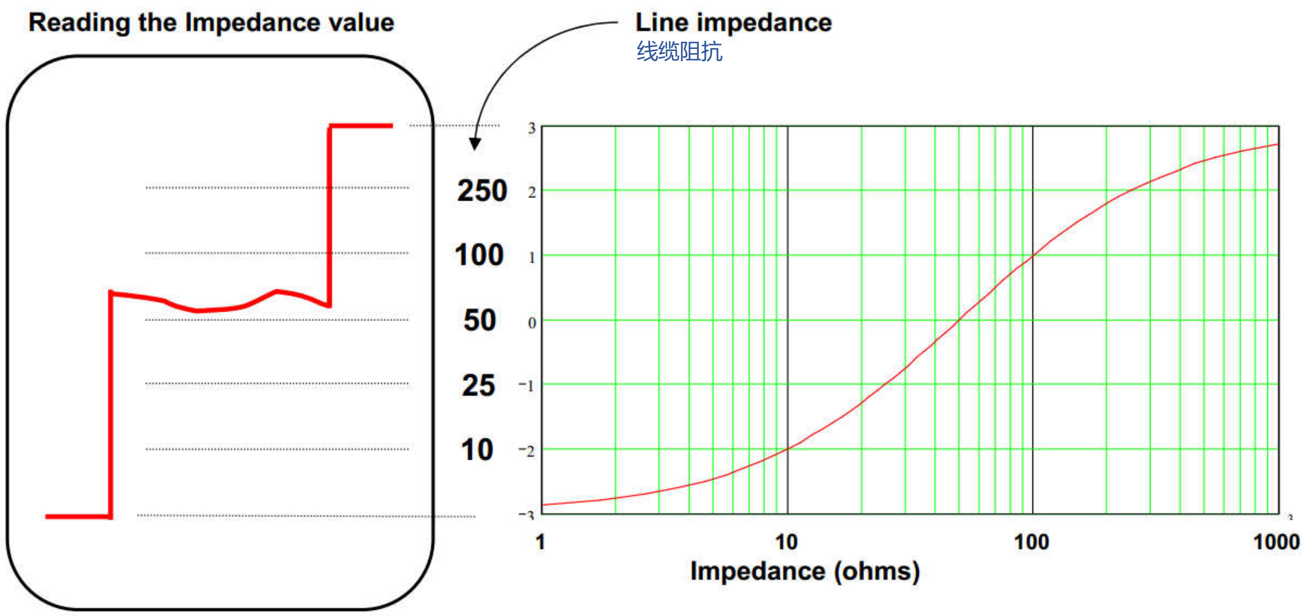


Time Domain Reflectometer - Impedance measurements



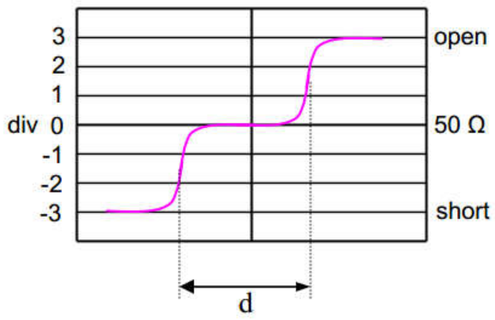
- Modern TDR's directly read the impedance and the reflection coefficient with a cursor.
- The Vf factor may be found from the pulse length and the line length.
- Given the Vf factor, the distance is read from the time axis.
- This is the quickest method for measuring Zo.

- 现代 TDR 可以直接用读取光标处的阻抗、反射系数。
- 速度系数 Vf 可以由 TDR 波形上的时延与被测电缆的物理长度经计算得到。
- 对于给定的 Vf，距离可以从时间轴上读出。
- 这是最简便的线缆阻抗测量方法。



$$Z = Z_0 \cdot \frac{(3 + \text{div})}{(3 - \text{div})}$$

此处的“div”即示波器 Y 轴上的 1 格



$$\text{Vf} = 2.033 \cdot \frac{d}{t}$$

Vf = velocity factor
d = distance in feet
t = tdr waveform delay in nS

见上文

# divisions above 50Ω	Ohms
0	50
0.1	53.4
0.2	57.1
0.3	61.1
0.4	65.4
0.5	70
0.6	75
0.7	80.4
0.8	86.4
0.9	92.9
1	100
1.1	107.9
1.2	116.7
1.3	126.5
1.4	137.5
1.5	150

50Ω 中间电平以上部分的读数对应关系

# divisions below 50Ω	Ohms
-1.5	16.7
-1.4	18.2
-1.3	19.8
-1.2	21.4
-1.1	23.2
-1	25
-0.9	26.9
-0.8	28.9
-0.7	31.1
-0.6	33.3
-0.5	35.7
-0.4	38.2
-0.3	40.9
-0.2	43.8
-0.1	46.8
0	50

50Ω 中间电平以下部分的读数对应关系

↓↓↓↓↓↓↓↓↓ 附录 ↓↓↓↓↓↓↓↓↓

附录 A

全文链接 http://ve2azx.net/technical/Degrees-Length.pdf

角度与长度的计算　作者 VE2AZX

Degrees and Length Calculations

c is the speed of light in megafeet / sec = 983.57 　$c := 983.57$

Vf is the velocity factor

f is the frequency in MHz

deg is the line length in degrees

λ is the wavelength in feet

L is the length in feet

C 为光速，单位为 **兆英尺每秒**

Vf 为速度系数

f 为频率 单位为 **兆赫兹**

deg 为线缆长度对应的角度，单位为°

λ 为波长，单位为**英尺**

L 为长度，单位为**英尺**

The wavelength times the frequency = speed of propagation of signal

$$\lambda \cdot f = c \cdot Vf$$

Solving for λ:

$$\lambda = \frac{c \cdot Vf}{f} \qquad \text{(Eq. 1)}$$

The number of degrees in length L is:

$$deg = \frac{L}{\lambda} \cdot 360$$

Solving for L:

$$L = \frac{deg \cdot \lambda}{360} \qquad \text{(Eq. 2)}$$

Substitute Eq. 1 into Eq. 2, we get:

$$L = \frac{deg \cdot c}{360} \cdot \frac{Vf}{f}$$

L is in feet 英尺

Setting L in inches = Li

$$Li = \frac{deg \cdot c \cdot 12}{360} \cdot \frac{Vf}{f}$$

Li is in inches **英寸**

The above may be simplified:

$$\frac{c \cdot 12}{360} = 32.786$$

$$\boxed{Li = 32.786 \cdot deg \cdot \frac{Vf}{f}}$$

Where Li is the length in inches **英寸**

Example

$Vf := 0.67$ 　 $f := 146$ 　 $deg := 28.5$

$Li := deg \cdot 32.785 \cdot \frac{Vf}{f}$ 　 $Li = 4.288$ 　 in inches **英寸**

Setting deg = 360 gives the actual wavelength in inches at freq. f

附录 B

From Tektronix application note 来自泰克应用手册：

TDR Impedance Measurements: A Foundation for Signal Integrity

全文链接：www.tek.com/dl/55W_14601_2.pdf

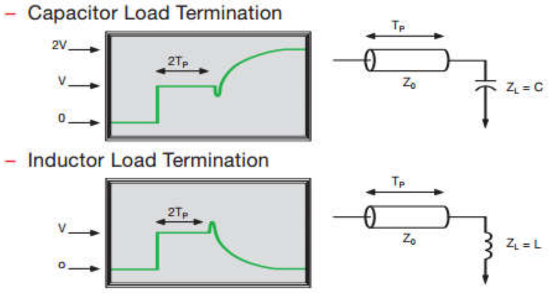


Figure 6. Capacitive and inductive load terminations

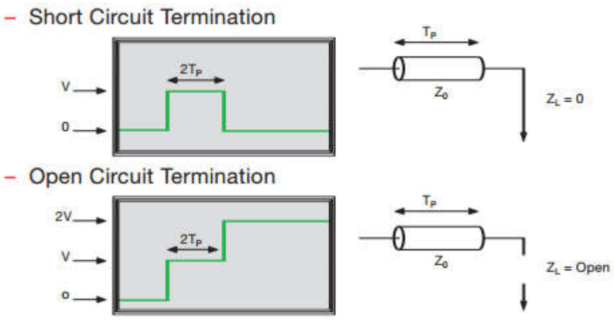


Figure 4. Short and open circuit terminations

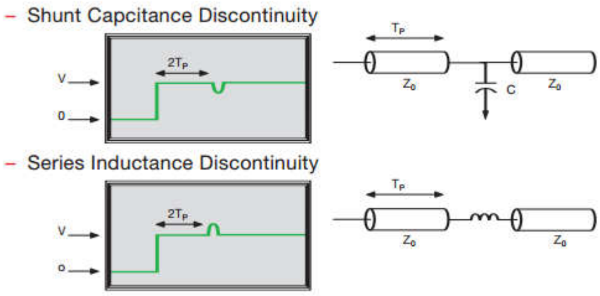


Figure 7. Capacitive and inductive discontinuities

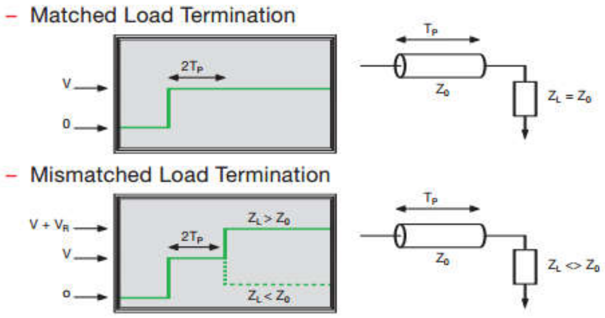


Figure 5. Matched and mismatched load terminations

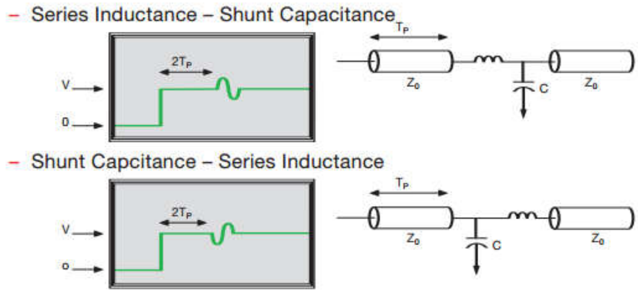


Figure 8. Mixed capacitive and inductive loading

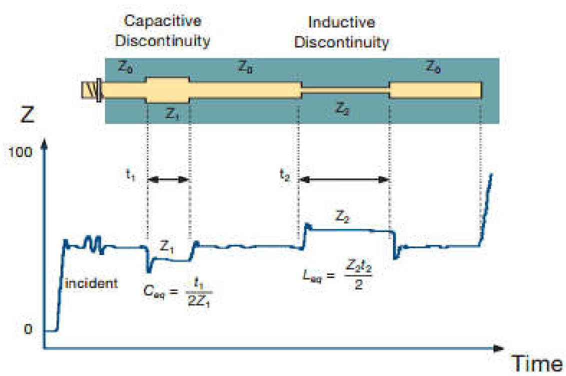


Figure 9. The TDR waveform reveals trace discontinuities