用實測教導模型歸納與分析
—以訊號之反射實驗為例

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如果小的時候只會考試，我怕

老了連試都考不好

相當多的研究是無法預知結果的，而是從現有的實驗結果，做分析與歸納，找出規律，進而建立物理模型，再而能預測類似實驗的結果或做出新穎的設計。

個人發現，學生普遍欠缺此類經驗。學生的物理模型，多由書本或教師告知而來；學生研究工作中的預測或設計，常由老師代勞。畢竟，此類工作極依賴經驗(沒有人生下來就有經驗)，大部分的學生無法立即進行上述完整的研究流程。

為此，本人設計了一套題目，要求學生在一週內，由自己的實驗結果建立模型，並互相驗證，優者可試著做出新設計。有趣的是，在此練習中，愈年輕的學生反應愈好。

My Goal is

To Simulate a Research Process

with Real Experiments.

There is no substitution for experiments.

A Research Process:

To measure something new

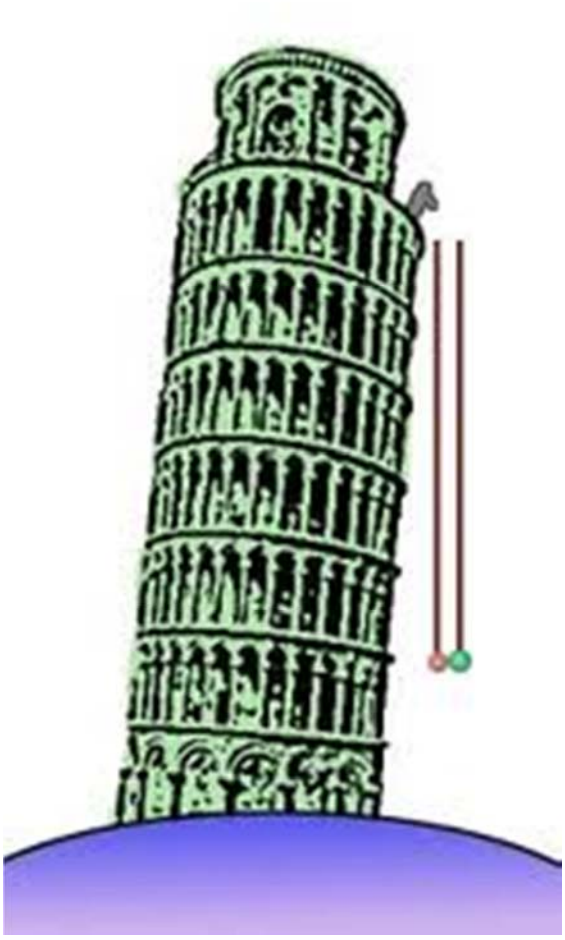
To describe and explain the measurements

(科學家 or 記者)

To build a model

To test the model by more experiments

To predict new things with the model



Why Simulation?

Faster	< 1 week
Lower cost	< 10,000 NTD
More exact	< 10% error

Why 訊號之反射實驗？

When I was young, ...

It is not easy to find the answer on Web.

Difficult enough ...
yet easy enough ...

It happens everyday.

只給實驗目標、不給步驟

要求學生自行決定測量範圍

逐日檢查實驗結果：

1) 避免錯得太遠 (小錯是好的)

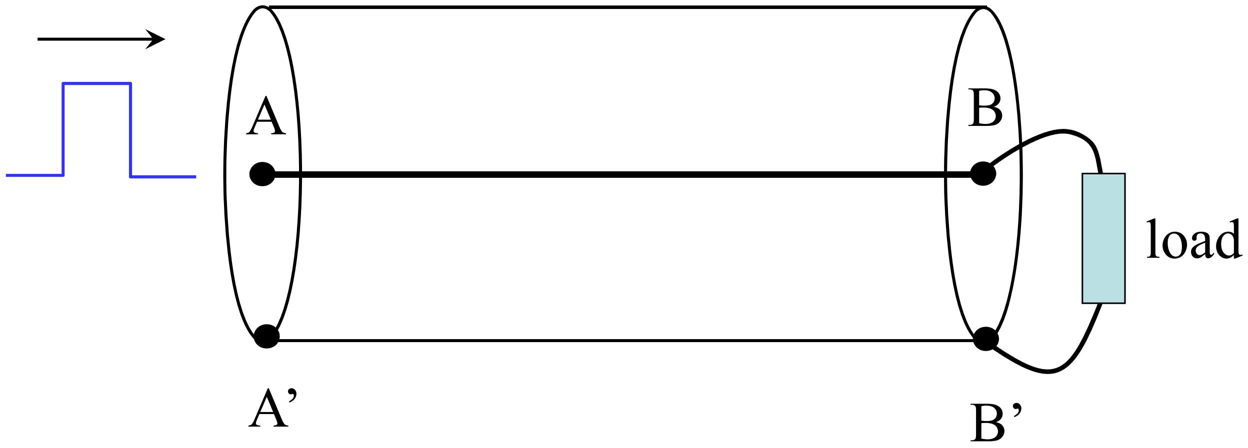
2) 確定達到該有的精確度

3) 協助養成良好的實驗習慣

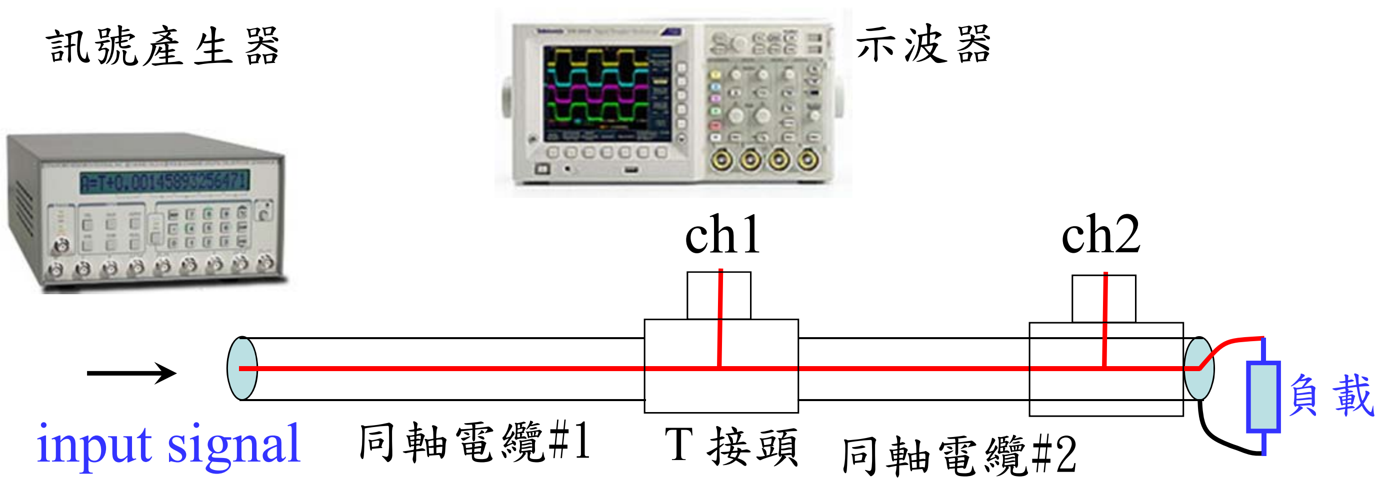
For example: (after a simple demo experiment)

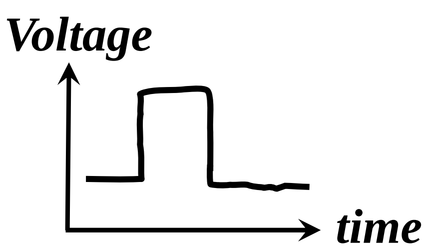
Mission 1:
(1a) Measure the speed of an electric pulse propagating in a coaxial cable.
(1b) Measure the voltage reflection coefficient of a 50Ω coaxial cable which is terminated with: (i) resistive loads; (ii) capacitive loads; (iii) inductive loads.
You should choose a suitable range of resistors, capacitors and inductors and a suitable frequency range (pulse width) to make the measurements **meaningful**.
(1c) Make a R+C load that matches a 50Ω coaxial cable for fast pulses (width <=100 ns) but has almost zero current for dc voltage (>= 1 us). Also check pulses of very large widths.
(1d) Make a short pulse generator, of which the pulse width is controlled by the cable length. A fast high voltage switch is provided. [Do (1d) after all other training missions].

(Long) Coaxial Cable ($Z_0 = 50\ \Omega$)

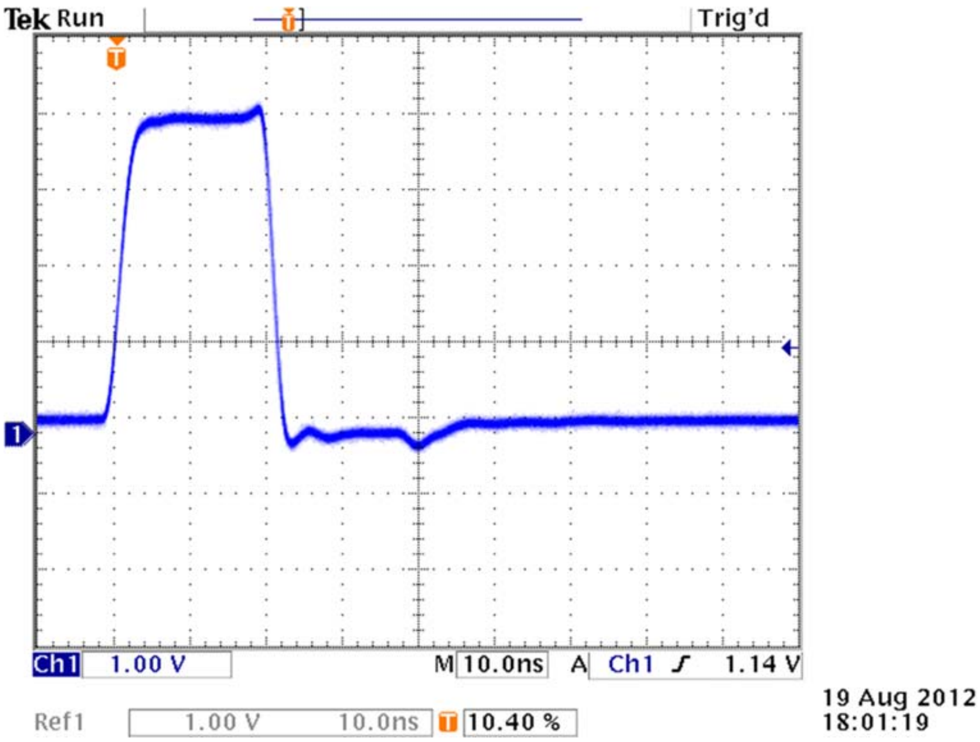


To Monitor: Waveforms at A/A’ and B/B’

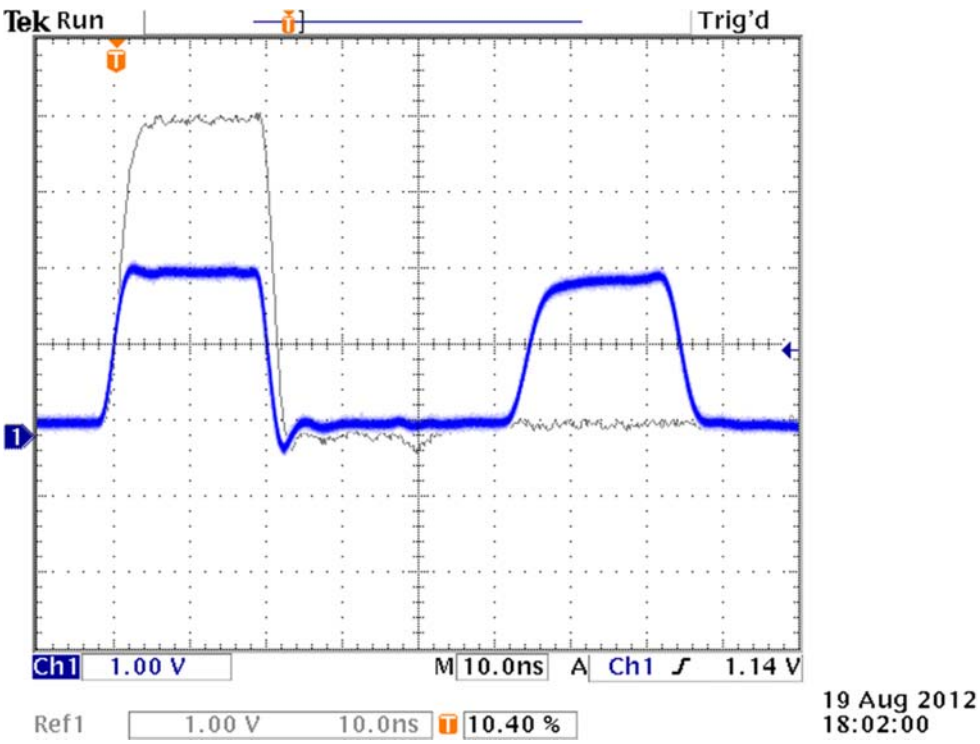




Only cable #1

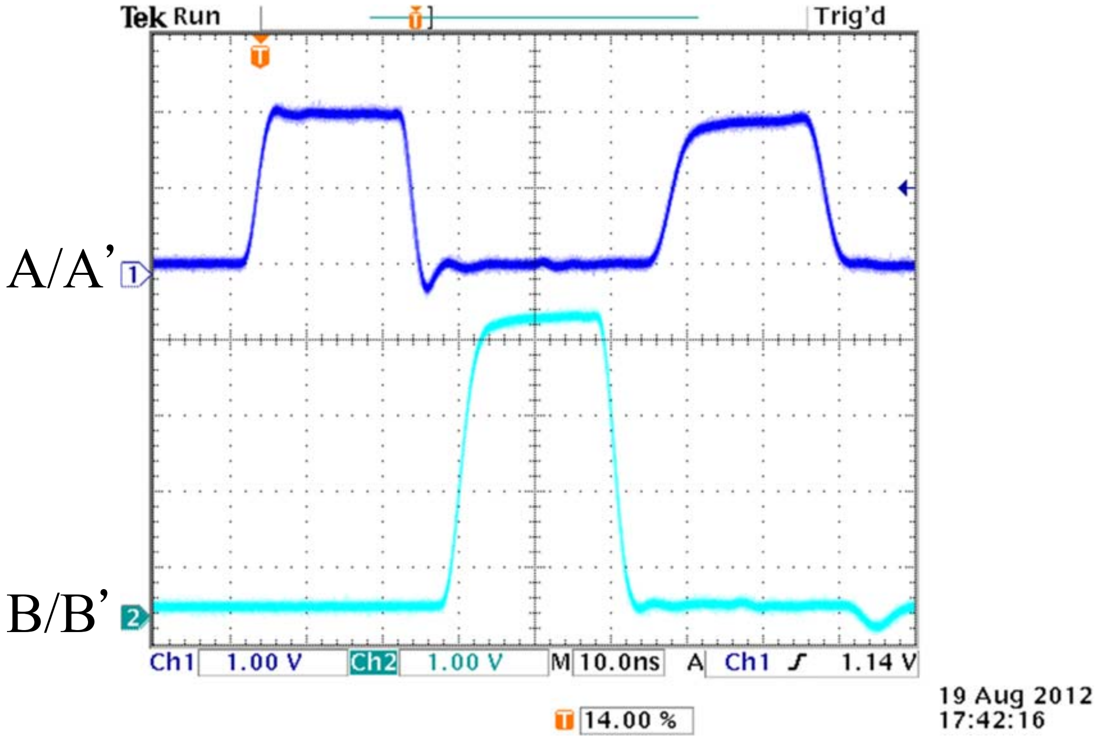


cable #1 and cable #2

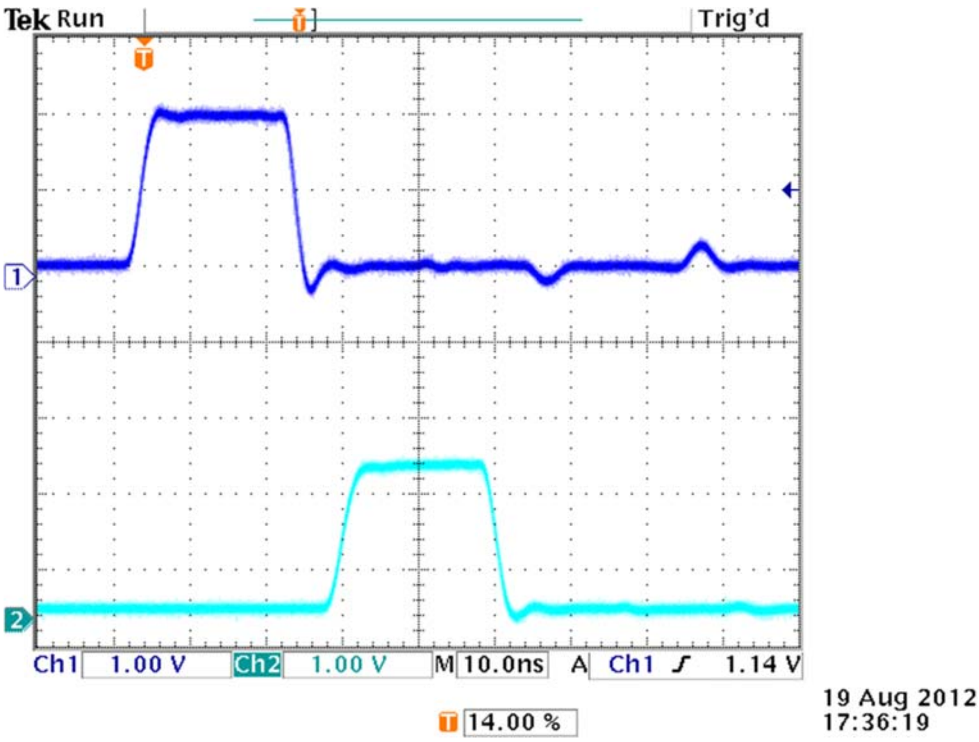


Not only surprise. We require the student to perform analysis

Load = open (∞ Ω)

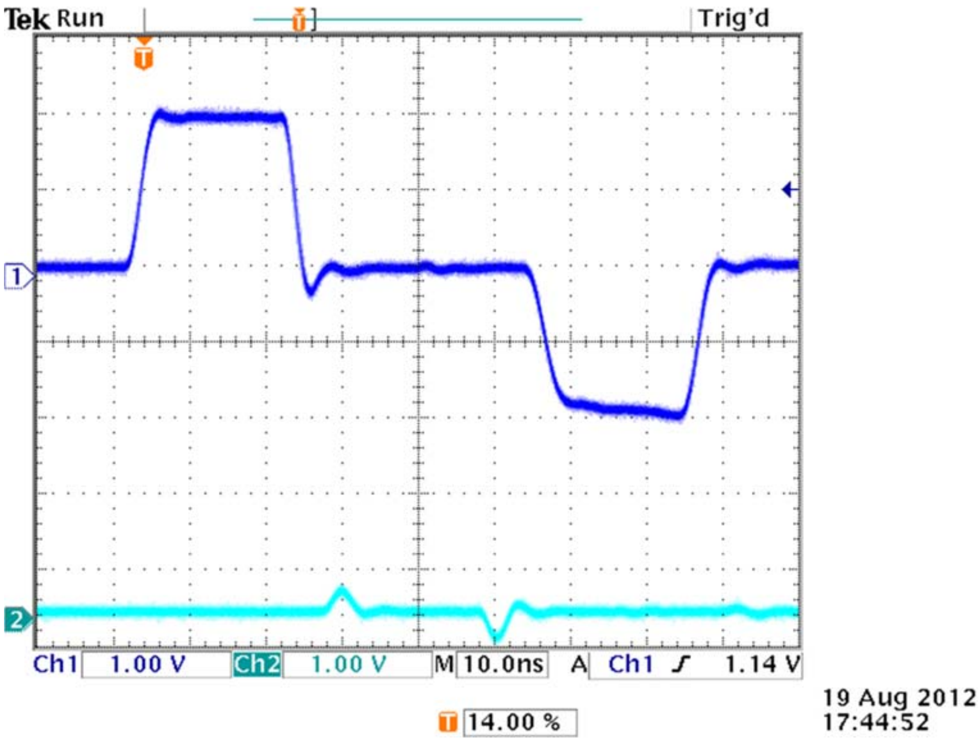


Load = 50 Ω (impedance matched)

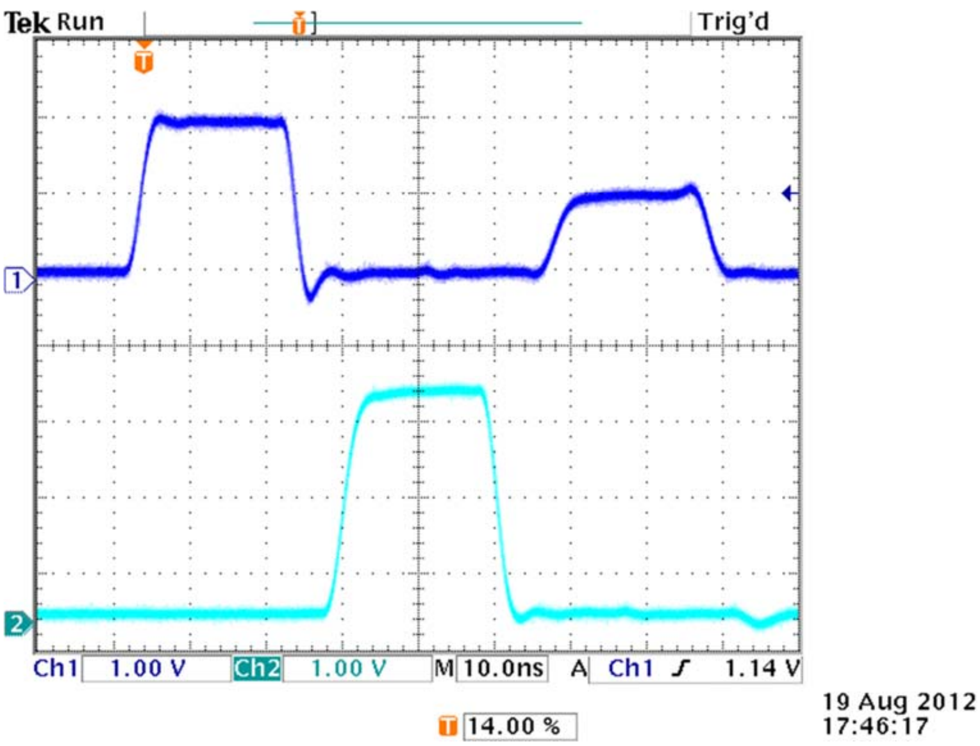


Delay is due to the length of the cable

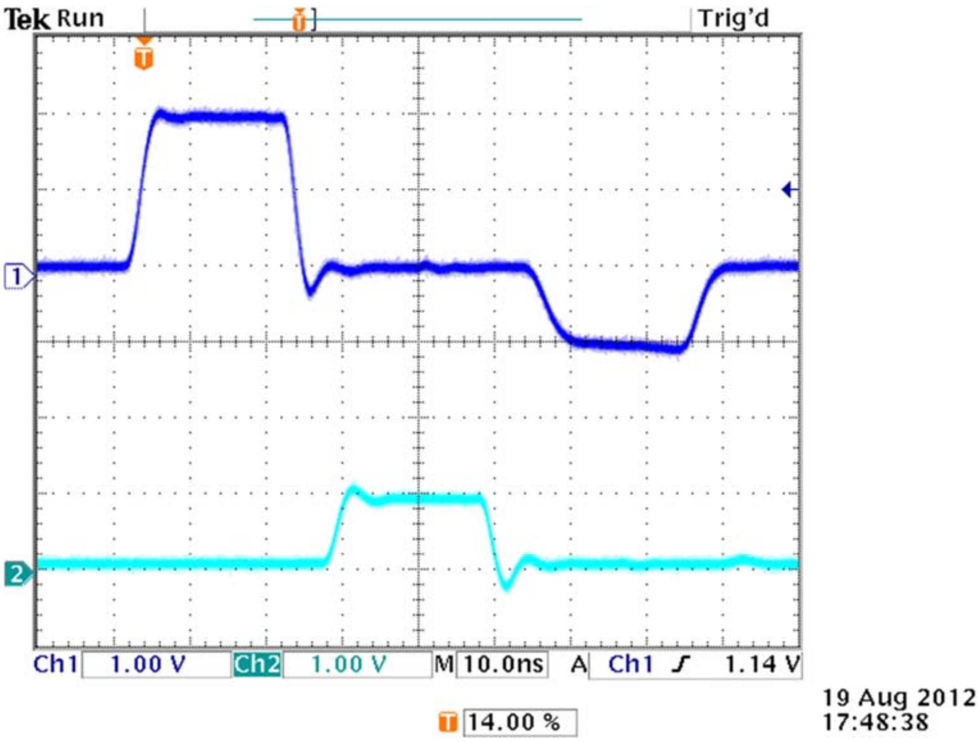
Load = short (0 Ω)



Load = 172 Ω



Load = 15 Ω



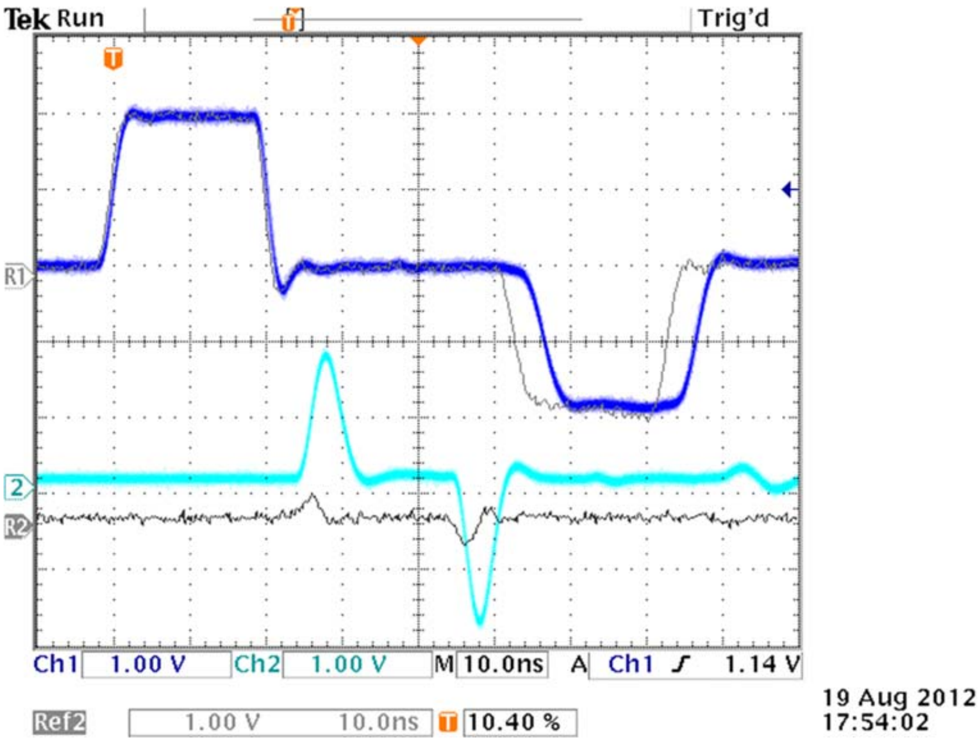
Essential Concepts:

1. Length matters at short time scales.

Length of a coaxial cable causes time delay.

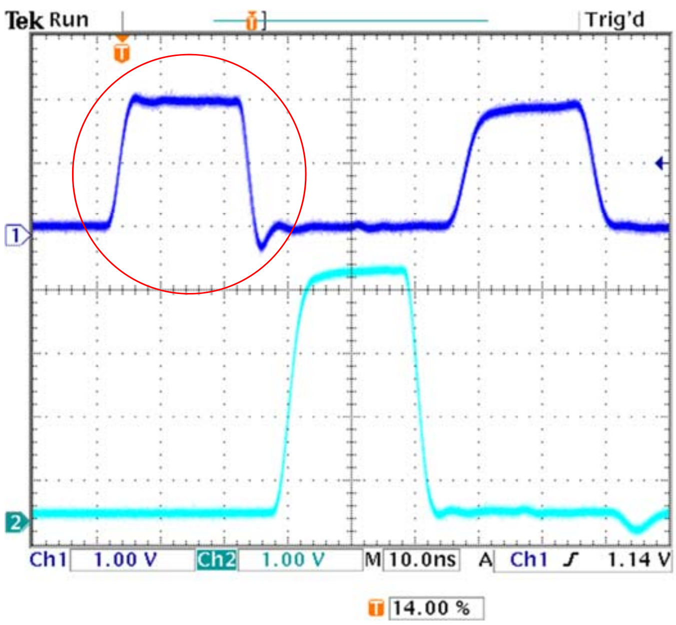
For non-coaxial cable, using very short wires to approximate the ideal case.

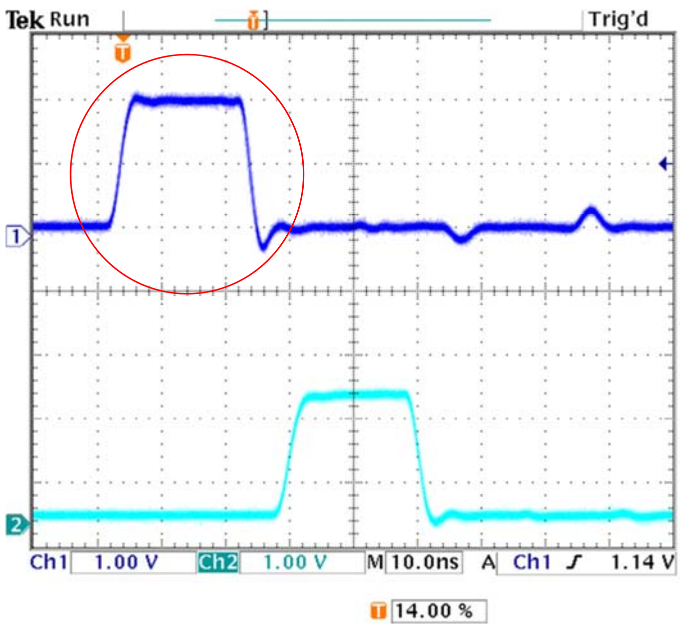
Load = copper wires **15 cm *Vs.* 1 cm**



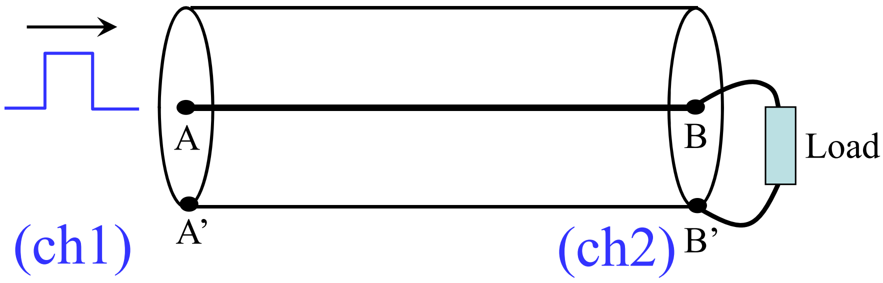
Essential Concepts:

2. What happens before the signal reaching the cable end?





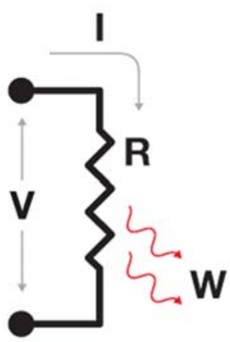
Clues:



1. Signal propagation speed can be measured. $\cong \dfrac{2\,m}{10\,ns}$
2. The reflected signal can be monitored at A/A' if the coaxial cable is long enough.
3. The load voltage can be measured at B/B'.
4. The impedance concept of a coaxial cable can be verified by using a matched termination.

Essential Concepts:

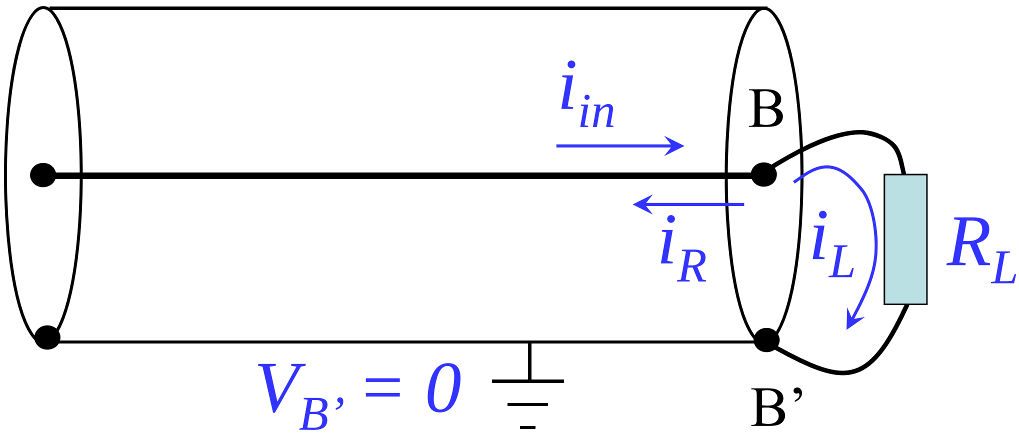
1. Length matters at short time scales.
2. What happens before the signal reaching the cable end?
3. Apply the Ohm's Law **<u>carefully</u>**.



Voltage Drop $\Delta V = i\,R$

Not V

$$i_{in} = i_L + i_R$$

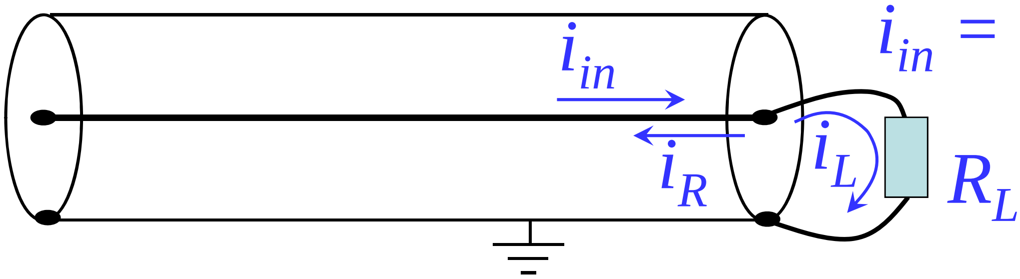


inside cable

outside cable

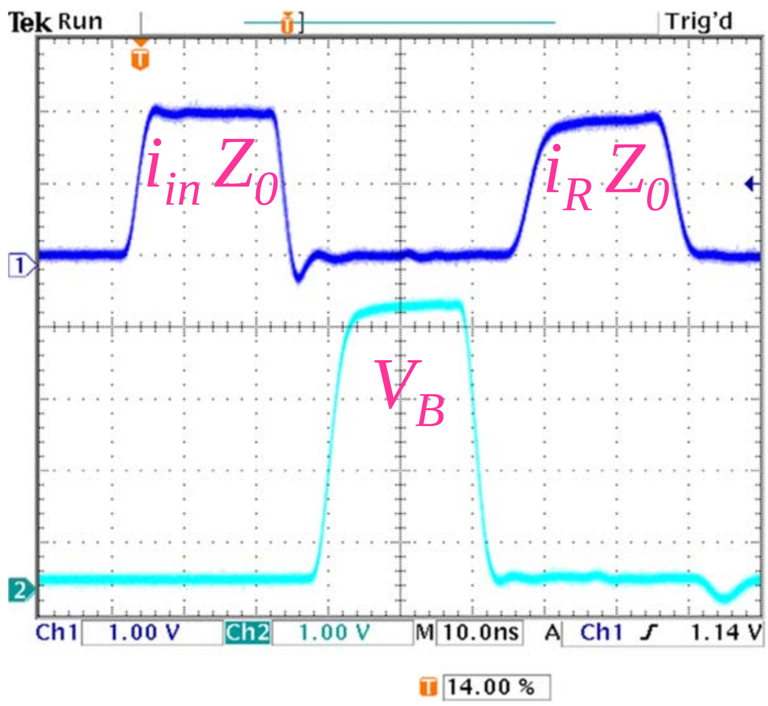
$$V_B = i_{in} Z_0 + i_R Z_0 \qquad V_B = i_L R_L$$

not $V_B = i_{in} Z_0 - i_R Z_0$, *why?*



$$i_{in} = i_L + i_R$$

$$V_B = i_{in} Z_0 + i_R Z_0$$

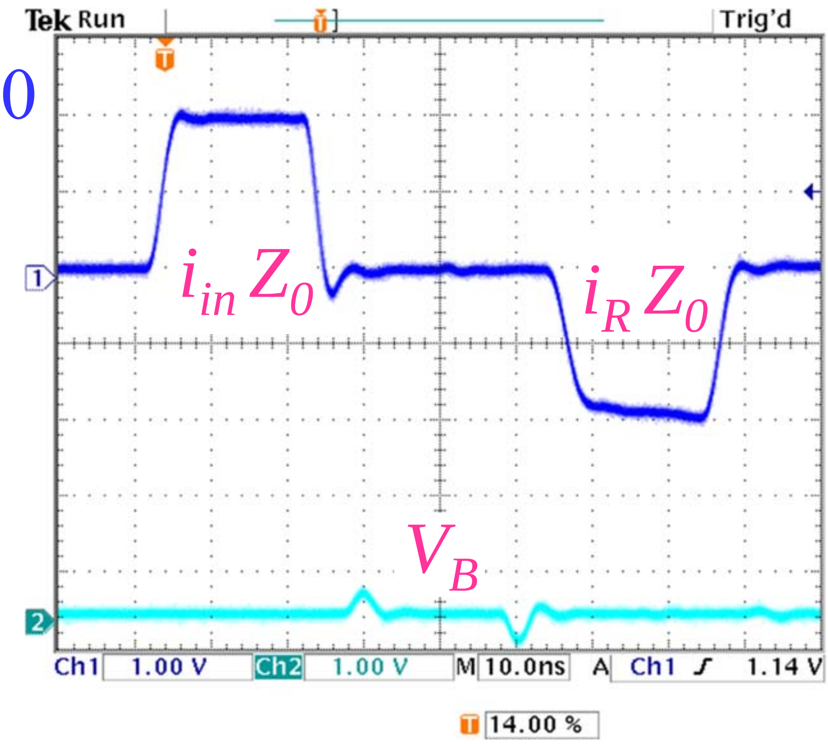


Load = short (0 Ω)

$$V_B = i_{in} Z_0 + i_R Z_0 = 0$$

$$i_R = -i_{in}$$

$$\boxed{i_L = i_{in} - i_R = 2\, i_{in}}$$



General solution:

$$\Gamma = \frac{i_{in}}{i_R} = \frac{R - Z_0}{R + Z_0}$$

Doing this Simulated Research:

To measure something new (at least for the students)

To describe and explain the measurements

(記者 → 科學家)

To build a model (think, analysis, be creative)

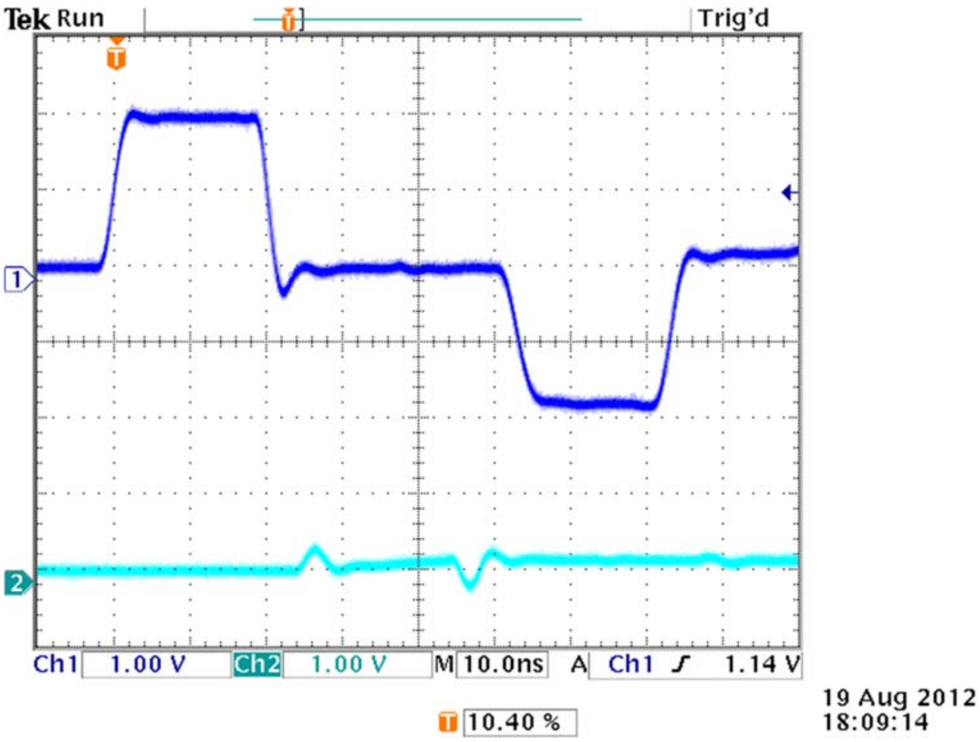
To confirm every assumption of the model by experiments

(be careful)

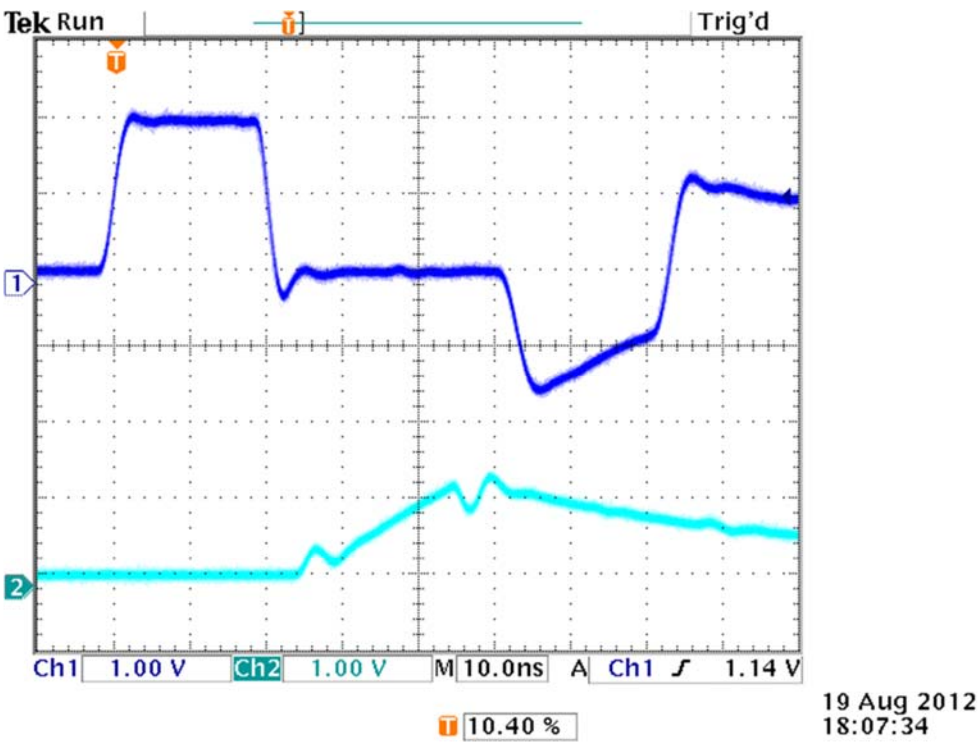
To predict new things with the model

(knowledge becomes useful)

Load = 10 nF (capacitor)

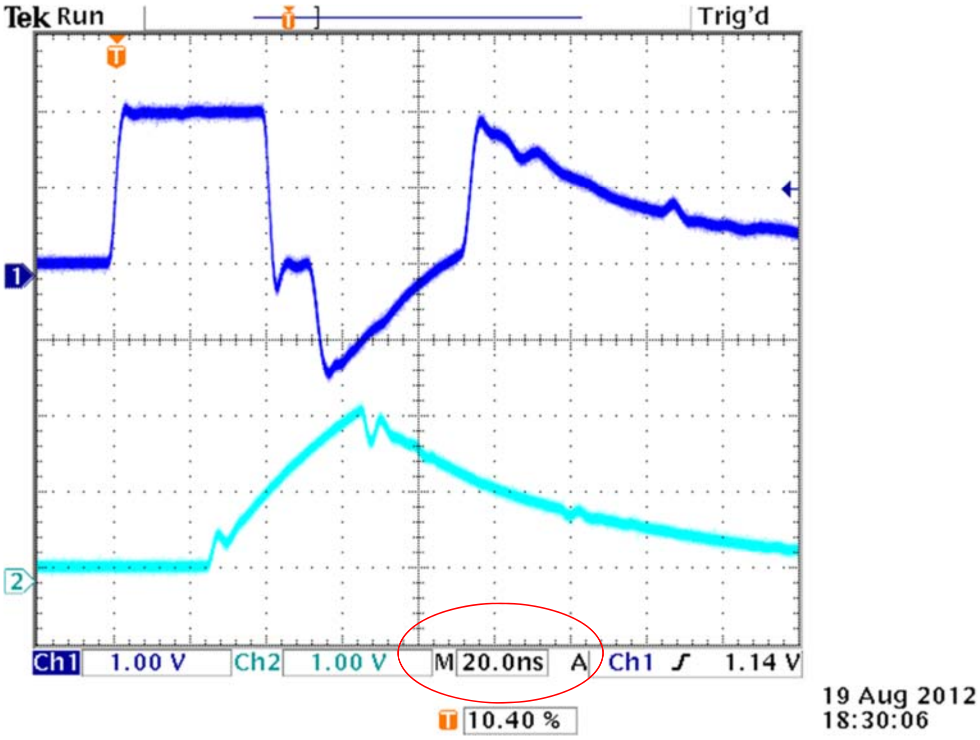


Load = 1 nF (capacitor)

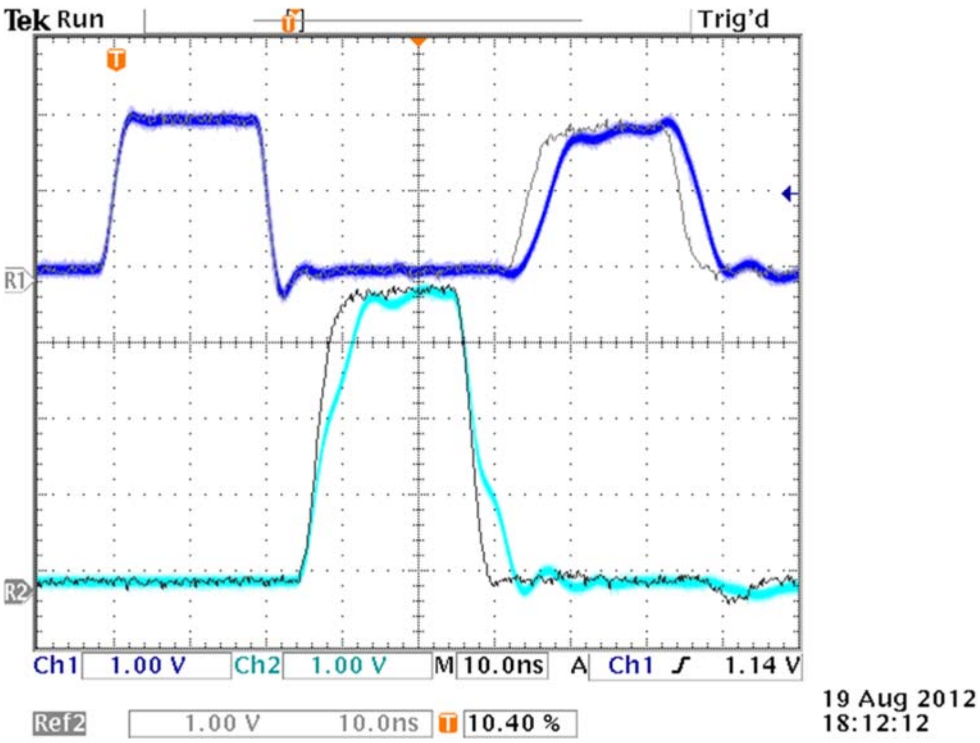


Load = 1 nF (capacitor)

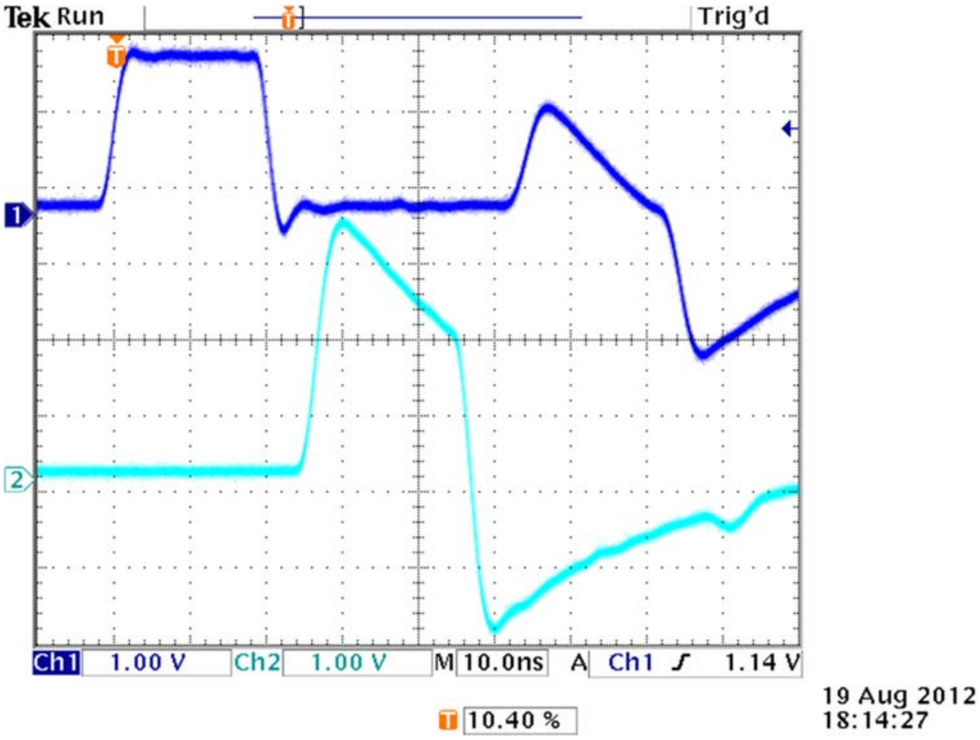
At longer pulse width and time scale



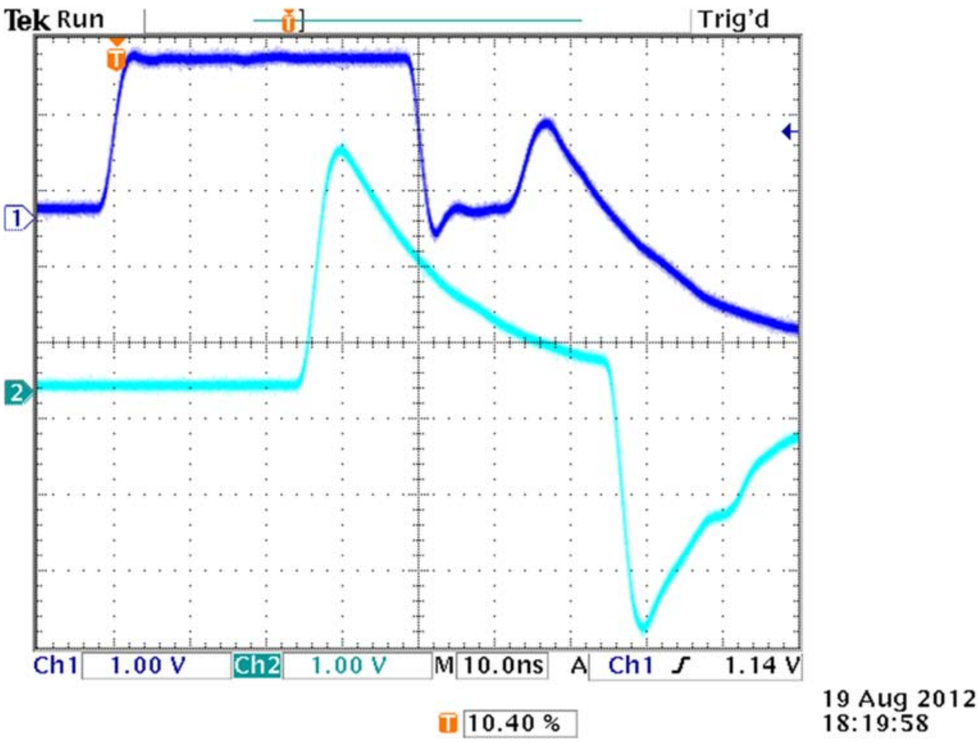
Load = an iron-core Coil (inductor)



Load = an air-core Coil (inductor)

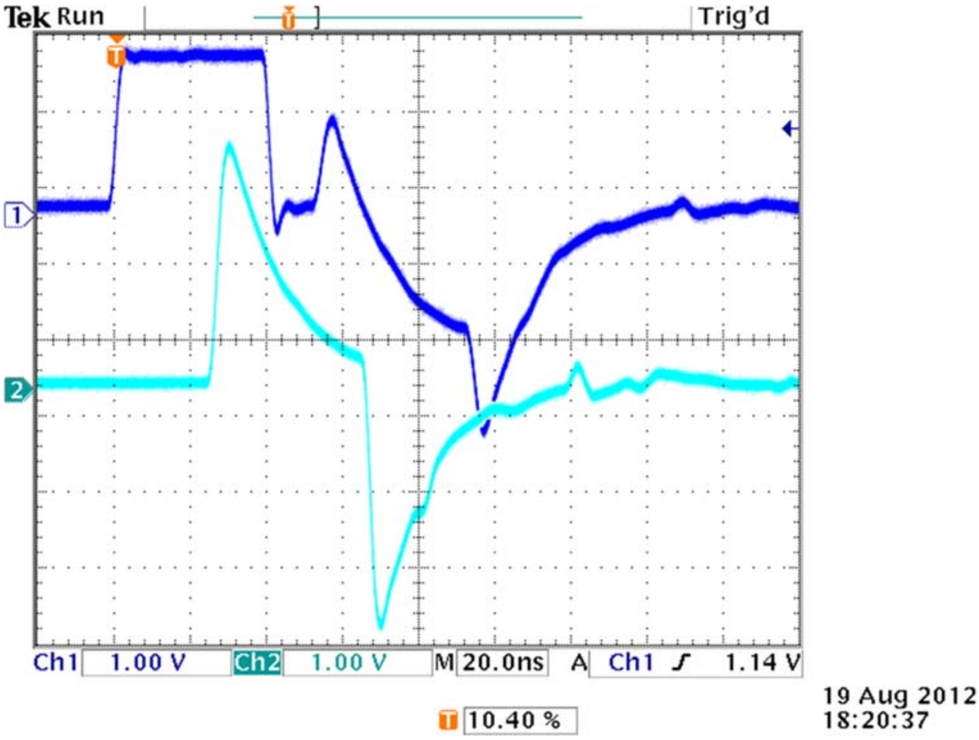


Load = a Shorter air-core Coil & Longer pulse width



Load = a Shorter air-core Coil & Longer pulse width

Shown at a longer time scale

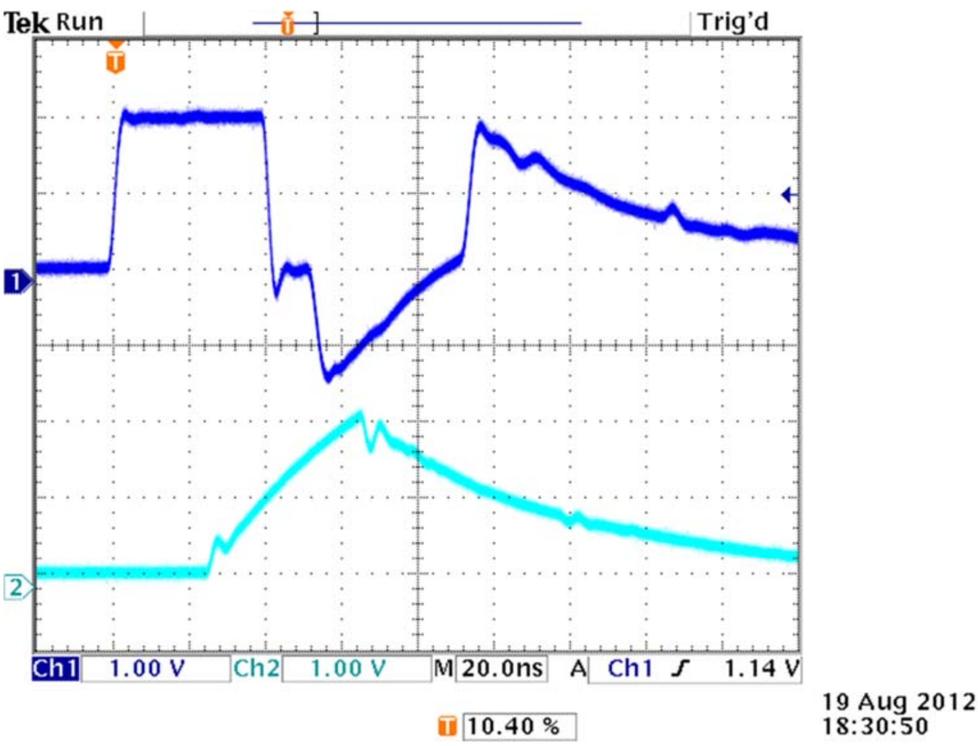


More Physical Concepts:

1. For a capacitor, its Voltage is a continuous function of time because Q is a continuous function of time.

$$Q = CV = \int i\, dt$$

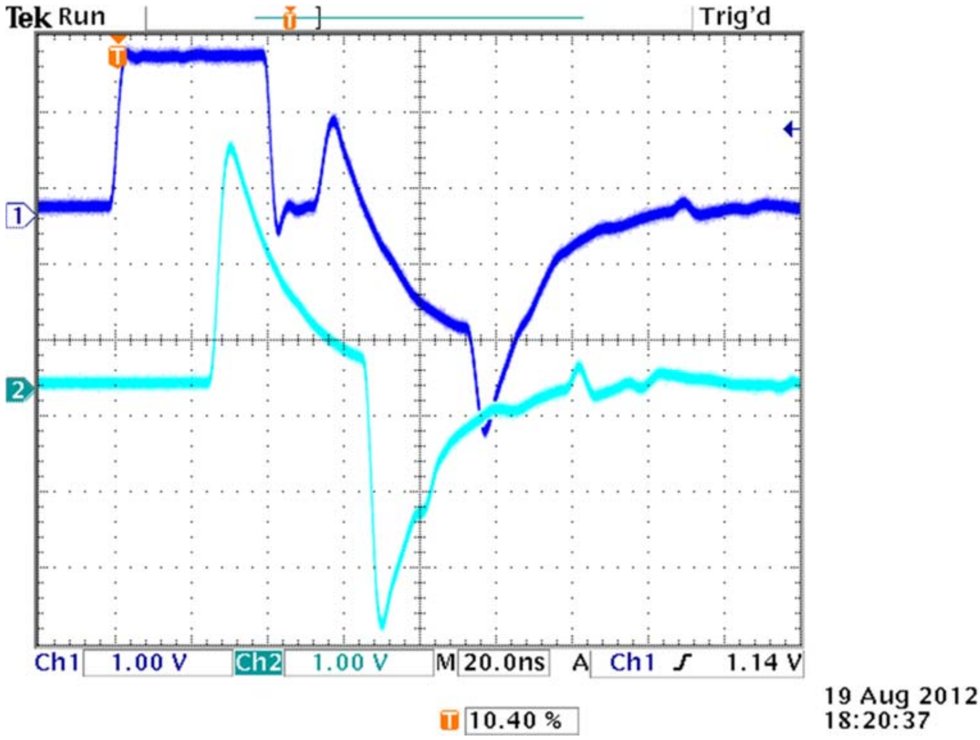
$$i = \frac{dQ}{dt}$$



More Physical Concepts:

2. For an Inductor, its Current *i* is a continuous function of time because *V* is finite.

$$V = L\frac{di}{dt}$$



More surprises in the experiments.

Interesting Observation #1:

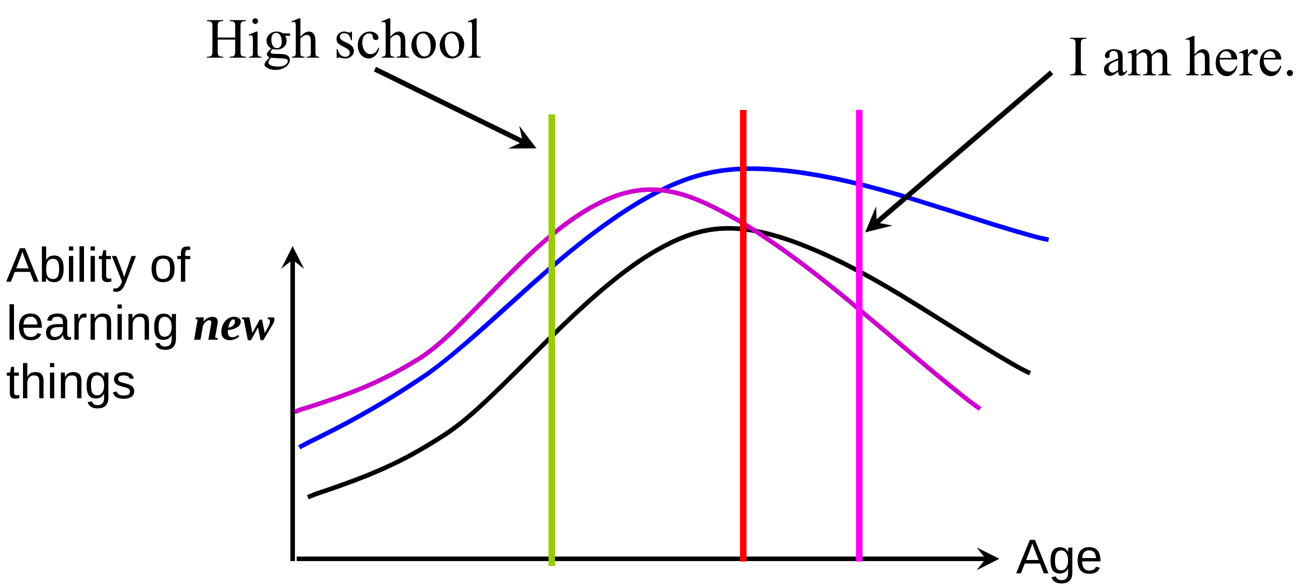
For ≦ 100 students, from high school to postdoc,

Performance does not depend on previous level of education; Knowing calculus helps a bit but is not enough.

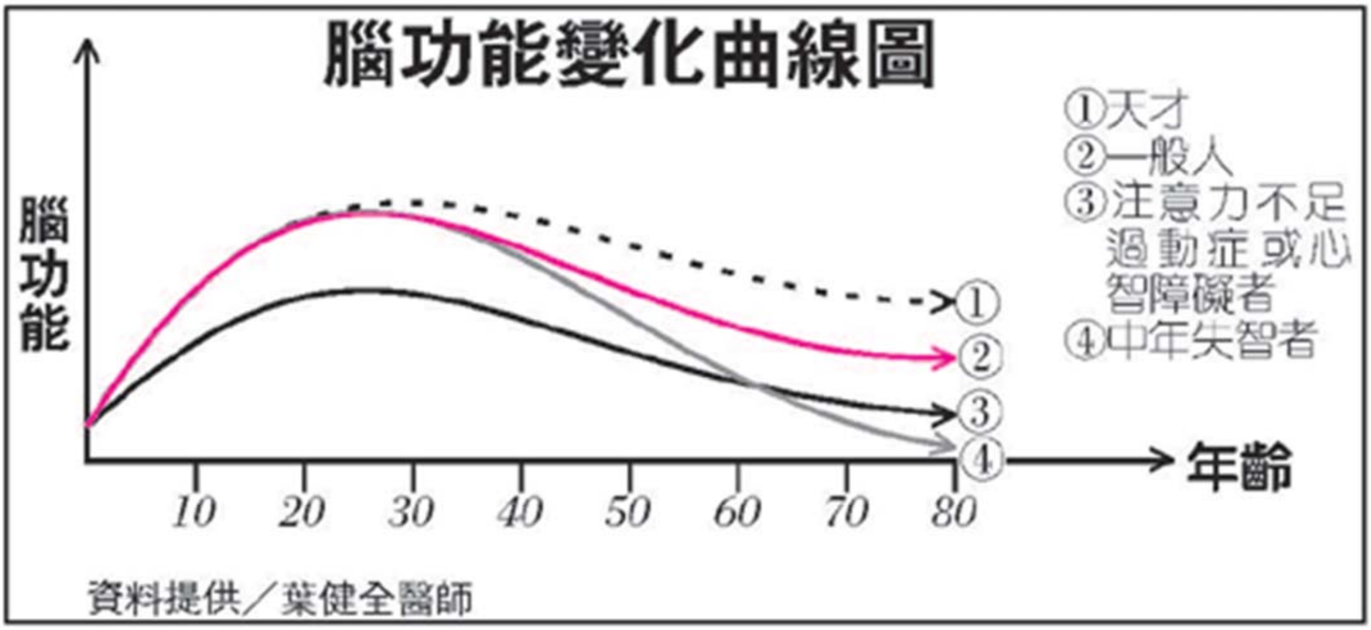
Persistence to think is important.

In average, the older, the worse.

It is true that an old dog can't learn new tricks.
It may be different for *Homo sapiens*.



by 林志民



Interesting Observation #2:

≦ 100 students,

Some are very impressed, but some are not. Some of them forget after a while.

Some students who figured out the model by themselves appreciate this course very much.

Important aspects of doing experiments:

Separate <u>meaningful physical quantities</u> from those caused by imperfection of instruments and human operations. Thus, a model is useful.

To examine the assumptions of the model by experiments.

產生高電壓短脈衝方波的經濟方法

A New Economic Method to Generate Fast High Voltage Pulse

科儀新知第二十六卷第二期 93.10　　65

鍾介文、林志民
Jieh-Wen Tsung, Jim Jr-Min Lin

利用電荷在傳輸線 (此為同軸電纜) 中等速傳輸的特性，將一定長度的同軸電纜充電至高壓後，再用快速電晶體開關瞬間將電荷導向與傳輸線匹配的負載，即可產生方波，其寬度由傳輸線的長度與訊號傳遞的速度來決定。此裝置可以輸出極高瞬間功率的脈衝，實測輸出至 50 Ω 負載之最高電壓達 1380 V，最短脈寬小於 20 ns。此法取材容易，造價低廉，產生脈衝的波形相當接近理想的方波，且穩定度極佳，具有不下於高價儀器的品質，應有很高的應用價值。

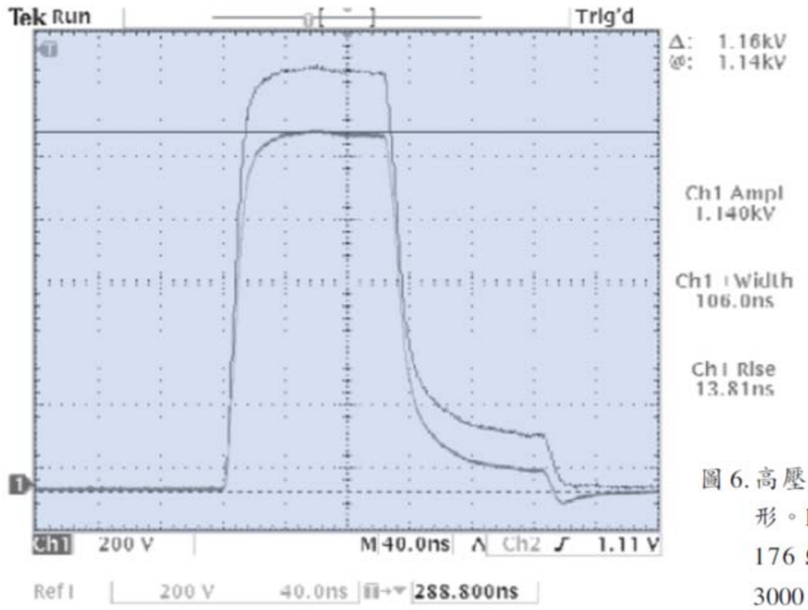
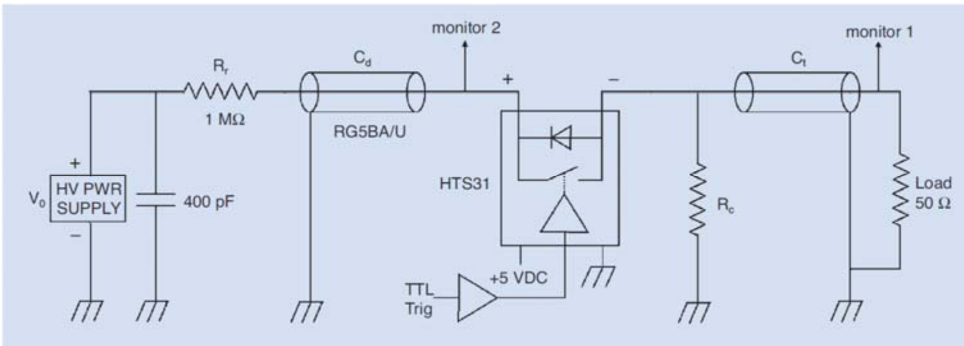


圖 6. 高壓短脈衝反射之波及其經過補償後的波形。Ref1 是未經過補償的波形，Ch1 是經過 176 Ω 阻補償後的波形。兩訊號之 V_0 皆為 3000 伏，C_d 長度為 11.579 公尺。



Important aspect of education:

Too easy is not interesting, but

too difficult is scaring.

Partial solution:

Provide necessary background knowledge (math).

Thanks to

those students who spent a lot of time and

thought

on

these experiments.