Tests proposed to investigate the origin of the rebounds in the C$_6$D$_6$ signals

V. Babiano, L. Caballero, D. Calvo, C. Domingo-Pardo, D. Esperante, I. Ladarescu, J.L. Taín (IFIC)
The n_TOF Collaboration
Outline:

• Nature & impact of the signal ringing and rebounds
• First obvious things to check
• Impedance matching on a distributed transient-signal system
• Impedance measurements
• Examples with a similar PMT+VD
• Proposed tests for the n_TOF set-up during LS2
Digitized C6D6 signals:

Rebounds time-distribution:

Rebounds amplitude-distribution:

Capture Neutron Spectra:

See Adrià Casanovas and Victor Babiano’s talks from Granada’s n_TOF Collaboration Meeting, 2018
The first obvious things to check with an oscilloscope:

a) inspect output signal “directly” from detector
b) inspect output signal after Patch-Panel (PP)
c) inspect output PMT signal at Digitizer input
Prompt rebounds: ringing from VD?

5.1.5 Countermeasures for fast response circuits

As shown in Figure 5.12, inserting a lowpass filter comprised of $R_1$ and $C_1$ into the high-voltage supply line is also effective in reducing noise pickup from the high-voltage line. The resistor $R_1$ is usually several tens of kilohms, and a ceramic capacitor of 0.001 to 0.05 microfarads which withstands high voltage is frequently used as $C_1$.

In applications handling a fast pulsed output with a rise time of less than 10 nanoseconds, inserting damping resistors $R_0$ into the last dynode as shown in Figure 5.11 and if necessary, $R_0$ into the next to last dynode can reduce ringing in the output waveform. As damping resistors, noninduction type resistors of about 10 to 200 ohms are used. If these values are too large, the time response will deteriorate. Minimum possible values should be selected in the necessary range while observing the actual output waveforms. Figure 5-13 shows typical waveforms as observed in a normal voltage-divider circuit with or without damping resistors. It is clear that use of the damping resistors effectively reduces ringing.

HAMAMATSU photomultiplier tubes Basics and Applications, Handbook
Prompt rebounds: impedance ($Z$) mismatch along the transmission lines?

Impedance mismatch?
(just an option between many other hypothesis)

delayed (500-1000 ns)
RF Simulation (LT-Spice) of our problem: a perfectly Z-matched set-up

The setup:

Detector

Coaxial cable 1 50ns

Patch Panel

Coaxial cable 2 50ns

Digitizer

50 Ω

The model (ideal):

Simulation Program with Integrated Circuit Emphasis
The setup:

The model (ideal):

The result (ideal):

RF Simulation (LT-Spice) of our problem: a perfectly Z-matched set-up
RF Simulation (LT-Spice) of our problem: a perfectly Z-matched set-up

The setup:

The model (ideal):

The result (ideal):
RF Simulation (LT-Spice) of our problem:

The setup:

Detector

Coaxial cable 1

50Ω

50ns

Patch Panel

Coaxial cable 2

50ns

Digitizer

50 Ω

The model (ideal):

The result (ideal):
RF Simulation (LT-Spice) of our problem:

The setup:

Detector

Coaxial cable 1

50 ns

Patch Panel

Coaxial cable 2

50 ns

Digitizer

50 Ω

The model (ideal):

The result (ideal):

current (mA)

0

10 mA

45 mA

voltage (V)

-1 V

0 V

5 V

10 V

0 ns

30 ns

60 ns

90 ns

120 ns

150 ns

180 ns

210 ns

240 ns

270 ns

300 ns

330 ns

V(n001) V(n002) V(n003) V(n005)
RF Simulation (LT-Spice) of our problem:

The setup:
- Detector 50 Ω
- Coaxial cable 1 50ns
- Patch Panel
- Coaxial cable 2 50ns
- Digitizer 150 Ω

The model (ideal):
- Circuit diagram showing R2 50 Ω, T1 and T2, R3 150 Ω, with a V1 source and .tran 0 350n 0 simulation command.

The result (ideal):
- Current (mA) and voltage (V) graphs over time from 0ns to 330ns.
The setup:

![Diagram showing the setup with Detector, Coaxial cable 1, and Digitizer connected by 50 Ω and 150 Ω resistors.]

The model (ideal):

![LT-Spice simulation diagram with resistors R1, R2, R3, and cables T1, T2. The simulation uses a SINE wave function for input.]

The result (ideal):

![Graph showing current (mA) and voltage (V) over time. The graph highlights the current and voltage waveforms for V(n002), V(n001), V(n003), and V(n005).]
RF Simulation (LT-Spice) of our problem:

The setup:

The model (ideal):

The result (ideal):
The setup:

Detector

Coaxial cable 1
50ns

Coaxial cable 2
50ns

Patch Panel

Digitizer

150 Ω

50 Ω

The model (ideal):

RF Simulation (LT-Spice) of our problem:

The result (ideal):
The setup:

Detector: 150 Ω 50ns
Coaxial cable 1
Patch Panel 50ns
Coaxial cable 2
Digitizer 50 Ω

The model (ideal):

The result (ideal):

RF Simulation (LT-Spice) of our problem:
RF Simulation (LT-Spice) of our problem:

**The setup:**
- Detector: 150 Ω
- Coaxial cable 1: 50ns
- Patch Panel
- Coaxial cable 2: 50ns
- Digitizer: 50 Ω

**The model (ideal):**

**The result (ideal):**

- Voltage (V)
  - V(n002)
  - V(n001)
  - V(n003)
  - V(n005)

- Current (mA)
  - 50mA
  - 23mA
  - 5mA
RF Simulation (LT-Spice) of our problem:

The setup:

The model (ideal):

The result (ideal):

Detector

Digitizer

Coaxial cable 1

75 Ω

50 Ω

Coaxial cable 2

50ns

50ns

Current (mA)

Voltage (V)

100 Ω

SINE(0 10 100meg 0 0 0.5)

 transient 0 350ns 0
RF Simulation (LT-Spice) of our problem:

The setup:

The model (ideal):

The result (ideal):

Detector

Digitizer

Coaxial cable 1 50ns

Coaxial cable 2 50ns

100 Ω

75 Ω

50 Ω

100 Ω

SINE(0 10 100meg 0 0 0.5)

R2

T1

R3

T2

R1

current (mA)

voltage (V)

 tran 0 350n 0

V(n001) V(n002) V(n003) V(n004) V(n005)

0ns 30ns 60ns 90ns 120ns 150ns 180ns 210ns 240ns 270ns 300ns 330ns
If it is a poor Z-matching... measure impedances at detector, cables and digitizers...

A detector response (impulse) is actually a contribution of many frequencies (in the frequency domain):

So we need to inspect IMPEDANCE as a function of FREQUENCY, across the full bandwidth of the sampling digitizer.

DC-World:

\[ Z_{DC} = 100k \Omega \]

RF-World:
Impedance Z measurement across full bandwidth (0-500MHz) using a Vector-Network-Analyzer (VNA)

A VNA produces a RF signal (a1) and measures the reflected wave (b1). A frequency sweep is made to cover the full range:

\[ \Gamma = S_{11}(f) = \frac{b_1}{a_1} = \frac{Z_L(f) - Z_S(f)}{Z_L(f) + Z_S(f)} \]

Scattering coefficients measured with a VNA (reflection coefficient S11):
Impedance Z measurement using an arbitrary PMT+VD (just one example):
Impedance Z measurement using an arbitrary PMT+VD (just one example):
What says Hamamatsu-san about this?

### 5.3.4 Output circuit for a fast response photomultiplier tube

For the detection of light pulses with fast rise and fall times, a coaxial cable with 50-ohm impedance is used to make connection between the photomultiplier tube and the subsequent circuits.

To transmit and receive the signal output waveform with good fidelity, the output end must be terminated in a pure resistance equal to the characteristic impedance of the coaxial cable as shown in Figure 5-35. This allows the impedance seen from the photomultiplier tube to remain constant, independent of the cable length, making it possible to reduce "ringing" which may be observed in the output waveform. However, when using an MCP-PMT for the detection of ultra-fast phenomena, if the cable length is made unnecessarily long, distortion may occur in signal waveforms due to a signal loss in the coaxial cable.

If a proper impedance match is not provided at the output end, the impedance seen from the photomultiplier tube varies with frequency, and further the impedance value is also affected by the coaxial cable length, and as a result, ringing appears in the output. Such a mismatch may be caused not only by the terminated resistance and the coaxial cable but also by the connectors or the termination method of the coaxial cable. Thus, sufficient care must be taken to select a proper connector and also to avoid creating impedance discontinuity when connecting the coaxial cable to the photomultiplier tube or the connector.

Transmission line impedance equation:

\[
Z_{in} = Z_0 \left( \frac{Z_L + j Z_0 \tan \beta \ell}{Z_0 + j Z_L \tan \beta \ell} \right)
\]

\[
\lambda = \frac{2\pi}{\beta}
\]

**Special cases of lossless terminated lines:**

- **Short circuit** \((Z_L = 0 \rightarrow \Gamma = -1)\):
  \[
  V(z) = V_o^+ e^{-j\beta z} + V_o^- e^{j\beta z} \quad \quad V(z) = V_o^+ (e^{-j\beta z} + \Gamma e^{j\beta z}).
  \]
  \[
  I(z) = \frac{V_o^+}{Z_0} e^{-j\beta z} - \frac{V_o^-}{Z_0} e^{j\beta z} \quad \quad I(z) = \frac{V_o^+}{Z_0} (e^{-j\beta z} - \Gamma e^{j\beta z}).
  \]

- **Open circuit** \((Z_L = \infty \rightarrow \Gamma = 1)\):
  \[
  V(z) = V_o^+ (e^{-j\beta z} - e^{j\beta z}) = -2j V_o^+ \sin \beta z.
  \]
  \[
  I(z) = \frac{V_o^+}{Z_0} (e^{-j\beta z} + e^{j\beta z}) = \frac{2V_o^+}{Z_0} \cos \beta z
  \]

**HAMAMATSU photomultiplier tubes Basics and Applications, Handbook Microwave Engineering, David M. Pozar, 4th Ed. Wiley (Chapter 2.3)**
## Proposed tests with C6D6: Summary

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backup slides
RF Simulation (LT-Spice) of our problem:

The setup:

Detector

Coaxial cable 1

100 Ω

Coaxial cable 2

Digitizer

The model (ideal):

The result (ideal):
RF Simulation (LT-Spice) of our problem:

The setup:

The model (ideal):

The result (ideal):
First basic test:

Detector

Coaxial cable

Digitizer

Diagrams showing circuitry and simulations with specific components labeled and values indicated.
First basic test:

Detector

Coaxial cable

Digitizer

V1

200

R2

T1

Td=50n Z0=50

R3

100

T2

Td=50n Z0=50

R1

50

SINE(0 10 100meg 0 0 0 0.5)

.tran 0 350n 0
\[ b_1 = S_{11} a_1 + S_{12} a_2 \]

and

\[ b_2 = S_{21} a_1 + S_{22} a_2 . \]

\[ S_{11} = \frac{b_1}{a_1} = \frac{V_1^-}{V_1^+} \quad \text{and} \quad S_{21} = \frac{b_2}{a_1} = \frac{V_2^-}{V_1^+} . \]

Similarly, if port 1 is terminated in the system impedance then \( a_1 \) becomes zero, giving

\[ S_{12} = \frac{b_1}{a_2} = \frac{V_1^-}{V_2^+} \quad \text{and} \quad S_{22} = \frac{b_2}{a_2} = \frac{V_2^-}{V_2^+} . \]