

Alternative Toroidal Transformer Designs and Measurements

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N. Kitamura

University of Wisconsin-Madison / SSEC

Background Notes

The PMT pulse-coupling transformer in the current design employs the RG174 coaxial cable as a winding material (ERD 3.3.1.3).

The voltage rating of the RG174 cable has come into question (PDR-4), and a justification for the use of RG174 is being sought.

The present study investigates the pulse transmission characteristics of a more conventional transformer design, employing a pair of hook-up wires, rather than a single strand of coaxial cable.

A typical Teflon hook-up wire has a voltage rating of 600V over -60 to $+200^{\circ}\text{C}$, regardless of the wire gauge size. Apparently, no Teflon-insulated wires have a rating exceeding 2000VDC.

So called test-lead wires are rated at sufficiently high voltage for our purpose, but the operating temperature does not go down very low. Since there will be no flexing, that would not be a problem.

Braidless-silicone-rubber-insulated wires from Harbour Industries (e.g., Cat # BSR3239-2210) are rated at 10 to 50kVDC with a maximum temperature of 150°C .

Table 1 Physical and Electrical Characteristics of the M17/93-RG178 Cable

(Source: <http://www.harbourind.com/catalogs/M17.pdf>)

Center Conductor	PTFE Dielectric Diameter	Overall diameter	Minimum recommend- ed bend radius	Operating Temperature	Impedance	Capacitance	Max Operating Voltage
0.0120"	0.033"	0.71"	0.4"	-55 - +200°C	$50 \pm 2 \Omega$	29.4 pF/ft	1000 Vrms

Why Use Silicone Rubber*

Extreme temperature applications, -180°F to 600°F (-118°C to 316°C)

Inert, odorless, tasteless, stainless -- ideal for medical and food applications

High resistance to weathering and oxidation

Excellent electrical qualities -- many superior dielectric and insulation characteristics in special compounds

Superior resistance to many chemicals

High resistance to ozone and corona

Very good thermal resistance -- special flame retardant compounds are available

Superior water resistance -- low water absorption.

***Source: Silicone Rubber Right Products, Inc., webpage:
<http://www.siliconerubber.com/home.html>**

Conclusion

The pulse response very similar to that of the RG178 coaxial transformer is obtained from a transformer employing a pair of stranded hook-up wire as the winding material.

Silicone-rubber-insulated stranded wire rated at 10-50kV (UL 3239) is readily available in gauge sizes suitable for the transformer winding.

→ The pulse-coupling transformer with satisfactory pulse-response characteristics and a sufficient operating voltage margin can be constructed without difficulty based on the finding of this study.

Proposed specification:

Toroidal core	Magnetics Cat. # ZH-42206-TC
Winding material	Harbor Industries 3239, 22 AWG 7/30, 10kV, 150°C
Number of turns	TBD

Samples

Sample A: RG174 wound on a toroidal core (18 turns)

➔ Current specification

Sample B: Solid 24 gauge wires twisted into a pair and wound on a toroidal core (15 turns).

Sample C: Stranded 18 gauge wires wound side-by-side on a toroidal core (10 turns).

Two ferrite cores were used:

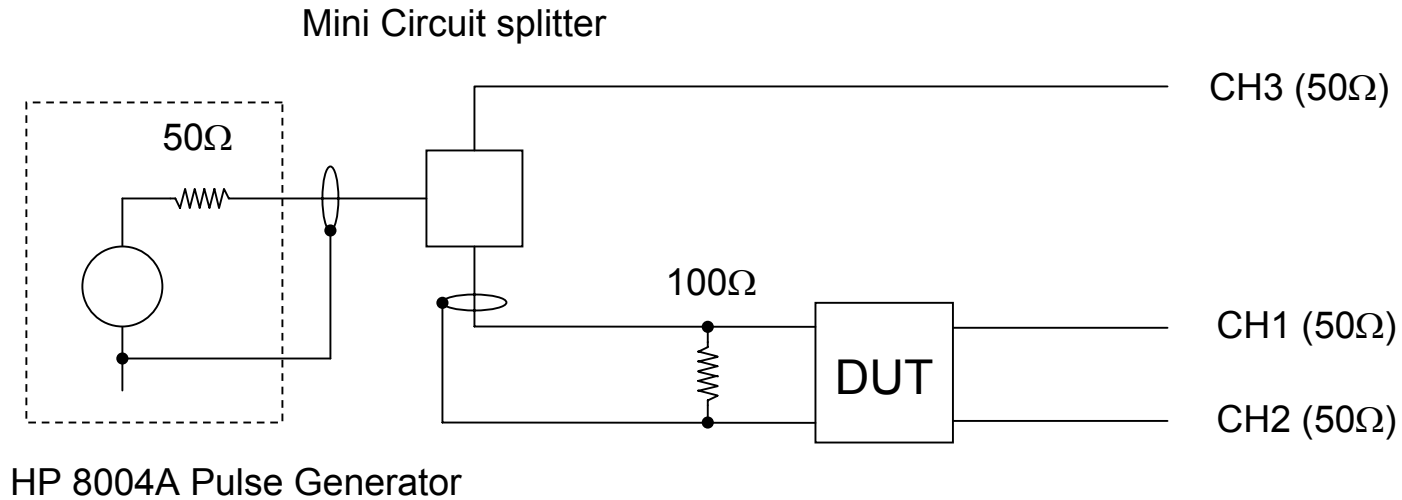
They are similar in dimensions

Core #1 was found in the Physics Lab

Core #2 is from Magnetics™ as specified in the current design.
(Cat # ZH-42206-TC)



Measurement Setup

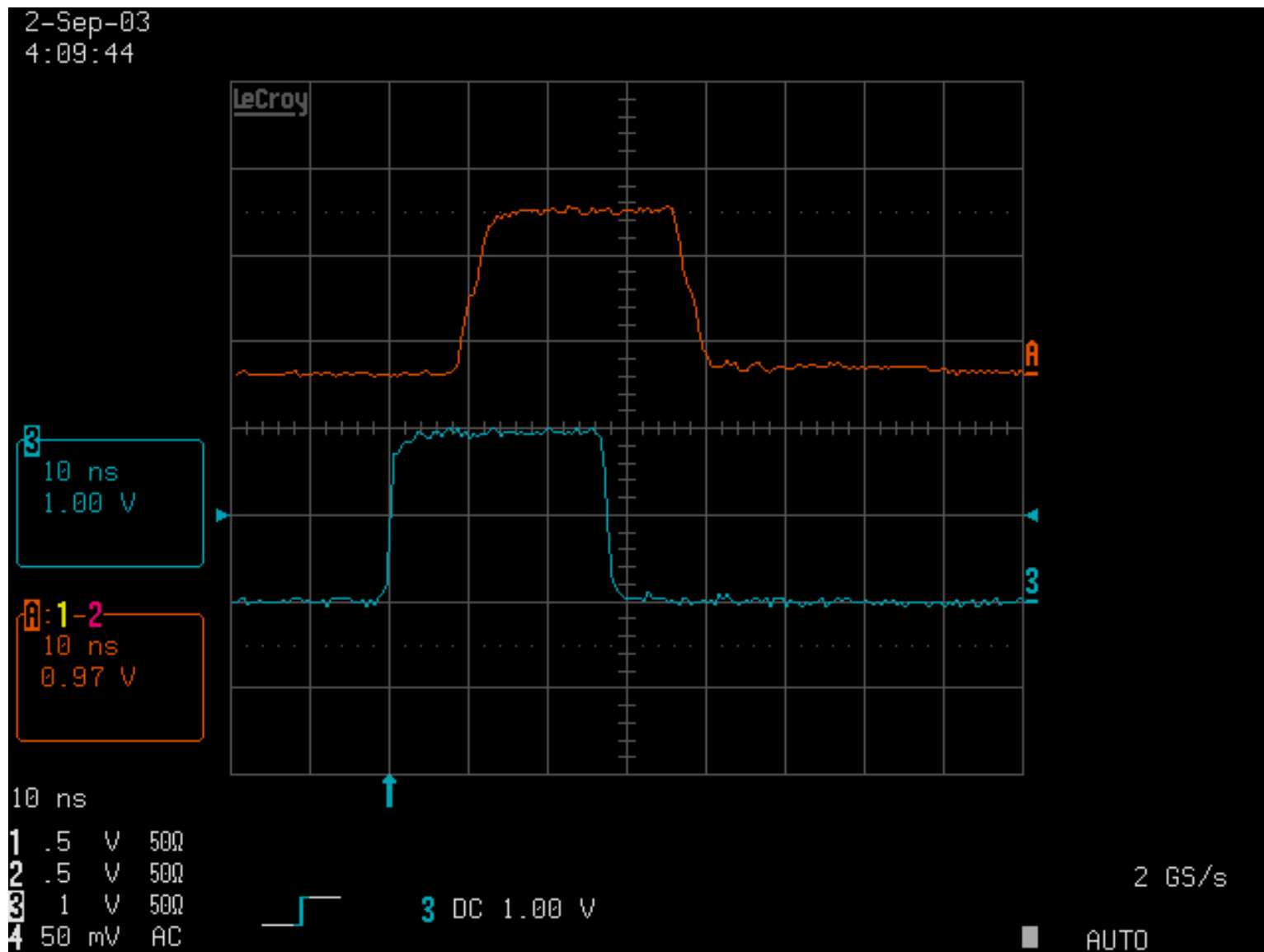


CH3 ➔ Input pulse

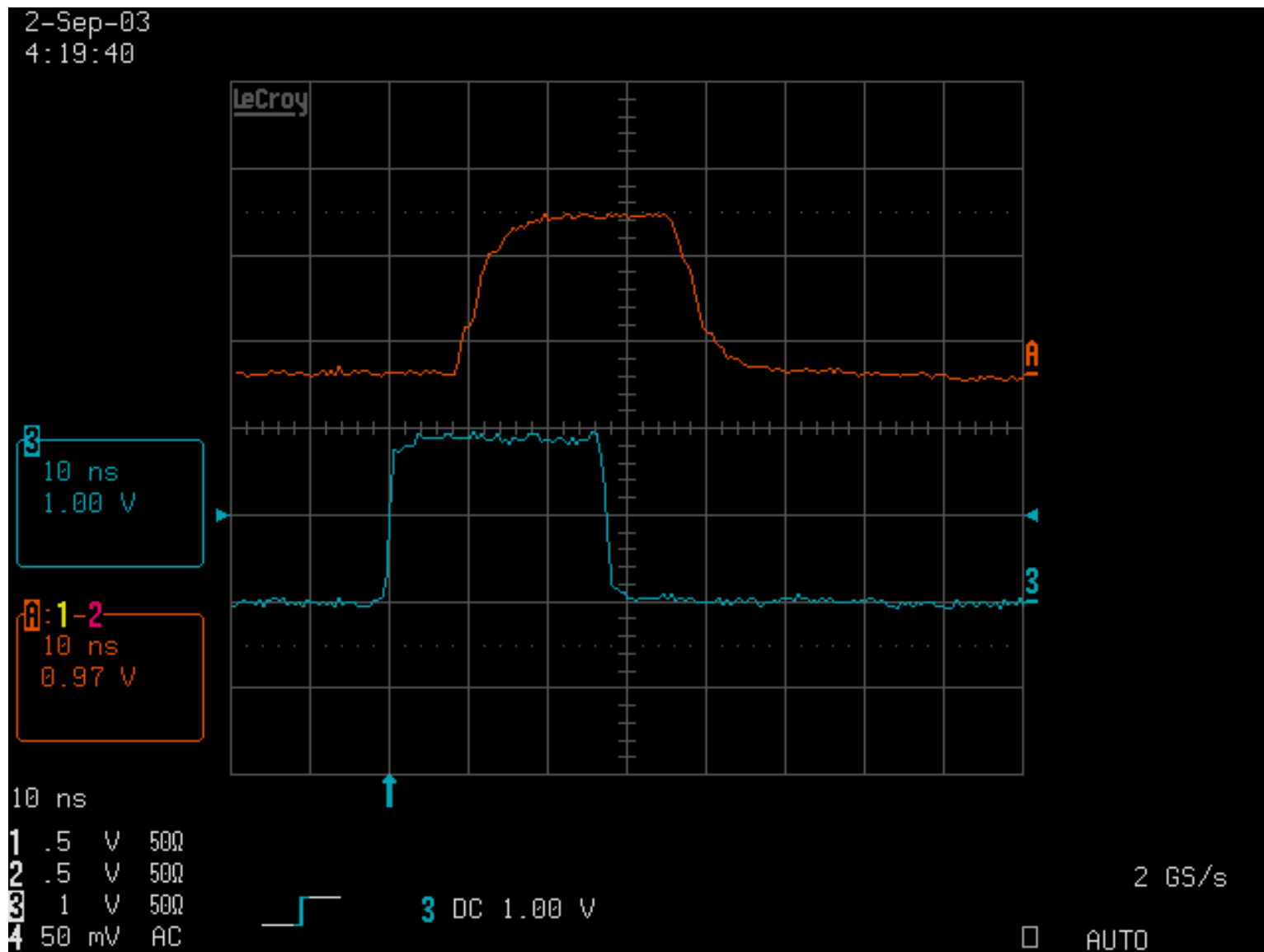
Trace "A" = (CH1 – CH2) ➔ Output pulse

The output pulse was measured in a differential mode

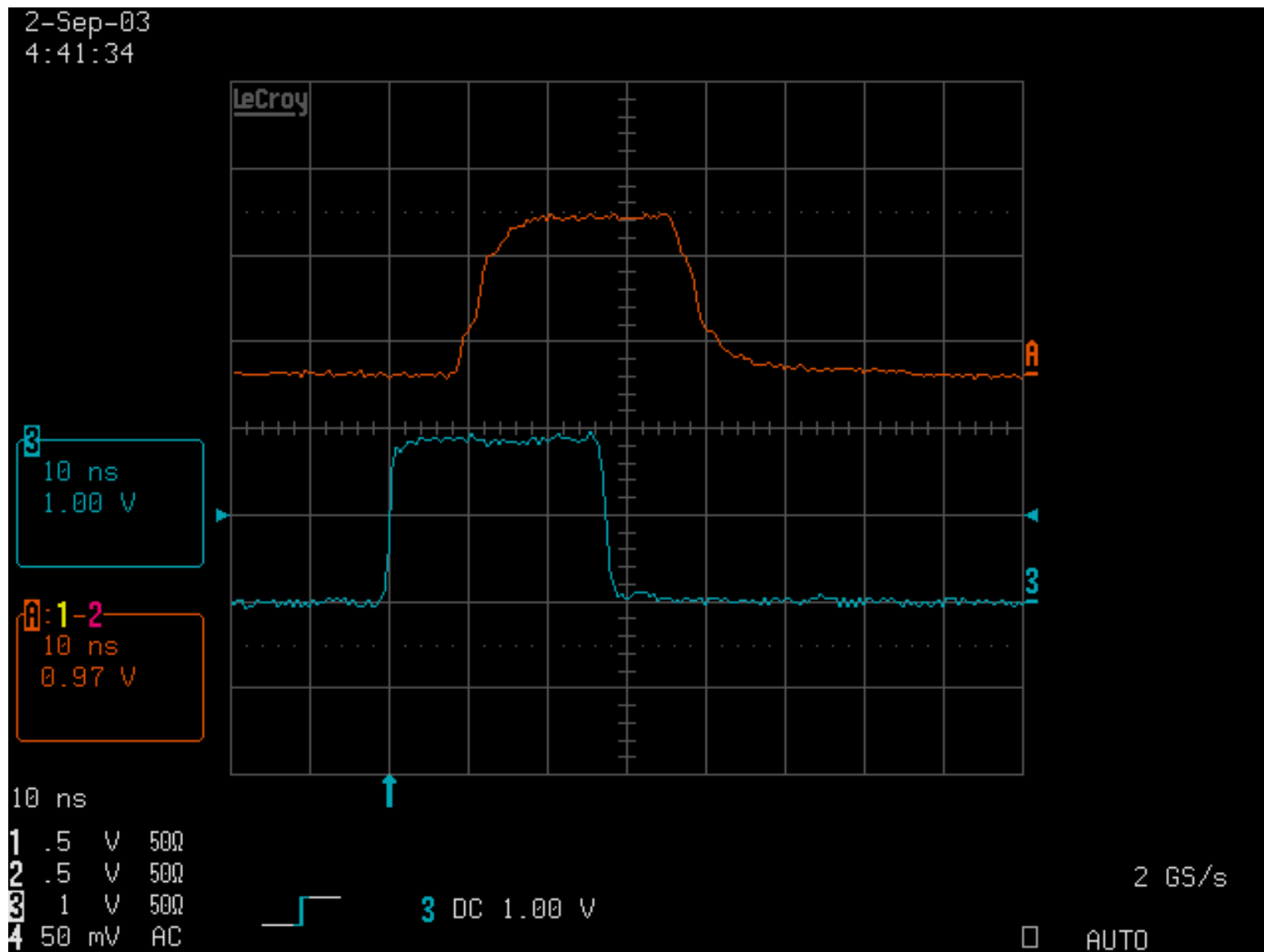
Sample A (RG174 on core #2)



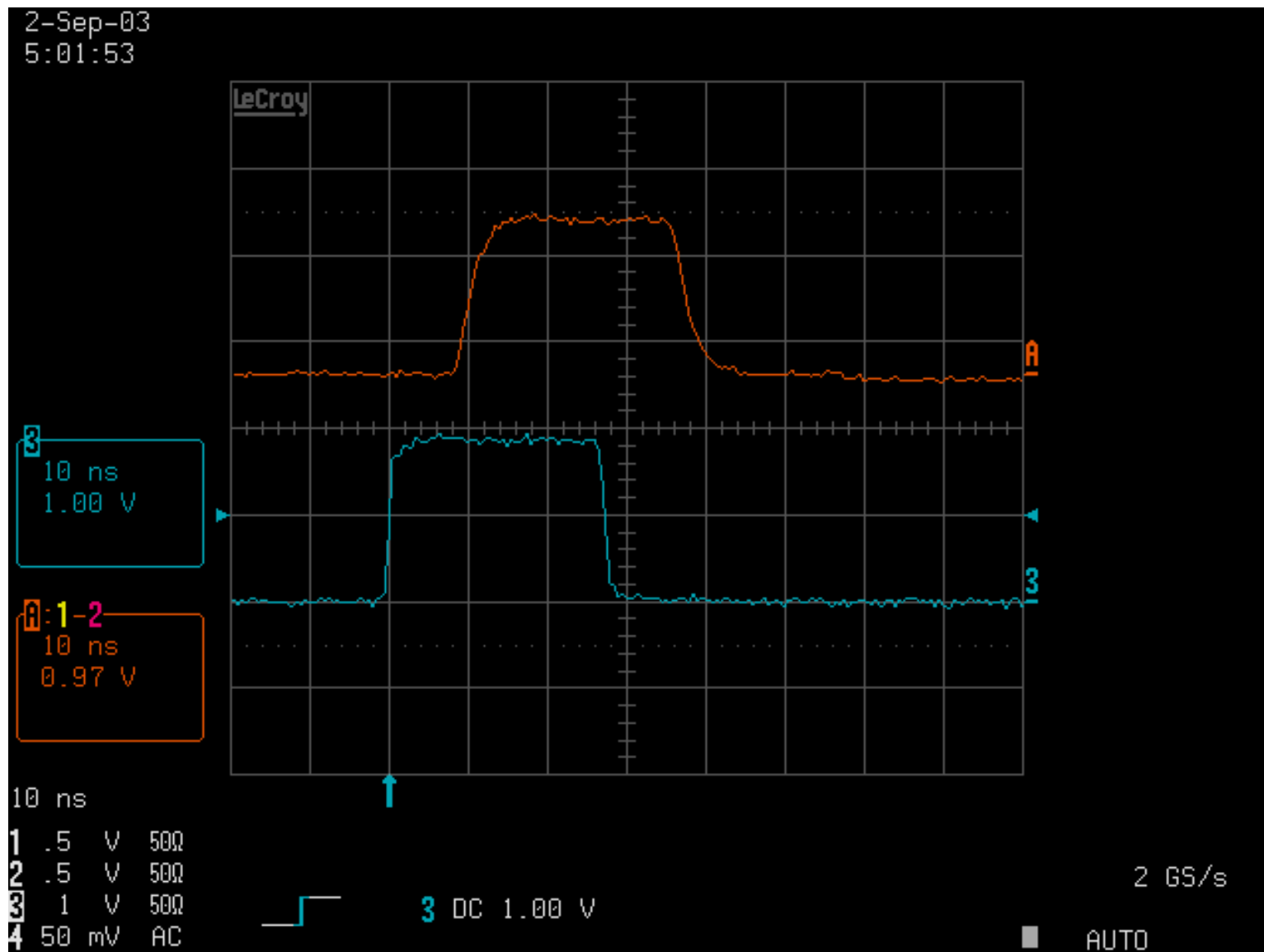
Sample B (24 AWG twisted pair on core #1)



Sample B' (24 AWG twisted pair on core #2)



Sample C (18 AWG on core #1)



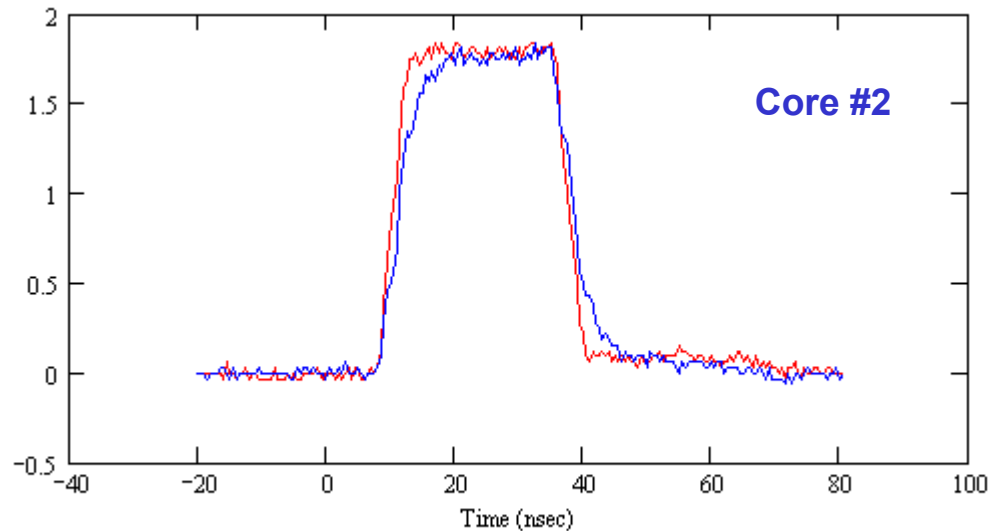
Comparison between Core #1 and Core #2

The output of Sample A is being compared with the output of Sample B and Sample B'.

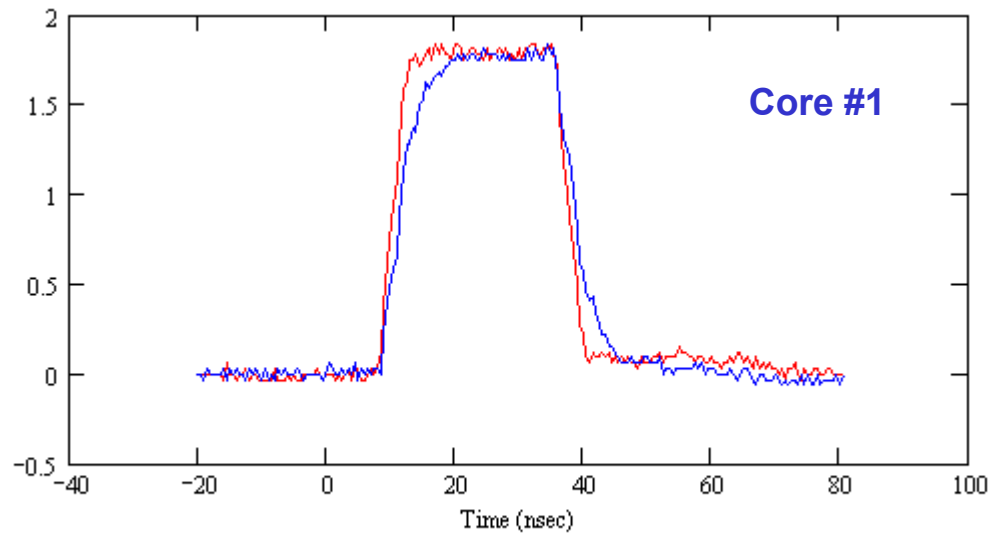
The output of Sample A is superior to that of Sample B and Sample B'.

The pulse response does not seem to depend on the choice between Core #1 and Core #2.

This is consistent with the understanding that the high-frequency response of the transformer is largely determined by the capacitive coupling between the primary and the secondary, rather than the magnetic coupling.



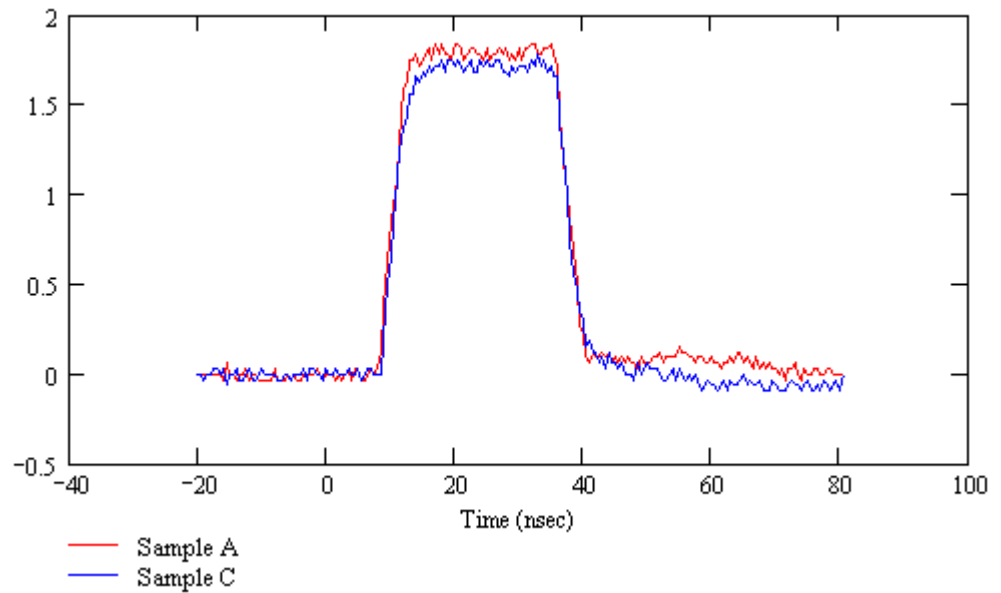
— Sample A
— Sample B'



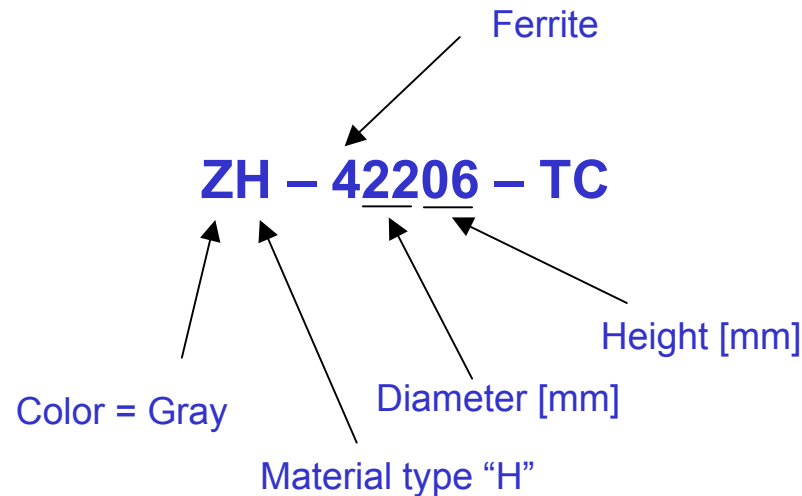
— Sample A
— Sample B

Comparison between Sample A and Sample C

The output of Sample C is practically identical to the output of Sample A.



The Toroidal Ferrite Core Facts



Material Characteristics*

Initial permeability $\mu_i = 15000 \pm 30 \%$

Curie temperature $T_c > 250 \text{ }^\circ\text{C}$

Max. usable frequency $< 150 \text{ kHz}$

The permeability decreases by a factor of two and the loss factor increases by a factor of two as the temperature is varied from RT to $-25 \text{ }^\circ\text{C}$.

*Source: www.mag-inc.com

For detailed data see: [ferrite_h_material.pdf](#)

Experiment with a Bare Coaxial Cable

The magnetic permeability of the toroidal ferrite core has a high-frequency cut-off (50%) of about 150kHz, which means that **the predominant coupling mechanism for the PMT pulses is capacitive, rather than magnetic.**

This is demonstrated by the next scope shot that shows a pulse transfer characteristic of a **bare RG178 cable** with the connections similar to Sample A.

It is seen that the bare RG178 cable has a good ac response--the rise-time and the fall-time are comparable to Sample A. The bare RG178, however, has a very poor low-frequency response.

Bare RG178 Cable

