ELTEC INSTRUMENTS, INC.

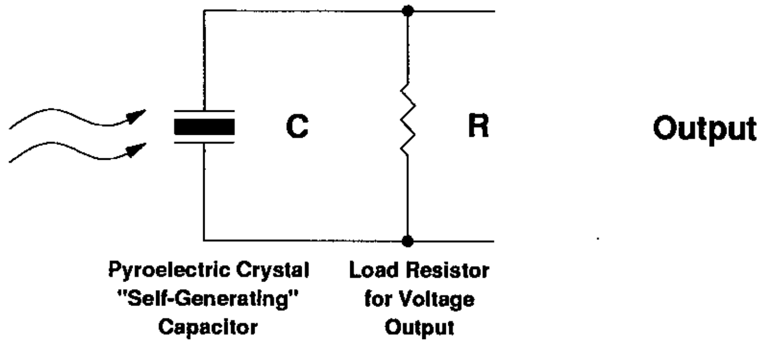
ELTECdata #134

LASER PULSE DETECTION: The Tradeoff between Pulse Resolution and Responsivity

By: David Cima

ELTEC Instruments, Inc.

I. VOLTAGE MODE APPROACH



Electrical time constant: (t) = RC
Pulse Width = t/3
So if desired pulse width is:
10 nanoseconds, then t = 30 nanoseconds
If 1 millisecond, then t = 3 milliseconds

Also, electrical time constant $(t) = \frac{1}{2\pi f}$

So if t = 30 nanoseconds, then f = 5.3 MHz
if t = 3 milliseconds, then f = 53 Hz

Also: $f = \frac{1}{2\pi RC}$ **when t = RC**

So if the capacitance is fixed (which it is by the geometry of the part, e.g. a given sensing area, and the material's dielectric constant) then the value of the load resistor is determined by that capacitance and the desired frequency response or pulse width.

For example, the calculated capacitance for a crystal 1x1 millimeter (and 0.05 millimeters thick) is 9 picofarads.

So for our examples where t=30 nanoseconds (f=5.3MHz) and C=9 picofarads then R=3,333 ohms.

Or for t=3 milliseconds then $R=3.33 \times 10^{8}$ ohms

These, then, are the maximum resistor values which will provide at least the specified time constant stated. Naturally, lower value resistors (with the capacitance fixed) would provide shorter time constants (or narrower pulse widths) in all cases.

Before considering the effect of the electrical time constant on Responsivity it is well to note that **the time constant is the limiting factor in following pulse duration**. Namely, the output will decay from a step function to 37% of peak response within 1 time constant (t). Thus extreme pulse resolution may actually distort pulse duration data. **Moreover, the thermal time constant also limits pulse duration determination**, with a thermal time constant (t_t) of about 0.032 seconds for most hard-mounted laser detectors and 0.65 seconds for most loop-mounted crystals. (see ELTECdata #102).

RESPONSIVITY

The current responsivity for a lithium tantalate crystal 0.05 mm thick = $R_{current}$ = 1.10×10^{-6} Amps/Watt (see ELTECdata #100, Pg 3)

The voltage responsivity is the current responsivity times the effective impedance.

$$\textbf{Responsivity}_{voltage} = \textbf{Responsivity}_{current} \times \textbf{Z}_{effective}$$

$$\textbf{R}_e = \textbf{R}_c \times \textbf{Z}_e \quad \textbf{(see ELTECdata \#103)}$$

The effective impedance (Z_{eff}) $= \dfrac{R_L}{\sqrt{1 + (R_L C_T \omega)^2}}$

where R_L = **load resistance across crystal, C_T = total capacitance (dominated by crystal capacitance), and $\omega = 2\pi f$**

So for our examples:

A. Pulse Width = 10 nanoseconds

t = time constant = 30 nanoseconds

C_C = crystal capacitance = 9 picofarads (1x1mm crystal)

R_L = 3,333 ohms

f = 5.305 MHz

Thus with the above values:

$$Z_{eff} = \frac{3{,}333}{\sqrt{1 + (3{,}333 \times 9 \times 10^{-12} \times 2 \times \pi \times 5.305 \times 10^6)^2}} = 2357 \text{ Ohms}$$

and R_c = 1.10×10^{-6} A/W

and R_v = $R_c \times Z_{eff}$

thus R_v = 2.593×10^{-3} V/W

B. Pulse width = 1 millisecond

t = time constant = 3 milliseconds

C_C = crystal capacitance = 9 picofarads (1 x 1 mm crystal)

R_L = 3.33×10^8 ohms

f = 53.05 Hz

Thus with the above values:

$$Z_{eff} = \frac{3.33 \times 10^8}{\sqrt{1 + (3.33 \times 10^8 \times 9 \times 10^{-12} \times 2 \times \pi \times 53)^2}} = 2.357 \times 10^8 \text{ Ohms}$$

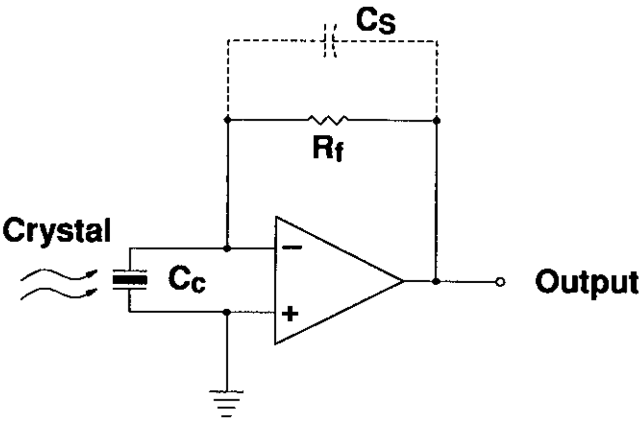
and R_c = 1.10×10^{-6} A/W
and R_v = $R_c \times Z_{eff}$
thus R_v = 259.3 V/W

NOTE: Actual capacitance values may be larger due to shunt capacitance from interconnecting leads and possibly 3 to 4 pF of input capacitance to a JFET or opamp.

CONCLUSION: Voltage responsivity decreases linearly with frequency/rise time/resolution

II. CURRENT MODE APPROACH

One way to achieve gain at high frequencies/short response times is to operate in the transimpedance mode:



The "ideal" transfer function for this circuit is:

Voltage Responsivity = Current Responsivity x Feedback Resistance

Thus the feedback resistor is the gain-controlling element.
However, the combination of the feedback resistor and stray capacitance (C_S) RC-time constant determines the high frequency 3 dB rolloff point.

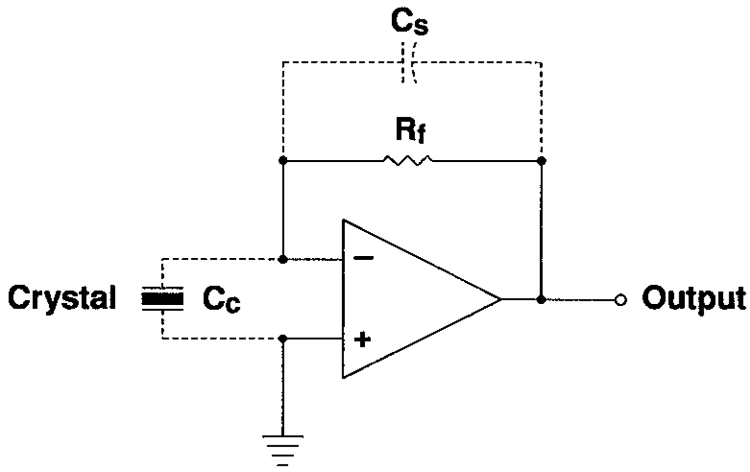
$$f = 1 / 2\pi RC$$

In a hybrid device with the operational amplifier and feedback resistor in the same package as the sensing crystal, the stray capacitance is typically 0.1 picofarad.

The other obvious limitation of this approach is the slew rate of the op-amp. Theoretical gain can't be achieved if the op-amp can't deliver the voltage fast enough.

Moreover, noise is amplified throughout the operational frequency range of the circuit, increasing 20 dB/decade above the corner frequency, leading to severe problems with low level signals.

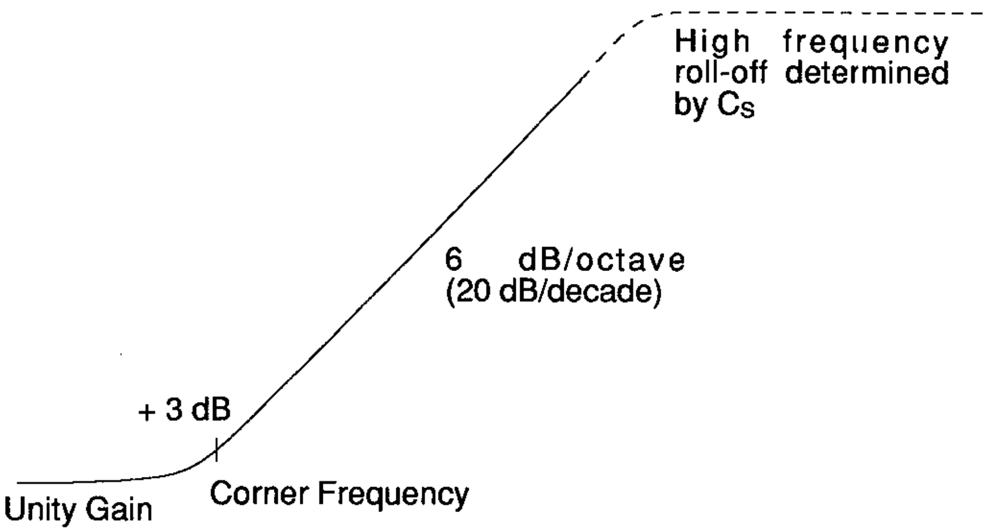
NOISE GAIN OF CURRENT MODE DETECTORS



With no crystal, noise gain = 1.00 (Unity Gain Amplifier)

With crystal, noise gain rises 6 dB/octave (20 dB/decade) starting at the corner frequency

Corner frequency = $\frac{1}{2\pi C_C R_F}$ **at a gain of 3 dB (1.413X)**



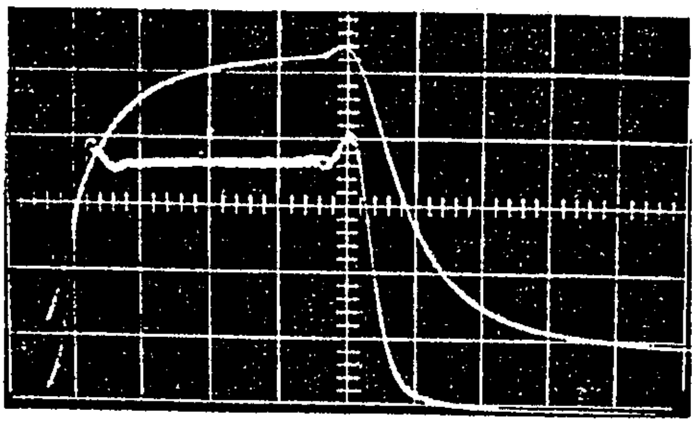
PYROELECTRIC LASER DETECTORS:

SIGNAL STRENGTH vs SPEED/RISE TIME/PULSE RESOLUTION

Absorption of laser energy by a pyroelectric crystal produces charge...in a crystal with capacitance into a resistive load. The conversion of charge to a voltage is a temporal process adding time/frequency to the parameters. Thus the voltage output magnitude is dependent on the detector's impedance which is in turn dependent on the detector's capacitance & resistance as well as the frequency or period of the physical phenomena.

In the scope photo below the 2 traces are from 2 identical photonic events(in magnitude and temporal characteristics) upon the same pyroelectric detector. In the top trace the load upon the crystal was 22 megohms and in the bottom the load was 1 megohm. While the bottom trace differs from the top by a factor of 22x less magnitude, the temporal resolution of the chopped signal is much better. See ELTECdata #102 and #134 for quantification procedures.

(data from pages 23 and 26 of of Advances in Pyroelectric Detectors, doctoral dissertation by Carlos Roundy for Stanford University, 1972)



0.1 v/div.
(0.005 v/div.)

(a)

1 msec/div.

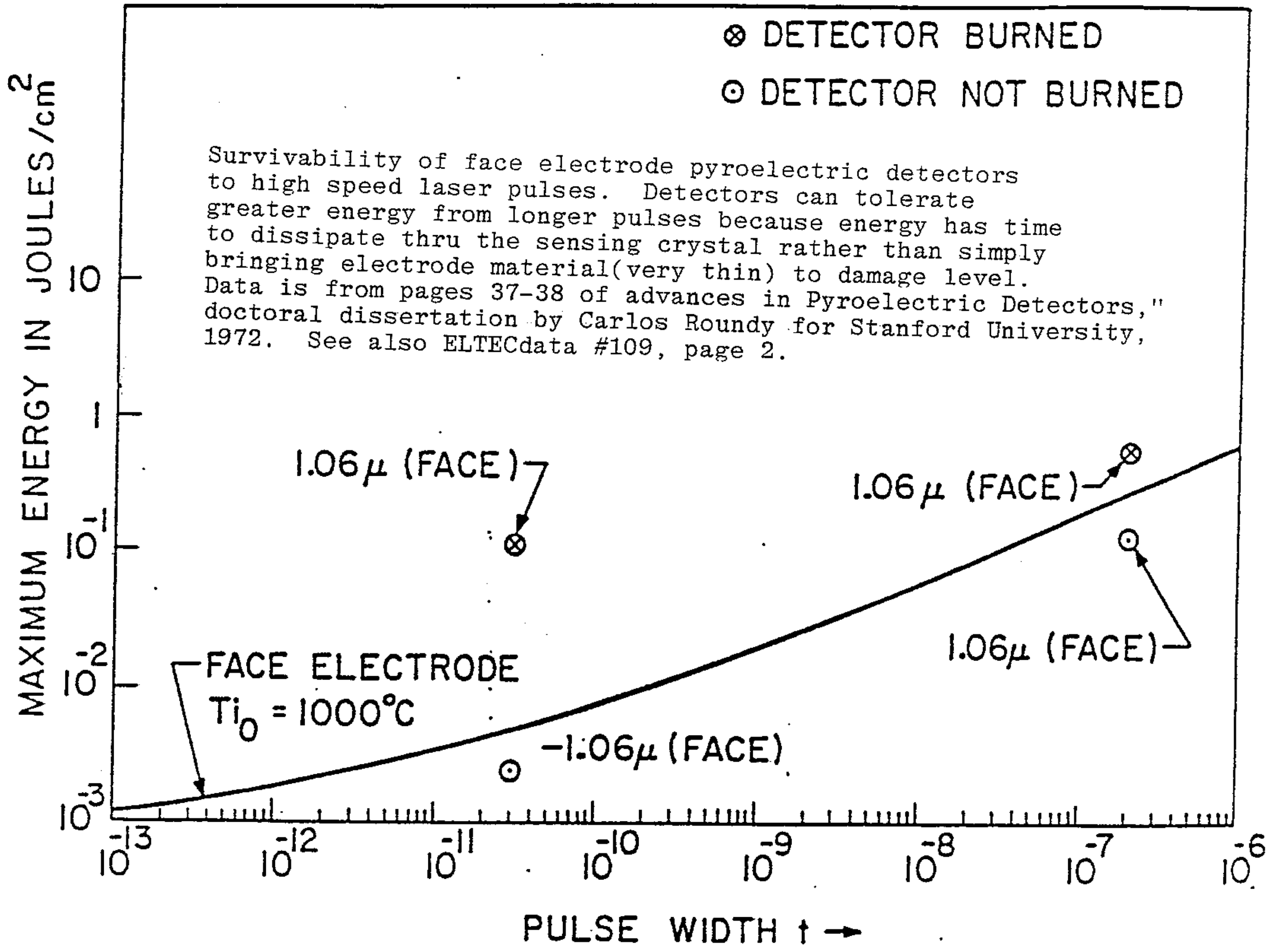
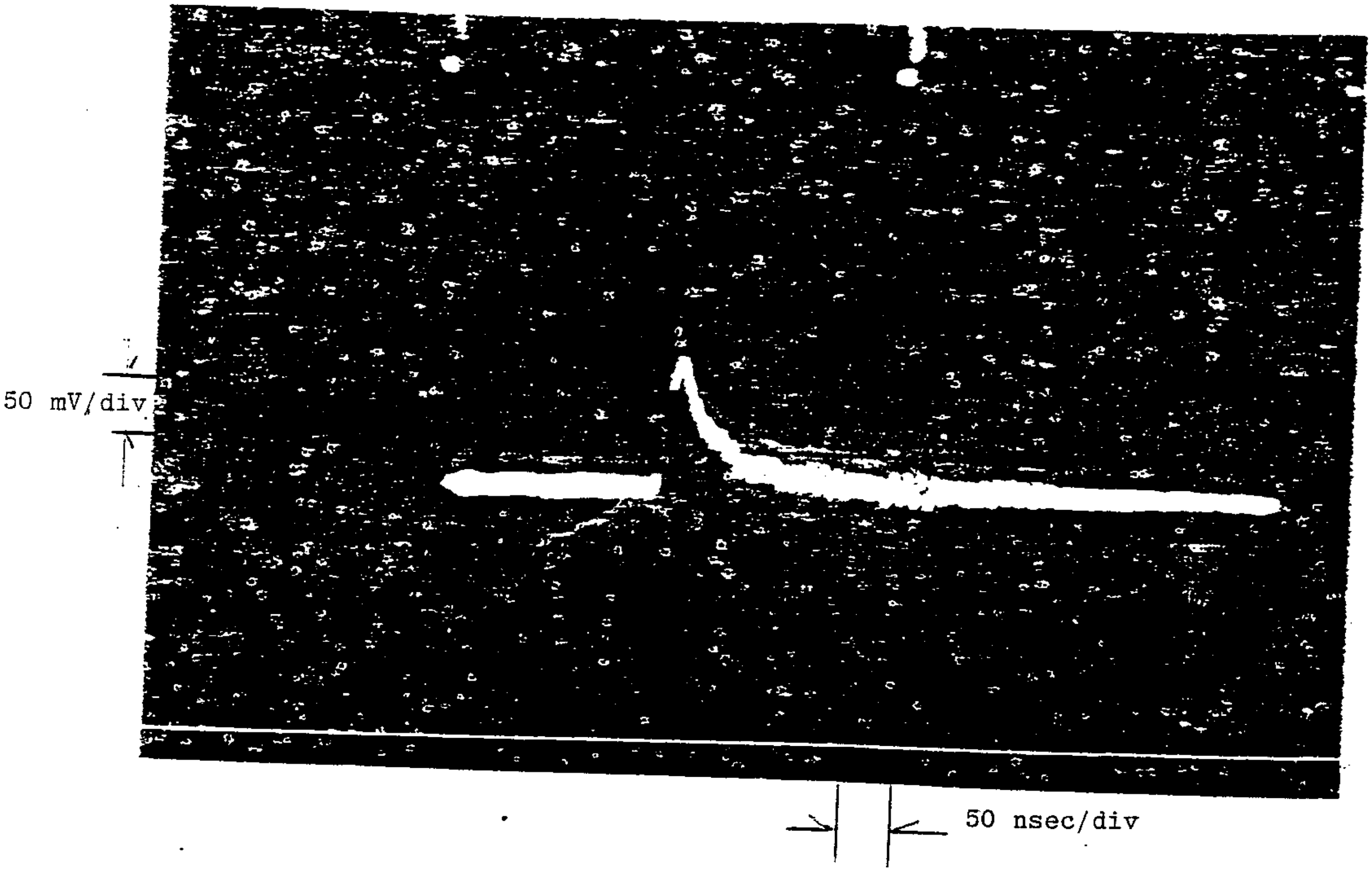


FIG. 13--Maximum energy density of pyroelectric detectors versus pulse width t



Eltec 420-0 laser detector into 50-ohm Tektronix 7A19 plug-in
into Tektronix 7834 storage scope (single shot)

Nitrogen laser, University of Utah, March 2, 1934