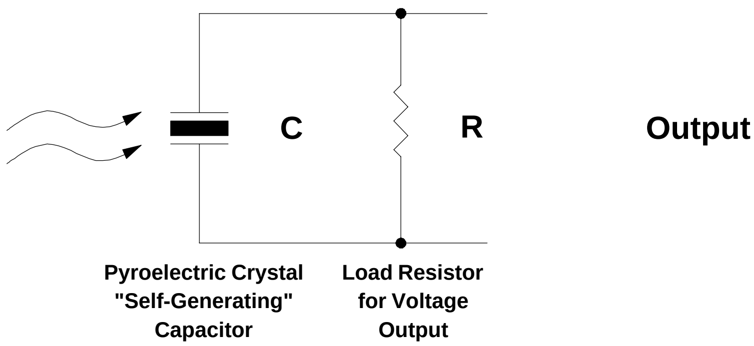
ELTEC INSTRUMENTS, INC.

ELTECdata #134

LASER PULSE DETECTION: The Tradeoff between Pulse Resolution and Responsivity

I. VOLTAGE MODE APPROACH



Electrical time constant: (τ_e) = RC
Pulse Width = Approximately $\tau_e/3$ (provided that the pulse width is relatively short)
So if desired pulse width is:
10 nanoseconds, then τ_e = 30 nanoseconds
If 1 millisecond, then τ_e = 3 milliseconds

Also, electrical time constant $(\tau_e) = \dfrac{1}{2\pi f_e}$

So if τ_e = 30 nanoseconds, then f_e = 5.3 MHz
if τ_e = 3 milliseconds, then f_e = 53 Hz

Also: $f_e = \dfrac{1}{2\pi RC}$ **when τ_e = 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 τ_e = 30 nanoseconds (f_e = 5.3MHz) and C = 9 picofarads then R=3,333 ohms.

Or for τ_e = 3 milliseconds then R=3.33×10^8 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 electrical and thermal time constants are 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 (τ). 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 (τ_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 = $R_{current}$ = 0.5 to $1.0\text{x}10^{-6}$ Amps/Watt (see ELTECdata #100, Pg 3)

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

$$\textbf{Responsivity}_{voltage} = \textbf{Responsivity}_{current} \cdot Z_{effective}$$
$$R_v = R_i \cdot Z_{eff} \quad \textbf{(see ELTECdata \#103)}$$

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 C_c), and $\omega = 2\pi f$**

So for our examples:

A. Pulse Width = 10 nanoseconds

τ_e = time constant = 30 nanoseconds

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

R_L = 3,333 ohms

f = 5.305 MHz

Thus with the above values:

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

and R_i = $1.0\text{ x }10^{-6}$ A/W

and R_v = $R_i \cdot Z_{eff}$

thus R_v = $2.357\text{ x }10^{-3}$ V/W

B. Pulse width = 1millisecond

τ_e = time constant = 3 milliseconds

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

R_L = $3.33\text{ x }10^{8}$ ohms

f = 53.05 Hz

Thus with the above values:

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

$$\text{and } R_i = 1.0 \times 10^{-6} \text{ A/W}$$
$$\text{and } R_v = R_i \cdot Z_{eff}$$
$$\text{thus } R_v = 235.7 \text{ V/W}$$

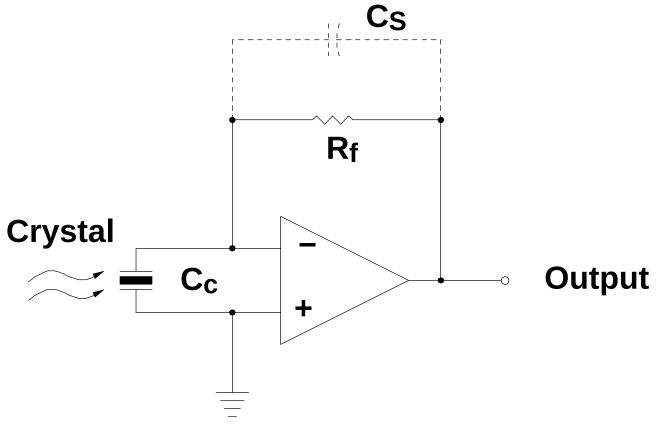
NOTE: Actual capacitance values may be larger due to shunt capacitance from interconnecting leads and possibly 3 to 4 pF of input capacitance to a JFET or opamp.

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), which is the RC-time constant, determines the high frequency 3 dB cutoff point.

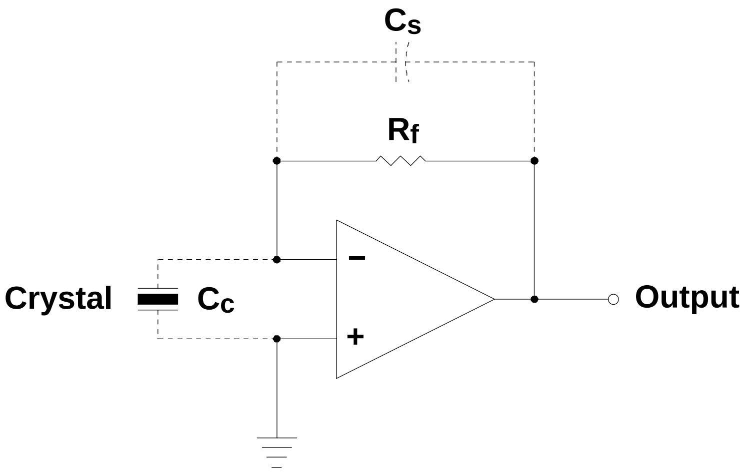
$$f_C = 1 / 2\pi RC$$

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.

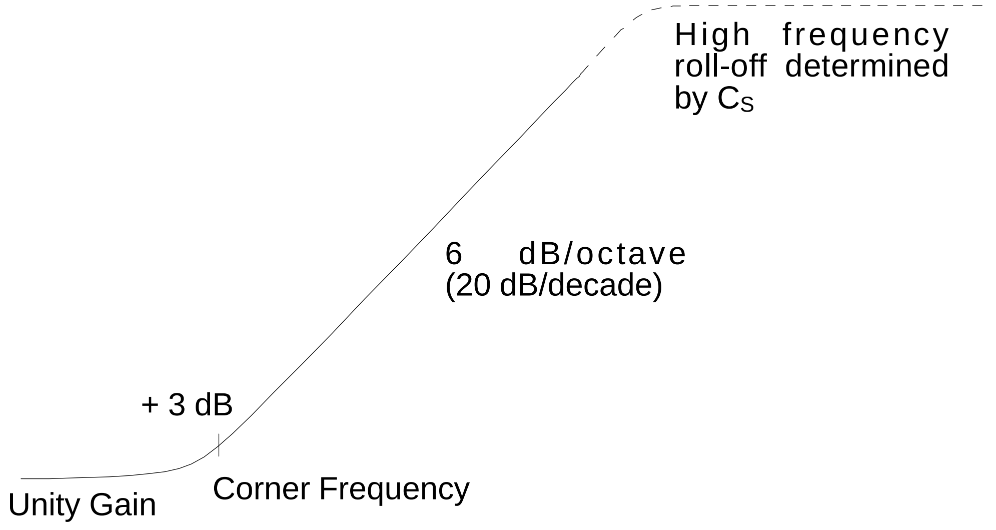
NOISE GAIN OF CURRENT MODE DETECTORS



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



CURRENT MODE PYROELECTRIC DETECTORS:

THE INFLUENCE OF THE FEEDBACK RESISTOR VALUE AND THE DETECTOR RESPONSIVITY AND NOISE

This is average data from pairs of prototype detectors made several years ago. The sensing crystal is 2.5 x 2.5 millimeters and the same operational amplifier is used in all units. A single bladed chopper wheel was used from 1 to 100 Hz (responsivity), and a multislotted wheel was used at 1,000 Hz. Noise was measured through a lock-in amplifier. Performance of ELTEC current mode detectors has improved significantly since these tests were done, but the data does give indications of relative changes of signal and noise through frequency.

Feedback Resistor	Frequency Hz	Responsivity V/W	Noise (1 Hz BW)	S/N
$1 \times 10^{11}\Omega$	1	136,000	155 µV	8.8×10^{9}
	10	75,800	160 µV	4.74×10^{8}
	100	25,900	350 µV	7.4×10^{7}
	1,000	945	105 µV	9×10^{6}
$1 \times 10^{10}\Omega$	1	15,700	30 µV	5.2×10^{8}
	10	10,900	25.5 µV	4.3×10^{8}
	100	8,840	50 µV	1.8×10^{8}
	1,000	1,290	26 µV	5.0×10^{7}
$1 \times 10^{9}\Omega$	1	1,290	36 µV	3.6×10^{7}
	10	884	5 µV	1.8×10^{8}
	100	816	7 µV	1.2×10^{8}
	1,000	112	30 µV	3.7×10^{6}
$1 \times 10^{8}\Omega$	1	116	6 µV	1.9×10^{7}
	10	109	1.5 µV	7.3×10^{7}
	100	109	1.8 µV	6.1×10^{7}
	1,000	137	3.5 µV	3.9×10^{7}

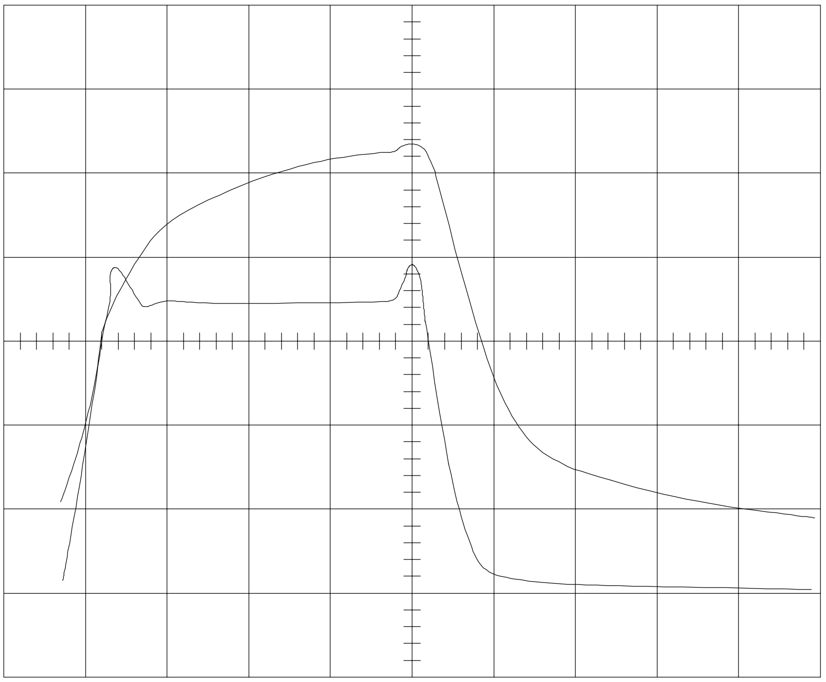
PYROELECTRIC LASER DETECTORS:

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 physical phenomena.

In the simulated 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 earlier herein for quantification procedures.

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

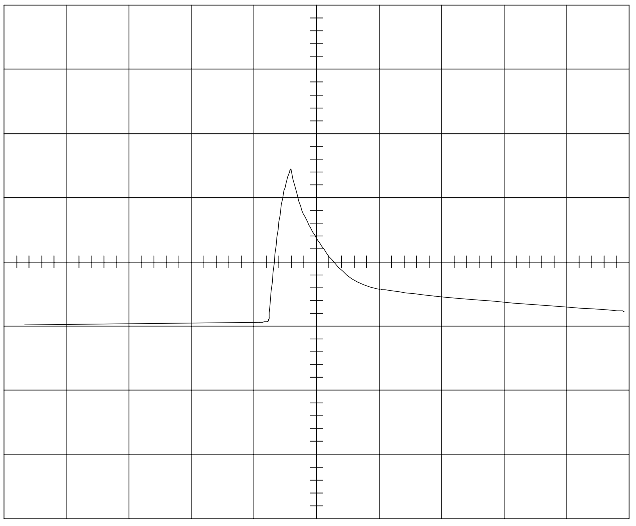


0.1 V/div.

(0.005 V/div.)

(a)

1 msec/div.



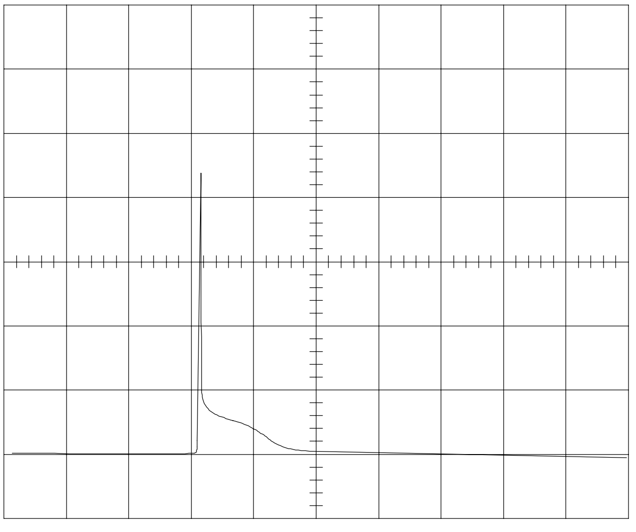
Eltec Model 420-0 Laser Detector

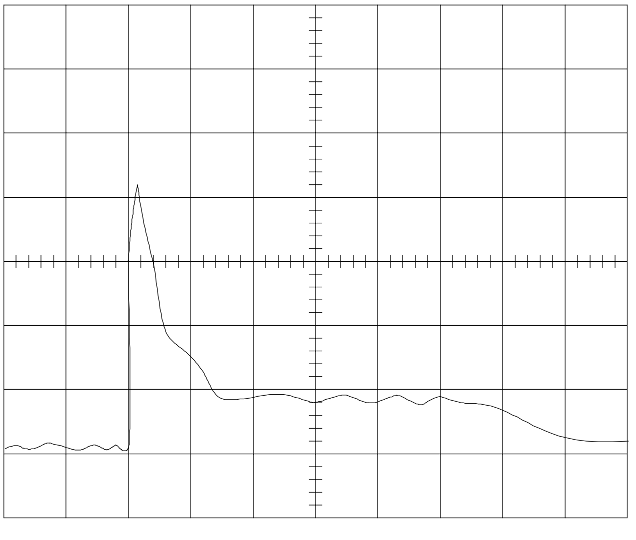
Simulated scope photo of detector into 50Ω Tektronix 7A19 plug-in into Tektronix 7834 storage scope (single shot)

Vertical: 50 mV/division

Sweep: 50 nsec/division

Nitrogen laser, University of Utah, March 2, 1984





Eltec Model 420-2 Laser Detector

Detector is about 1 foot from carbon dioxide laser. Detector output goes directly into a 50Ω scope. (Simulated scope photos)

Top:

Vertical: 200 mV/division

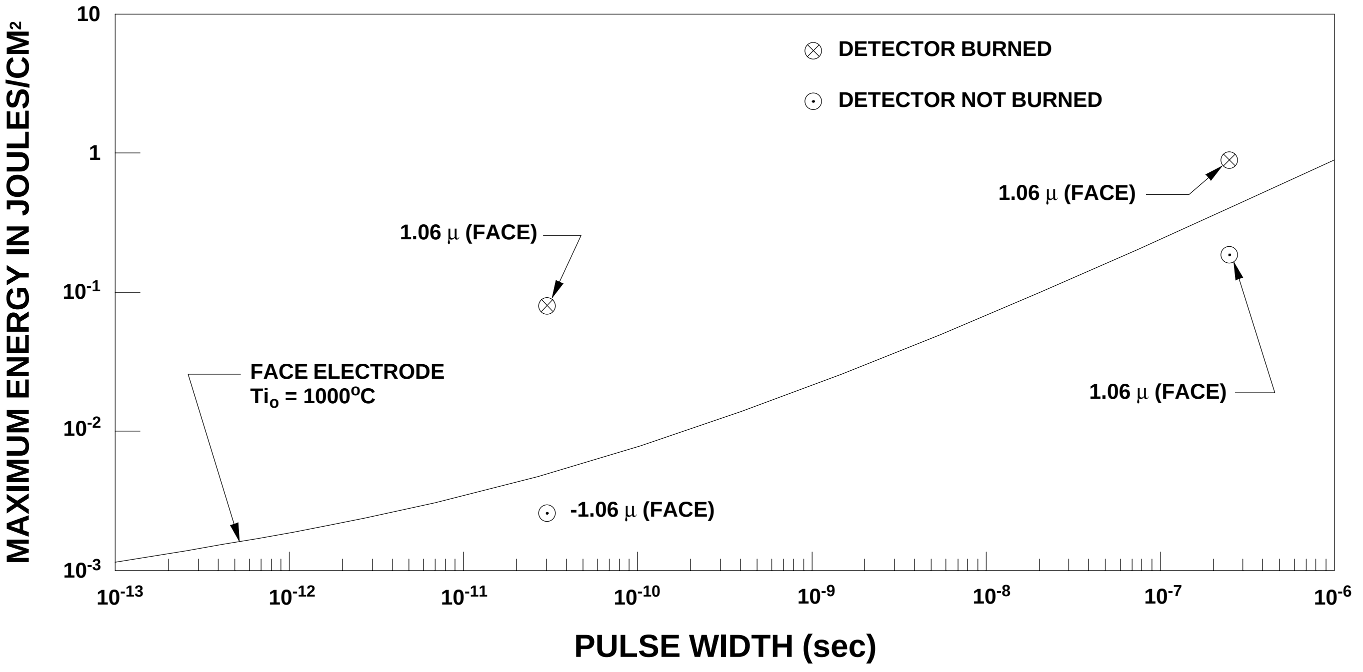
Sweep: 2 μsec/division

Bottom:

Vertical: 200 mV/division

Sweep: 200 nsec/division

MAXIMUM ENERGY DENSITY OF PYROELECTRIC DETECTORS vs. PULSE WIDTH



Survivability of face electrode pyroelectric detectors to high speed laser pulses. Detectors can tolerate greater energy from longer pulses because energy has time to dissipate through the sensing crystal rather than simply bringing electrode material (very thin) to damage level. Data is from pages 37 - 38 of "Advances in Pyroelectric Detectors", doctoral dissertation by Carlos Roundy for Stanford University, 1972. See also ELTECdata # 109, page 2.

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