# Status of the FEE developments for diamond detectors at GSI - Detektorlabor


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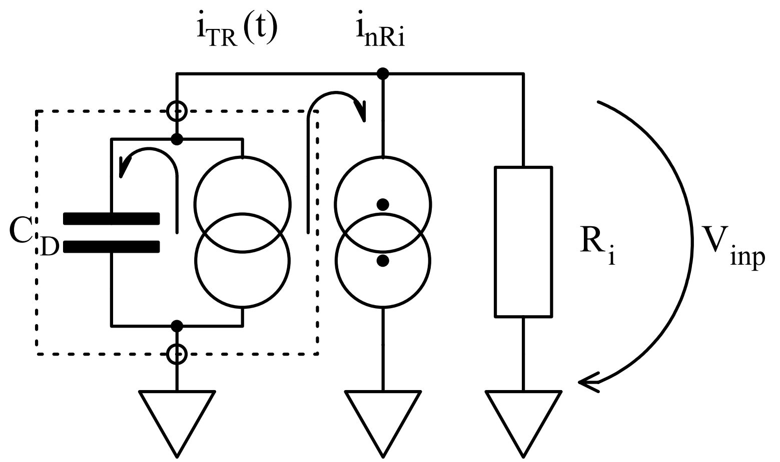
# Outline

- A trial for the analytical model of the Diamond Detector – FEE Assemblies
- PADI-4 , a fast Preamplifier-Discriminator for Diamond Detectors
- DLNA, a Low Noise Amplifier for Diamonds Detectors
- Summary and Outlook

# A trial for the analytical model of the Diamond Detector – FEE Assemblies

# The First Step: Detector ideal (the charge is instantaneously collected) and FEE consists just from one resistor




$$\int_{-\infty}^{\infty} i_{TR}(t)dt = \int_{-\infty}^{\infty} Q_{col}\cdot\delta(t)dt = Q_{col}$$

$$i_C(t) = I_0 e^{-t/\tau_S} \qquad Q_{col} = \int_0^{\infty} i_C(t)dt = I_0\cdot\tau_S$$

$$i_C(t) = Q_{col}/\tau_S\cdot e^{-t/\tau_S} \quad V_S = R_i\cdot i_C(0) = Q_{col}/C_D$$

$$v_{S\delta}(t) = Q_{col}/C_D\cdot e^{-t/\tau_S}$$

*Simplified equivalent schematic for noise estimations: DD is connected to a simple measurement device represented by the $R_i$ resistor.*

$$P_n(T,\Delta f) = 4\cdot k\cdot T\cdot\Delta f = i_{nRi}^2\cdot R_i$$

$$V_{Nin}^2(f) = i_{nRi}^2/\Delta f\cdot|Z(f)|^2 = i_{nRi}^2/\Delta f\cdot R_i^2/(1+f^2/f_{uS}^2)$$

$$V_{Nin}^2 = i_{nRi}^2/\Delta f\cdot R_i^2\cdot f_{uS}\cdot\pi/2 = 4\cdot k\cdot T/(4\cdot C_D) = k\cdot T/C_D$$

**SLUO LECTURE SERIES. LECTURE # 10**
**H. SPIELER. December 18,1998**

$$\sigma_t = \sigma_n/(dv/dt)$$

$t_{rA} = 0.35/BW_A$
$dv/dt = 0.8\cdot V_s/t_{rA} = 2.28\cdot Q_{col}\cdot BW_A/C_D$

$$S/N = Q_{col}/\sqrt{k\cdot T\cdot C_D}$$

$$\sigma_t = \frac{\sqrt{k\cdot T/C_D}}{2.28\cdot Q_{col}\cdot BW_A/C_D} = \frac{\sqrt{k\cdot T\cdot C_D}}{2.28\cdot Q_{col}\cdot BW_A}$$

# The Second Step: Detector ideal, FEE consists from one amp. with Noise Factor F and the frequency bandwidth BW

$$F = \frac{e^2{}_{nRs} + e^2{}_{neq}}{e^2{}_{nRs}} = 1 + \frac{e^2{}_{neq}}{e^2{}_{nRs}} \qquad e^2{}_{neq} = (F-1)\cdot e^2{}_{nRs} \qquad i^2{}_{neq} = (F-1)\cdot i^2{}_{nRs}$$

$$i^2{}_{neq} / \Delta f = 4k \cdot T \cdot (F-1)/R_i \qquad S/N = Q_{col} / \sqrt{k \cdot T \cdot (F-1) \cdot C_D}$$

$$\left|G_A(f)\right| = G_0 /(1 + f^2 / f^2_{uA})^{1/2}$$

$$V^2_{Nou}(f) = i^2_{nRi} / \Delta f \cdot \left|Z(f)\right|^2 \cdot \left|G_A(f)\right|^2 = i^2_{nRi}/\Delta f \cdot R_i^2 \cdot G_0^2 / [(1 + f^2/f^2_{uS}) \cdot (1 + f^2/f^2_{uA})]$$

$$V^2_{Nou} = i^2_{nRi}/\Delta f \cdot R_i^2 \cdot G_0^2 \cdot f_{uS} \cdot f_{uA} /(f_{uS} + f_{uA}) \cdot \pi/2 = \frac{k \cdot T \cdot (F-1) \cdot G_0^2}{C_D \cdot (1 + \tau_A / \tau_S)}$$

$$v_{A\delta}(t) = V_A \cdot e^{-t/\tau_A} \qquad \int_{-\infty}^{\infty} v_{A\delta}(t)dt = V_A \cdot \tau_A = G_0 \cdot \int_{-\infty}^{\infty} \delta(t)dt = G_0 \cdot 1$$

$$v_{out}(t) = v_{S\delta}(t) \otimes v_{A\delta}(t) = \int_{-\infty}^{\infty} v_{S\delta}(u) v_{A\delta}(t-u)du = V_S \cdot V_A \cdot e^{-t/\tau_A} \cdot \int_{-\infty}^{\infty} e^{u(1/\tau_A - 1/\tau_S)} du$$

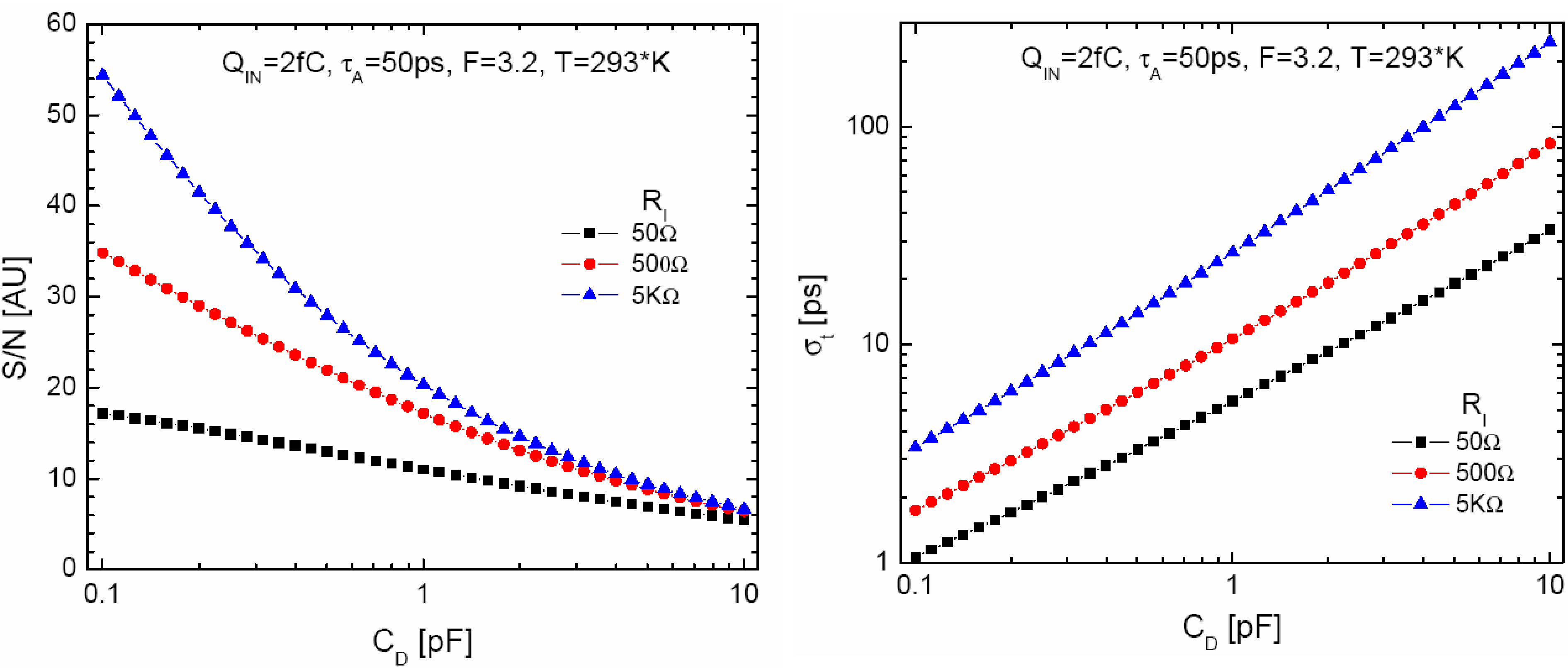
$$\tau_A = \tau_S \quad v_{out}(t) = V_S \cdot V_A \cdot e^{-t/\tau_A} \cdot t = \frac{Q_{col}}{C_D} \cdot \frac{G_0}{\tau_A} \cdot e^{-t/\tau_A} \cdot t \qquad v_{out}(t_M) = \frac{Q_{col}}{C_D} \cdot \frac{G_0}{e}$$

$$\tau_A \neq \tau_S \quad v_{out}(t) = \frac{Q_{col}}{C_D} \cdot G_0 \cdot \frac{\tau_S}{\tau_S - \tau_A} \cdot (e^{-t/\tau_S} - e^{-t/\tau_A}) \qquad v_{out}(t_M) = \frac{Q_{col}}{C_D} \cdot G_0 \cdot \frac{1}{1-m} \cdot (e^{\frac{m \cdot \ln m}{1-m}} - e^{\frac{\ln m}{1-m}})$$

$$S/N = \frac{Q_{col}}{\sqrt{k \cdot T \cdot (F-1) \cdot C_D}} \cdot \frac{\sqrt{1+m}}{1-m} \cdot (e^{\frac{m \ln m}{1-m}} - e^{\frac{\ln m}{1-m}}) \qquad \sigma_t = \frac{\tau_A \cdot \sqrt{k \cdot T \cdot (F-1) \cdot C_D}^{\;\tau_A = \tau_S}}{Q_{col}} \cdot \frac{1-m}{\sqrt{1+m}} \cdot \frac{1}{e^{\frac{\ln m}{2(1-m)}} - m e^{\frac{m \ln m}{2(1-m)}}}$$

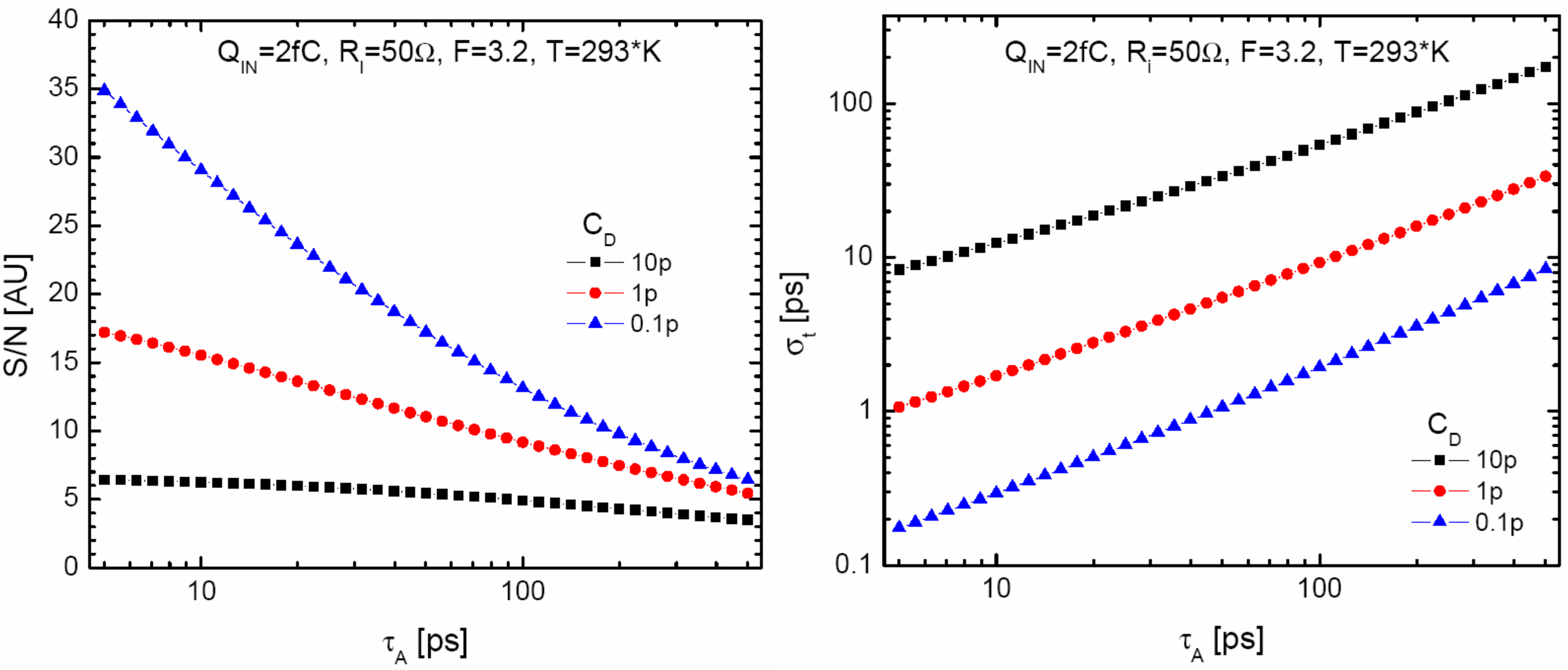
$$m = \tau_A / \tau_S$$

# Results 1 for the Ideal case



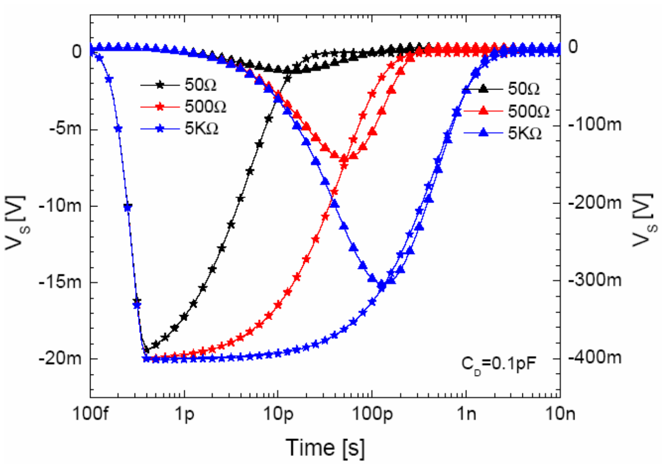

*S/N (left) and $\sigma_t$ (right) as a function of $C_D$ with $R_i$ as parameter*

# Results 2 for the Ideal case

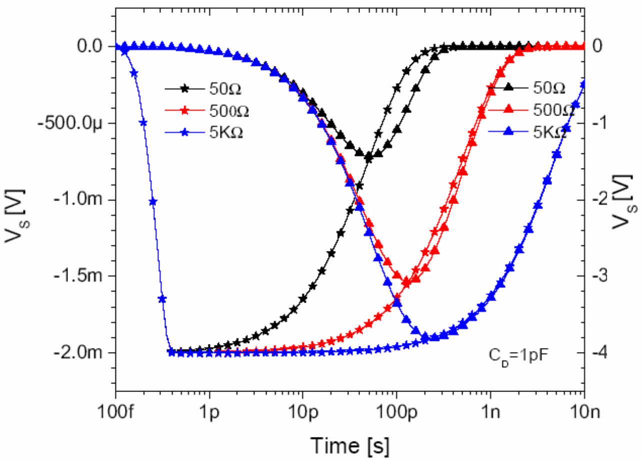



*S/N (left) and $\sigma_t$ (right) as function of $\tau_A$ with $C_D$ as parameter*

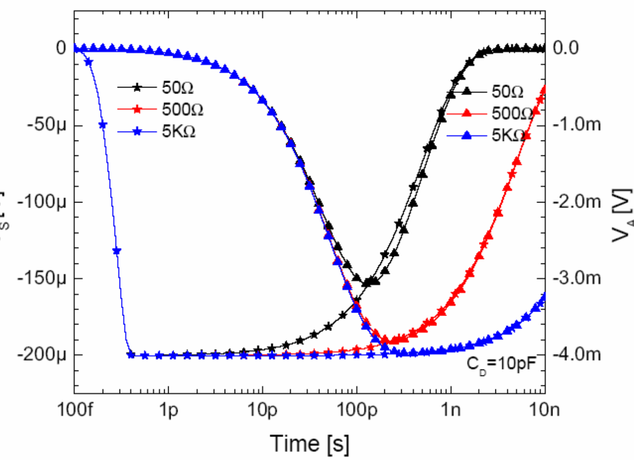
# APLAC simulations for intuitive understanding of "ballistic deficit" errors




$C_D$=0.1pF and $\tau_S$ =5ps, 50ps and 500ps




$C_D$=1pF and $\tau_S$ =50ps, 500ps and 5ns




$C_D$=1pF and $\tau_S$ =500ps, 5ns and 50ns

*Simulated signals of a DD-FEE ensemble. Stars denote the detector output signals (referring to the left ordinate), triangles the corresponding BBA output signals (right ordinate). Three different values of $R_i$ are shown (50Ω, 500Ω and 5KΩ) ; $\tau_A$=50ps*

# The Third Step: The real detector is a scCVD diamond; we can apply the Shockley-Ramo theorem, for a parallel-plate detector

under the assumption of a homogenously distributed space charge :

$$i_{e,h}(t) = \frac{Q_{gen} \cdot v(E)_{e,h}}{d} e^{t/\tau_{eff} - t/\tau_{e.h}}$$

where $Q_{gen}$ is the generated charge, $v(E)_{e,h}$ is the charge velocity, $d$ is the detector thickness, $\tau_{e,h}$ denotes the lifetime of excess electrons and holes and $\tau_{eff}$ is given by

$$\tau_{eff} = \frac{\varepsilon \cdot \varepsilon_0}{q \cdot \mu_{e,h} \cdot N_{eff}}$$

with $\mu_{e,h}$ the effective mobility of electrons and holes, $\varepsilon$ the diamond permittivity, $\varepsilon_0$ the vacuum permittivity and $q$ the elementary charge. $N_{eff}$ denotes the net effective fixed space charge in the diamond bulk. If the carrier lifetime is sufficiently long:

$$v_{dr} = \frac{d}{t_{tr}} \qquad i_{e,h}(t) = \frac{Q_{gen}}{t_{tr}} = const \qquad \text{for } 0<t<t_{tr}$$

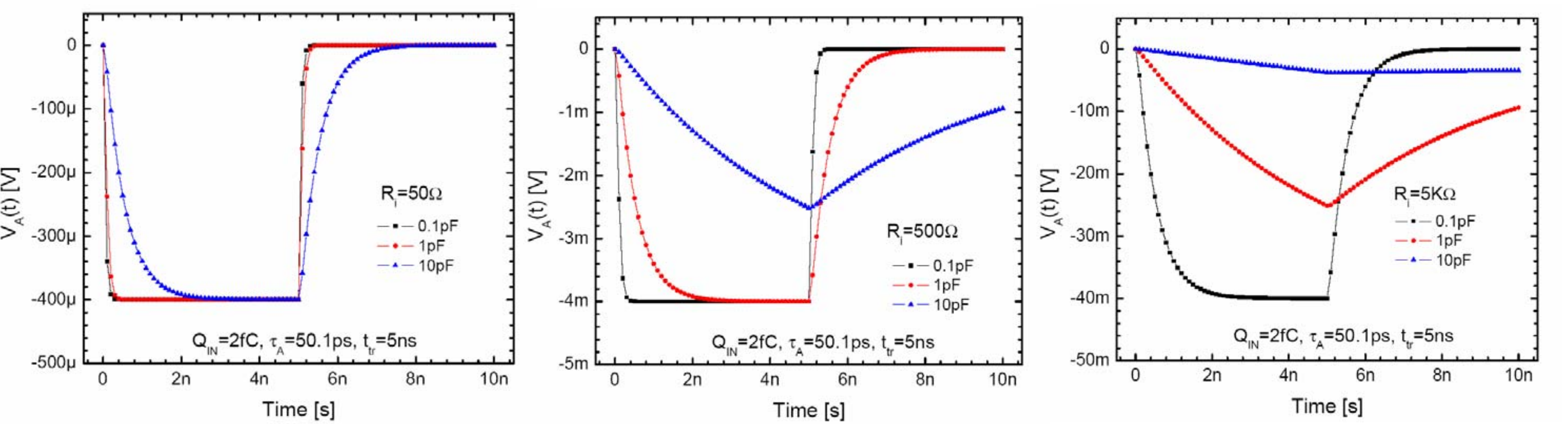
$$v_{out\delta}(t) = v_{out}(t)/Q_{col} \qquad v_P(t) = v_{out\delta}(t) \otimes i_{e,h}(t) = \int_{-\infty}^{\infty} v_{out}(u) \cdot i_{e,h}(t-u)du$$

a) for $t \le t_{tr}$

$$v_P(t) = \frac{Q_{gen} \cdot G_0}{C_D} \cdot \frac{\tau_S}{t_{tr}} \cdot \frac{(-e^{-t/\tau_S} + m \cdot e^{-t/\tau_A} + 1 - m)}{1-m}$$

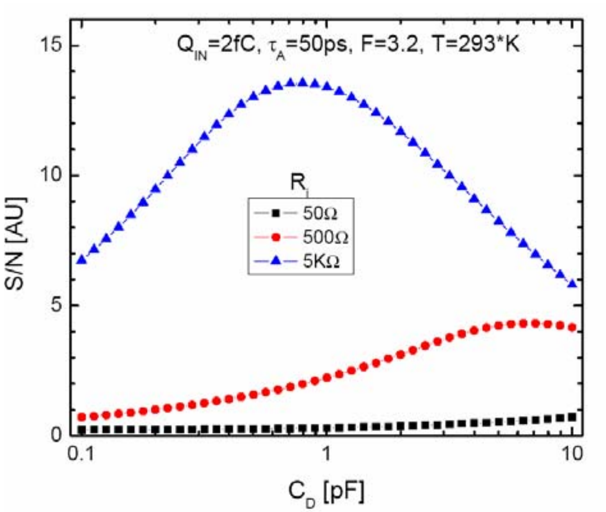
b) for $t > t_{tr}$

$$v_P(t) = \frac{Q_{gen} \cdot G_0}{C_D} \cdot \frac{\tau_S}{t_{tr}} \cdot \frac{(-(e^{-t/\tau_S} - e^{-(t-t_{tr})/\tau_S}) + m \cdot (e^{-t/\tau_A} - e^{-(t-t_{tr})/\tau_A}))}{1-m}$$

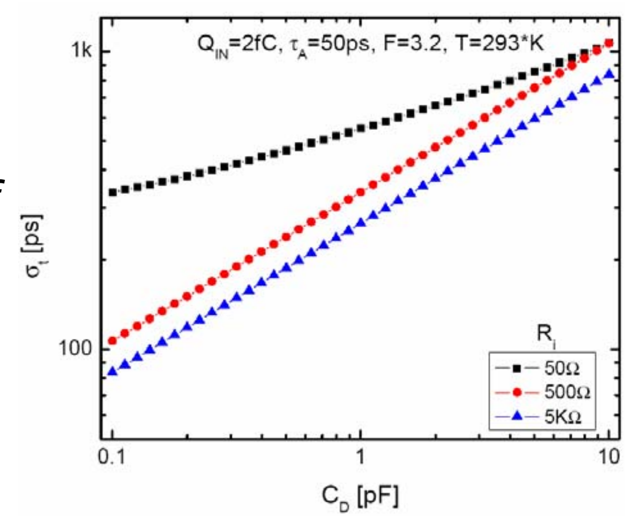



*Transient response of a scCVD DD having $t_{tr}$=5ns and three values of $C_D$=0.1pF, 1pF and 10pF, for $R_i$=50Ω (left), $R_i$=500Ω (middle) and $R_i$=5KΩ (right).*

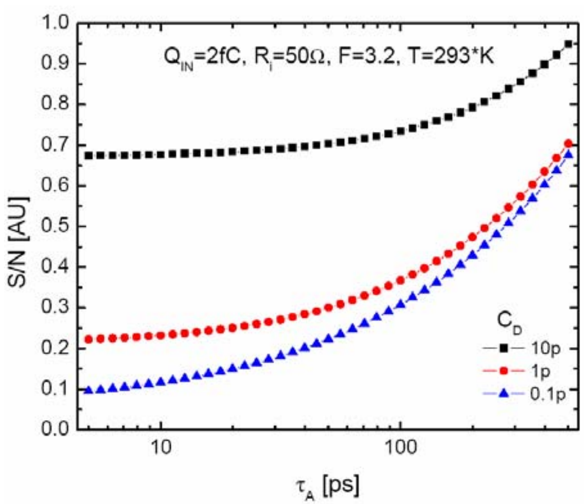
$$S/N = \frac{Q_{gen}}{\sqrt{k \cdot T \cdot (F-1) \cdot C_D}} \cdot \frac{\sqrt{1+m}}{1-m} \cdot \frac{\tau_S}{t_{tr}} \cdot \left(-e^{-t_{tr}/\tau_S} + m \cdot e^{-t_{tr}/\tau_A} + 1 - m\right)$$



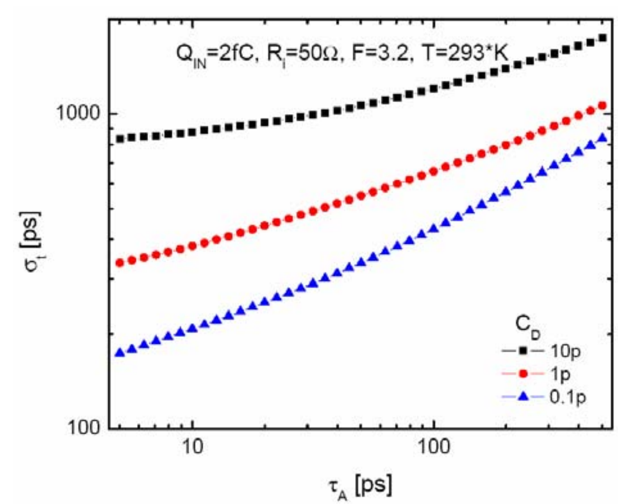

*S/N ratio (left) and $\sigma_t$ (right) as a function of $C_D$, for three values of $R_i$.*

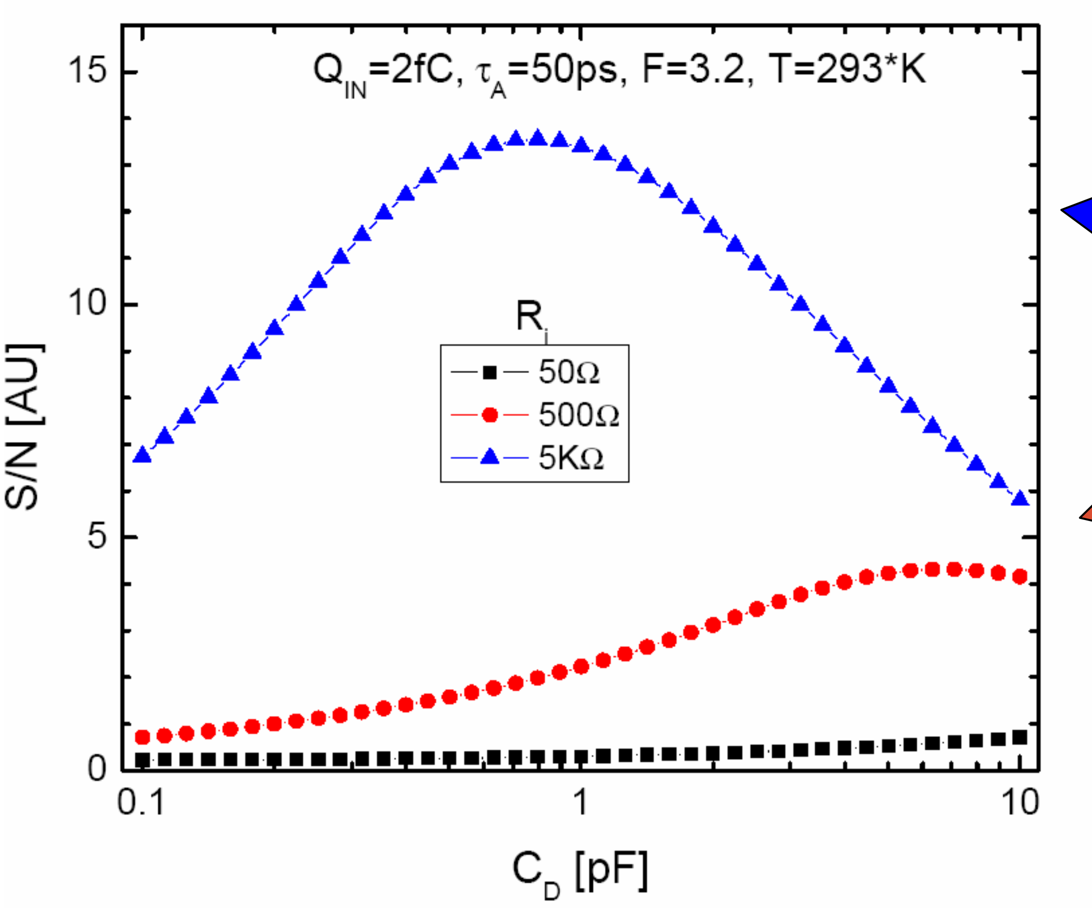



$$\sigma_t = \frac{t_{tr} \cdot \sqrt{k \cdot T \cdot (F-1) \cdot C_D}}{Q_{gen}} \cdot \frac{1-m}{\sqrt{1+m}} \cdot \frac{1}{e^{\frac{m \cdot \ln m}{2\cdot(1-m)}} - e^{\frac{\ln m}{2\cdot(1-m)}}}$$




*S/N ratio (left) and $\sigma_t$ (right) as a function of $\tau_A$, for three values of $C_D$ .*






Maximums:

$\tau_{S1}$=1pF*5000Ω=5ns
$\tau_{S2}$=10pF*500Ω=5ns

in the analyzed case,
$t_{tr}$=5ns

The Signal/Noise ratio has a maximum for $\tau_S$ = collection time

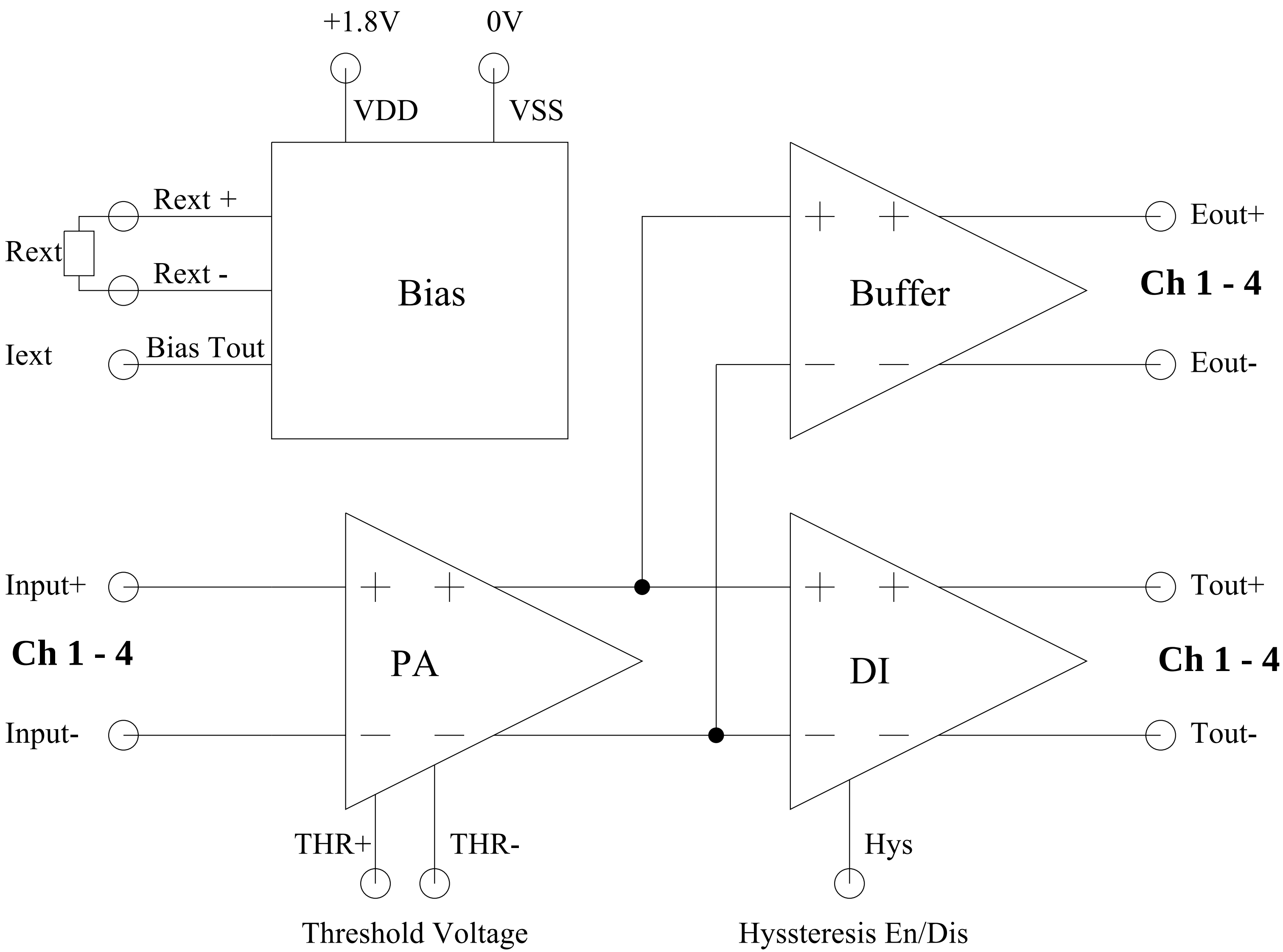
Good lectures:

Helmudt Spieler
Radiation Detectors and Signal Processing (lecture series presented at University of Heidelberg, Oct. 10-14, 2005)
http://www-physics.lbl.gov/~spieler/Heidelberg_Notes_2005/pdf/IV_Signal_Processing.pdf

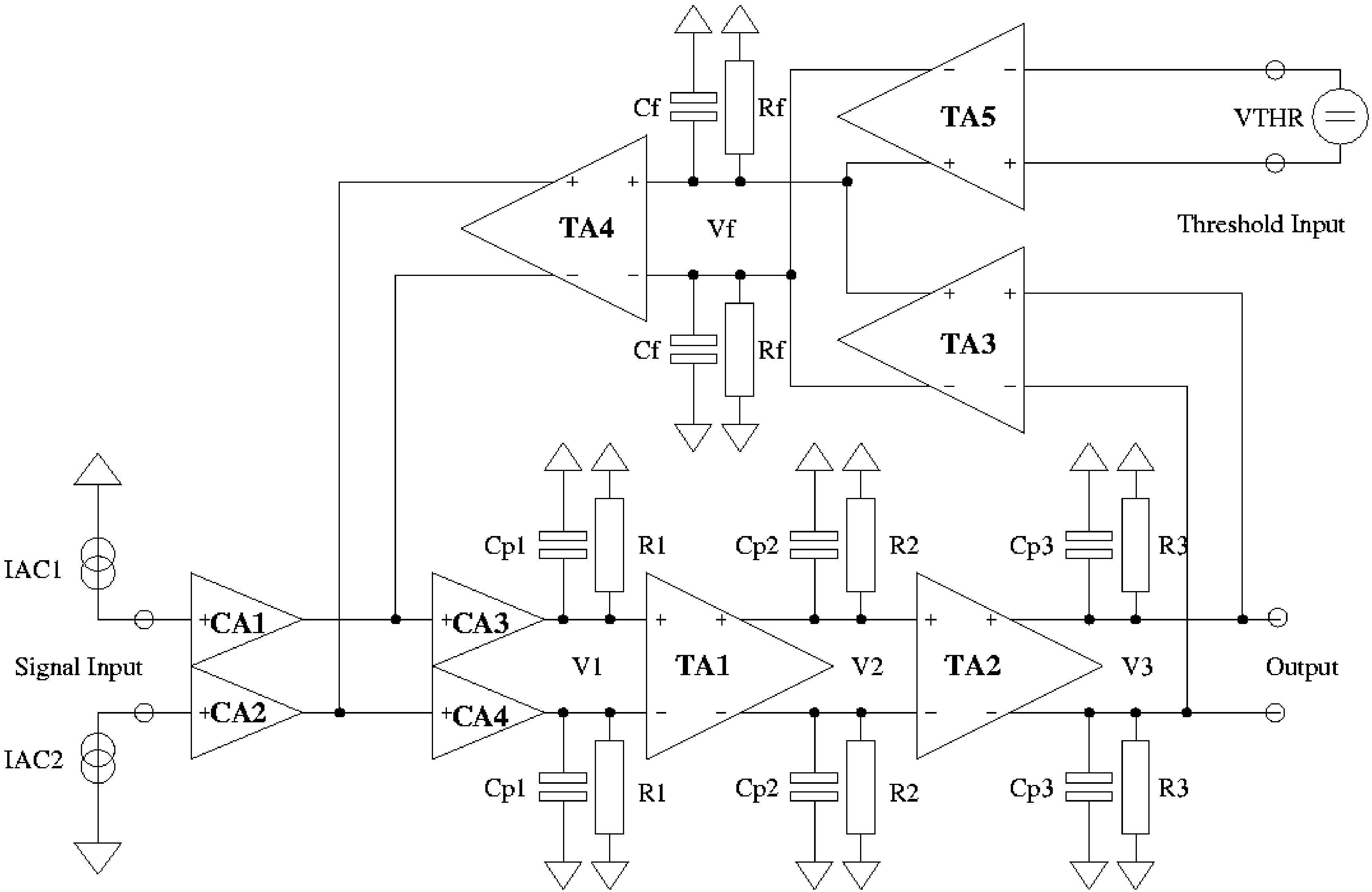
# PADI

# a fast PreAmplifier DIscriminator

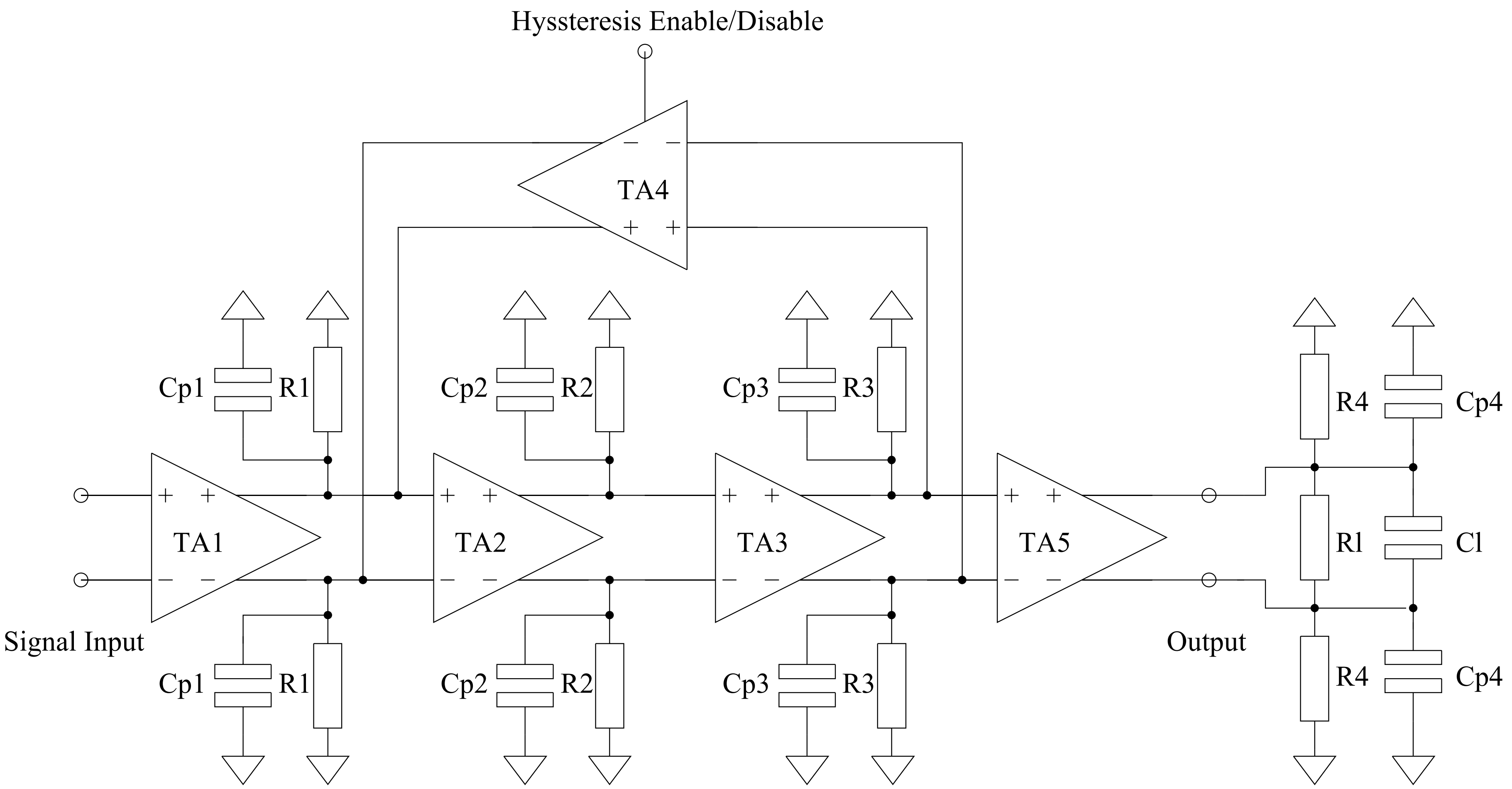
# PADI : block diagram



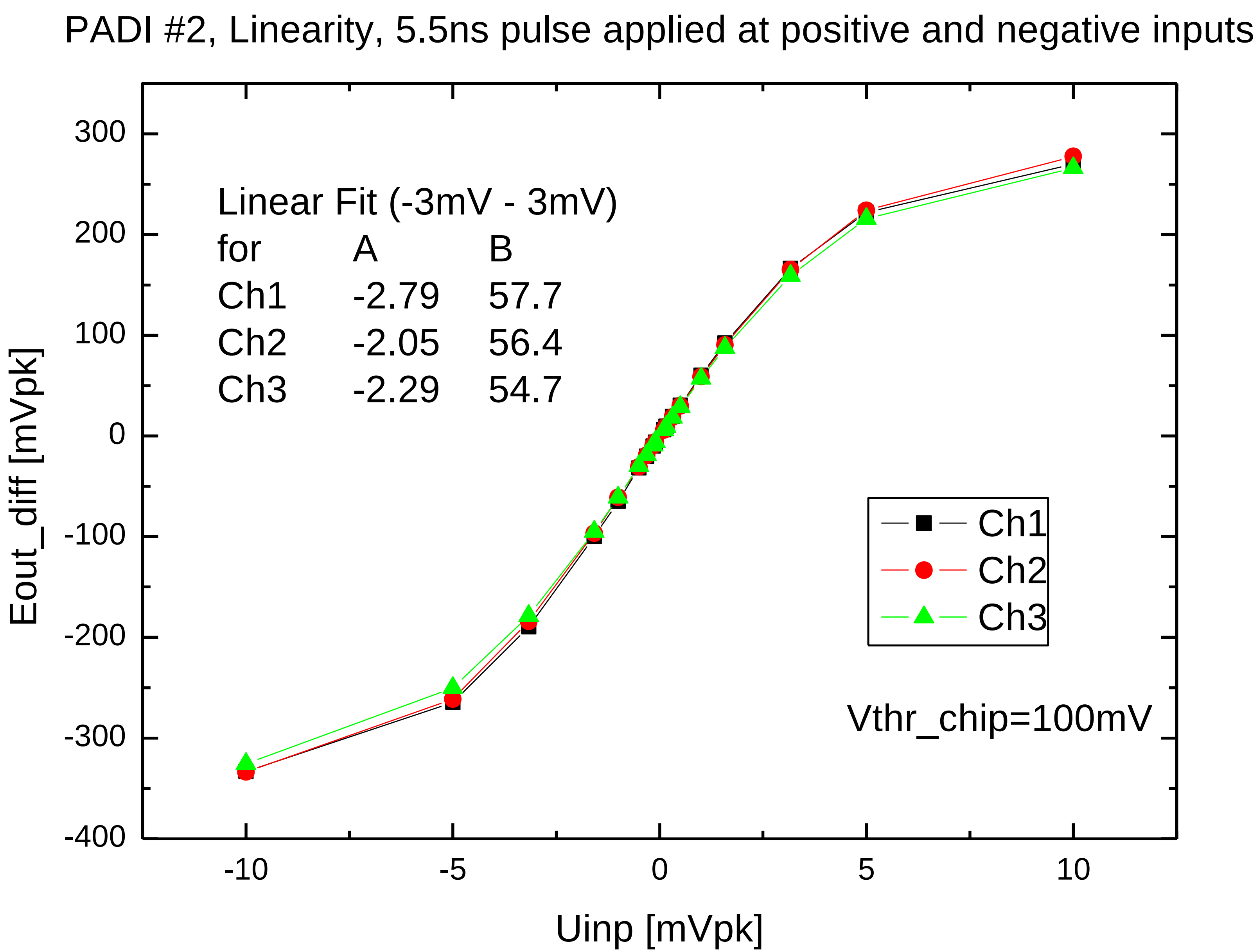
# Preamplifier: *AC equivalent diagram*



# Discriminator: AC equivalent diagram



# Linearity: Pulse Measurement




First results from PADI, CBM Collaboration Meeting Febr. 2007

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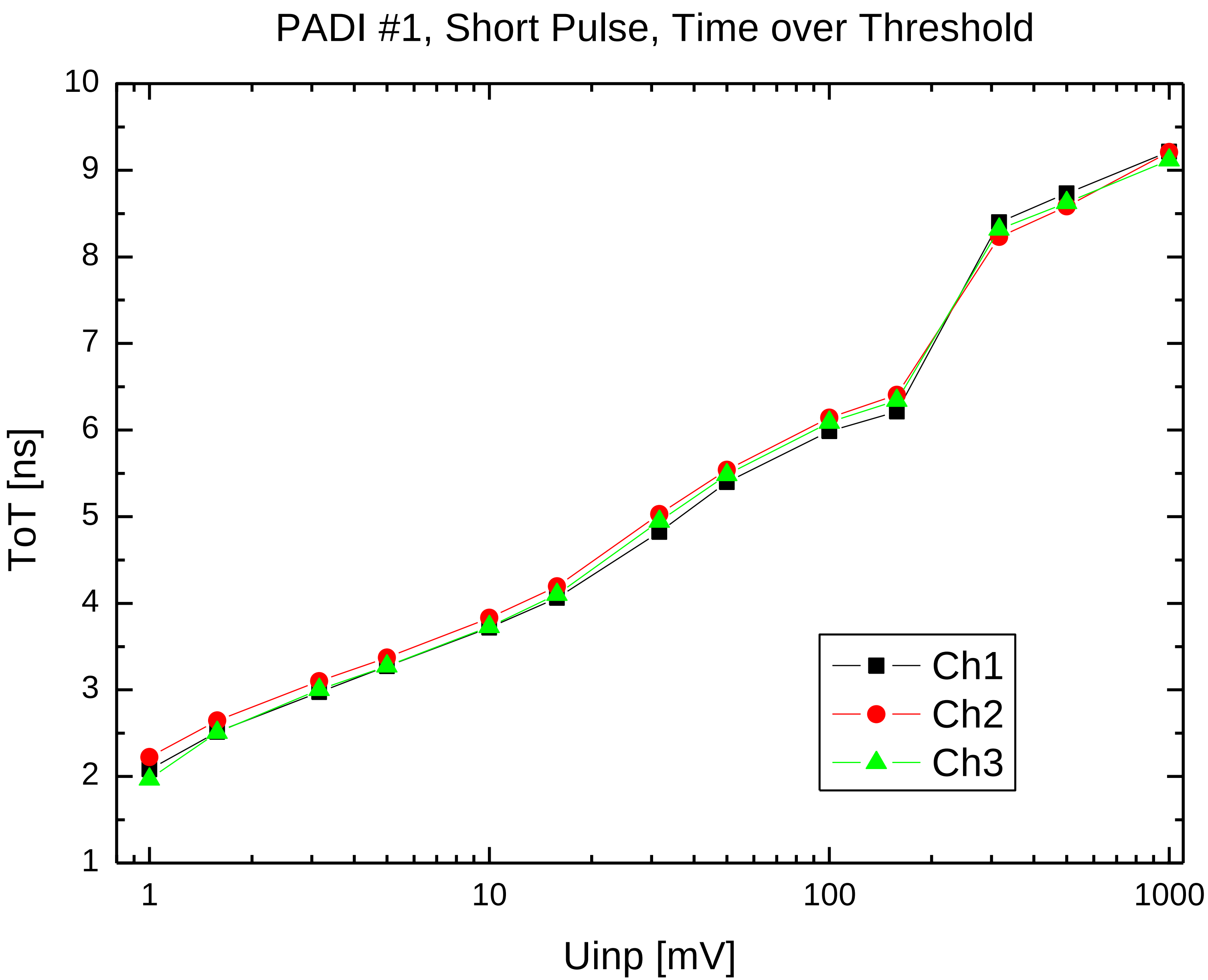
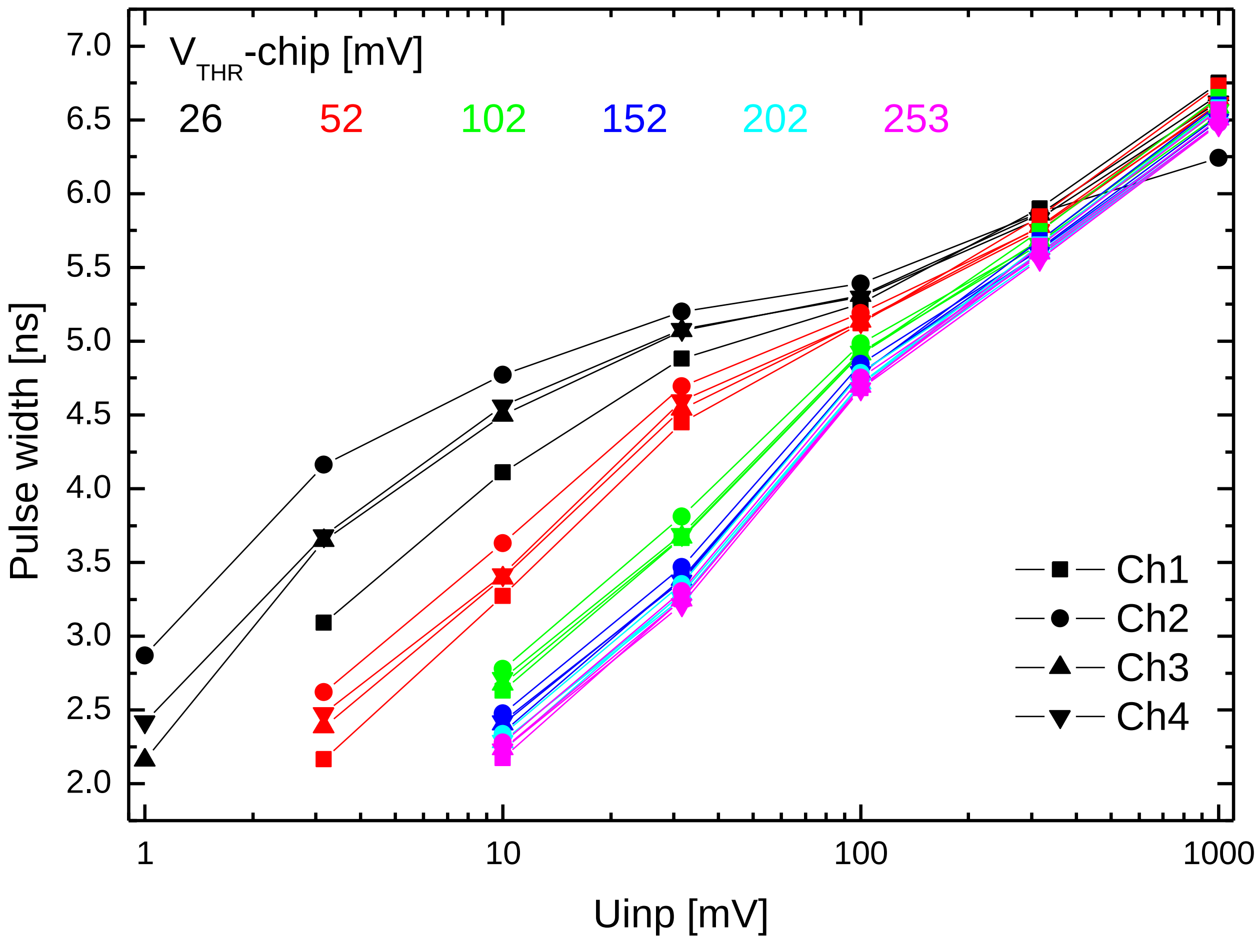


First results from PADI-2, CBM Collaboration Meeting March. 2009

# Time over Threshold behavior



# PADI-4
# A variant for Diamond detectors

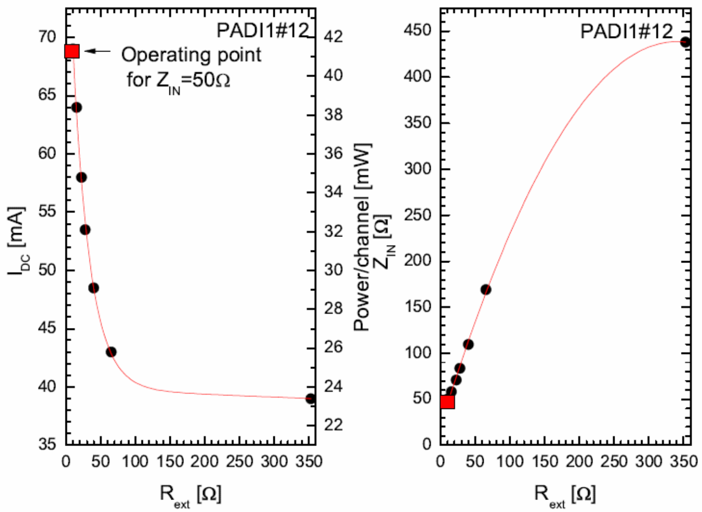
# Main differences of PADI4 relative to PADI2, 3 are in the Preamplifier Design:

1. Input Cascode transistors have a area size 16 times smaller.
2. The Cascode load transistors have a area size ~ 4 times smaller.
3. The current of the input stage is 14 times smaller.

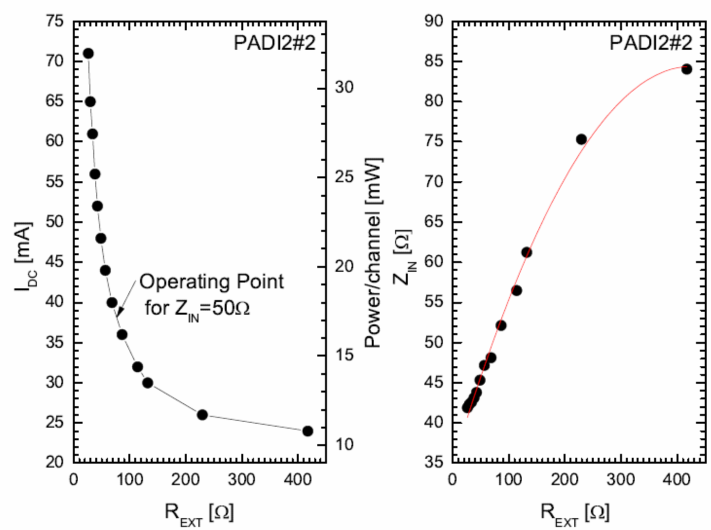
The consequences are the followings:

1. The AC small signal gain is ~ 2 times smaller.
2. The AC input impedance is bigger (see graphs).
3. The output Noise is ~ 1.5 times bigger.
4. The Charge responsivity is ~ 2.7 times bigger.

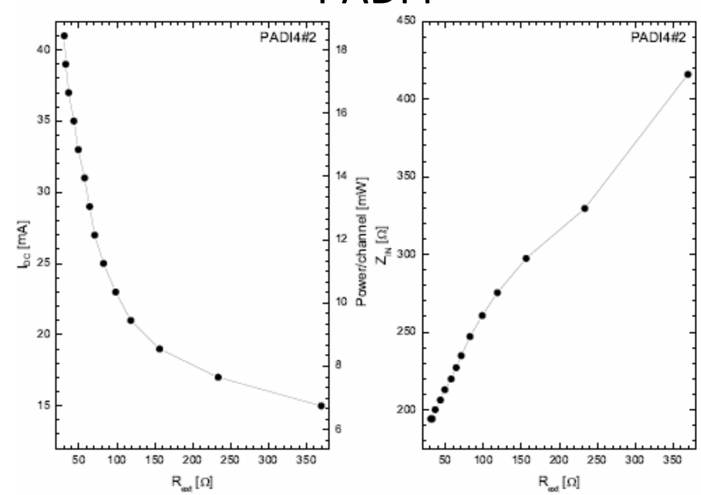
PADI1

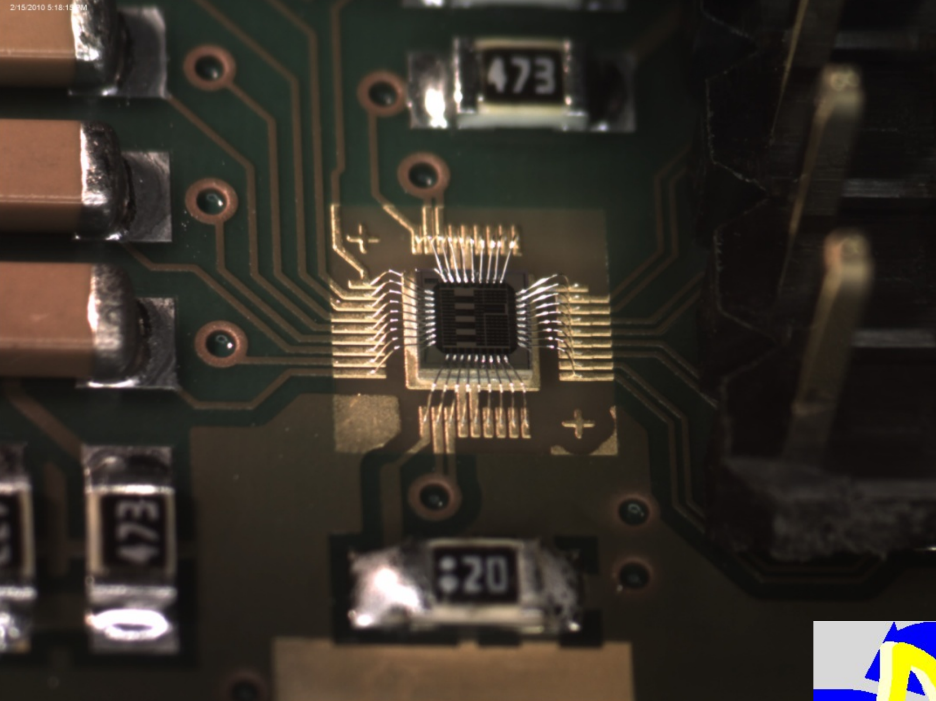



PADI2,3




PADI4

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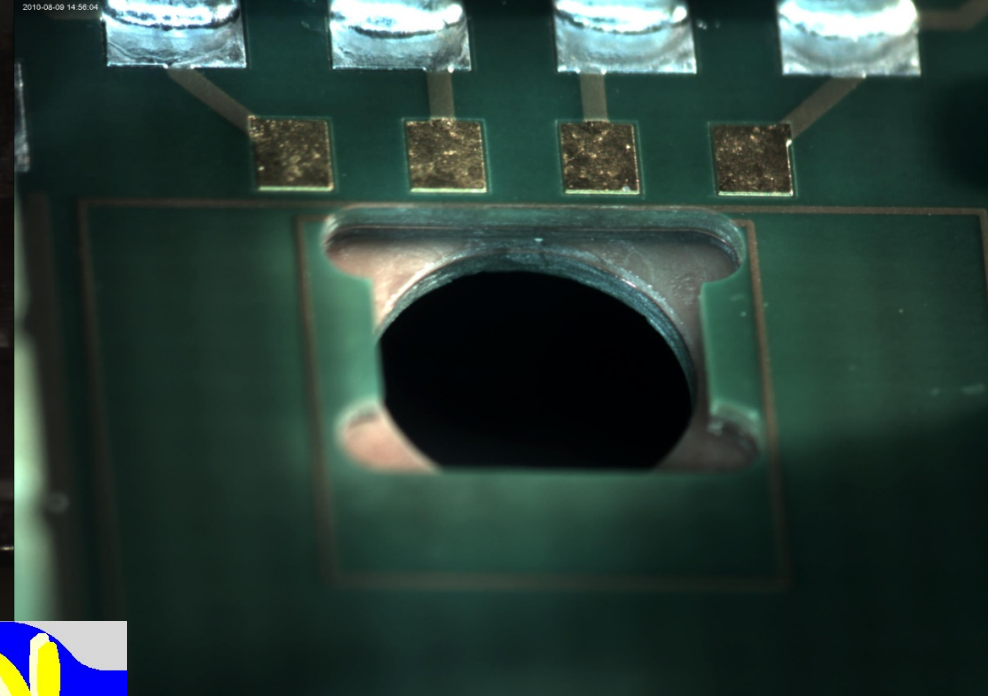
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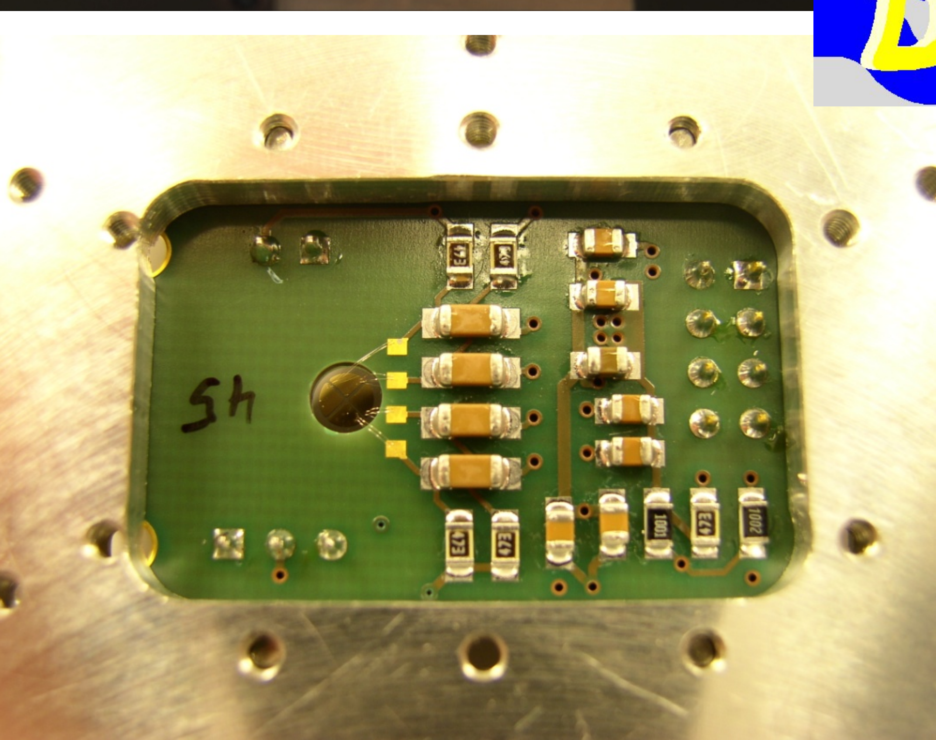
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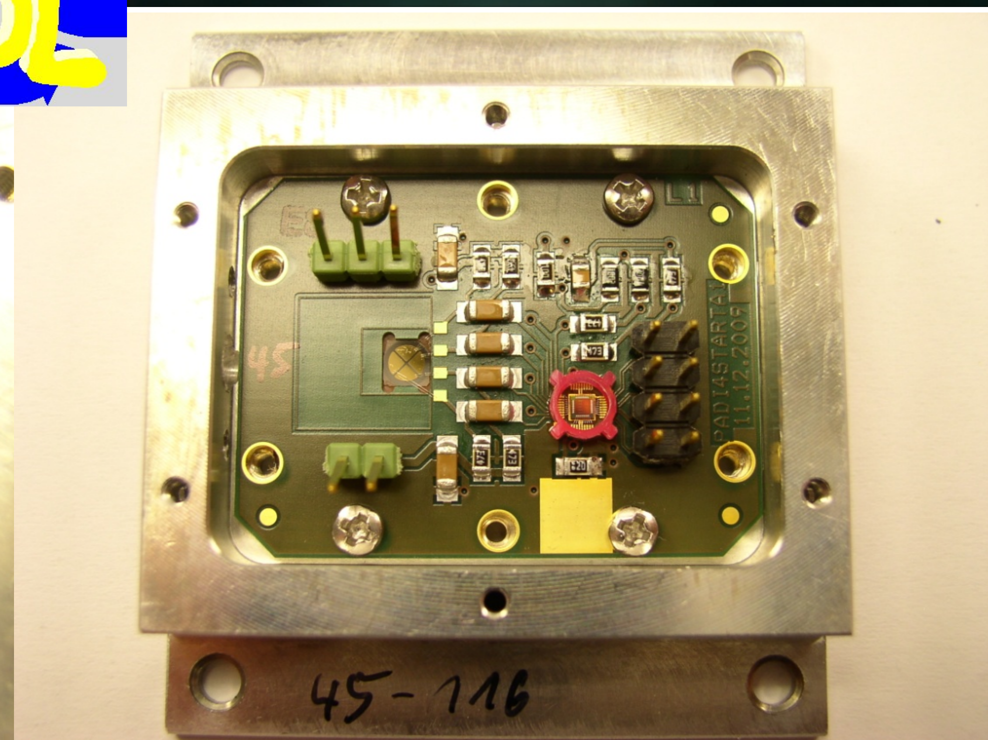
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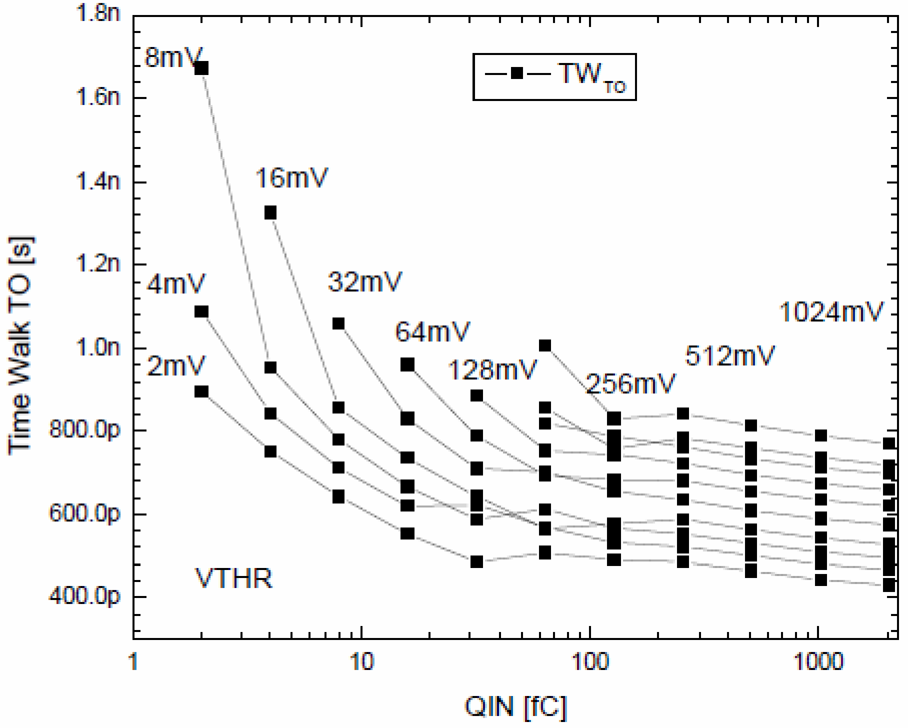
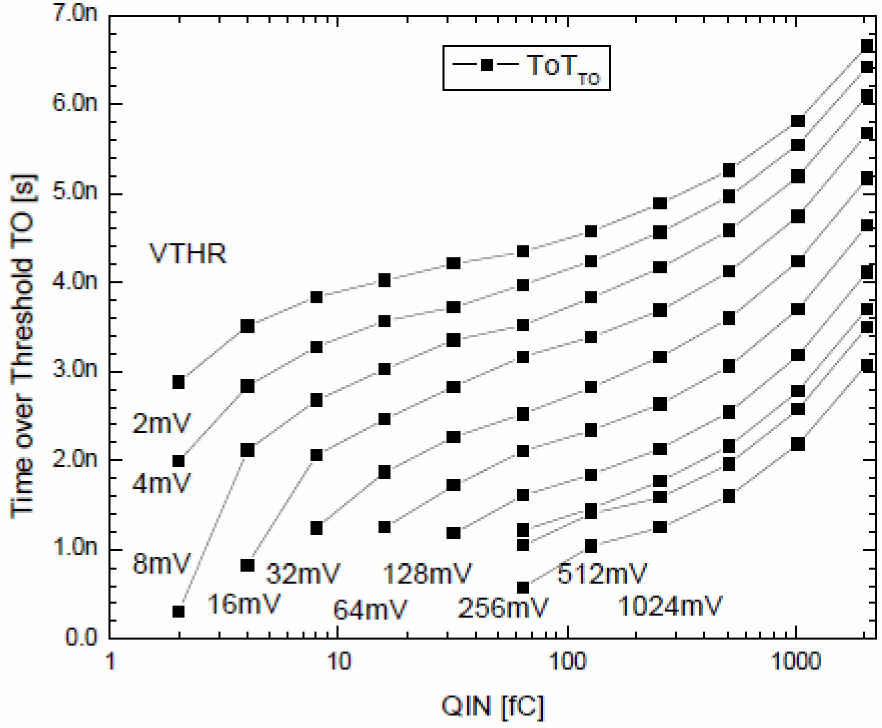
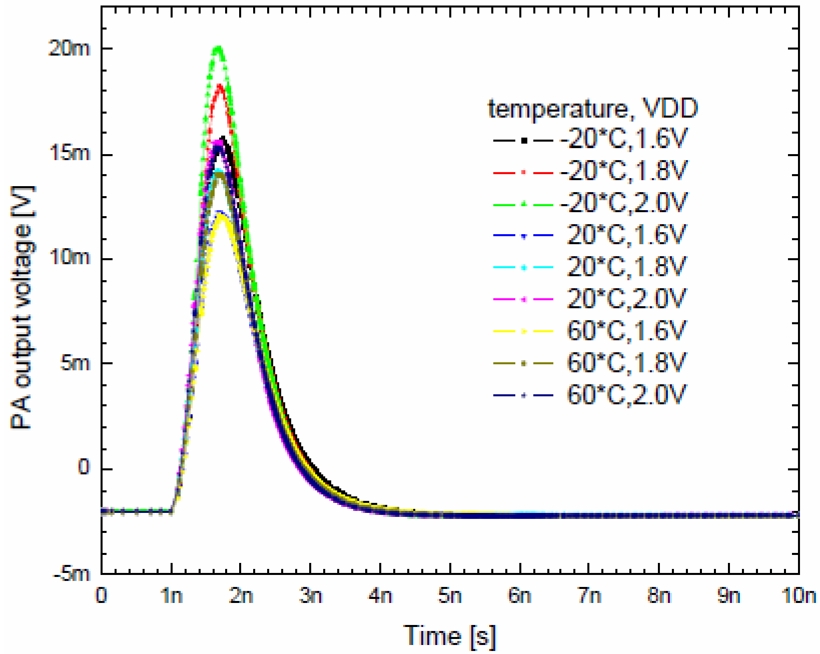
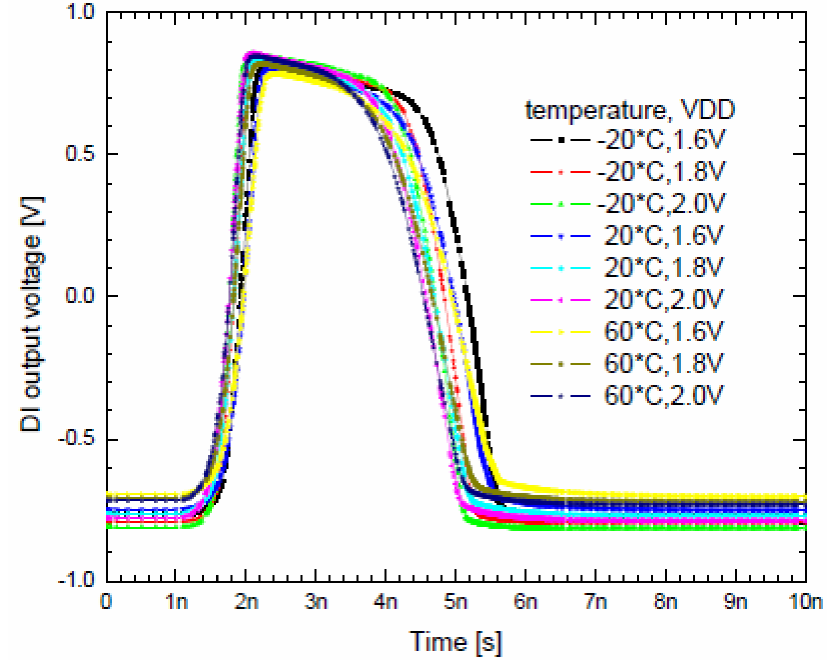
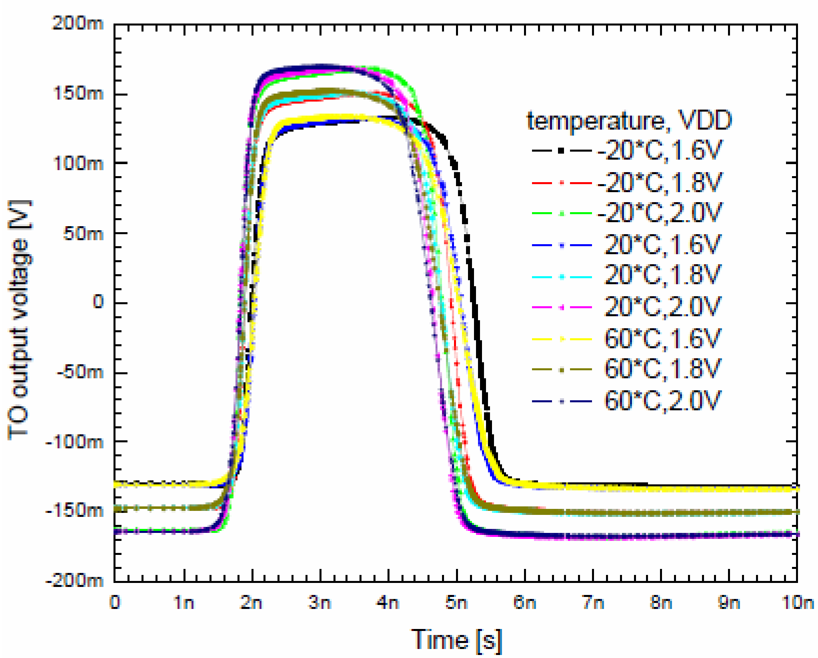
# PADI-5; Time Walk and Time over Threshold dependence to QIN and VTHR





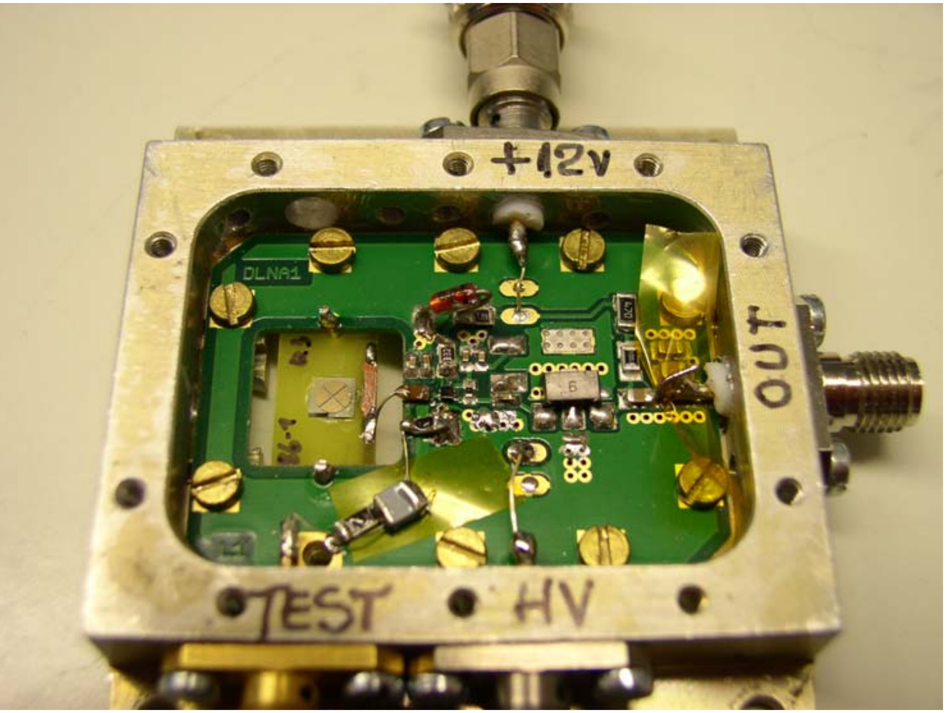



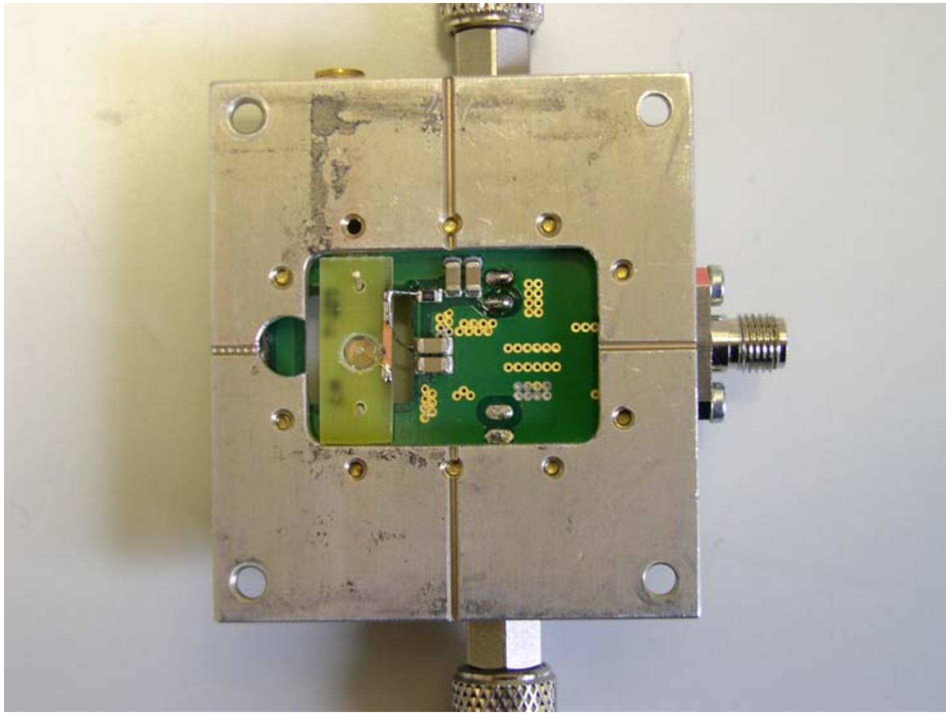




# PADI-5 Transient response to QIN=2fC, at VTHR=2mV, for different temperatures (-20, 20, 60*C) and VDD (1.6, 1.8, 2.0 V)

# DLNA
# (Diamond Low Noise Amplifier)

The BGU7003 MMIC is a wideband amplifier in SiGe:C technology from NXP Semiconductors (Philips)-2009: low noise and high gain, recommended for frequency interval 40MHz - 6GHz, made in large scale, for handy's – low cost!.

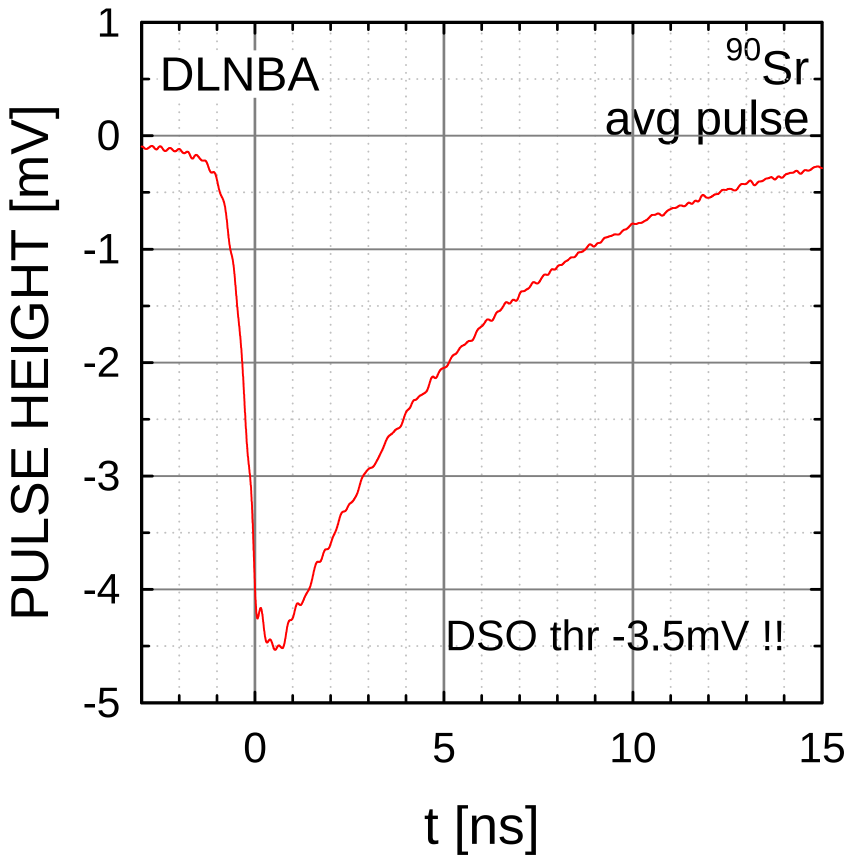


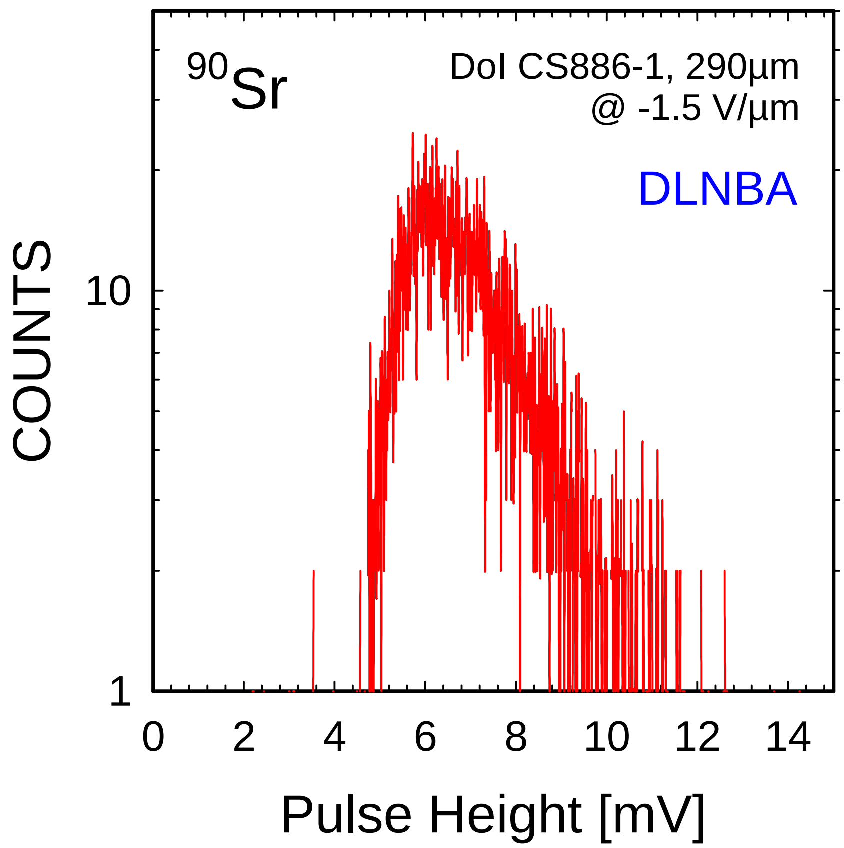



# DEVELOPMENT OF NEW PAD ASSEMBLIES (GSI)

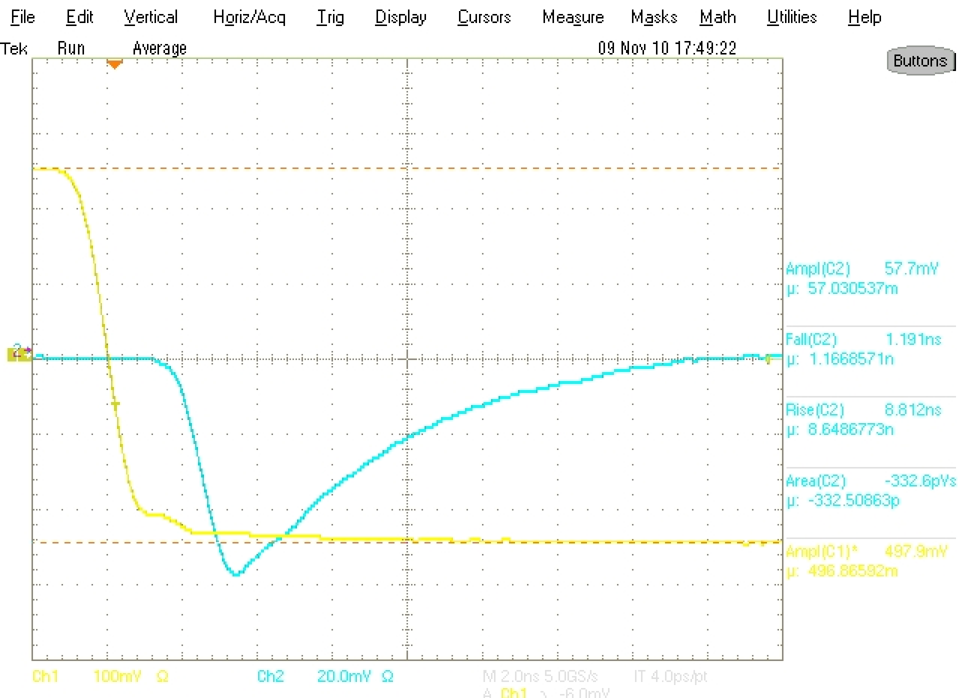
## First laboratory tests with the new Diamond Low Noise Broadband Amplifier DLNBA

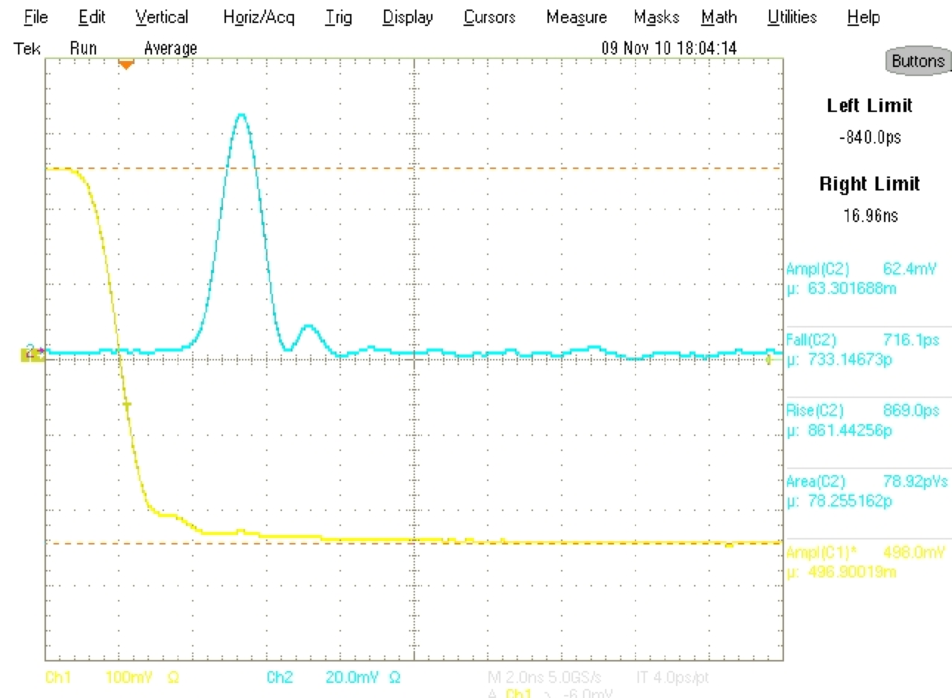
M. Ciobanu, M. Träger, S. Rahman, EBe



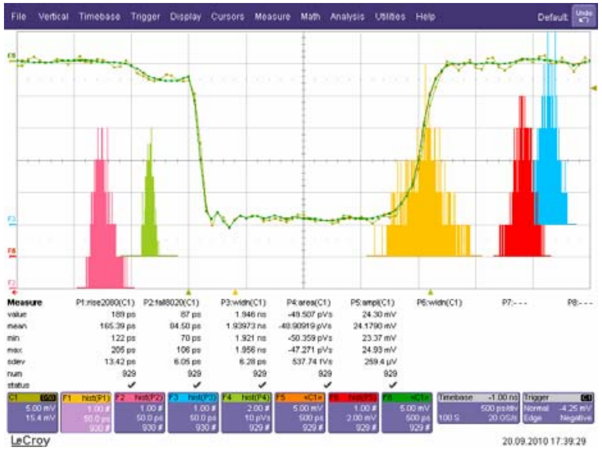
## DLNA through 0.4pF   Step pulse excitation   DBA2 through 1pF

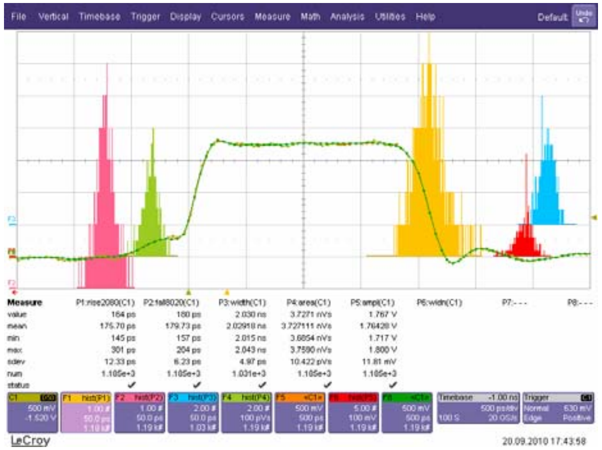


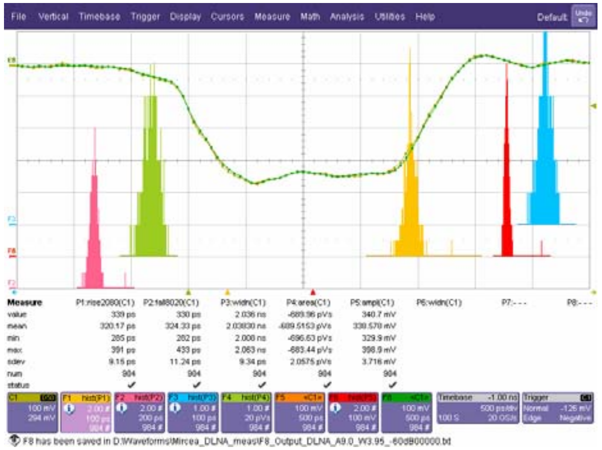




| | DBAII- | DBAII+ | DLNA2- | DLNA2+ | Ratio |
|---|---|---|---|---|---|
| UOUT [mV] | 63.3 | -62.64 | -57.03 | 57.76 | |
| UIN [mV] | -15.71 | 15.71 | -15.71 | 15.71 | |
| QIN [fC] | 15.71 | 15.71 | 6.284 | 6.284 | |
| RQVpk[mV/fC] | -4.03 | -3.99 | 9.08 | 9.19 | 2.3 |
| UN [mVrms] | 1.600 | 1.600 | 1.306 | 1.306 | 0.82 |
| ENC [fC] | 0.397 | 0.4 | 0.143 | 0.142 | 0.355 |
| tR [ns] | 0.733 | 0.840 | 1.18 | 1.2 | 1.47 |
| tF [ns] | 0.861 | 0.991 | 8.5 | 8.48 | 9.4 |
| AREA [pVs] | 78.26 | -92.52 | -332 | 320.6 | 3.8 |
| RQVint [Ω] | 5410 | | 51870 | | 9.6 |
| ZIN [Ω] | ~50 | | ~470* | meas. at 1/2 max | 9.5 |

# Pulse excitation measurements set-up DBA2 DLNA

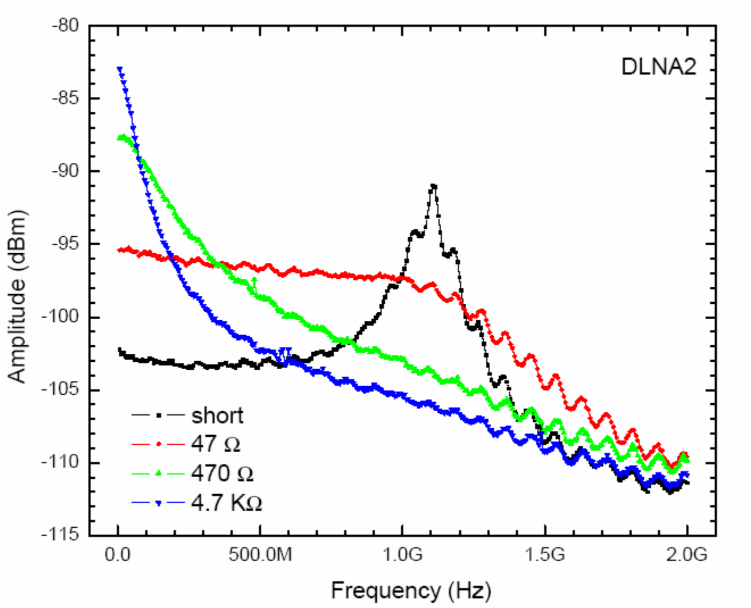


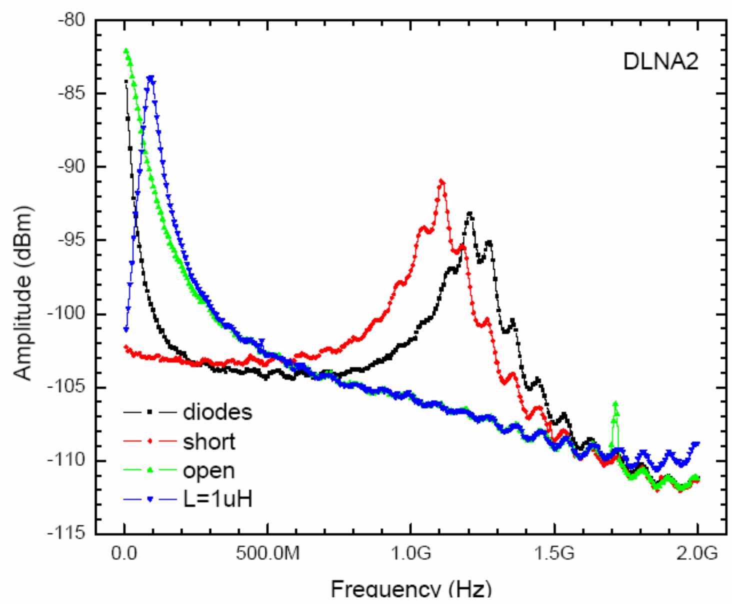


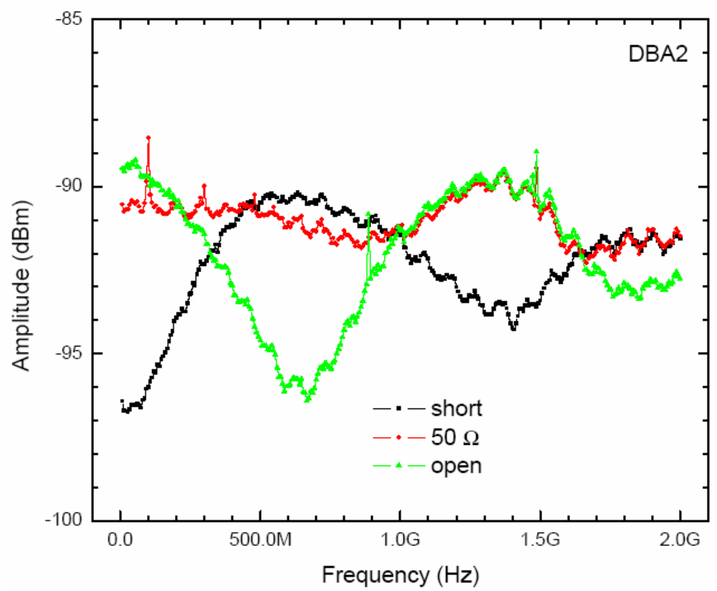


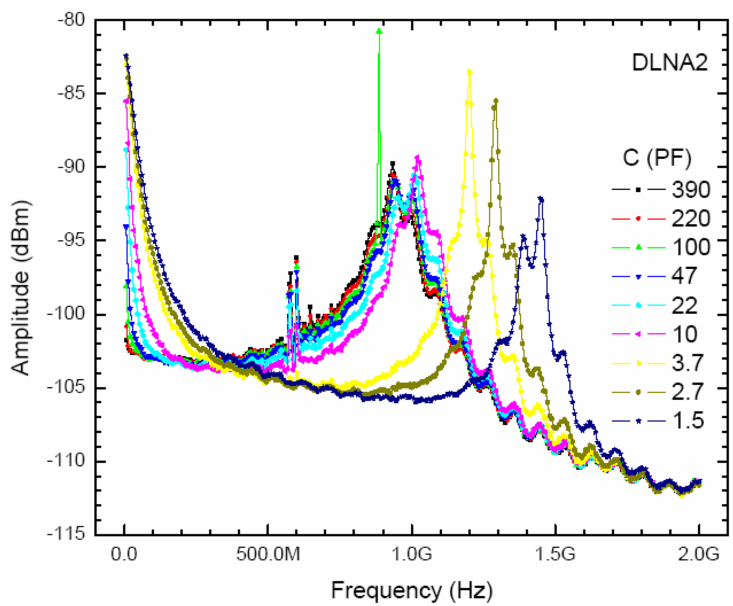
| | AVTEK +Lecroy | DBA2 | DLNA1 | |
|---|---|---|---|---|
| amplit. | 24.30mV | 1767mV | 340.7mV | |
| t1 | 87ps | 164ps | 330ps | |
| t2 | 189ps | 180ps | 339ps | |
| tW | 1.946ns | 2.03ns | 2.036ns | |
| AREA | 49.5pVs | 3.727nVs | 689.96pVs | 0.185 |
| gain | | 72.7 | 14.02 | 0.192 |
| tR corrected | | 139ps | 318ps | 2.3 |

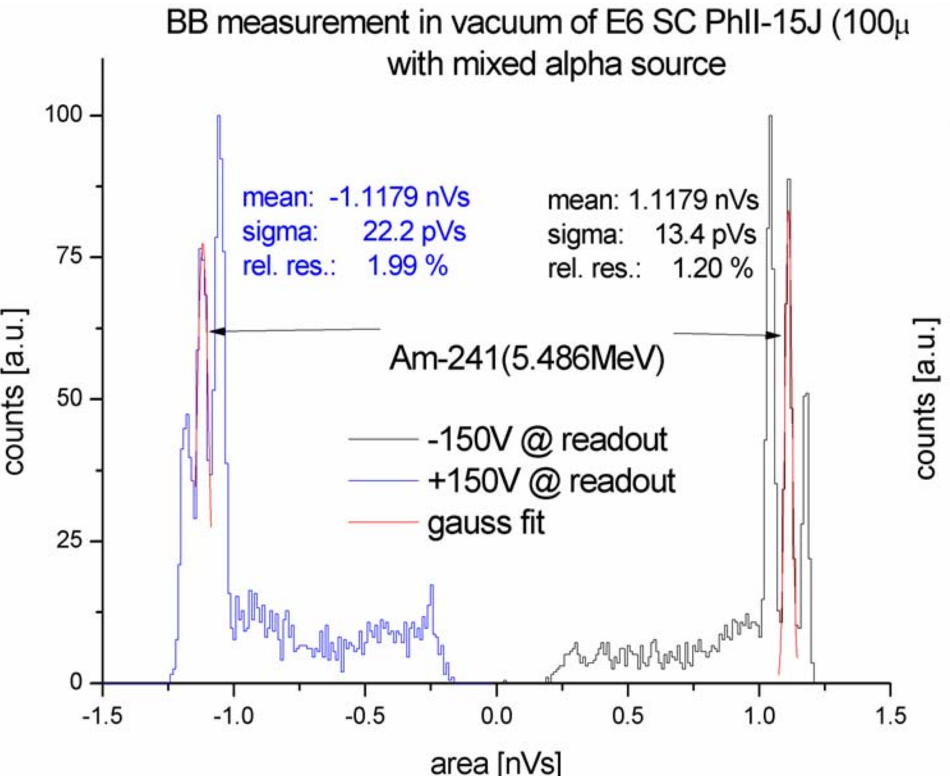
# Comparative Noise density measurements

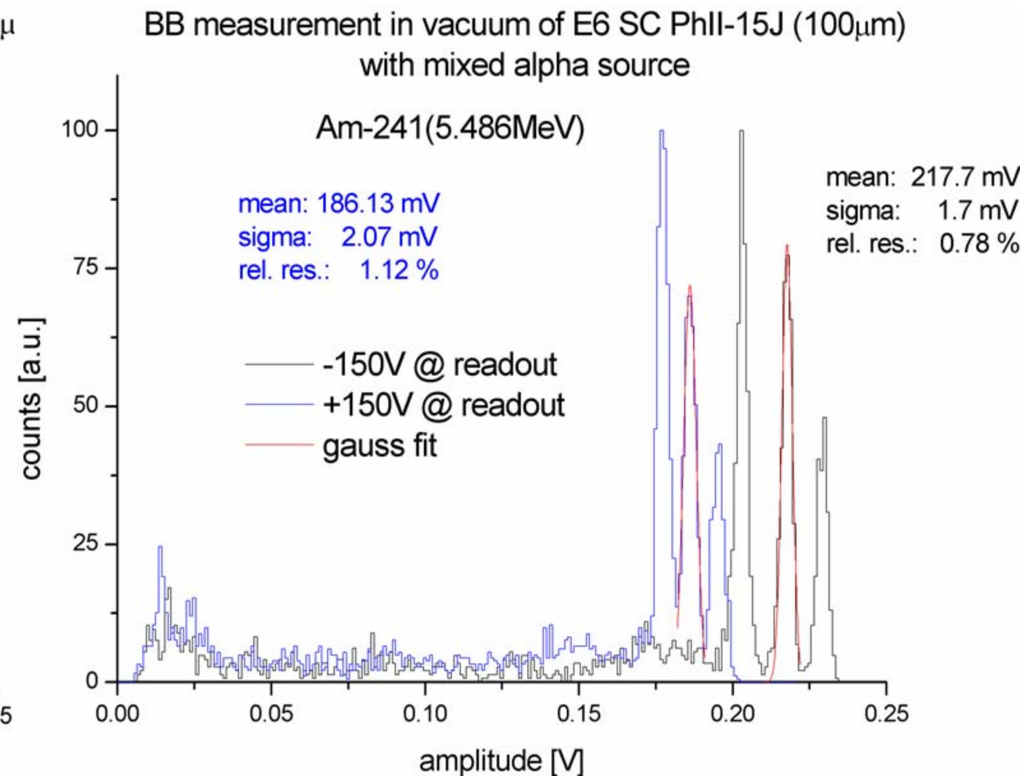


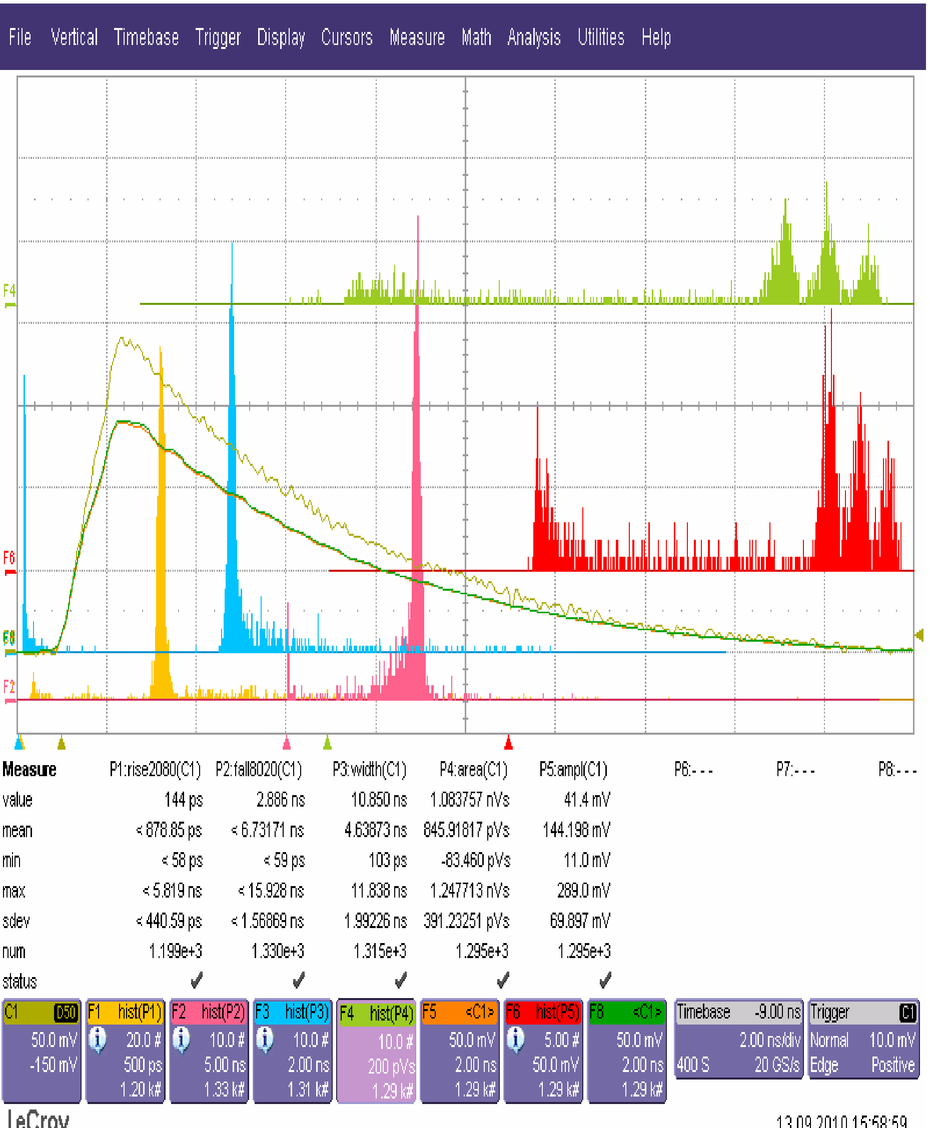



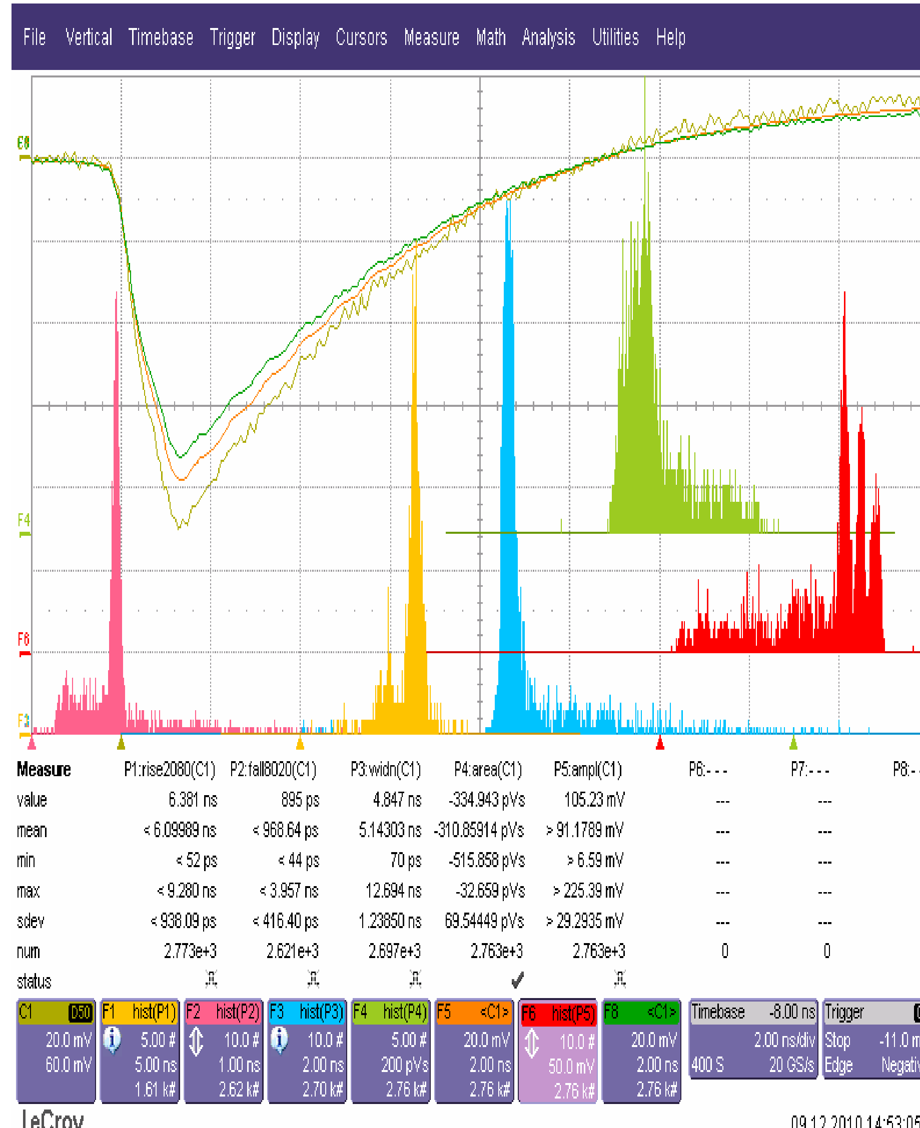




BB measurement in vacuum of E6 SC PhII-15J (100μ
with mixed alpha source
mean: -1.1179 nVs
sigma: 22.2 pVs
rel. res.: 1.99 %
mean: 1.1179 nVs
sigma: 13.4 pVs
rel. res.: 1.20 %
Am-241(5.486MeV)
-150V @ readout
+150V @ readout
gauss fit
counts [a.u.]
area [nVs]


BB measurement in vacuum of E6 SC PhII-15J (100μm)
with mixed alpha source
Am-241(5.486MeV)
mean: 186.13 mV
sigma: 2.07 mV
rel. res.: 1.12 %
mean: 217.7 mV
sigma: 1.7 mV
rel. res.: 0.78 %
-150V @ readout
+150V @ readout
gauss fit
counts [a.u.]
amplitude [V]

# Tests with Alpha: DLNA with input protection (right) comparative to without (left)



# • Summary

- We have an analytical model of the Diamond Detector – FEE Assemblies

PADI

- PADI-1 and -4 have been tested together with different diamond detectors and the differential connection is stable
- **The use of Time over Threshold information for walk correction was tested in connection with the CAEN-TDC and real detector: works stable**
- The connection PADI to the TDC-GET4 works (see Jochen Fruehauf talk).

DLNA

- The first tests are promising.
- The Bandwidth specified in BGU7003 "Data Sheets" is not reached yet.

# • Outlook

- We will try to complete the model with the general case of the Shockley-Ramo theorem:

$$i_{e,h}(t) = \frac{Q_{gen} \cdot v(E)_{e,h}}{d} e^{t/\tau_{eff} - t/\tau_{e.h}}$$

Then, the model will be very useful for DoI better understanding!

- When the Data Acquisition based on GET-4 will be finished, together with PADI will be a good candidate for multi channels diamond detection assemblies.

- We will continue to clarify the DLNA schematics to obtain the specified <6GHz Bandwidth. With the input protected and in the specified bandwidth, will be a good tool.

THANK YOU!