KNU 검출기학교 2024

SiPM, Preamp, DAQ

김상열

노티스

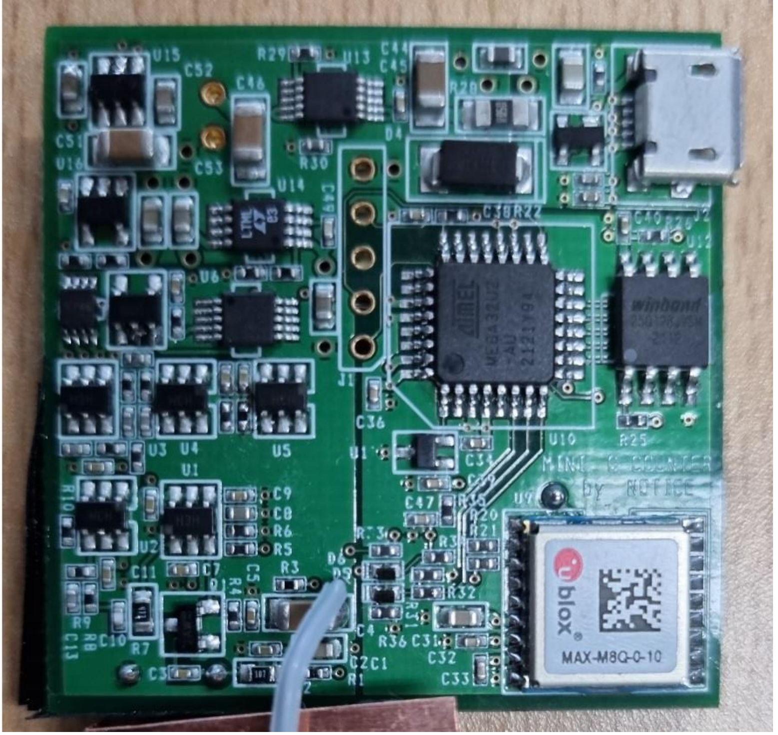
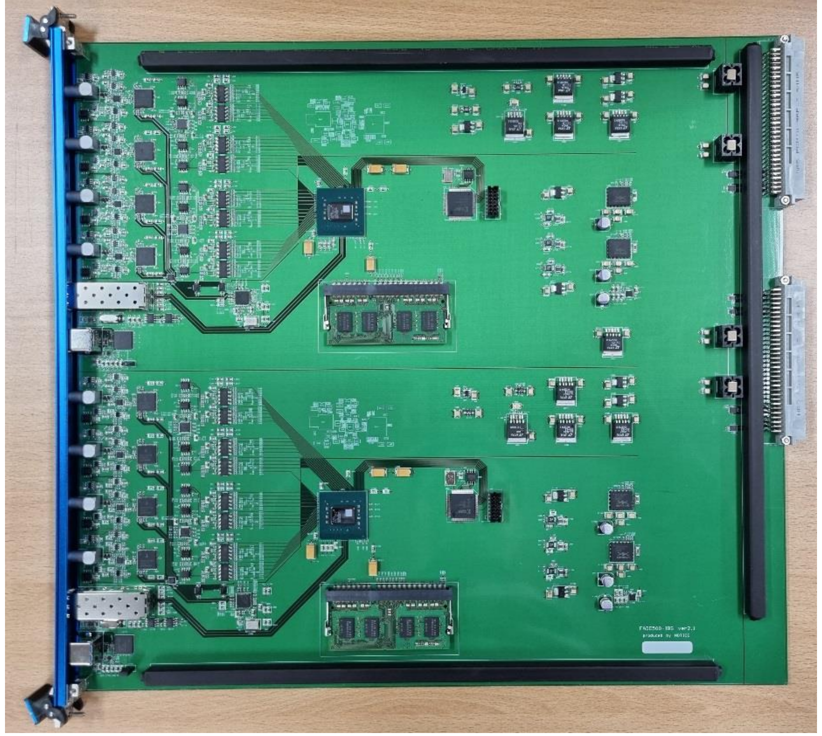
Why Electronics?

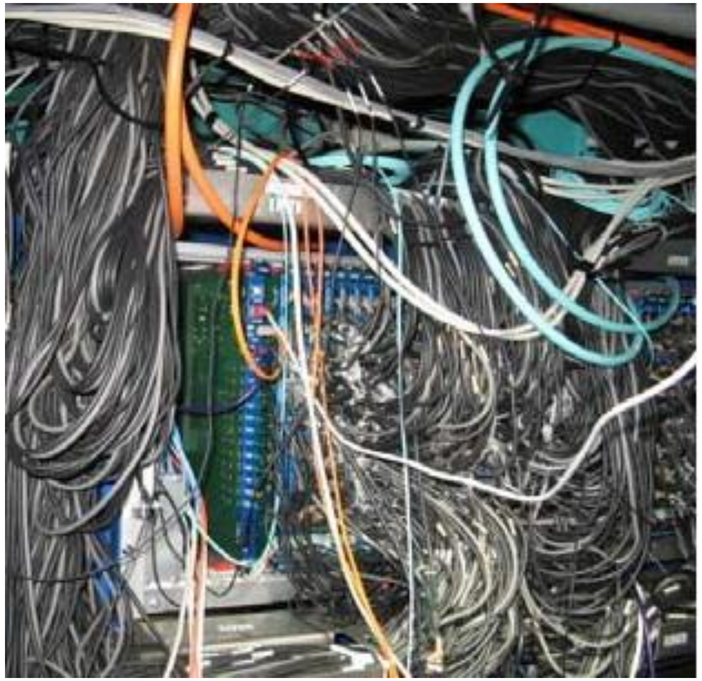
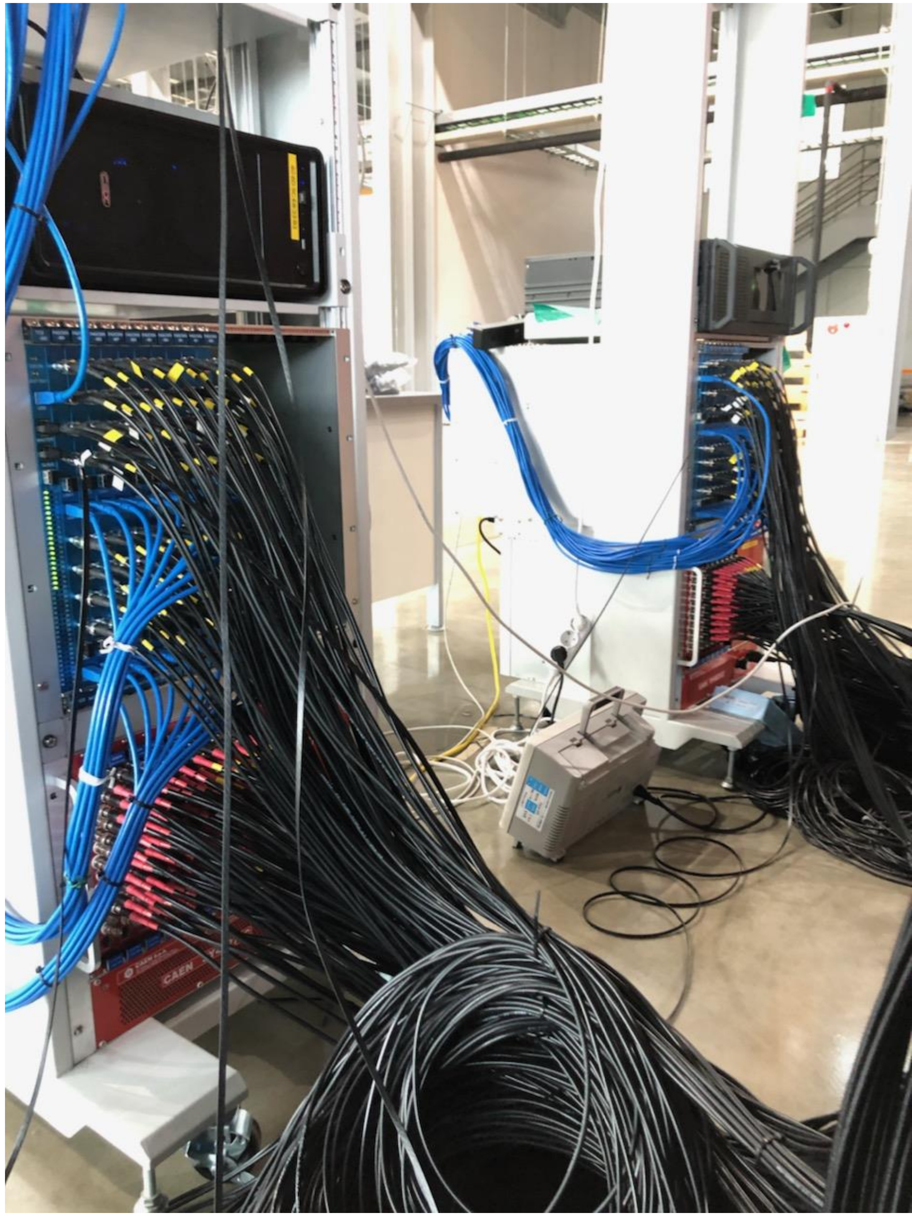
Detector + Electronics + Analysis = Experiment

Detector + Electronics + X = Development

X + Electronics + Analysis = Not Bad?

Detector + X + Analysis = ????


MAX-M8Q-0-10
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We will see :

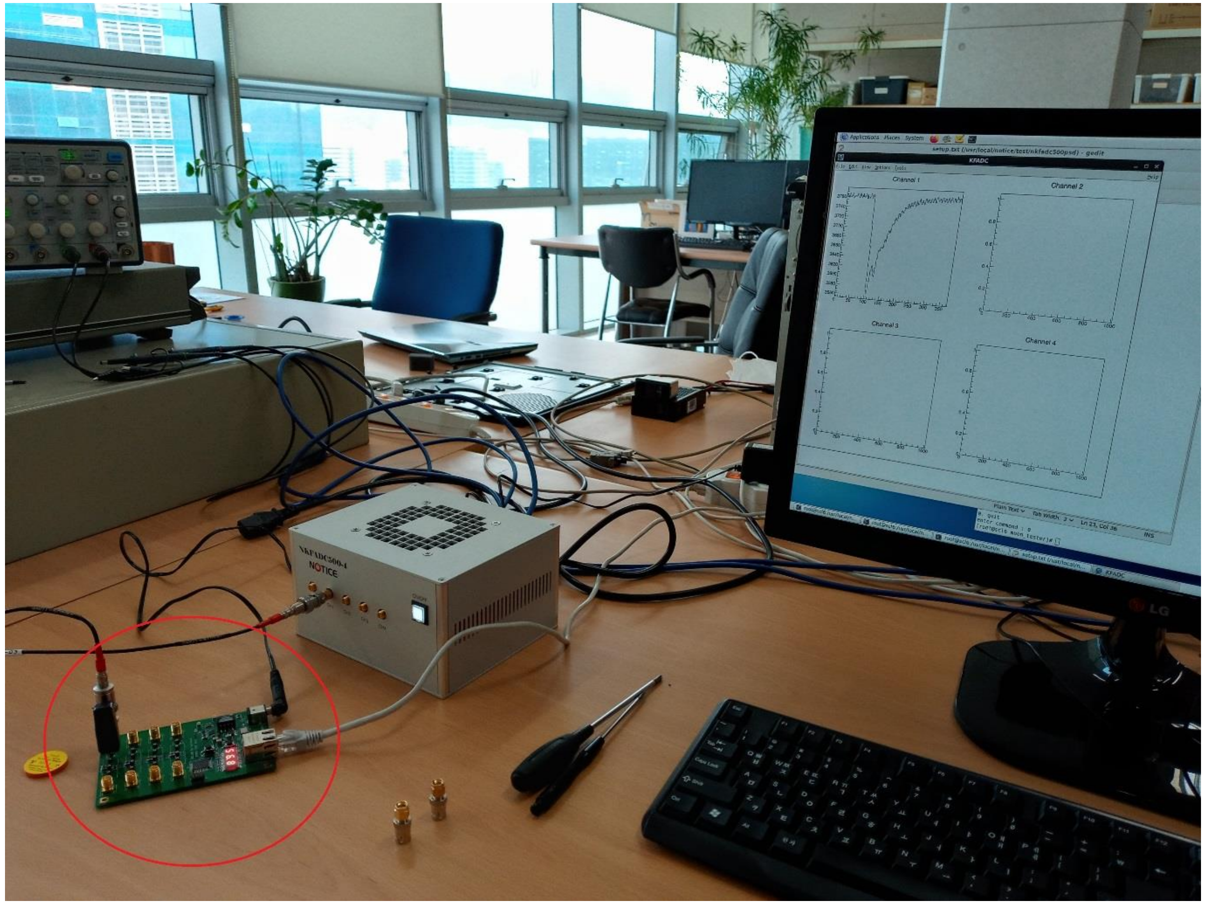
1. What electronics are used?

2. How they work?

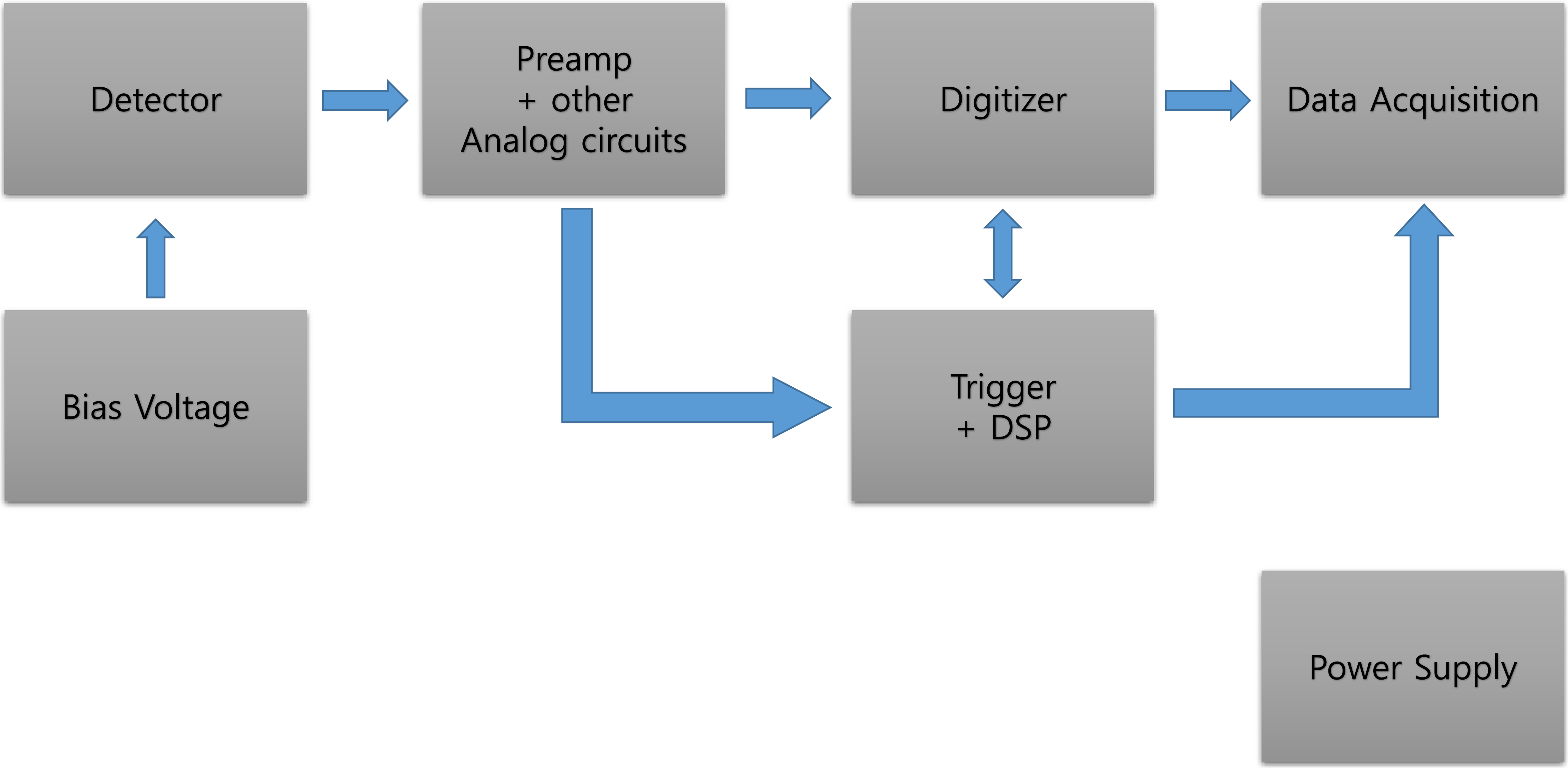
3. How to make them?

~~4. Where to sell?~~

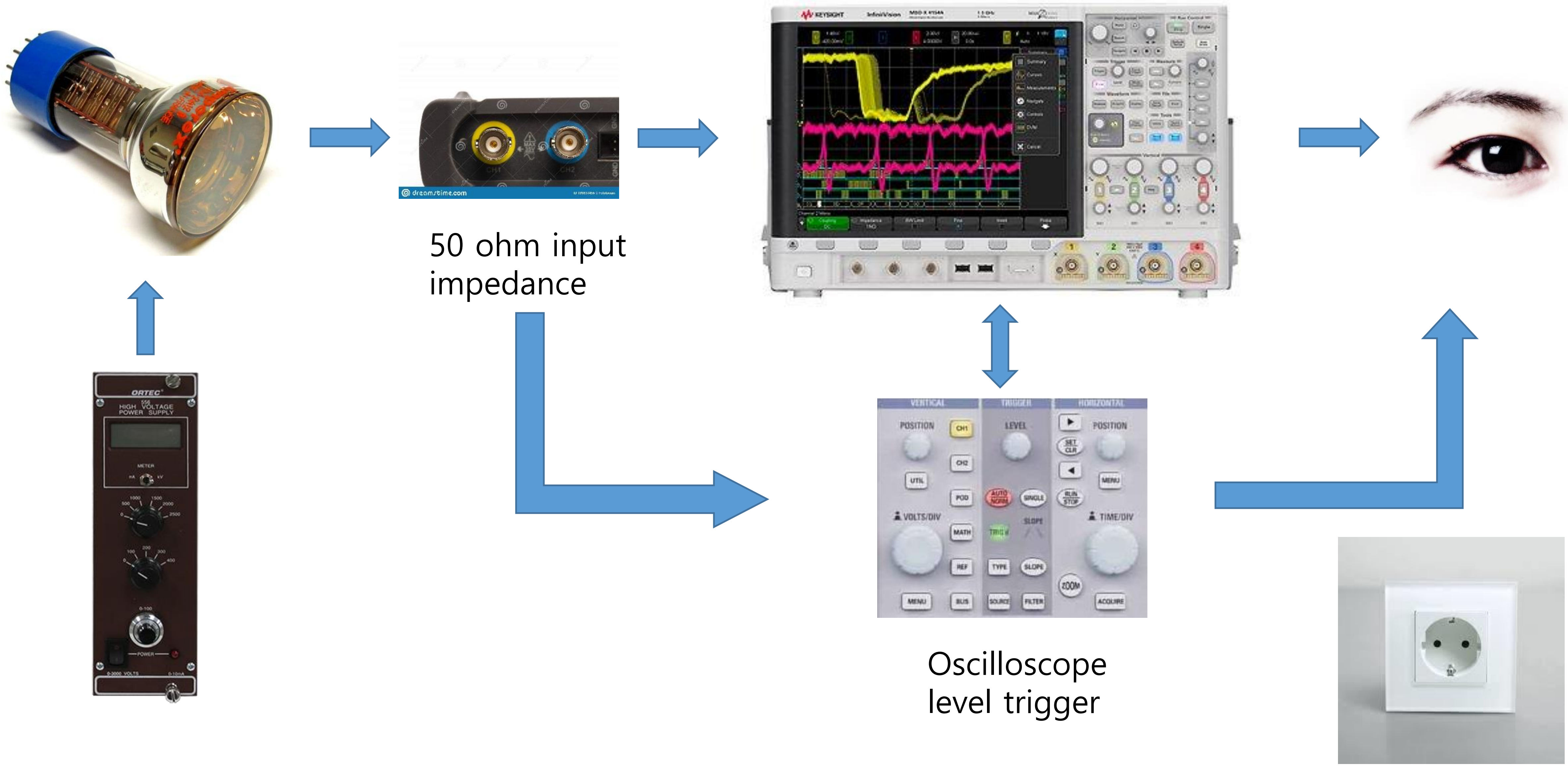
Goal :



Electronics for High energy or Nuclear physics experiment

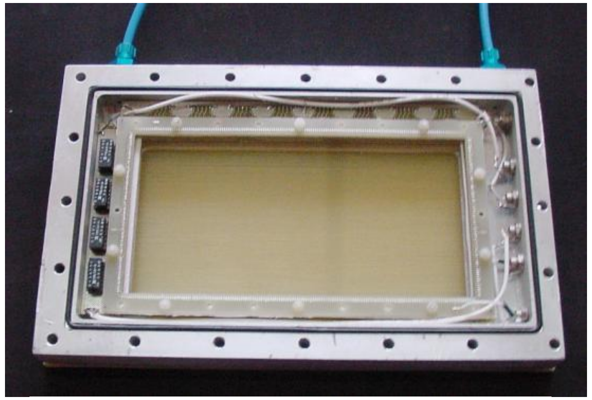


Frequently used example



Signal from some detectors

PMT, SiPM… : gain ~ 10^6
-> ~ 10^10 electrons/MeV
= ~ nC/MeV



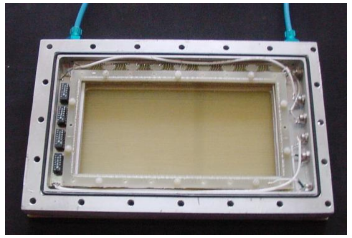
Wire chamber, GEM… : gain ~ 10^2~3
-> ~ 10^6~7 electrons/MeV
= ~ pC/MeV

Photodiode, Ion chamber… : gain ~ 1
-> ~ 10^3~5 electrons/MeV
= ~ fC/MeV

How to measure signal

Typical detector's capacitance
= 10 ~ 1000 pF
and V = Q/C

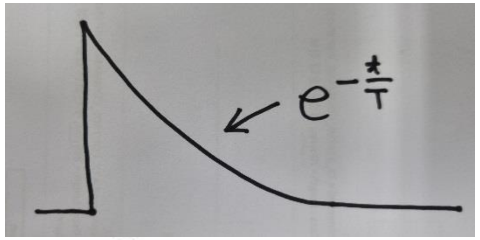
~ nC/100 pF/MeV = ~ V/MeV (OK)



~ pC/100 pF/MeV = ~ mV/MeV (?)

~ fC/100 pF/MeV = ~ uV/MeV (X)

What we measure actually? Charge? Current?



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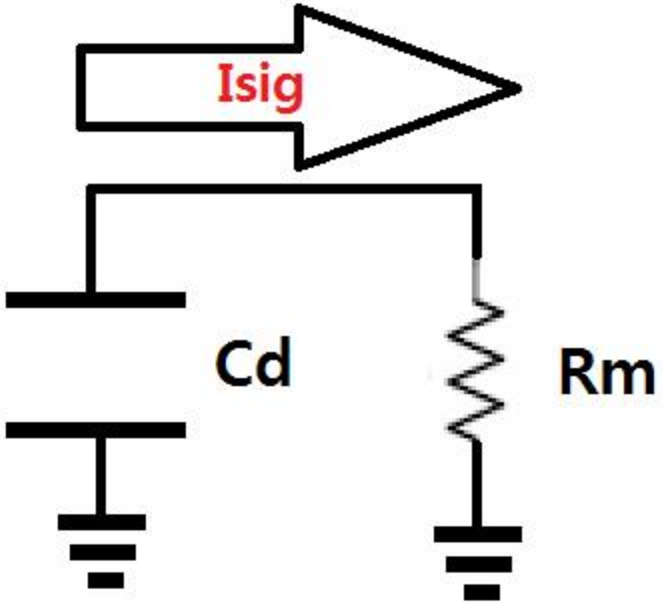


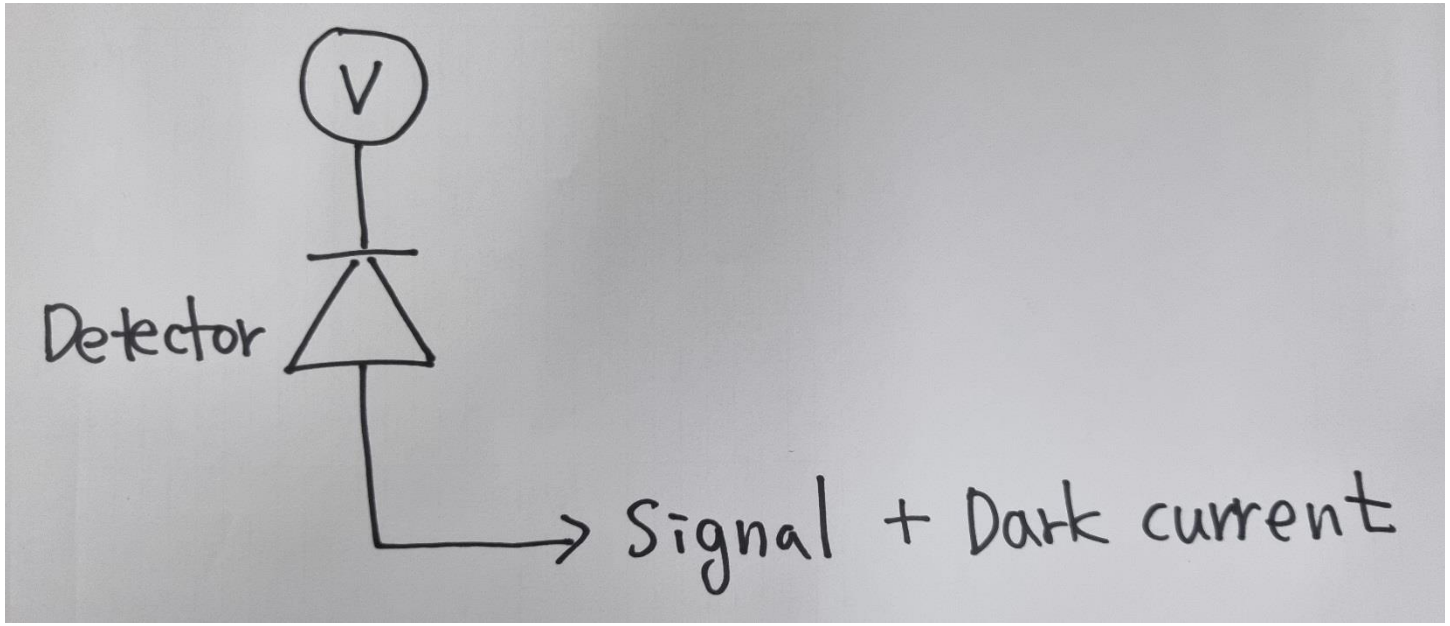
When Idet(detector current) is very fast,

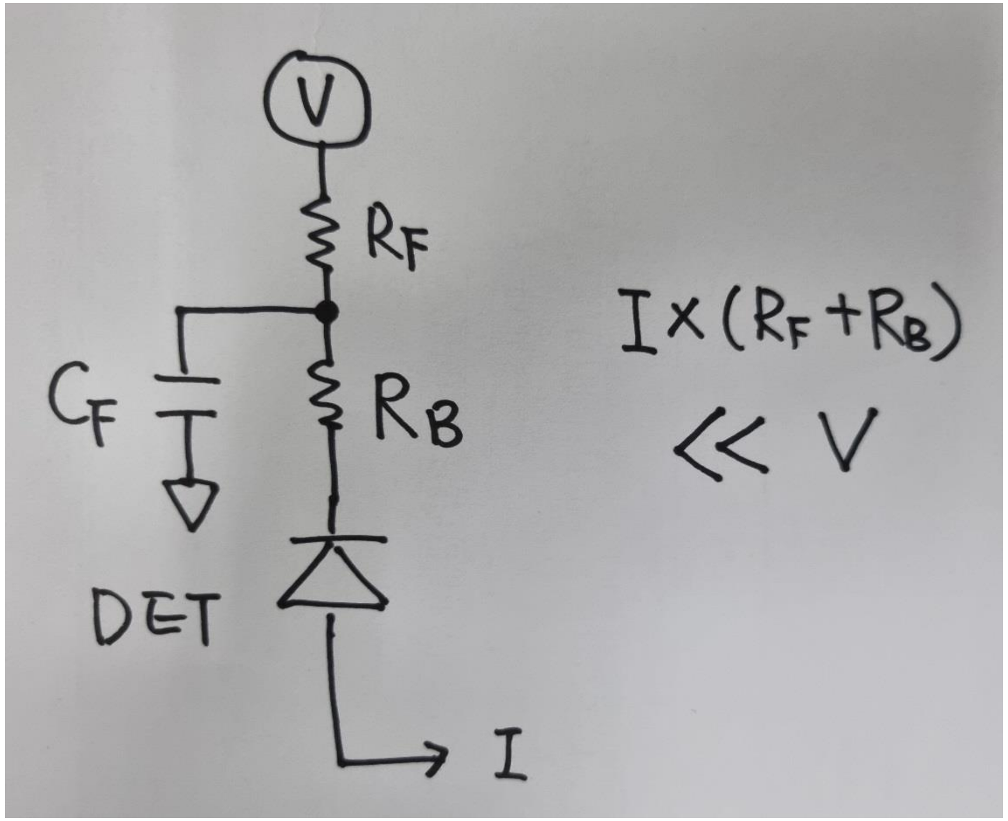
Isig = Qdet x exp(-t/T) where T = Cd x Rm = 100 pF x 10 Mohm

= ~ ms -> very long!

Detector signal :

Where it comes from? = Bias Voltage Source (few ~ 10,000 V)



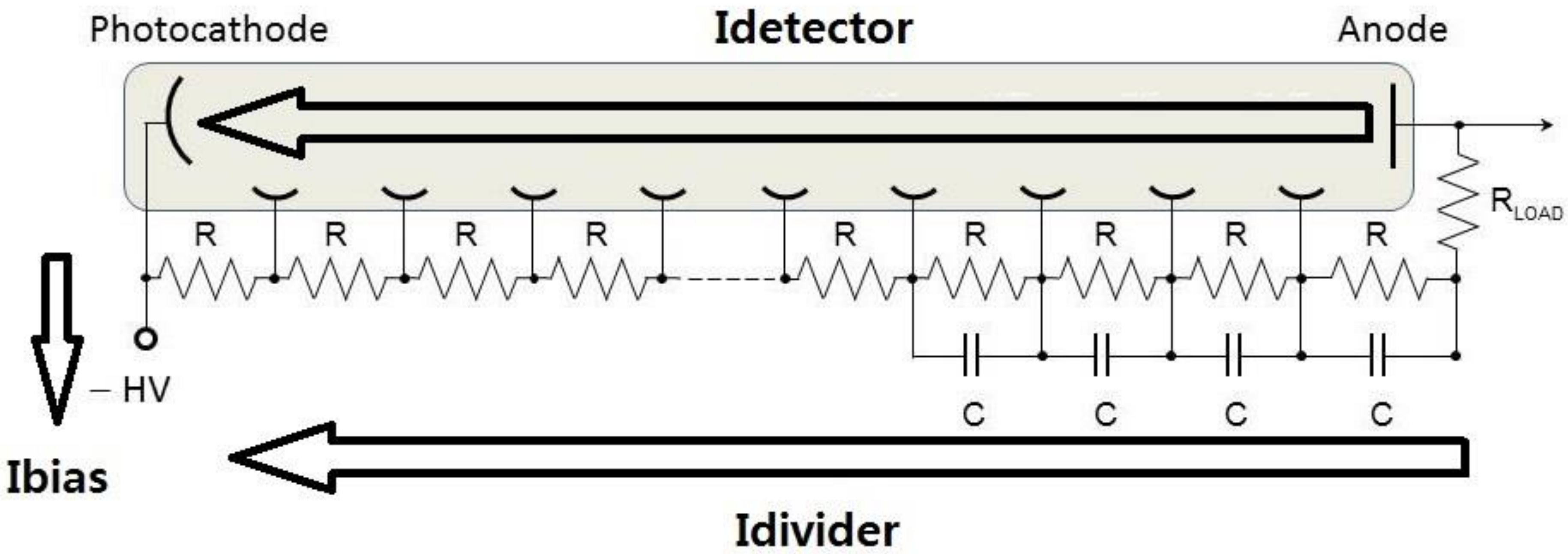


Ibias(max) > Isig + Idark

Isig = Signal x Count rate

Bias Filter

PMT example



$$\text{Ibias} = \text{Idetector} + \text{Idivider}$$

$$\text{Qdetector} = \int \text{Idetector}\ dt$$

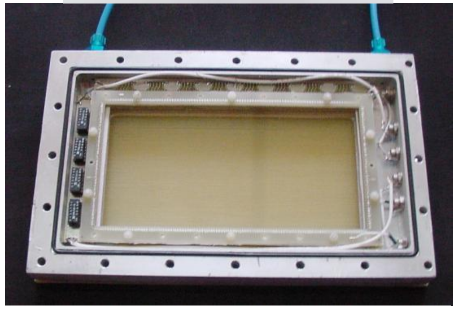
Usually Idivider >> $\overline{\text{Idetector}}$ (100 times or greater)

Bias voltage supplier should supply

If count rate = ~ 100 kcps (when no Dark current)

PMT : nC x 100 kcps x (10 ~ 100 : Divider)
= 10 uA -> 1 mA @ a few kV -> W

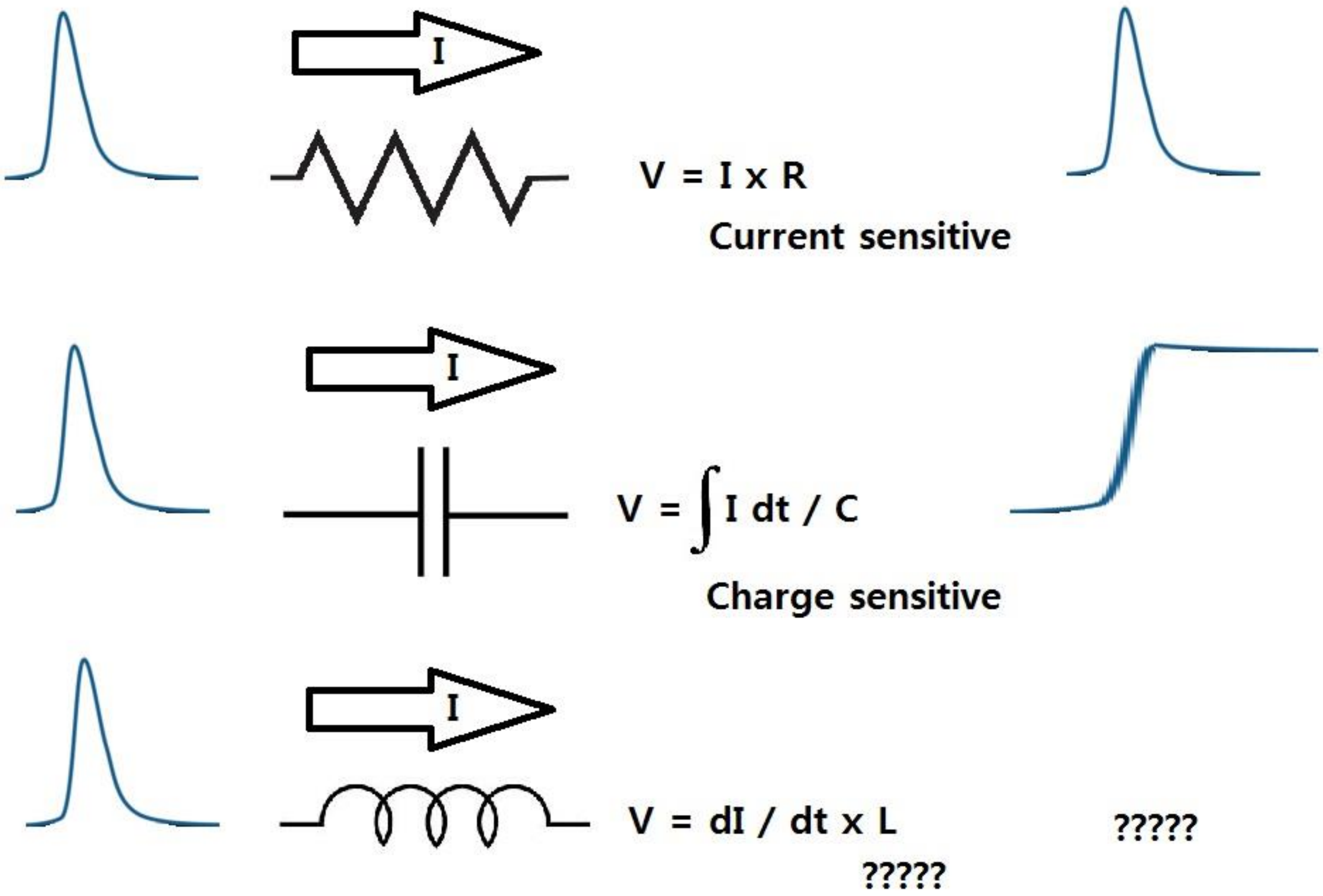
SiPM : nC x 100 kcps
= 10 uA @ 20 ~ 60 V -> mW



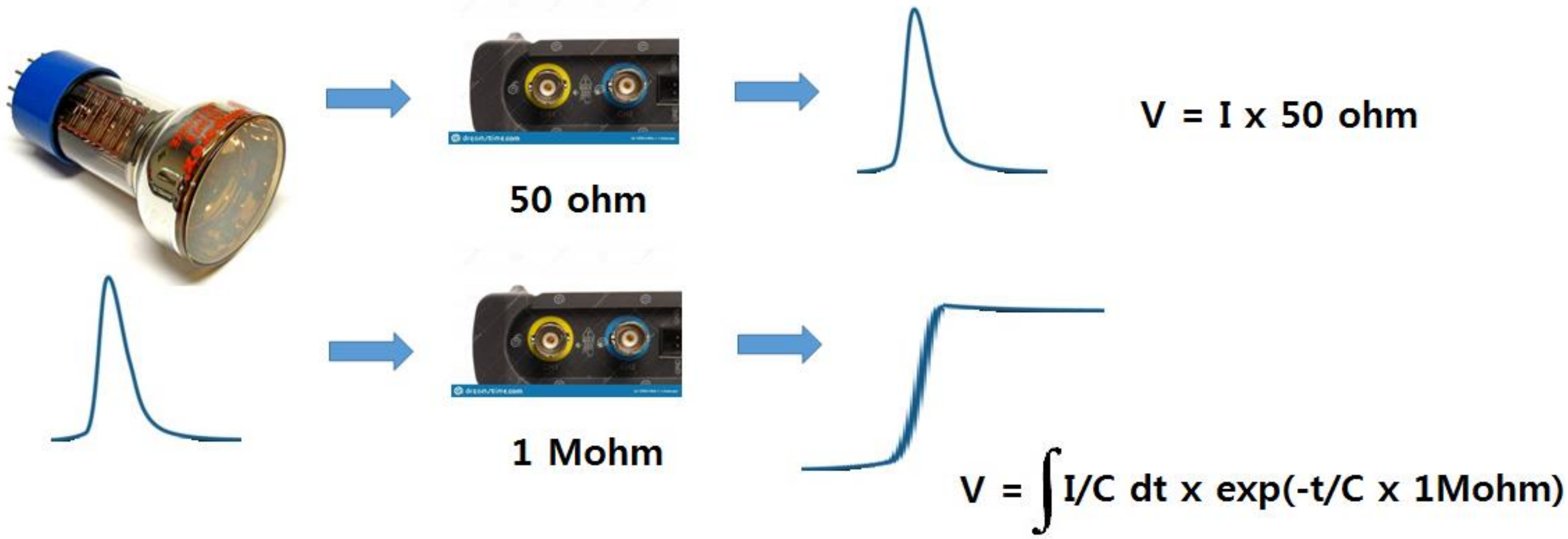
Wire chamber, GEM… : pC x 100 kcps
= 0.1 uA @ kV -> mW

Photodiode, Ion chamber… : fC x 100 kcps
= ~1 nA @ a few ~ kV -> uW

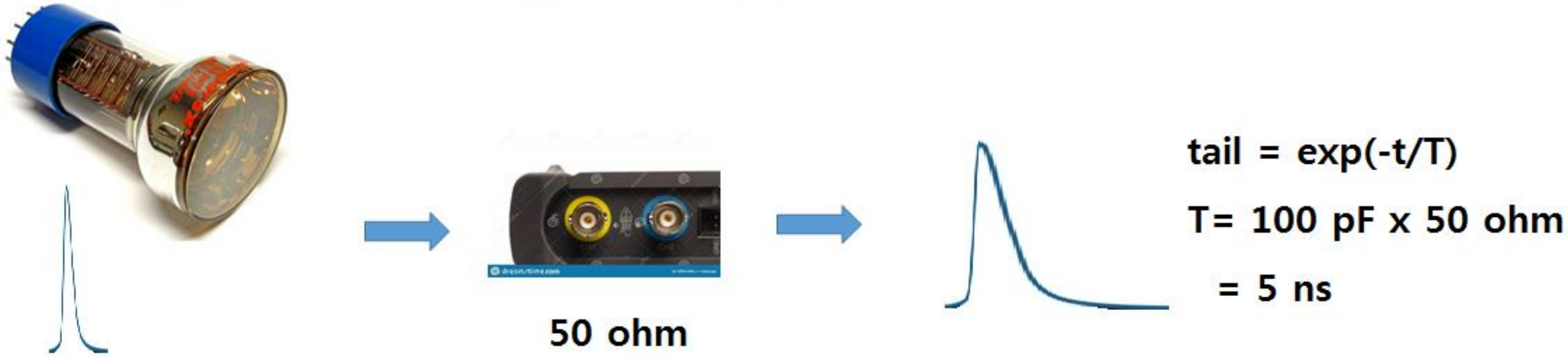
First thing to do :
Preamplifier converts Idet to Voltage signal.



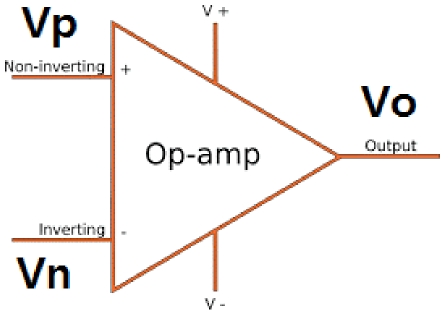
Take a look at PMT oscilloscope shot again



What happens if detector response is very short?

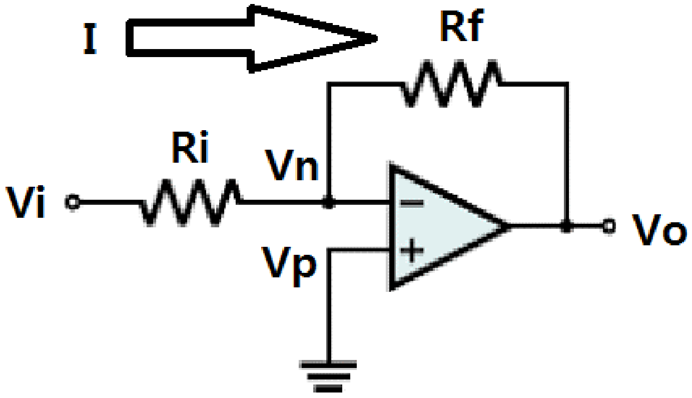


OpAmp basics



Vo = A x (Vp - Vn)

where A is very large



Vp = 0

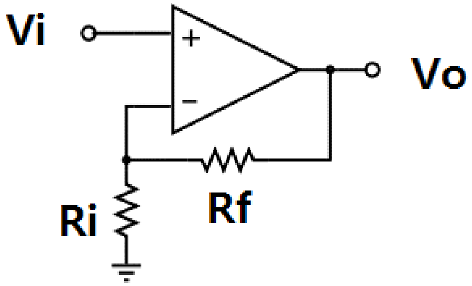
Vn = Vi - Ri x I

Vo = Vn - Rf x I

= A x (Vp - Vn)

$$V0 = -Vi \times \frac{Rf}{Ri} \times \frac{1}{1 + [(1 + Rf/Ri) / A]}$$

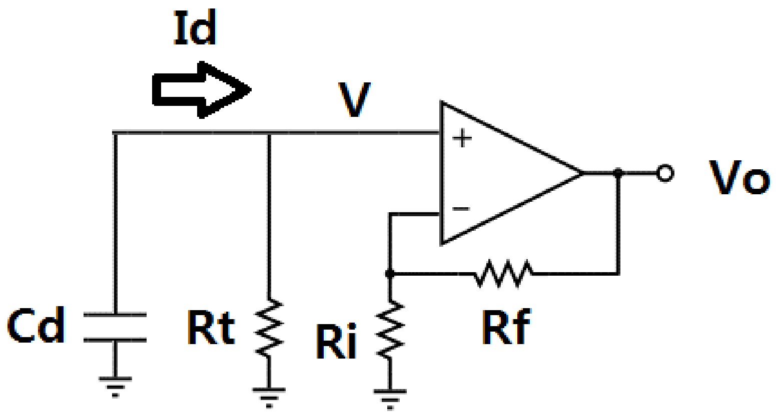
= -Vi x Rf/Ri



Similary,

Vo = Vi x (1 + Rf/Ri)

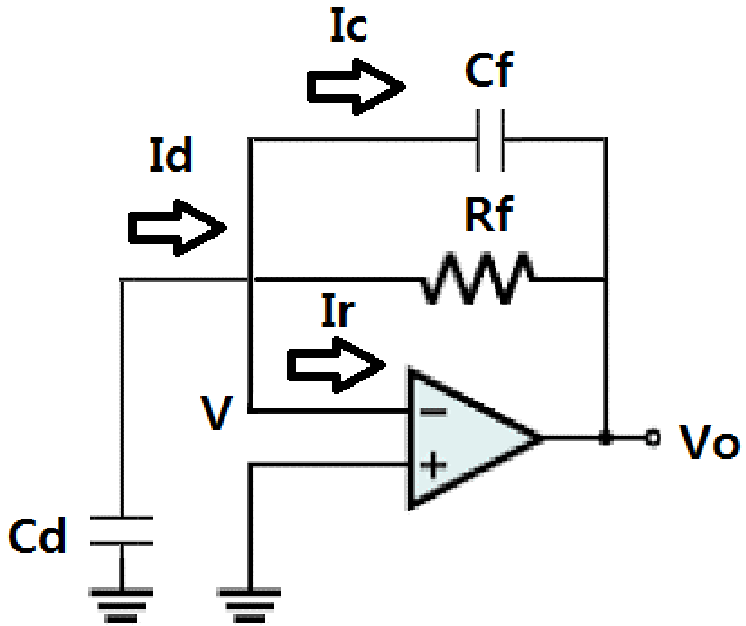
Current Sensitive Preamp



$$V = Qd / Cd = Id \times Rt = -dQd/dt \times Rt$$

$$Qd = Q \times \exp(-t/Rt \times Cd)$$

$$Vo = (1 + Rf/Ri) \times Q/Cd \times \exp(-t/Rt \times Cd)$$

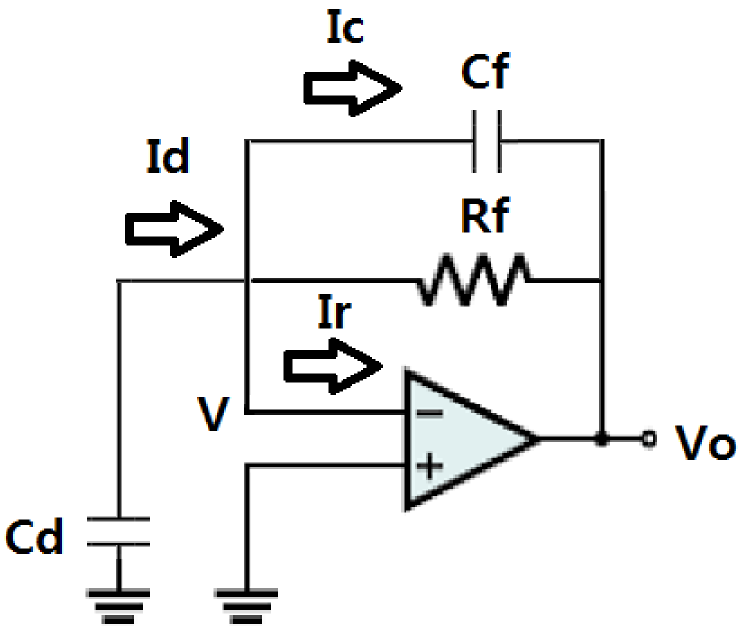


If $Ir >> Ic$, $Ir = Id$

$$V - Vo = -Vo = Ir \times Rf$$

$$Vo = -Id \times Rf$$

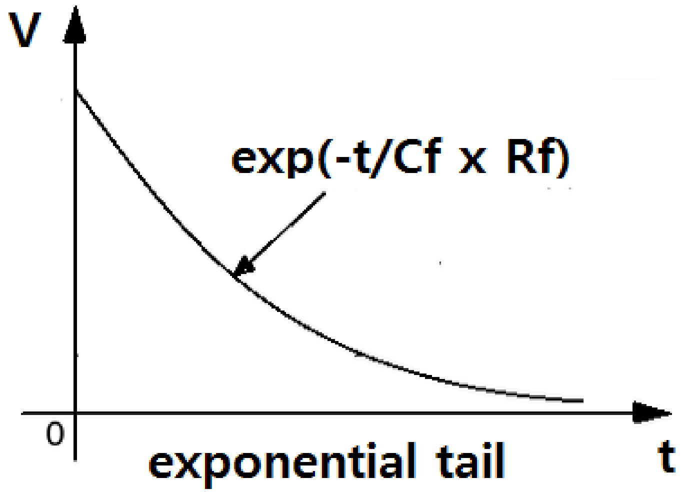
Charge Sensitive Preamp



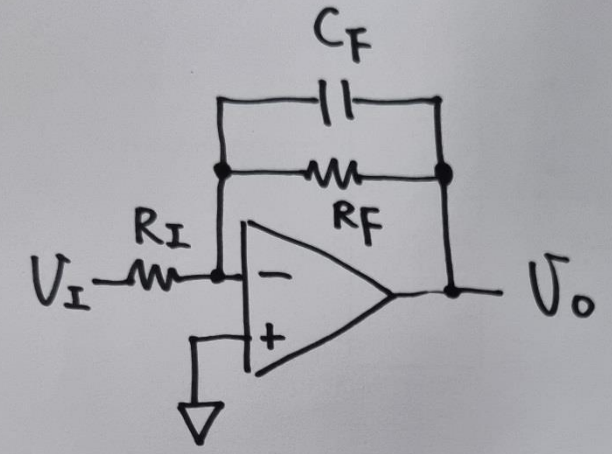
If $I_c \gg I_r$, $I_c = I_d$

$$V - V_0 = -V = \int I_r \, dt \times 1/C_f$$

$$V_o = -1/C_f \times \int I_d \, dt = -Q_d/C_f$$



Filter : Modify preamplifier pulse to better shape for later stage



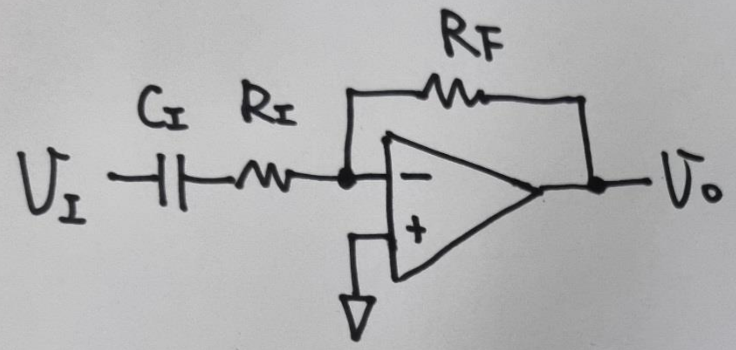
$$V_o = -\frac{Z_F}{R_I} V_I$$

$$Z_F = C_F // R_F = \frac{R_F}{1 + 2\pi f R_F C_F}$$

$$V_o = -\frac{R_F}{R_I} \times \frac{1}{1 + 2\pi f R_F C_F} V_I$$

$$V_o = -\frac{1}{2} V_I \text{ when } f = \frac{1}{2\pi R_F C_F}$$

Low Pass Filter



$$V_o = -\frac{R_F}{Z_I} V_I$$

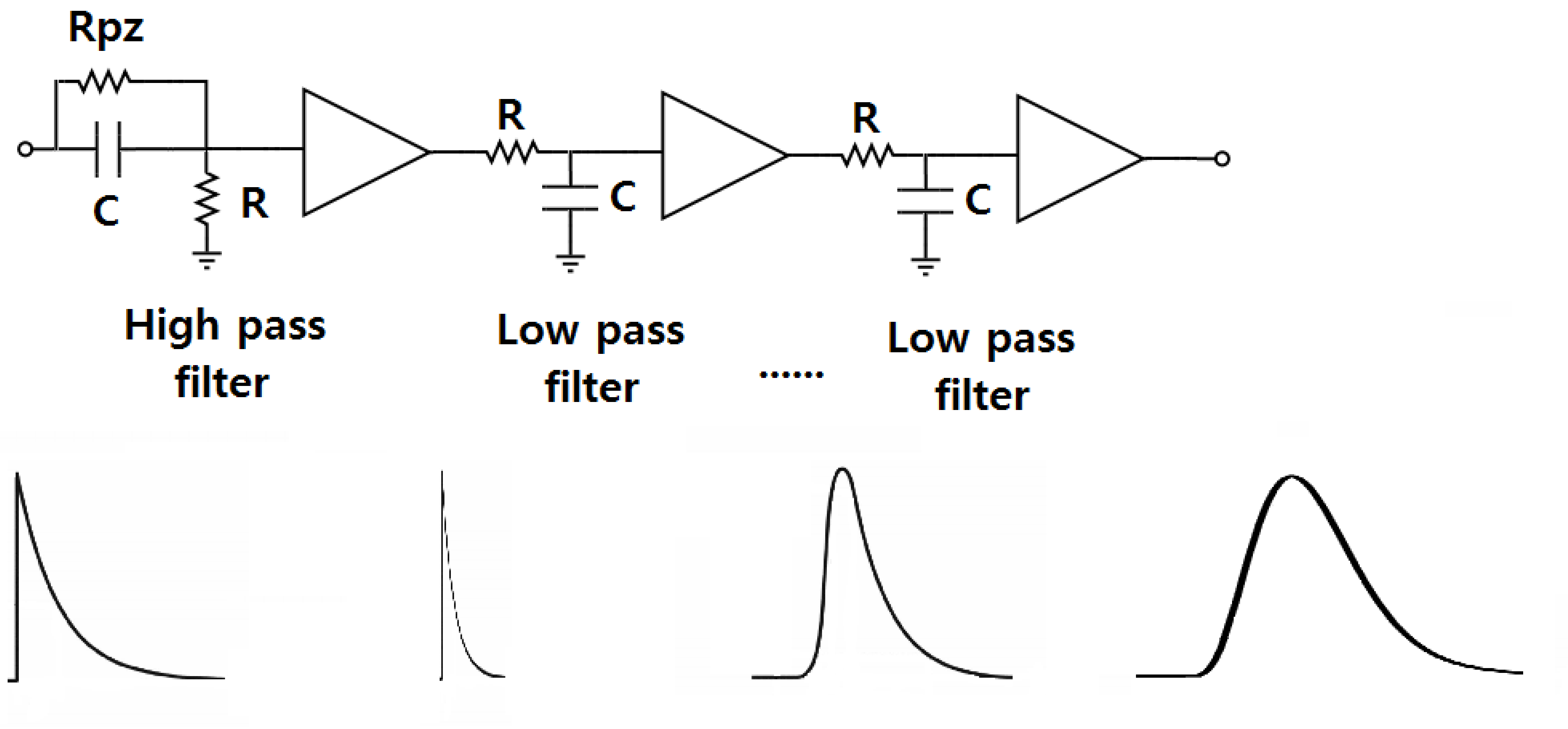
$$Z_I = \frac{1}{2\pi f C_I} + R_I = \frac{1 + 2\pi f R_I C_I}{2\pi f C_I}$$

$$V_o = -\frac{R_F}{R_I} \times \frac{2\pi f R_I C_I}{1 + 2\pi f R_I C_I}$$

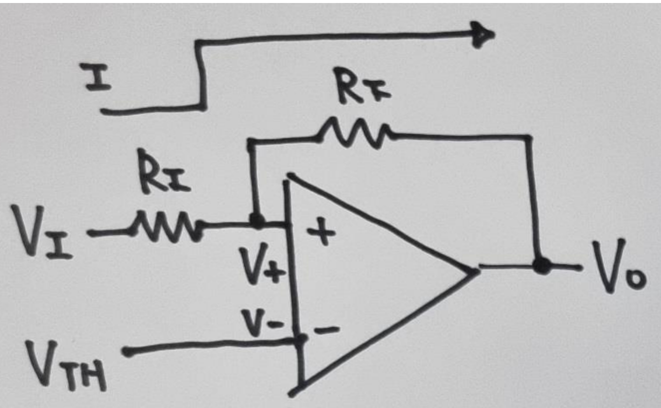
$$V_o = -\frac{1}{2} V_I \text{ when } f = \frac{1}{2\pi R_I C_I}$$

High Pass Filter

Example of Shaping Amplifier : next to Charge sensitive preamplifier



Voltage Comparator



$$V_I - V_+ = I \times R_I$$

$$V_+ - V_o = I \times R_F$$

$$V_I = \left(1+\frac{R_I}{R_F}\right)V_+ - \frac{R_I}{R_F}V_o$$

$$\simeq V_+ - \frac{R_I}{R_F}V_o \quad (R_F \gg R_I)$$

~~$V_I - V_{TH} = I \times R_I$~~

~~$V_{TH} - V_o = I \times R_F$~~

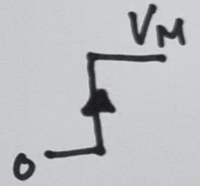
~~$V_o = -\frac{R_F}{R_I}V_I + \left(1+\frac{R_F}{R_I}\right)V_{TH}$~~

↓

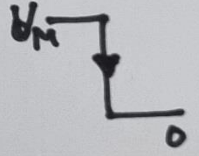
$$\because V_- = V_{TH} \neq V_+$$

$$V_o = \begin{cases} V_M & \text{when } V_+ > V_{TH} \\ 0 & \text{when } V_+ < V_{TH} \end{cases}$$

=



when $V_I > V_{TH}$

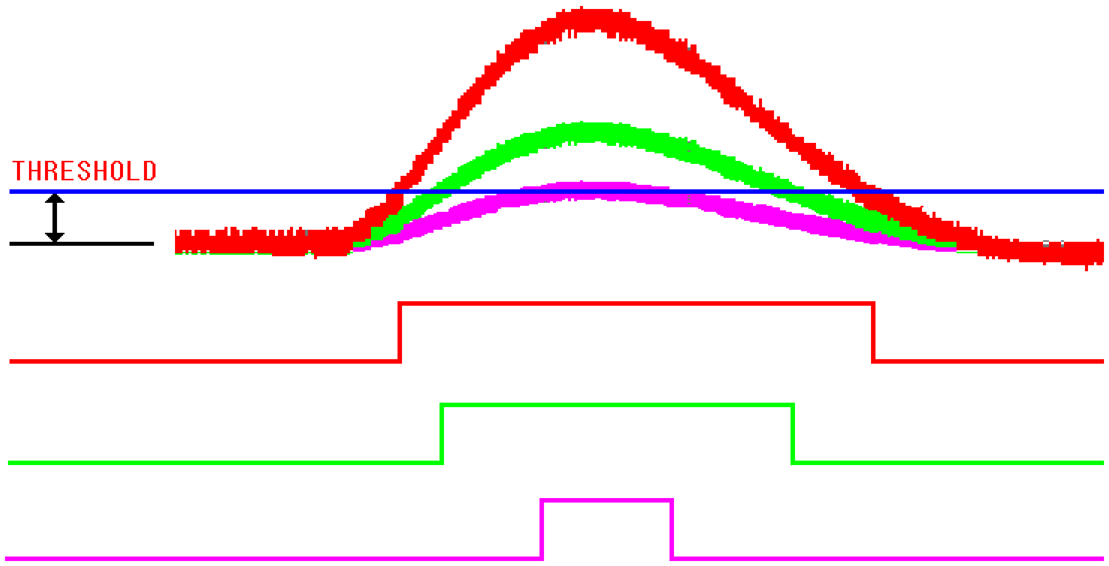


when $V_I < V_{TH} - \frac{R_I}{R_F}V_M$

→ Hysteresis

Discriminator

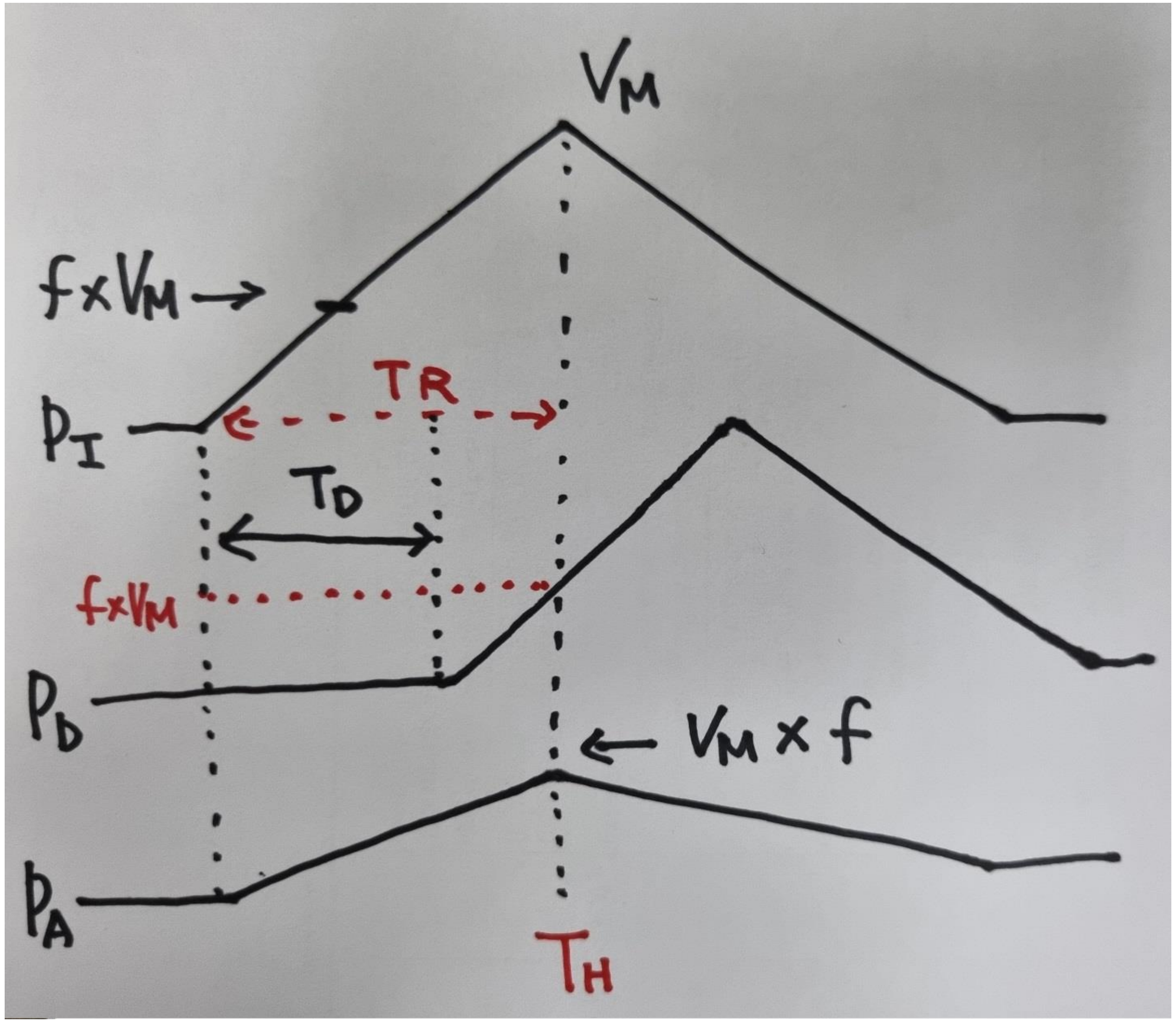
1. To discriminate noise
2. To get pulse timing



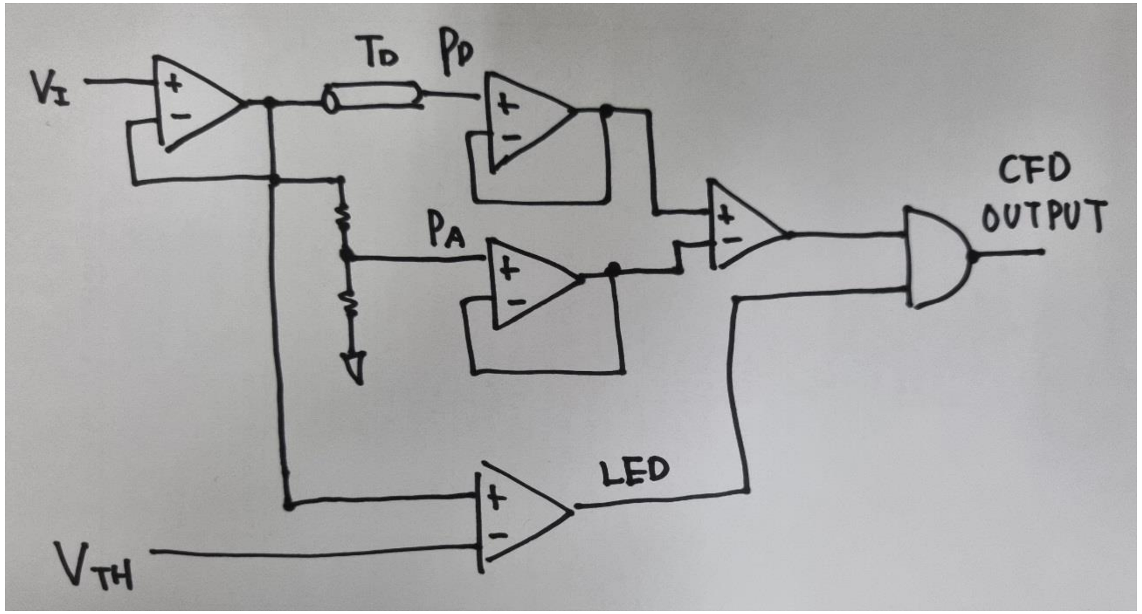
Leading edge discriminator

1. Simple
2. Large time walk

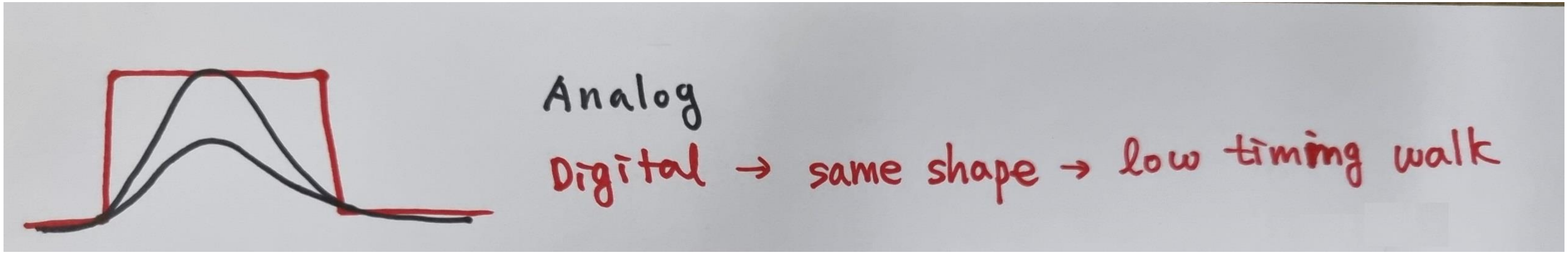
Constant Fraction Discriminator



Input pulse is fan out to
  Pd : Delayed (by 1 – f x Tr)
  Pa : Attenuated (by f)
Then Pd and Pa have same Voltage @ Th
Pd has voltage f x Vm @ Th

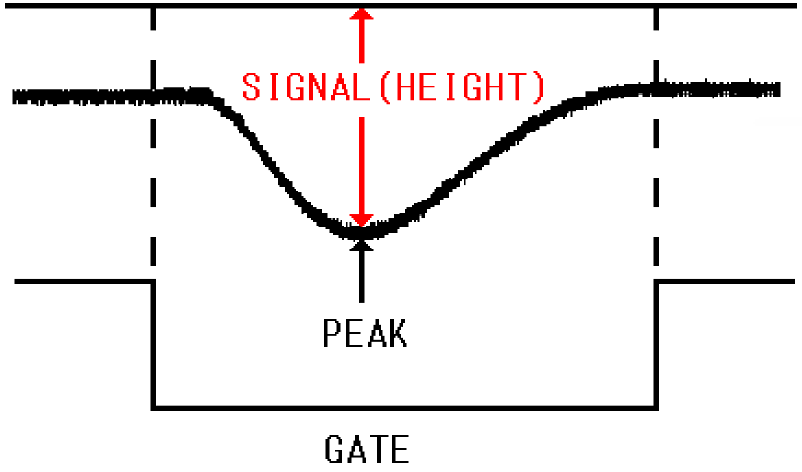


Logic(or Digital) Signal

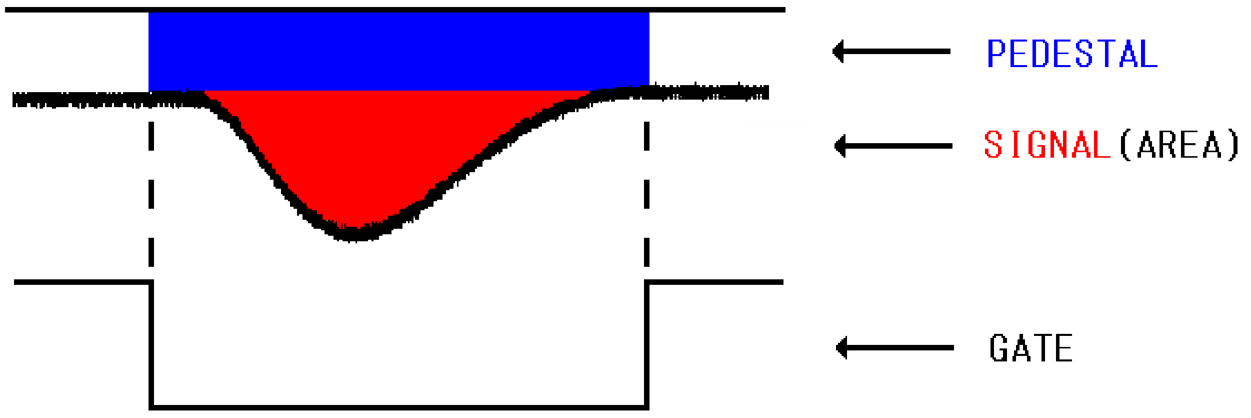


	Type	Low (0)	High (1)
TTL/LVTTL	Single ended	< 0.8 V	> 2.0 V
NIM(slow)	Single ended	< 1.5 V	> 3.0 V
NIM(fast)	Single ended	> -200 mV(-4 mA)	< -600 mV(-12 mA)
ECL	Differential	< -1.48 V	> -0.81 V
LVDS	Differential	< 1.0 V	> 1.4 V

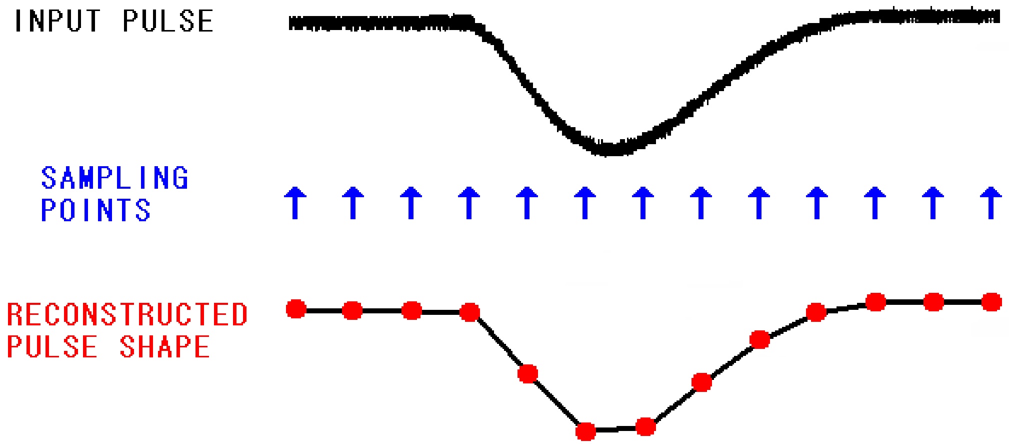
Analog to Digital Converter(ADC)



Peak sensing ADC

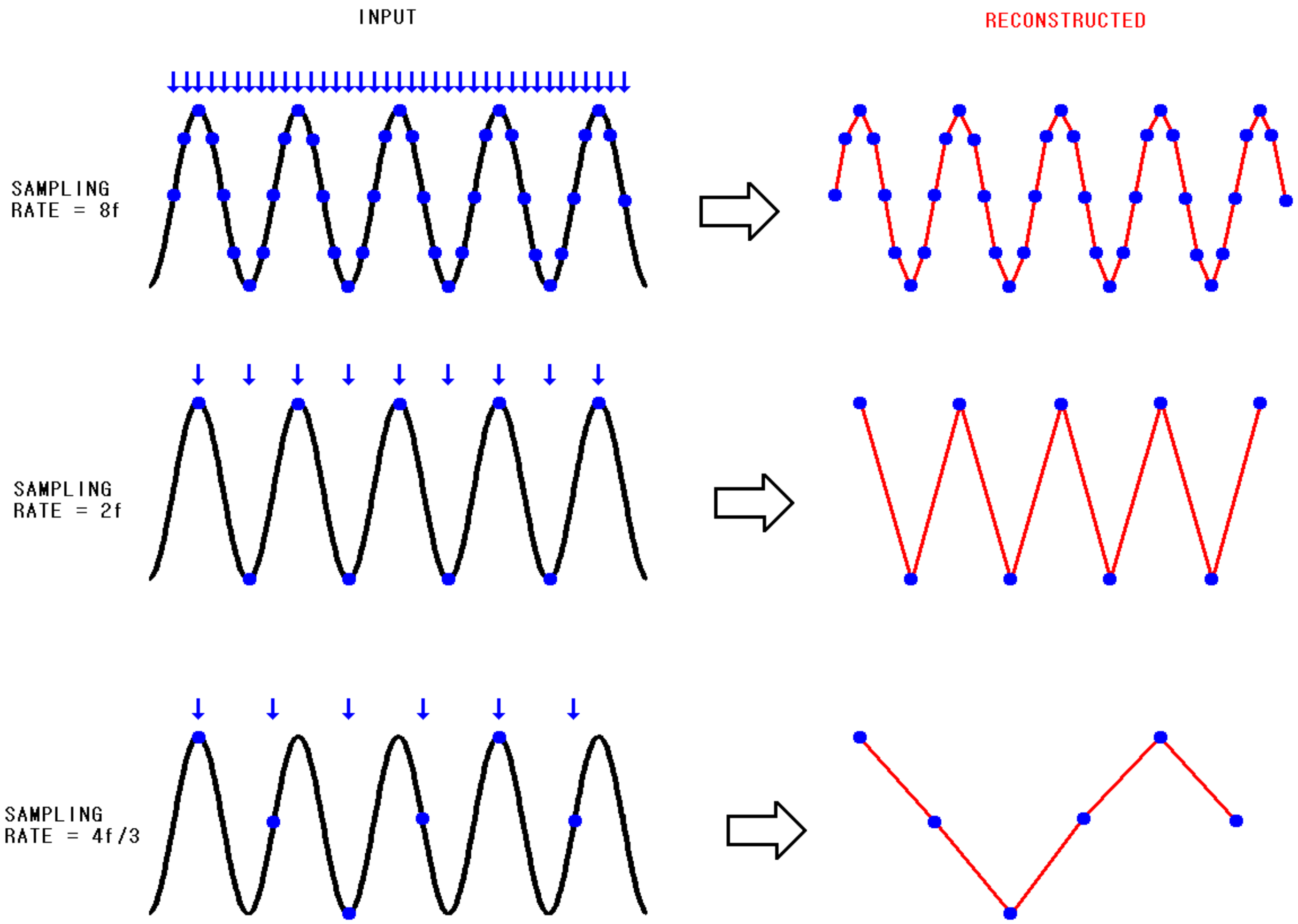


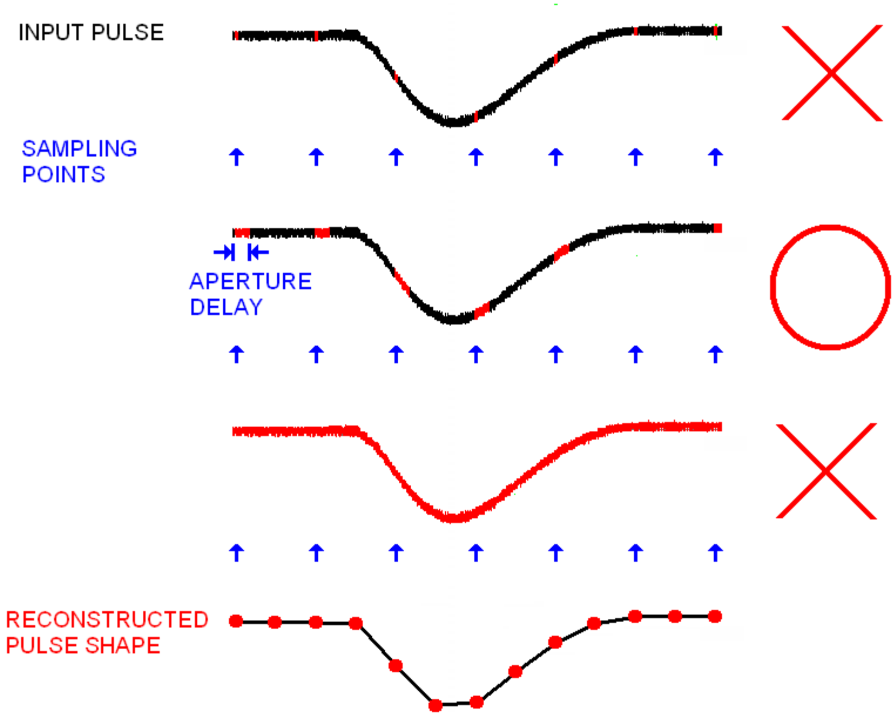
Charge sensing ADC



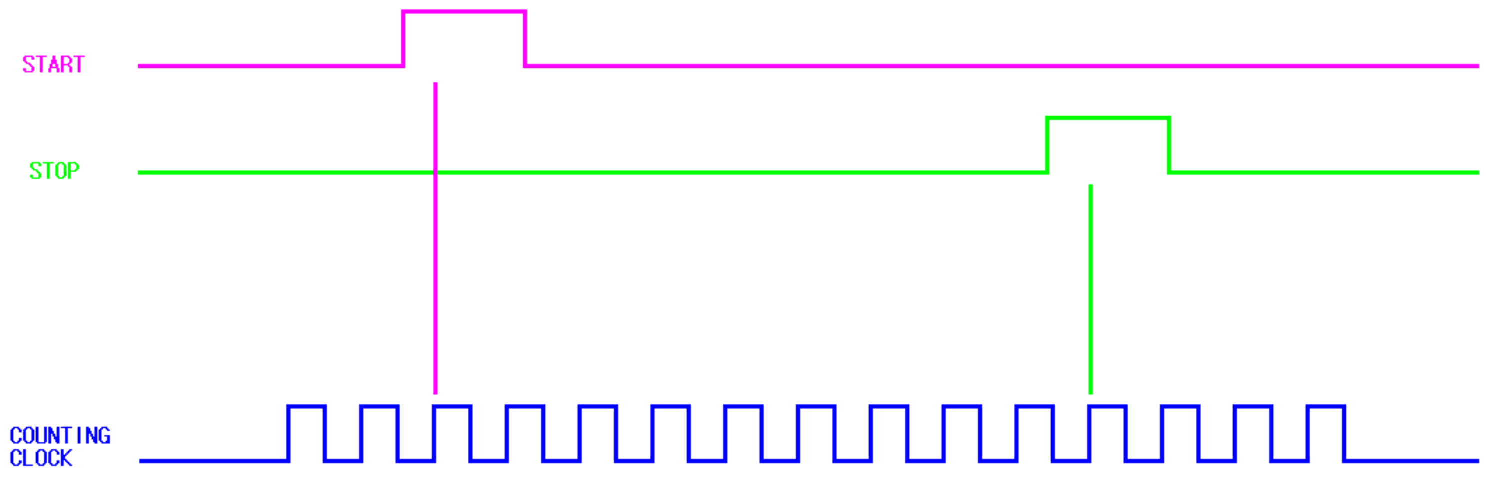
Flash ADC

ADC sampling



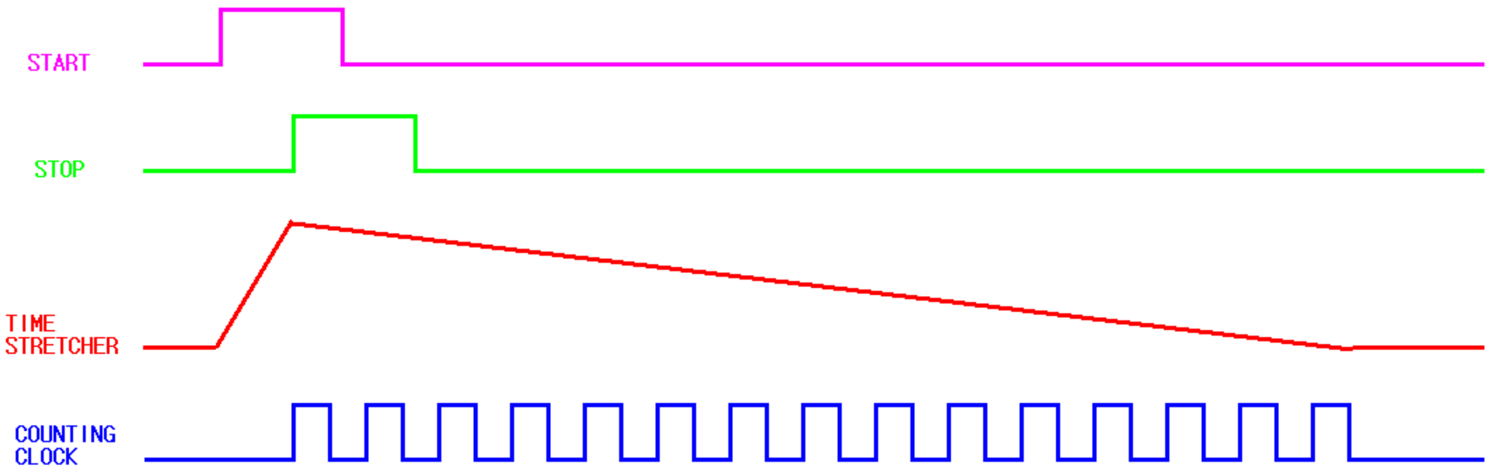


Time to Digital Converter(TDC)



Direct counting

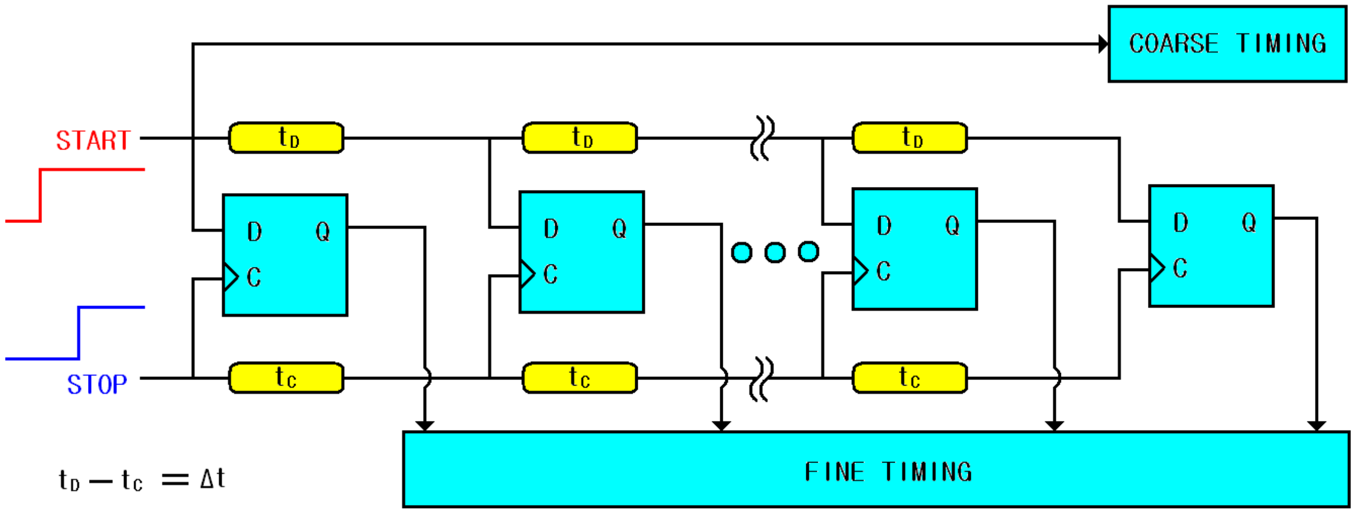
Resolution ~ 1 ns



Time stretching

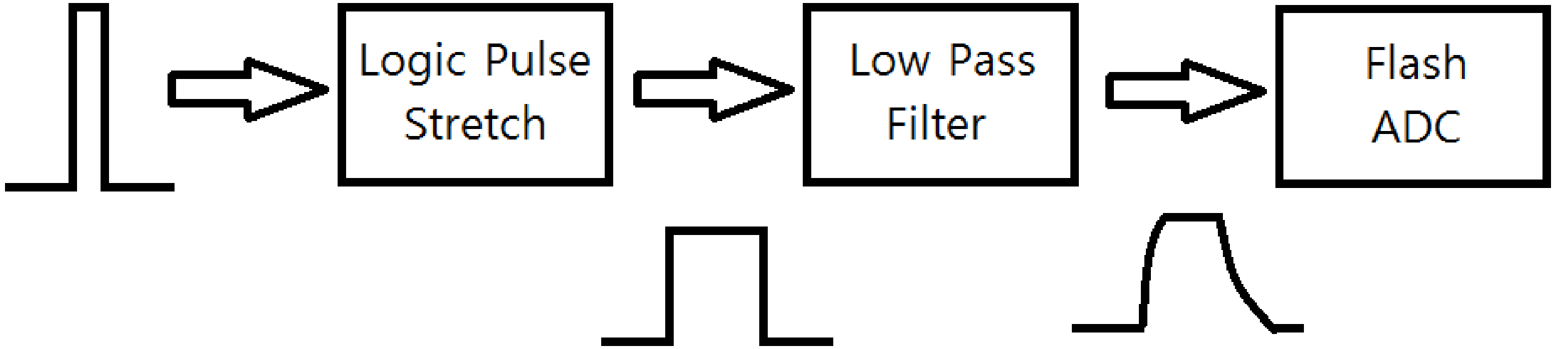
Resolution ~ 10 ps

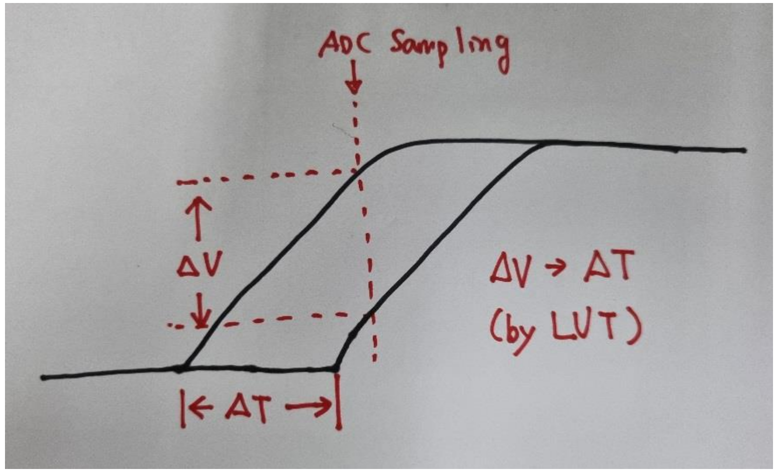
Time to Digital Converter



Time interpolation

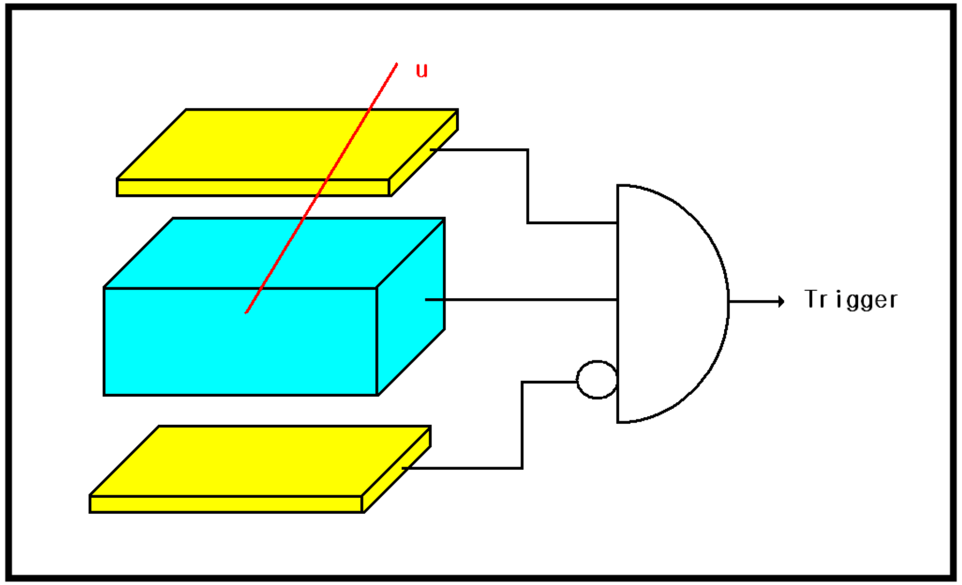
Resolution ~ 10 ps
Multi-hit TDC

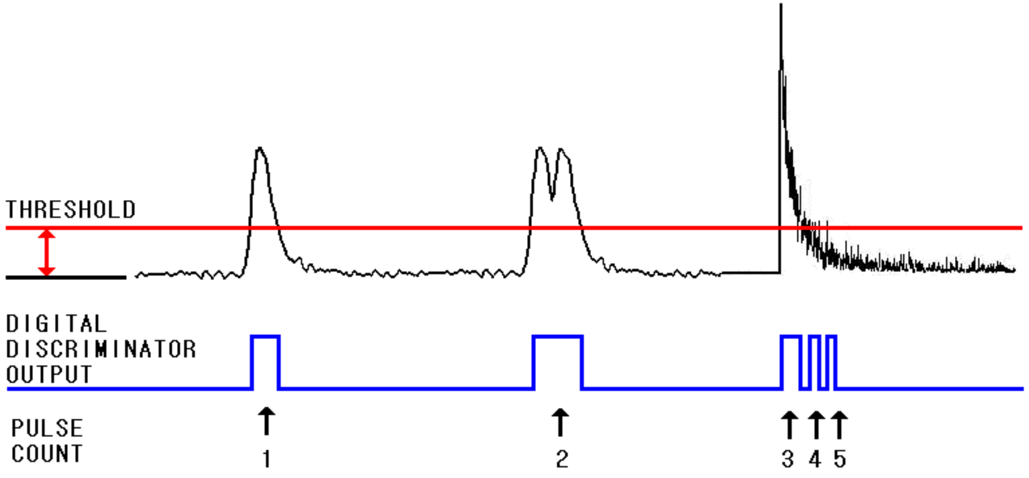




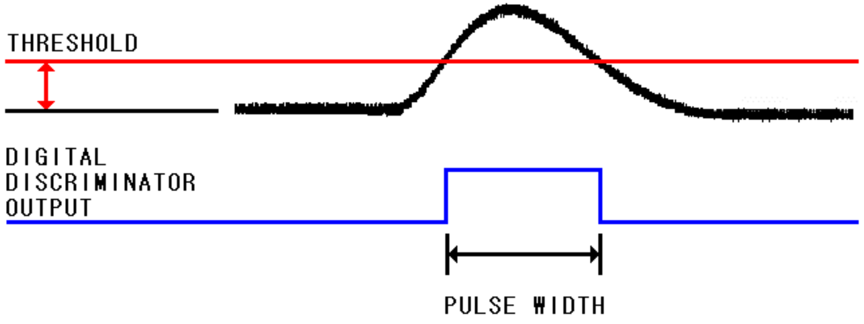
Pulse shaping TDC : resolution ~ 10 ps, multi-hit

Trigger

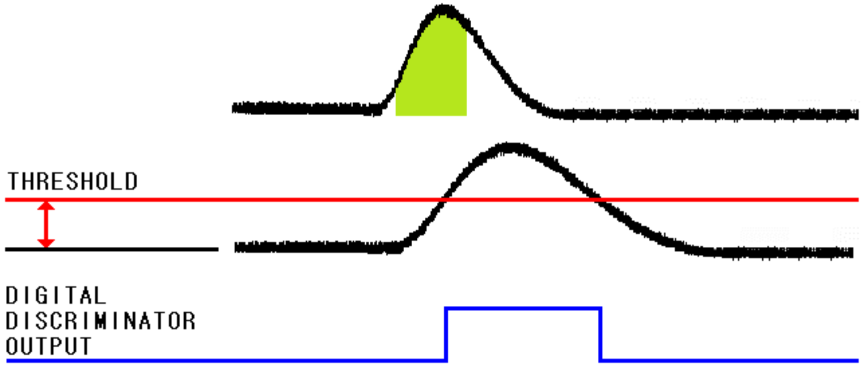




Pulse Count Trigger

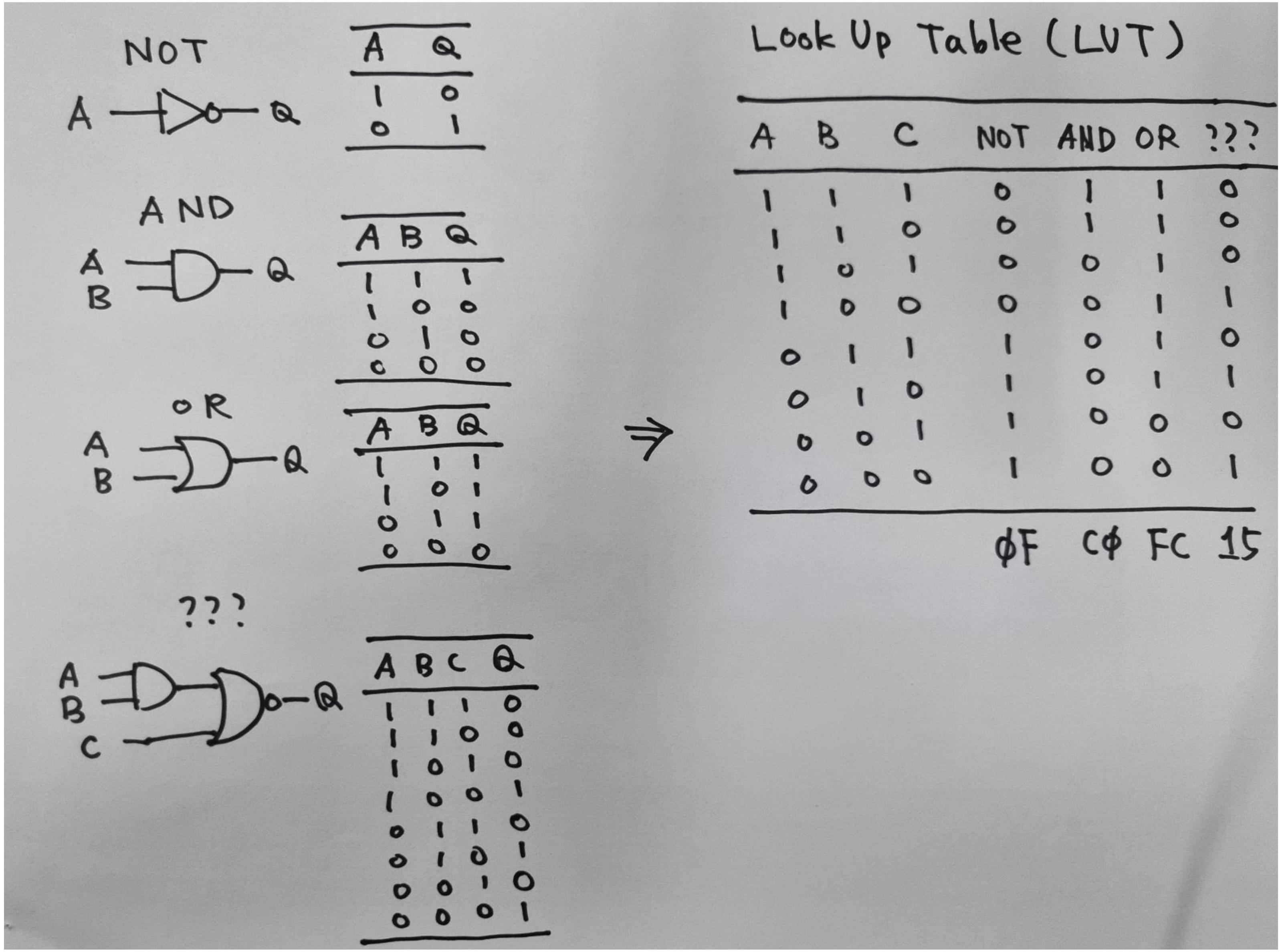


Pulse Width Trigger

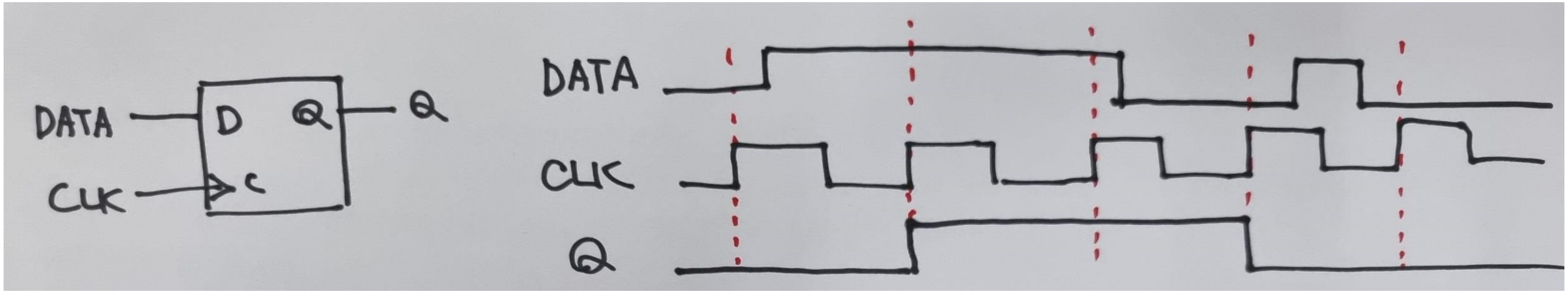


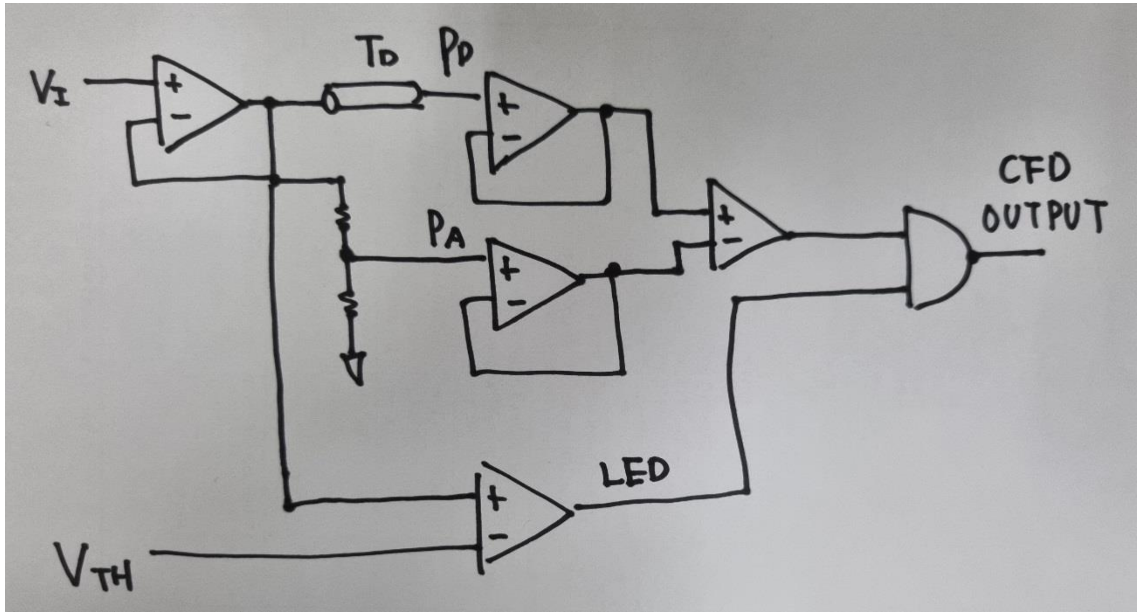
Peak Sum Trigger

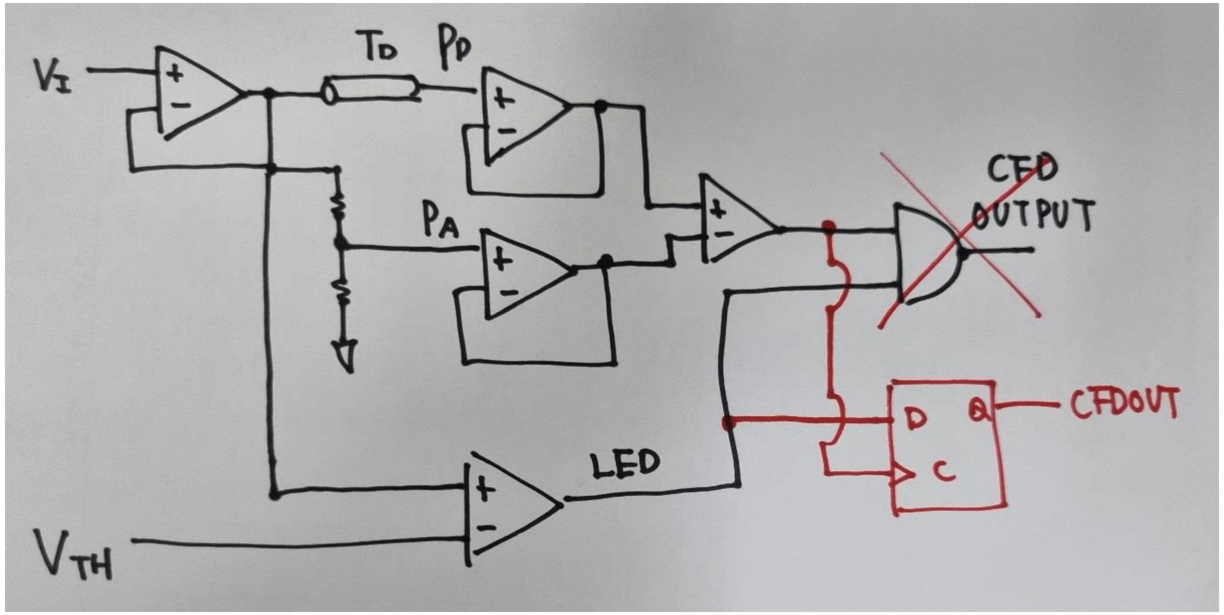
Combinational Logic



Sequential Logic



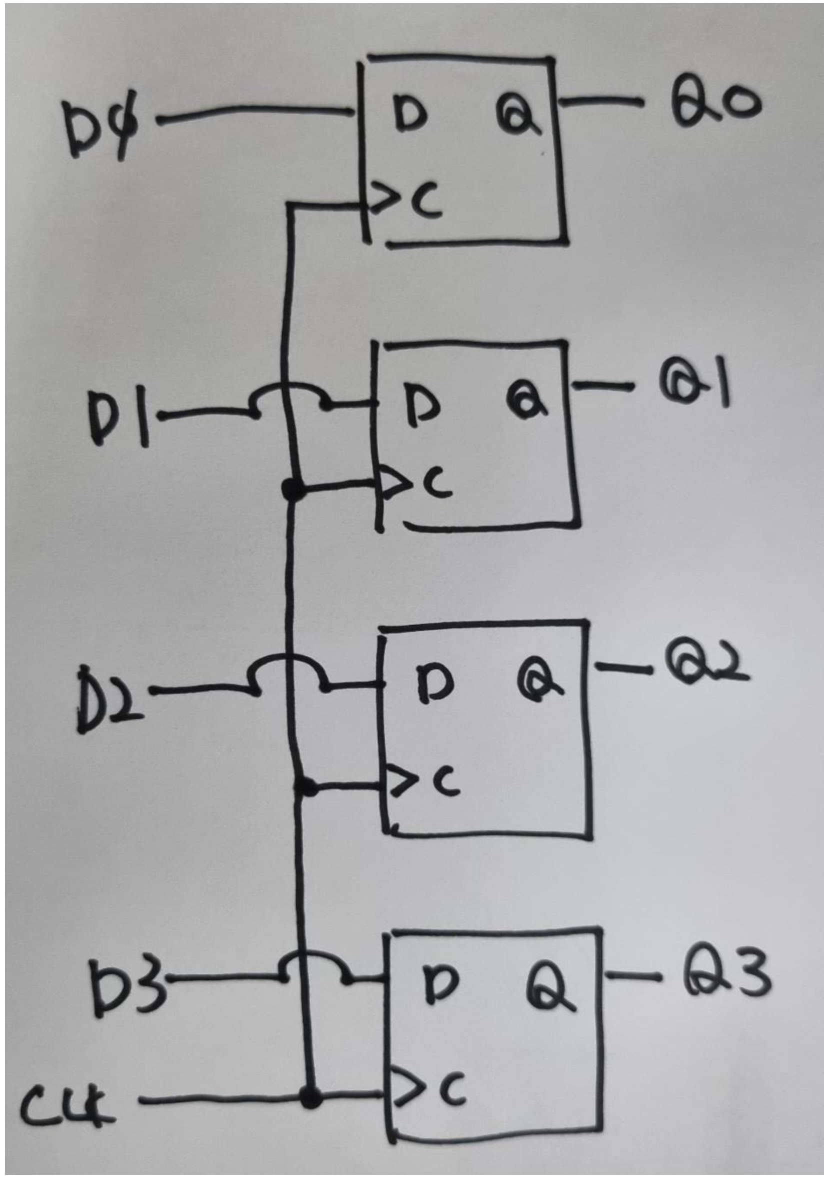




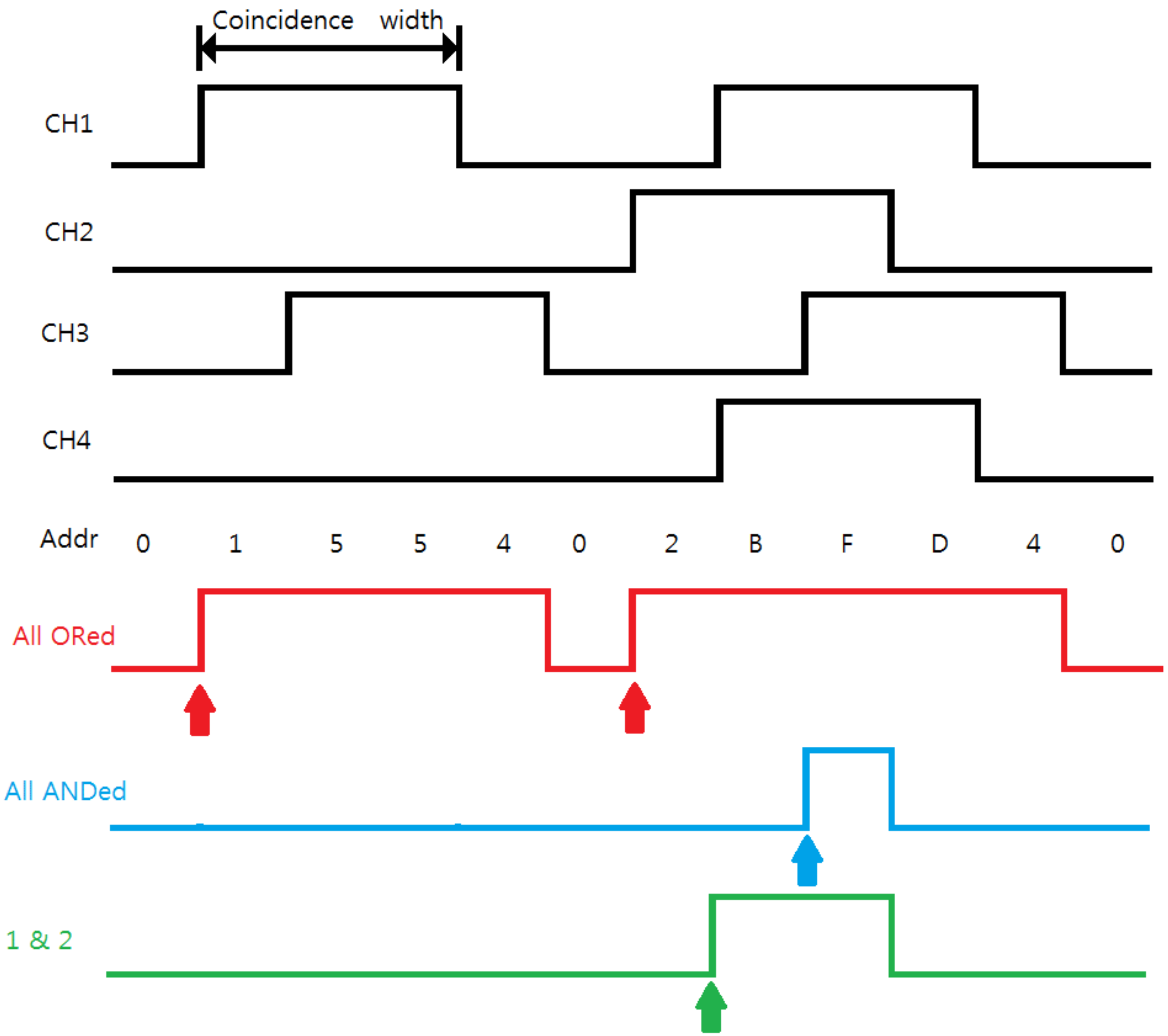
Examples of Sequential Logic

Q0	Q1	Q2	Q3	D3	D2	D1	D0
1	1	1	1	0	0	0	0
1	1	1	0	1	1	1	1
1	1	0	1	1	1	1	0
1	1	0	0	1	1	0	1
1	0	1	1	1	1	0	0
1	0	1	0	1	0	1	1
1	0	0	1	1	0	1	0
1	0	0	0	1	0	0	1
0	1	1	1	1	0	0	0
0	1	1	0	0	1	1	1
0	1	0	1	0	1	1	0
0	1	0	0	0	1	0	1
0	0	1	1	0	1	0	0
0	0	1	0	0	0	1	1
0	0	0	1	0	0	1	0
0	0	0	0	0	0	0	1

Q0	Q1	Q2	Q3	D3	D2	D1	D0
1	1	1	1	0	0	0	0
1	1	1	0	0	0	0	0
1	1	0	1	0	0	0	0
1	1	0	0	0	0	0	0
1	0	1	1	0	0	0	0
1	0	1	0	0	0	0	0
1	0	0	1	0	0	0	0
1	0	0	0	1	0	0	1
0	1	1	1	1	0	0	0
0	1	1	0	0	1	1	1
0	1	0	1	0	1	1	0
0	1	0	0	0	1	0	1
0	0	1	1	0	1	0	0
0	0	1	0	0	0	1	1
0	0	0	1	0	0	1	0
0	0	0	0	0	0	0	1



Trigger by combination



Trigger Lookup Table

CH 4 3 2 1	Addr	All ORed	All ANDed	1 & 2
1 1 1 1	F	1	1	1
1 1 1 0	E	1	0	0
1 1 0 1	D	1	0	0
1 1 0 0	C	1	0	0
1 0 1 1	B	1	0	1
1 0 1 0	A	1	0	0
1 0 0 1	9	1	0	0
1 0 0 0	8	1	0	0
0 1 1 1	7	1	0	1
0 1 1 0	6	1	0	0
0 1 0 1	5	1	0	0
0 1 0 0	4	1	0	0
0 0 1 1	3	1	0	1
0 0 1 0	2	1	0	0
0 0 0 1	1	1	0	0
0 0 0 0	0	0	0	0
		0xFFFE	0x8000	0x8888

Data Acquisition

CAMAC

VME

Standard

Custom

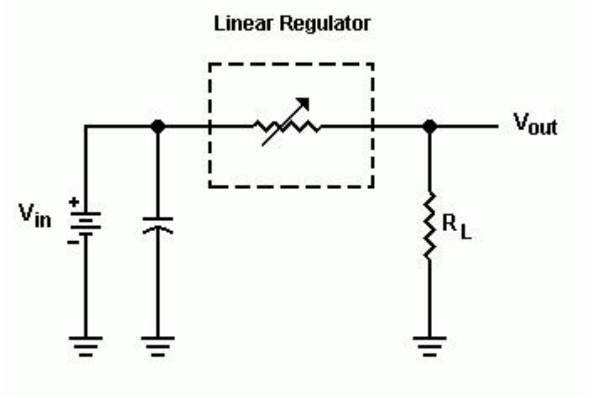
Data Acquisition

Ethernet : 125 MB/s max, ~30 MB/s typically

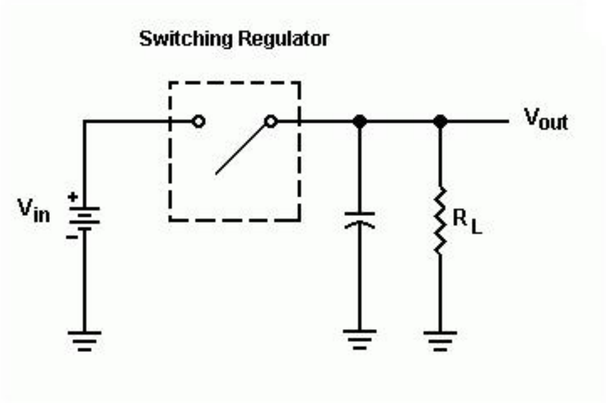
USB : 500 MB/s max, ~100 MB/s typically

PCI : 63 GB/s max, ~??? typically

Power Supply



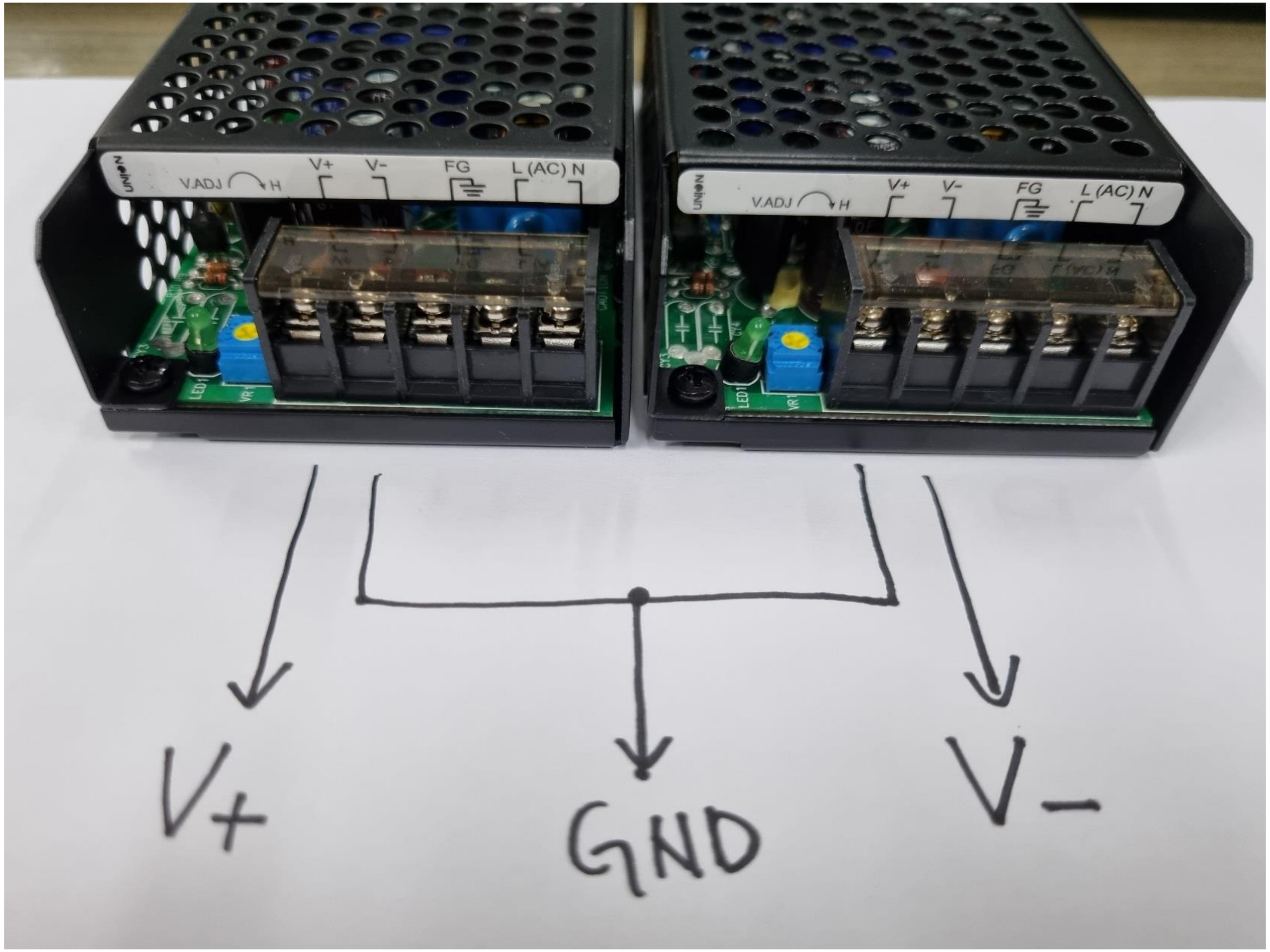
Linear



Switching

!

Power Supply Example



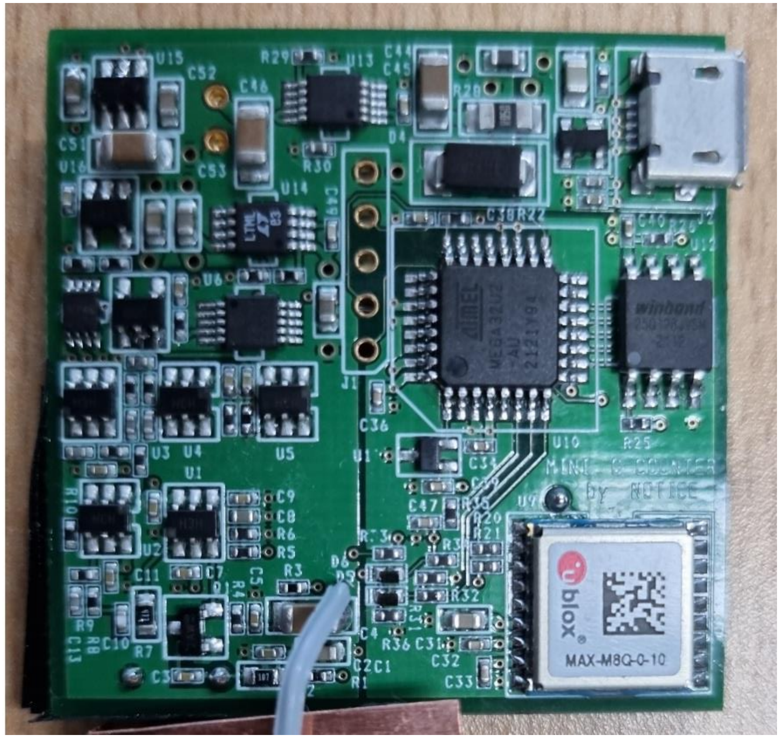
1. L, N to

2. FG to GND

3. Check FG & V- are not shorted

4. Variation :
   V- to GND
   GND to V1
   V+ to V1 + V2
   even if V1 is HV!

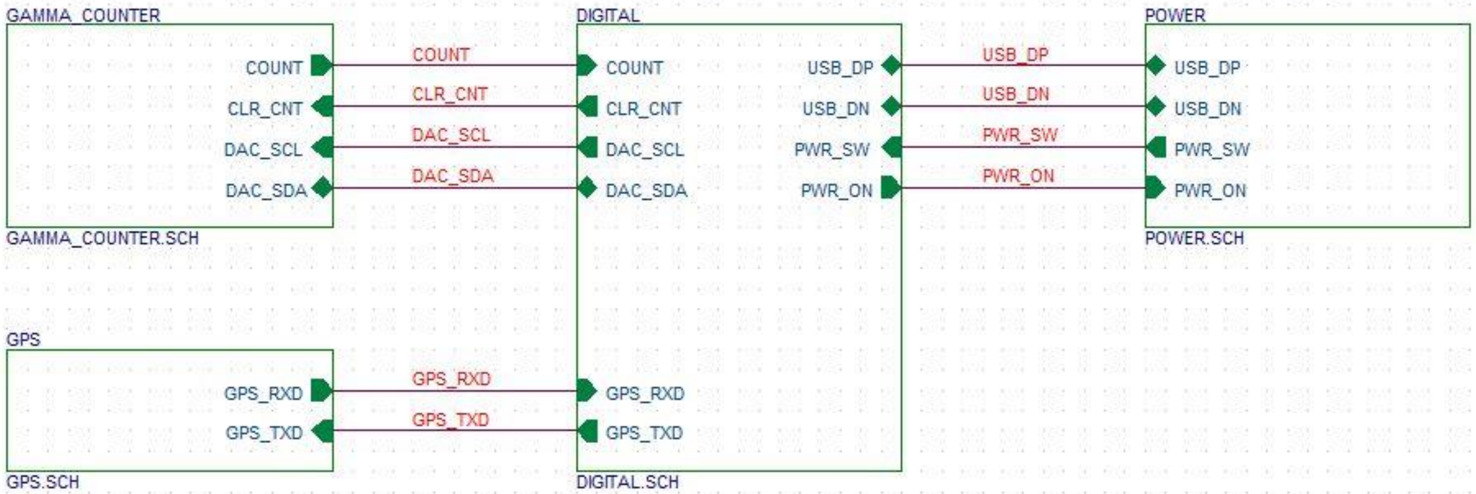
Example of electronics board : Gamma ray counter board



1. Pin PD to detect Gamma ray directly
2. Charge sensitive preamplifier
3. CR-RC2 shaping amplifier
4. Leading edge discriminator
5. MCU for counting logic
6. USB2 interface
7. GPS

Electronics board manufacturing process

1. Conceptual design and colleting parts
2. Draw schematics
3. Draw Printed Circuit Board(PCB) layout
4. Solder and assemble parts on PCB
5. Write Firmware(MCU, FPGA …)
6. Write Software
7. Test and Debug



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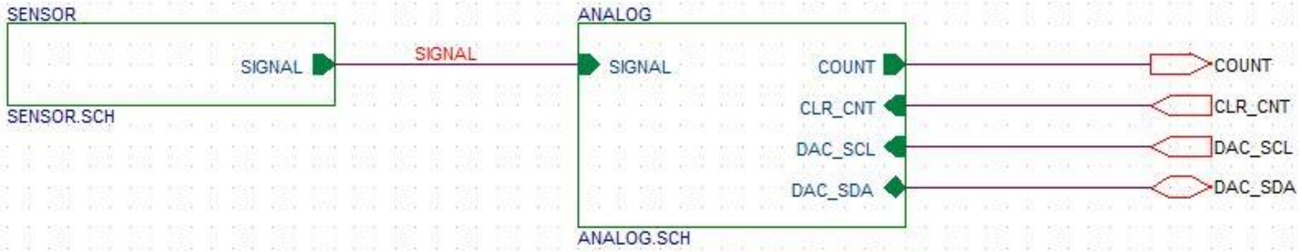
Size A	Document Number <Doc>	Rev 1.0
Date: Friday, August 06, 2021	Sheet 1 of 1	



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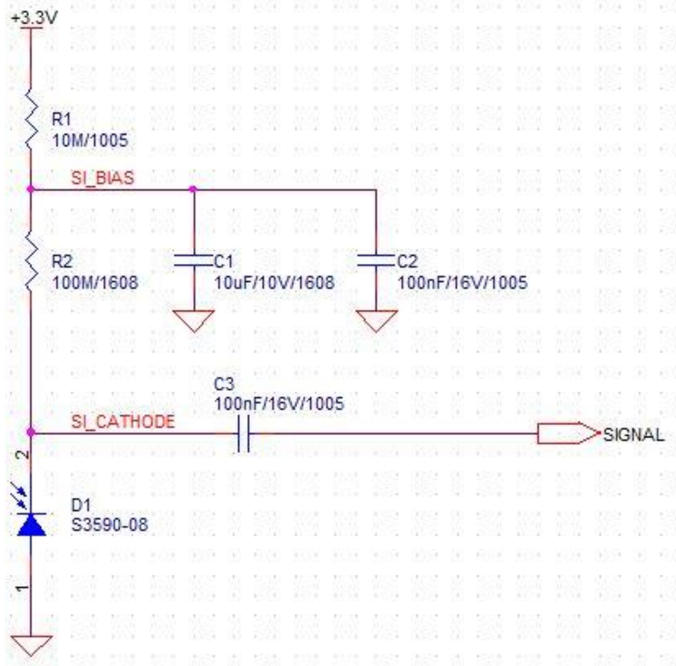
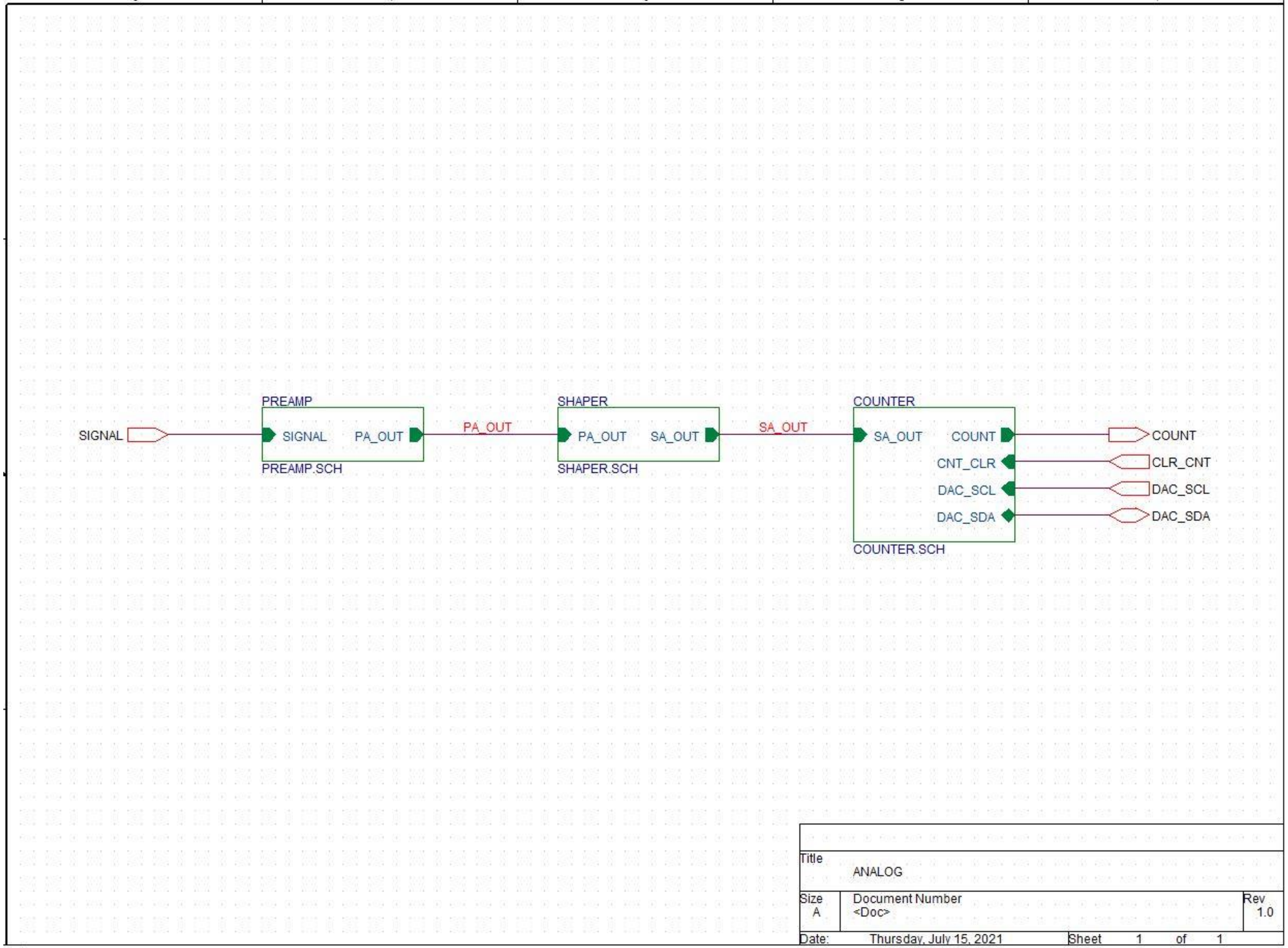
Size A	Document Number <Doc>	Rev 1.0
Date:	Friday, August 06, 2021	Sheet 1 of 1



Title	SENSOR	
Size A	Document Number <Doc>	Rev 1.0
Date: Friday, August 06, 2021	Sheet 1 of 1	


SIGNAL
PREAMP
SIGNAL
PA_OUT
PREAMP.SCH
PA_OUT
SHAPER
PA_OUT
SA_OUT
SHAPER.SCH
SA_OUT
COUNTER
SA_OUT
COUNT
CNT_CLR
DAC_SCL
DAC_SDA
COUNTER.SCH
COUNT
CLR_CNT
DAC_SCL
DAC_SDA
Title
ANALOG
Size
A
Document Number
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1.0
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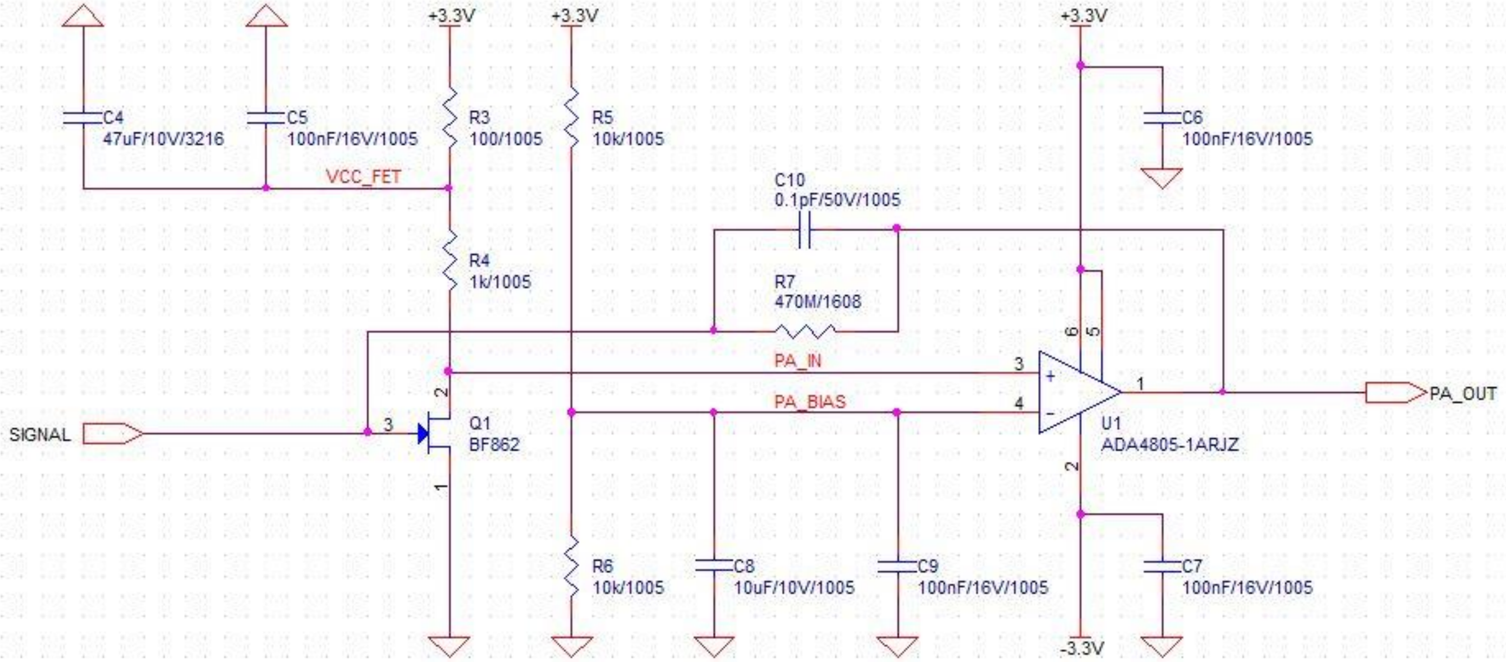

Title
PREAMP

Size A
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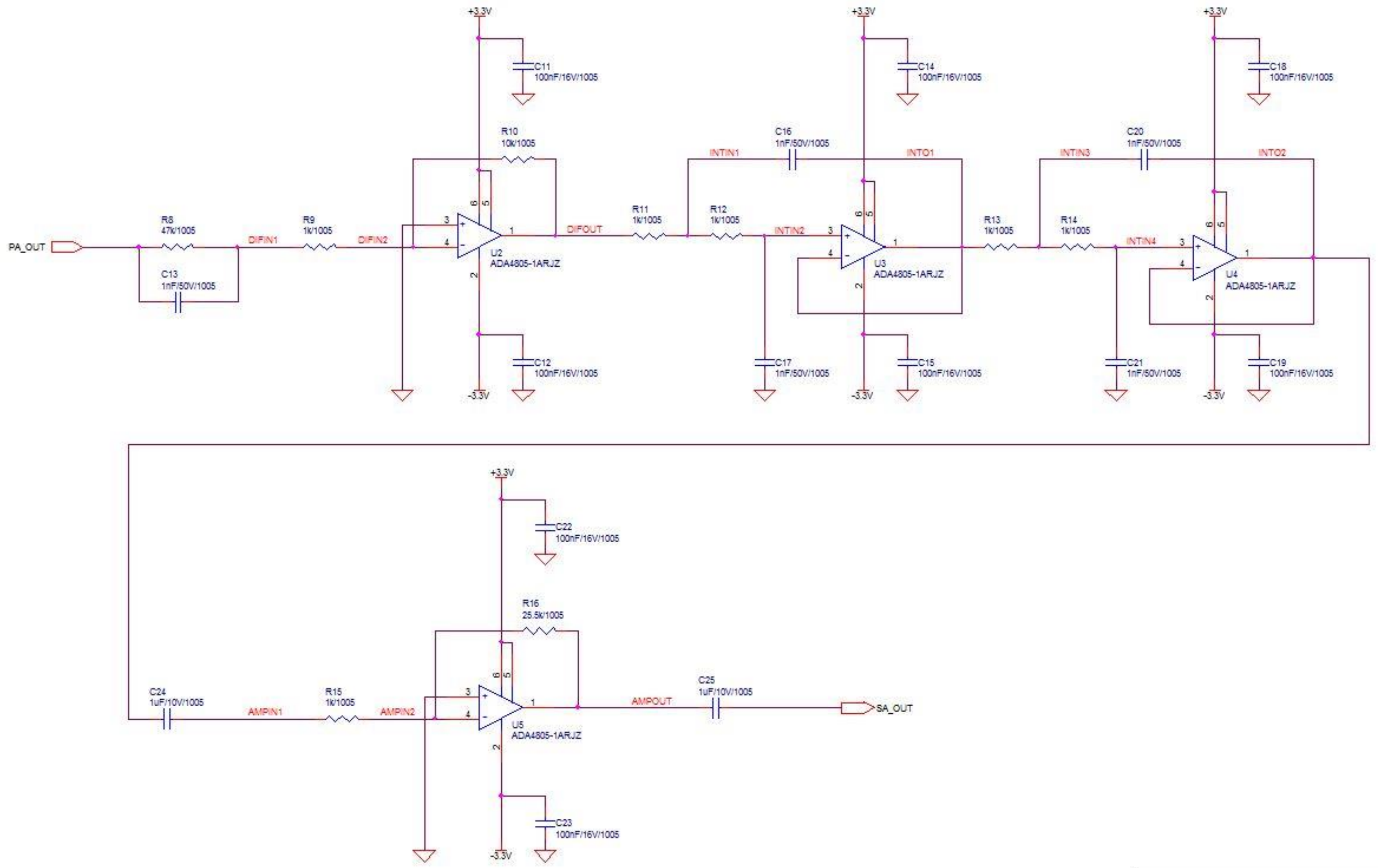
Rev 1.0

Date: Thursday, July 15, 2021
Sheet 1 of 1



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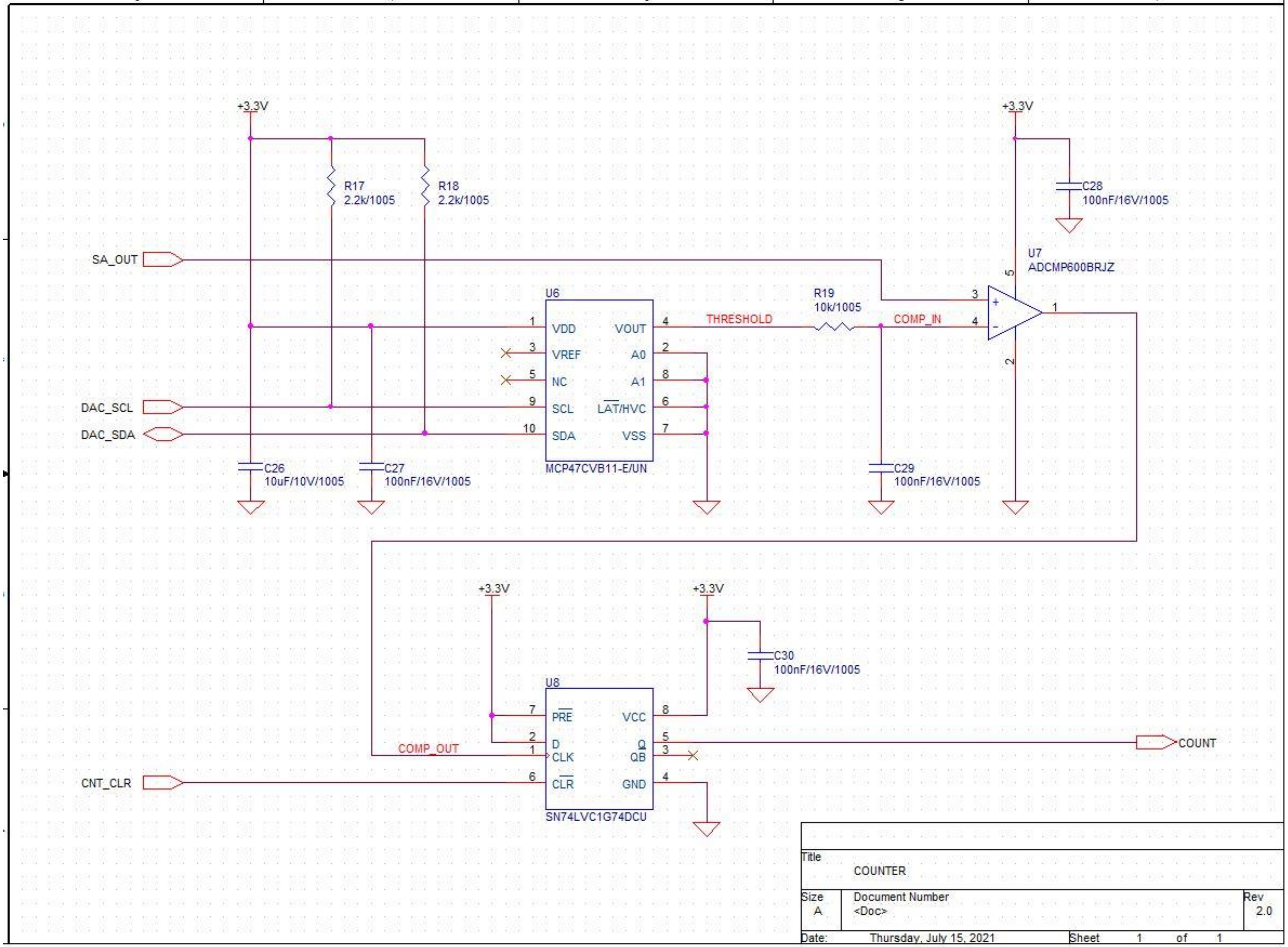
Size: B	Document Number: <Doc>	Rev: 1.0
Date: Thursday, July 15, 2021	Sheet 1 of 1	


+3.3V
R17
2.2k/1005
R18
2.2k/1005
C28
100nF/16V/1005
SA_OUT
U7
ADCMP600BRJZ
U6
R19
10k/1005
THRESHOLD
COMP_IN
VDD
VOUT
VREF
A0
NC
A1
DAC_SCL
SCL
LAT/HVC
DAC_SDA
SDA
VSS
MCP47CVB11-E/UN
C26
10uF/10V/1005
C27
100nF/16V/1005
C29
100nF/16V/1005
C30
100nF/16V/1005
U8
PRE
VCC
D
Q
COMP_OUT
CLK
QB
COUNT
CNT_CLR
CLR
GND
SN74LVC1G74DCU
Title
COUNTER
Size
A
Document Number
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2.0
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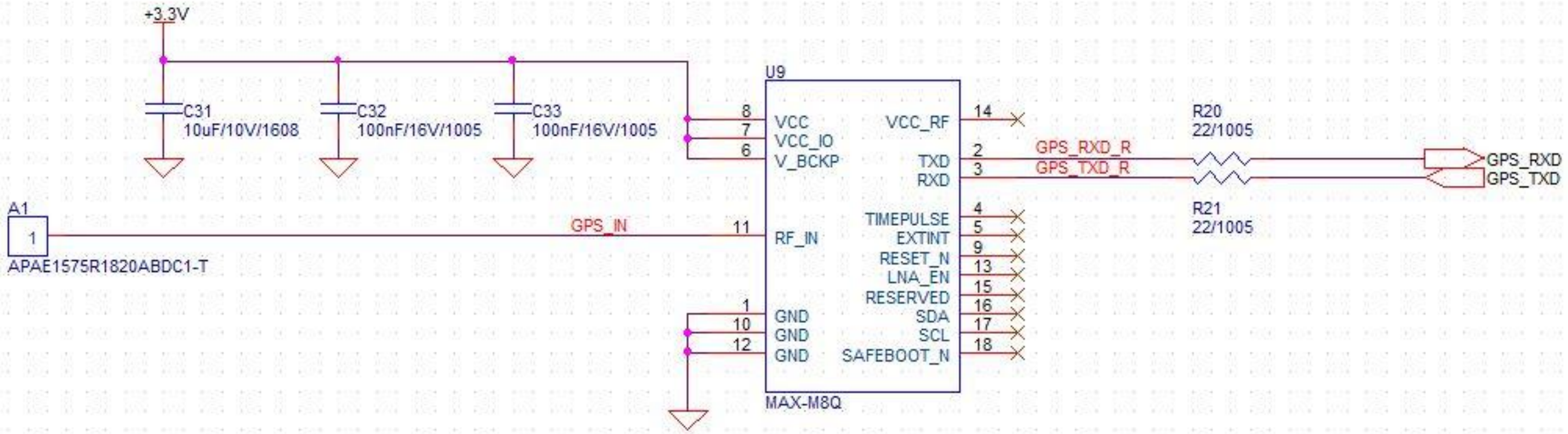
1
of
1



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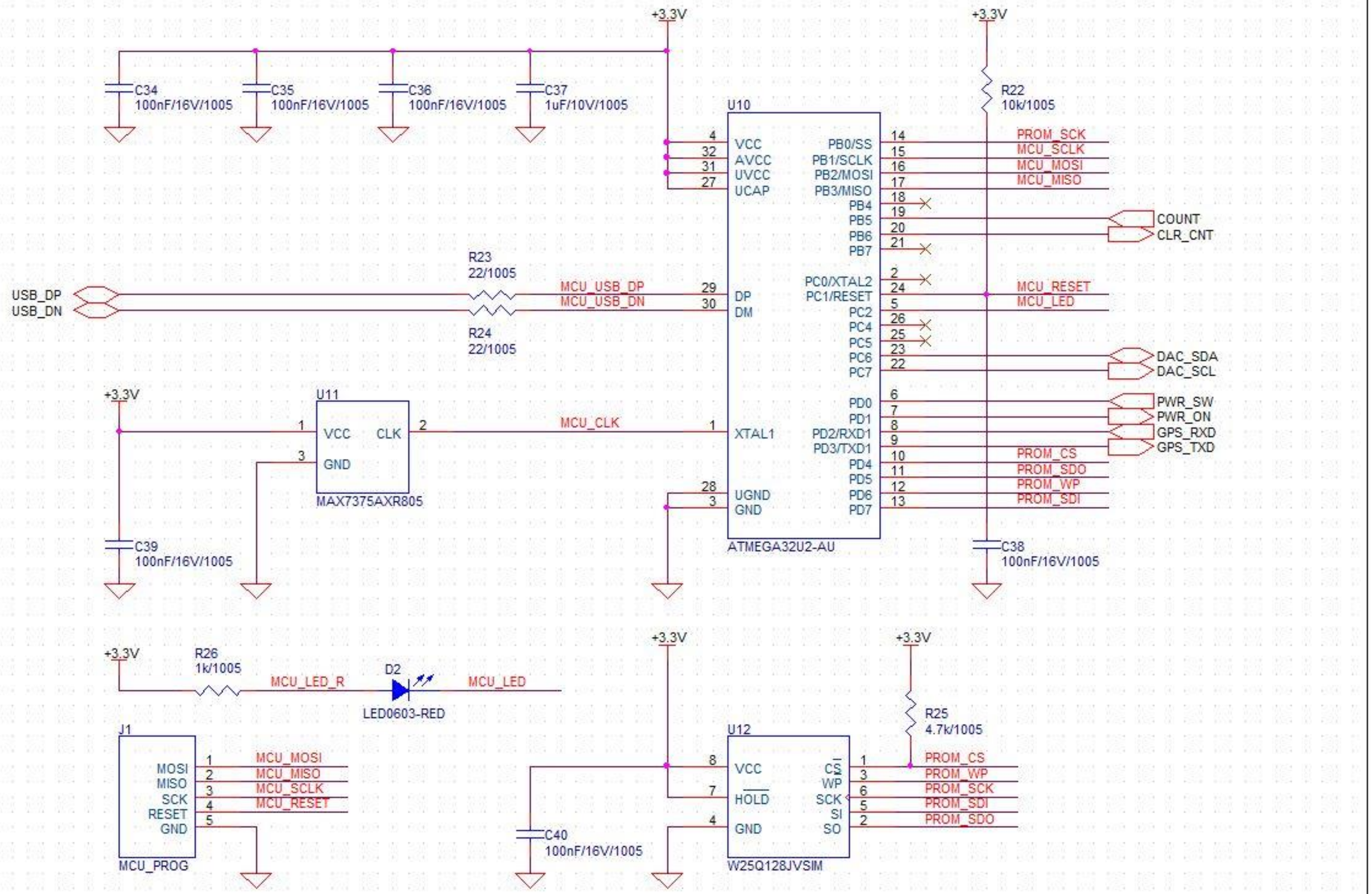
Size A	Document Number <Doc>		Rev 1.0
Date:	Tuesday, August 24, 2021	Sheet 1 of 1	



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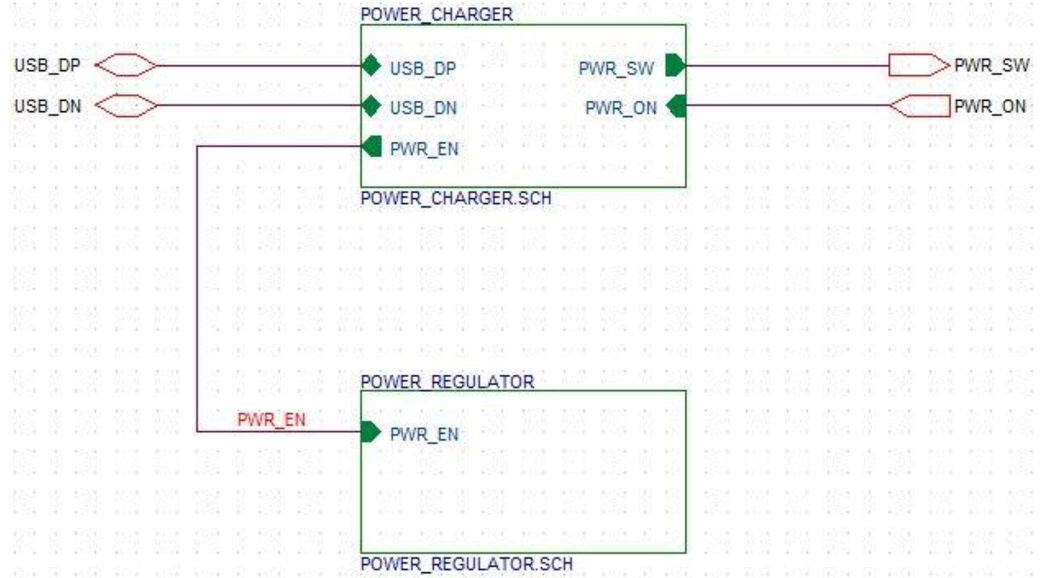
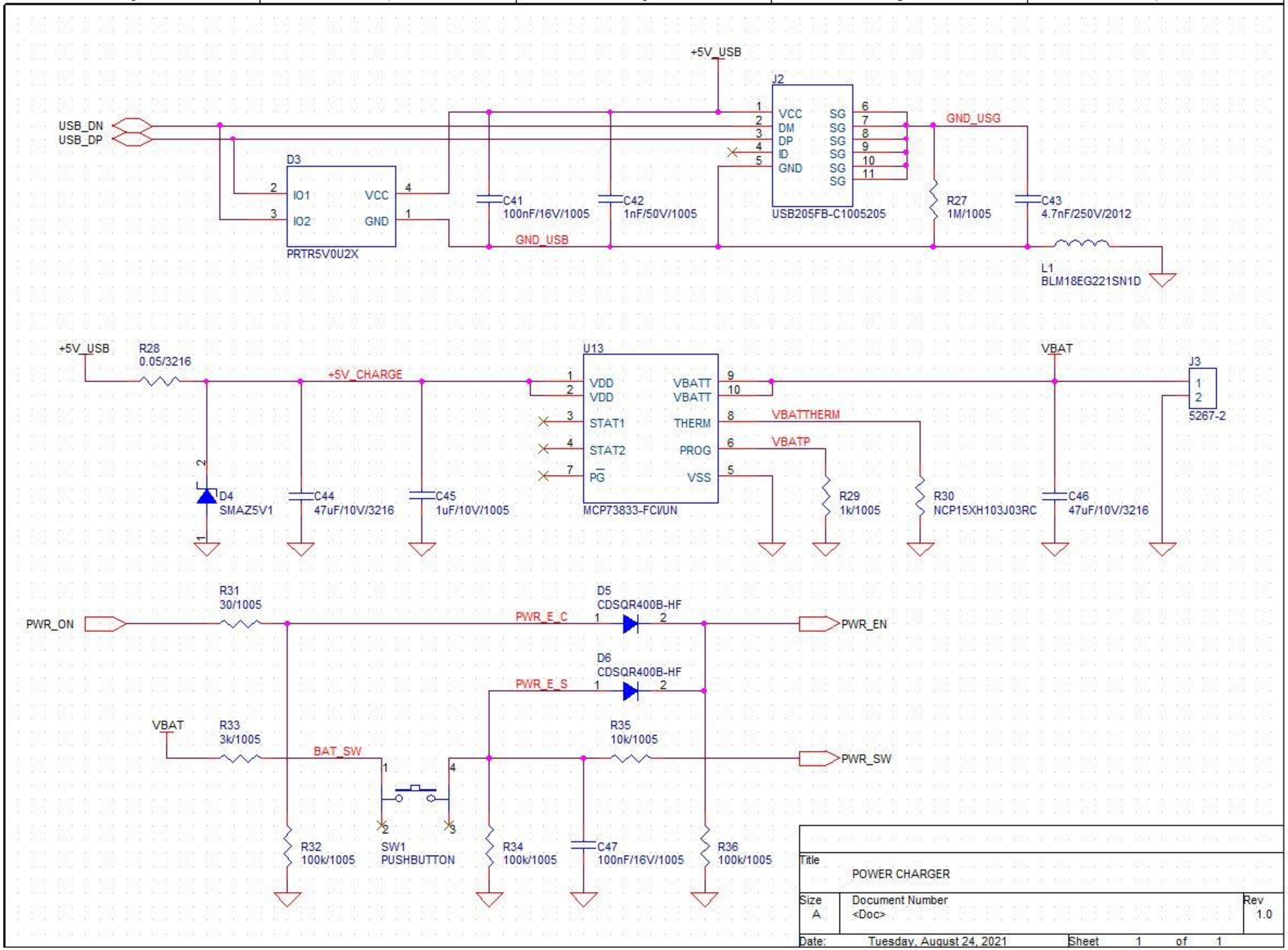
Size A	Document Number <Doc>	Rev 2.0
Date: Tuesday, August 24, 2021	Sheet 1 of 1	



Title	POWER		
Size A	Document Number <Doc>		Rev 1.0
Date:	Friday, August 06, 2021	Sheet 1 of 1	


+5V_USB
J2
USB_DN
USB_DP
1 VCC
2 DM
3 DP
4 ID
5 GND
SG 6
SG 7
SG 8
SG 9
SG 10
SG 11
SG
GND_USG
D3
2 IO1
3 IO2
VCC 4
GND 1
PRTR5V0U2X
C41
100nF/16V/1005
C42
1nF/50V/1005
USB205FB-C1005205
R27
1M/1005
C43
4.7nF/250V/2012
GND_USB
L1
BLM18EG221SN1D
+5V_USB
R28
0.05/3216
+5V_CHARGE
U13
1 VDD
2 VDD
3 STAT1
4 STAT2
7 PG
VBATT 9
VBATT 10
THERM 8
PROG 6
VSS 5
MCP73833-FCI/UN
VBATTHERM
VBATP
VBAT
J3
1
2
5267-2
D4
SMAZ5V1
C44
47uF/10V/3216
C45
1uF/10V/1005
R29
1k/1005
R30
NCP15XH103J03RC
C46
47uF/10V/3216
PWR_ON
R31
30/1005
PWR_E_C
D5
CDSQR400B-HF
PWR_EN
D6
CDSQR400B-HF
PWR_E_S
VBAT
R33
3k/1005
BAT_SW
R35
10k/1005
PWR_SW
R32
100k/1005
SW1
PUSHBUTTON
R34
100k/1005
C47
100nF/16V/1005
R36
100k/1005
Title
POWER CHARGER
Size
A
Document Number
<Doc>
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1.0
Date: Tuesday, August 24, 2021
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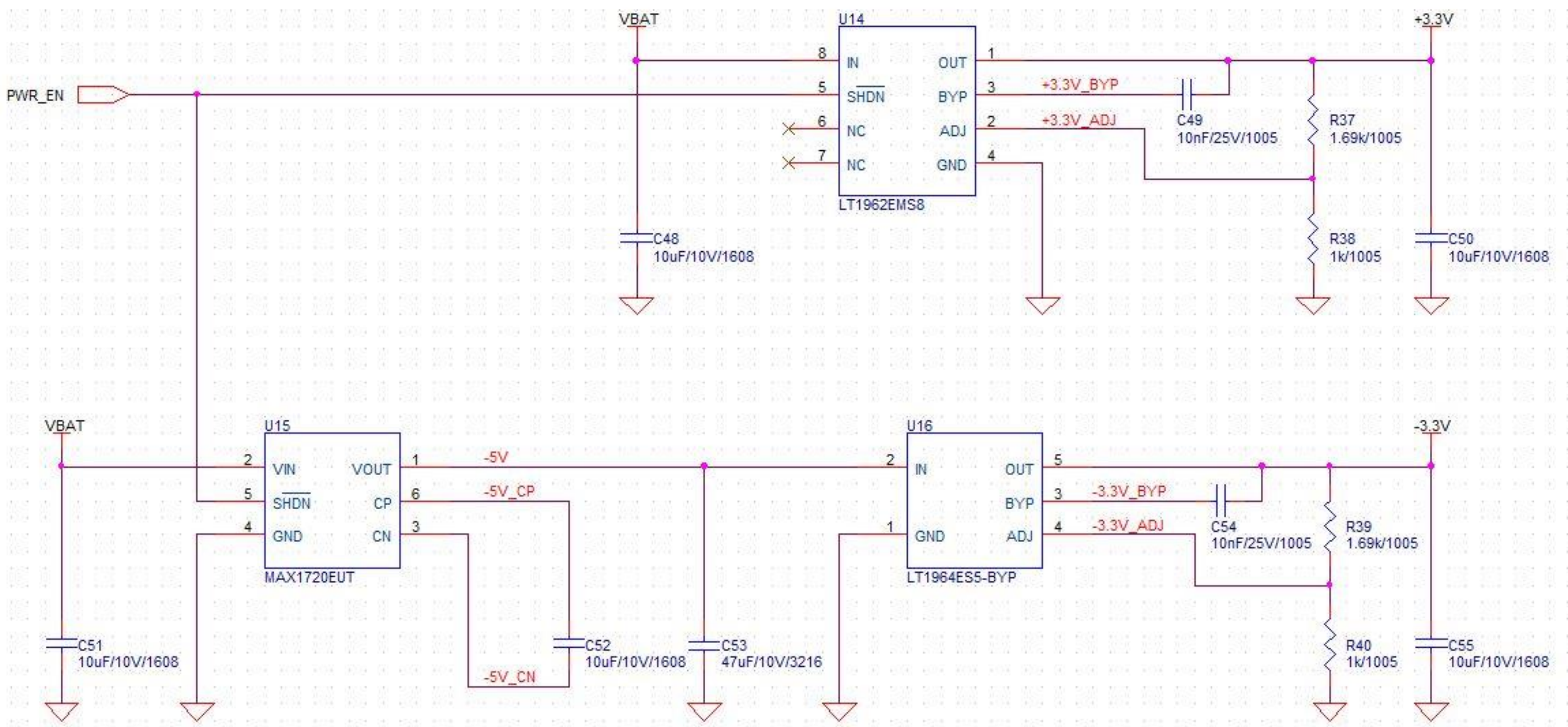

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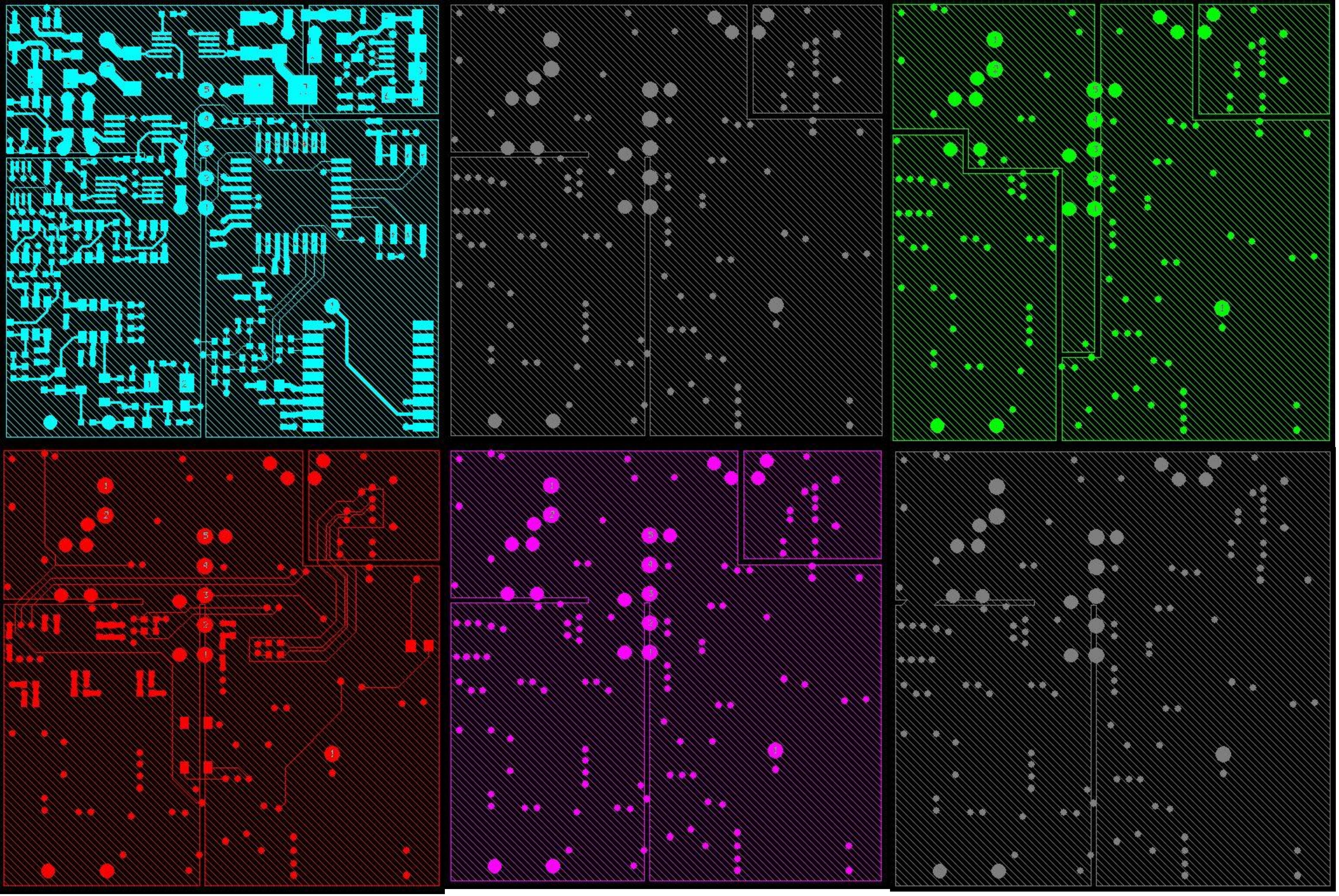
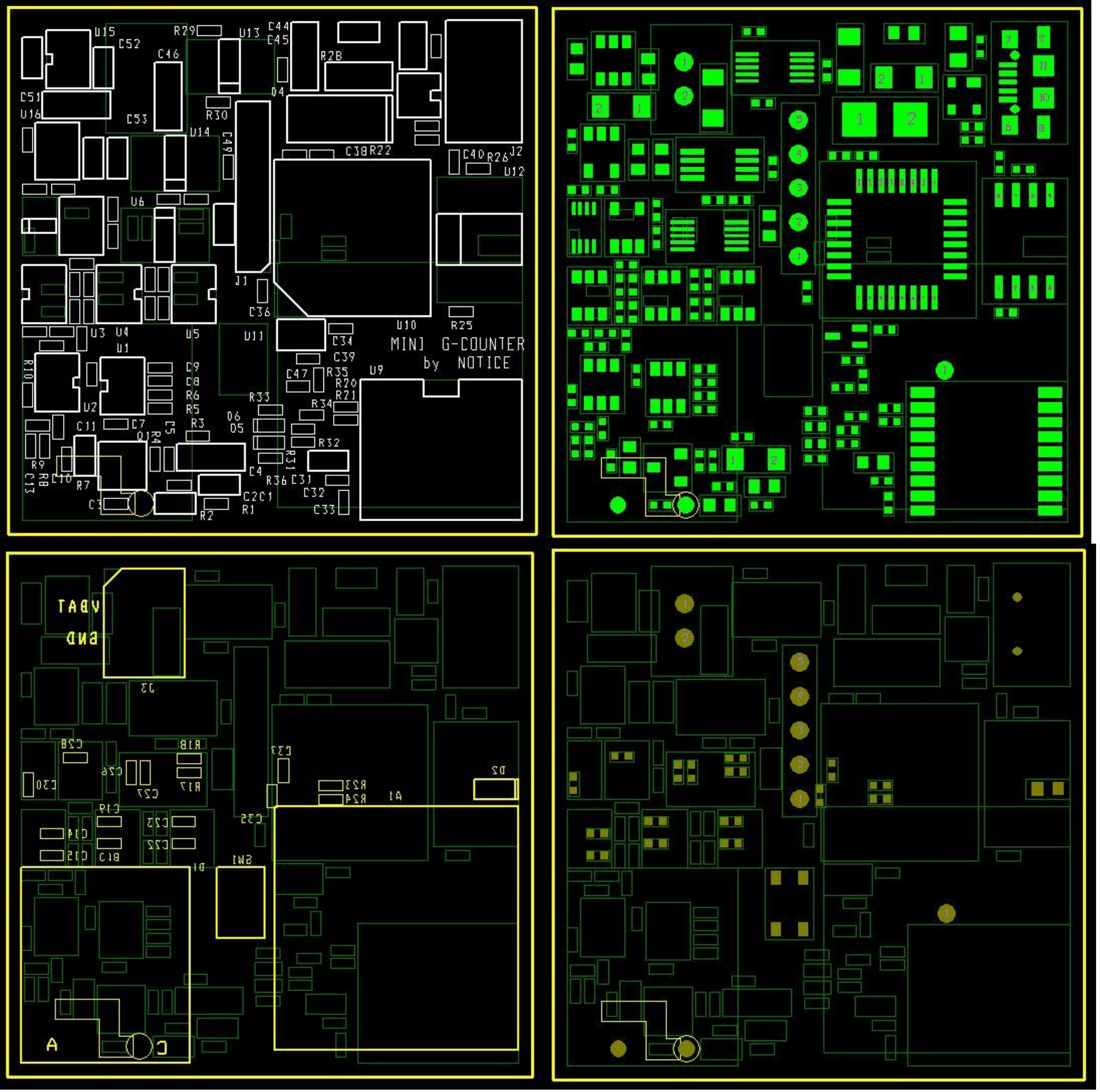
Date:	Friday, August 06, 2021	Sheet 1 of 1




MINI G-COUNTER
by NOTICE