**PM Operation**

Fast PM: pulse rise time $\sim 2\text{ns}$, gain: $3 \cdot 10^7$

- Philips XP2041
- 5” dia cathode
- 14 dynodes
- + focusing electrodes

Socket FE1120
pin connections

PM schematic

PM Voltage divider (progressive)

$U_0=2000\text{V}$

Sockets

mu-metal shield tube provides protection from external B field.

mu metal soft iron
Pre-Amplifiers

Amplify weak detector signals (mV) $\rightarrow 1V$, transmit through cable. Main types: charge-sensitive or voltage-sensitive

Charge sensitive preamps integrate directly $Q(t) \propto E_{\text{deposit}}$

For semiconductor IC diodes (small signals).

Voltage sensitive preamps amplify $U(t) = Q(t)/C$, $C = \text{const.}$ $\rightarrow$ PM, PC

Detector: capacitor $C_d$, $\rightarrow$ charge $Q(t)$, current $I = dQ/dt$

For $E$ measurement, integrate $Q$

For $t$ measurement, differentiate $Q$

Use operational amplifiers (op-amp) for both.

Replacement circuit for detector and decoupling.
Basic Counting System

Charge sensitive preamplifier: Voltage output pulse height (1V) independent of detector C

- **R**: Load resistor
- **C**: Insulate electronics from HV (det. Bias)
- Pulse height ~100 mV

Amplifier/Shaper: differentiates (1x or 2x)

Final amplitude 2-10V

Pulse Height Analysis → Digitization

Binary data to computer
Operational Amplifier Principle

Op Amp inputs:
Inverting (-), non-inverting (+)

\[ U_{out} = G \cdot \left[ U_{in}^+ - U_{in}^- \right] \]

Gain \( G \approx 10^6 \)

\( U_{out} \approx 1V \rightarrow U_{in}^+ - U_{in}^- \ll 1V \)

Internal resistance \( R_{int} \approx M\Omega - T\Omega \)

Input currents \( I_{in}^{+,-} \approx 0 \)
Operational Amplifiers

Inverting amplifier (gain \( G \approx 10^6 \)).

Properties of amp determined by feedback:

Feed back negative of input signal to the summation point cancels the signal at \( \Sigma \), \( I_\Sigma = 0 \)

\[
I_\Sigma = 0 = I_{in} + I_f = \frac{U_{in}}{R_{in}} + \frac{U_{out}}{R_f} \quad \rightarrow \quad U_{out} = -\frac{R_f}{R_{in}} \cdot U_{in}
\]

\[
0 = I_{in} + I_f = \frac{U_{in}}{R_{in}} + C_f \frac{dU_{out}}{dt} \quad \rightarrow \quad U_{out} = -\frac{1}{R_{in}C_f} \cdot \int U_{in} \, dt
\]

Integrator

\[
U_{out} = -C_{in} \cdot R_f \cdot \frac{dU_{in}}{dt}
\]

Differentiator
Comparator/Digitizer

Functionality:
\[ 0 \leq U_{\text{out}} \leq +5V \]

Initially \((U_{\text{in}} \text{ open, not connected})\)  
+ input at \(U_{\text{Thr}} = +2.5\) V

If \(U_{\text{in}} < +2.5\) V  \(\rightarrow\) \(R_3\) no current  \(\rightarrow\) \(U_{\text{out}} = 5V\)

If \(U_{\text{in}} > +2.5\) V  \(\rightarrow\) \(R_3\) max current  \(\rightarrow\) \(U_{\text{out}} = 0V\)

Device essentially digitizes analog pulse amplitude.  
Stack of several \(\rightarrow\) ADC
Inverting, integrating preamp

Pulse decay governed by $t_{\text{dec}} \approx \frac{1}{R_f C_f}$.

Additional amplifier necessary for pulse shaping and gain.
Main/Shaping Amplifiers

Tasks: 1) **Linear** amplification to pulse heights of $U \approx (1-10)V$
2) Improvement of signal/noise ratio (integration)
3) Pulse shaping (Gaussian shape is best)

More versatility: RC-circuits $\rightarrow$ active filters
NIM Signal Standards

(National Instruments Methods)

Linear analog NIM signals

+10V

0V

Slow logical NIM (TTL) pulses: discriminators, gates, ...

+10V

0V

“1”

“0”

+5V

0V

TTL-Logic

“1”

“0”

≤2ns

Fast logical NIM signals for fast timing/triggering

-16mA

-0.8V/50Ω

NIM-gate/trigger signal

W. Udo Schröder, 2009
Task: Produce a logical signal, whenever analog signal exceeds threshold \( U_{\text{disc}} \). Use for logical decisions (open acquisition,…). Exists for slow and fast pulses.

For fast timing, use negative NIM logic units.
Zero-Crossing Triggering

Produce fast, bipolar linear pulse. Possible: different gains for positive and negative parts $\rightarrow$ zero crossing at different times (fraction of time to maximum)

Produce “saturated” uniform pulse

Differentiate saturated pulse, use triplet pulse as input for trigger (negative pulse polarity).

Trigger output appears at zero crossing

(Internal delays here neglected)
Constant-Fraction Discriminator

Amplitude dependent leading edge discr. output timing

Zero crossing timing (@ fraction $f$ of amplitude): always at same physical $t$ independent of amplitude (fixed pulse shape): No "walk" with energy

Can utilize for PSD!
Logic Modules

Overlap Coincidence
\[ U_{\text{out}} = U_1 \land U_2 \]

Or (inclusive)
\[ U_{\text{out}} = U_1 \lor U_2 \]

Anti-Coincidence/Veto
\[ U_{\text{out}} = U_1 \land \neg U_2 \]

For fast timing: use fast negative logic
Coaxial cables/transmission lines $\leftrightarrow$ traveling waves in cavity resonators

Wave equation (R=0):

$$\frac{\partial^2 U}{\partial z^2} = L \cdot C \cdot \frac{\partial^2 U}{\partial t^2}$$

signal propagation speed (speed of light):

$$c = \frac{1}{\sqrt{LC}}$$

typically $c^{-1} = 5 \text{ ns/m}$

characteristic resistance $Z_0=$Ohmic resistance!

For $R\neq 0$, $Z_0(\omega)$ complex

$$Z_0 = \sqrt{L/C}$$

$Z_0 = 50 \Omega$ or $93 \Omega$

used for timing, spectroscopy, resp.
For impedance matching, $R_{\text{load}}=Z_0$, cable looks infinitely long: no reflections from end.

For mismatch, $R_{\text{load}} \neq Z_0$, reflection at end, traveling back, superimpose on signal → terminate with $R_{\text{term}}$.

\[
\frac{U_{\text{refl}}}{U_{\text{in}}} = \frac{R_{\text{load}} - Z_0}{R_{\text{load}} + Z_0}
\]

Polarity of reflected signal $R_{\text{load}}=0$, $\infty$
Receiver input impedance $R_{\text{load}} \neq Z_0$, \(\rightarrow\) use additional Ohmic termination in parallel

Open end: $R_{\text{load}} = \infty$
Input and reflection equal polarity, overlap for $t > 2T_{\text{cable}}$

$T_{\text{cable}} = \frac{2L}{c}$

Short: $R_{\text{load}} = 0$, Input and reflection opposite polarity, superposition = bipolar

Multiple (n) reflections attenuated by $R^{-n}$
The End