TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

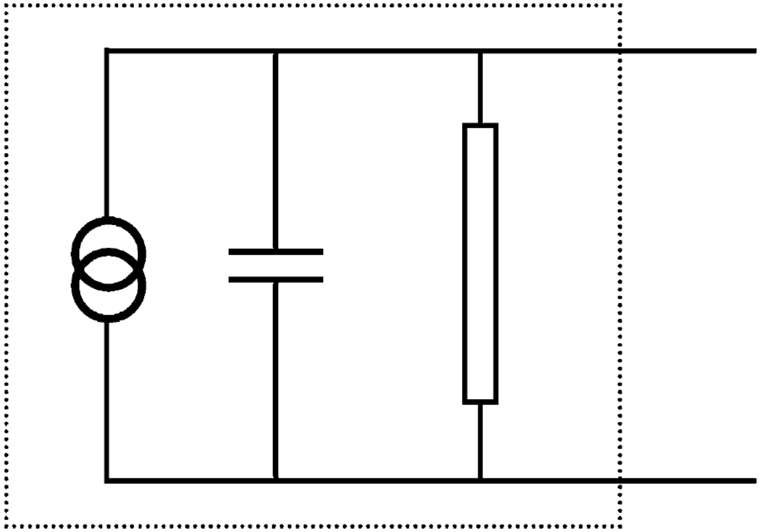
Detector Physics

Support Electronics

November 24, 2015

D. Lascar | Postdoctoral Fellow | TRIUMF

Outline



- Signal Basics
- Crate standards
  - NIM
  - CAMAC
  - VME
- Processing electronics
- Analysis Electronics
- Transmission and Noise Reduction

Signals are small…(for the most part)

- You are (almost) always trying to extract an electrical signal from your detector
  - Phosphor screens are a notable exception
- Gaseous detectors and photomultiplier tubes can make life easier with charge multiplication but semiconductors normally don't multiply
- Electronics can…

Two different ways for measuring signals

Pulse Mode

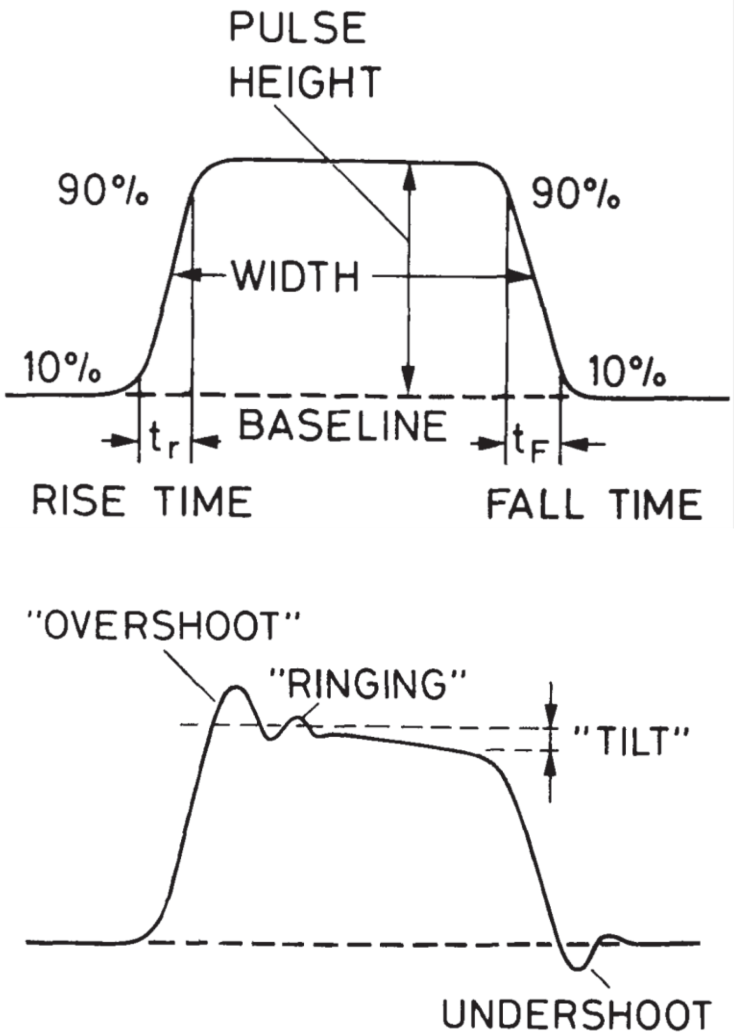
- Most common
- Observe and count individual pulses
- Timing preserved
- Amplitude (Energy) is measured
- Rate limited.

Current mode

- Not uncommon
- All charge is measured via integration
- Rate independent
  - Pileup is ok
- Timing information lost
- Amplitude is lost

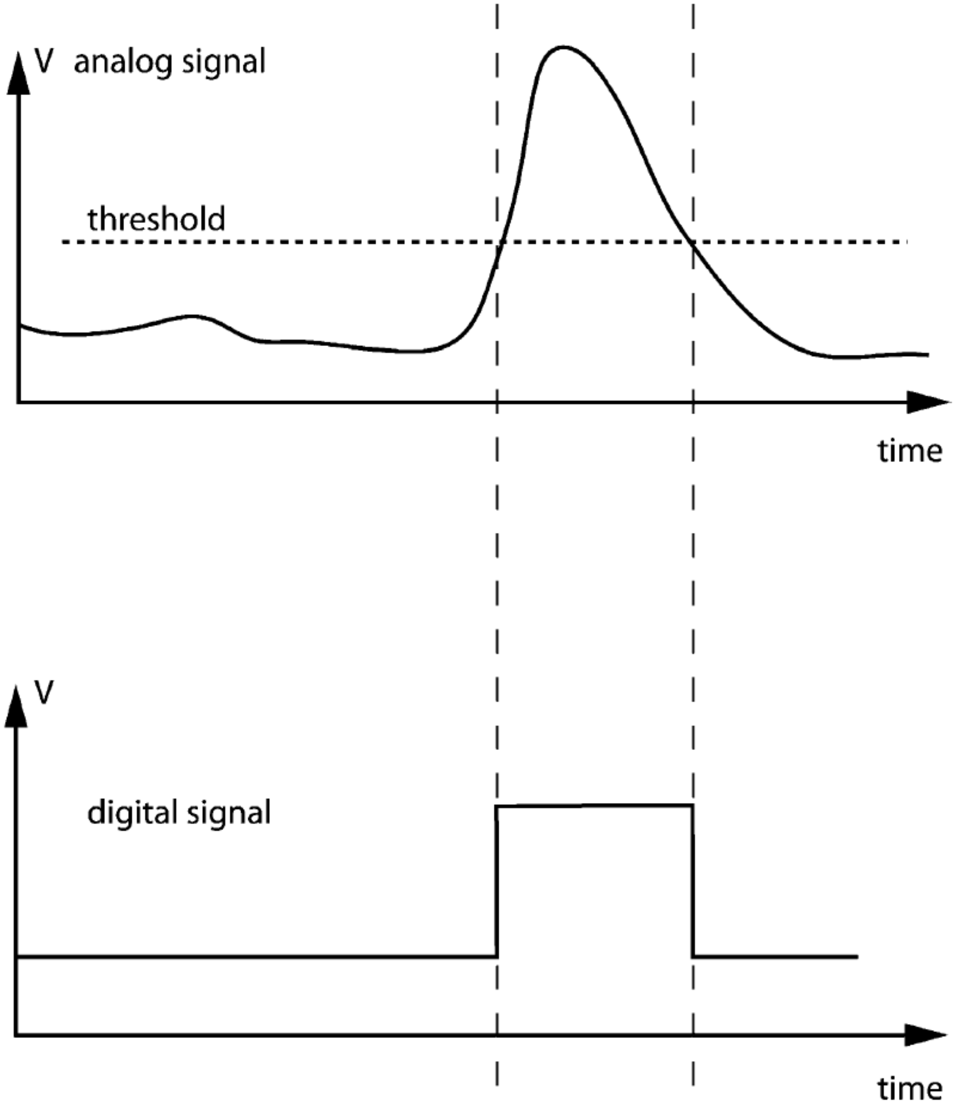
Analog pulse signals

- Brief surges of current or voltage
- We measure
  - Existence
  - Polarity
  - Shape
  - Amplitude
  - Width
  - Timing



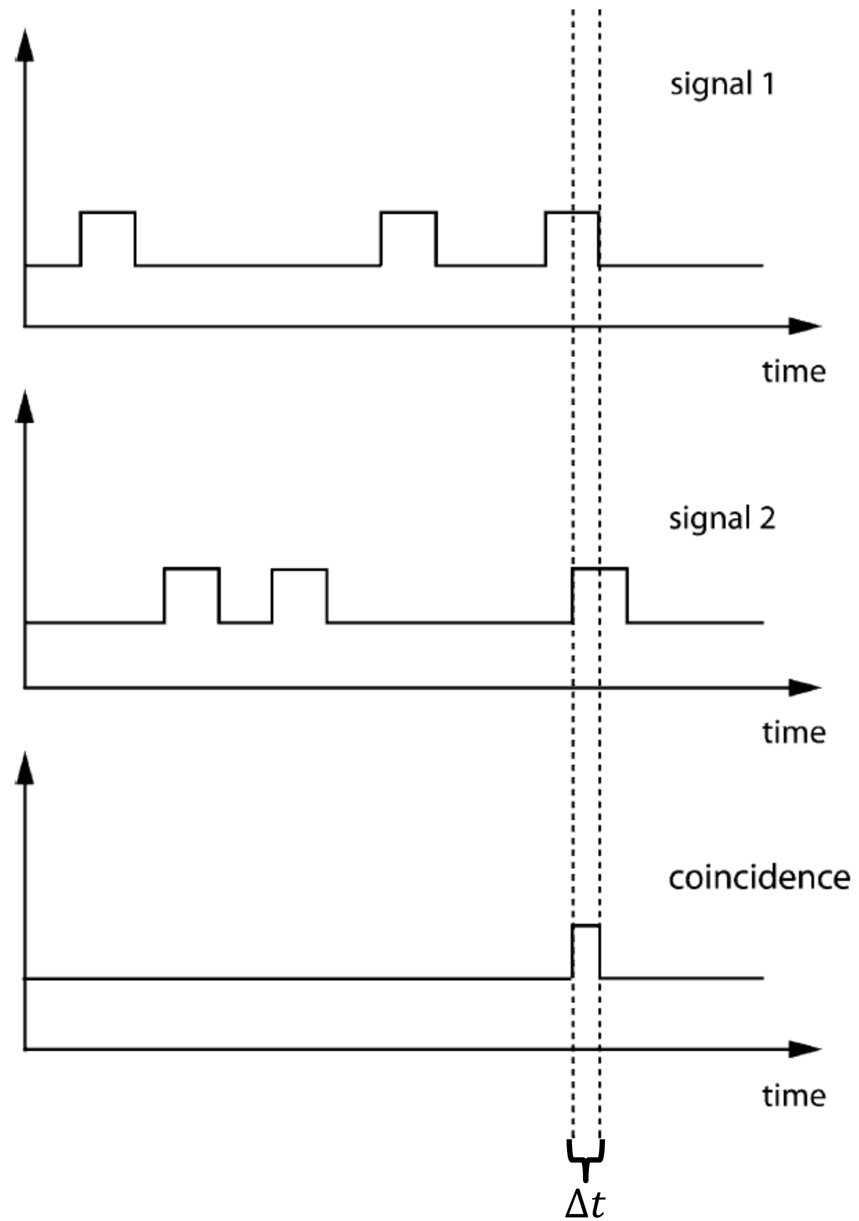
The discriminator – measuring existence

- The input signal is always on.
- A reference voltage is set by the user – *threshold*
- When the voltage on the input goes higher than the threshold: *Output = 1*
  - 1 and 0 set by user/device



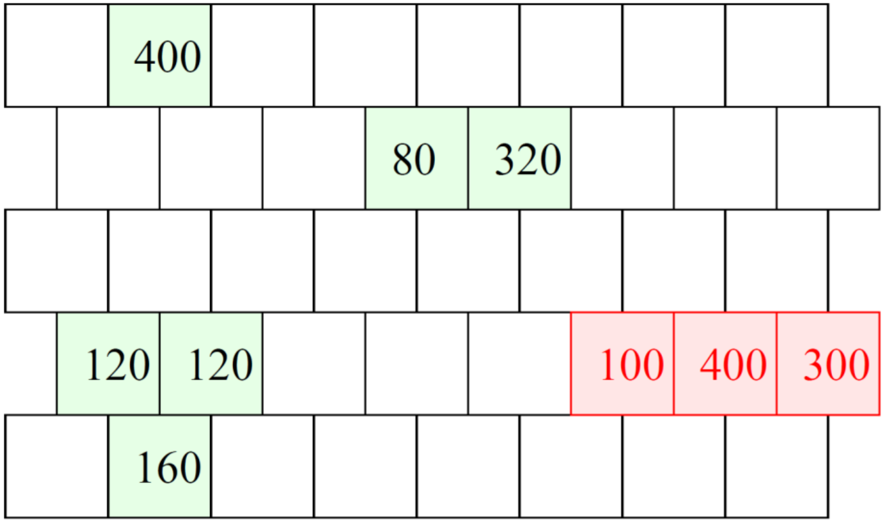
Coincidence measure

- Not every signal has inherent value
- Most events generate multiple signals
- Timing correlates multiple signals with the same events
- Random events must be accounted for
  - $\frac{dN_{\text{Rand}}}{dt} = \frac{dN_1}{dt}\frac{dN_2}{dt}\Delta t$



Photon calorimeter

- Consider a segmented calorimeter designed to measure γ's from 300 MeV to 2000 MeV.
  - γ can deposit energy in groups of one or more cells.

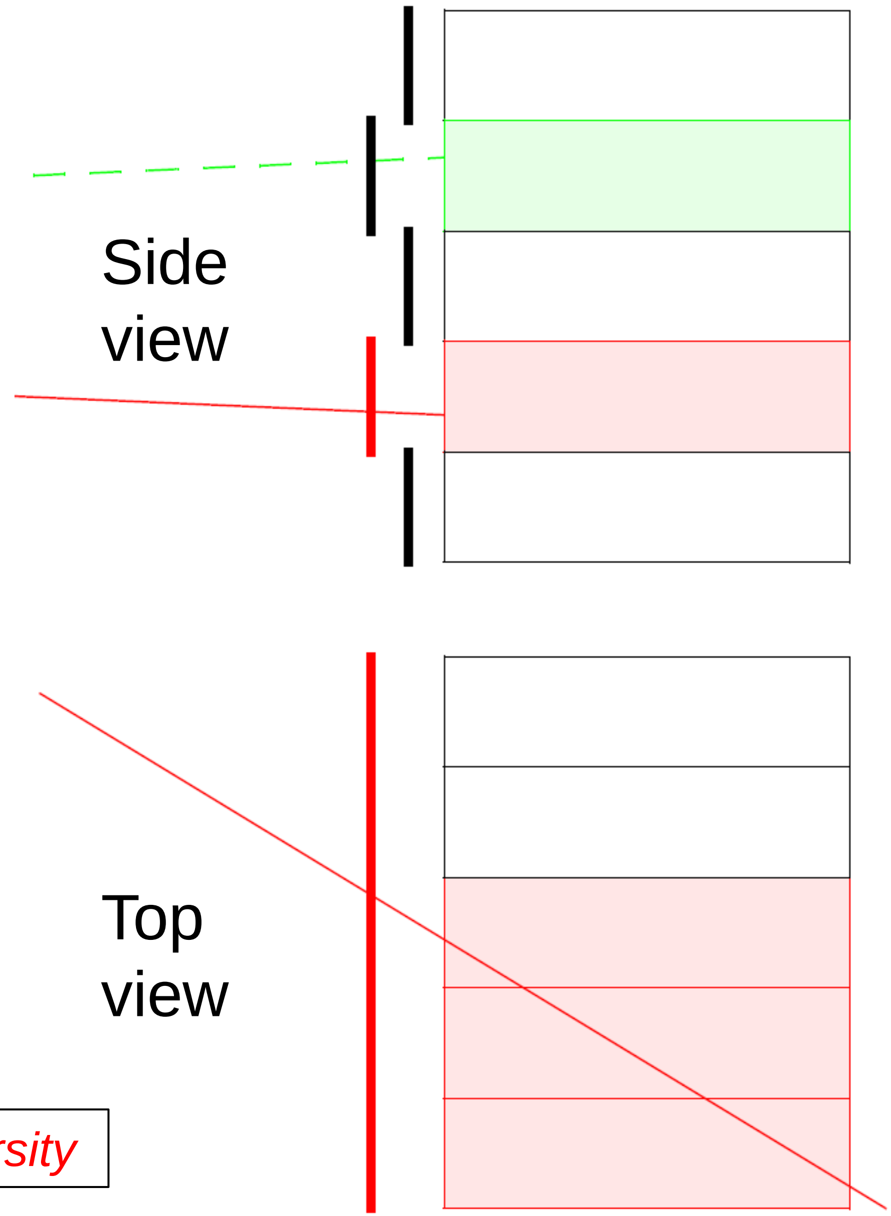


- A charged pion might pass through the detector and leave energy that should be rejected.

Slide courtesy of M. Fortner, N. Illinois University

Veto Detector

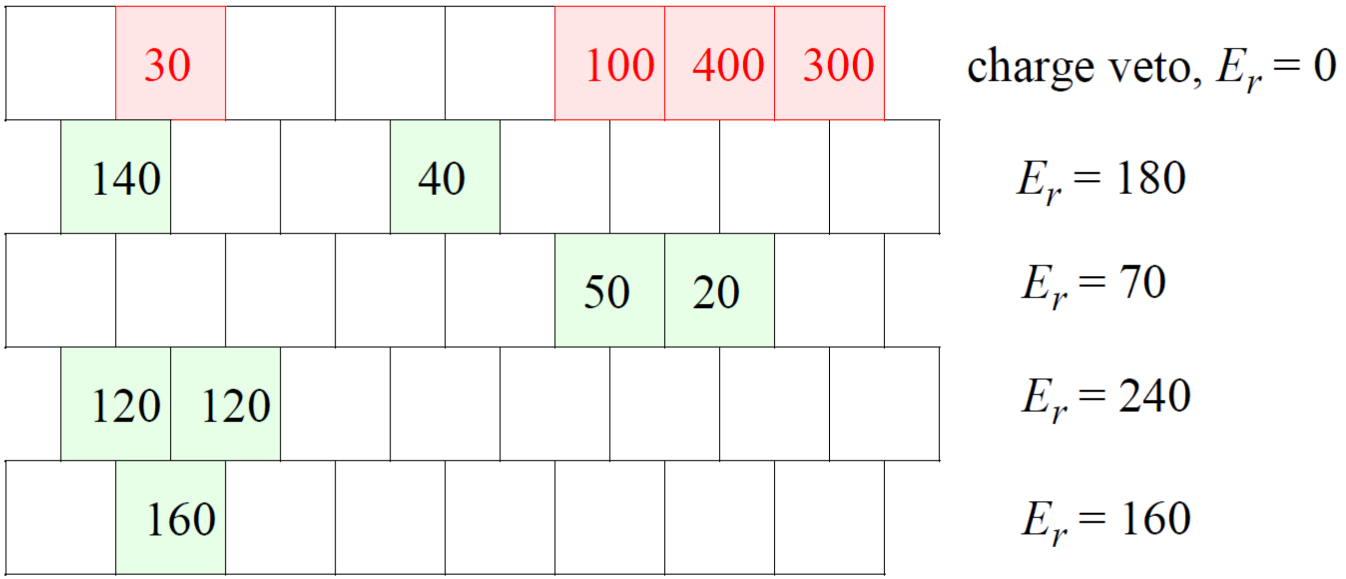
- Set of scintillators placed in front of a calorimeter to act as simple counters.
- A charged particle will create a signal in the scintillator, but a photon will not.



Slide courtesy of M. Fortner, N. Illinois University

Neutral rows

- Simple trigger solution: Sum all the energy in a row when not vetoed by the scintillator.
  - If any row exceeds 300 MeV it's a good event.

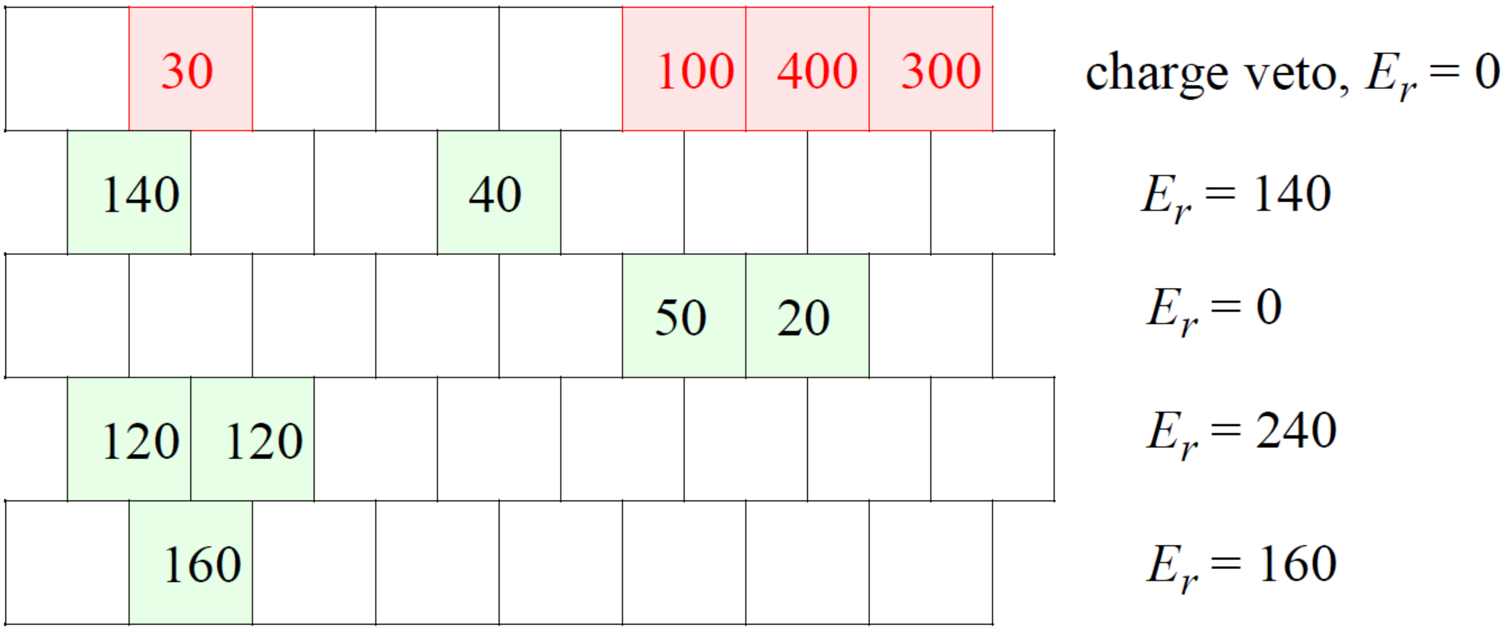


- Trigger will exclude π's & soft-γ spray.
- Trigger inefficient when a good γ spreads energy between two rows

Slide courtesy of M. Fortner, N. Illinois University

Selected Sum

- Better trigger sums all blocks not vetoed, but insist that each cell exceed a 75 MeV threshold



- Excludes π's and soft-γ spray
- Better at finding 2-row γ's

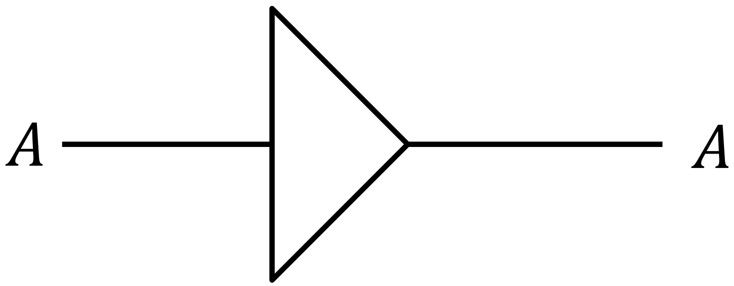
Slide courtesy of M. Fortner, N. Illinois University

Logic gates

- A *gate* is a circuit element that operates on a binary signal
- Logic operations typically have three methods of description:
  - Equation symbol
  - Truth table
  - Circuit symbol
- When levels refer to Boolean expressions they are referred to as *True* and *False*.
  - Logic levels are *T*=True & *F*=False
  - Binary levels are *1*=True & *0*=False
- When levels refer to electronic voltage levels they are called *High* and *Low*
  - Logic *H*=High & *L*=Low
  - Binary levels are *1*=High & *0*=Low

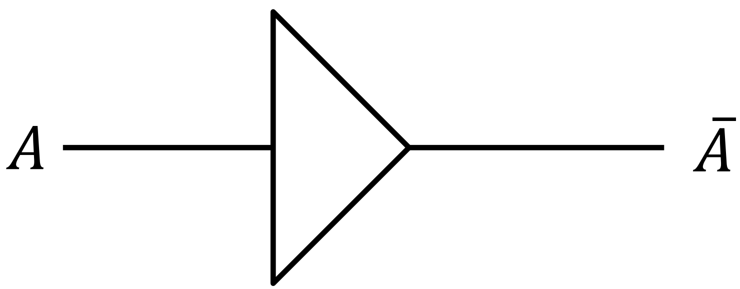
Unary operators – 1 input

- The identity operator leaves the value unchanged



A_{in}	A_{out}
0	0
1	1

- The inverse operation reverses the value and is called NOT.

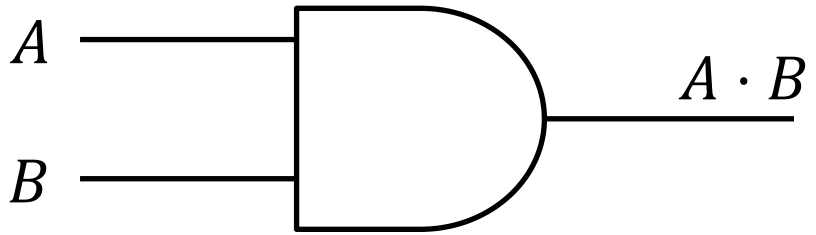


A_{in}	A_{out}
0	1
1	0

Slide courtesy of M. Fortner, N. Illinois University

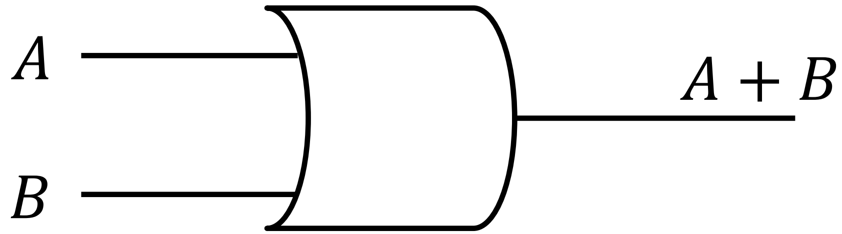
Binary operators – 2 inputs

- AND operator acts like multiplication



A	B	$A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

- OR operator acts like addition

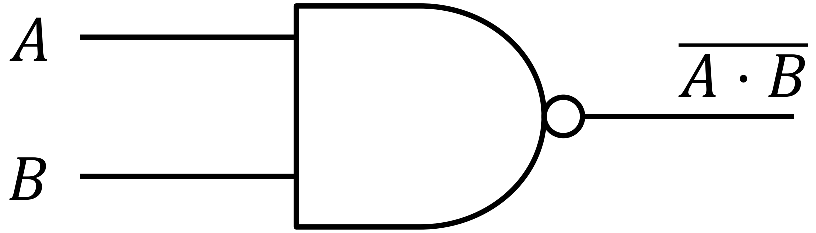


A	B	$A + B$
0	0	0
0	1	1
1	0	1
1	1	1

Slide courtesy of M. Fortner, N. Illinois University

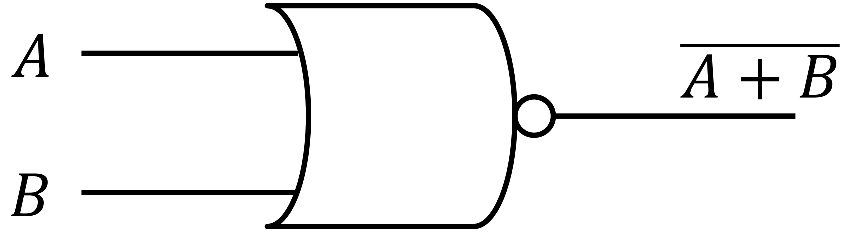
Compound operations

- Combination of NOT & AND is NAND



$\boldsymbol{A}$	$\boldsymbol{B}$	$\overline{\boldsymbol{A} \cdot \boldsymbol{B}}$
0	0	1
0	1	1
1	0	1
1	1	0

- Combination of NOT & OR is NOR



$\boldsymbol{A}$	$\boldsymbol{B}$	$\overline{\boldsymbol{A} + \boldsymbol{B}}$
0	0	1
0	1	0
1	0	0
1	1	0

Slide courtesy of M. Fortner, N. Illinois University

Compound operations

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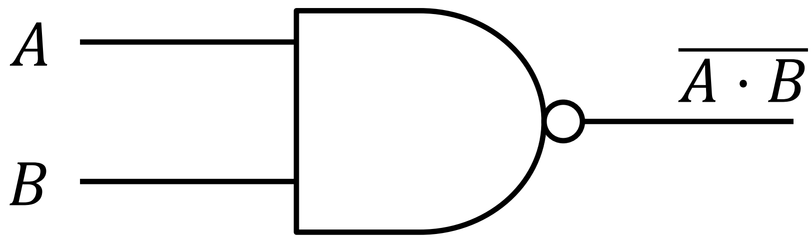


- Combination of NOT & OR is NOR

- Either NAND or NOR gates can be used to create other logic gates

$$\overline{(\overline{A \cdot B}) \cdot (\overline{A \cdot B})} = A \cdot B$$

$$\overline{(\overline{A + A}) + (\overline{B + B})} = A \cdot B$$

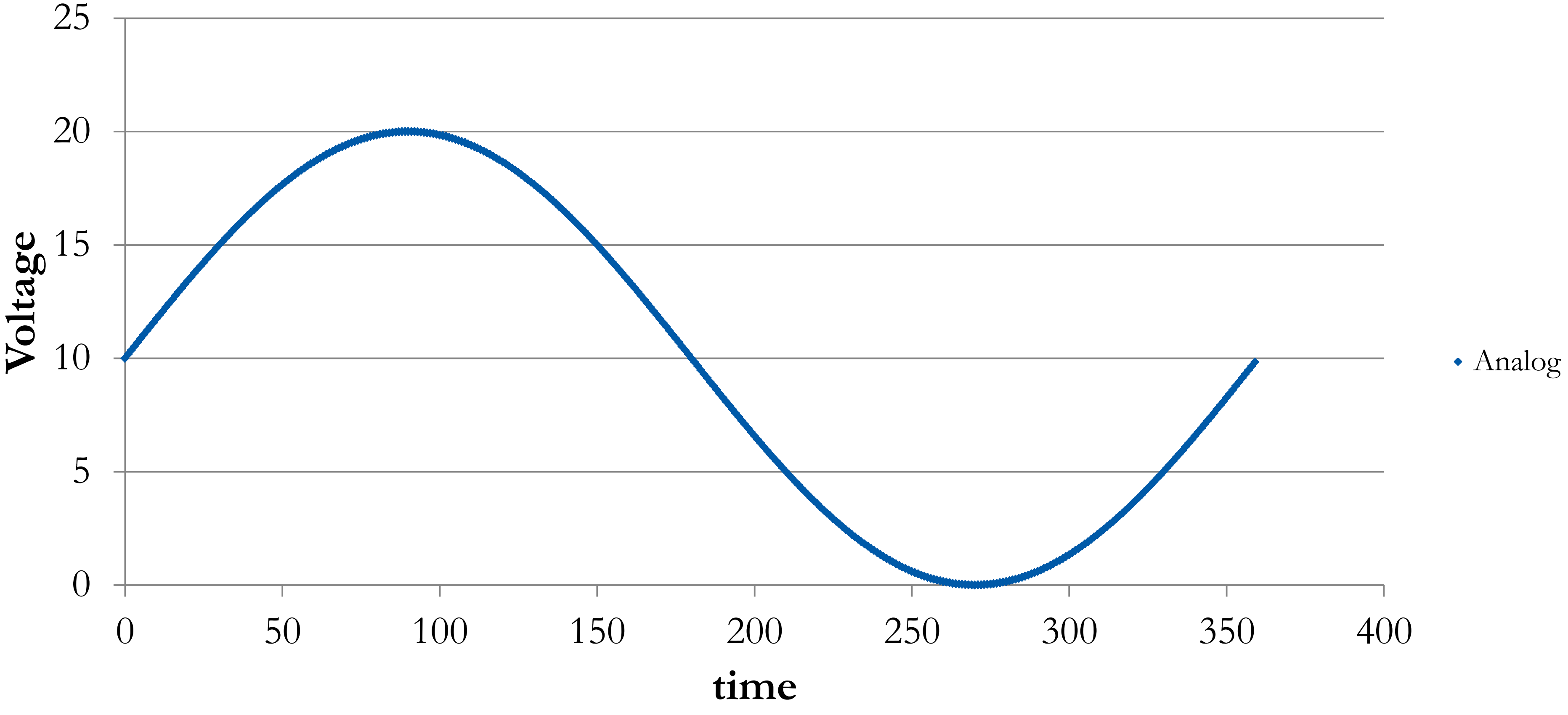
Slide courtesy of M. Fortner, N. Illinois University

Many many many many many more

- Exclusive OR
- Flip-Flops
- Clocks
- Counters
- Multistage dividers
- A plethora of amplifiers
  - Summation
  - Difference
  - Multipliers

Analog to digital conversion

- Signal attributes are most easily processed when converted to a digital signal



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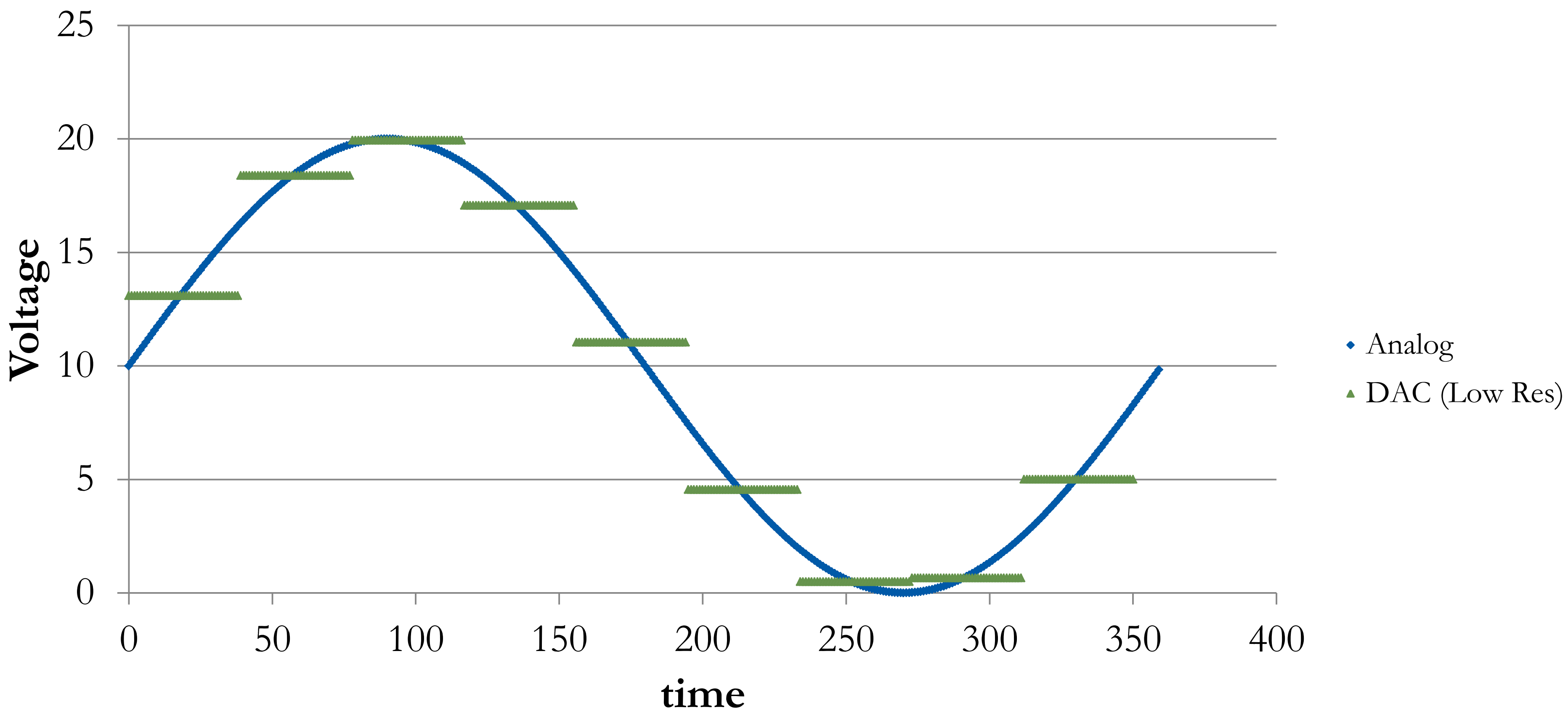

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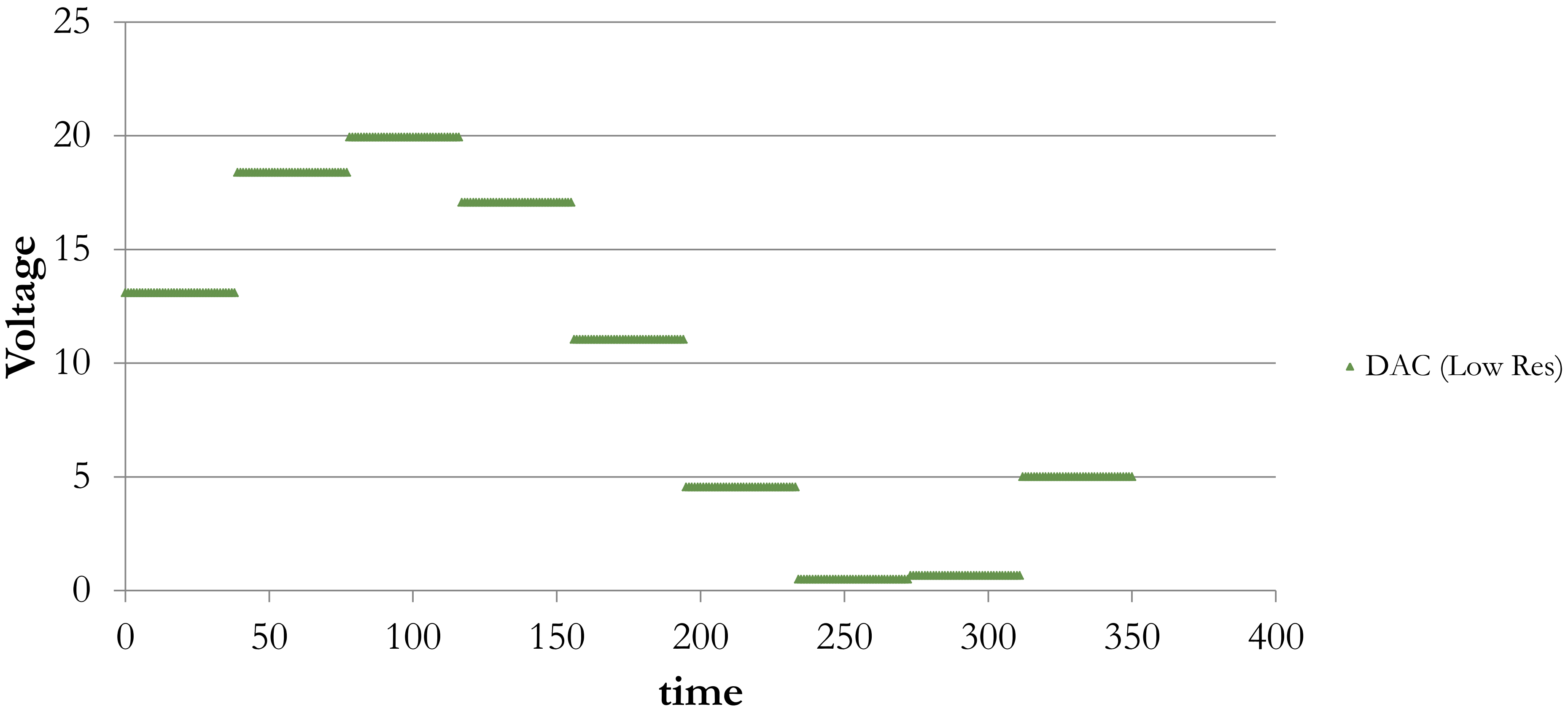

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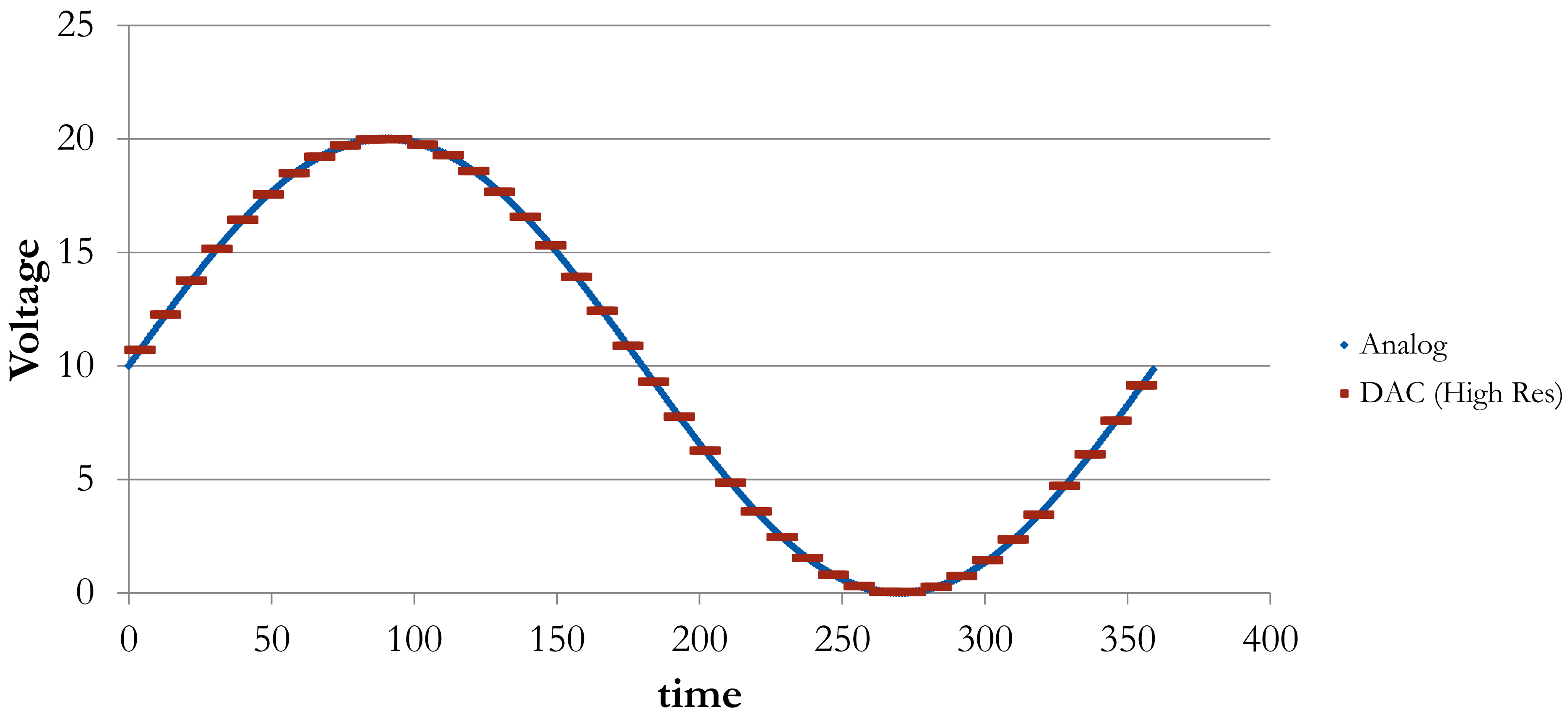

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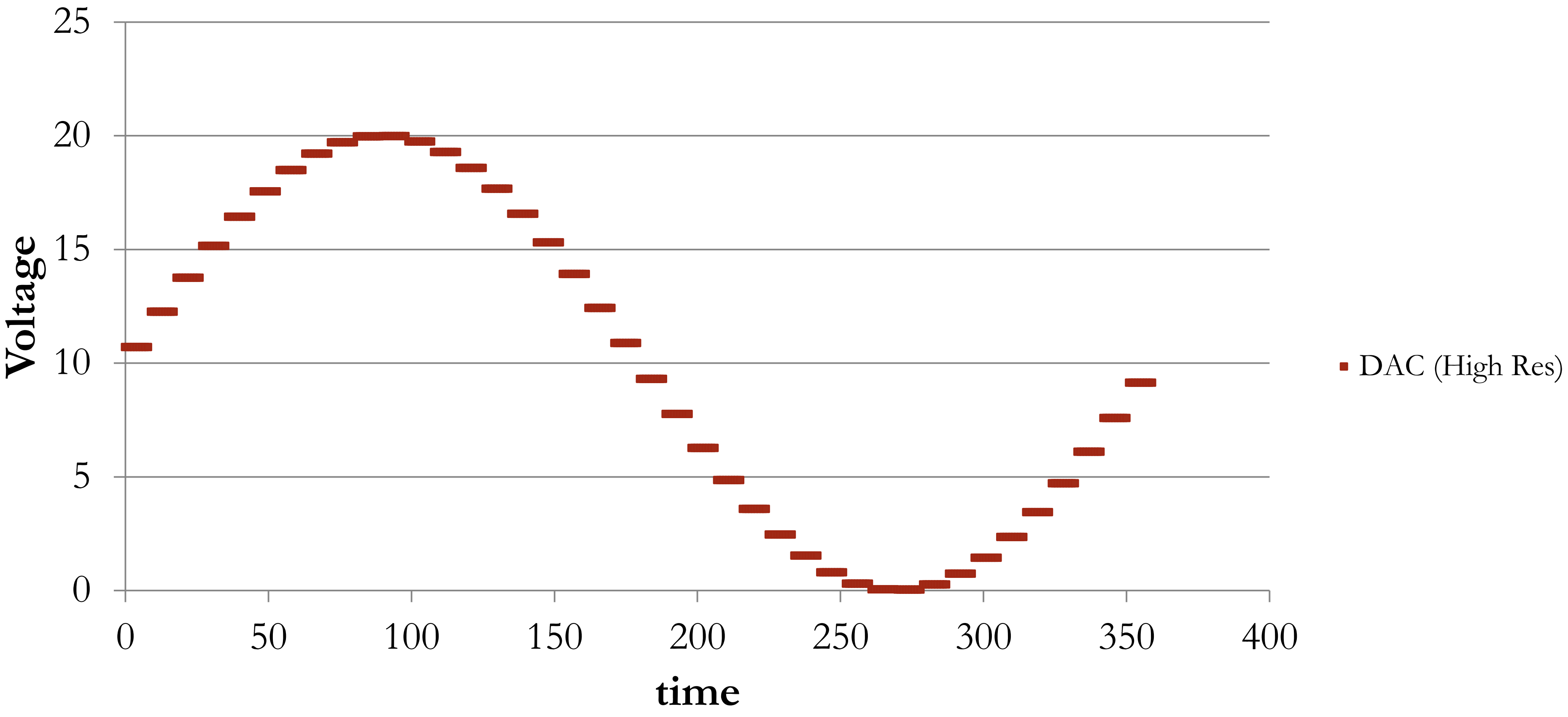
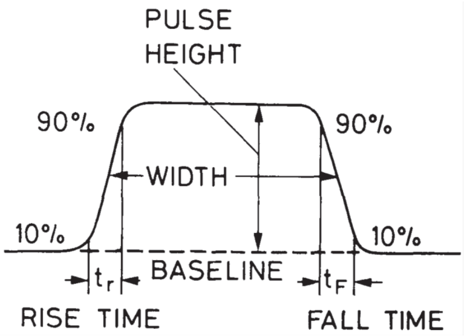
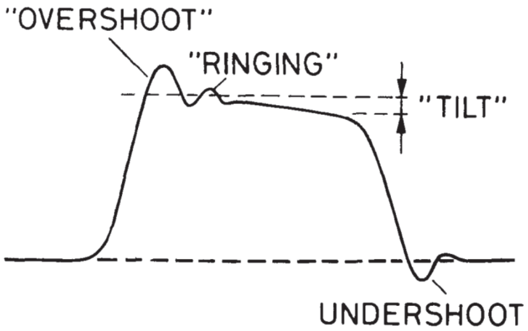


Digital signals make logic easy/possible

- Electronics that analyze systems to be when measuring quantized pieces of information.
- Improving the sampling rate allows for finer “level-splitting” but most electronics only have two states: 0 and 1 – Logic signals
- Logic carries less information more reliably
  - Don’t have to worry about maintaining the full waveform





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- Improving the sampling rate allows for finer "level-splitting" but most electronics only have two states: 0 and 1 – Logic signals
- Logic carries less information more reliably
  - Don't have to worry about maintaining the full waveform
- It would be easier to define a standard
  - Or 5 standards, it doesn't really matter as long as we know what we're dealing with

The Nuclear Instrument Module (NIM) standard

Slow positive logic

- Slow rise time
  - ≥ 100 ns
- Positive polarity
- Designed for high input impedance (≥ 1000 Ω)
  - Low current
  - **Can't be transmitted over long cable**
- Not used so often

	Output must deliver	Input must accept
Logic 0	-2 to +1 V	-2 to +1.5 V
Logic 1	+4 to +12 V	+3 to +12 V

Fast negative logic (NIM logic)

- Fast rise time
  - ~1 ns
- Negative polarity
- Current based standard & low impedance
  - Current into 50 Ω
    - Logic 0: 0 V
    - Logic 1: -0.8 V

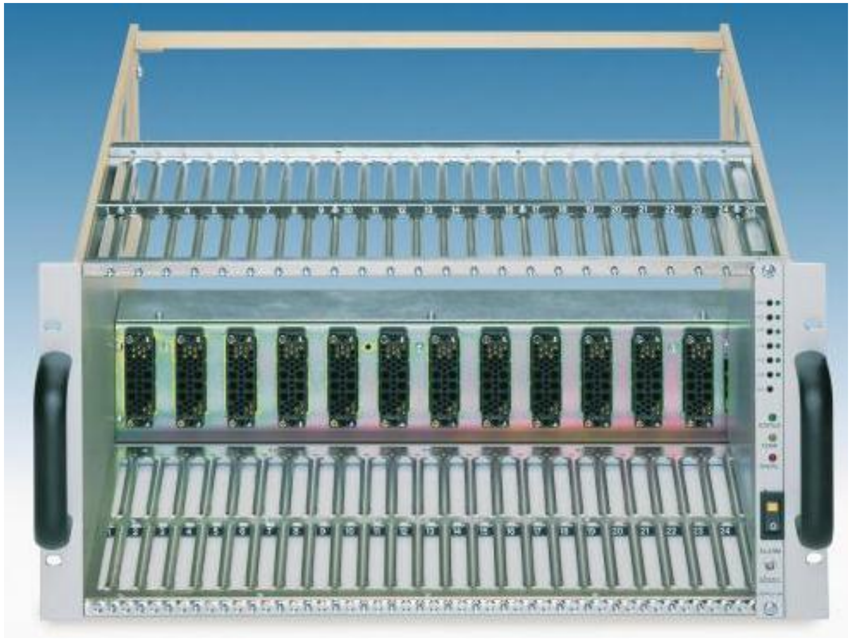
	Output must deliver	Input must accept
Logic 0	-1 to +1 mA	-4 to +20 mA
Logic 1	-14 to -18 mA	-12 to -36 mA

But wait…there's more

- NIM is also a standard for electronics modules.
  - Can be single-wide, double-wide or triple-wide

But wait…there's more

- NIM is also a standard for electronics modules.
- Modules are designed to mate with a crate



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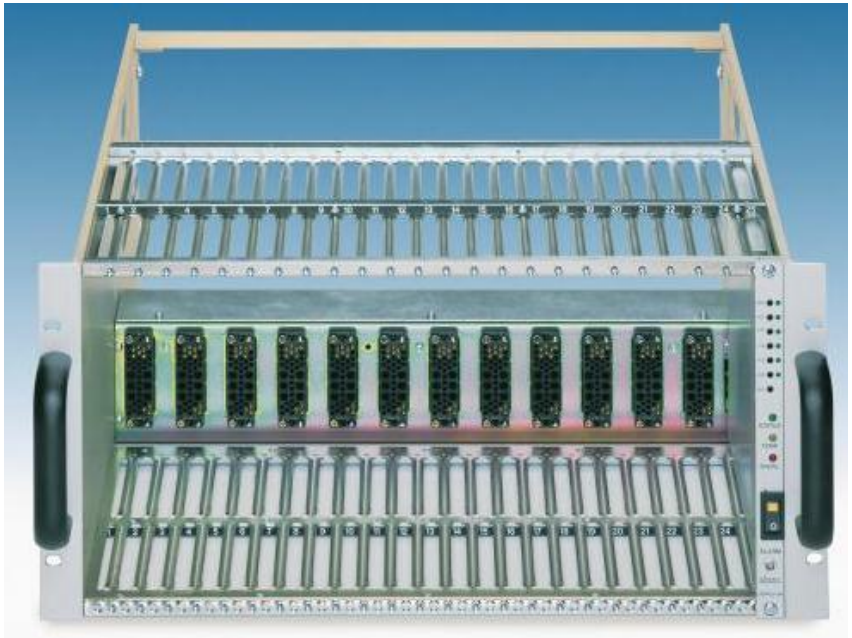
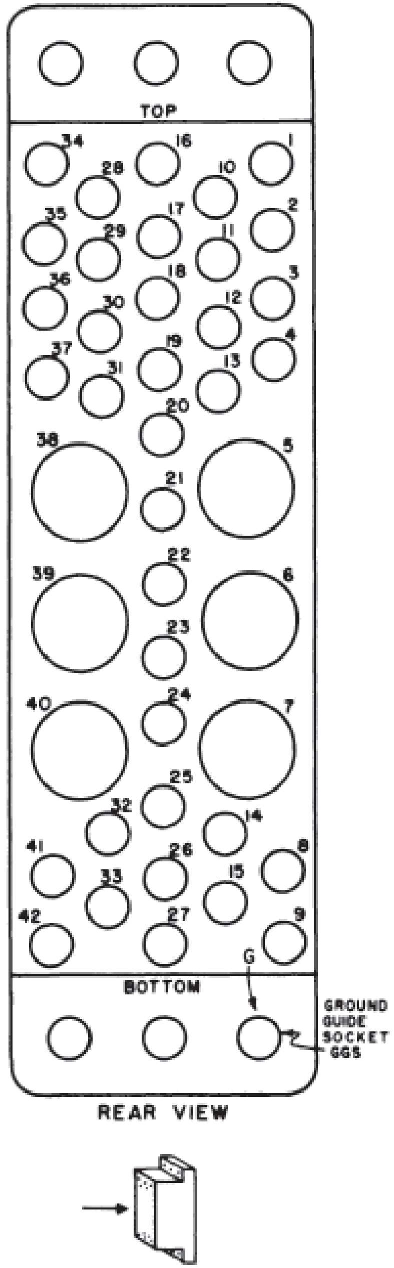


- NIM is also a standard for electronics modules.
- Modules are designed to mate with a crate
- Crate provides
  - ±6V
  - ±12V
  - ±24V
- All pins bussed
- No communication between modules
- Modules can be quickly added for different experimental needs
- Many lab have pools of NIM modules

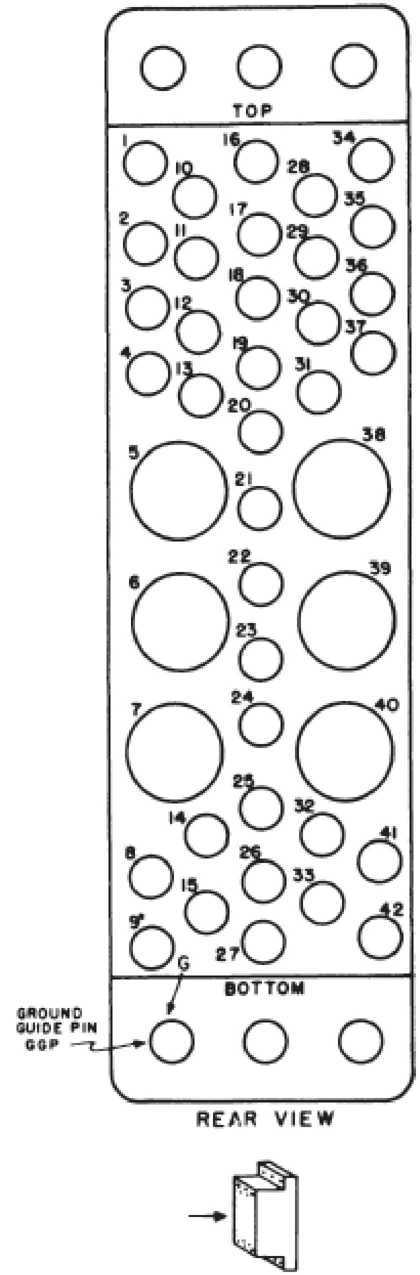
BIN CONNECTOR



	PIN	FUNCTION
	1	+ 3 VOLTS
	2	− 3 VOLTS
	3	SPARE
	4	RESERVED
	5	COAXIAL
	6	COAXIAL
	7	COAXIAL
	8	+ 200 VOLTS D.C.
	9	SPARE
*	10	+ 6 VOLTS
*	11	− 6 VOLTS
	12	RESERVED
	13	CARRY NO. 1
	14	SPARE
	15	RESERVED
*	16	+ 12 VOLTS
*	17	− 12 VOLTS
	18	SPARE
	19	RESERVED
	20	SPARE
	21	SPARE
	22	RESERVED
	23	RESERVED
	24	RESERVED
	25	RESERVED
	26	SPARE
	27	SPARE
*	28	+ 24 VOLTS
*	29	− 24 VOLTS
	30	SPARE
	31	CARRY NO. 2.
	32	SPARE
*	33	117 VOLTS A.C. (HOT)
*	34	POWER RETURN GND
	35	RESET
	36	GATE
	37	SPARE
	38	COAXIAL
	39	COAXIAL
	40	COAXIAL
*	41	117 VOLTS A.C.(NEUTRAL)
*	42	HIGH QUALITY GND
	G	GROUND GUIDE PIN

* MUST BE BUSSED TO ALL BIN CONNECTORS PG1B THROUGH PG12B

MODULE CONNECTOR

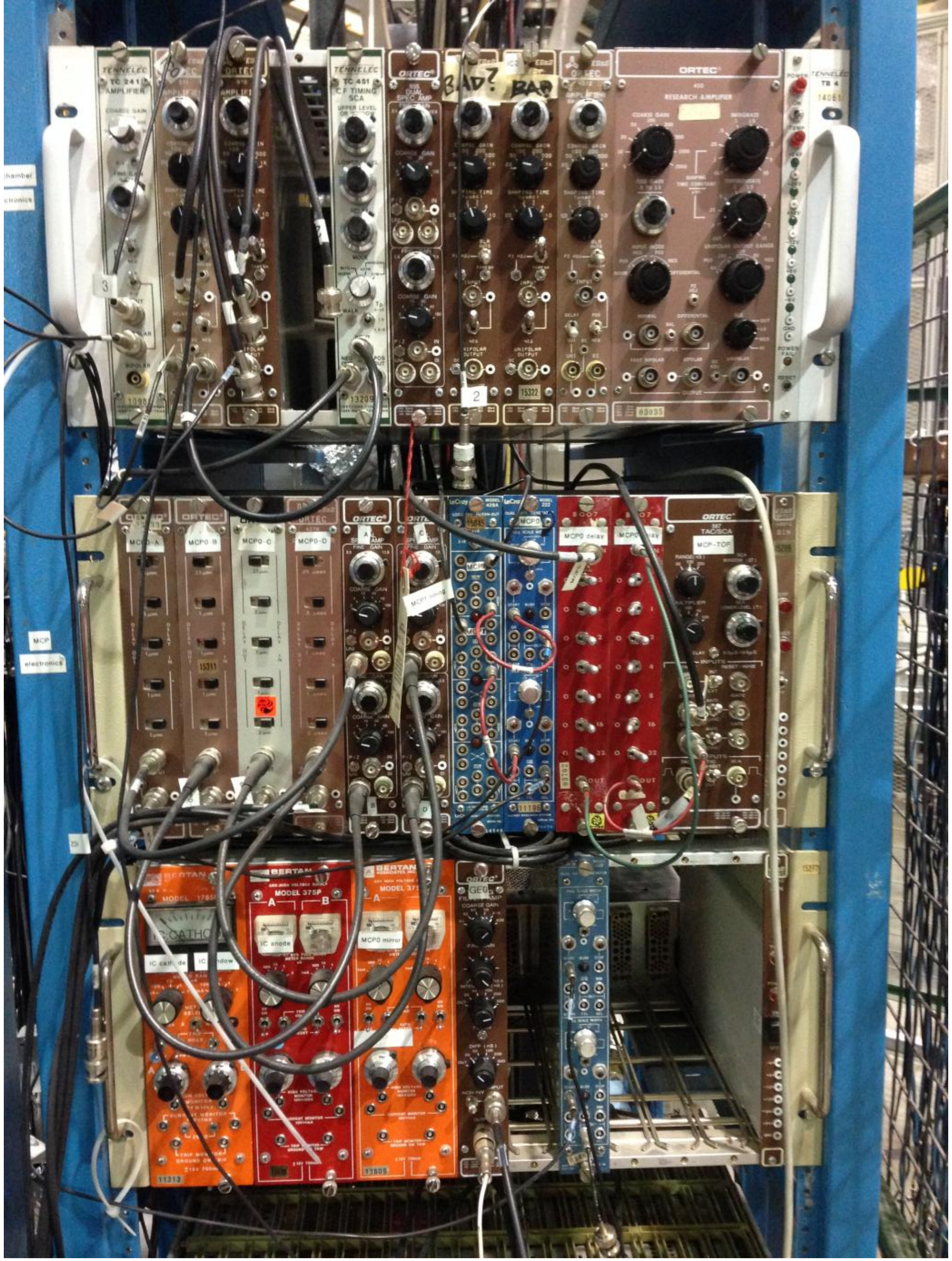


Common off-standard logic

- NIM signals can be counterintuitive or limiting so other signal standards are often included
- Transistor-Transistor Logic (TTL)
  - Positive going logic
- Emitter Coupled Logic (ECL)
  - Faster & easier to use than fast negative NIM

	TTL	ECL
Logic 0	+0 to +0.8 V	-1.75 V
Logic 1	+2 to +5 V	-0.90 V

Note the smaller jump


TENNELEC
ORTEC
BAD?
400 RESEARCH AMPLIFIER
MCP-TOP
BERTAN
MODEL 375P
IC anode
MCP0 mirror

CAMAC: Time to make life more ~~complicated~~…interesting

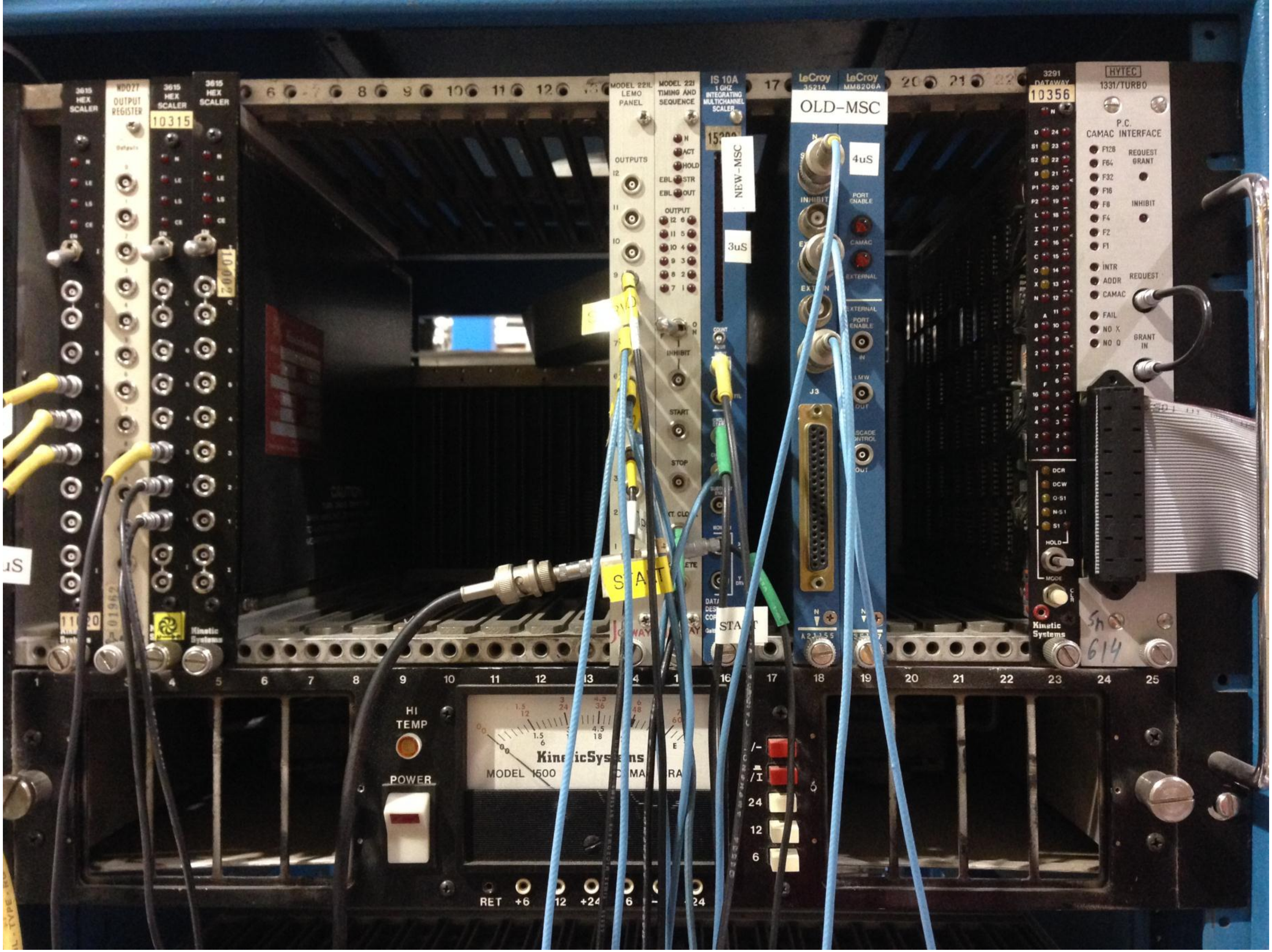
- The NIM standard:
  - Doesn’t handle large amounts of digital data easily
  - Interface with a computer is done on a module by module basis
  - Modules are normally wider than they need to be if no readout meter is required.
- A new standard to:
  - Make the modules thinner
  - Include a common dataway for communication
  - Still fit in a standard 19” rack

The Computer Automated Measurement And Control (CAMAC) Standard

- Introduced in 1969 and adopted in 1972
- 25 module stations 17.2 mm wide
  - Double- and triple-wide modules are allowed
- Modules normally made of a single PCB with an edge connector of 86 contacts.
- Every station has:
  - ±6V
  - ±12V (not required by standard but normally there)
  - ±24V
  - Separate *read* and *write* lines (24 pairs in total)

The CAMAC controller

- The extreme right station is the control station
  - All *read* and *write* lines connect.
- A special crate controller module must go in the last station
  - System won't function without a controller
- Controller
  - Transfers data to/from control PC
  - Communicates with all modules
  - Mediates communication between modules
- Communication designed for FORTRAN but by now there's translators for every language


OLD-MSC
NEW-MSC
4uS
3uS
HYTEC
1331/TURBO
P.C.
CAMAC INTERFACE
LeCroy
MODEL 221
TIMING AND
SEQUENCE
3615
HEX
SCALER
OUTPUT
REGISTER
IS 10A
Kinetic
Systems
HI
TEMP
POWER
MODEL 1500

For more on CAMAC

- Entire classes could be given on the CAMAC standard and communication
- *Leo* Chapter 18 is a great start
- Fermilab's *Introduction to CAMAC*
  - http://cdorg.fnal.gov/ese/prep/introCamac.php
- CAMAC Tutorial Issue, *IEEE Trans. Nucl. Sci*. **NS-20** 2 (1973)
  - http://ieeexplore.ieee.org/xpl/tocresult.jsp?isnumber=4327008&punumber=23

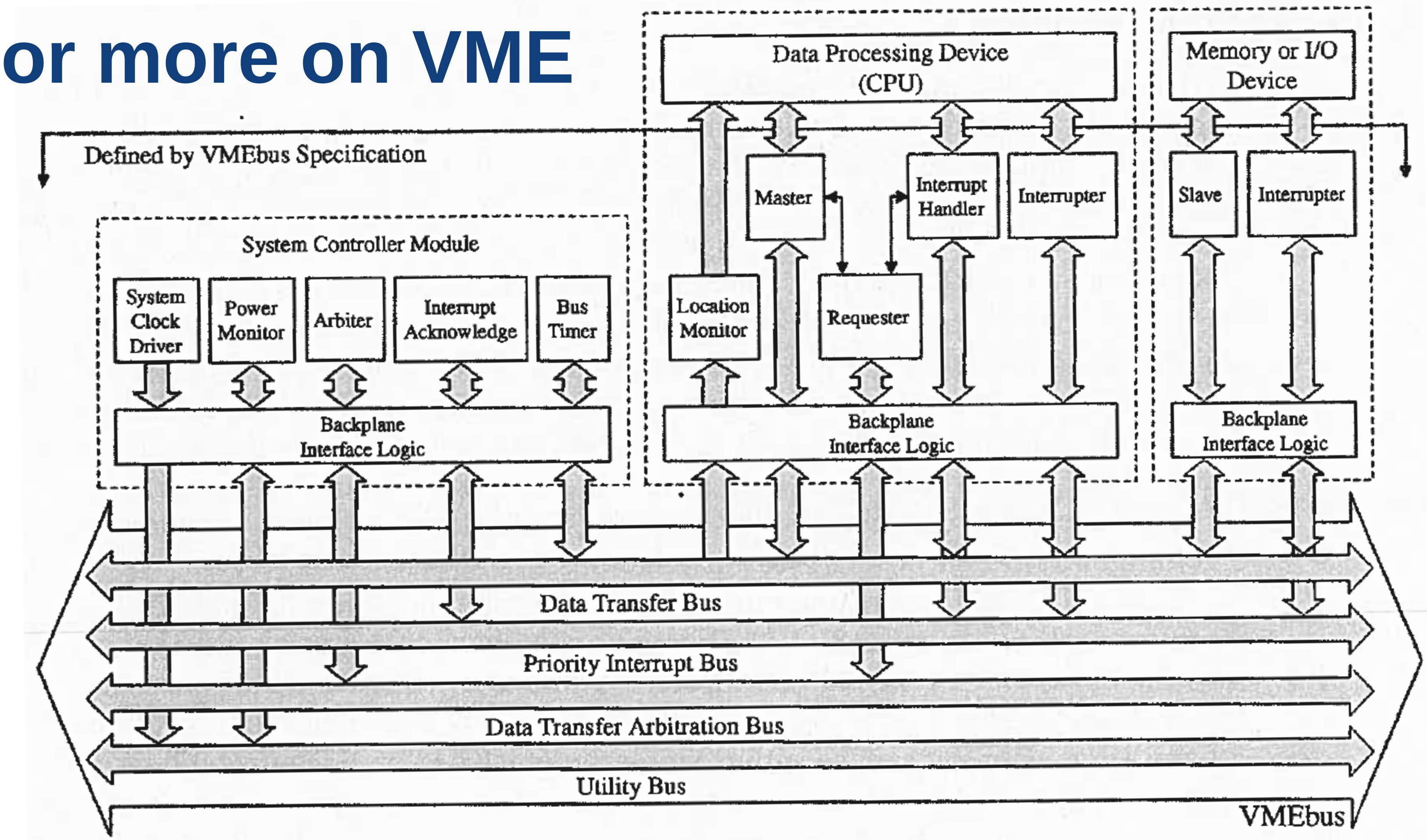
From CAMAC to VME

- As experiments grew larger, the CAMAC data busses couldn’t keep up and latency increased
  - Dead time = Bad
- Modules expensive
- Not hot-swappable
- VME designed to accommodate fast microprocessor control
- Made with industry standard parts so *cheaper*

From CAMAC to VME

- VME crate requires a controller
  - Performs bus arbitration
  - Provides and maintains timeout errors
  - System clock
  - Other system utilities
- Modules can send messages directly to each other
  - Controller only opens and closes access to dataway
- Communication is asynchronous and can proceed as fast as the slowest communicator
- VMEbus modules tend to be set via software only

For more on VME



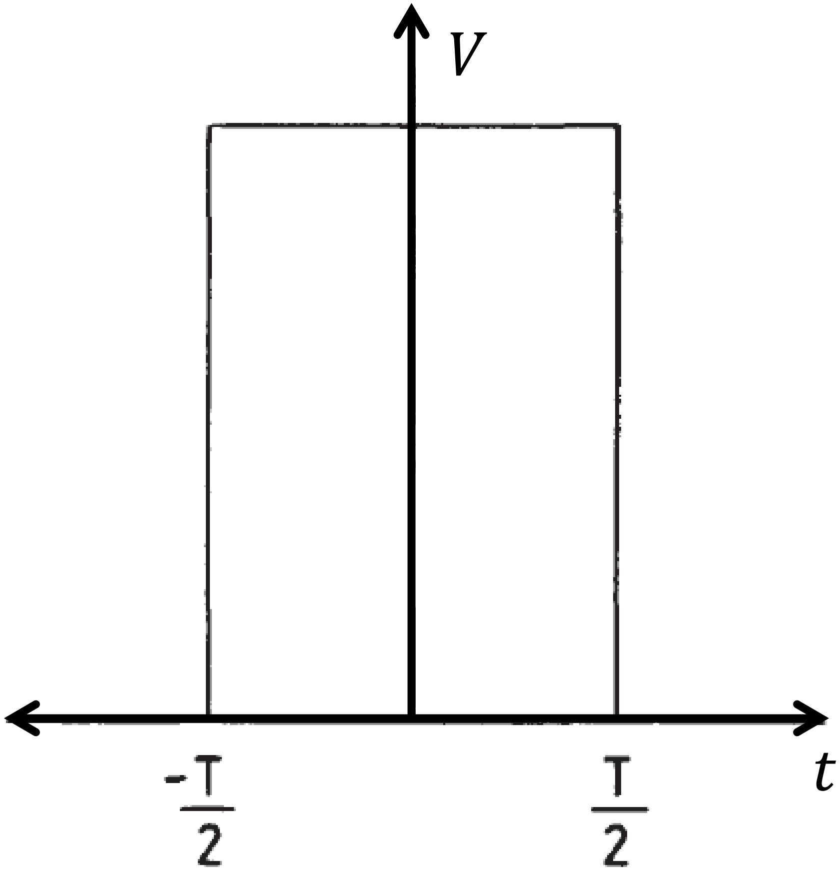
- W. D. Peterson, *The VMEbus Handbook*, VITA, Scottsdale, Az 1997.
- American National Standard for VME64 Extensions for Physics and Other Applications
  - https://ph-dep-ese.web.cern.ch/ph-dep-ese/crates/standards/Av23.pdf

Transmission lines

- The goals of signal transmission
  - Get the signal from point A to point B
  - Preserve the signal's information
- We tend to think of a connecting wire as something with negligible *C* and negligible self-inductance where any voltage applied at one end is immediately present at the other end.
- **Not So**
  - Rule of thumb: $l_{\text{line}} \leq 0.02 t_r c$
    - For $t_r = 10$ ns: $l_{line} \leq$ **6 cm**
- Need transmission lines (wave guide)

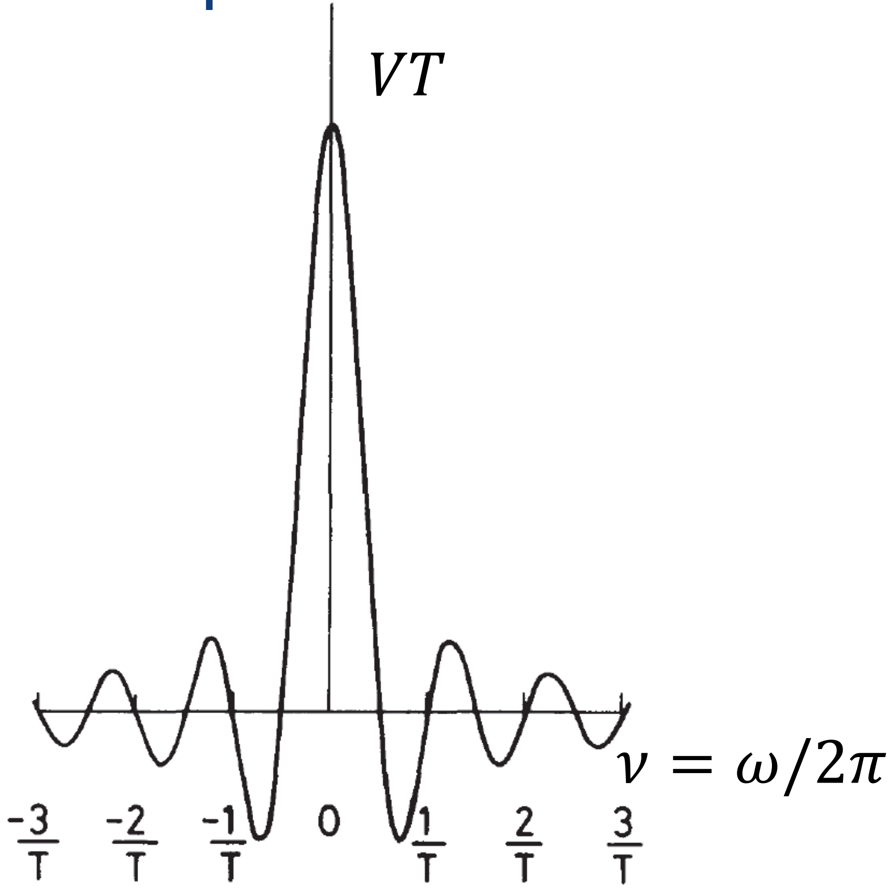
Transmission lines

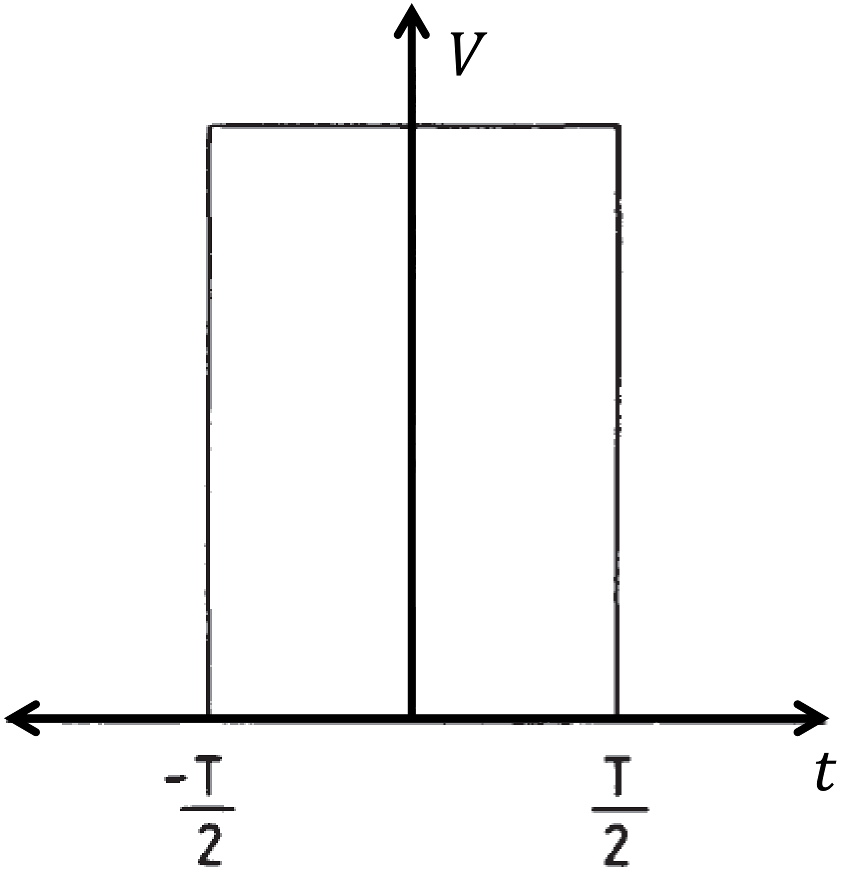
- Transmission lines carry rf signals efficiently
- But a pulse isn't rf.
- What gives?



Fourier Analysis

- Any pulse can be decomposed into a superposition of many pure sinusoidal frequencies



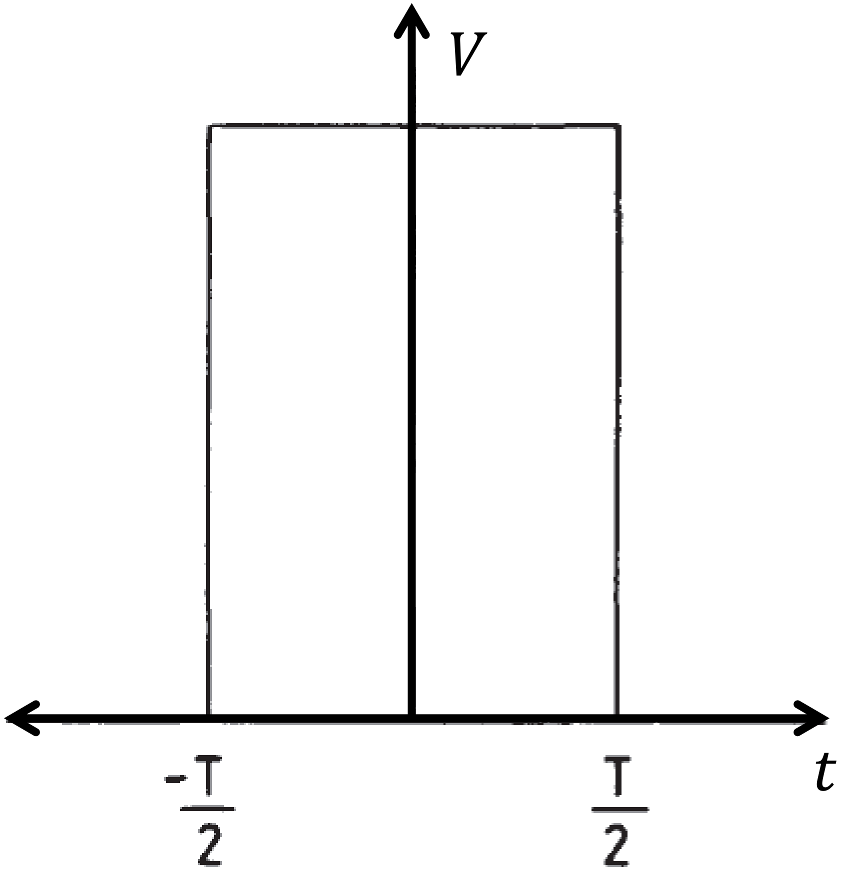


Fourier Analysis

- Any pulse can be decomposed into a superposition of many pure sinusoidal frequencies
- A pulse:
  - Shape in time $f(t)$

$$f(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} g(\omega) e^{i\omega t} d\omega$$

$$g(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt$$



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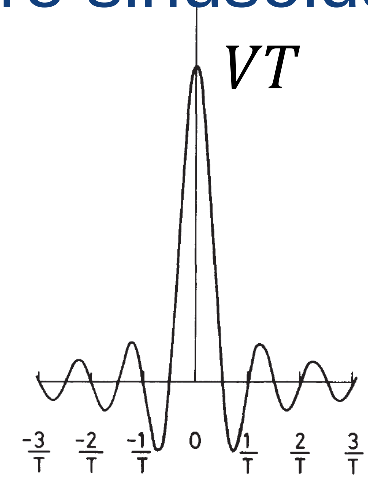
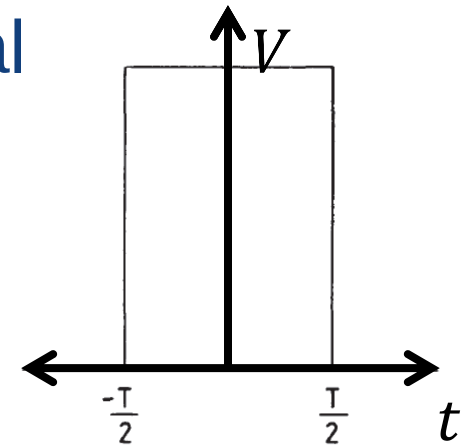




$$f(t) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} g(\omega)e^{i\omega t}\,d\omega$$

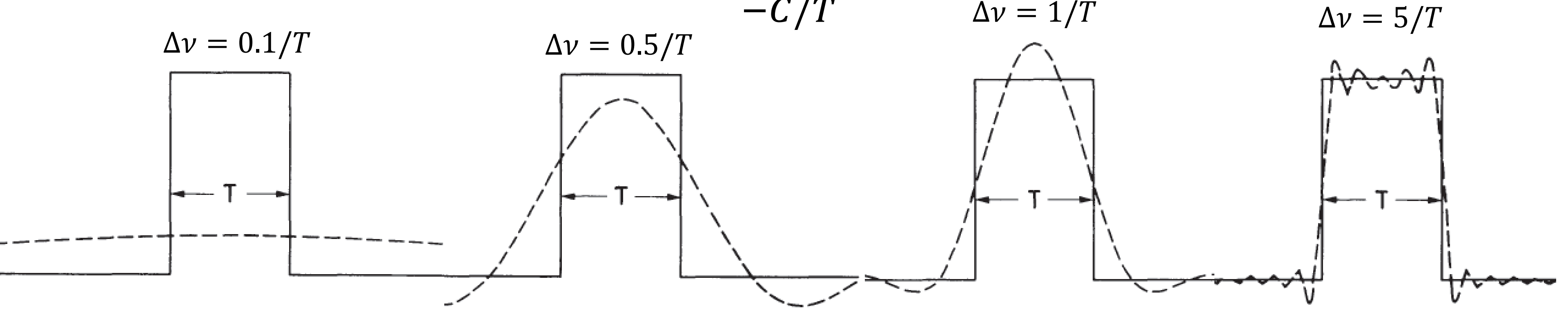
$$g(\omega) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} f(t)e^{-i\omega t}\,dt = \frac{V}{\sqrt{2\pi}}\int_{-\frac{T}{2}}^{\frac{T}{2}} e^{-i\omega t}\,dt = \frac{VT}{\sqrt{2\pi}}\frac{\sin\left(\omega T/_{2}\right)}{\left(\omega T/_{2}\right)}$$

$$f(t) = \begin{cases} V & |t| < T/_{2} \\ 0 & |t| > T/_{2} \end{cases}$$

Bandwidth

- All frequencies contribute in a perfect reproduction…but who wants to be perfect?
- If you perform the inverse Fourier transform over a fixed interval:

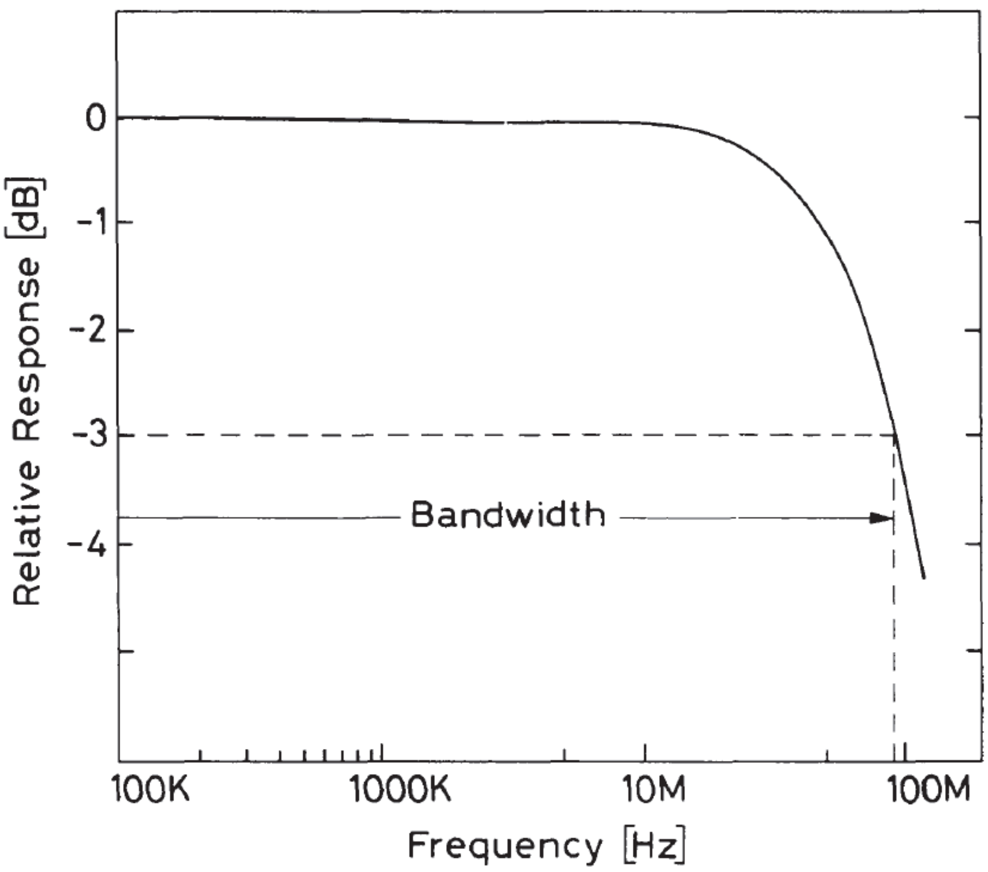
$$f(t) = \frac{1}{\sqrt{2\pi}} \int_{-C/T}^{C/T} g(\omega) e^{i\omega t} d\omega$$



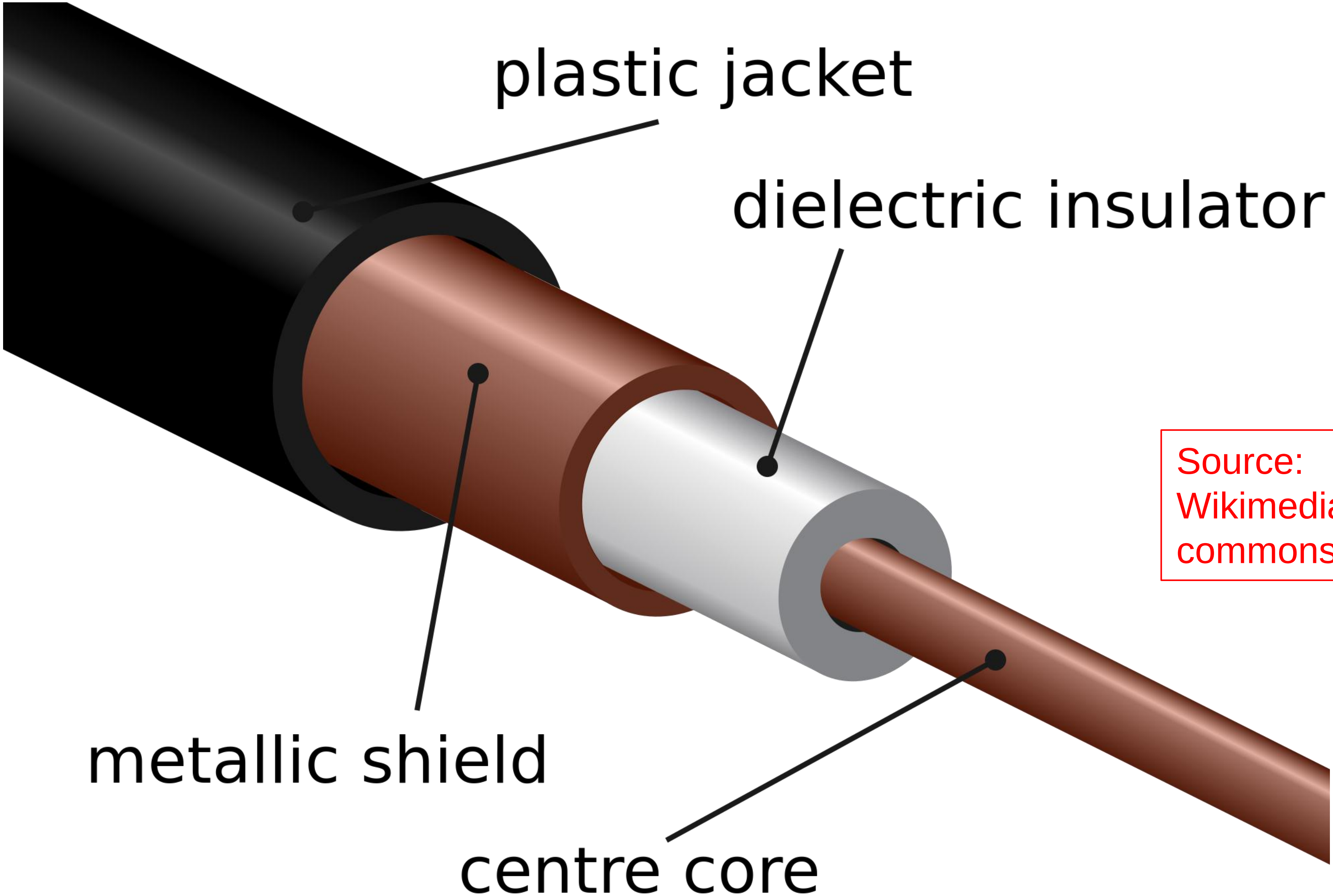
- $\Delta\nu > {}^{1}/_{T}$ for reasonable approximation
  - For a 10 ns pulse: $\Delta\nu \geq 100$ MHz

Bandwidth

- $\Delta\nu > {}^{1}/_{T}$ for reasonable approximation
  - For a 10 ns pulse: $\Delta\nu \geq 100$ MHz
- 3 dB decline in response: *bandwidth*
  - Corresponds to ~70% of the original signal

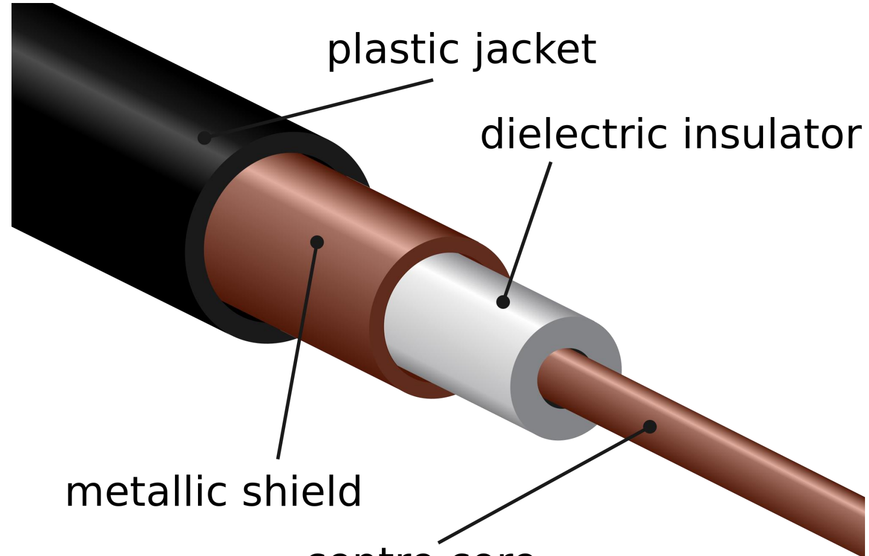


The coaxial cable



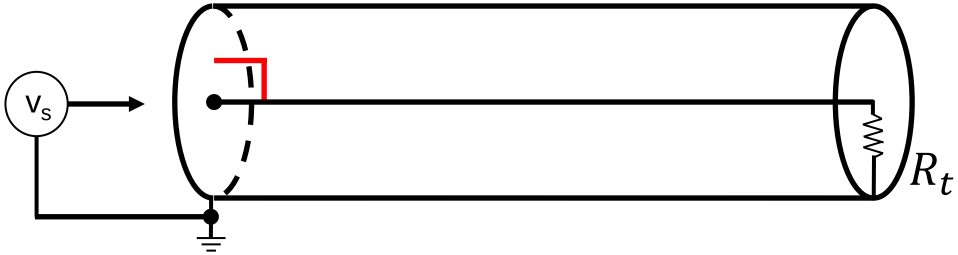
Source: Wikimedia commons

The coaxial cable



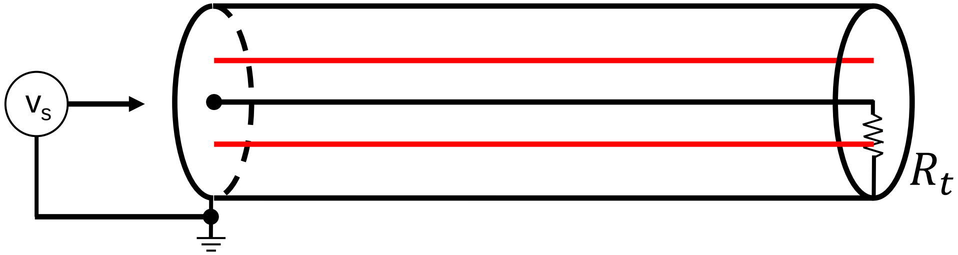
- Minimizes pickup from electric and electromagnetic fields
- Shield is normally braided for flexibility
- Velocity of propagation (v_p) a function of:
  - $1/\sqrt{k}$
  - Separation between inner and outer conductor
  - $v_p(\text{polyethelyne}) \approx 0.66c$
- Characteristic impedance also a function of:
  - k
  - Separation between inner and outer conductor

Termination



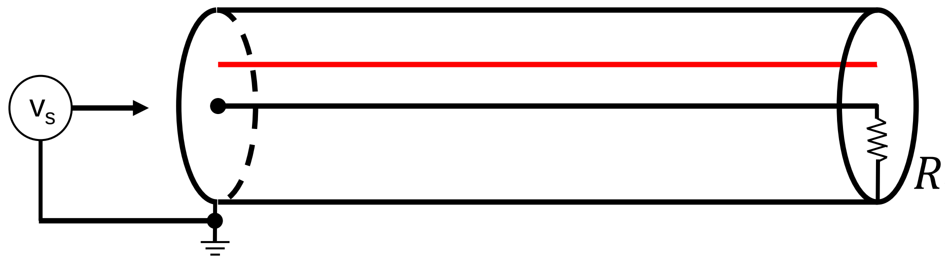
- Cable has characteristic impedance R
- Imagine a generator creating a step voltage change from 0 to V_0 at $t = 0$
  - Step travels along at v_p drawing $I = \frac{V_0}{R}$ until the signal reaches the end of the cable

Termination



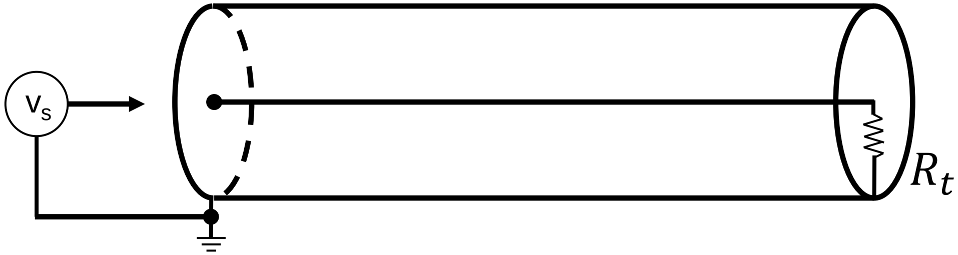
- Cable has characteristic impedance R
- Imagine a generator creating a step voltage change from 0 to V_0 at $t = 0$
  - Step travels along at v_p drawing $I = \frac{V_0}{R}$ until the signal reaches the end of the cable
- Things get interesting at the end
  - If $R_t = R \rightarrow$ The signal won't reflect
  - If $R_t = 0 \rightarrow$ Inverted signal reflected

Termination



- Cable has characteristic impedance Z_0
- Imagine a generator creating a step voltage change from 0 to V_0 at $t = 0$
  - Step travels along at v_p drawing $I = \frac{V_0}{Z_0}$ until the signal reaches the end of the cable
- Things get interesting at the end
  - If $R_t = Z_0 \rightarrow$ The signal won't reflect
  - If $R_t = 0 \rightarrow$ Inverted signal reflected
  - If $R_t = \infty \rightarrow$ Same polarity signal reflected

Termination



- Given a cable with
  - Characteristic impedance Z_0
  - Input waveform with amplitude A_0

R_t	Reflected amplitude, A
0	$-A_0$
$0 < R_t < Z_0$	$-A_0 < A < 0$
Z_0	0
$Z_0 < R_t < \infty$	$0 > A > A_0$
∞	A_0

Thank you!
Merci

Canada's national laboratory for particle and nuclear physics

Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

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