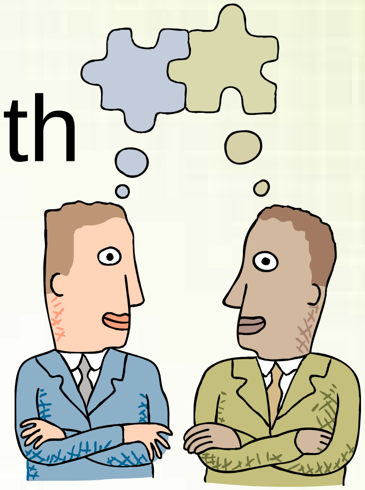
926 EFA

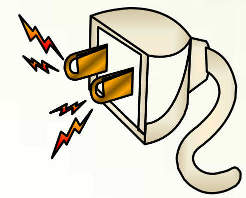
Designing PIC® Microcontroller Circuits for EFT/ESD Compatibility - I

Objectives

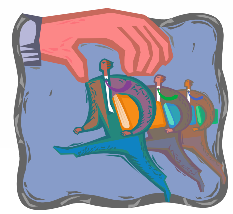


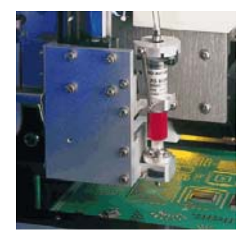
- Get basic understanding of EMC with emphasis on
  - Electrostatic Discharge (ESD)
  - Electrical Fast Transients
- Understand component selection criteria
- Get some guidelines on component placement

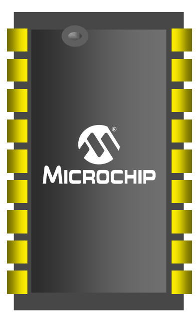
Agenda



- EMC overview
- What is ESD?
- What is EFT?
- Component selection
- Component placement
- Microcontroller systems







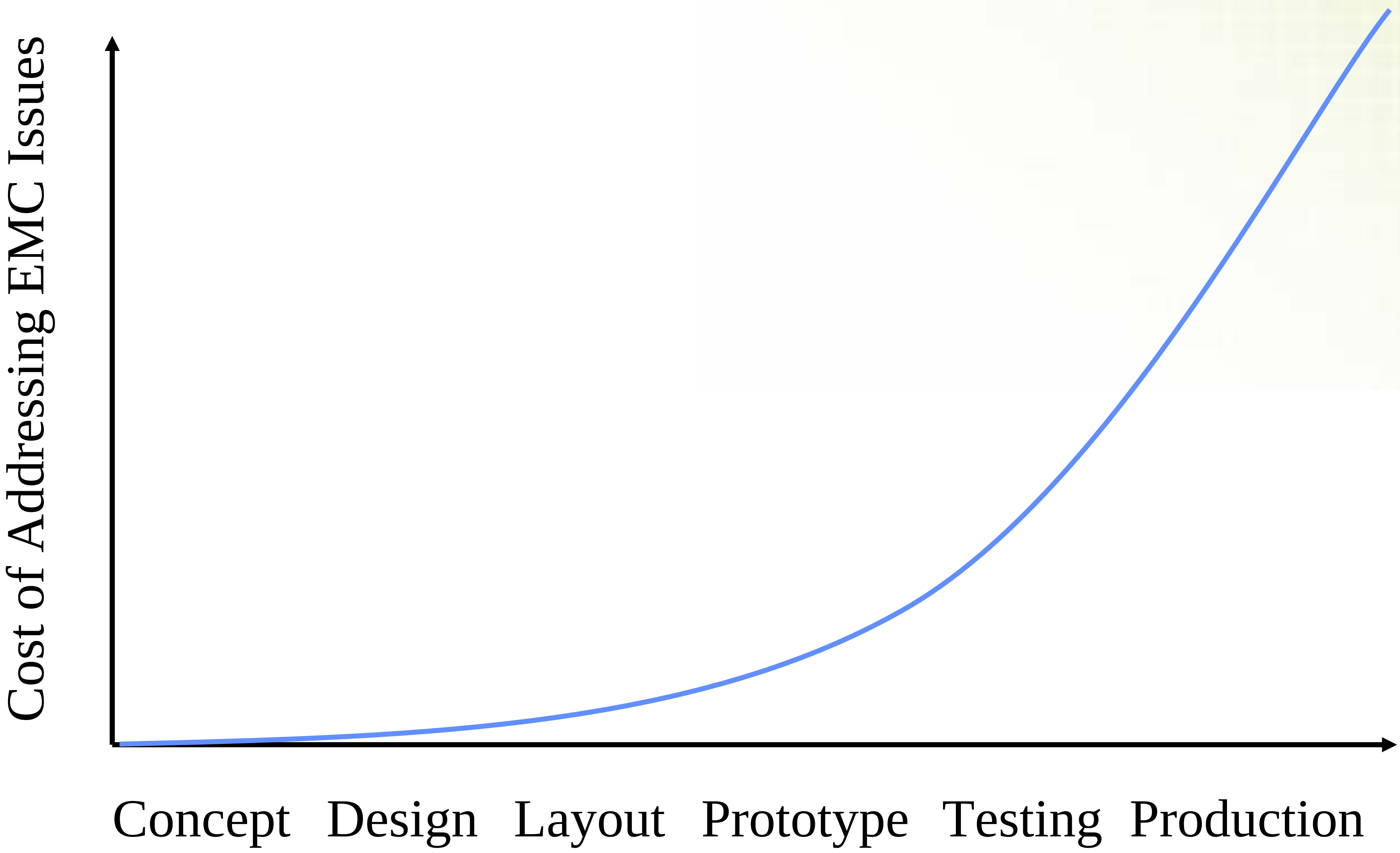
Overview of EMC

- EMC- Electromagnetic Compatibility
  - Capability of an electronic system to function compatibly with other electronic systems and not produce or be susceptible to interference
  - A system is electromagnetically compatible if:
    - It does not cause interference with other systems
    - It is not susceptible to emissions from other systems
    - It does not cause interference with itself

IEC Standards

- 60601 -> Medical electrical equipment
- 61000-3 -> Electromagnetic Compatibility
- **61000-4-2 -> ESD**
- 61000-4-3 -> Radiated Electromagnetic Field
- **61000-4-4 -> EFT/Burst**
- 61000-4-5 -> Surge
- 61000-4-6 -> RF Field Conducted disturbances
- 61000-4-11 -> Voltage dips and interruptions

Cost of Addressing EMC

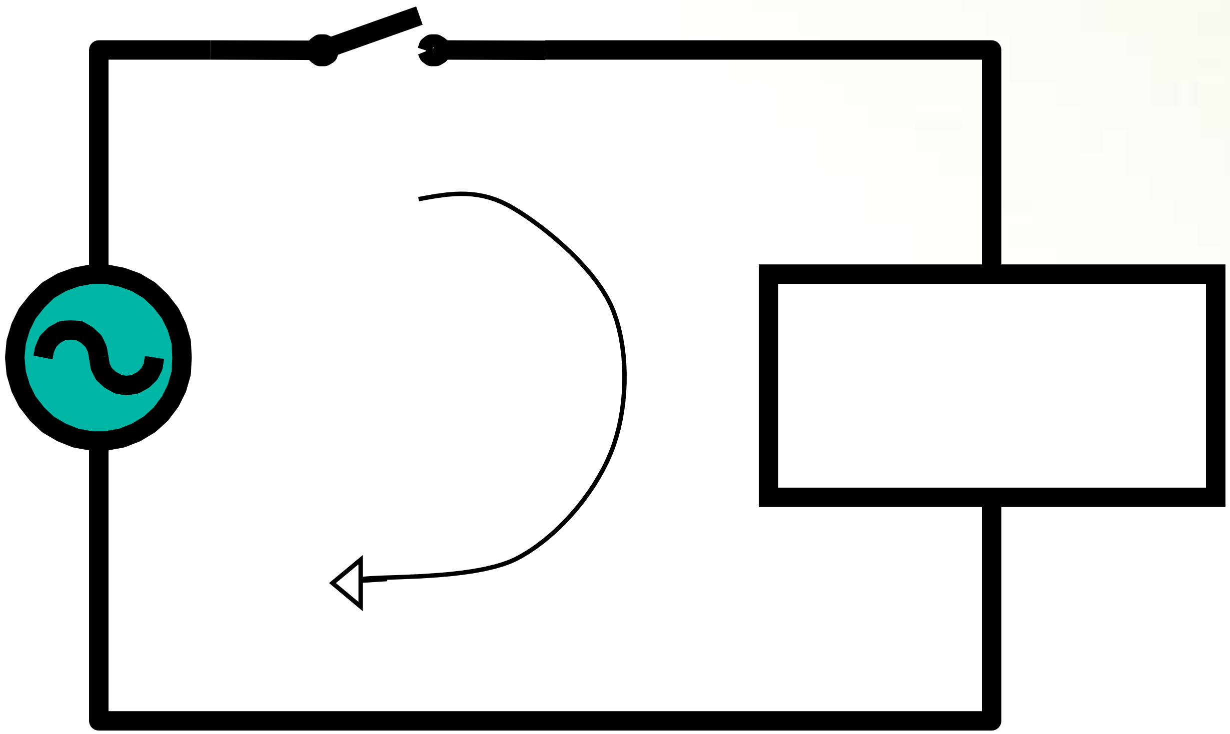


Microchip EMC resources

- EMC Newsletter
  - Available on Appliance and Automotive design center
- EMC Webinars

Noise fundamentals

- Loop



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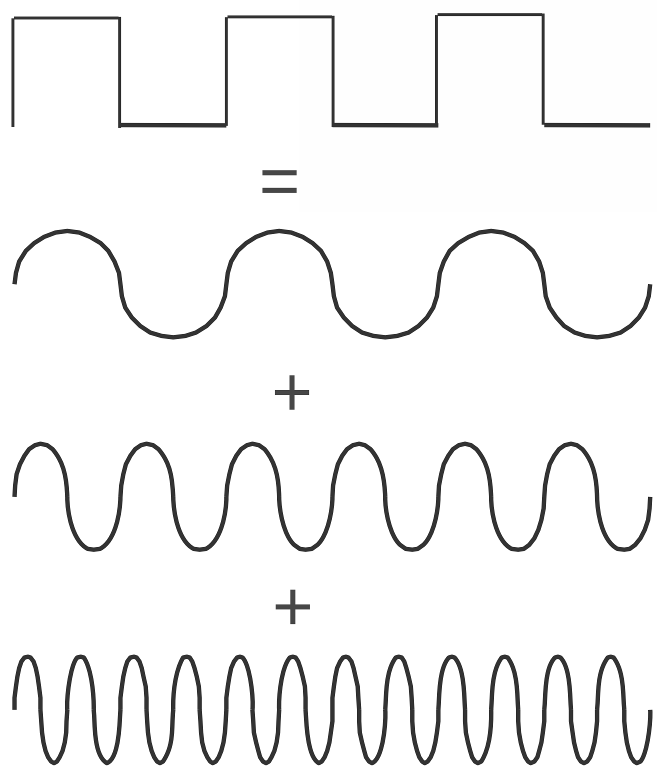
Issue 2: Every Loop is an antenna, like it or not

Noise fundamentals

- Internal
  - Switching (for Gaussian system 3dB $BW=\frac{0.35}{t_r}$)



MICROCHIP MASTERs

What is ESD?

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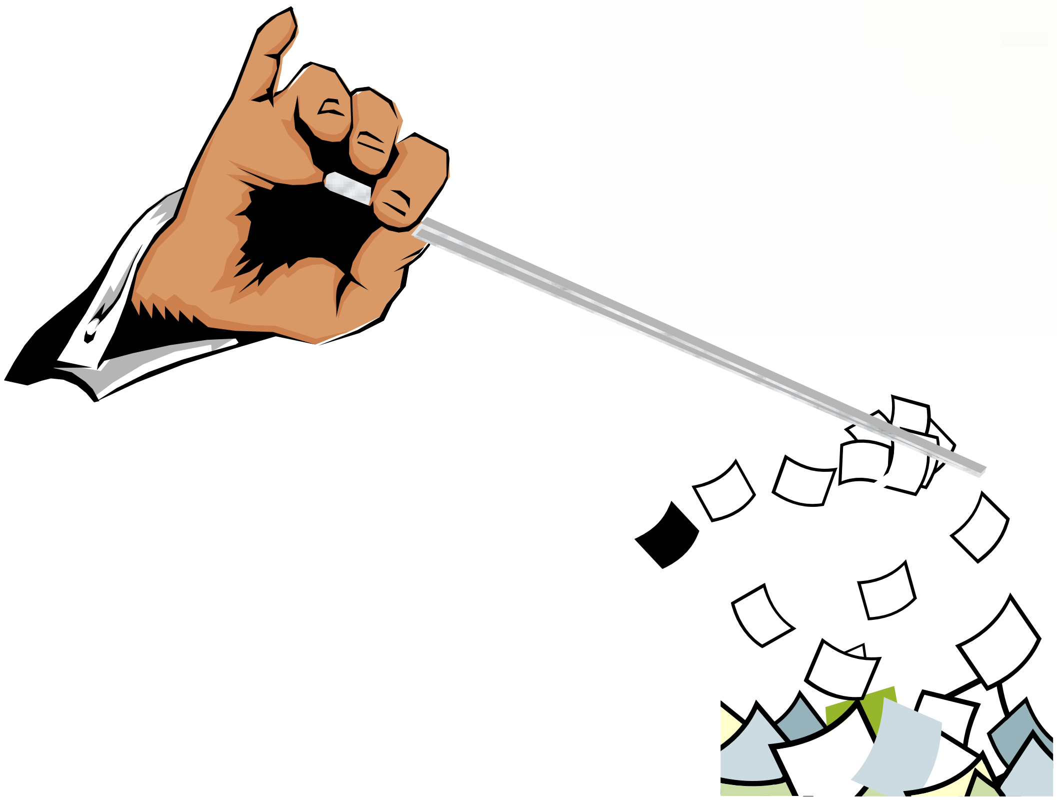
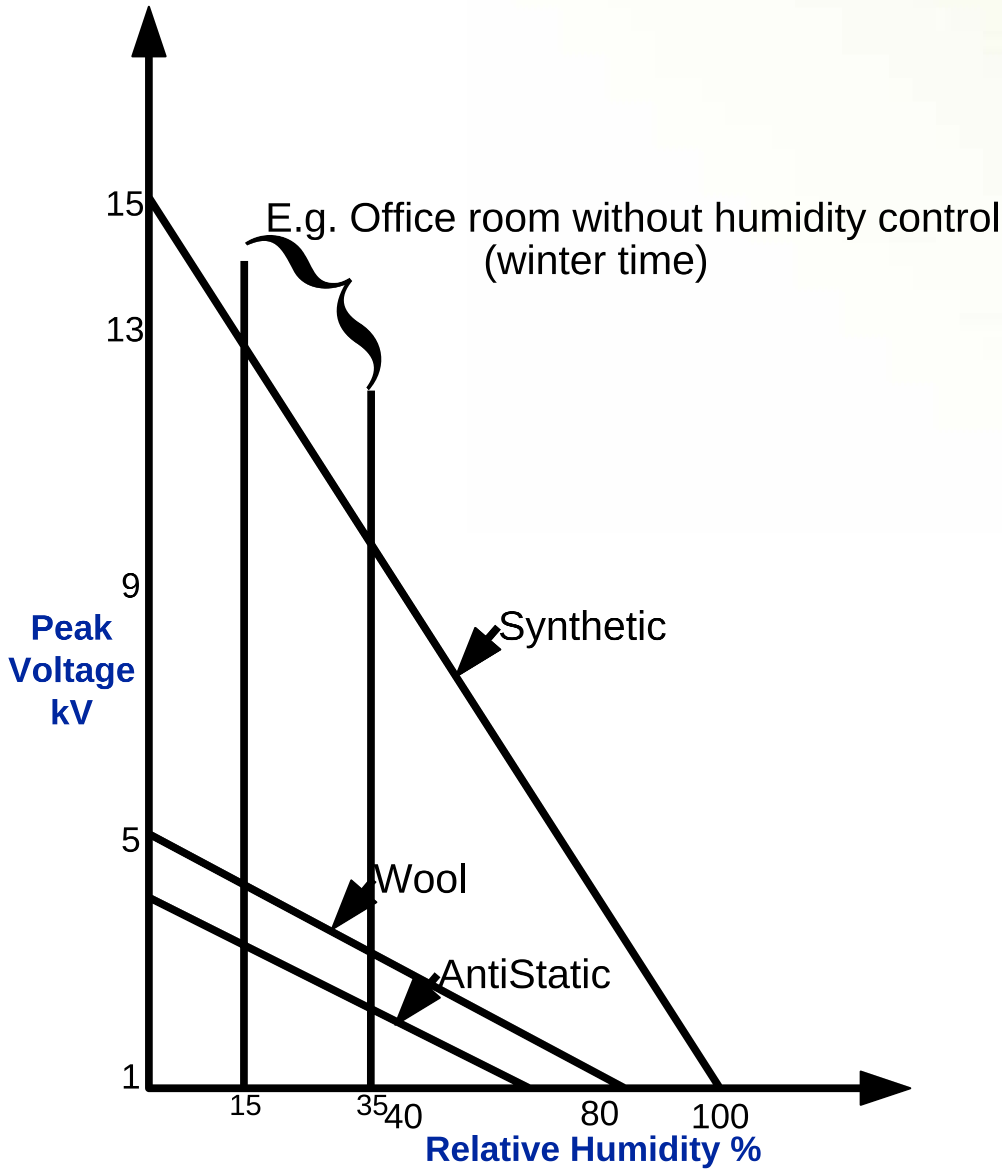
Issue 1: What is ESD?

What is ESD?

- Discharge of Static Electricity



Why do we care for ESD?



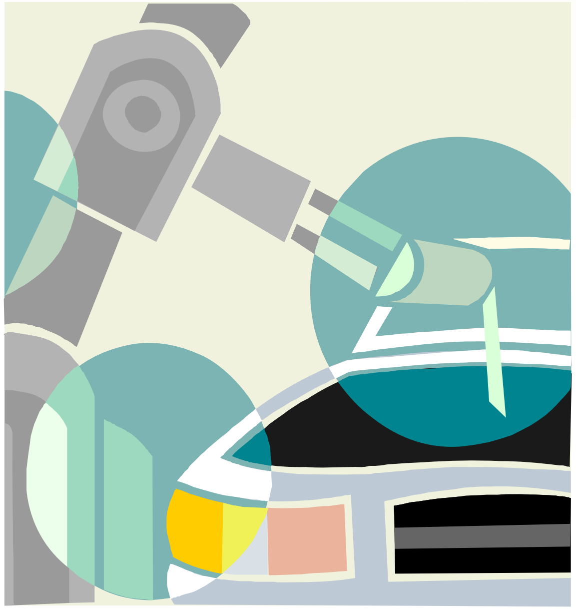
Why do we care for ESD?

- Common Static Voltages

Static Voltage as a function of Relative Humidity (RH)	20% RH kV	80% RH kV
Walking across a vinyl floor	12	0.25
Walking across a synthetic carpet	35	1.5
Picking up a polyethylene bag	20	0.6
Sliding a styrene box on carpet	18	1.5
Removing mylar tape from a PC board	12	1.5
Triggering a vaccum solder remover	8	1.0
Aerosol circuit freeze spray	15	5.0

ESD

- ESD a “Context Sensitive” issue
  - Semiconductor
  - Manufacturing
  - End user



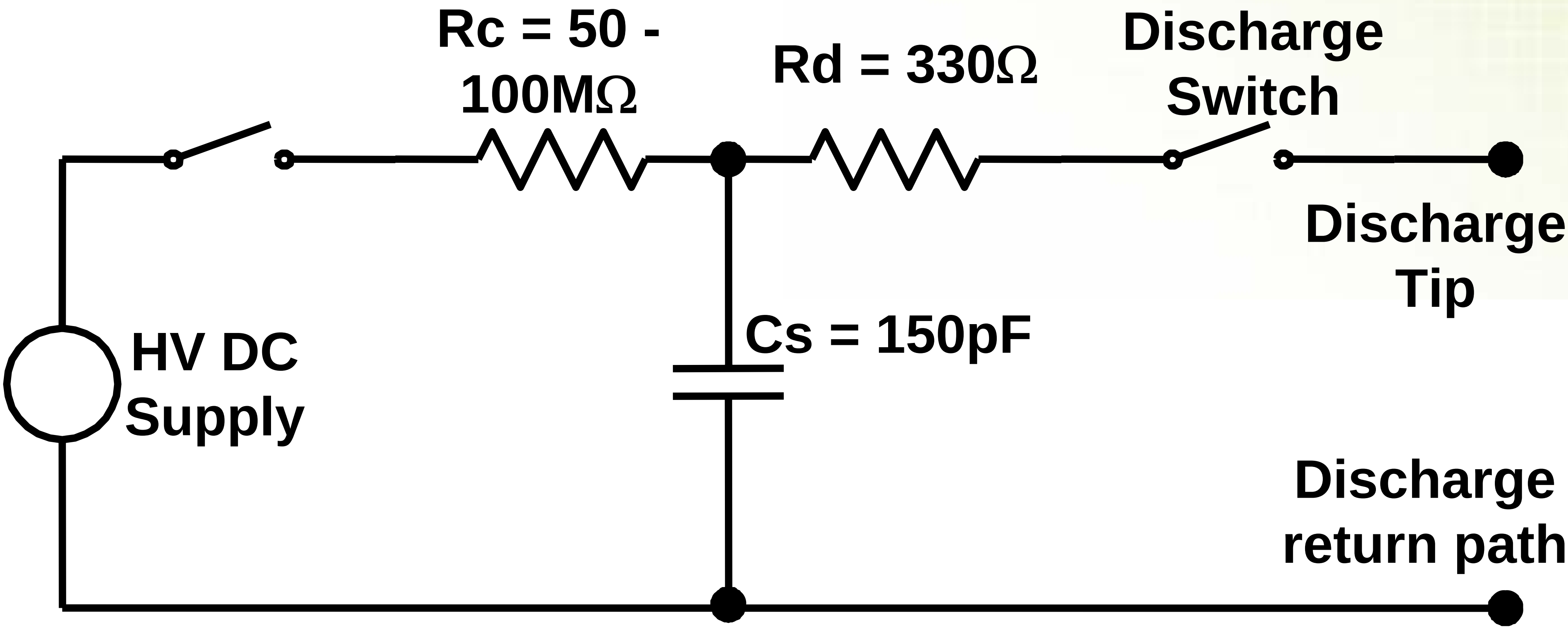
ESD

- Semiconductor perspective
  - JESD22-A114B for HBM
  - JESD22-A115A for MM
  - *Refer: Microchip Overview, Quality Systems And Customer Interface Systems Handbook*
- Manufacturing perspective
  - Anti static work station
  - Wrist band
  - Grounded systems

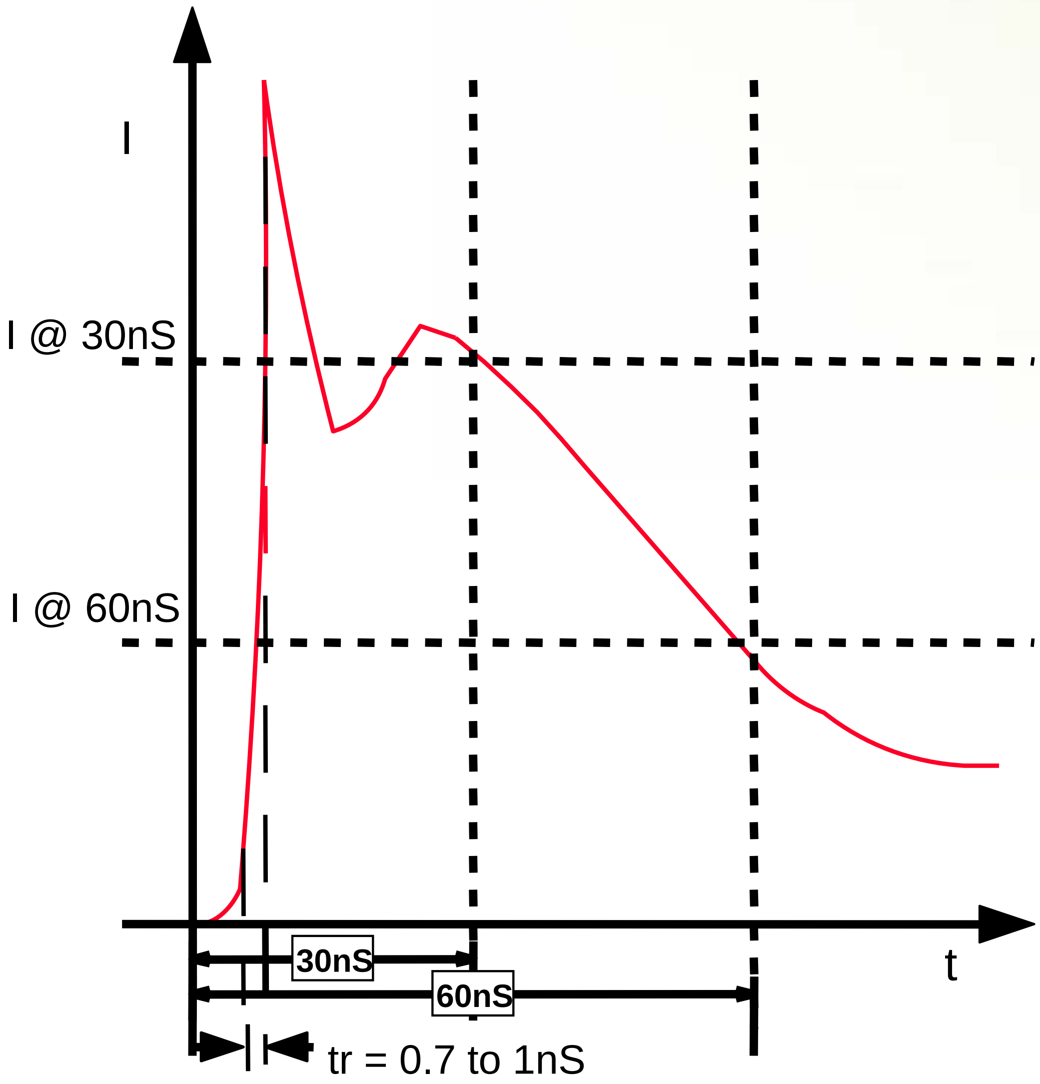
IEC 61000-4-2

- End User perspective
- The “System Level” standard defines
  - Test voltage waveform
  - Range of test levels
  - Test equipment
  - Test set-up
  - Test procedure

IEC 61000-4-2
Test equipment



IEC 61000-4-2
Test waveform



IEC 61000-4-2
Test Levels

Contact Discharge		Air Discharge	
Level	Test Voltage (kV)	Level	Test Voltage (kV)
1	2	1	2
2	4	2	4
3	6	3	8
4	8	4	15
X	Special	X	Special

IEC 61000-4-2
Waveform Parameters

Level	Voltage (kV)	First Peak Current (A)	Rise time tr nS	Current at 30nS (A)	Current at 60nS (A)
1	2	7.5	0.7 to 1	4	2
2	4	15	0.7 to 1	8	4
3	6	22.5	0.7 to 1	12	6
4	8	30	0.7 to 1	16	8

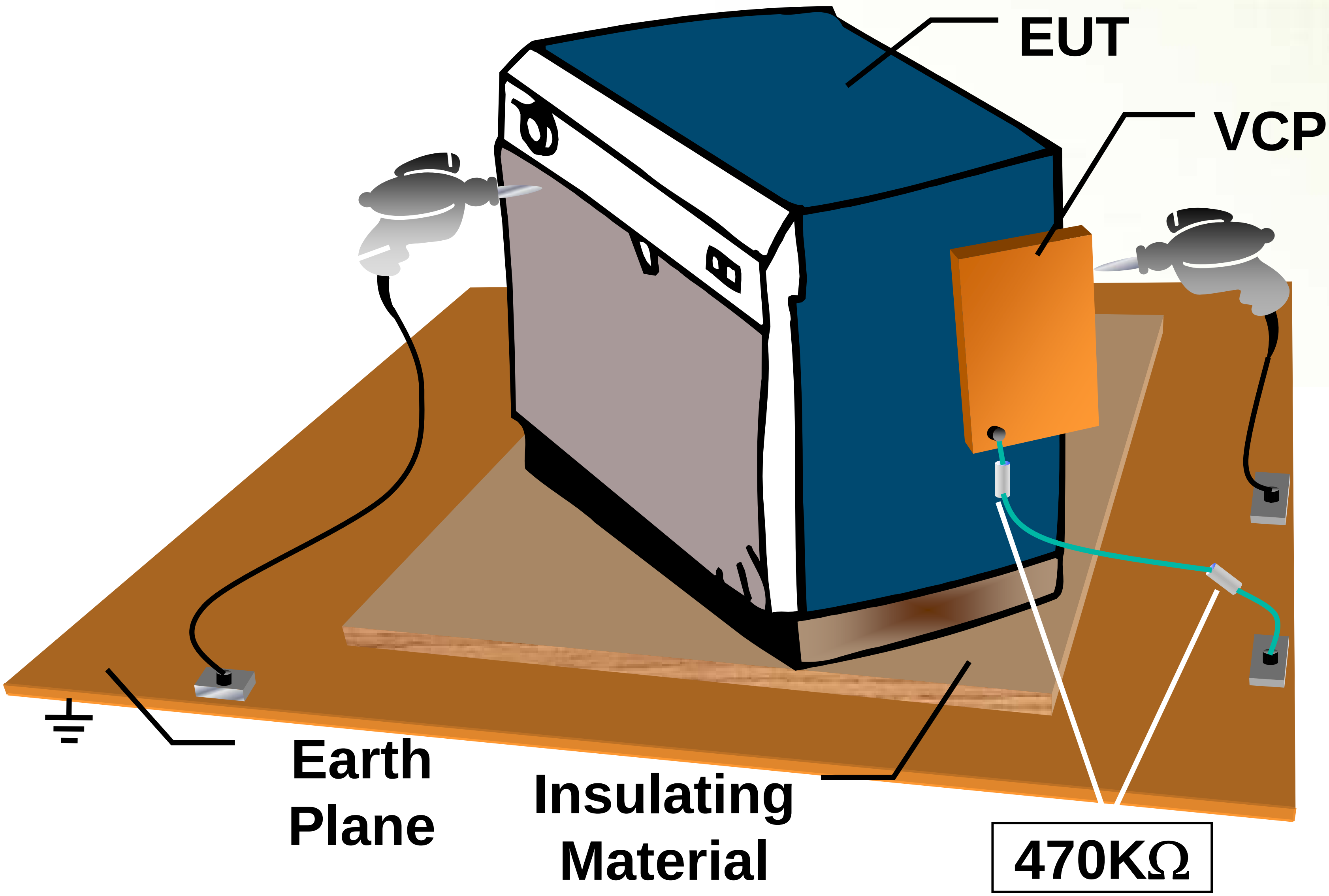
IEC 61000-4-2

Selection Of Test Levels

Class	Min RH	Antistatic material	Synthetic Material	Peak Voltage kV
1	35	√		2
2	10	√		4
3	50		√	8
4	10		√	15

IEC 61000-4-2

Test set-up (Floor Standing Equipment)



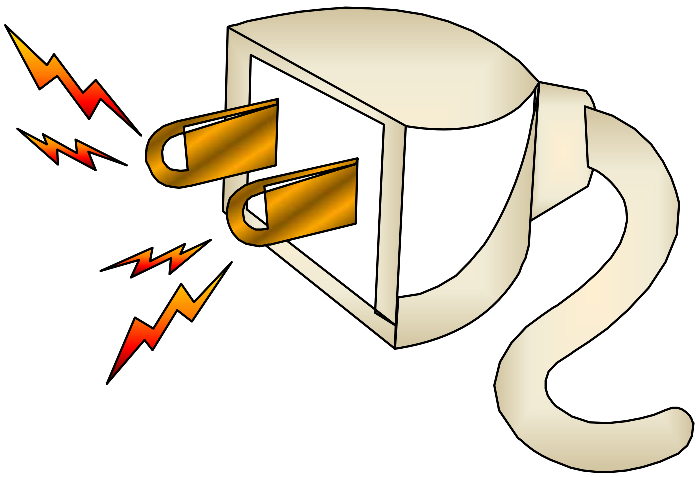
IEC 61000-4-2
Test Points

- Electrically isolated metallic sections
- Control or keyboard area and any other point of man-machine interface
- Indicators, LEDs, slots, grilles, connector hoods, etc.

ESD Strategy

- Material selection
- Determine first point of contact
- Limit the current
- Low- inductance ground

What is EFT?

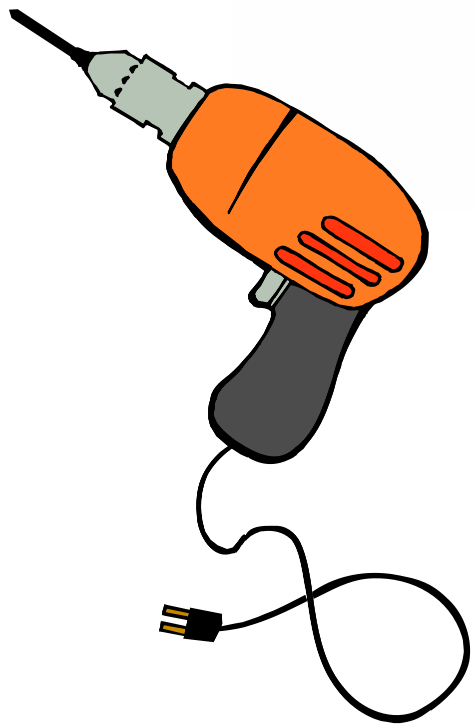


EMC Newsletter

Issue 1: What is EFT?

What is Electrical Fast Transients (EFT)?

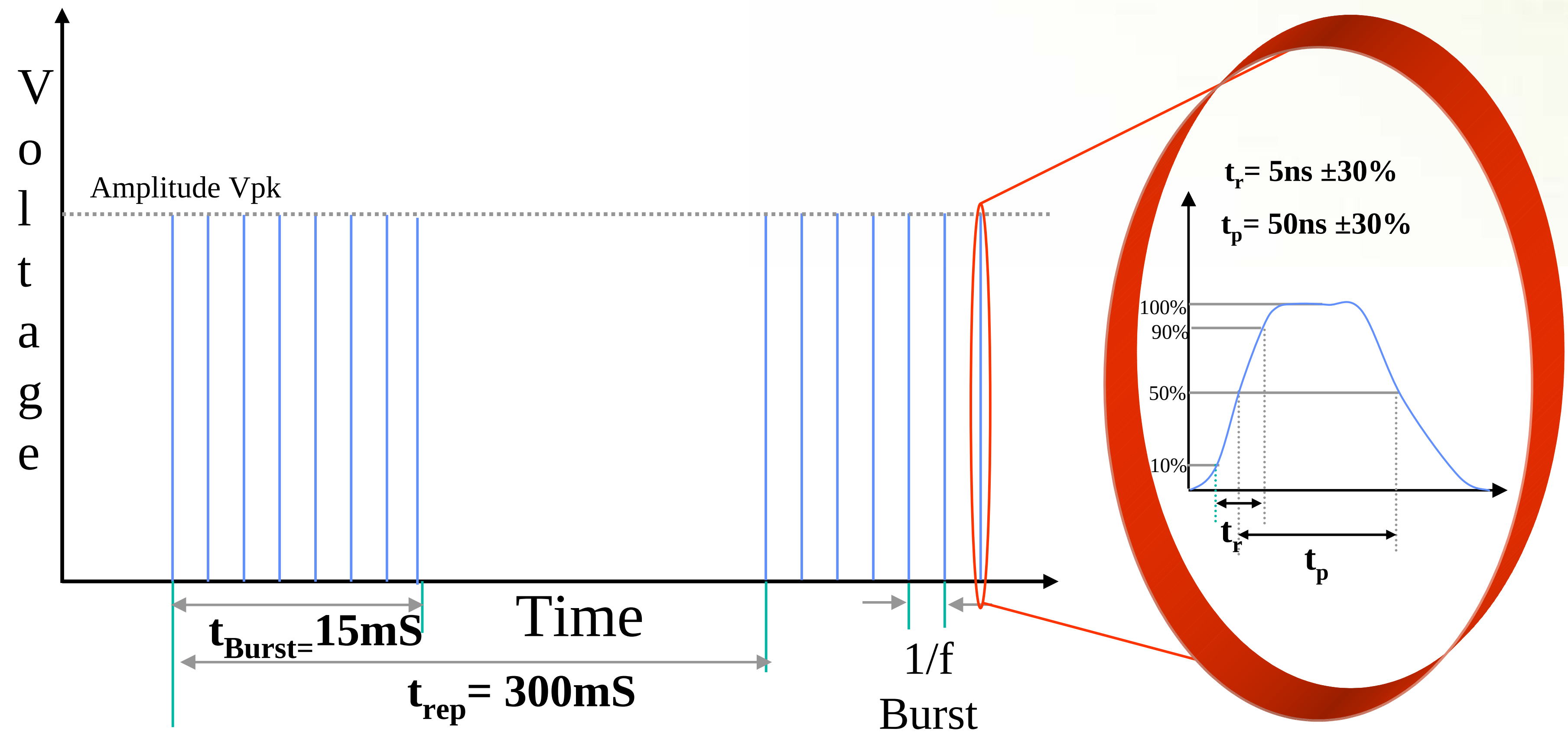
- Bursts of interference pulses simulates inductively loaded switches.



IEC 61000-4-4

- The “System Level” standard defines
  - Test voltage waveform
  - Range of test levels
  - Test equipment
  - Test set-up
  - Test procedure

IEC 61000-4-4
Test waveform



IEC 61000-4-4
Test Levels

Level	Power Supply Ports		I/O signal, data and control Ports	
	Voltage Peak kV	Repetition rate kHZ	Voltage Peak kV	Repetition rate kHZ
1	0.5	5	0.25	5
2	1	5	0.5	5
3	2	5	1.0	5
4	4	2.5	2.0	5
X	Special	Special	Special	Special

IEC 61000-4-4
Selection of Test Levels

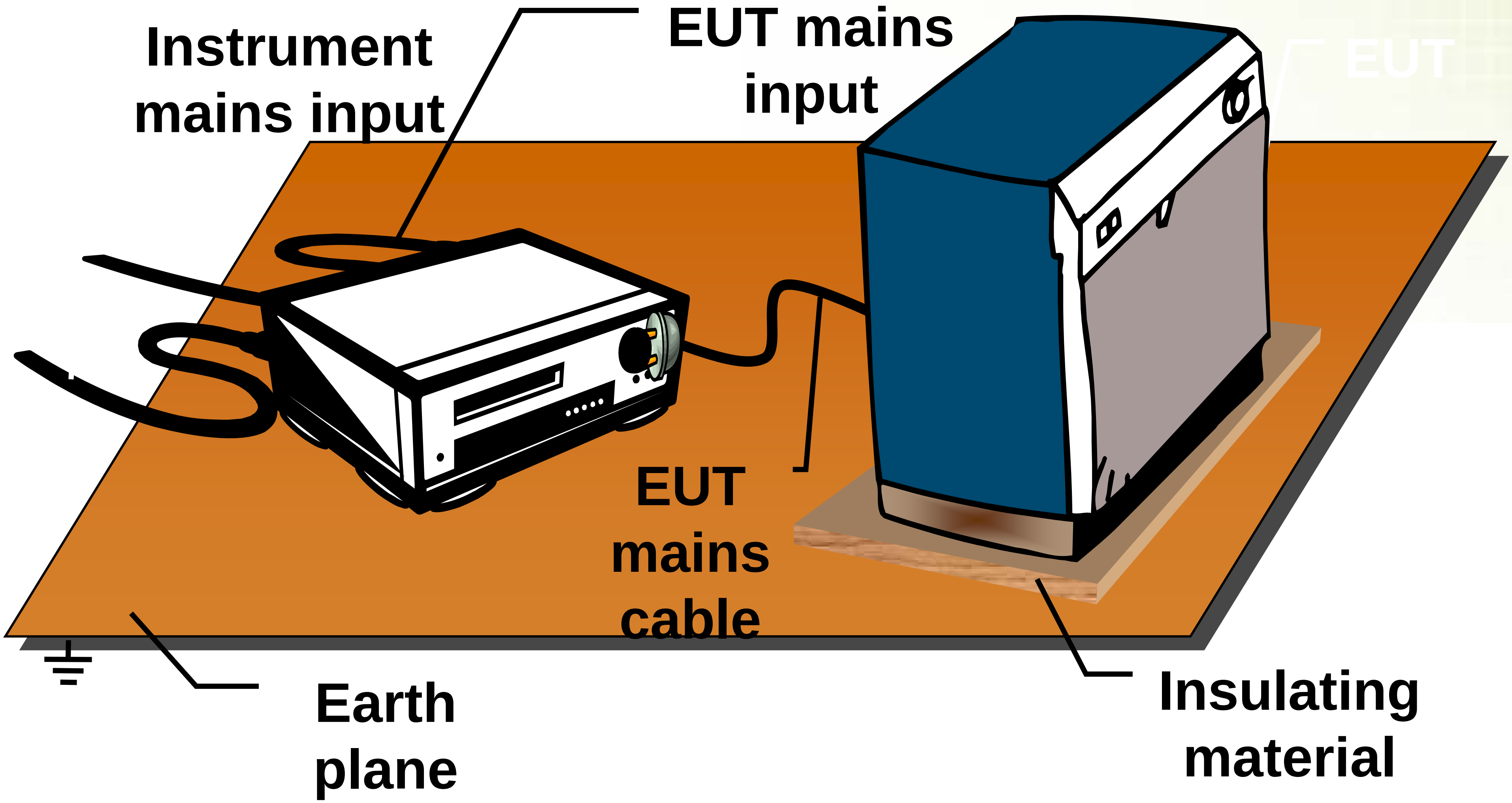
- Test level selection criteria
  - Well-protected environment -> Level 1
  - Protected environment -> Level 2
  - Typical industrial environment -> Level 3
  - Severe industrial environment -> Level 4

IEC 61000-4-4 Test equipment

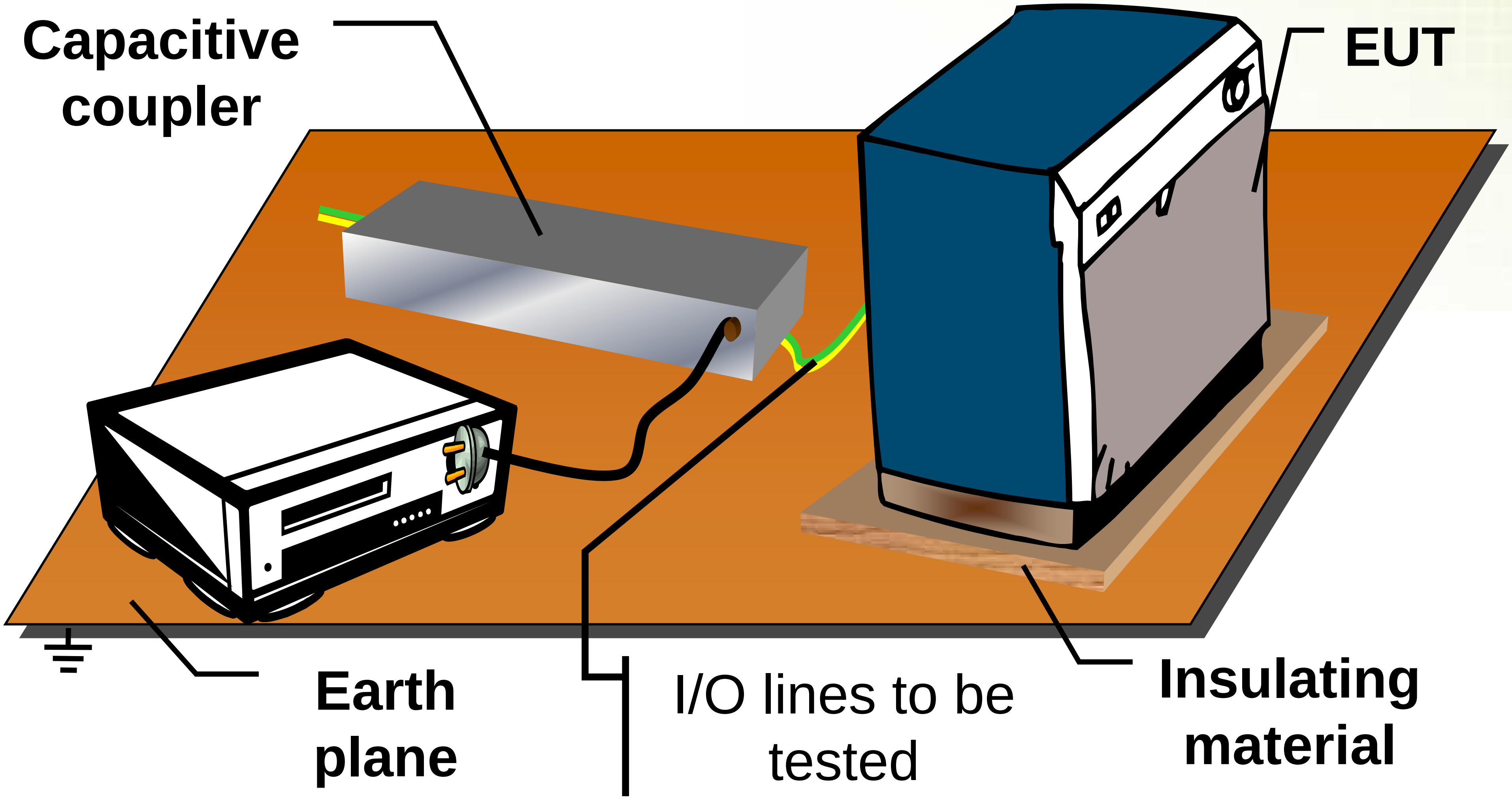
- Polarity: Positive/ Negative
- Asynchronous to power supply
- Coupling
  - Power supply ports
    - Internal: Asymmetric: L, N, PE, L-N, L-PE,
    - N-PE, L-N-PE, 3phase
  - I/O and communication ports
    - Capacitive coupler

IEC 61000-4-4

Test set-up (Power Supply ports)



IEC 61000-4-4
Test set-up (Data I/O ports)



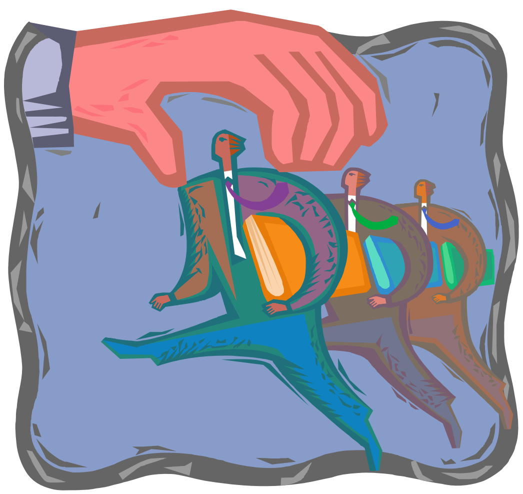
EFT Strategy

- Line filters
- Transient protectors
- Isolation transformers
- Voltage regulators
- Isolated high power circuit

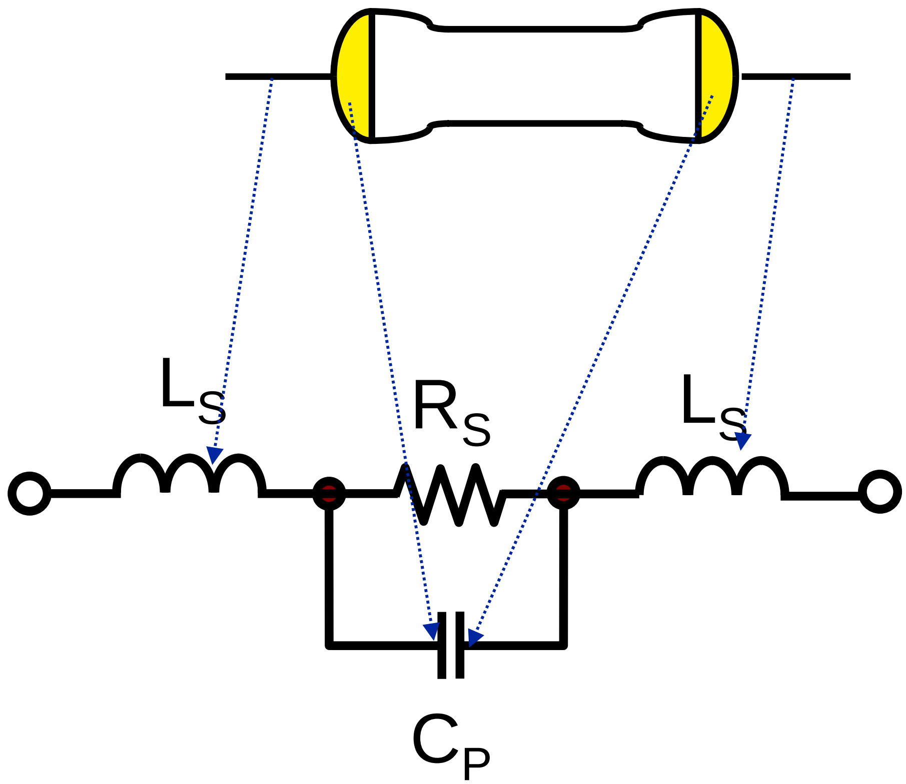
IEC 61000-(4-2 Vs 4-4)

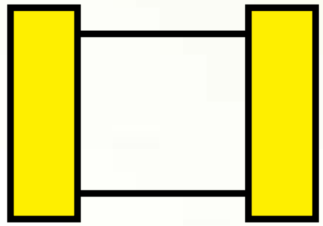
Characteristics	***ESD (4-2)***	***EFT (4-4)***
Max Voltage	Up to 15kV	Up to 4kV
Energy	<10mJ	<= 300mJ
Rep Rate	Single Impulse	Multiple Pulses @ 5KHz
Spectrum	˜1GHz	˜100MHz

Component Selection



Resistor Model





Example

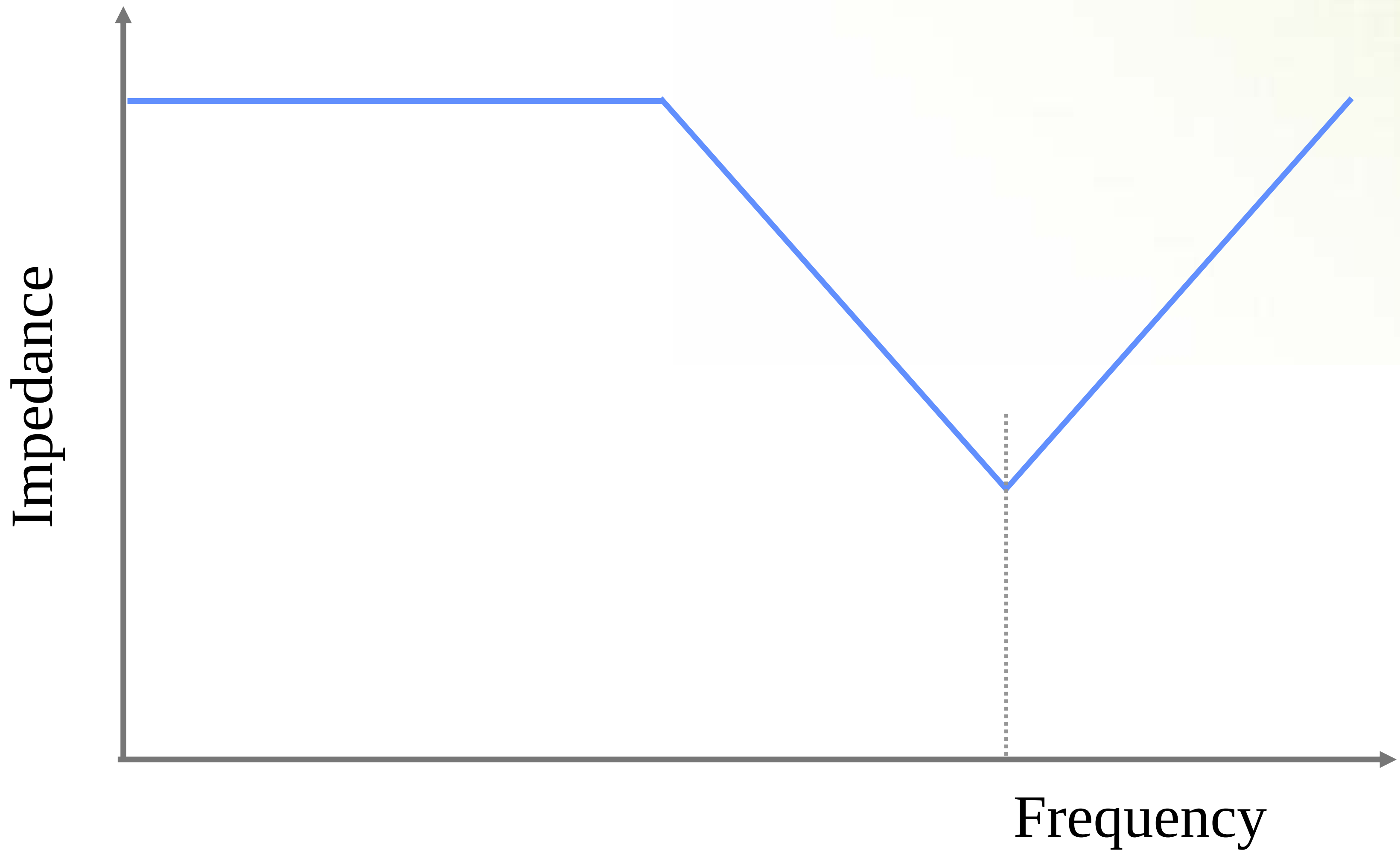
Metal film, axial resistor

$R = 1.00\ M\Omega \pm 1\%$

$L_S \approx 5\ nH$

$C_P \approx 0.5\ pF$

Resistor Impedance



Resistors

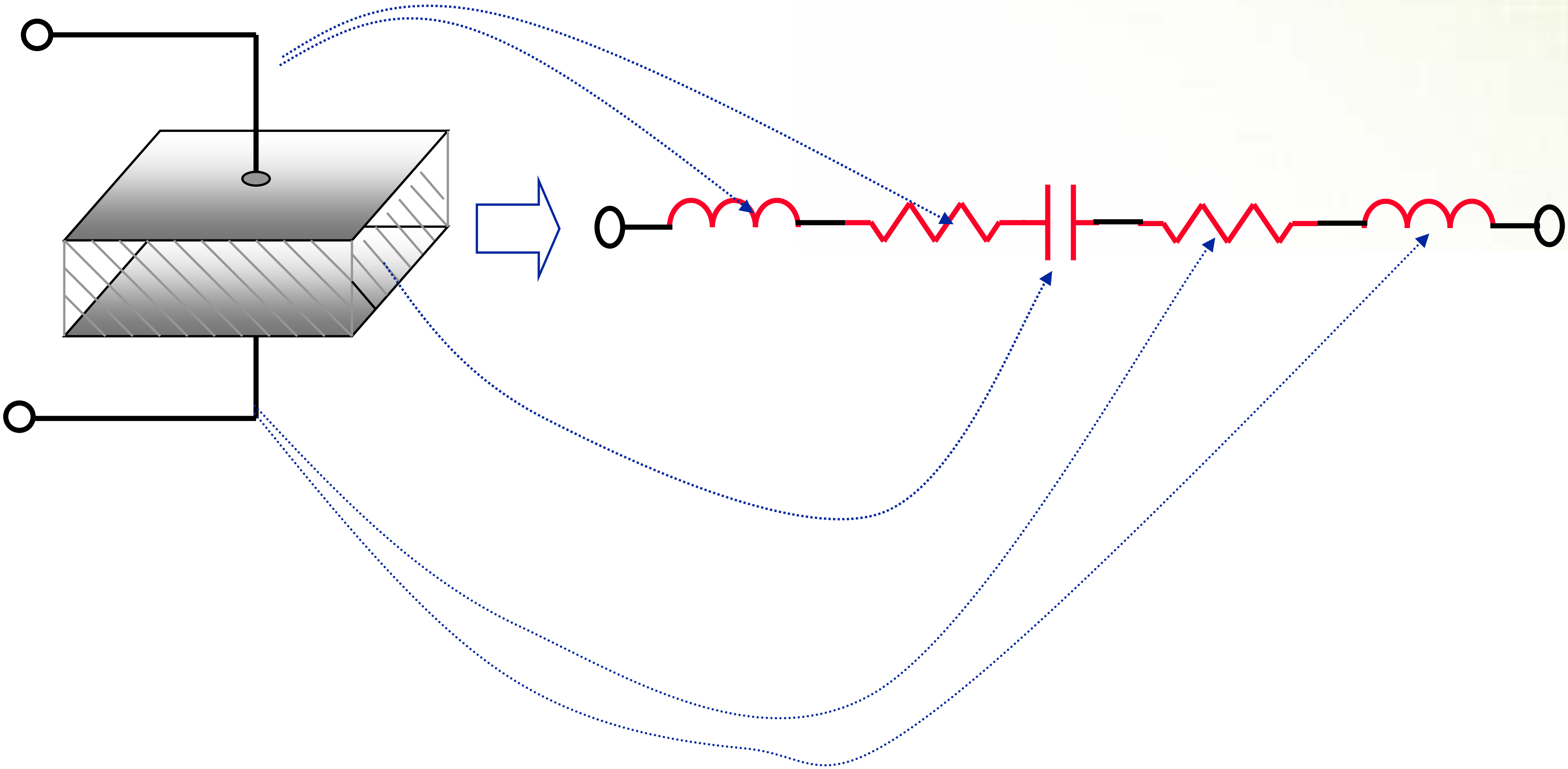
- SMT & Thin film resistors
  - Good for high frequency response
  - Not good for ESD protection. May arc around resistor.
- Metal film suitable for high power density or high accuracy circuits
- Wire wound resistors suitable for high power handling circuits
  - Don’t use in high frequency sensitive circuits

Capacitors - Construction

- Electrolytic - winds metal foil spirally between thin layer of dielectric
- Tantalum - block of dielectric with plates and pins attached
- Ceramic - multiple parallel metal plates in a ceramic dielectric

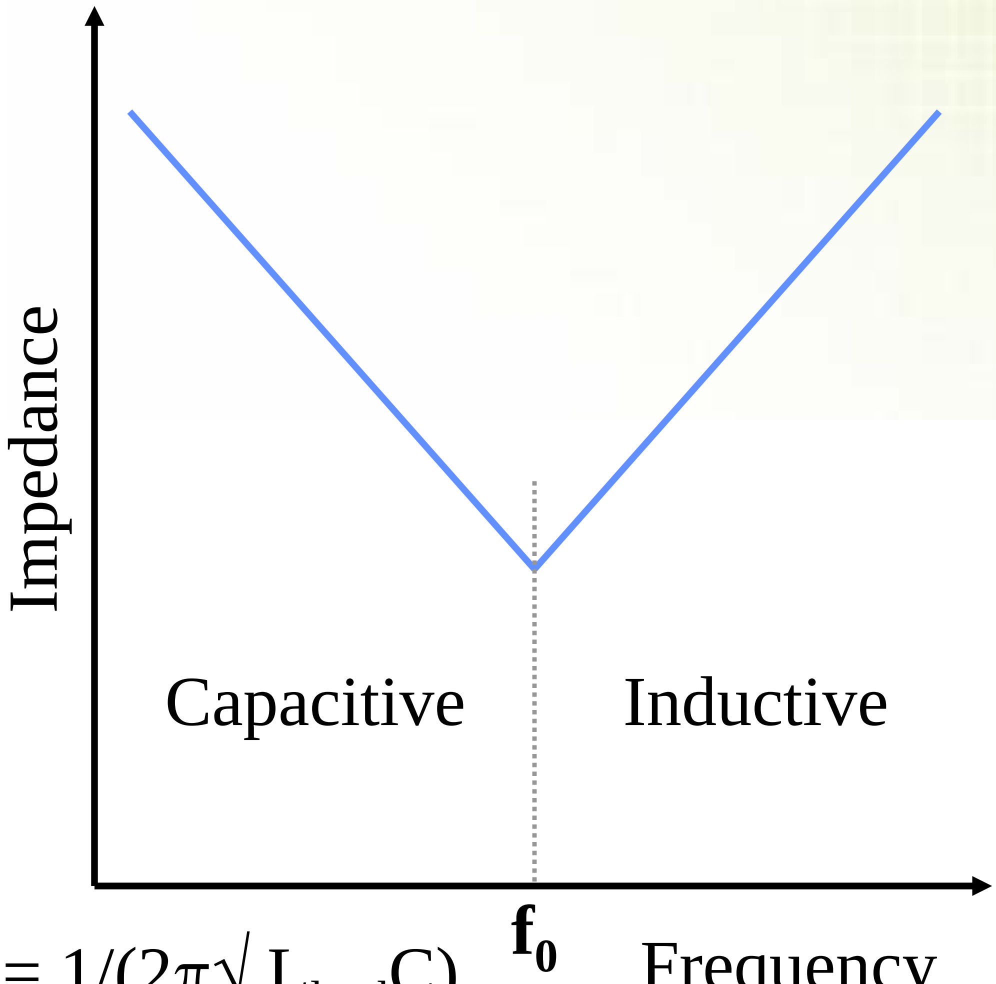
Capacitors - Construction

Capacitor Equivalent Model



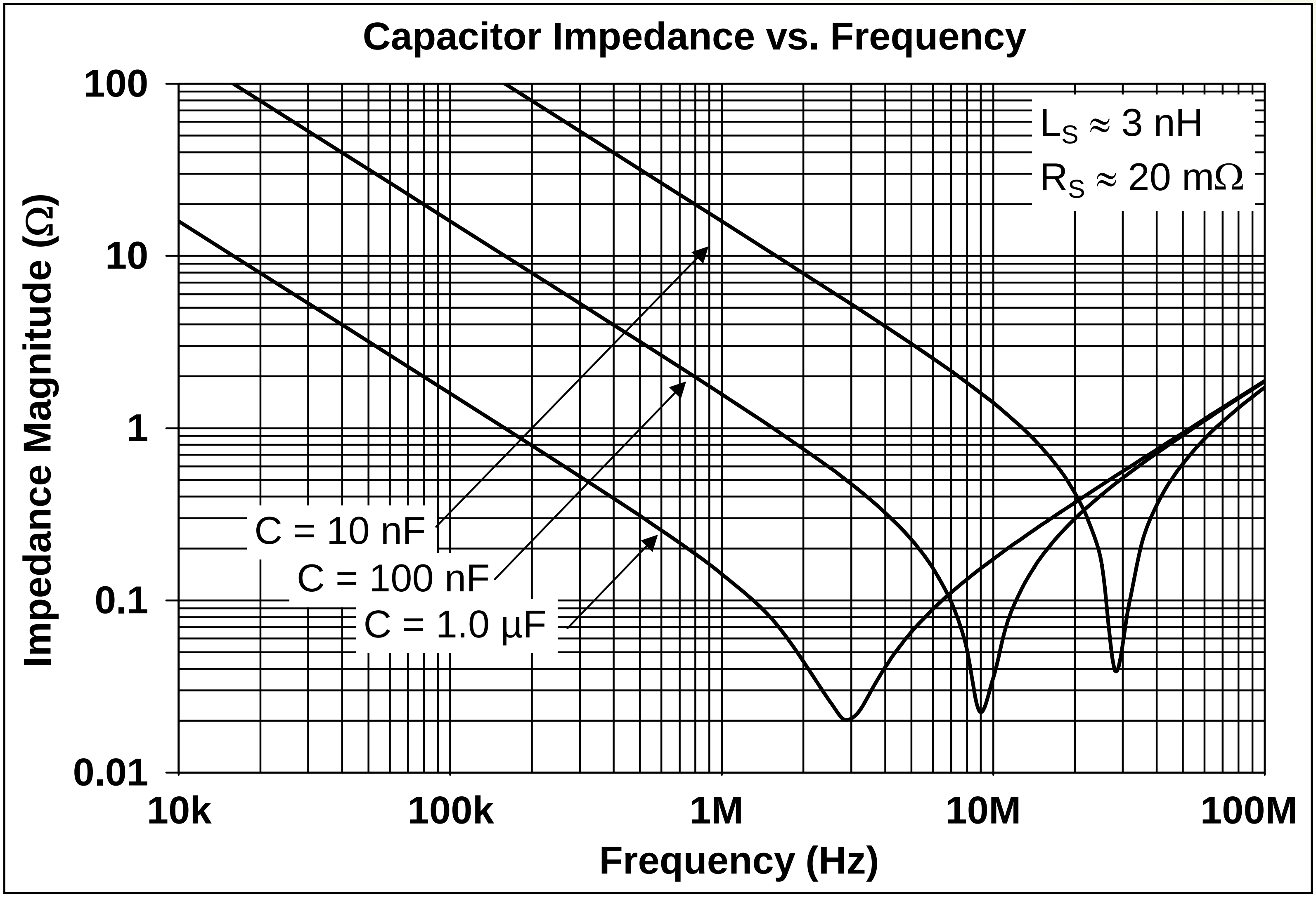
Capacitors

- Self Resonance (f_0)
  - Impedance of inductor equals that of capacitor
  - Magnitudes of the impedance are same but opposite in sign
  - Net impedance of the circuit is the resistance

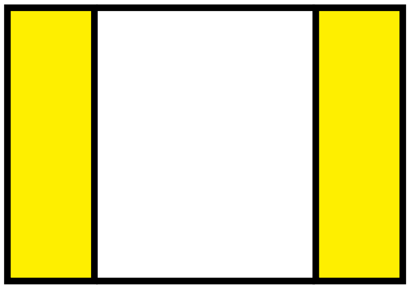


$f_0 = 1/(2\pi\sqrt{L_{lead}C})$

Capacitor Impedance



Tantalum Capacitor Model

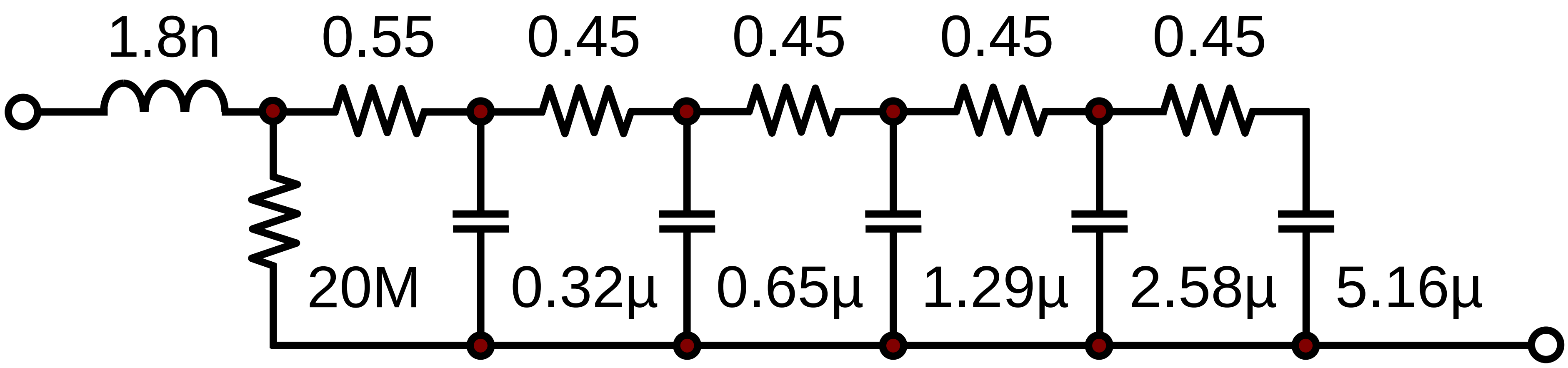


Example

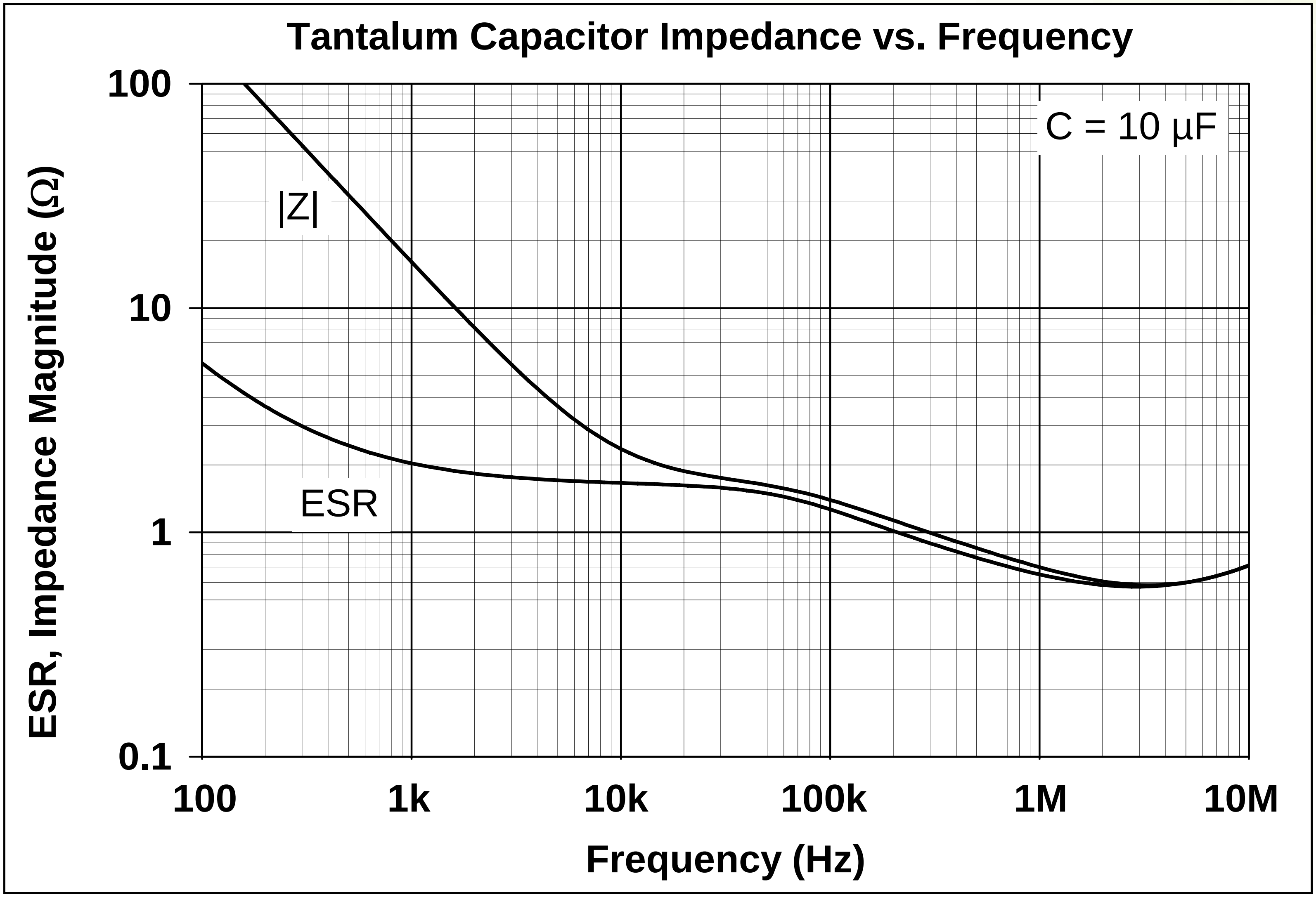
SMT tantalum capacitor

C = 10 µF ± 20%

W.V. = 10 V



Tantalum Capacitor Impedance



Capacitors

- Self resonance of various capacitance

Capacitor Value	Leaded	SMT
[illegible]	2.5MHz	5MHz
0.1uF	[illegible]	16MHz
0.01uF	[illegible]	50MHz
1000pF	80MHz	[illegible]
100pF	250MHz	[illegible]
10pF	800MHz	1.6GHz

Bigger is not always better

Capacitors

Type	Approx. Max Frequency
Electrolytic	100 kHz
Tantalum	1 MHz
Paper	5 MHz
Mica	500 MHz
Ceramic	1 GHz

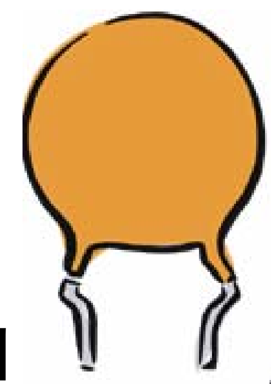
Capacitors

- To provide low impedance for shunting or diverting noise currents to ground
  - Frequency content must be below self resonance frequency
- Sometimes multiple capacitors are needed to provide wider frequency filtering
- Frequent mistake is to make capacitance bigger to fix problem

Capacitors

- Electrolytic & Tantalum
  - Higher capacitance values
  - Low frequency filtering
  - Used for bulk charge storage
  - Electrolytic have high inductance
  - Tantalum have low ESR

- Ceramic capacitors
  - Smaller values of capacitance
  - Maintain ideal behavior up to much higher freq
  - Mid to high frequency filtering



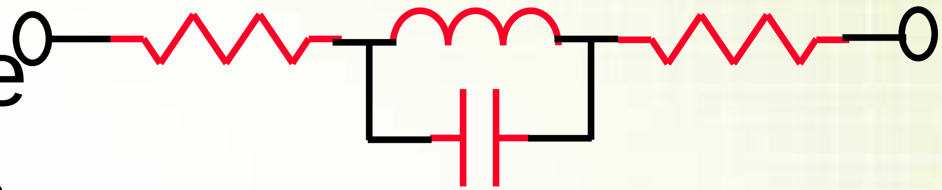
Capacitors

- Bypass
  - Shunts undesirable frequencies before they reach susceptible circuits
  - Watch self resonance frequency as well as high impedance circuits
  - Low impedance loads draw energy away from bypass capacitor
  - Usually larger capacitance from electrolytic or tantalum capacitors

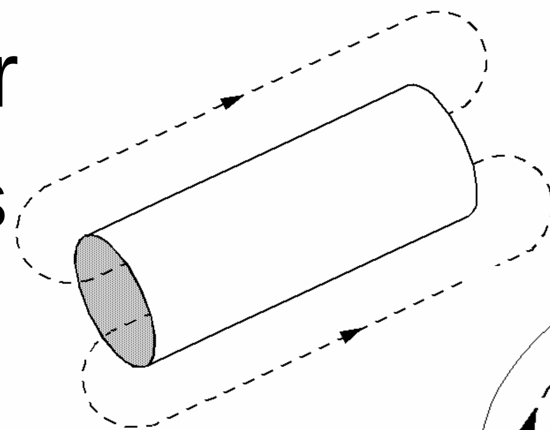
Capacitors

- Decoupling
  - Devices that are switching couple noise onto the power supply (VDD & GND)
  - Decoupling capacitors filter high frequency noise on power supply entering a device
  - Should be placed as close to the power pins on the device
  - Ceramic capacitors are usually used for decoupling because of the fast rise and fall times and their low ESR

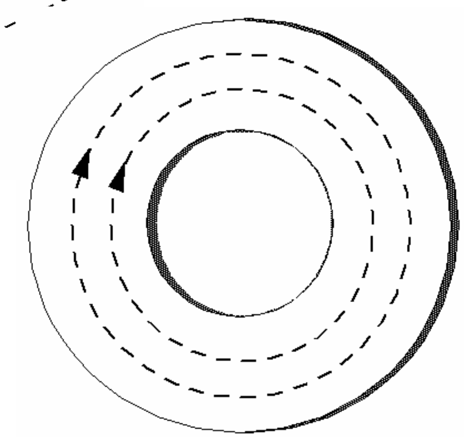
Inductors



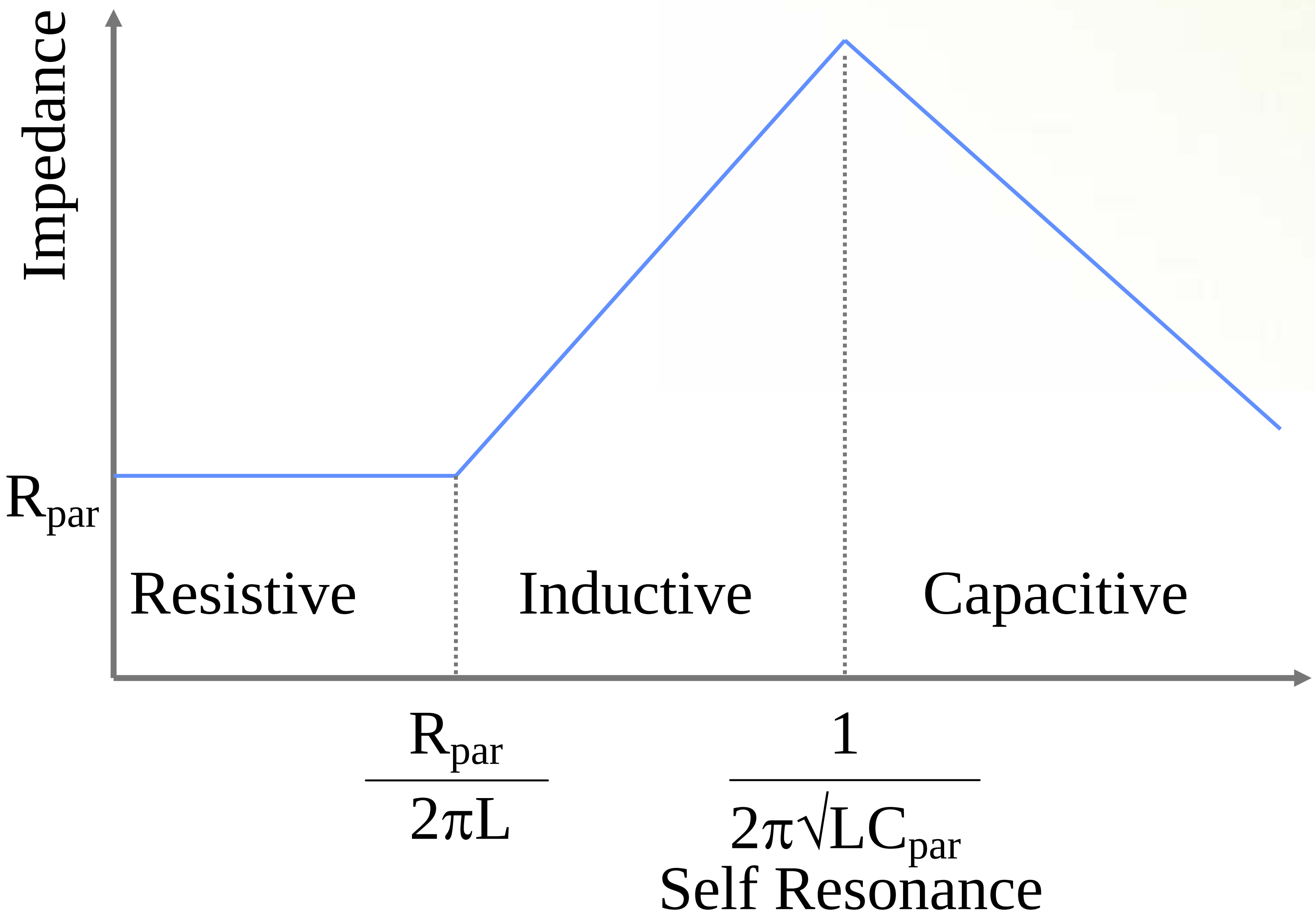
- No parasitic inductance
  - No difference between leaded & SMT
- Open loop: rod inductor
  - Magnetic field passes through air



- Closed loop: toroid
  - Magnetic field passes through core



Inductors


Impedance
R_{par}
Resistive
Inductive
Capacitive
$\frac{R_{par}}{2\pi L}$
$\frac{1}{2\pi\sqrt{LC_{par}}}$
Self Resonance

Inductors

- Open loop inductors increase EMI
- Closed loop inductors have very little susceptibility to external noise
- When using inductors to solve EMC issues
  - Usually only useful on signals that are DC or change infrequently
  - Impedance of load circuit is low
    - Parallel capacitors are better for high impedance loads

Inductors

- Two types of core material
  - Iron: useful for low frequency (kHz)
  - Ferrite: useful for high frequency (MHz)
- Ferrite bead is a single turn inductor
  - Provide ~10dB attenuation at high frequencies
  - Low attenuation or resistive at low frequencies
  - Check frequency / impedance curve

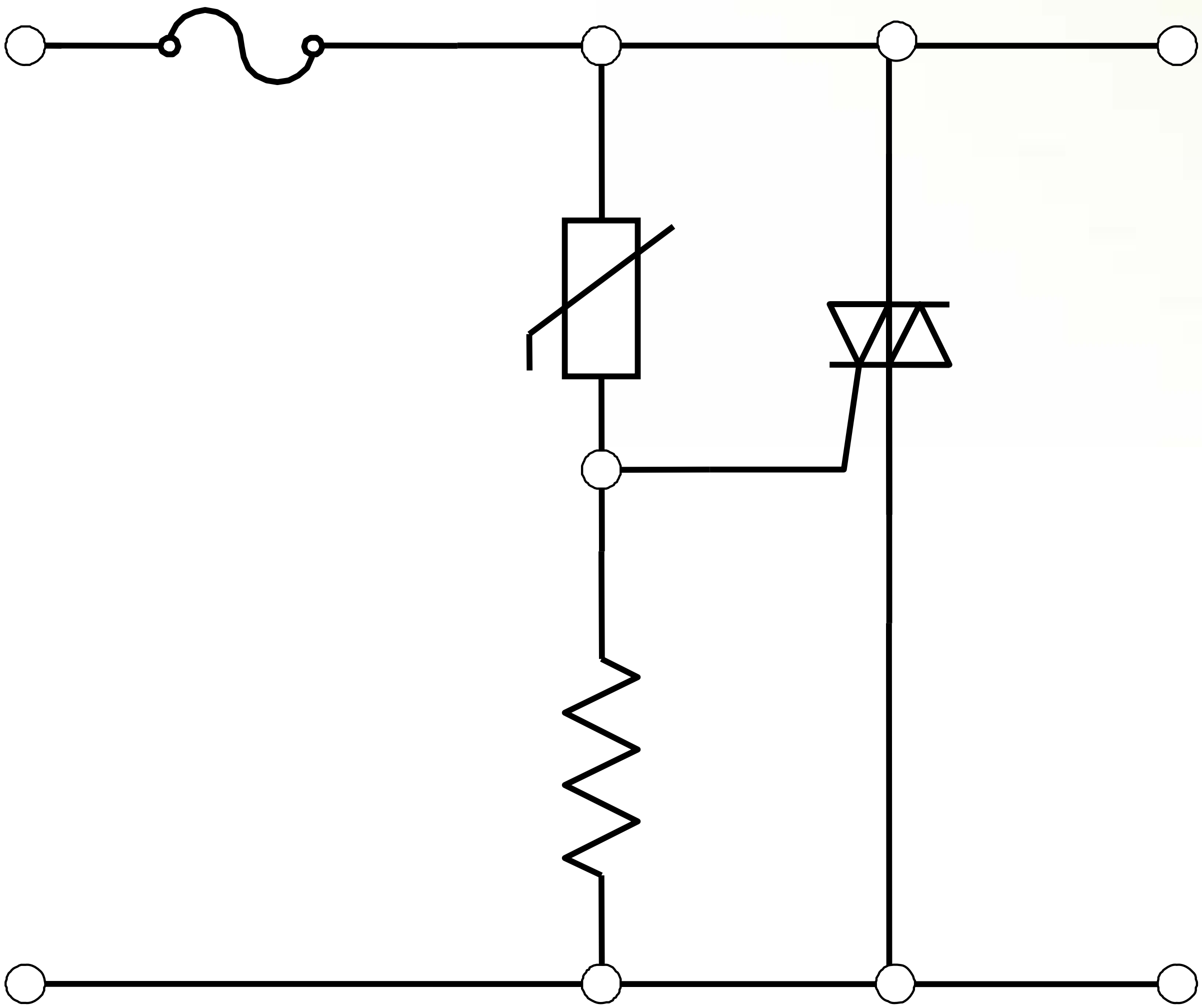
Transient Suppression Devices Comparison

Device	*V/I curve*	*Speed*	*Energy cap..*	*Loss*	*Cost*
Ideal	Sharp/ Flat	Fast	Infinite	None	Free
MOV	Sharp/ Non-Lin	Med	High	High	Low
SAD	Sharp/ Flat	Fast	Low	Low	Mod
GDT	Erratic/ Non-Lin	Slow	High	Low	Mod to High
Thyristor	Sharp/ Flat	Med	High	Low	Mod
Spark Gap	Erratic/ Non-Lin	Slow	High	Low	Low

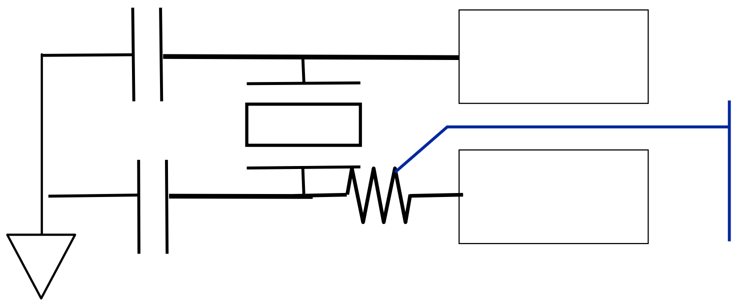
Metal Oxide Varistor (MOV)

- Voltage Dependant Resistor
- Higher capacitance (Typ 1500 pF)
- High power handling capability
  - E.g. 6500 Amps @ 8 X 20 uS Pulse for 20mmMOV
- Short - If fails
- Higher Leakage E.g. 5 mA @ operating V
- Performance degrades with transients

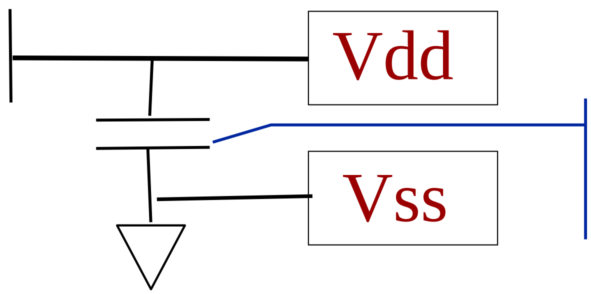
Hybrid TVS



Quiz time

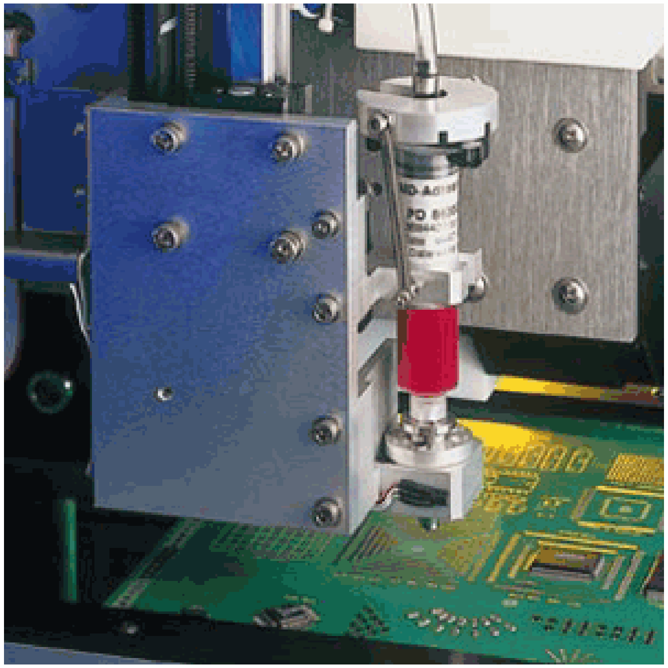


Wire wound?



1uF Electrolytic?

Component Placement



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Issue 2: The art or Science of component placement

Floor Planning

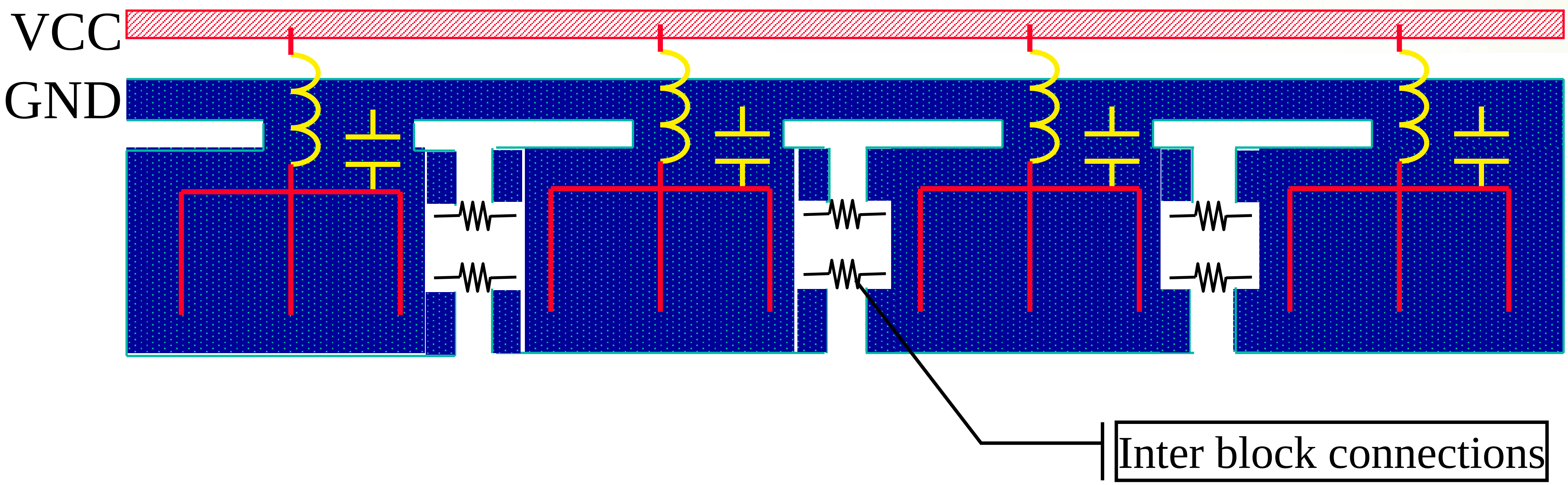
- Partition into functional areas
  - Separate different signals
    - Low frequency vs. high frequency
    - Low power vs. high power
  - Separate different functions
    - Analog vs. digital
    - Supply vs. signal
    - Power driver vs. signal conditioning

Floor Planning

- Add isolation
  - Make high frequency signal paths
    - Short
    - Near the PCB edge connector
  - Use guard rings and traces
  - Add spacing between sections
- Do not use auto routers for analog / power sections

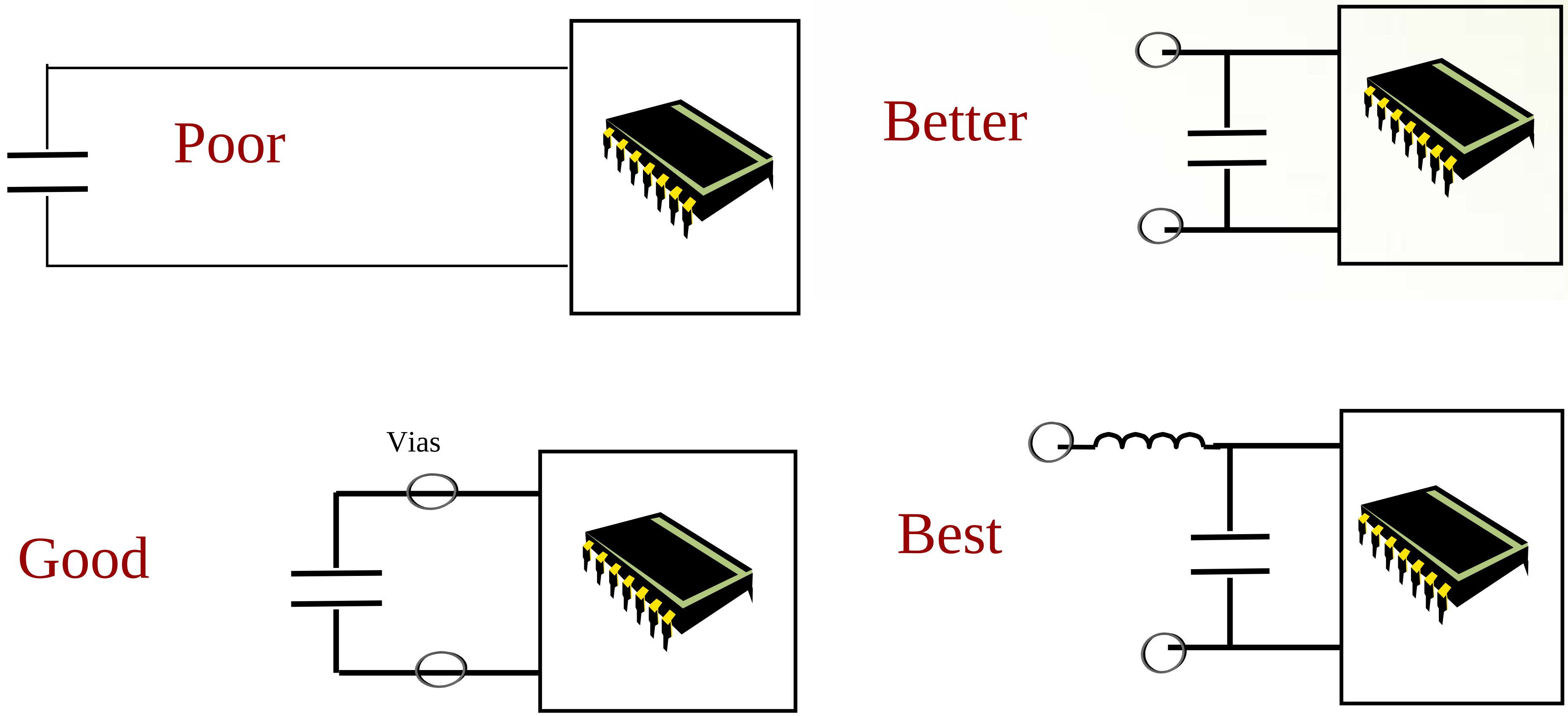
Circuit Segmentation

- Circuit Segmentation
  - Physically separate circuits to reduce coupling
  - High current or high switching frequency circuits should be close to power supply



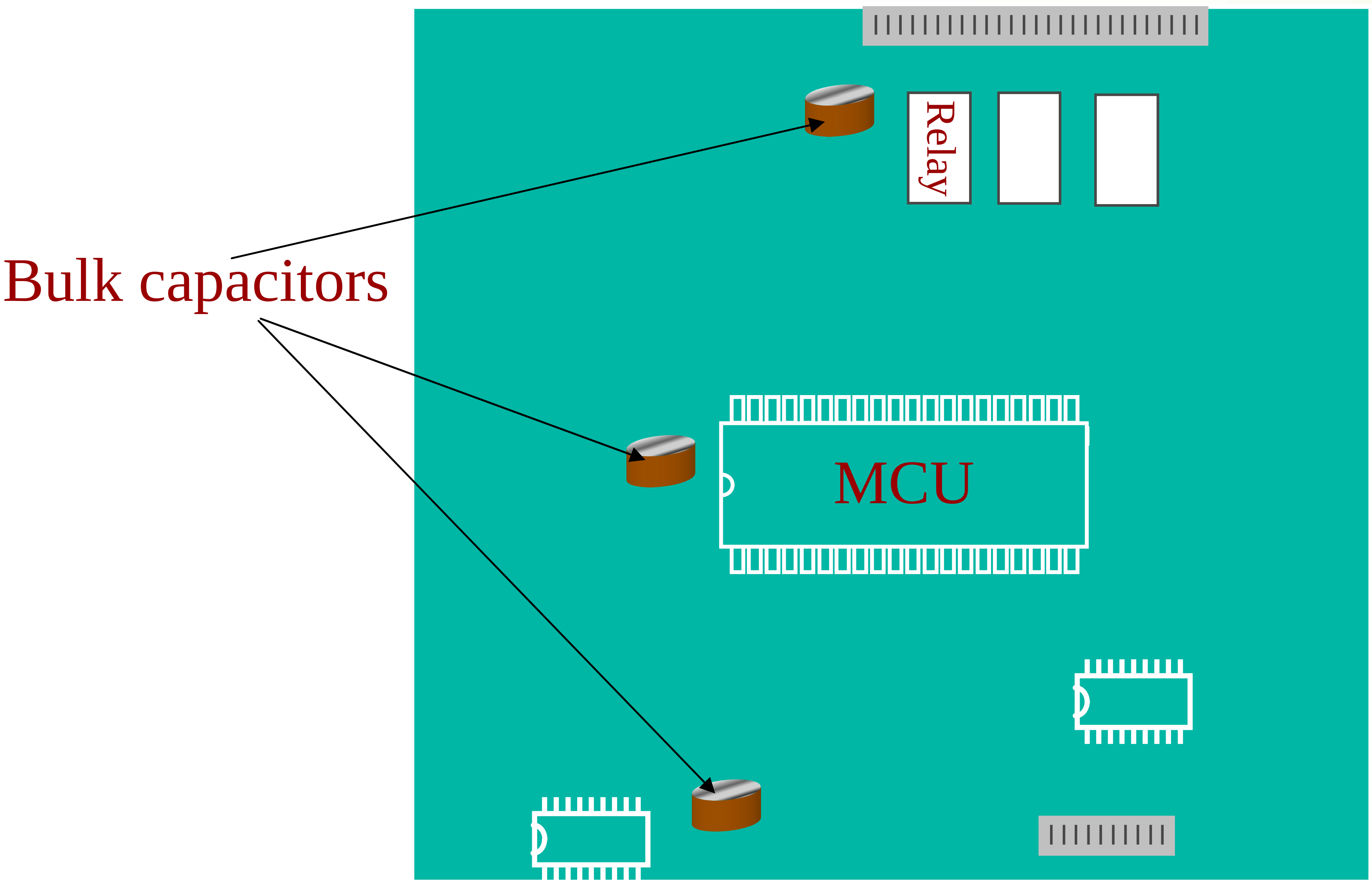
Decoupling

- Power supply decoupling



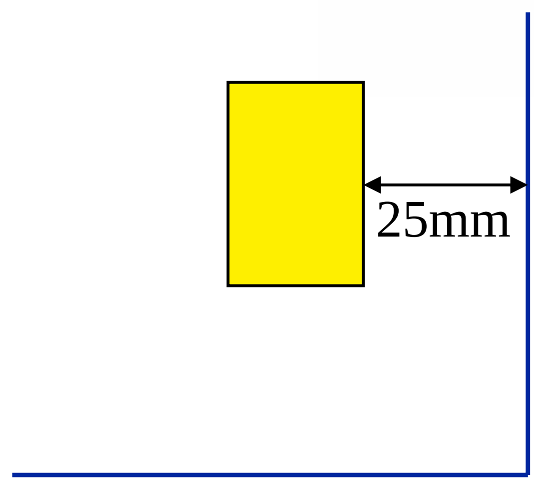
Capacitor Placement

- Place bulk capacitors close to demand



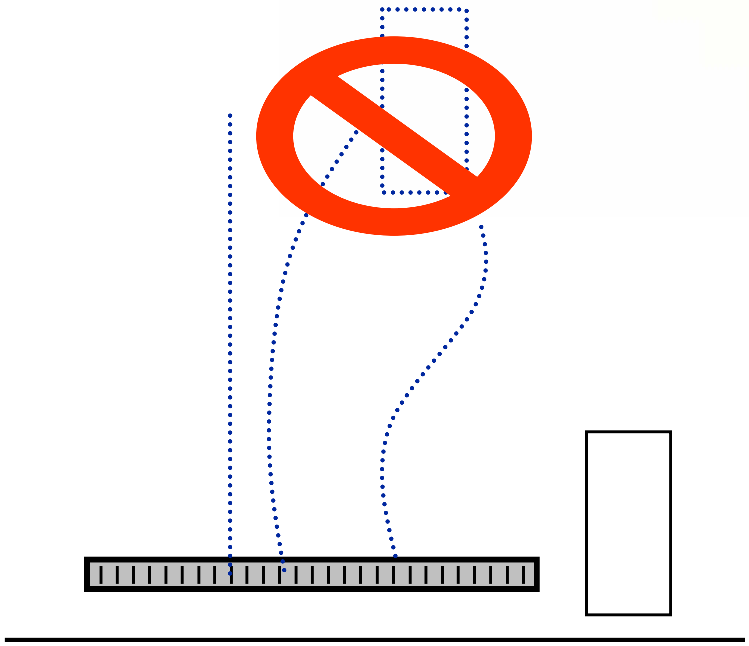
Component Placement

- Keep susceptible component away from PCB edge

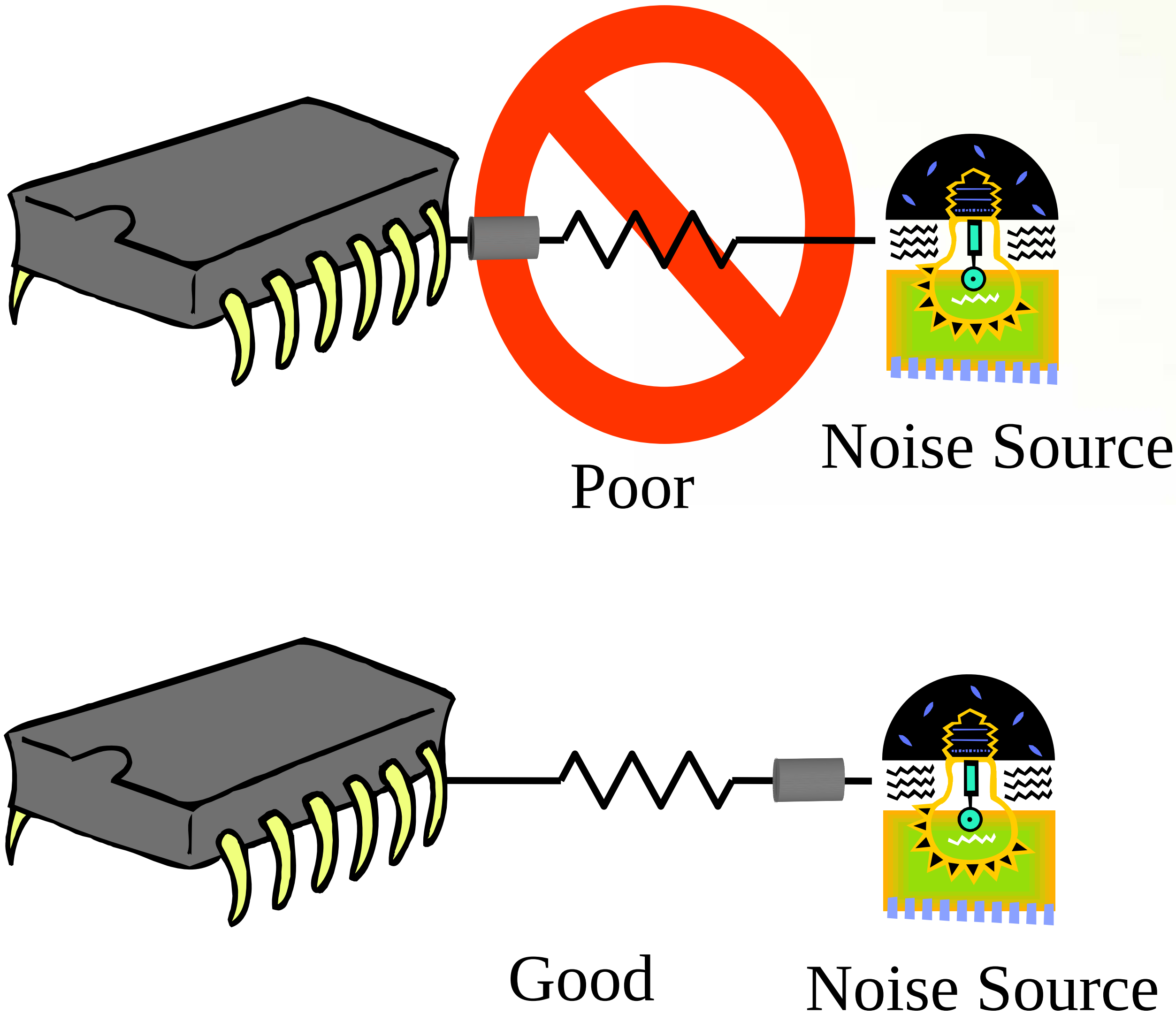


Component Placement

- Keep interfacing components close to PCB edge

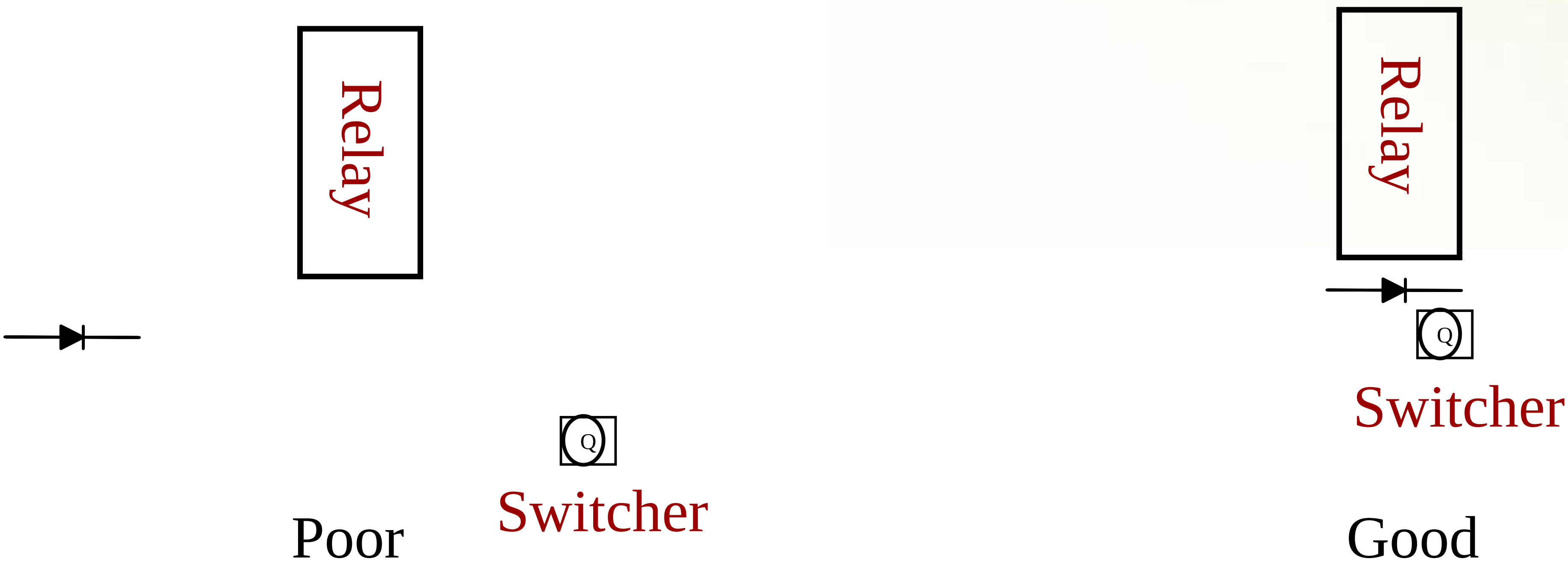


Ferrite Bead Placement



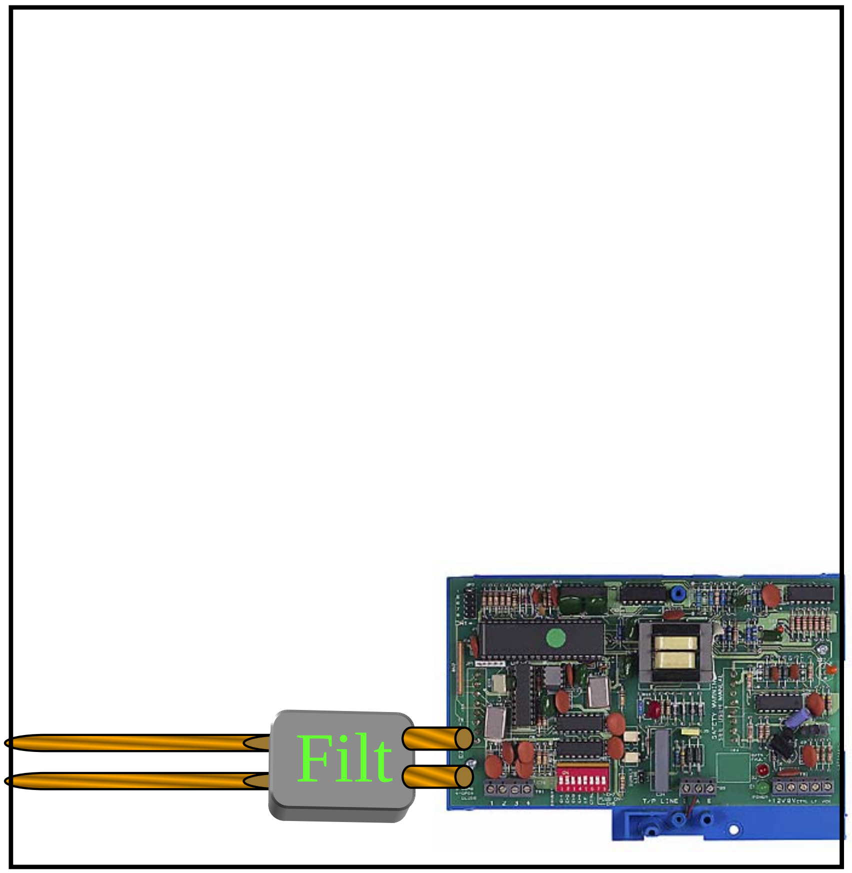
Component Placement

- Switcher & Load location

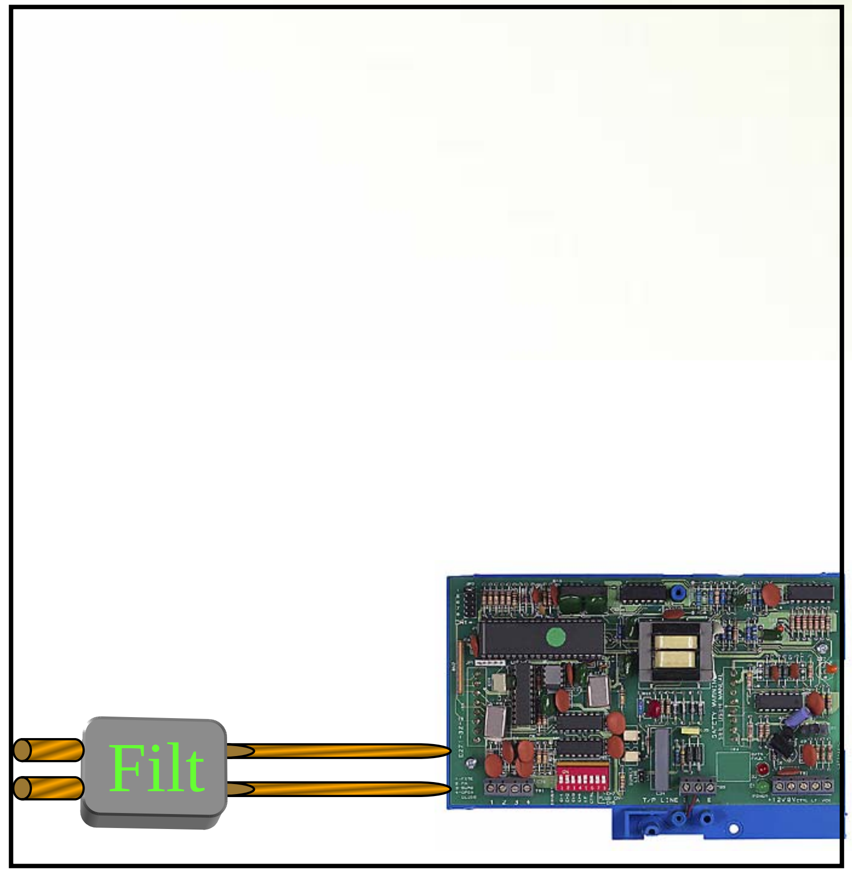


Power Line Filter Placement

- Power line filter location



Poor

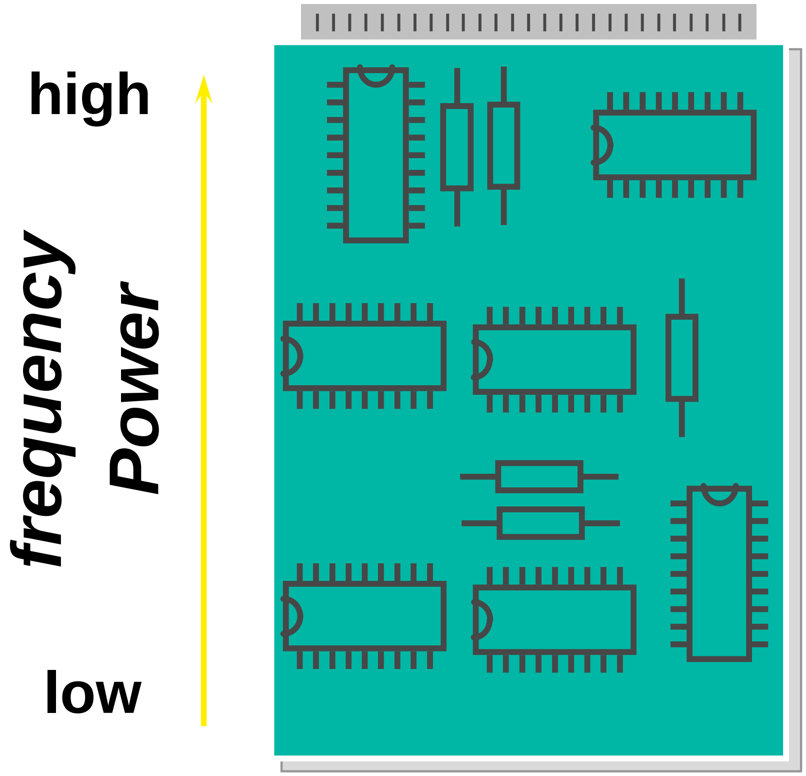


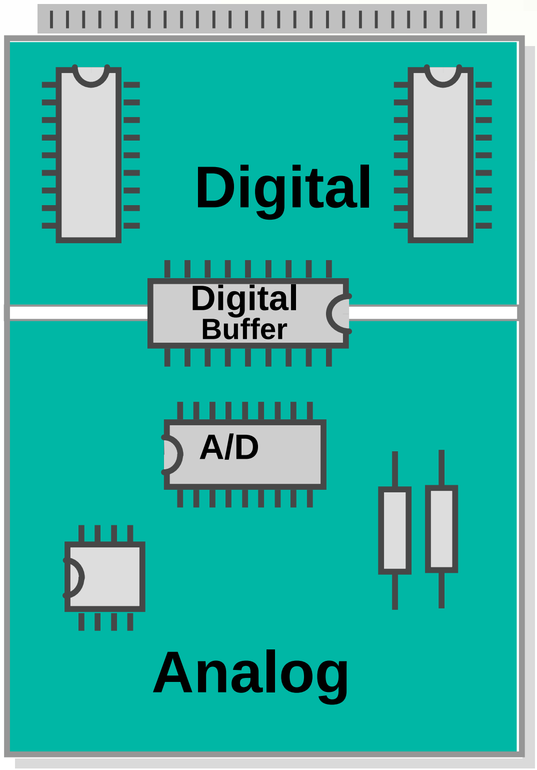
Good

Floor Planning

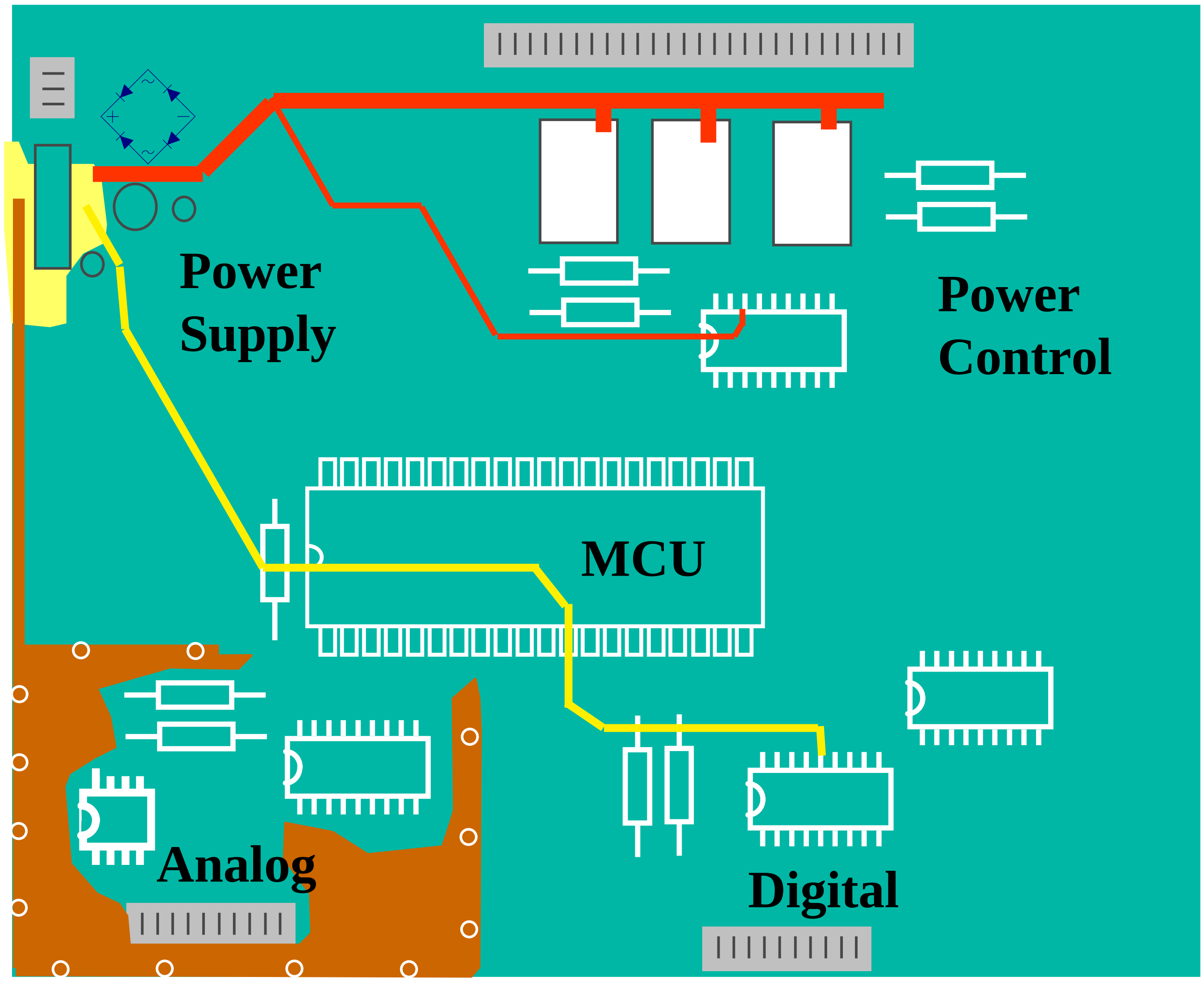
High Power / Frequency Components Placed Near Connector

Separate Digital and Analog Portions of the Circuit

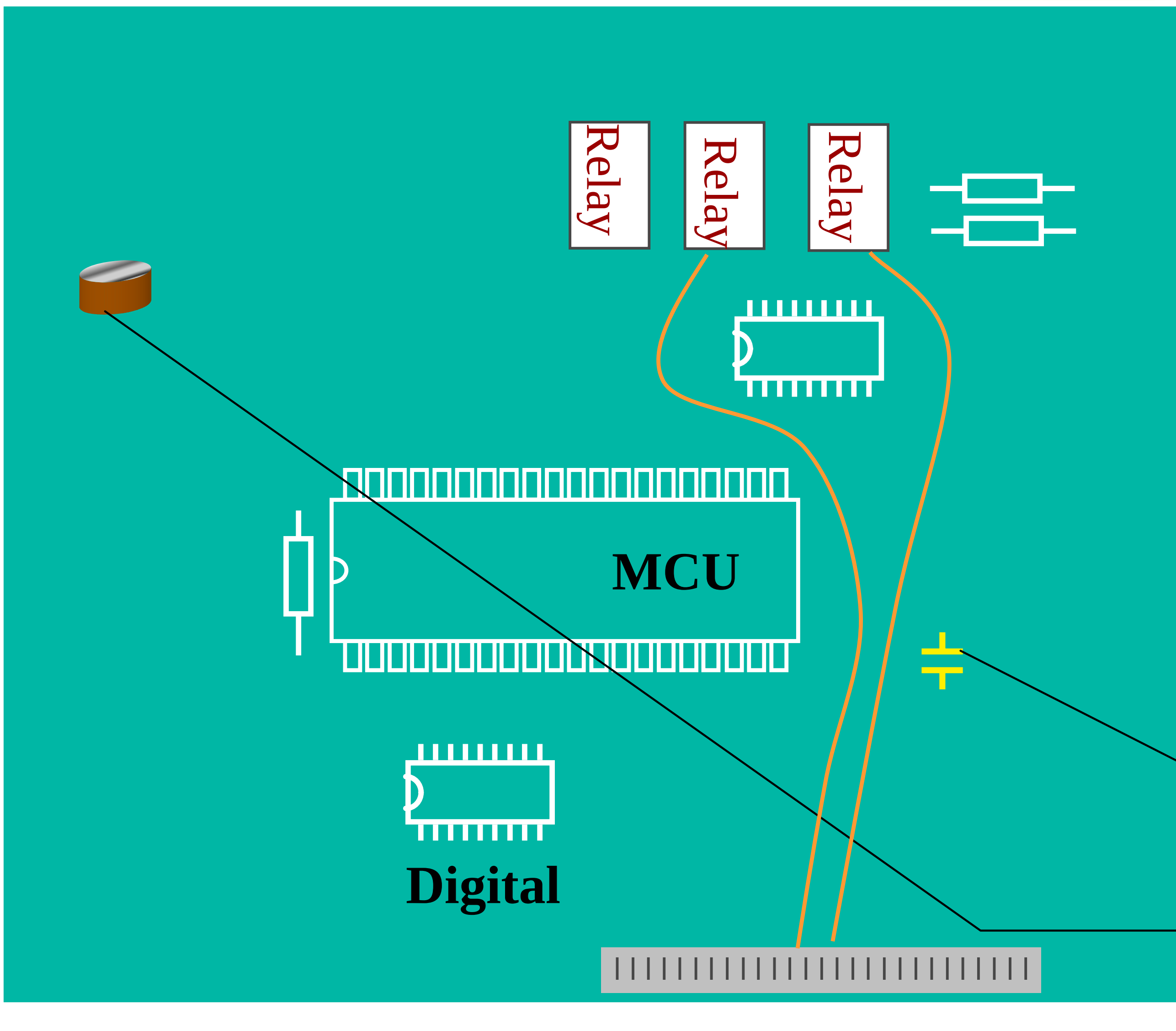


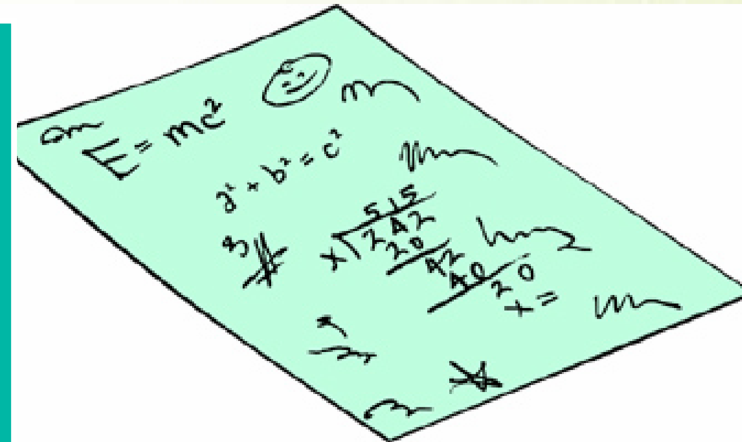


Floor Planning



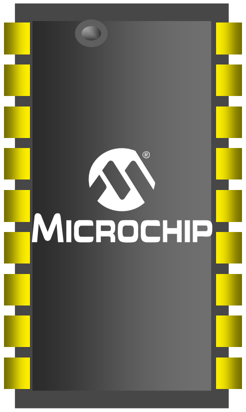
Quiz time


Relay
Relay
Relay
MCU
Digital
Decoupling cap for MCU
Bulk Cap



Tips & Tricks

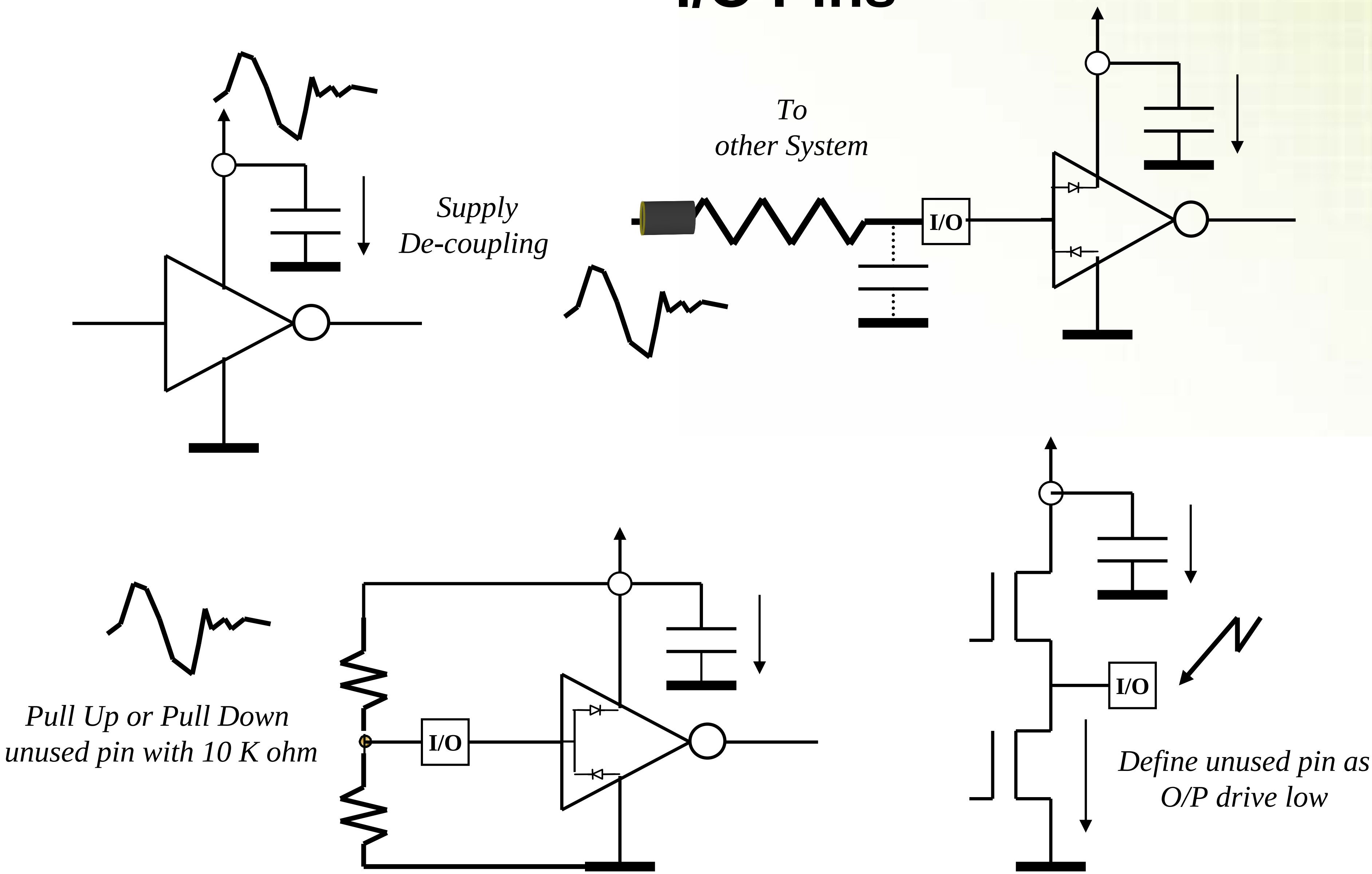
Microcontroller Circuits



Microcontroller Circuits

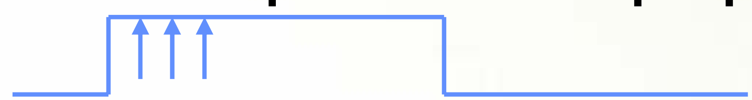
- I/O pins
- Interrupt pins
- Reset pin
- Power supply
- Oscillator
- Brown Out Reset (BOR)
- Watch Dog Timer (WDT)

Microcontroller Circuits
I/O Pins



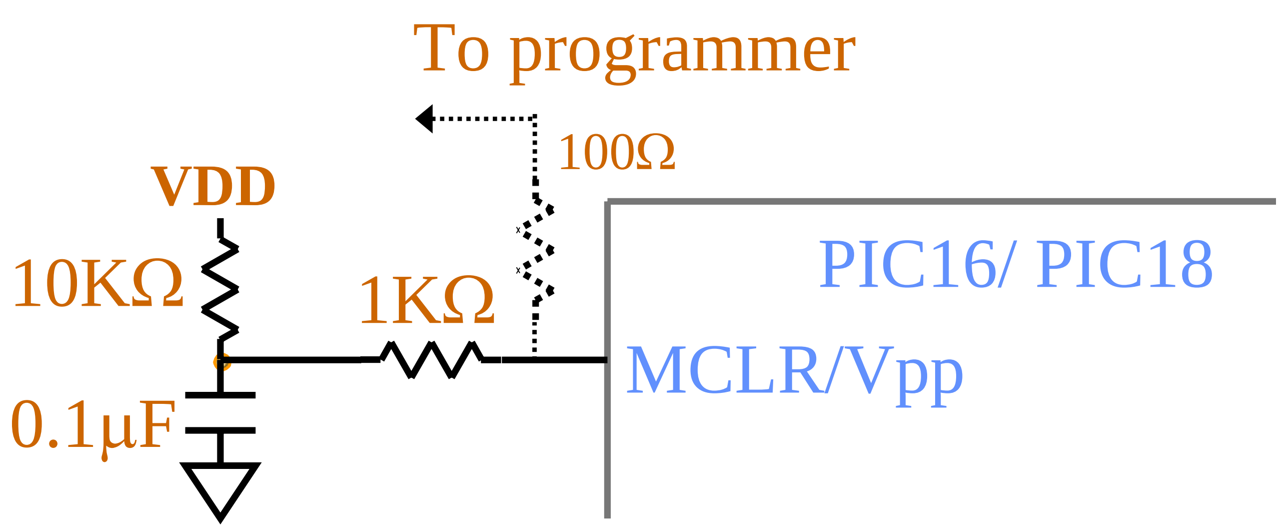
Microcontroller Circuits

- Interrupt Pins
  - Edge triggered interrupts susceptible to noise
  - Use level triggered type or sample interrupt pin inside ISR
  - Use line terminations to reduce reflections, ringing or overshoot which can cause false interrupts
  - Carefully route connections to interrupt traces/pins to reduce cross-talk



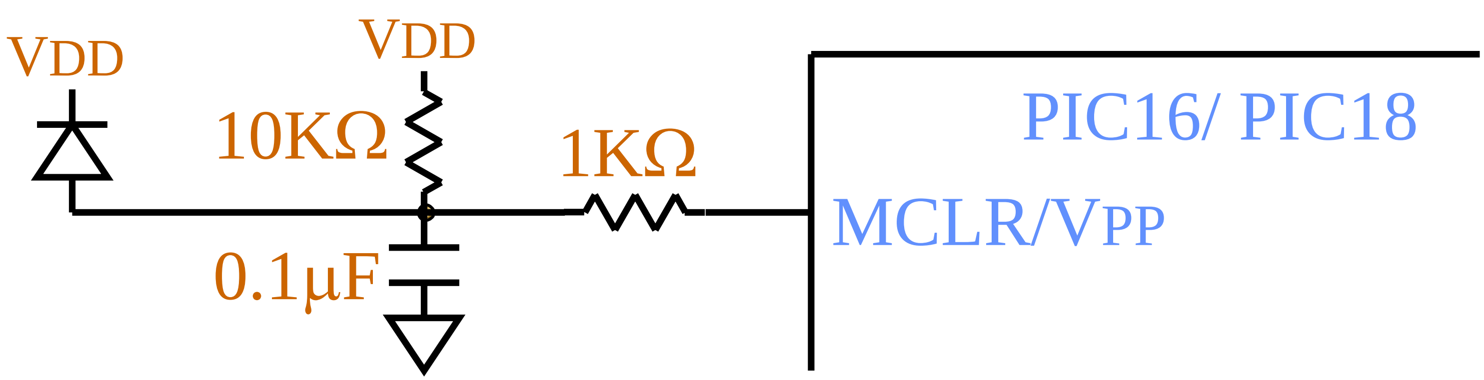
Microcontroller Circuits

- Reset Pins
  - A series resistor to limit the amount of current entering the MCLR pin due to ESD or EOS
  - A decoupling capacitor to attenuate high frequency noise
  - Recommends pull-up resistor to VDD of <40 KΩ



Microcontroller Circuits

- Reset Pins
  - MCLR is also VPP for programming
  - If not performing ICSP™ programming of the device in circuit, add diode to VDD for additional ESD protection



Microcontroller Circuits

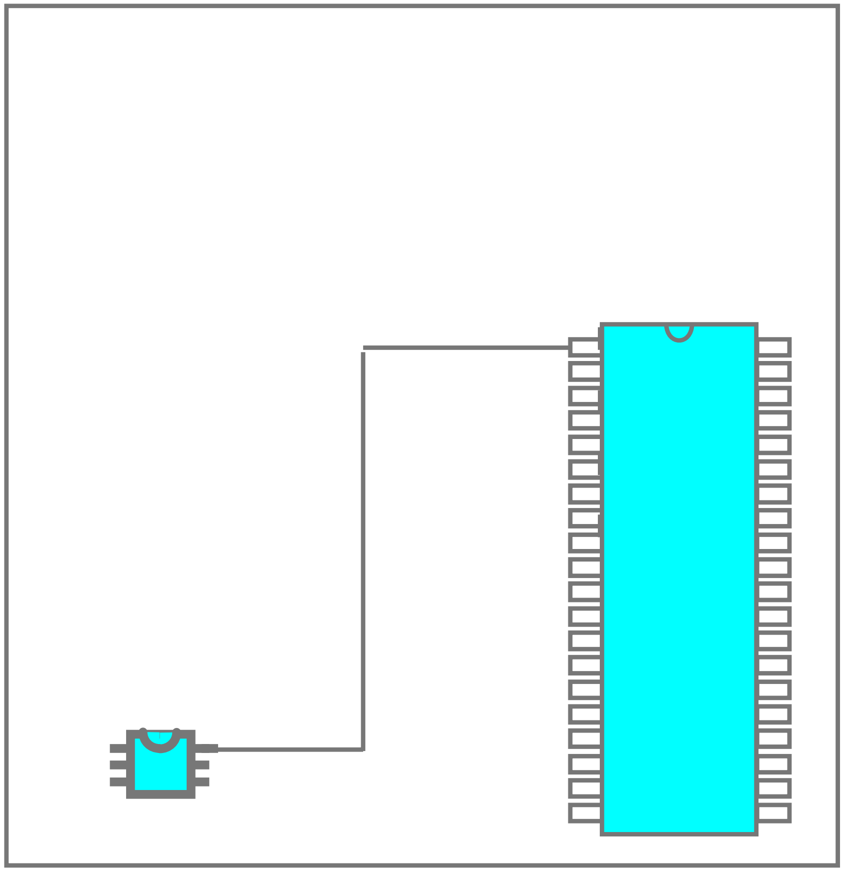
- Reset Pins
  - Some devices has a fuse setting to disable MCLR
  - If MCLR functionality is not required then disable it.
  - If MCLR disabled then..

Microcontroller Circuits

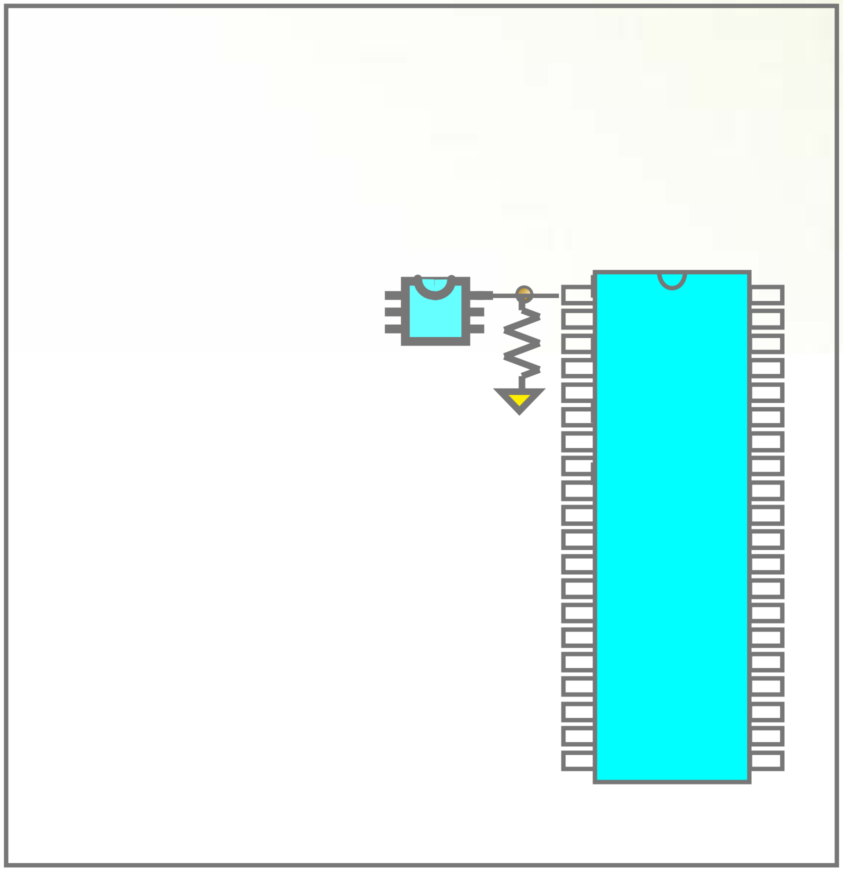
- Single Supply Programming (PGM pin)
  - If Single Supply Programming (LVP) is enabled then...

Microcontroller Circuits

- External Watch Dog / Reset Control



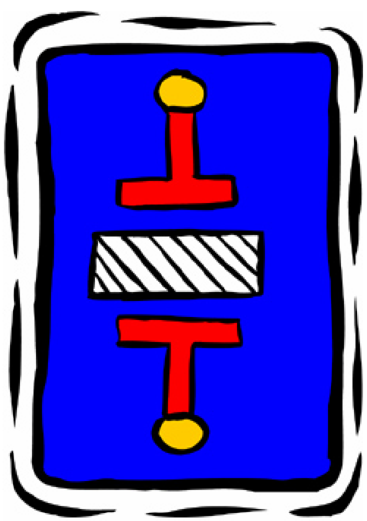
POOR



GOOD

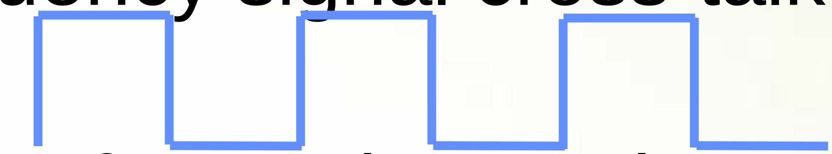
Microcontroller Circuits

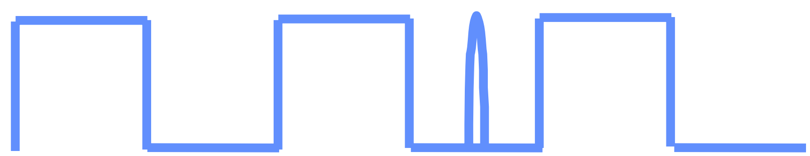
- Power Supply
  - Any noise on the power supply will enter all circuits on the board
  - Must have adequate decoupling caps AND bulk charge storage caps

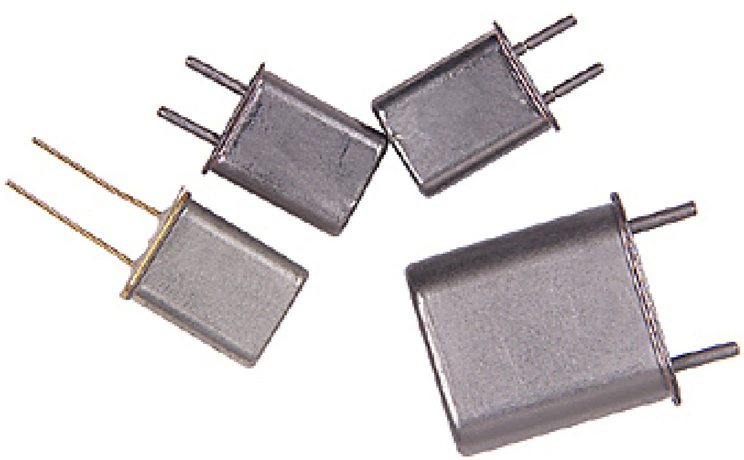


Microcontroller Circuits
Oscillator

- Oscillator
  - Oscillator circuits are generally high impedance
  - Susceptible to high frequency signal cross-talk or noise
    - Can induce jitter, out of spec duty cycle or complete oscillator failure

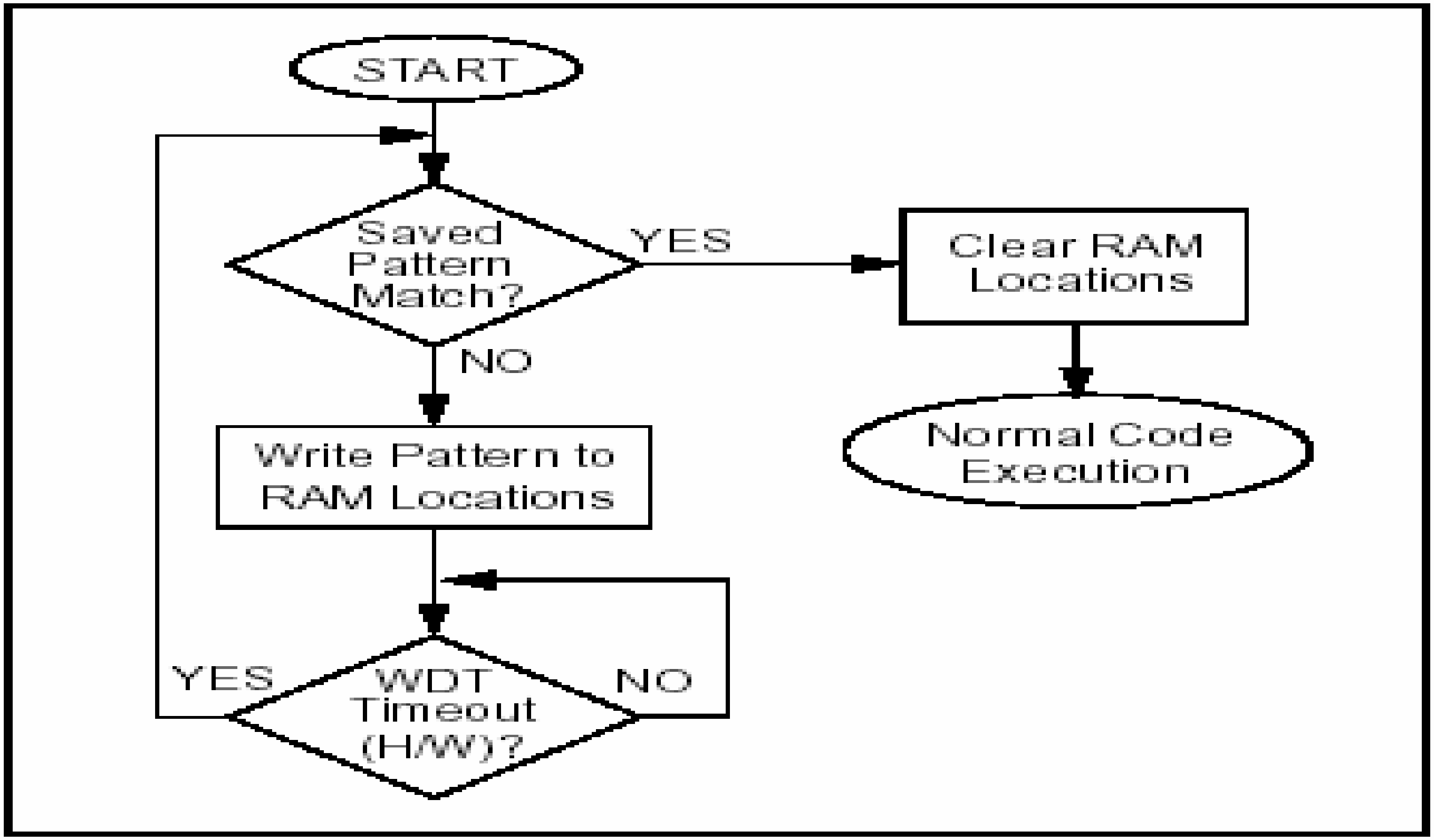






Flow chart for WDT based reset recovery

FIGURE 6: FLOW CHART OF "PATTERN MATCHING" WDT RESET



Code for WDT recovery

EXAMPLE 2: "PATTERN MATCHING" WDT RESET ROUTINE IN 'C'

```
const unsigned char PATTERN[]={"!@#$%^&*"}; //shift + <1 thru 8> on a 101 keyboard.
unsigned char Location[8]={0,0,0,0,0,0,0,0};
unsigned char i;

void main(void)
{
        for (i = 0;i < 8;)
                if (Location[i] != PATTERN[i])          // pattern match?
                        break;                          // no, then break
                else i++;                               // yes, then check next
        if (i != 8)                                     // all done
                {                                       // no, then write pattern...
                for (i = 0;i < 8; i++)                  // to RAM locations ...
                        Location[i] == PATTERN[i];      // and ...
                while(1);                               // wait for WDT timeout
                }
        else for (i = 0;i < 8;i++)                      // yes, then clear RAM
                Location[i] = 0;
// Rest of the code

}
```

Resets - Sources

- POR - Power-On Reset (VDD slope)
- MCLR - Master Clear Reset (pin voltage)
- WDT - Watch Dog Timer Reset (time-out period)
- BOR - Brown-Out Reset (VDD voltage)
- Software reset instruction (PIC18 only)
- Stack Condition (PIC18 only)

Identifying Reset Source

Condition	Program Counter	RCON Register	$\overline{\text{RI}}$	$\overline{\text{TO}}$	$\overline{\text{PD}}$	$\overline{\text{POR}}$	$\overline{\text{BOR}}$	STKFUL	STKUNF
Power-on Reset	0000h	0--1 1100	1	1	1	0	0	u	u
$\overline{\text{MCLR}}$ Reset during normal operation	0000h	0--u uuuu	u	u	u	u	u	u	u
Software Reset during normal operation	0000h	0--0 uuuu	0	u	u	u	u	u	u
Stack Full Reset during normal operation	0000h	0--u uu11	u	u	u	u	u	u	1
Stack Underflow Reset during normal operation	0000h	0--u uu11	u	u	u	u	u	1	u
$\overline{\text{MCLR}}$ Reset during SLEEP	0000h	0--u 10uu	u	1	0	u	u	u	u
WDT Reset	0000h	0--u 01uu	1	0	1	u	u	u	u
WDT Wake-up	PC + 2	u--u 00uu	u	0	0	u	u	u	u
Brown-out Reset	0000h	0--1 11u0	1	1	1	1	0	u	u
Interrupt wake-up from SLEEP	PC + 2(1)	u--u 00uu	u	1	0	u	u	u	u

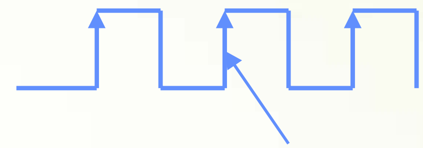
Legend: u = unchanged, x = unknown, - = unimplemented bit, read as '0'

Defensive Software

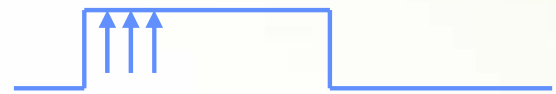
EMC Newsletter

Issue 4

- Periodic refresh of ports



- Polling inputs
- “Noise Proof” input scan



- Token passing or subroutine counters
- Reset based recovery
  - Simple State Machine
- Use the watchdog timer
  - Known reset loop,Fill unused memory with “goto $”

Summary

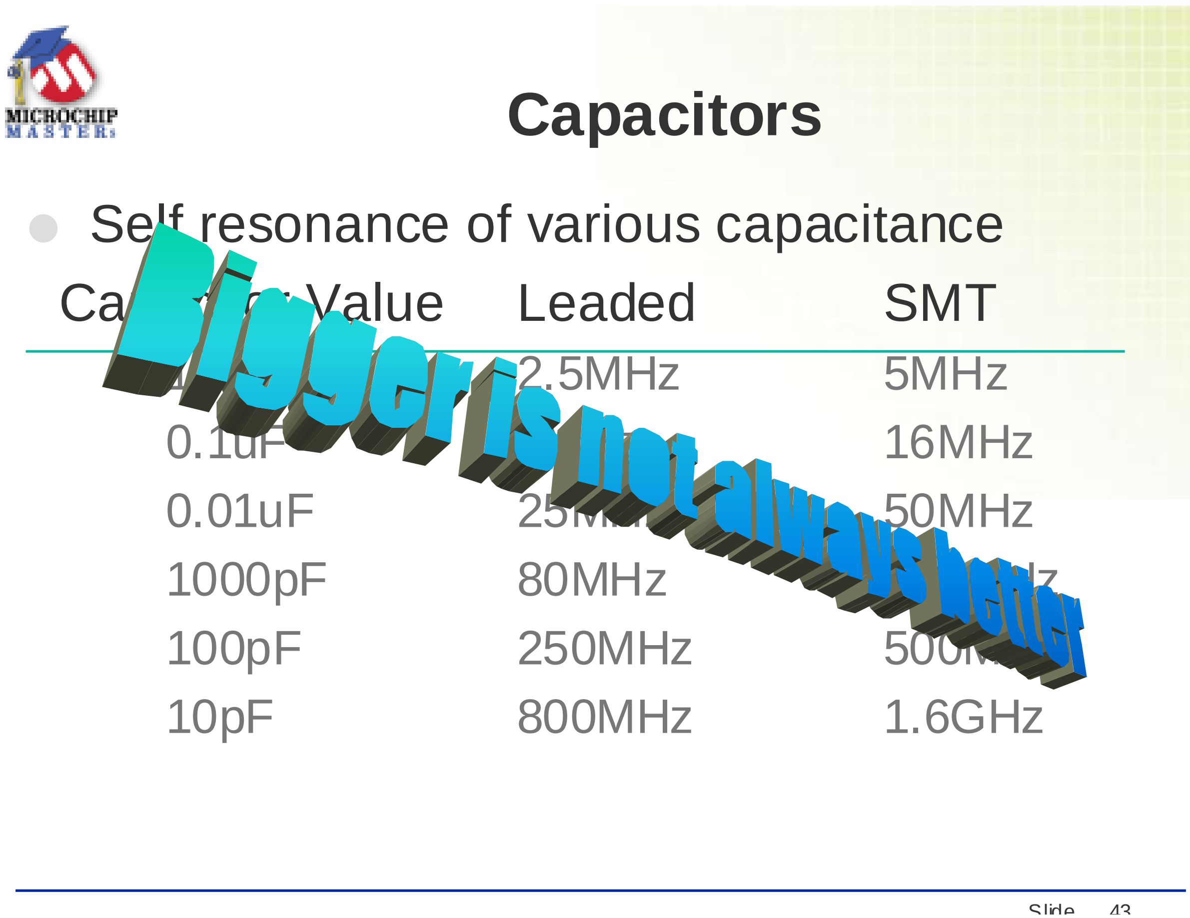
- IEC 61000-4-4 is a common system level standard for EFT/ Burst.
- IEC 61000-4-2 is a common system level standard for ESD.
- Many other standards are similar to this.
- Various systems requires various levels of protections

Summary

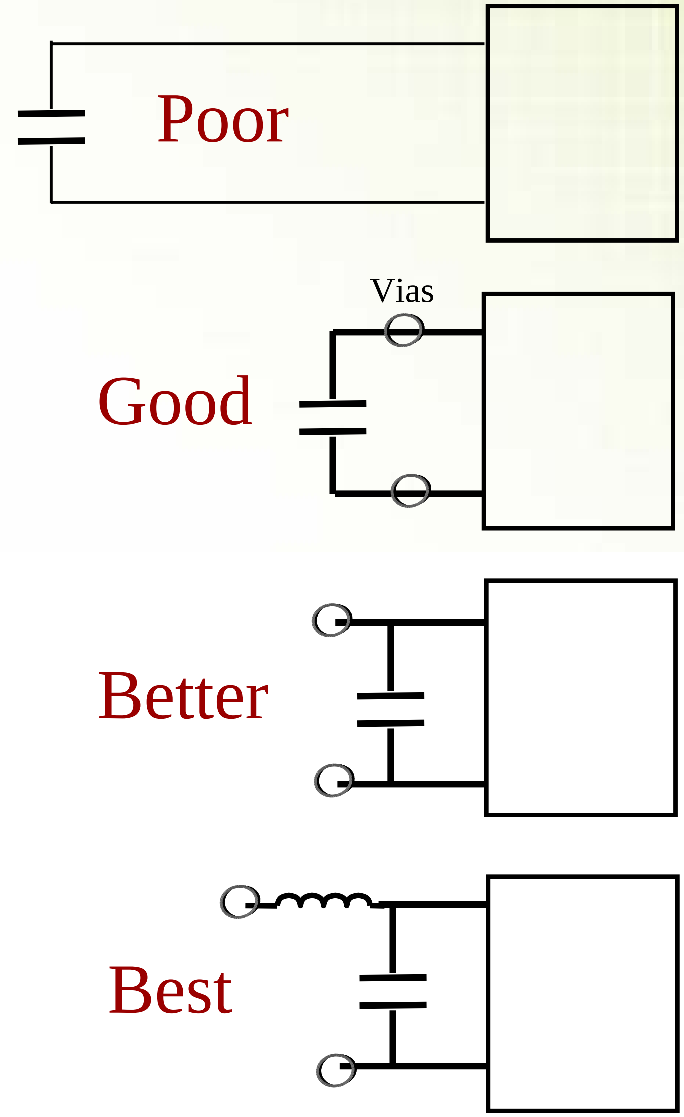
- Reviewed tips & tricks to improve the system susceptibility against EFT/ ESD
- Component selection and placement is very important.
- Looked at some important tips for microcontroller circuits
- Many fixes for EFT & ESD helps for other EMC issues

Top Fixes

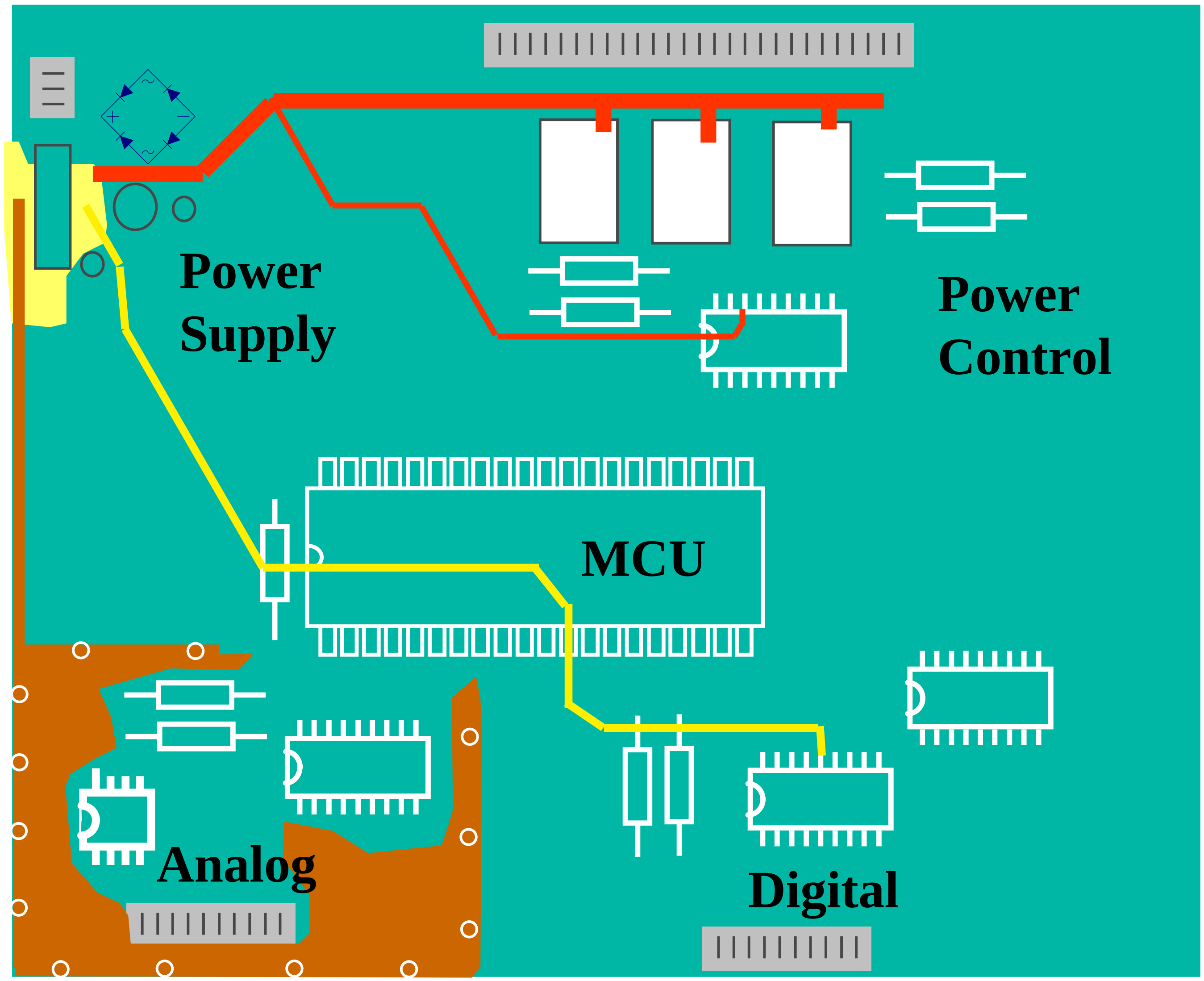
- Power supply decoupling



Ca[illegible] Value	Leaded	SMT
[illegible]	2.5MHz	5MHz
0.1uF	[illegible]	16MHz
0.01uF	[illegible]	50MHz
1000pF	80MHz	[illegible]
100pF	250MHz	[illegible]
10pF	800MHz	1.6GHz



Top Fixes



Top Fixes

- Reset Pins
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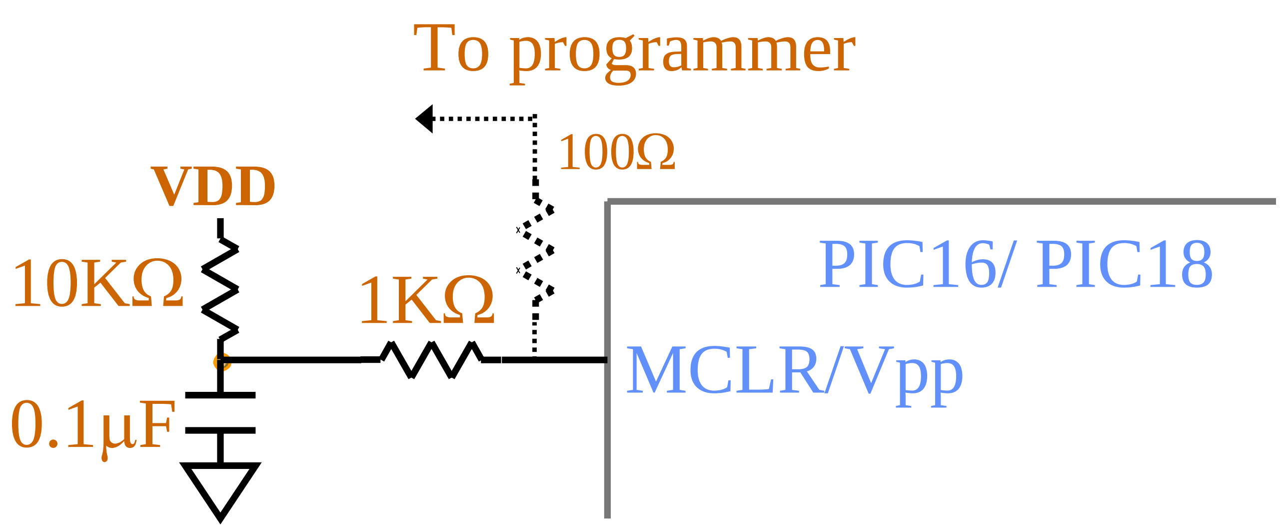

Microchip EMC resources

- EMC Newsletter
  - Available on Appliance and Automotive design center
- EMC Webinars

EMC References

- The Designer's Guide to Electromagnetic Compatibility
  by Daryl Gerke and Bill Kimmel
  EDN (www.ednmag.com)
- Noise Reduction Techniques in Electronic Systems
  by Henry W. Ott
- Printed Circuit Board Design Techniques for EMC Compliance
  by Mark I. Montrose
- Microchip MASTERs classes 720EMC, 719NRT, 649PCB, 844EMC

Standards Web Site

- Federal Communications Commission
  www.fcc.gov
- International Electrotechnical Commission
  www.iec.ch
- MIL Standards (military)
  www.mil-standards.com
- Society of Automotive Engineers
  www.sae.org