928 PGN

Managing Power, Ground, and Noise

Class Agenda

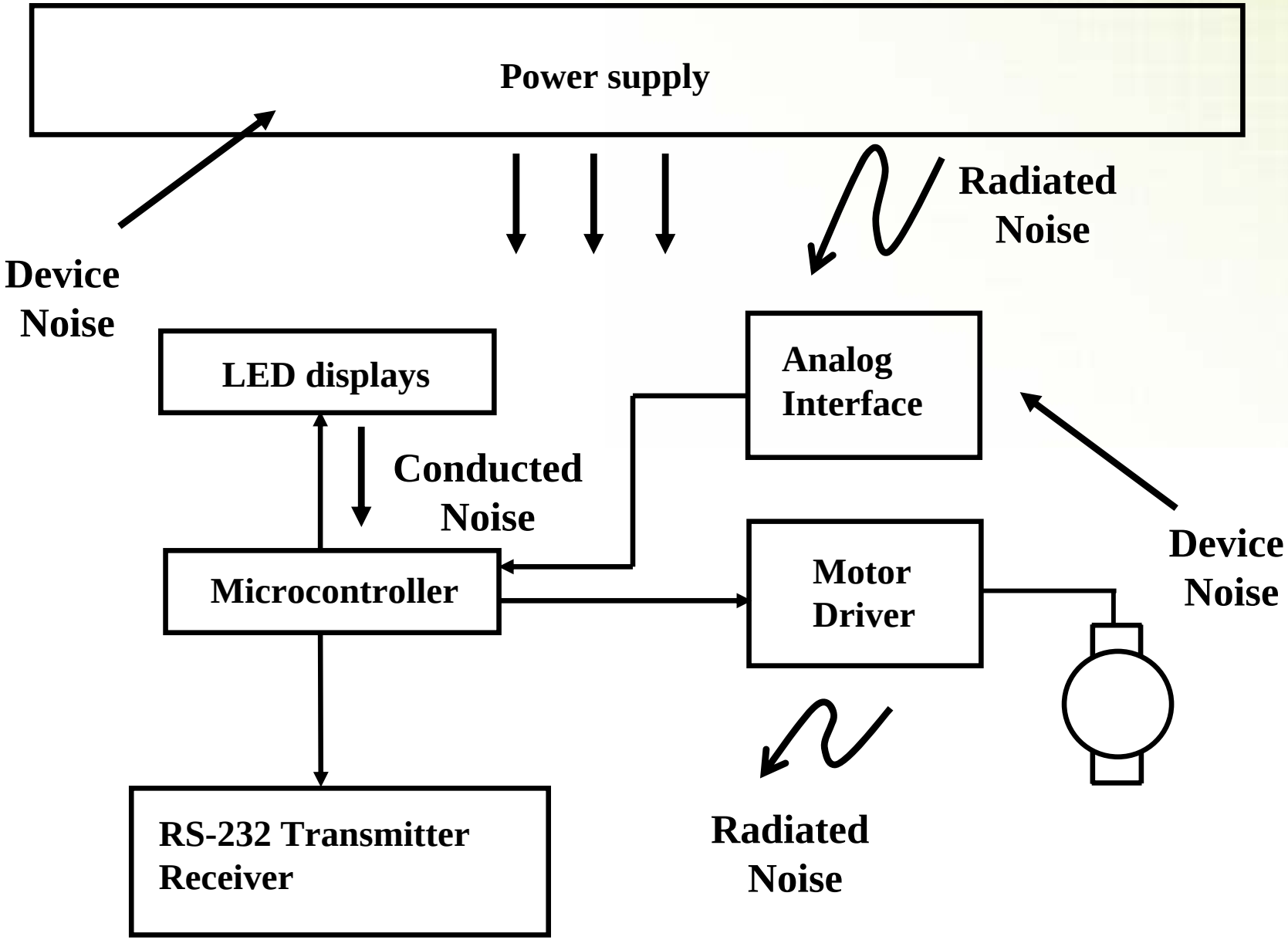
- Project Definition
- Analog Design
- Digital Design
- Pulling it all together

Definition of Project

- Has Analog and Digital Content

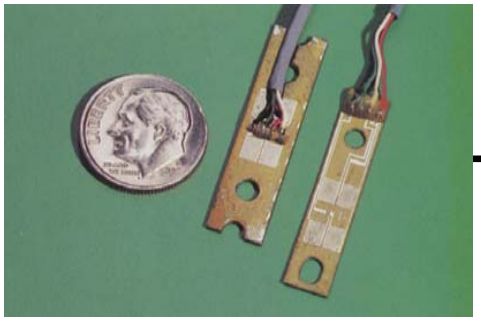
- Functions:
  - Measures Weight with Specified Load Cell
  - Displays results with LEDs
  - Communication to Computer through RS-232 Interface
  - PWM fan Motor Driver on board

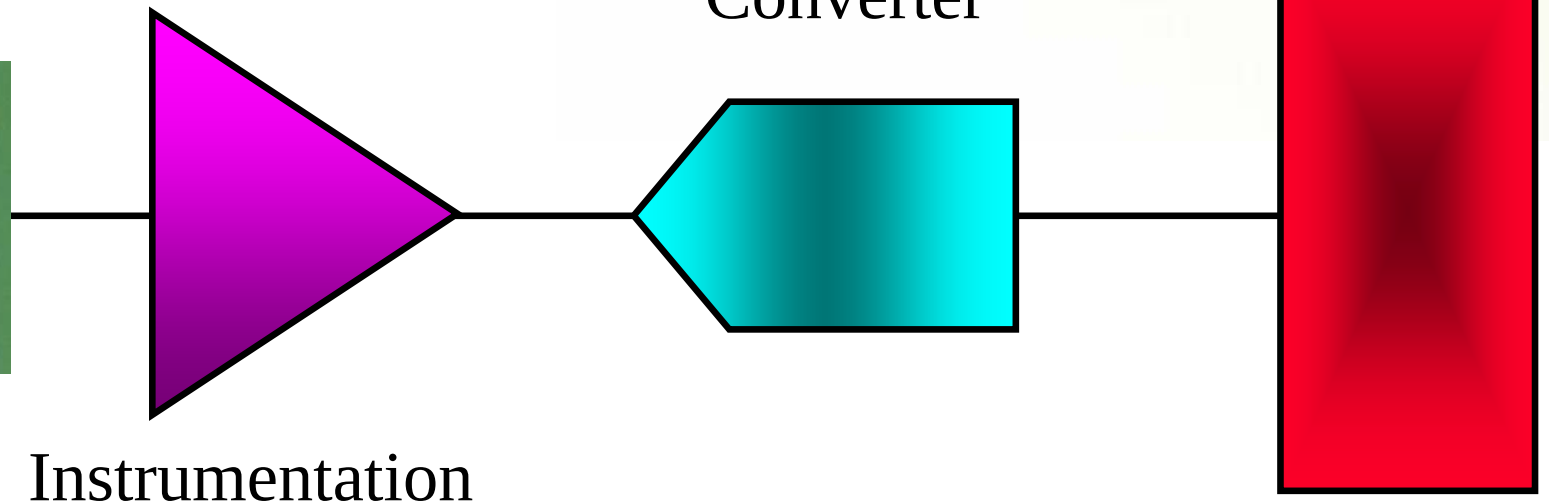
Analog/Digital System



Analog Section
Weigh Scale Circuit

Load Cell





Instrumentation Amplifier

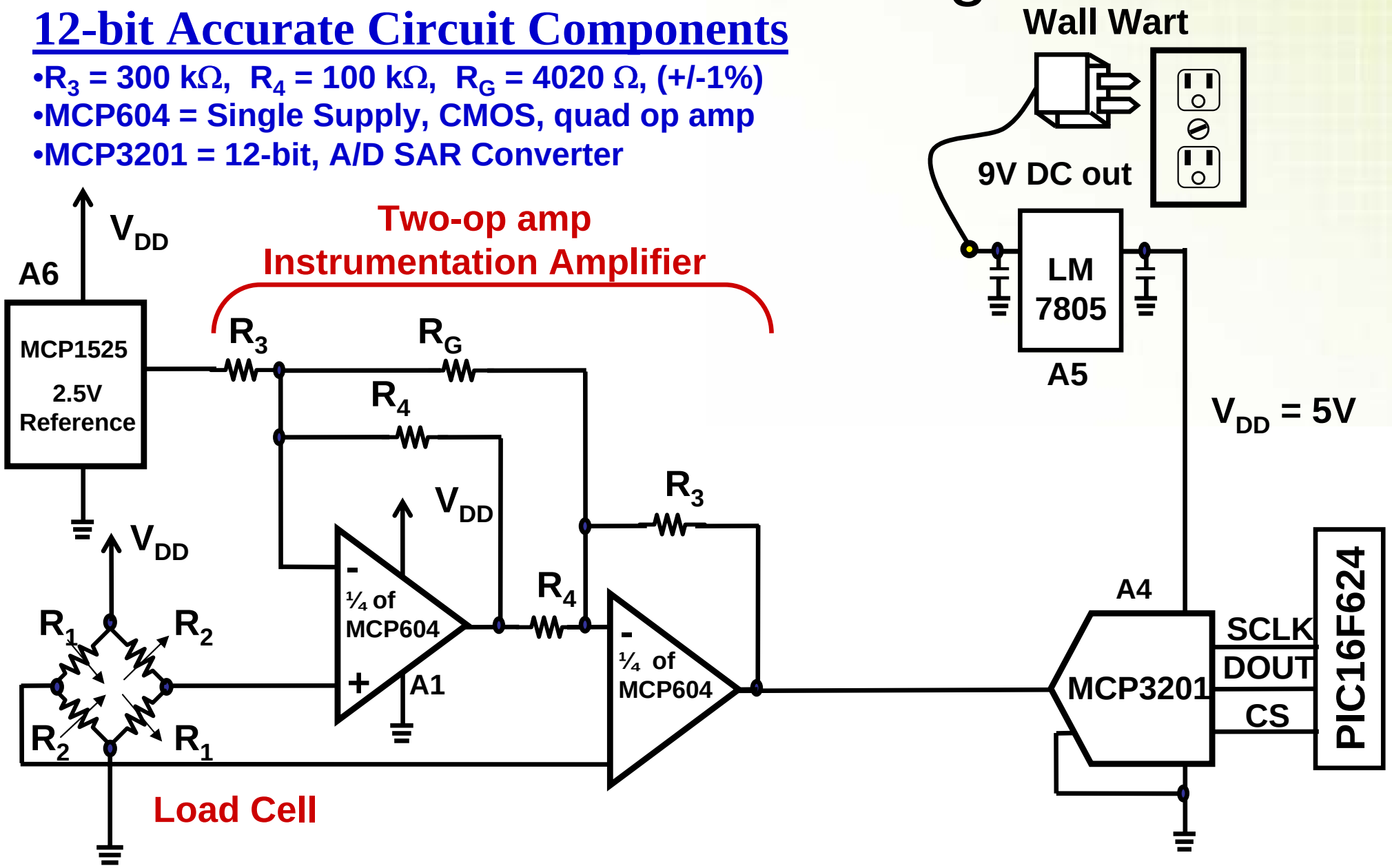
Analog-to-Digital Converter

Microcontroller

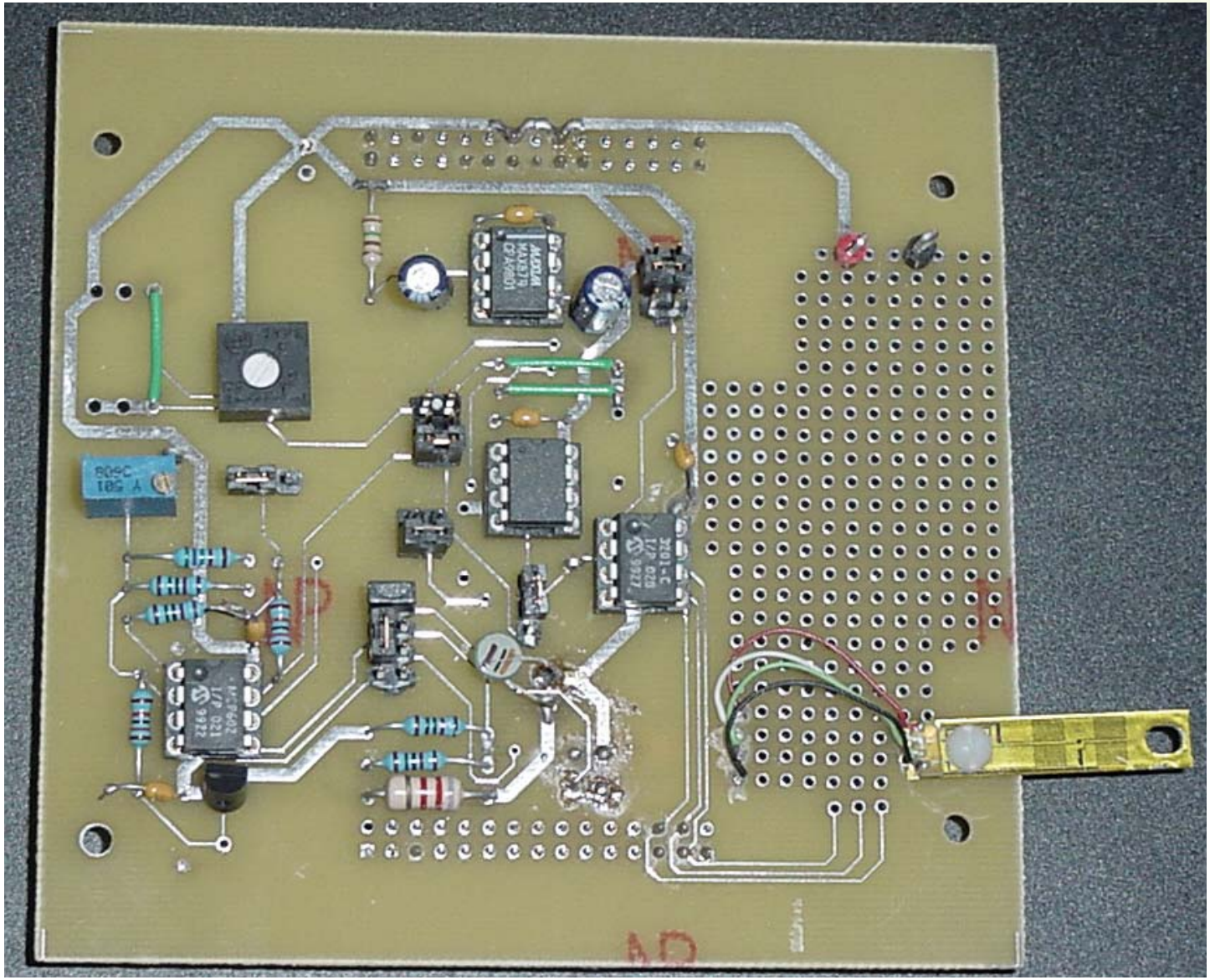
Schematic of Analog Section

12-bit Accurate Circuit Components

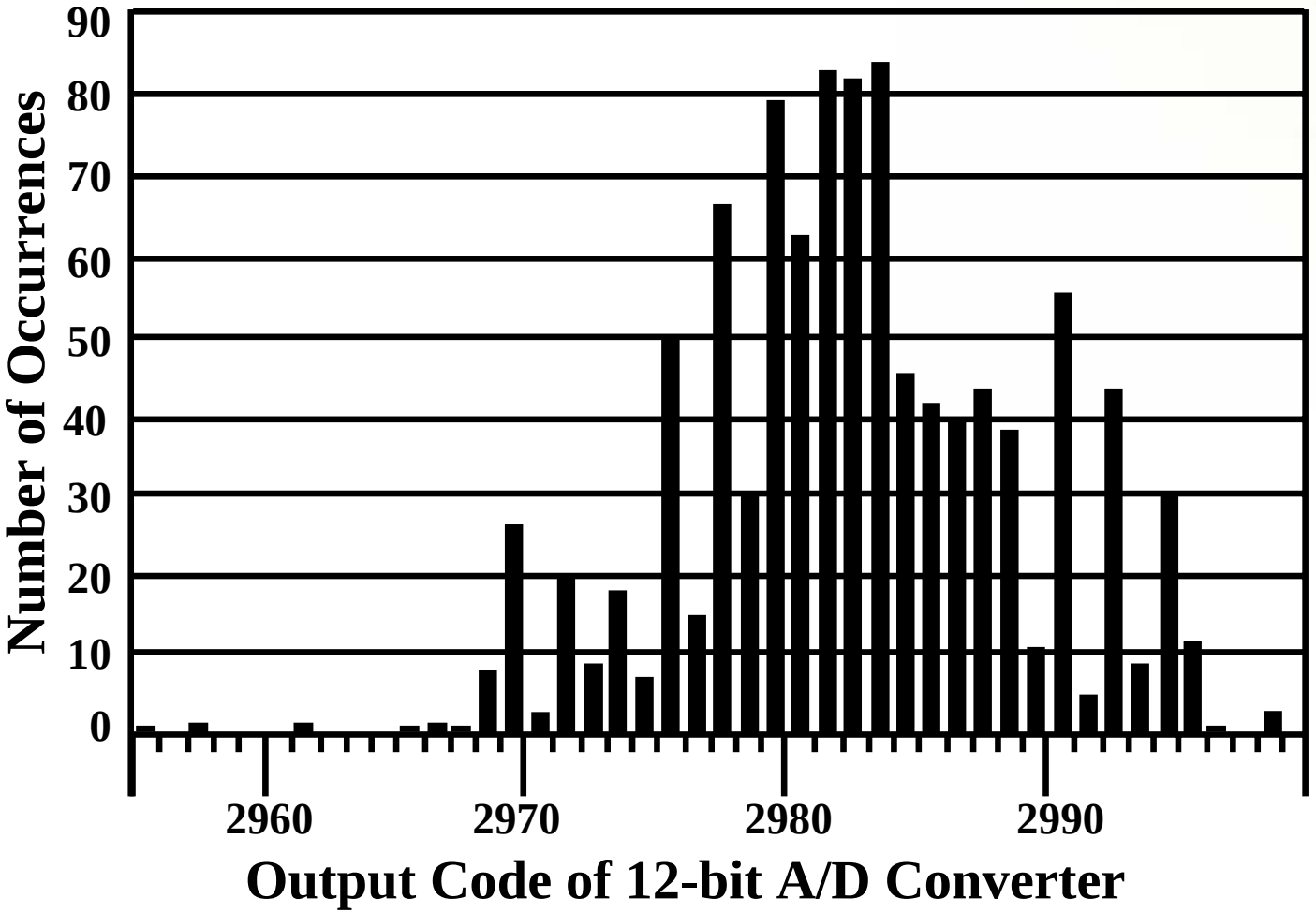
- R_3 = 300 kΩ, R_4 = 100 kΩ, R_G = 4020 Ω, (+/-1%)
- MCP604 = Single Supply, CMOS, quad op amp
- MCP3201 = 12-bit, A/D SAR Converter



Analog Layout #1



Analog Board : First Pass Test Results



Code Width of Noise = 44

(total samples = 1024)

How many bits?

6.54-bits

Low-Noise Design

- Device Noise – Created by the devices
  - Resistors – Reduce Values were possible
  - Op amps – Use Lower-Noise Amplifiers
  - Power Supply – Replace or Filter Switching Devices

- Emitted Noise – Externally Injected
  - Layout – Keep analog and digital Separate
  - Environment – Shield or change orientation

Device Noise

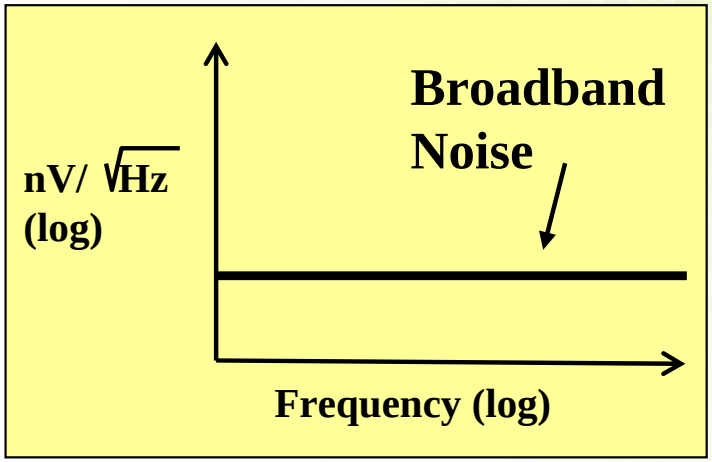
- Resistors
  - Johnson or Thermal Noise
  - $V_{RN} = \sqrt{4KTR(BW)}$ {Vrms}

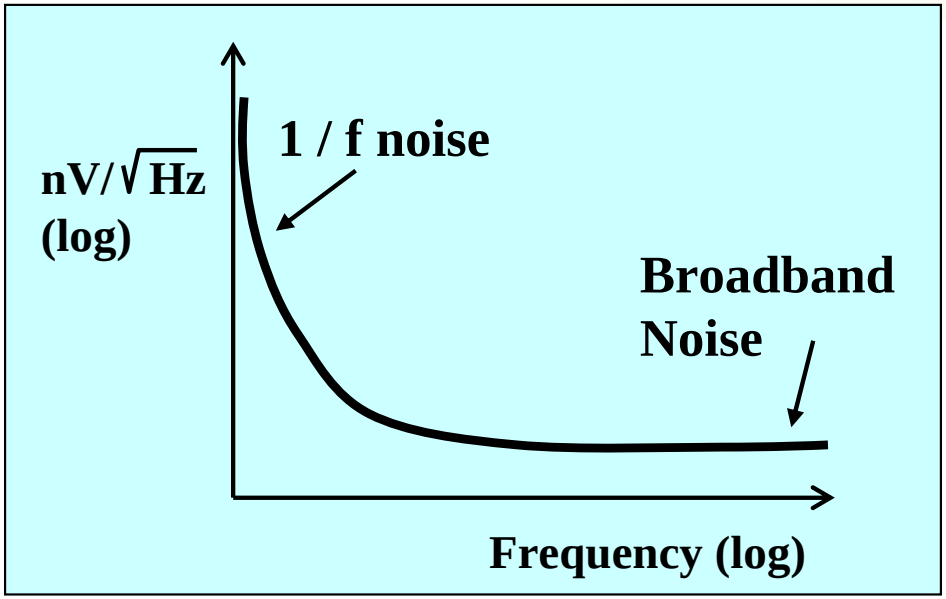
    K = Boltzman's Constant = 1.38e $^{-23}$ JK^{-1}

    T = Temperature in Kelvin

    R = Resistance in Ohms

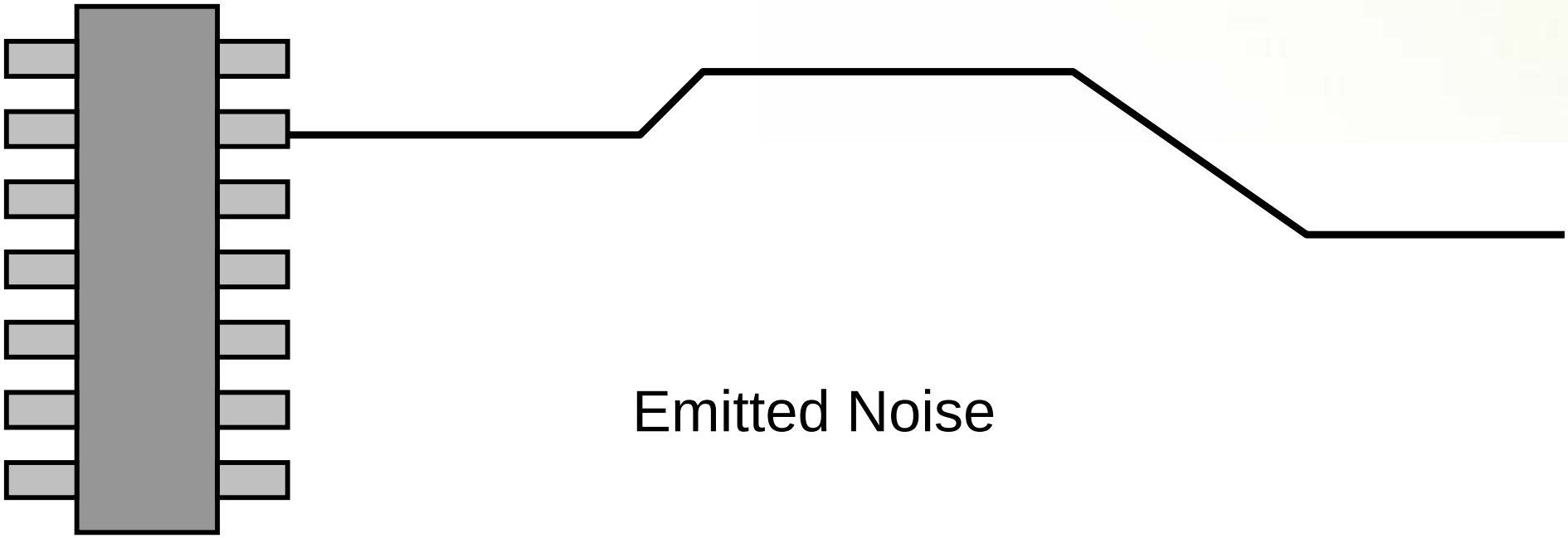
    (BW) = Noise Bandwidth in Hz
    - 1 kΩ = 4 nV / √ **Hz**
- Amplifiers
  - MCP604 Specification - 29nV/ √ **Hz** @ 10 kHz
  - MCP6024 Specification - 10nV/ √ **Hz** @ 10 kHz





Long Traces: Antenna

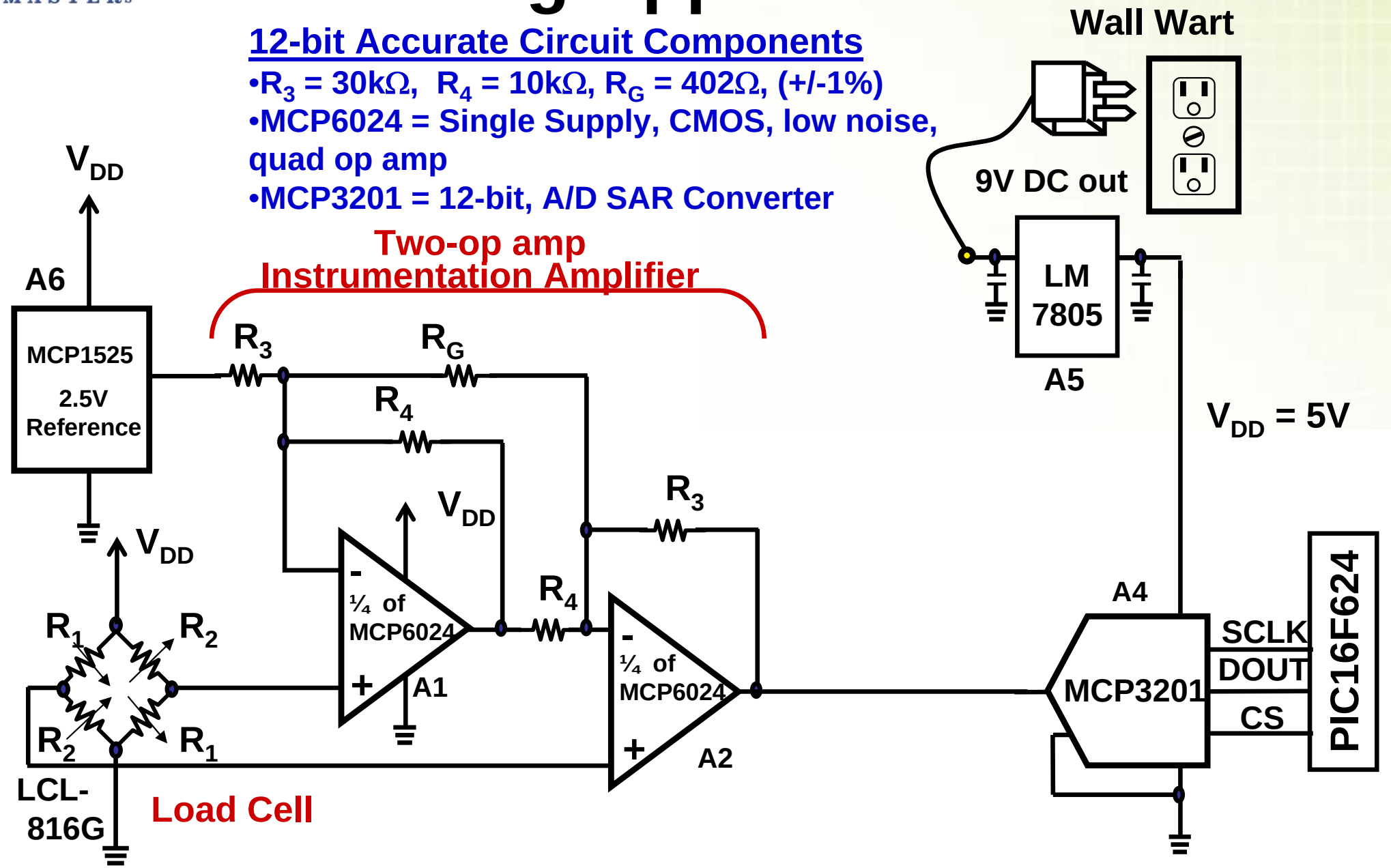
- Trace going into 10-bit or 12-bit ADC input is longer than a few inches



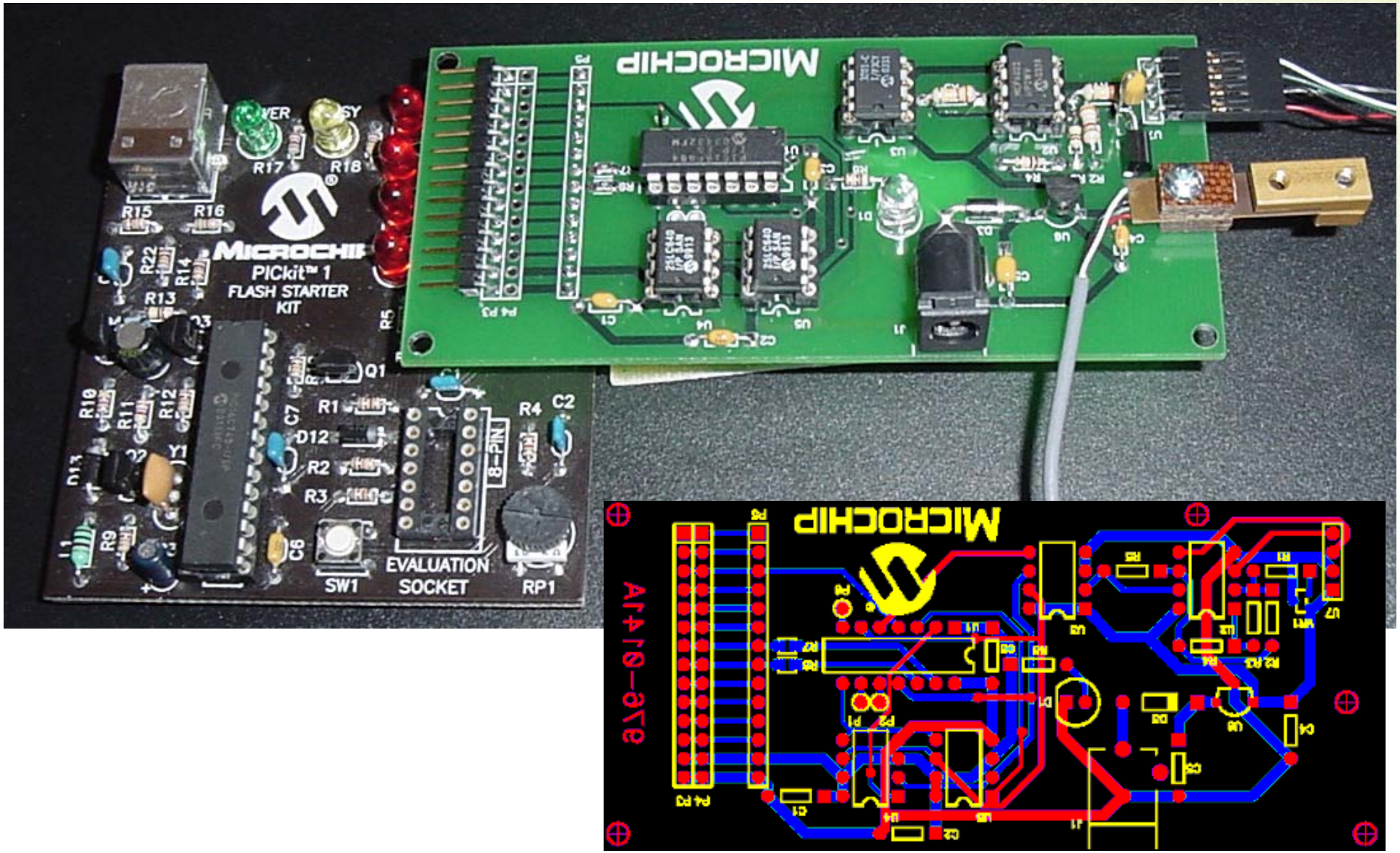
Analog Application Circuit

12-bit Accurate Circuit Components

- R_3 = 30kΩ, R_4 = 10kΩ, R_G = 402Ω, (+/-1%)
- MCP6024 = Single Supply, CMOS, low noise, quad op amp
- MCP3201 = 12-bit, A/D SAR Converter



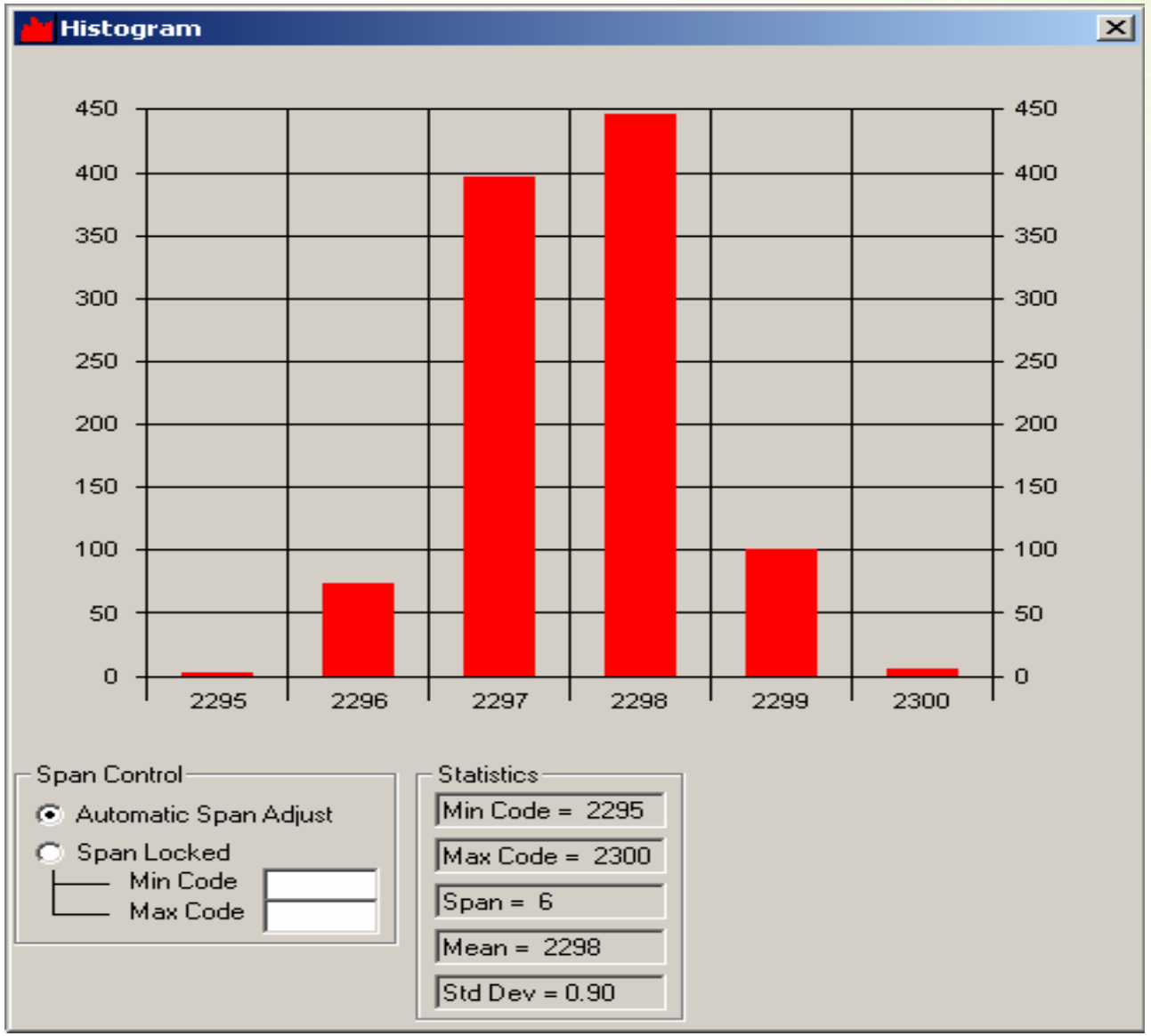
Analog Layout #2



Analog Application Board #2 Test Results

Code Width of Noise = 6

(total samples = 1024)



How many bits?

9.42-bits

Low-Noise Design

- Device Noise - Created by the devices
  - Resistors - Reduce Values were possible
  - Op amps - Use Lower-Noise Amplifiers
  - Power Supply – Replace or Filter Switching Devices
- Emitted Noise - Externally Injected
  - Layout - Keep analog and digital Separate
  - Environment - Shield or change orientation
- Conducted Noise - In the Circuit Traces
  - Use a Continuous Ground Plane
  - Filter Signal traces
  - Filter Supply traces

Conducted Noise

- Ground and Power
  - 50 Hz or 60 Hz
  - Ground and Supply Current Return Paths
- Solution: By-pass, Choke supply line

- Signal Path
  - Digital Switching
  - Noise generated by previous device
- Solution: Analog Filter, Re-layout

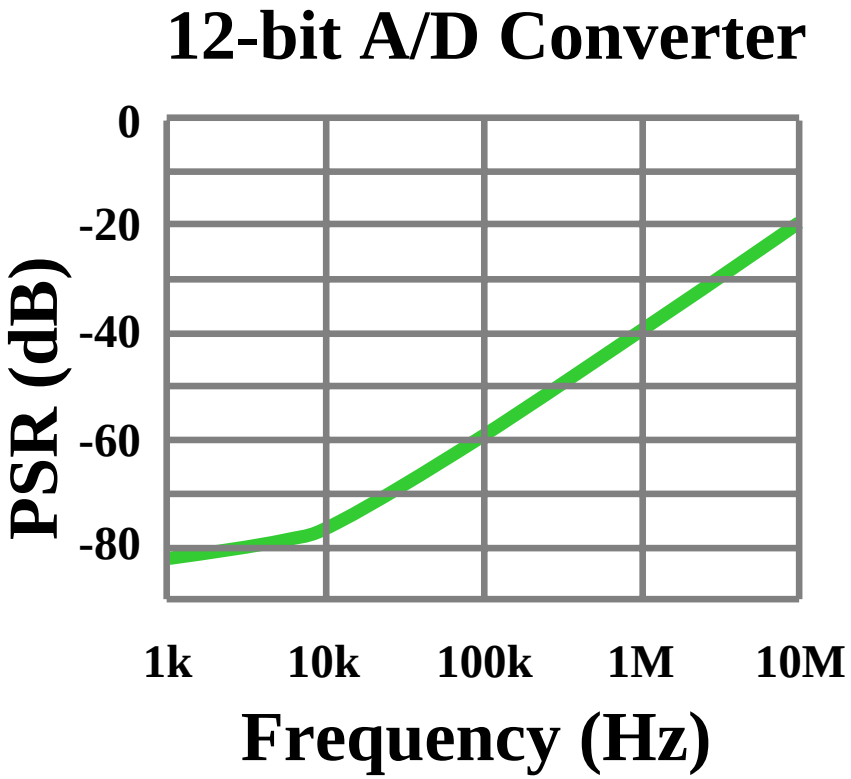
Discontinuous Ground Plane

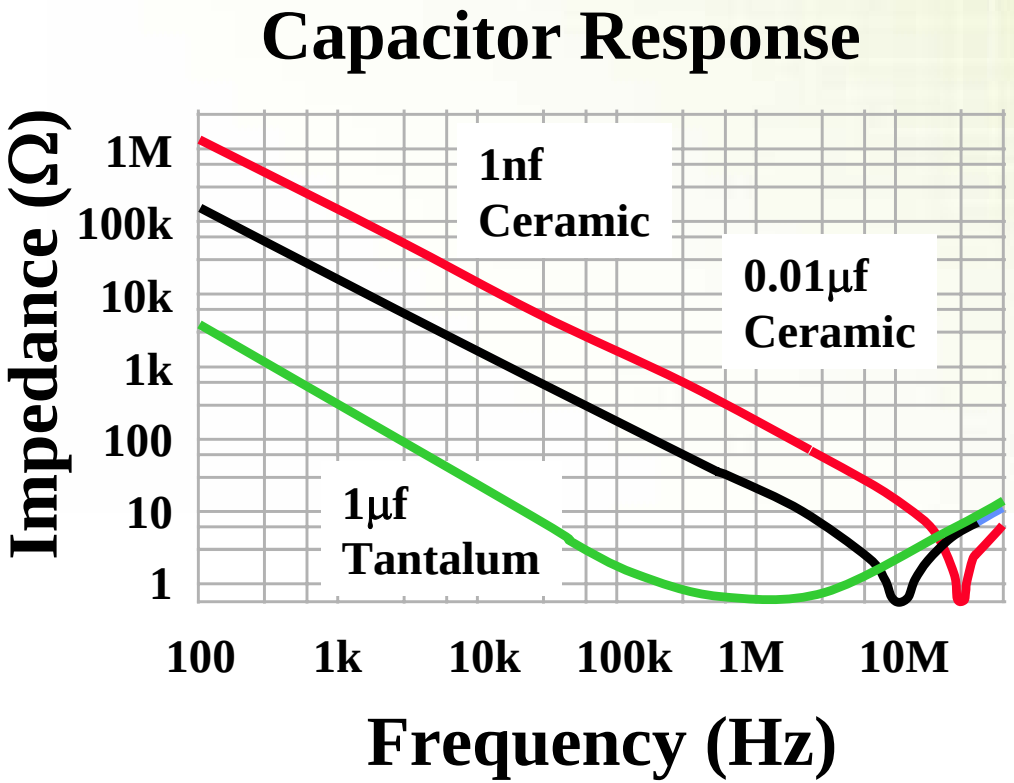
- Interrupted Ground Plane on the Back Side of the Board

Bypass Capacitors
No Black Magic Here

- As close to the device as possible
- Analog Circuits
  - Reduce power supply noise
  - Enhance Chip's Power Supply Rejection (PSR)
- Digital Circuits
  - Low Frequency system clocks have high frequency glitches
  -

Bypass Capacitors for Analog

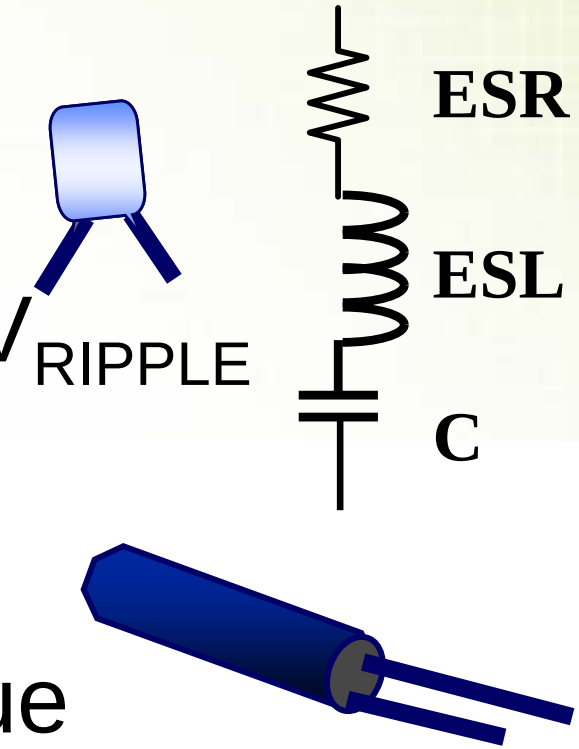




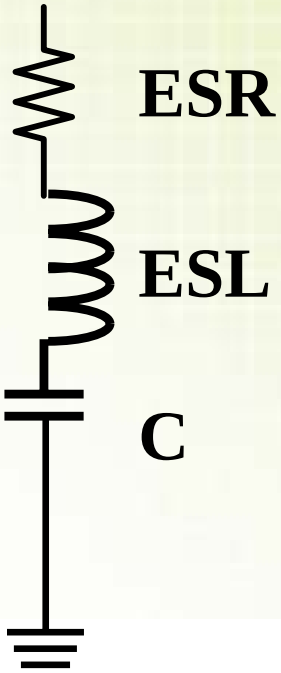
- Assume: Supply = 5V ± 20 mV (all white noise)
  - To bring the noise to ± 1/4 LSB (± 0.61 mV)
  - PSR < – 30.3 dB

Bypass Capacitors for Digital

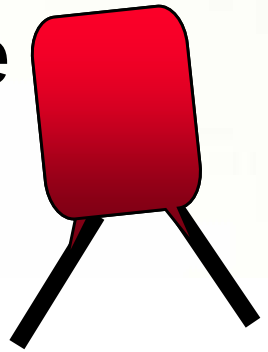
- Determine noise frequency
  $f_{noise} = 1/(2 * t_{rise})$
- Determine max. ripple voltage V_{RIPPLE}
- Approximate surge current
  $I_{SURGE} = I_{AVE} * f_{noise} / f_{MICRO}$
- Calculate bypass capacitor value
  $C_{BYPASS} = I_{SURGE} / (2 * \pi * f_{noise} * V_{RIPPLE})$



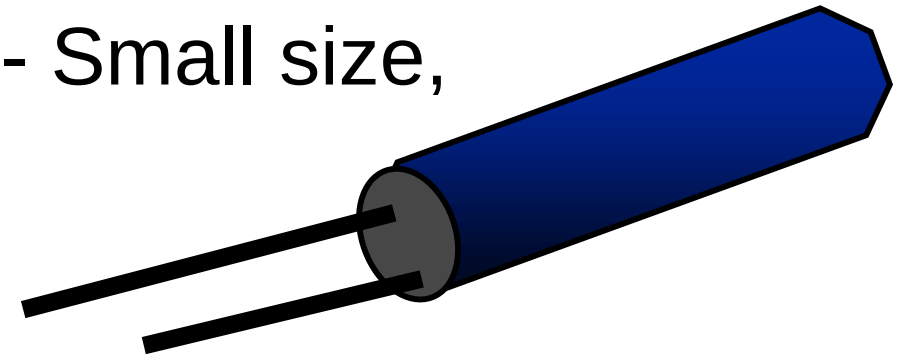
Bypass Capacitor Types



- Filters Noise at High Frequency
  - Ceramic - Small Case size, Inexpensive, Good Stability, Low Inductance
    - NPO
    - X7R

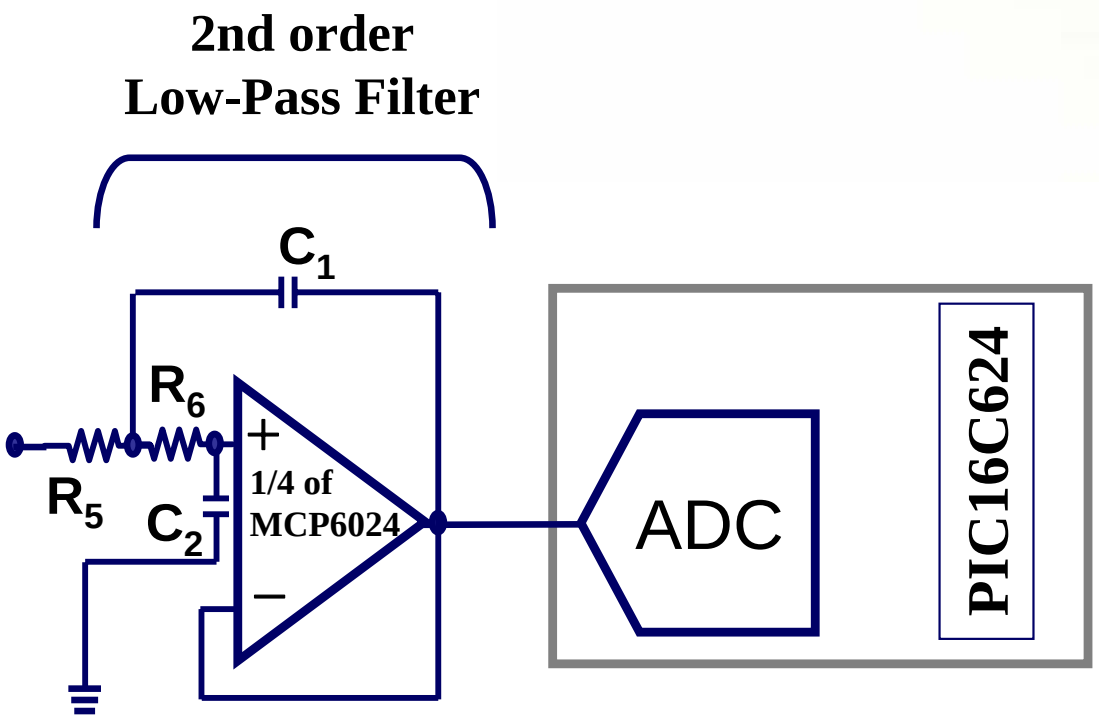


- Acts as a Charge Reservoir for Fast Changes
  - Tantalum Electrolytic - Small size, Large Values, Medium Inductance

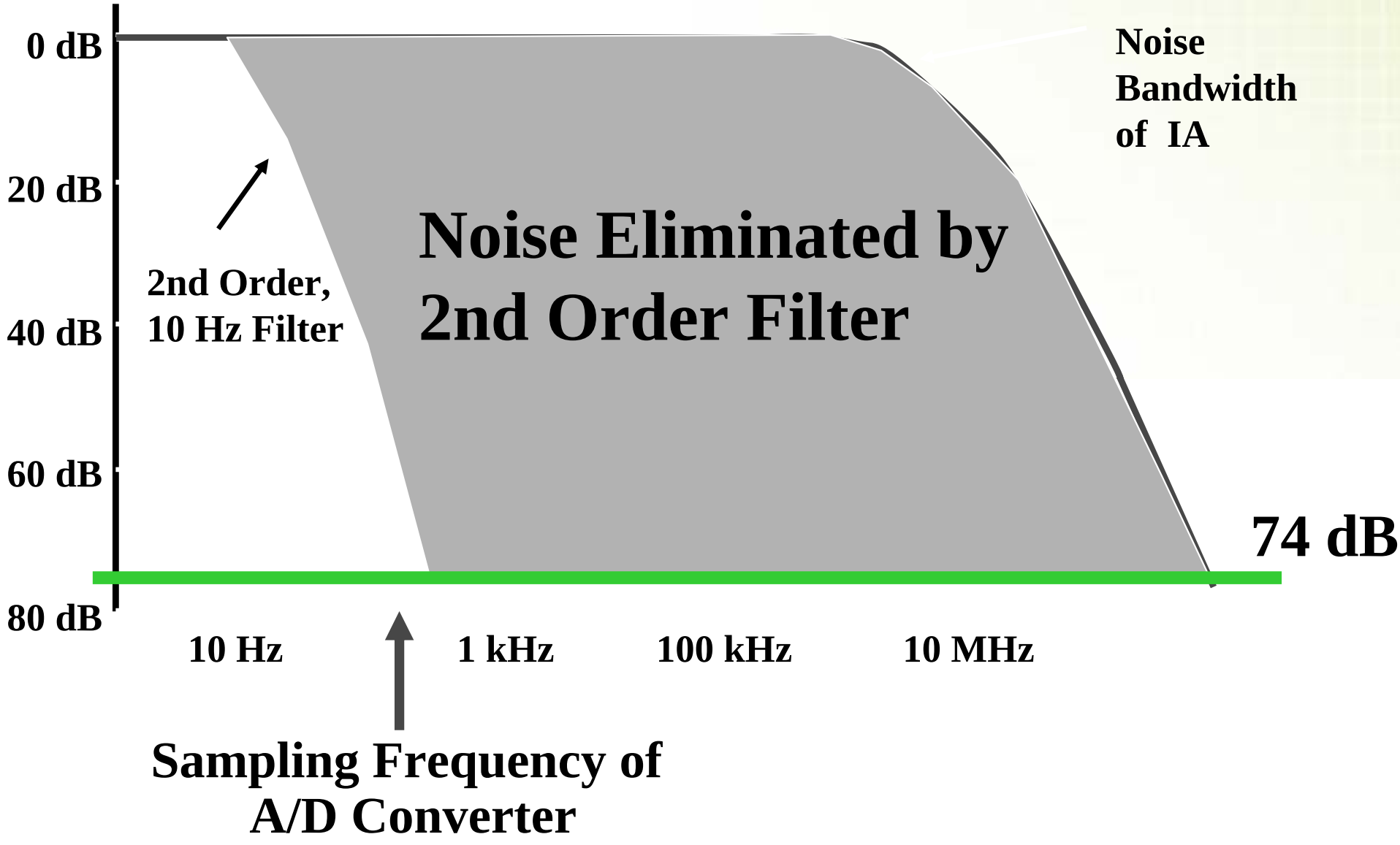


Low-Pass Filter Missing

- Add anti-aliasing (or Low-Pass) Filter at the input of the ADC



Noise Reduction with Low-Pass Analog Filter



Analog Application Circuit

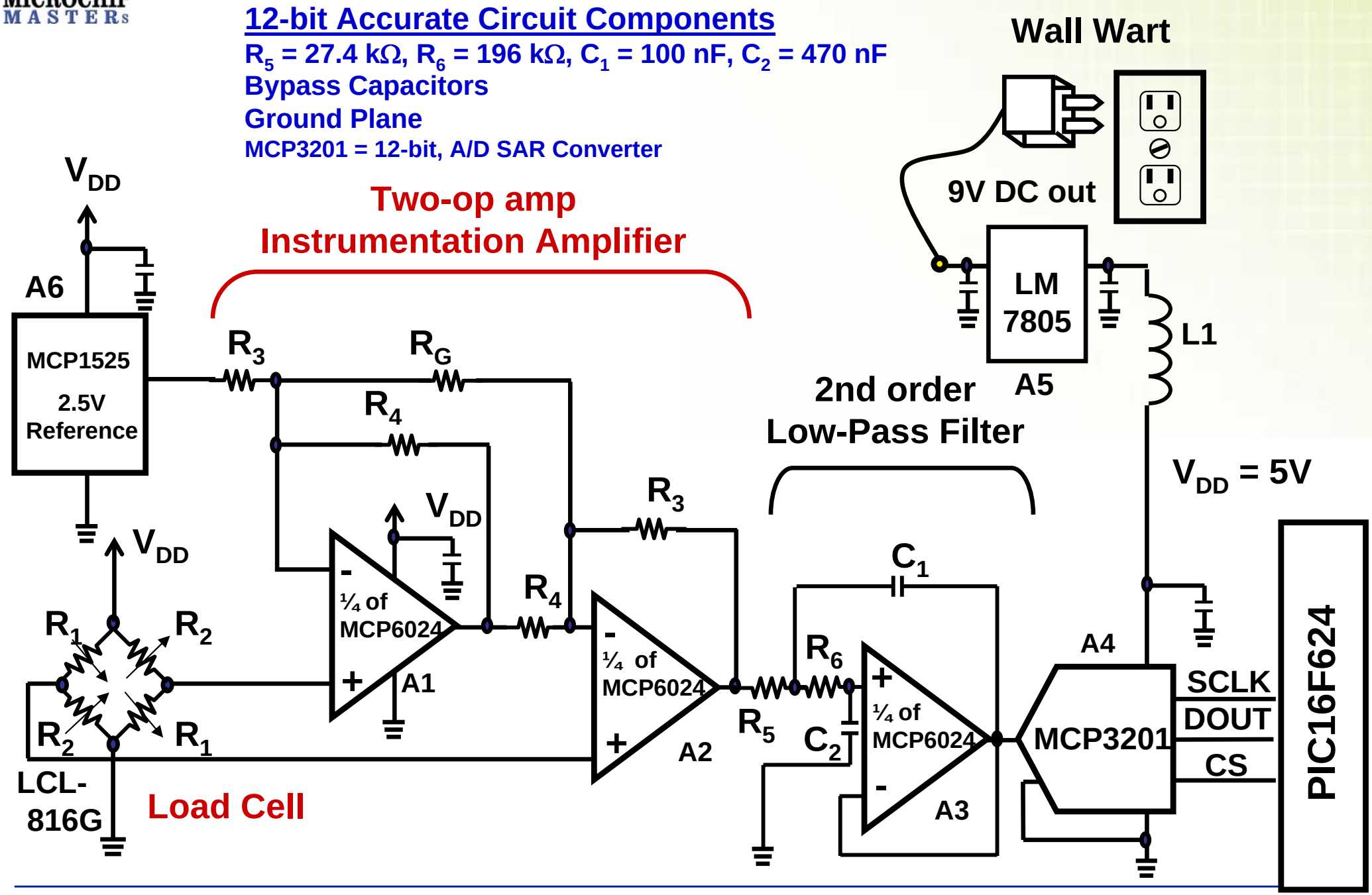
12-bit Accurate Circuit Components

R_5 = 27.4 kΩ, R_6 = 196 kΩ, C_1 = 100 nF, C_2 = 470 nF

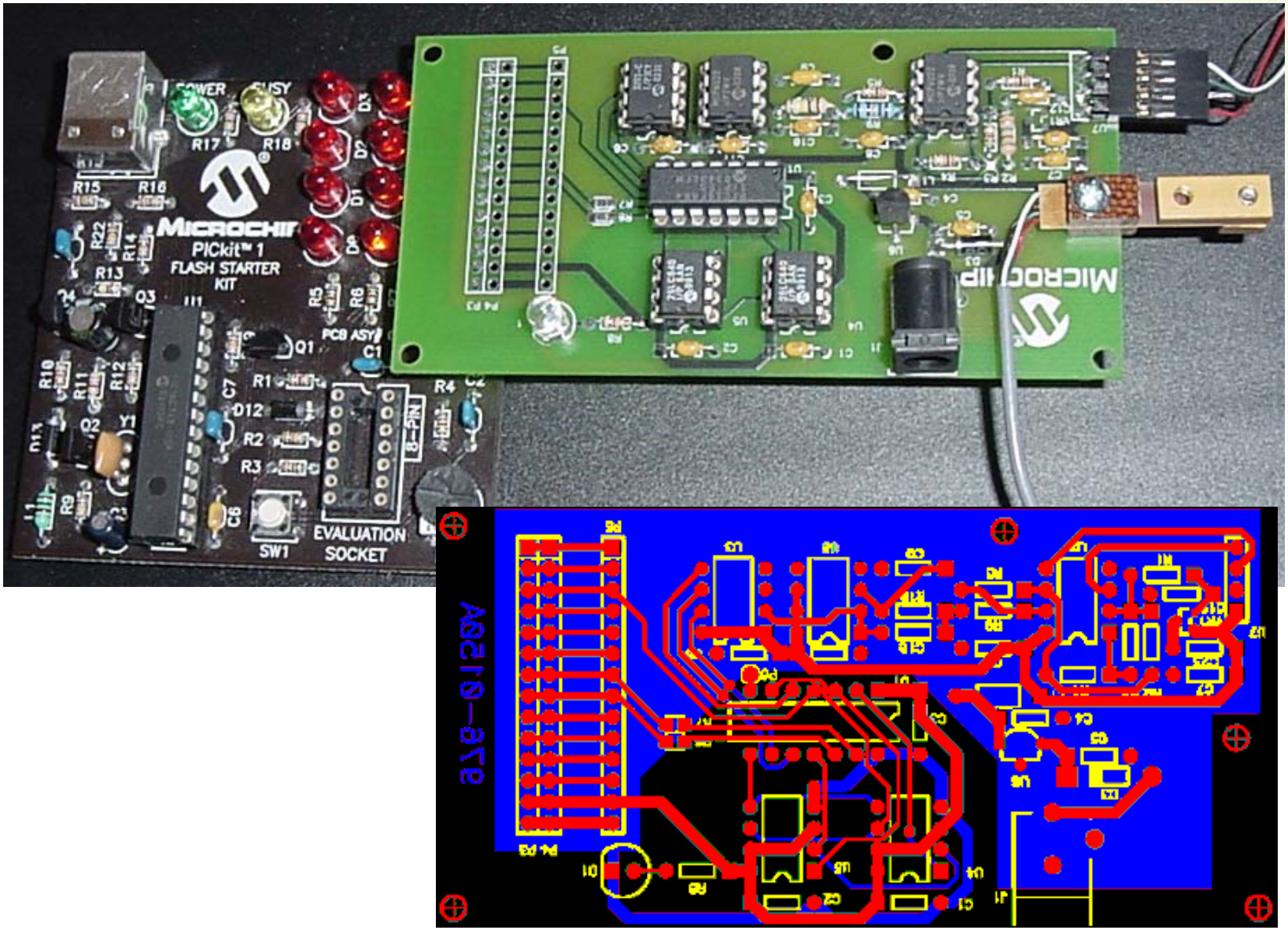
Bypass Capacitors

Ground Plane

MCP3201 = 12-bit, A/D SAR Converter



Analog Layout #3



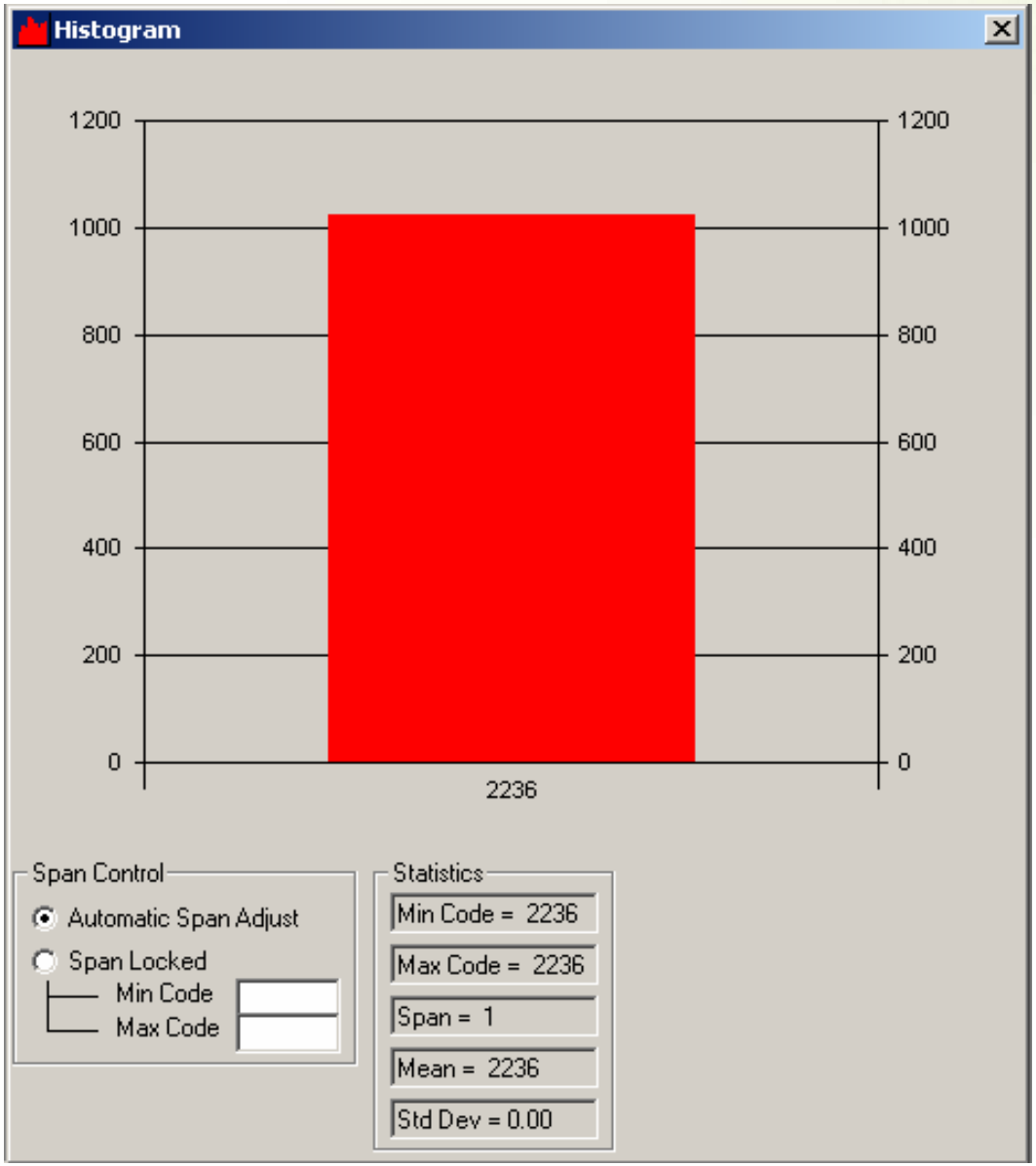
Analog Application Board #3 Test Results

Code Width of Noise = 1

(total samples = 1024)

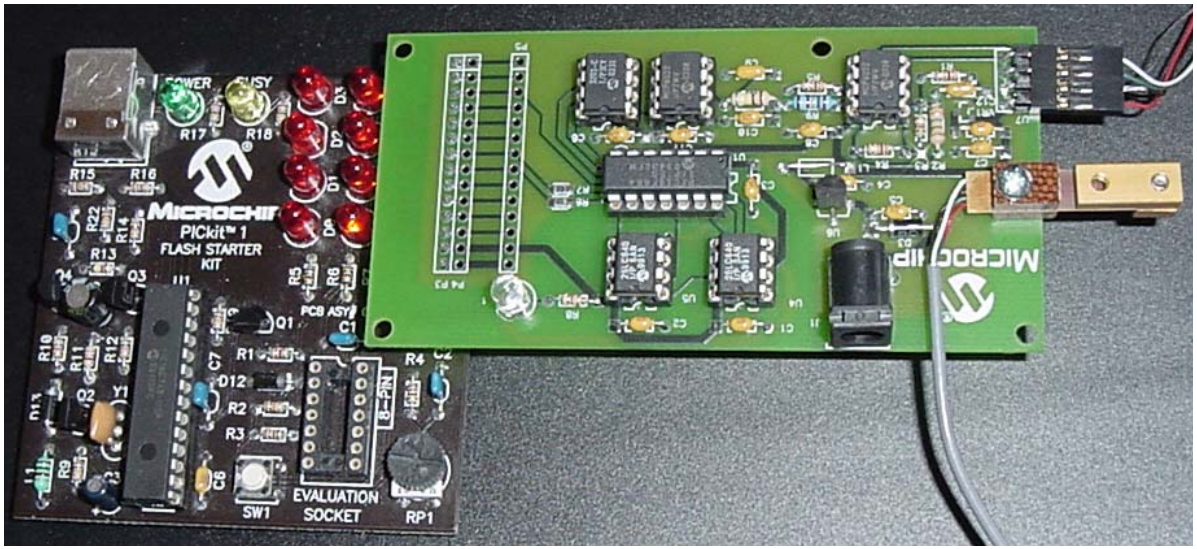
How many bits?

12-bits

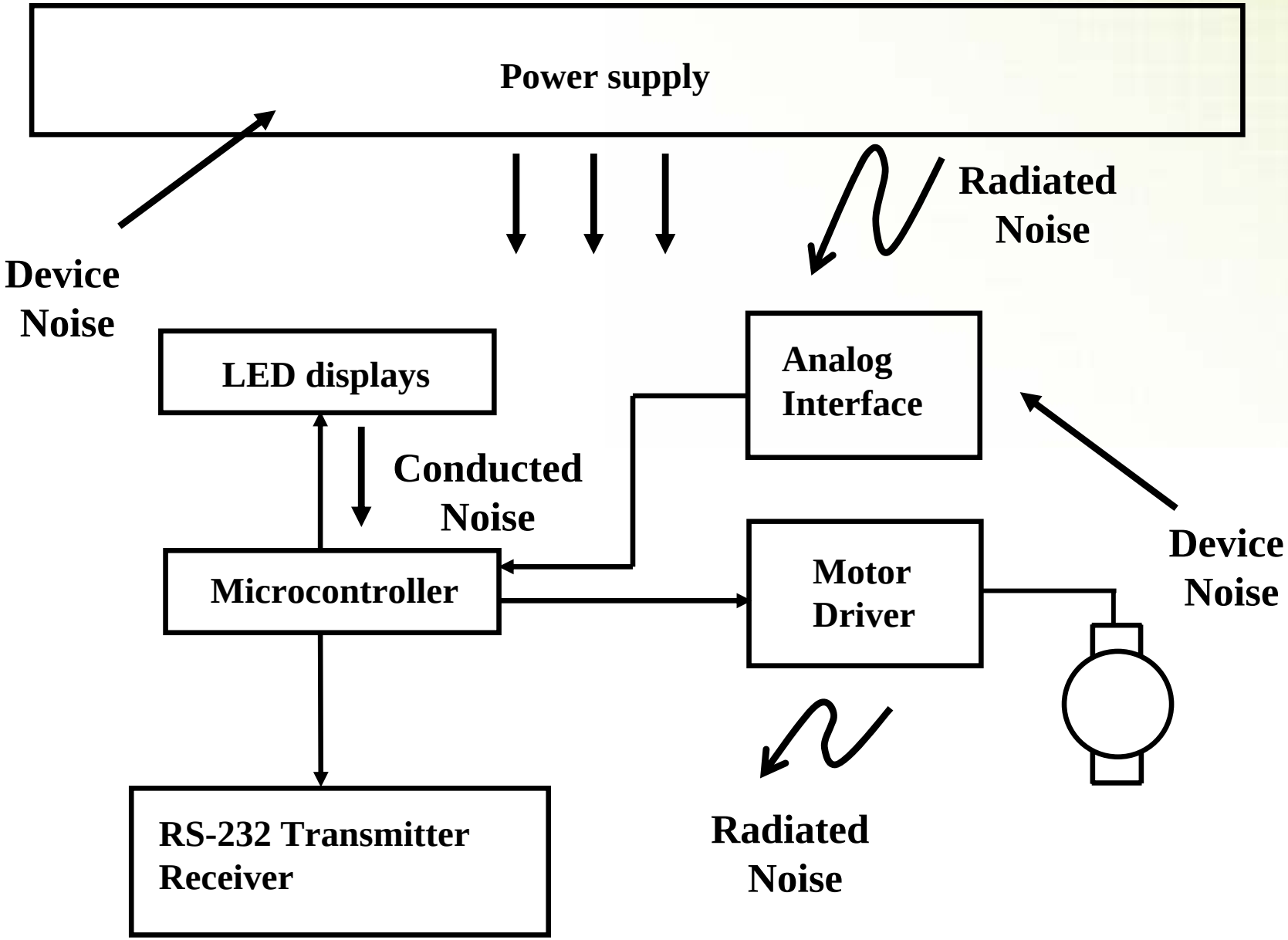


Analog Design Conclusions

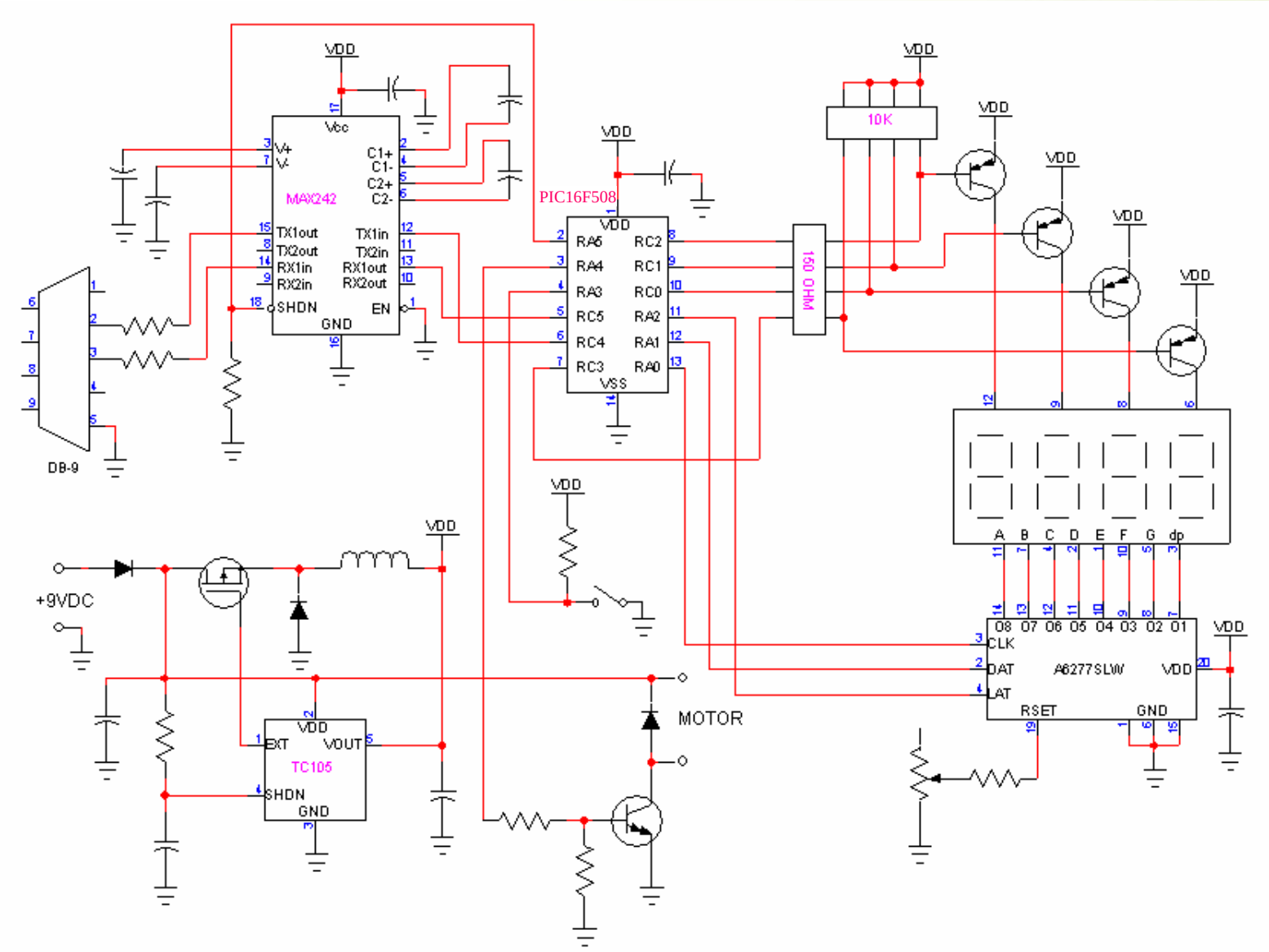
- Use
  - Low-noise devices
  - Uninterrupted ground plane
  - Low-pass anti-aliasing filter
- By-pass all devices
  - Place the capacitors as close to the power pins of the devices as possible.



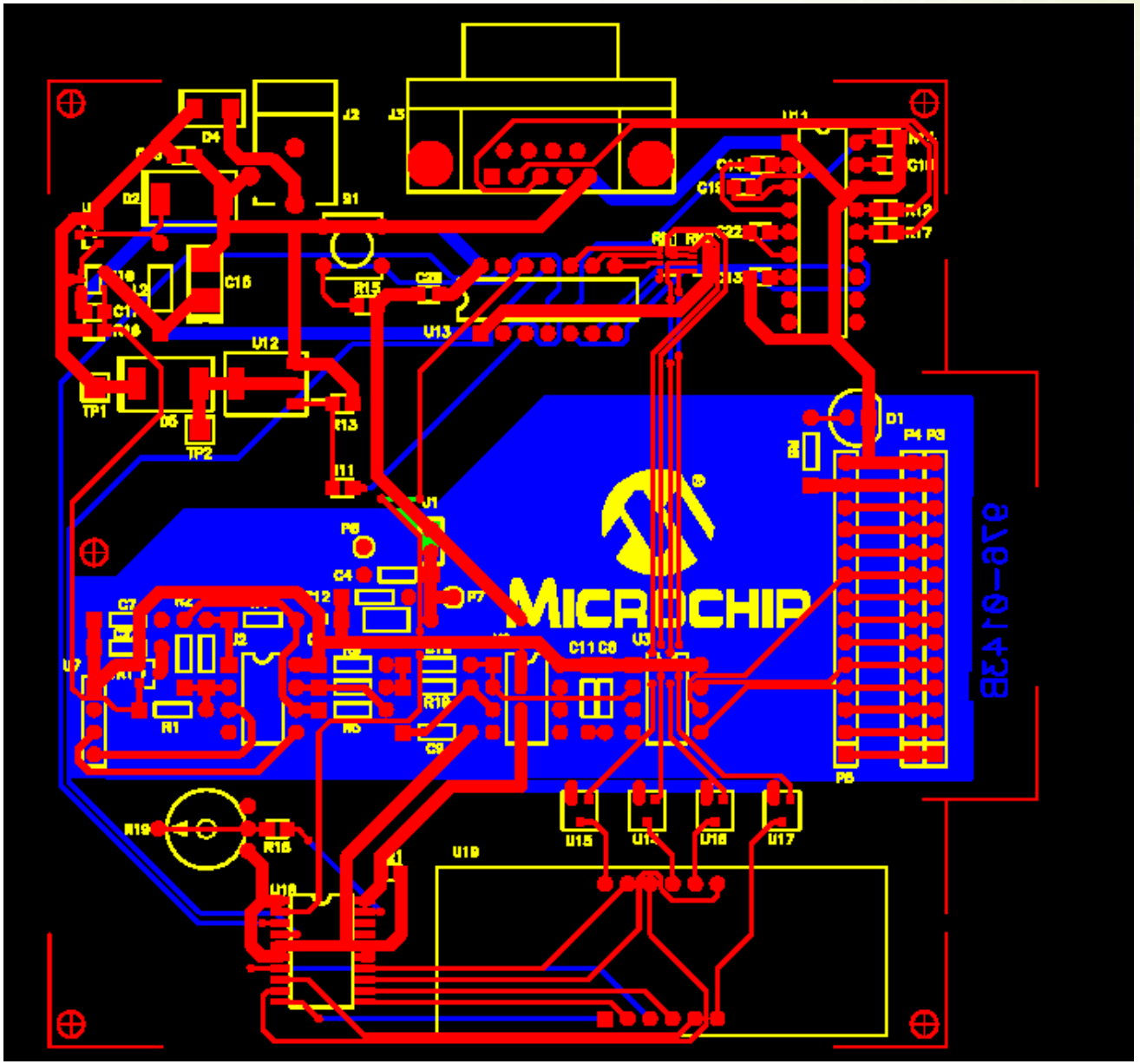
Adding the Digital System



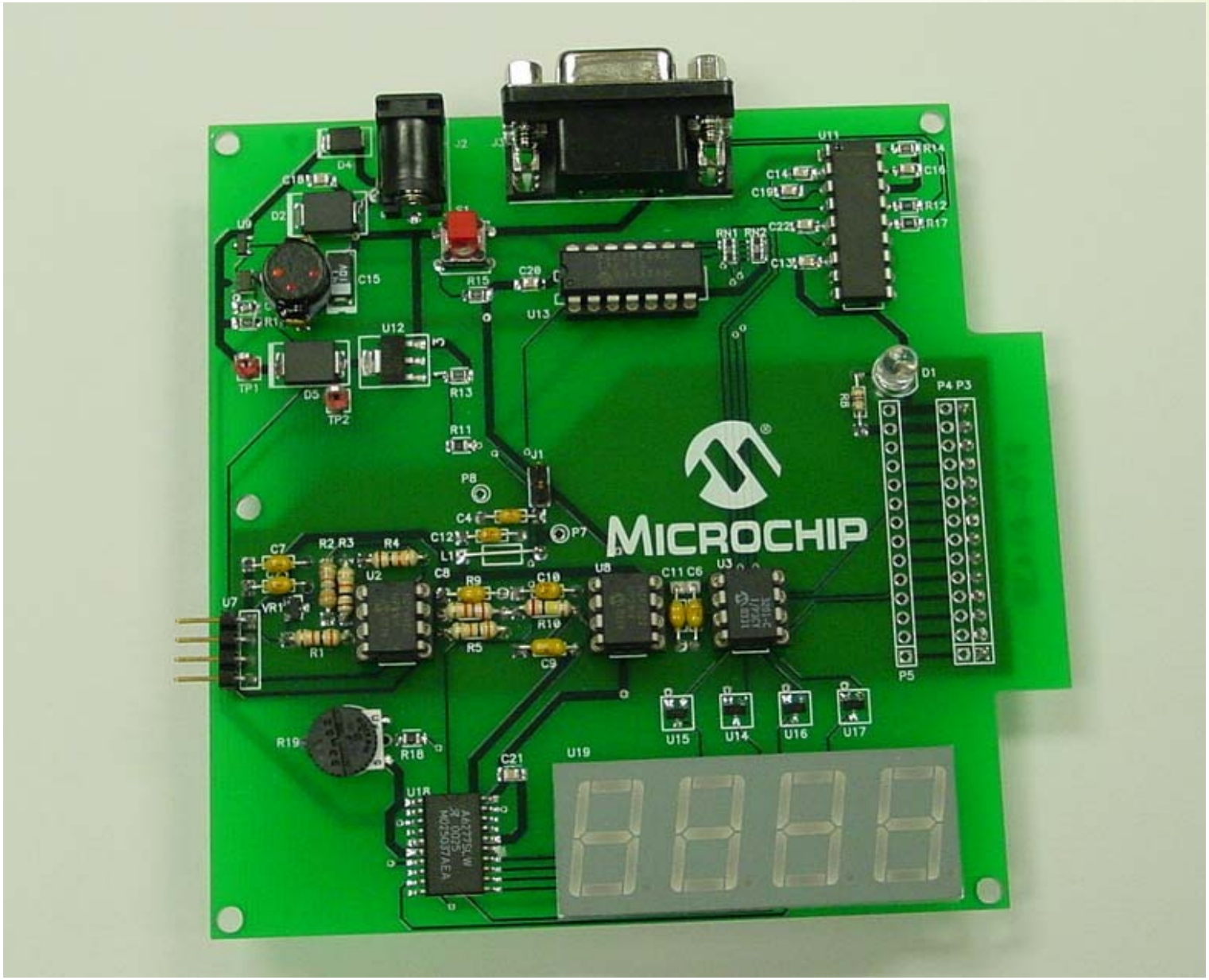
Schematic of the Digital Section



First Pass Combined Layout



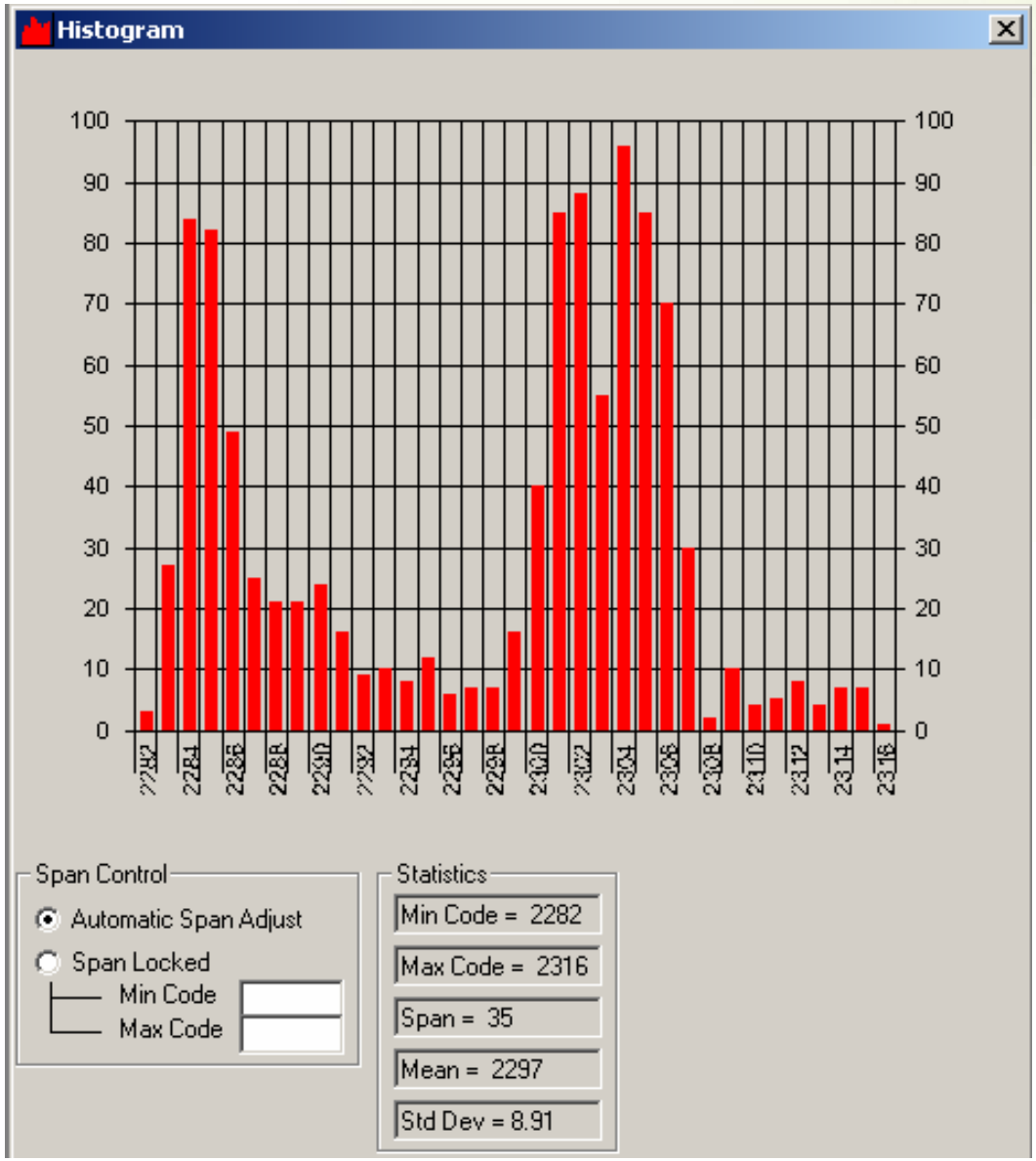
Application Board #4



Combined Analog/Digital Test-Board Results

Code Width of Noise = 35

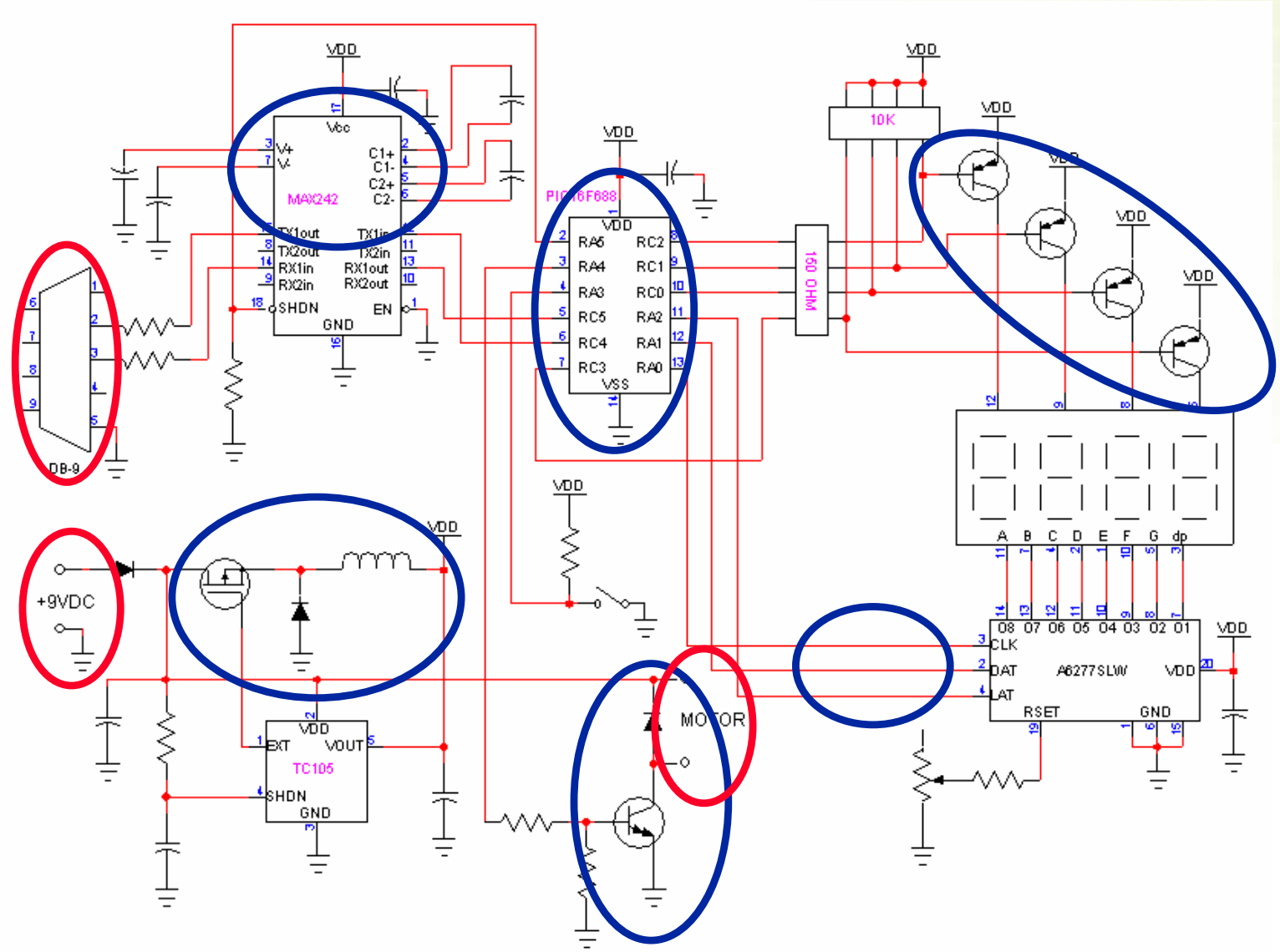
(total samples = 1024)



Identify the Noise Sources

- Device and Conducted noise sources
  - Switching noise generated by fast rise time signals
  - Switching noise generated by high voltage/current switching
- External noise sources
  - Externally generated Electro-Magnetic Interference or EMI
  - Externally generated Radio-Frequency Interference or RFI

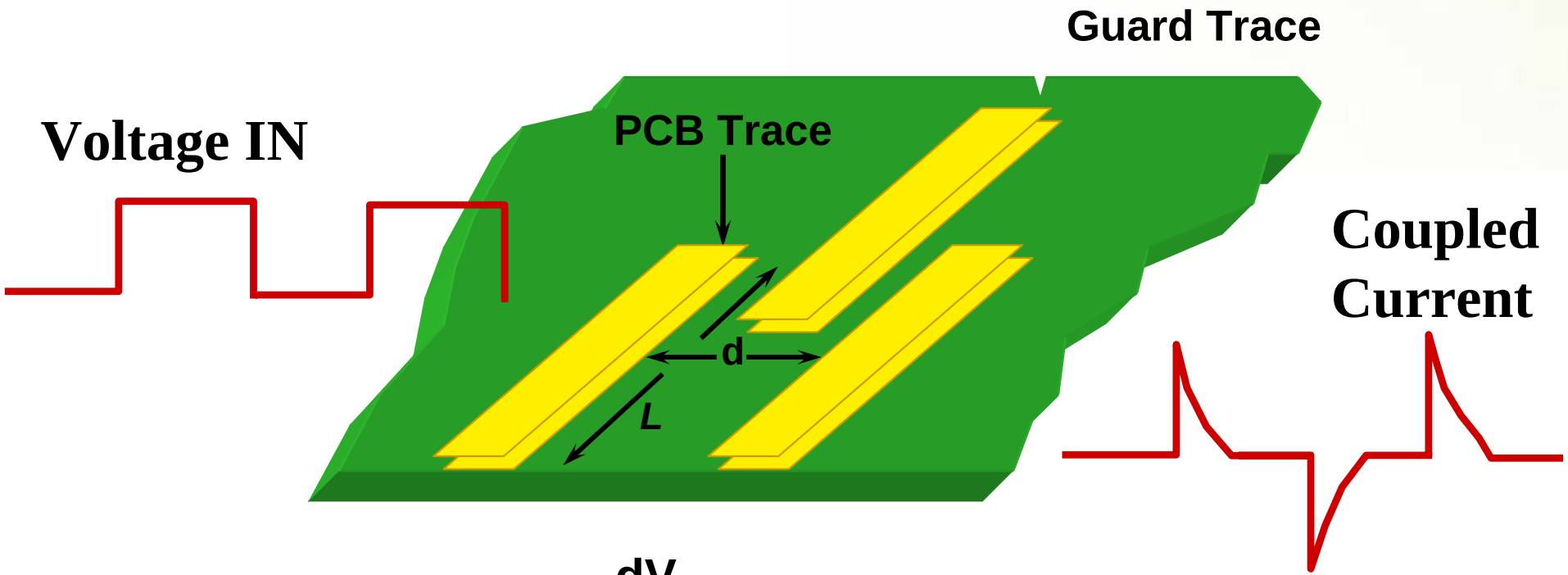
Identify the Noise Sources



PCB Capacitance

- Decrease “L” or Increase “d”
- Put Ground Guard Between Traces

$$C = \frac{w \cdot L \cdot e_o \cdot e_r}{d} \quad pF$$

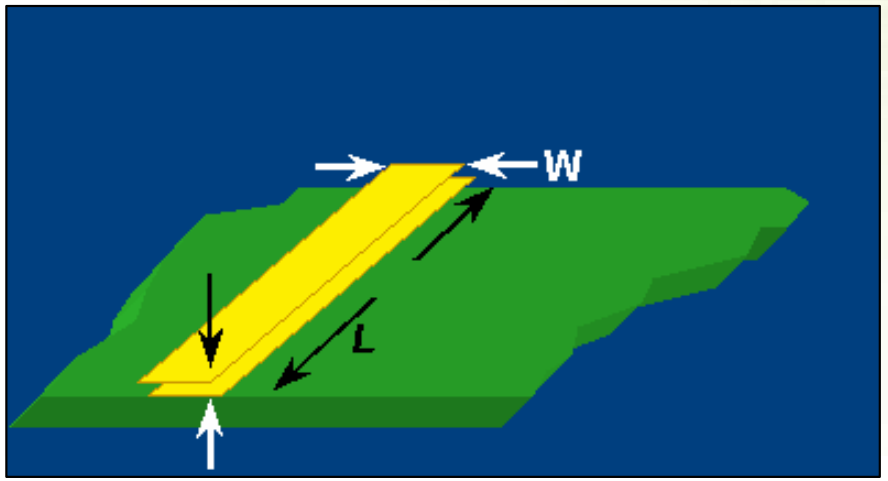


$$I = C \frac{dV}{dt} \quad (amps)$$

PCB Trace Resistance

$$R = \frac{L \bullet \square}{W \bullet H} \ \Omega$$

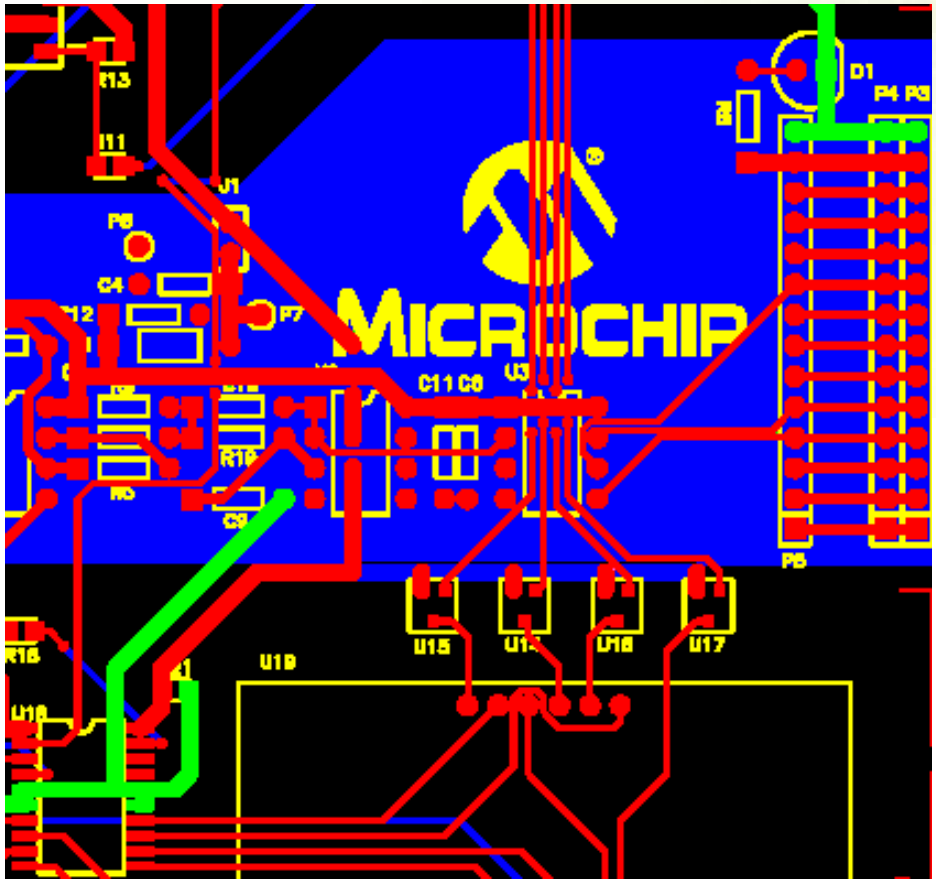
$$I = \frac{V}{R} \text{ amps}$$



- Reduce Noise by
  - ↑ W (width of trace)
  - ↓ L (length of trace)
  - ↑ H (thickness of trace)

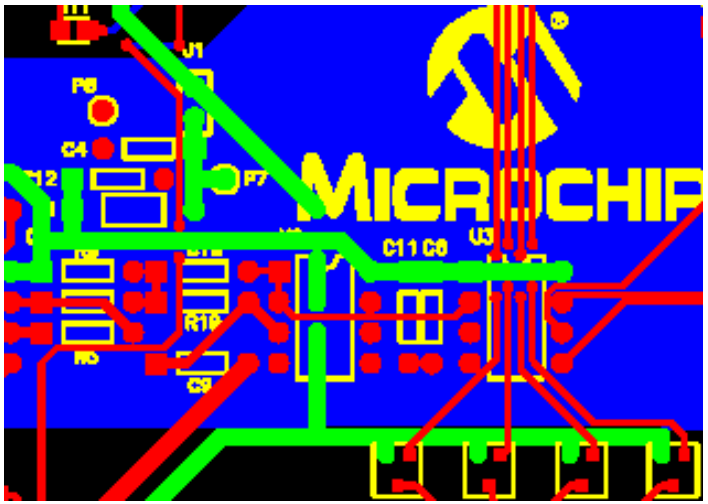
Conducted Noise Pathway: Ground

- Pathway:
  - Fast rise time currents react with trace inductance to generate noise voltages
  - High currents react with trace resistance to generate noise voltages



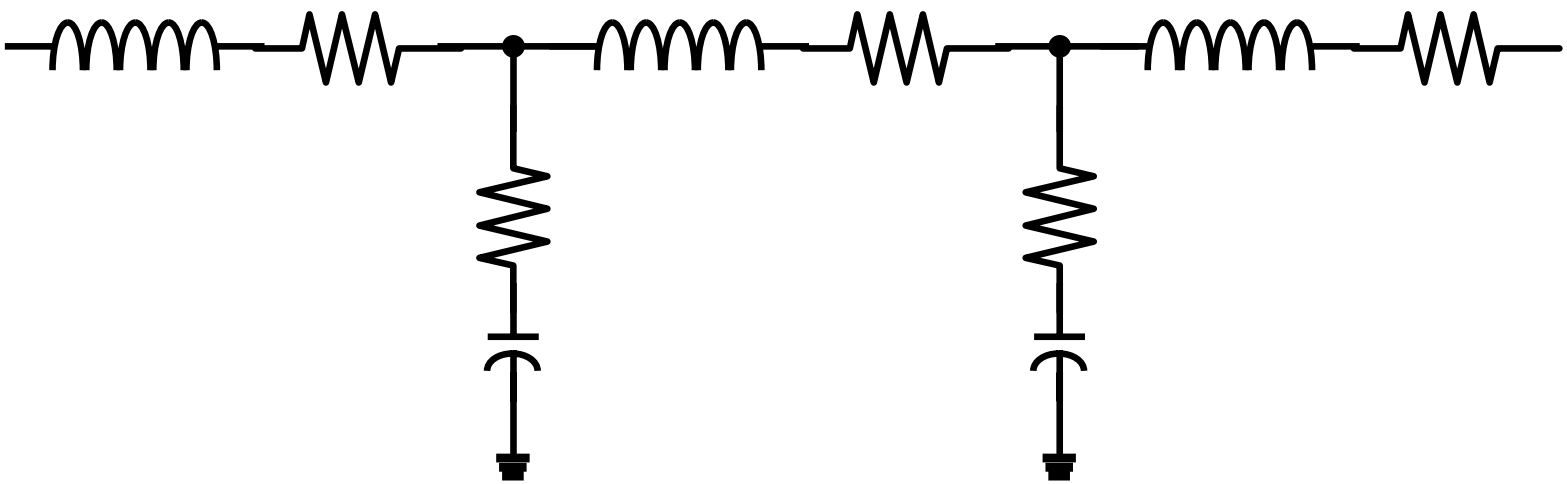
Conducted Noise Pathway: Power

- Pathway:
  - Fast rise time generate noise
  - High currents generate noise



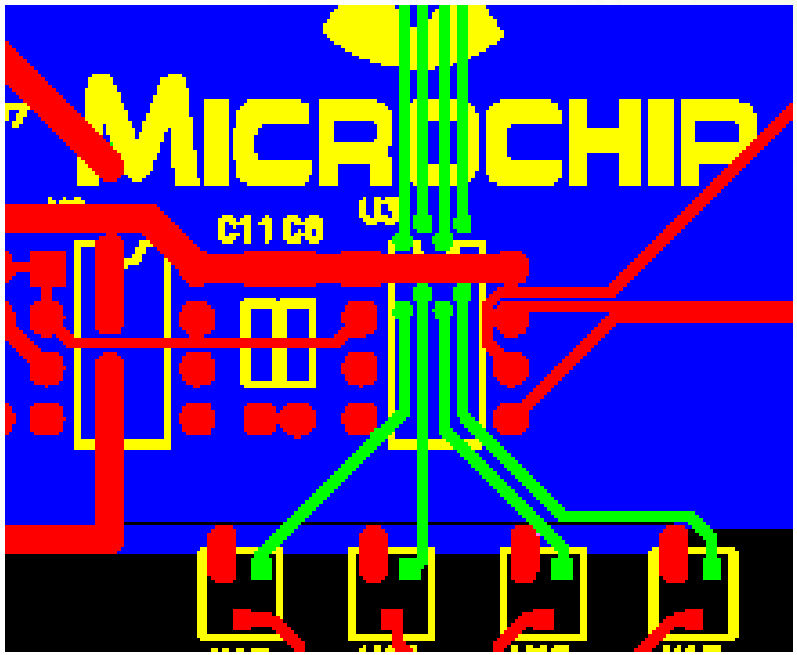
Conducted Noise Corrective Action: Power II

- Use low-pass filtering to isolate noise
  - Circuits on their own power traces
    - Creates higher series impedances
  - Bypass capacitors
    - present a low shunt impedance



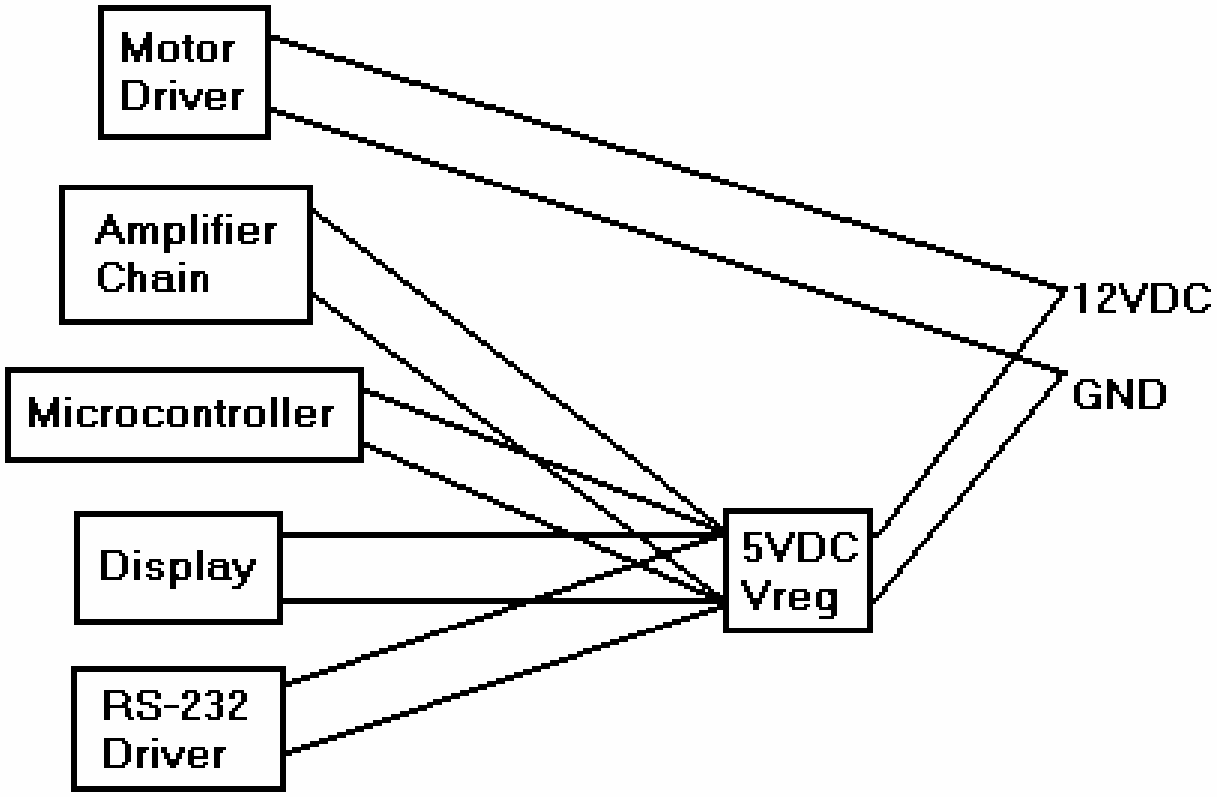
Radiated Noise: EMI

- Pathway: EMI
  - Adjacent traces create unintended capacitors
  - Adjacent traces create unintended transformers
- Corrective Action: EMI
  - Increased distance
  - Decrease common area



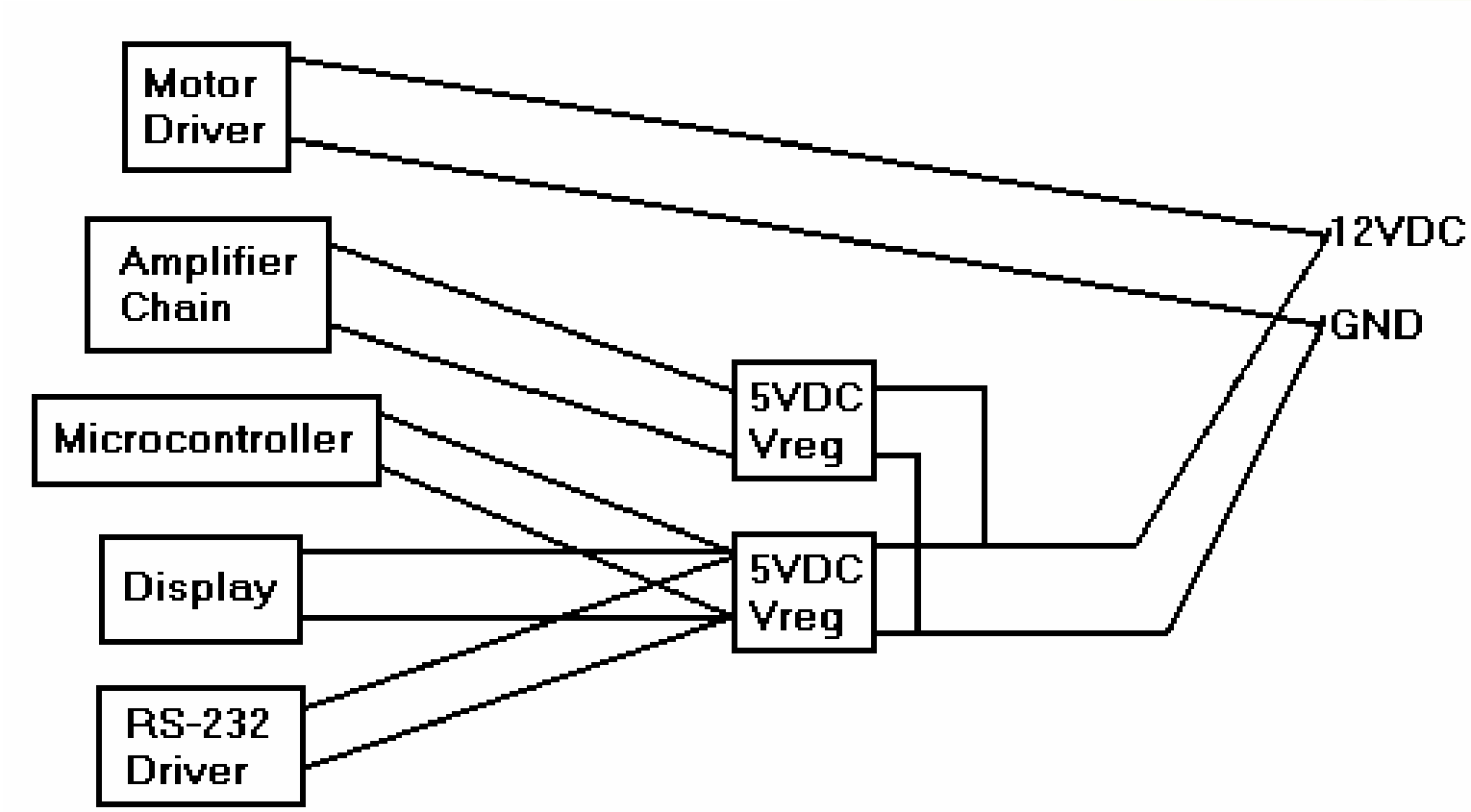
Mapping Out the Plan

- Draw design sections
- Add the connections



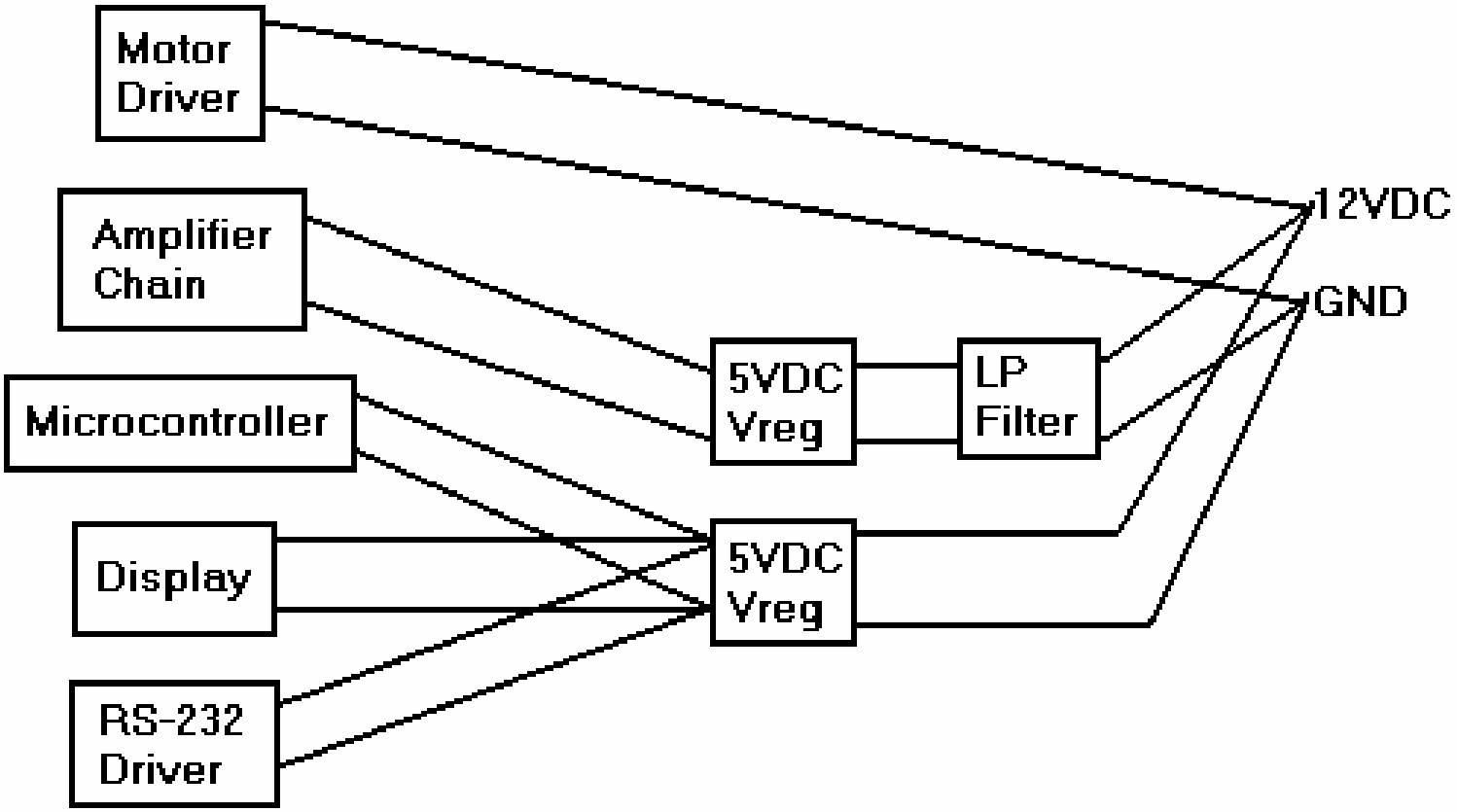
Revising the Plan

- Route to maximize isolation
  - Between noisy and sensitive blocks
  - Keep runs short



Revising the Plan Again

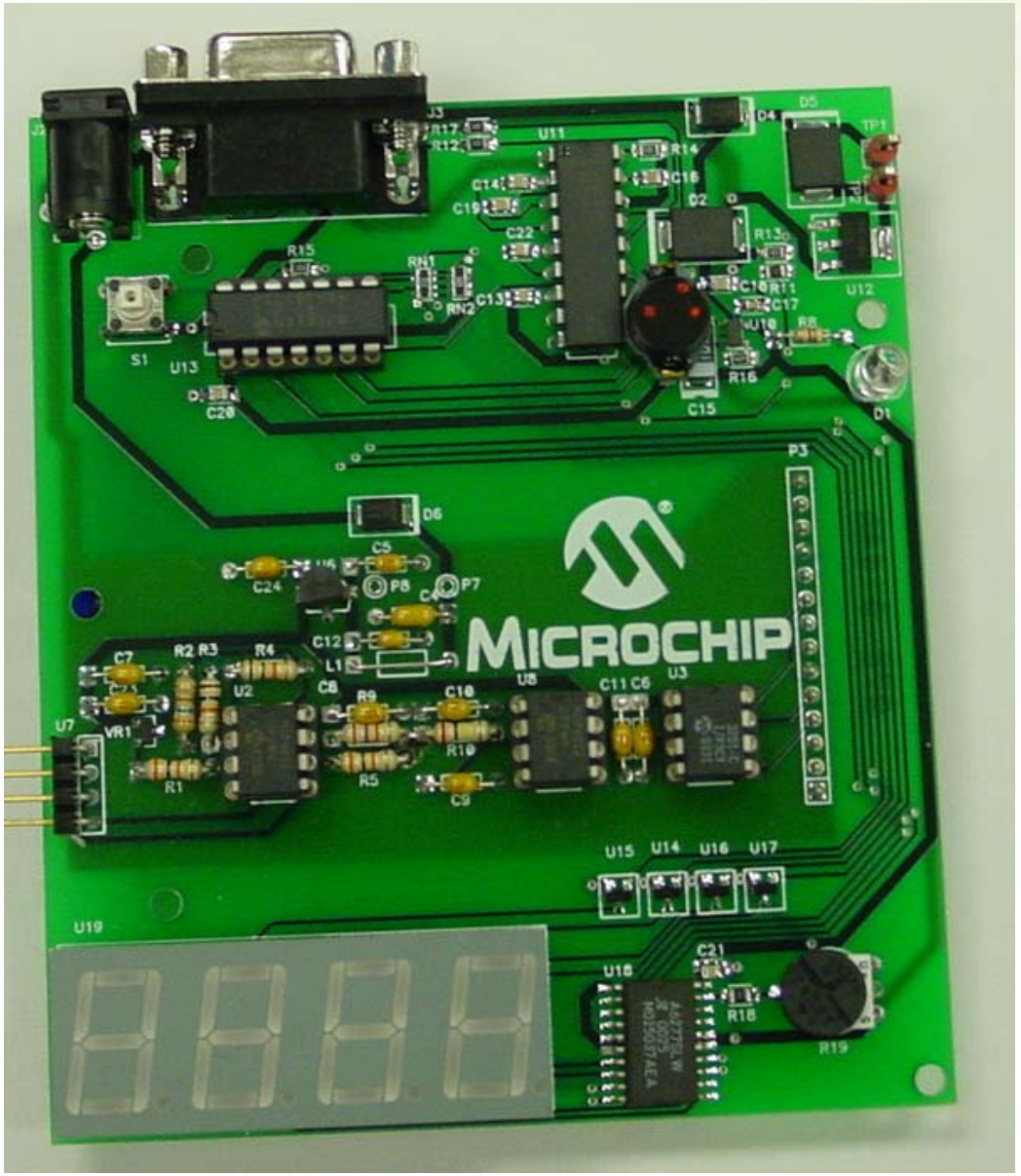
- Identify additional isolation requirements



Re-layout the Board

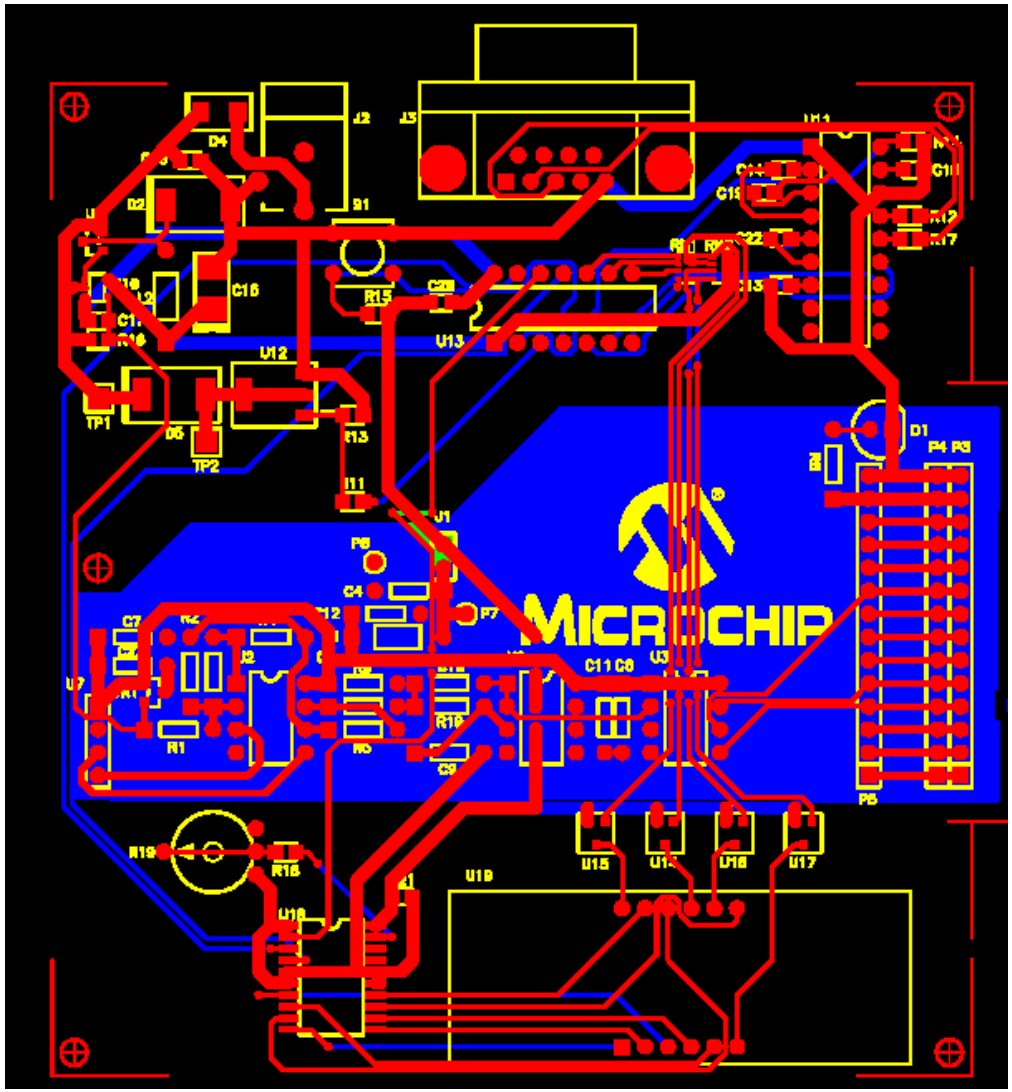
- Layout the board using the plan
  - Isolation each section
  - Plan routing of power and ground for each section
  - Isolate sensitive signals from fast- and high-current signals
  - Identify wide traces
  - Identify short and wide traces

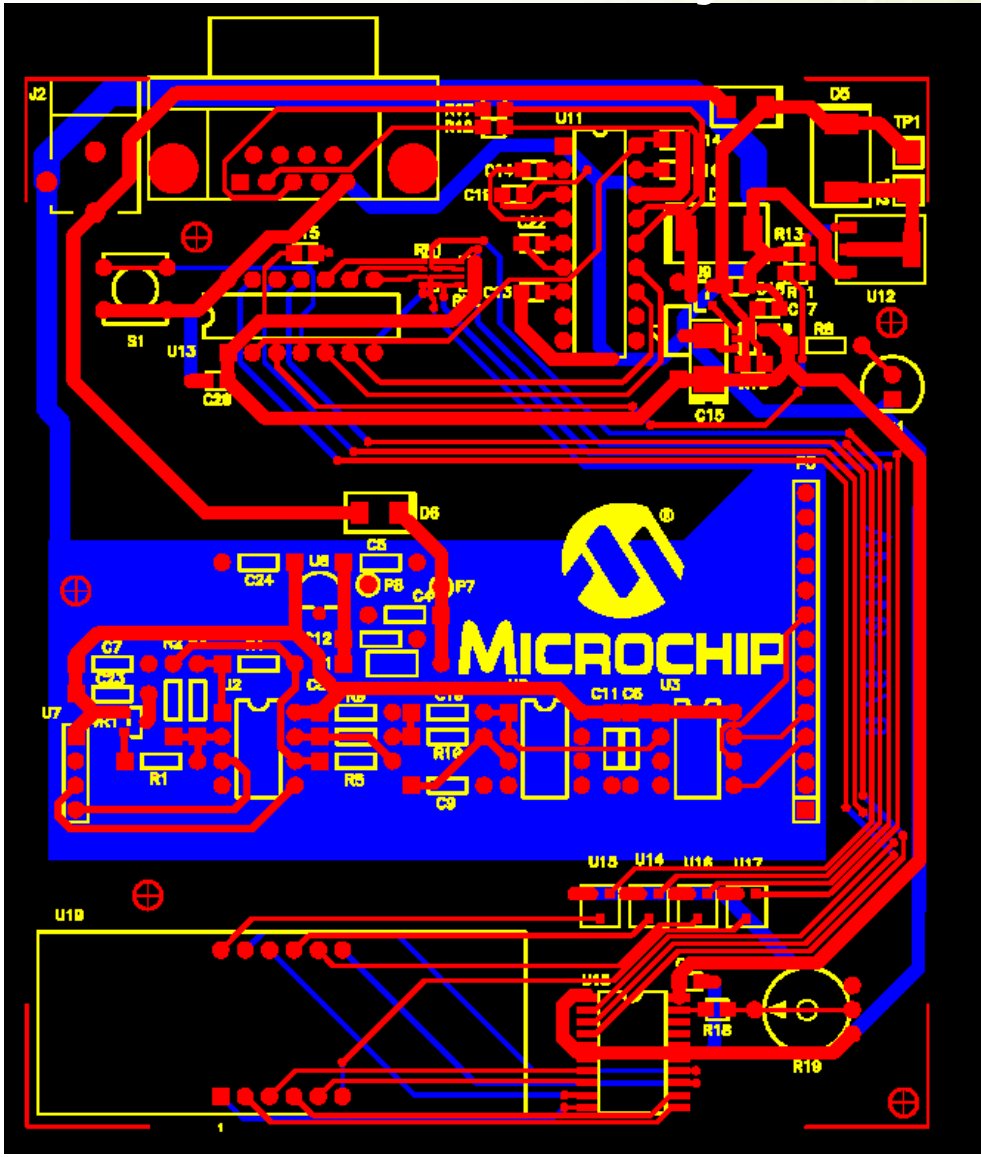
Application Board #5



Complete Board Layout

Final Layout

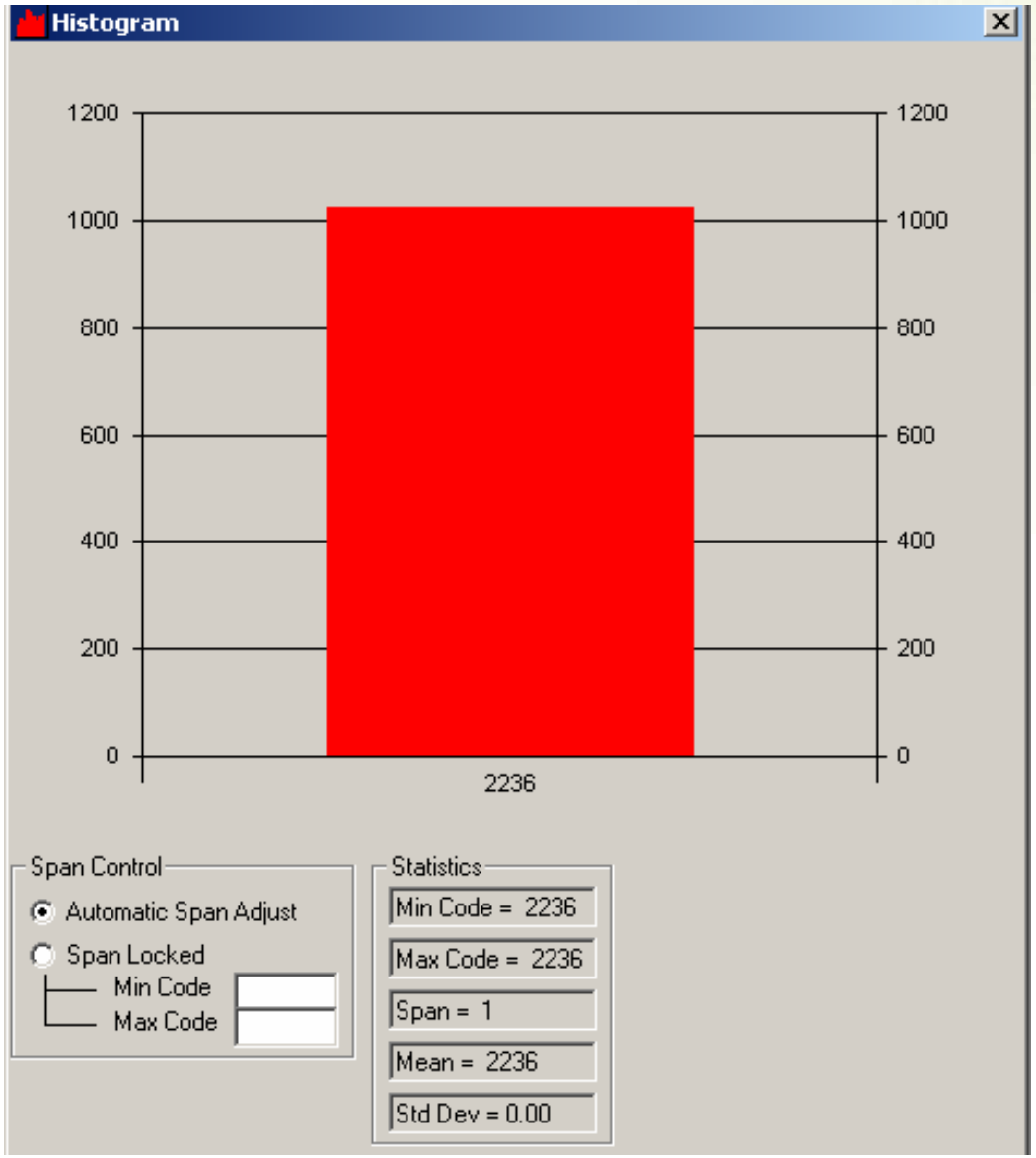




New Composite Board Test Results

Code Width of Noise = 1

(total samples = 1024)



System Solution: What You Should Do

- Use low-noise analog parts
- Use an uninterrupted analog ground plane
- Filter the ADC with an analog low-pass filter
- Bypass all devices properly
- Develop a power and ground plan for the whole circuit
- Use software to create quiet times for conversions
- Use separate analog and digital voltage regulators
- Isolate noisy sections

References

- Reference Books
  - *High-speed Digital Design: A Handbook of Black Magic*, Howard Johnson and Martin Graham, Prentice Hall, 1993.
  - Noise Reduction Techniques in Electronic Systems, Henry Ott, John Wiley, N.Y., 1998.
  - The RF Capacitor Handbook, from American Technical Ceramics Inc.
  - The Circuit Designer's Companion ,by Tim Williams
  - Reference Data for Engineers, 7th edition Edward C. Jordan, Editor in chief
  - ABC's of Transformers & Coils,by Edward J. Bukstein

Additional References

- Reference Application Notes
  - *ADN 007, Techniques that Reduce System Noise in ADC Circuits*
  - *AN681, Reading and Using Fast Fourier Transforms (FFTs)*
  - *AN699, Anti-Aliasing, Analog Filters for Data Acquisition Systems*
  - *AN695, Interfacing Pressure Sensors to Microchip's Analog Peripherals*
  - *AN688, Layout Tips for 12-Bit A/D Converter Application*
  - *AN823, Analog Design in a digital World using Mixed Signal Controllers*
- Web Addresses
  - http://www.csee.umbc.edu/~plusquel/650/slides/crosstalk1.html
- FilterLab® Active Filter Design Software
  - Down-loadable at www.microchip.com
  - Active, op amp filters