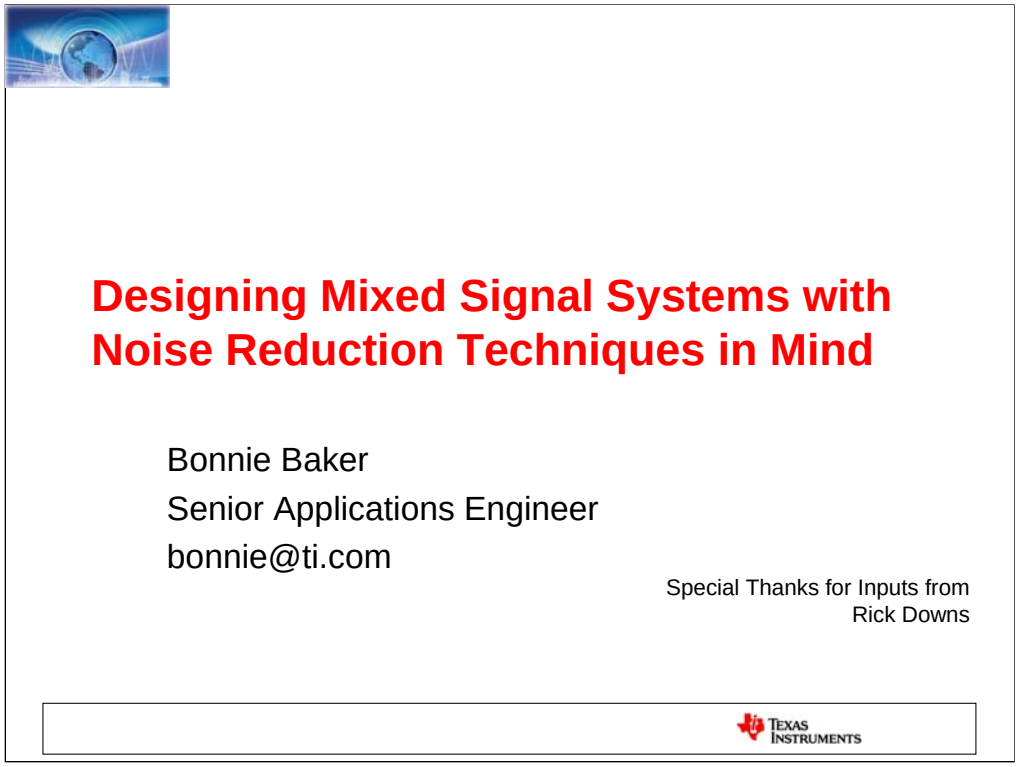


Sensor applications often have low-level signals. A peaceful co-existence of the sensor signal, analog circuitry, and processor requires careful attention to layout and noise reduction techniques. In this session we will discuss three sources of noise, the paths noise travels, and how to reduce noise to tolerable levels. We will discuss the proper selection and placement of noise isolating and limiting components to keep analog and digital noise out of sensitive input circuits.

We are going look at the performance of a board that was built in a Texas Instruments lab. From the board test results we will find that our first pass design is below expectations. In an effort to improve the performance of the board, we will discuss possible sources of noise. The noise topics that we will concentrate on are device noise, emitted noise, and conducted noise. The complete system that we will use in this seminar includes a load cell sensor, several amplifiers, and a 12-bit SAR analog-to-digital converter.

By the end of this hour we will successfully design a low noise, 12-bit system using the same converter that we started with.

Reactive Design Troubleshooting

- Implement the Circuit on PCB
- Check the Performance
- Ship it !!!

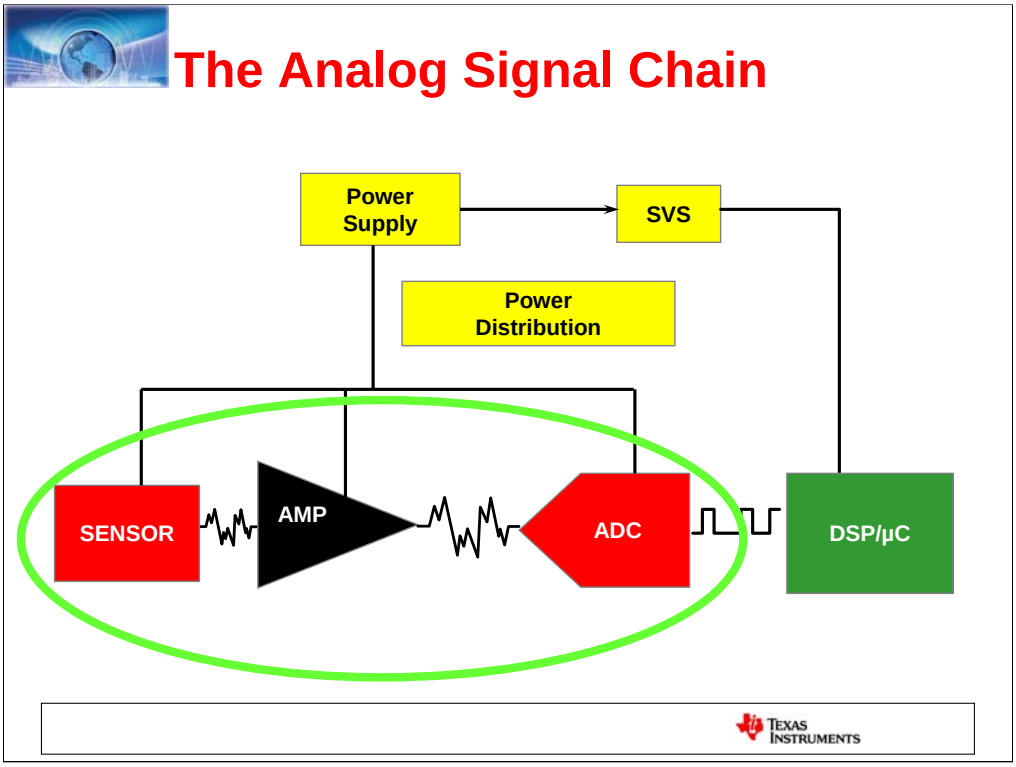
Texas Instruments

As a first pass, we have quickly designed a circuit and a PCB in-house. At this point in the development process, we will not know how the circuit will work, we will only hope that the circuit will produce “good results”. The idea for this first pass PCB are taken from text books, so it should work correctly.

Following the design of this circuit and PCB we will run tests to see if the digital output from the converter is believable.

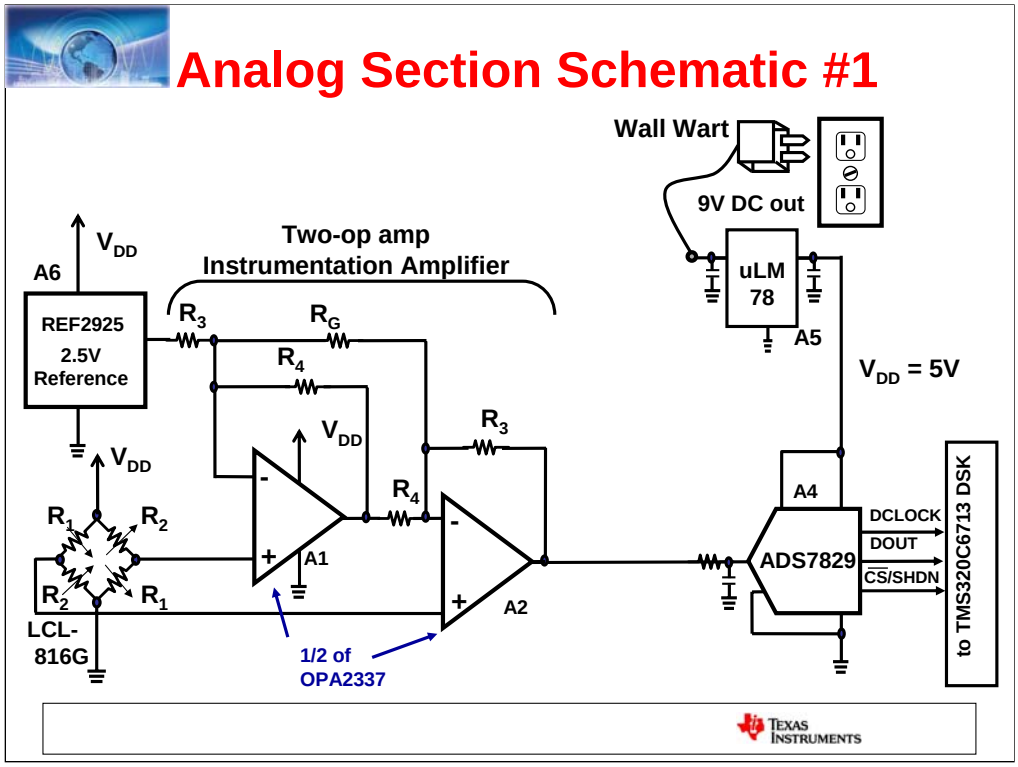
The hopes of this segment of the design process is that the first pass circuit that we have designed for this class will be acceptable. If this first pass design is acceptable, we will explain why the board meets our expectations and then send it to our marketing/sales department in anticipation of great sales numbers.

When this process is complete, we will be free to start the next project on our long “To Do” list.



Here is the analog signal chain for our sensing system. As you can see, the sensor is diagramed on the left side of the slide. The sensor is followed by an amplifier circuit, which is followed by an analog-to-digital converter. The digitized signal comes out of the converter and is transmitted to the processor.

You will notice that I have circled the sensor, amplifier, and converter. These are the devices that we will concentrate on today. Additionally, the power supply and its contribution to noise is briefly discussed in the conducted noise segment of this seminar. We are not going to talk about the processor, although the DSP/µC is an important part of the circuit. That discussion is reserved for future seminars.



In the real-world of analog, what you hear and what you see is all analog. Today it is very common to take those analog entities, convert them to analog voltages or currents, and then convert them to digital signals for the processor. This slide shows a typical system design that converts a weight on a load cell to a 12-bit digital word.

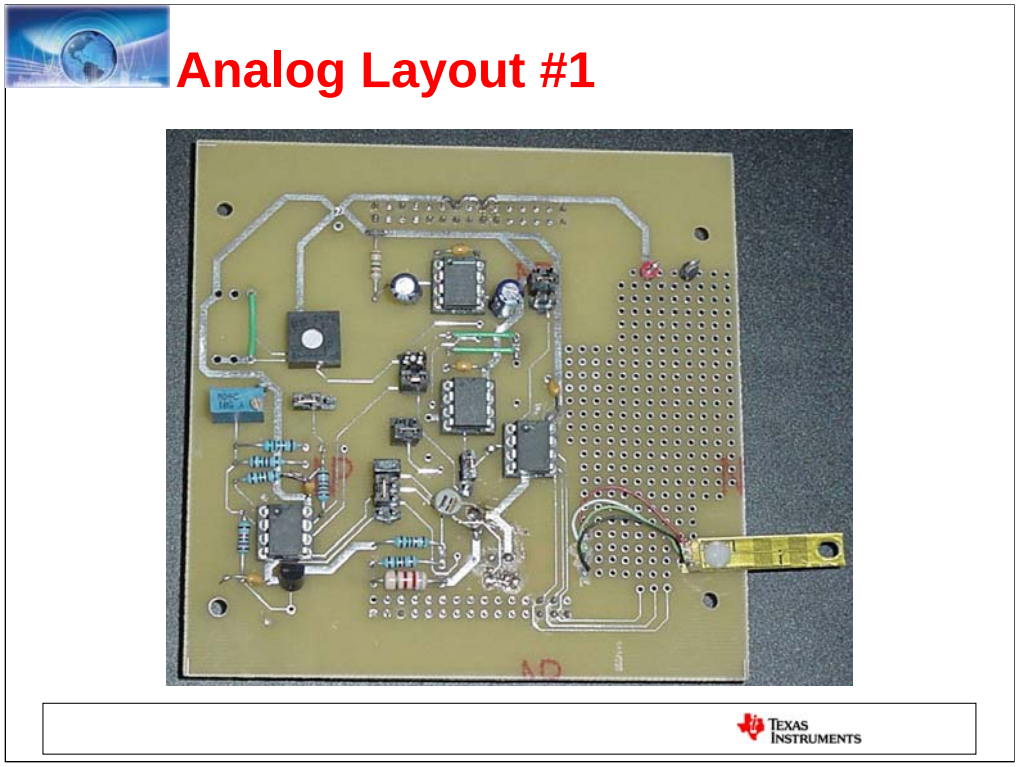
The sensor (left side of this slide) in this system is a 1.2kΩ, 2mV/V load cell with a full-scale load range of ±32 ounces. In this 5V system, the electrical full-scale output range of the load cell is ±10mV. An instrumentation amplifier, consisting of two operational amplifiers (A1 and A2) and five resistors, is configured with a gain of +153V/V. This instrumentation amplifier is a text book solution that uses discrete amplifiers.

The gain of +153 V/V matches the full-scale output swing of the instrumentation amplifier block to the full-scale input range of the A/D converter. The SAR A/D converter has an internal input sampling mechanism. With this function, a single sample is taken for each conversion. The microcontroller acquires the data from the SAR converter, performs some calibration, and translates the data into a usable format for tasks such as displays or actuator feedback signals.

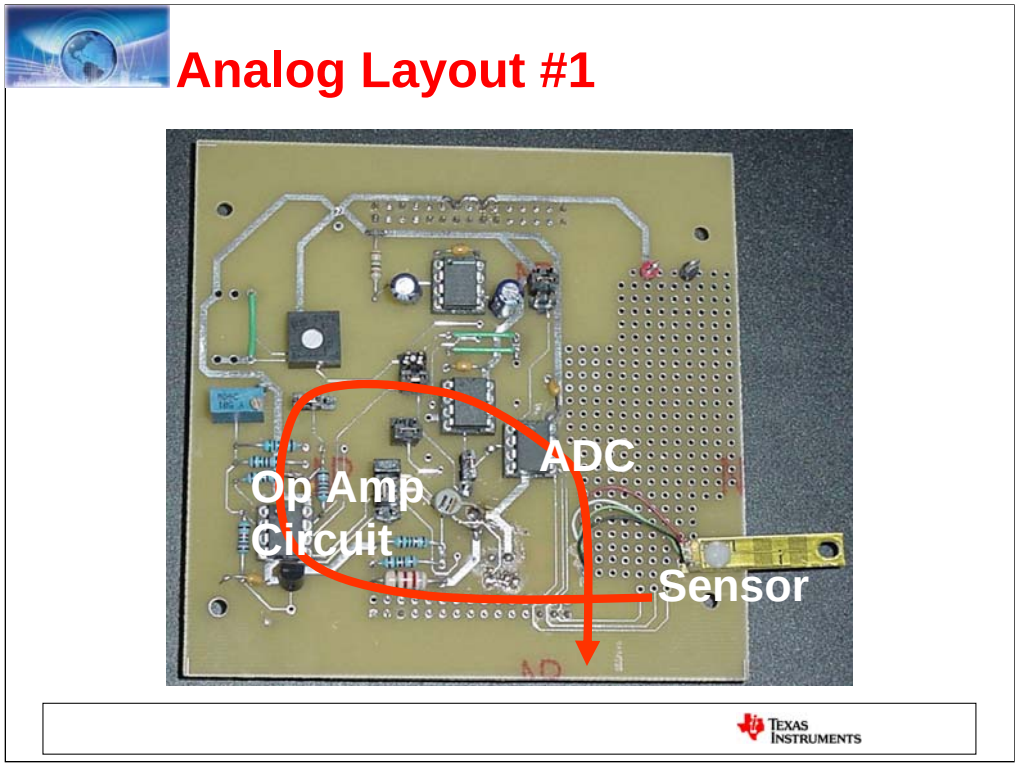
Component Values

- Resistors around Instrumentation Amplifier
  - R_3 = 400 kΩ
  - R_4 = 100 kΩ
  - R_G = 5.33 kΩ
- OPA2337 = Single Supply, CMOS, dual OPA
- ADS7829 = 12-bit, A/D SAR Converter

There are five resistors around the discrete instrumentation amplifier. I chose these resistor values quickly because of their availability in the lab. They are a bit large and later on we will find out how large they are compared to the noise that they generate.



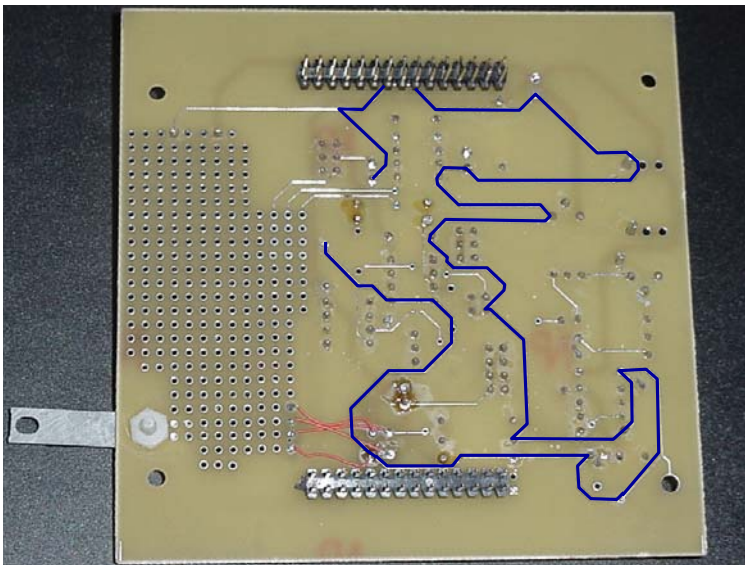
The layout person for this circuit quickly put the devices on the board with an auto-routing utility. Additionally, there are other circuits on the board, such as an adjustable, voltage-reference generator for the ADC and a thermistor temperature sensor. The target of the thermistor circuit is not for this system, but it came in useful for other tests that the staff in my lab wanted to perform.



This picture of the board shows the locations of the sensor (load cell), dual op amp, and ADC.

The signal in this system starts at the load cell. The load cell is the metal flap on the right side of the board. The load cell PCB traces travel a fairly long distance across the board to the amplifier circuit. This long distance is required because of the other (non-essential) circuits on this board. The signal then travels around to the 12-bit, analog-to-digital converter (ADC). After the converter digitizes the analog signal, the digital code is then sent to the connectors at the bottom (right) of the board. These connections are routed to the processor on a second board. You might have an issue with the fact that the ADC signal goes underneath the sensitive load cell traces. At this point, I am going to assume that this is not a problem. After all, this system does not use a 24-bit $\Delta\Sigma$ ADC, it only uses a 12-bit SAR-ADC!!!

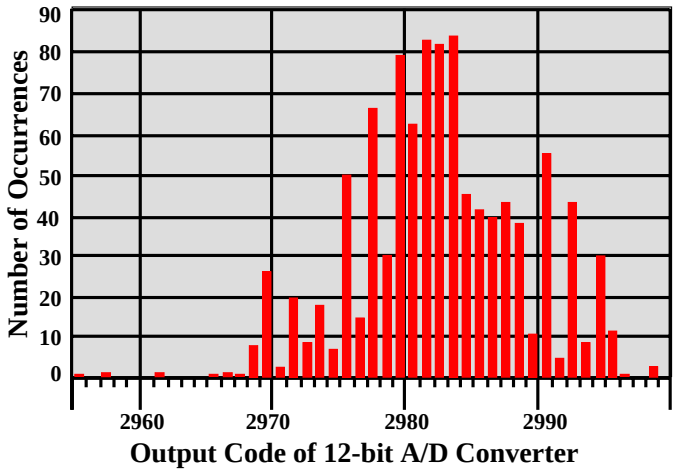
Board #1 Bottom



This is the backside of the PC board. As you can see there is no ground plane. However, all of the components are connected to ground with traces. The black line on this board shows how the grounds are connected. There is little regard with the ground trace for interference from device to device. As a matter of fact, the currents from the ADC travel all the way through every component on the board. This is not the best approach to lay out your grounds, but this board does meet the objective of having a two layer board. The auto router for the backside of this board did not do us any favors.

If the design of this system is poorly implemented, it could be an excellent candidate for noise problems. The symptom of a poor implementation is an intolerable level of uncertainty with the digital output results from the A/D converter. It is easy to assume that this type of symptom indicates that the last device in the signal chain generates the noise problem. But, in fact, the root cause of poor conversion results could originate with the devices on the board, the PCB layout, or even extraneous noise sources.

1st Pass Test Results



Code Width of Noise = 44

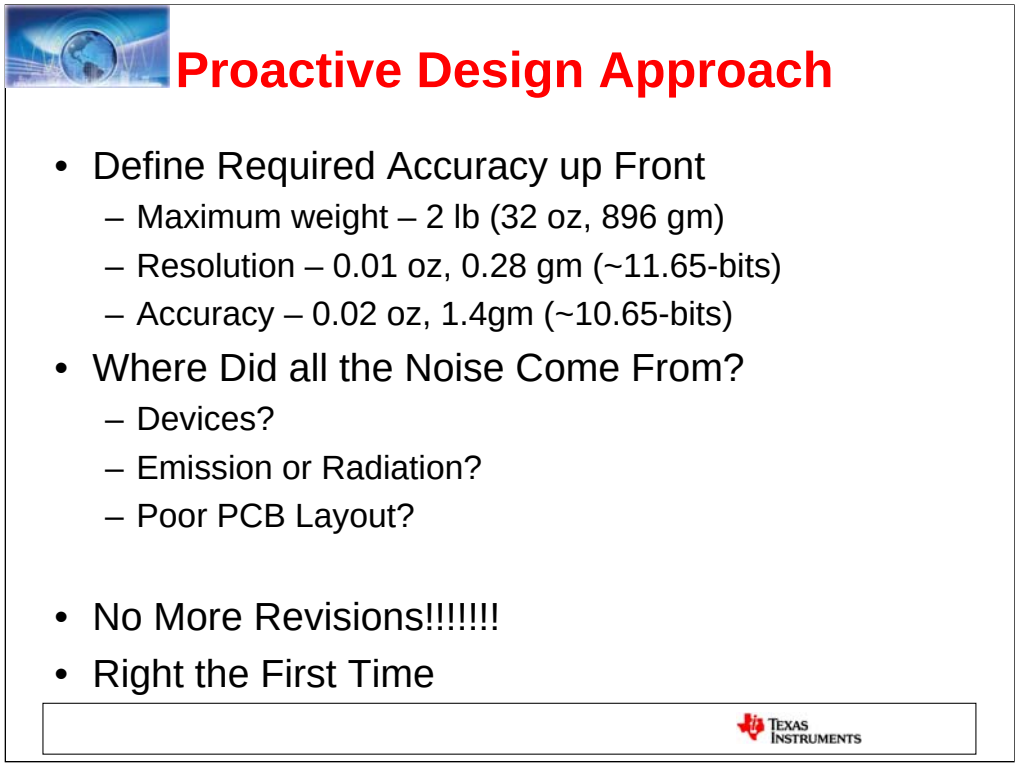
(total samples = 1024)

How many bits?

6.54-bits

This is a histogram plot of the 12-bit ADC data taken from the board. The load-cell on the board was not exercised while this data was collected, so theoretically a DC signal is presented to the inputs of U1 and U2 (the amplifiers). Along the y-axis the units of measure is number of occurrences of the 12-bit digital words and the x-axis identifies the 12-bit ADC output codes.

The data shown in this slide is far from optimum. This data proves that auto-routed boards do **not** have noise improvement algorithms. A total of 1024 samples were taken from the ADC. The width of the collected codes is forty-four codes. Forty-four different codes suggests a peak-to-peak noise error in the system. This error is probably caused by several sources of noise, somewhere in the circuit. Mathematically, the peak-to-peak error translates into 6.5-bits from a 12-bit converter system.

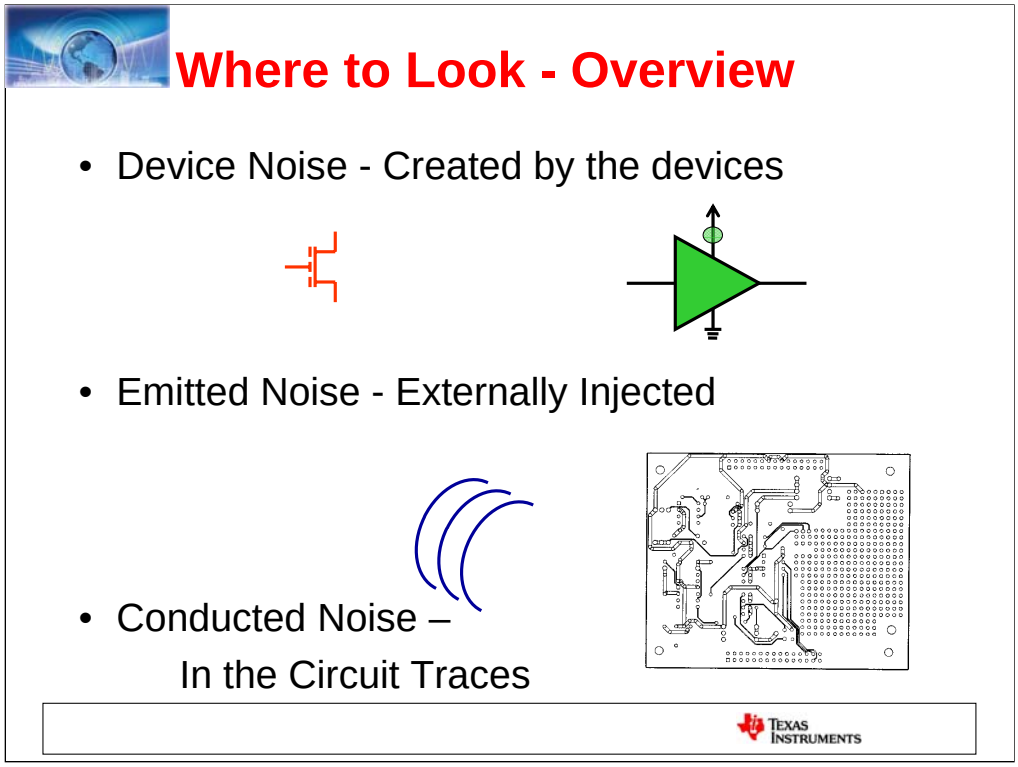


One fallacy of this design is that we did not define the requirements of the circuit. We are interested in designing a weigh-scale that has a maximum weight range of 2 lb (32 oz, 896 gm). The resolution on our system is 0.01 oz which translates into a ADC resolution of 11.65-bits. Because of this system specification, a 12-bit SAR-ADC is the proper converter for our system. Although we have chosen a 12-bit converter, the actual noise accuracy of the system need only be 0.02 oz or 10.65 bits. Remember that our data indicates that we only have 6.54 effective number of bits (peak-to-peak).

Now we can start to think about the sources of noise in our circuit. Our circuit contains several components and devices, all of which can be noise generators. For instance, the resistors produce a thermal noise that spans considerably higher than the entire frequency range of our application. The operational amplifiers generate their own noise inside the IC circuit and the ADC generates at least quantization noise as a result of the digitization process.

If you think beyond the devices on the PCB, signals can be emitted or received from one trace to an adjacent trace. Additionally, signals in the ambient around the circuit board, such as 60 Hz from the wall or 120 Hz from florescent bulbs can be injected into the circuit board traces.

The reason that we are now looking at these noise sources is because we only want to design this circuit/PCB one more time. This time we are going to attempt to get it right.



Noise problems can be divided into three sub-categories when tackling design and troubleshooting challenges. These three categories are device noise, emitted or radiated noise, and conducted noise.

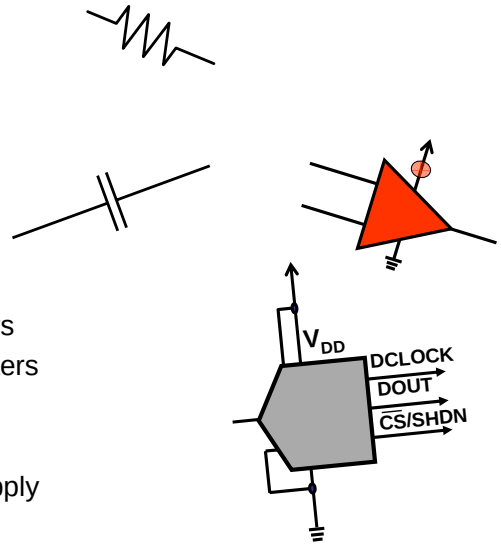
Device noise originates in the active or passive devices on the board. All of the passive devices, such as resistors, capacitors, and inductors can generate noise. Active devices, such as amplifiers, references, regulators, and ADC converters also generate noise that is injected into the PCB signal paths. Many times the challenge in dealing with noise from these noise sources is to either choose a lower noise device or follow the device with a filter.

Emitted noise is transmitted into the system by way of e-fields or b-fields. This type of noise could come from the lights in the form of 60 Hz or 120 Hz or it could arrive in your circuit because of a copy machine in an adjoining cubical.

The third sub-category of noise is conducted noise. Conducted noise appears in the PCB traces and needs to be addressed at that level. This type of noise originates in devices or from e-fields or b-fields.

Where to Look – Device Noise

- Passive Devices
  - Resistor
  - Capacitors
  - Inductors
  - Ferrite Beads
- Active Devices
  - Operational Amplifiers
  - A/D and D/A Converters
  - Voltage References
  - Voltage Regulators
  - Switching Power Supply



Texas Instruments

Device noise can be classified into two groupings; passive and active. Passive devices are constructed with materials, such as films and composites. Components such as resistors, capacitors, inductors, and transformers fall into this category.

Resistors generate a constant noise across the entire frequency range. This noise is multiplied by the square root of the actual resistor value.

Capacitors are generally identified as a device that reduces or filters system noise. Capacitors generally emit electric fields when they are used in switching networks.

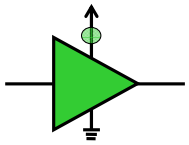
An ideal inductor would only have inductance, but actual inductors also have series resistance and distributed parallel capacitance between windings. An important characteristic is their susceptibility to and generation of stray magnetic fields in switching networks.

Active devices are fabricated in silicon. This class of device includes bipolar transistors, field effect transistors, CMOS transistors and integrated circuits that use these transistors.

The transistors inside integrated circuits, such as op amps, ADC, DAC, and references, etc. generate noise. With amplifiers, the differential input stage dominates the noise contribution. In contrast, the voltage reference and regulator noise is measured at the output. Switching power supplies generate their own type of noise because of the switching action across the inductor.

Device Noise for our Circuit

- Device Noise - Created by the devices
  - Resistors - Reduce Values were possible
  - Op amps - Use Lower-Noise Amplifiers



Texas Instruments

During this device noise discussion we are going to concentrate on the noise generated by the resistors and operation amplifiers in our circuit. In all cases, you can reduce the noise contribution from any of these devices if you replace the noisy part with a lower noise device.

For instance, you can reduce the noise contribution of a resistor by selecting a lower value resistor.

Resistors and OpAMP Noise

- Resistors
  - All Resistors Generate Noise
  - Resistor Noise Called Johnson or Thermal Noise
  - Ideal Noise = $V_{RN} = \sqrt{4KTR(BW)}$ {Vrms}
    - Ideal 1 kΩ ⇒ 4 nV / $\sqrt{Hz}$

Texas Instruments

There are many different classes of fixed resistors such as wire wound, film type, or carbon composition, to name a few. Regardless of their construction, all resistors generate a noise voltage. This noise is primarily a result of thermal noise. Thermal noise, which is also called Johnson noise, is generated by the random thermal motion of electrons in the resistive material and can never be lower than ideal.

Ideally, the voltage noise from a resistor equals

$V_{RN} = \sqrt{(4xKxTxRxBW)}$

where K is Boltzman's time constant (1.38×10^{-23})

T is temperature in Kelvin (add 273 to converter to °C)

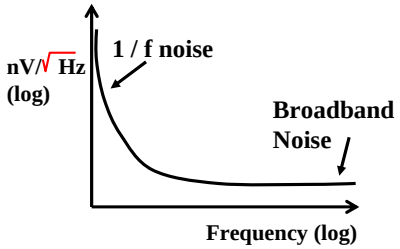
R is the value of the resistor

BW is the bandwidth of interest

For instance, the noise from an ideal 1 kΩ resistor is equal to 4 nV/√Hz

Resistors and OpAMP Noise

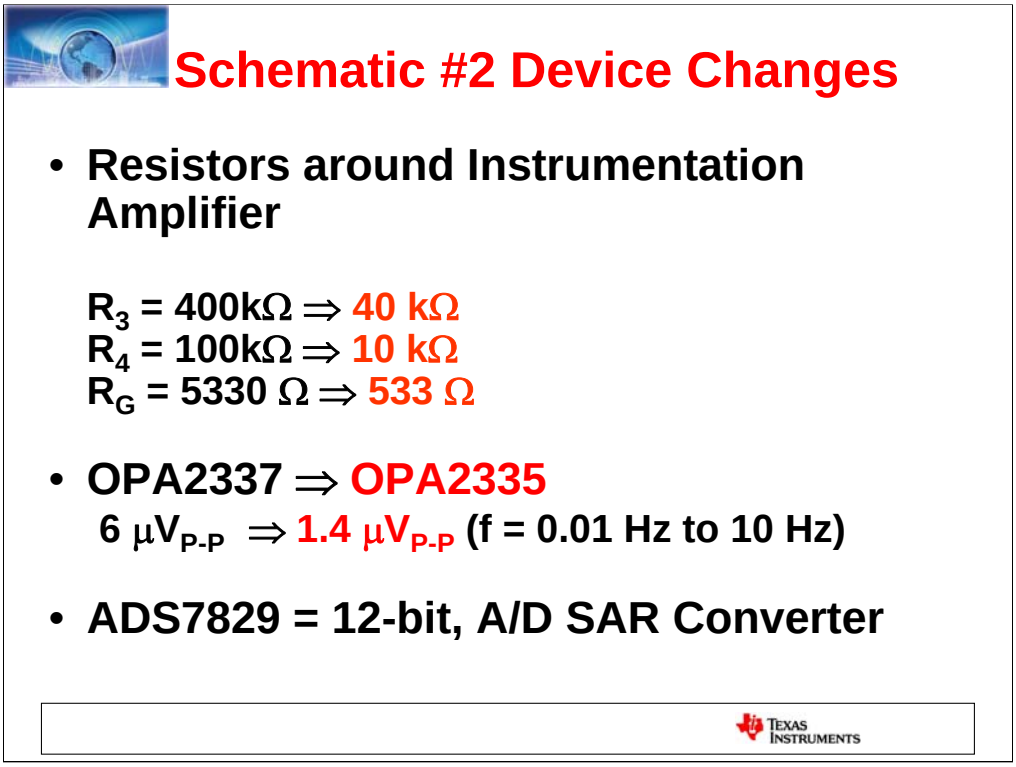
- Amplifiers
  - OPA2337 Specification
    - 6 μV_{P-P} (f = 0.1 Hz to 10 Hz)
  - OPA2335 Specification
    - 1.4 μV_{P-P} (f = 0.01 Hz to 10 Hz)



Texas Instruments

Pure analog devices include operational amplifiers, instrumentation amplifiers, voltage references, voltage regulators, to name a few. These devices are typically specified in terms of nV/√Hz, pA/√Hz, mVrms or mVp-p. The noise that is generated by these devices can be defined as current noise or voltage noise. The two fundamental frequency regions of noise that these devices produce are the 1/f and broadband. You can reduce the noise from noisy operational amplifiers by replacing the device with a low noise alternative.

The typical noise at the input of the operational amplifier in our circuit (OPA2337) is 6 μV_{P-P}(f = 0.1 Hz to 10 Hz). As an alternative, we are going to use the OPA2335. The typical noise at the input of the OPA2335 is 1.4 μV_{P-P} (f = 0.01 Hz to 10 Hz)



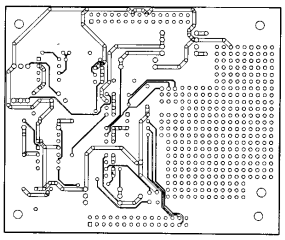
Here are the changes to the devices for our second schematic. The resistors use to be 400 k Ω, 100k Ω, and 5330 Ω. Now we will change these resistors to 40 k Ω, 10 k Ω and 533 Ω.

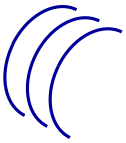
The operational amplifiers use to be a dual OPA2337 with 6 μV_{P-P} noise from 0.1 Hz to 10 Hz. We will now replace those amplifiers with a dual OPA2335 that has 1.6 μV_{P-P} noise from 0.01 Hz to 10 Hz.

We still have the same 12-bit converter. As long as the resistors are changed and the amplifier is upgraded to a lower noise device, we should get much better results from our circuit.

Radiated Noise: B-Field

- Sources (Transmitters)
  - On Board Transformers
  - Switching Regulators
  - External Noise
- Victims (Receivers)
  - Single-ended, High Impedance Inputs
  - Traces that a Form Circle
    - Classic Example : Ground Loop
    - Signal Loop
  - Long Traces (acts like an antenna)

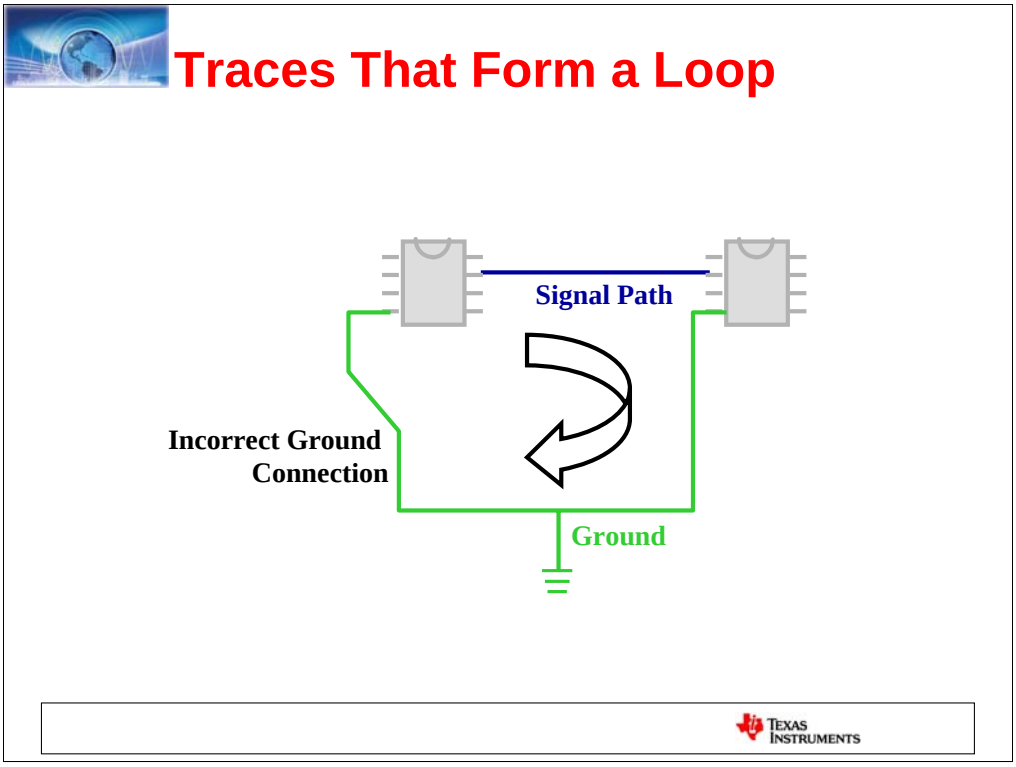




Texas Instruments

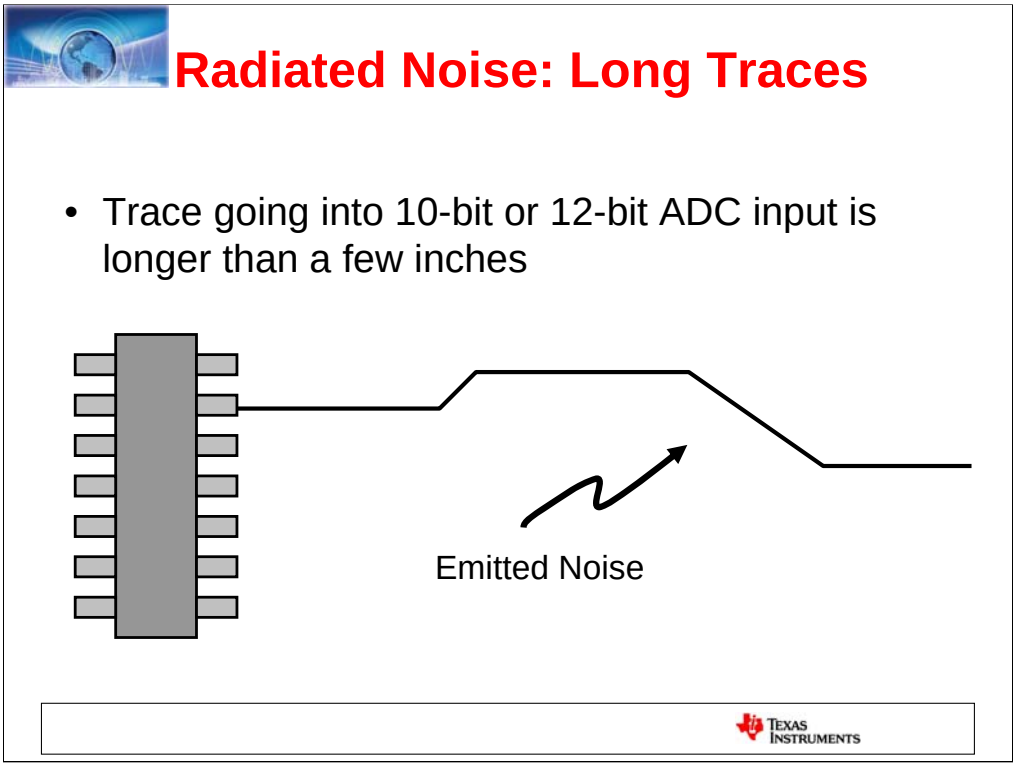
Radiation is a second method that noise can enter into your circuit traces. For instance, a trace that is carrying a digital signal can couple noise into a close, high impedance analog trace. You can build on-board transformers with your circuit and capture extraneous noise from the environment. Switching regulators, a common level conditioner for power, switches signal through a transformer. The switching regulator's inductor can emit noise across the PCB to sensitive circuitry. External radiating sources such as ac power (50 or 60 Hz) or signals coming from adjacent equipment (as simple as a copy machine) can send emitted signals across your PCB.

The level of susceptibility of the circuit to extraneous noise is directly related to the implementation of signal traces on your board, ground plane, and the power plane.



One structure that you can build with the PCB traces is a loop. With your loop, it can look like devices interrupt or dismantle the loop, however, the devices just act like another piece of the loop. A PCB loop operates the same as an inductor. It emits b-field noise and can receive b-field interference.

Traces that form a loop are an excellent receptor for radiated noise. You'll note in this diagram that I have not drawn a perfect loop without interruption however, there is enough connection around this loop through the devices to capture radiated signals in the air. With our first board design, we had a similar signal path on the top side of our board.



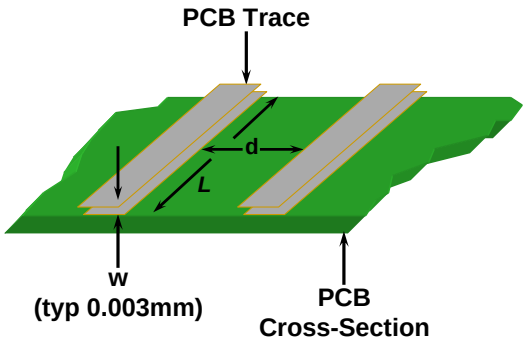
A trace going across a PCB to a connector can operate as an antenna. Likewise, wires that go to nowhere can act like antennas. A trace that goes all the way across the board can capture enough noise that even a 10-bit converter creates an inconsistent output.

As a basic guideline, both analog and digital signal traces on PC boards should be as short as possible. Shorter traces minimize the susceptibility of the circuit to on-board and extraneous signals. The amount of extraneous noise that can influence the PCB is dependent on the environment. Opportunities for on-board signal coupling, however, can be avoided with careful design. One set of terminals to be particularly cautious of are the input terminals of amplifiers and A/D converters. The problem arises because these terminals typically have high impedance inputs. As an example, the input terminals of an operational amplifier (IN+ and IN-) are extremely sensitive to coupled noise. The magnitude of the input resistance of these terminals is typically 10^9 to 10^{13} Ω.

PCB Capacitance : E-Field

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

$$I = C \frac{dV}{dt} \text{ amps}$$



w = thickness of PCB trace
L = length of PCB trace
d = distance between the two PCB traces
e_o = dielectric constant of air = 8.85 X 10^{-12} F/m
e_r = dielectric constant of substrate coating relative to air

Texas Instruments

Signal coupling problems occur when a trace that has a high impedance termination is next to a trace that has fast changing voltages, such as a digital or clock signal. In this situation, charge is capacitively coupled between the traces per the formula:

$I = C\delta V/\delta t$

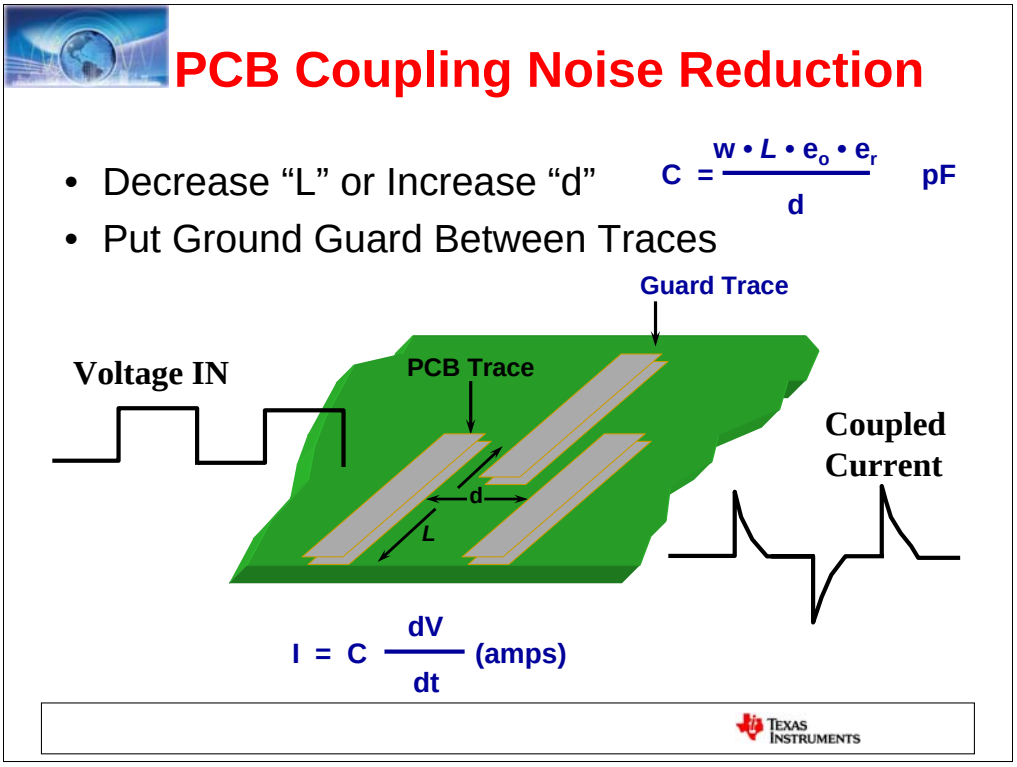
where I is current in amperes

C is capacitance

δV is change in voltage

δt is change in time

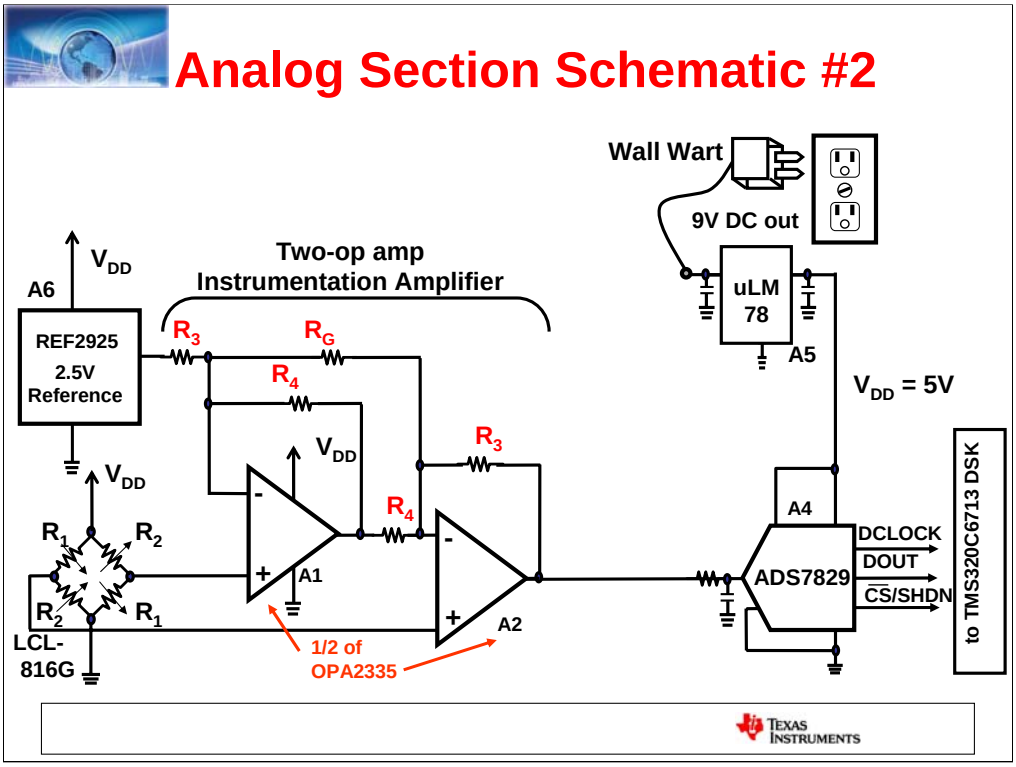
This slide illustrates how the value of the capacitance between two traces can be calculated. This capacitance is primarily dependent on the distance (d) between the traces and the distance that the two traces are in parallel (L).



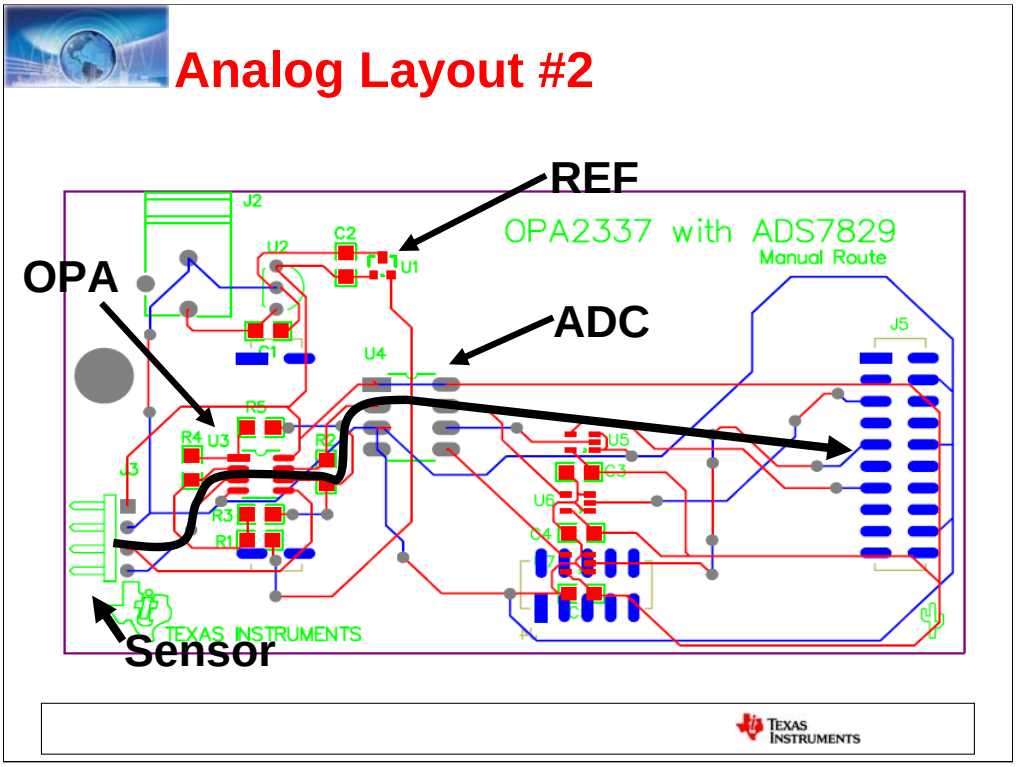
When there is a digital signal in one trace, the signal couples over to other traces and appears like a current instead of voltage. The key behind this phenomenon is that the voltage on the emitter trace needs to have a fast rise and fall time. Another condition that must exist is that the trace that receives the coupled signal must be high impedance termination.

A guard trace can be placed between these two traces. If this is done, the e-field is reduced.

Analog Section Schematic #2



Once again, here is our analog circuit. For this run, the resistors values have been reduced by 10x and the resistor type has been changed to wire-wound. Additionally, the amplifier has been changed from the OPA2337 to the OPA2335.



In addition to the 10x change in resistors and amplifiers, the layout has been changed quite a bit. First of all, the added temperature sensor circuit and reference block have be removed along with their jumper blocks.

The signal path is now stream-lined from one side (sensor) of the board to the other (ADC-connector). The length of traces have been reduced by about five times in an attempt to have the traces connect directly from device to device. You will note that the length of the trace that carries the digital code out of the ADC to the connector (on the right of the board) is long. The digital data at the output of the converter has high noise margins and is less susceptible to the same noise that causes significant problems in the analog circuitry.

System #2 Changes

- Device issues
  - Reduced resistors by 10 X
  - Replaced amplifier with lower noise version, OPA2335
- Radiation issues
  - Extra Circuits Removed
  - Loops Removed
  - Eliminated digital to analog trace coupling
  - Traces shorter

Texas Instruments

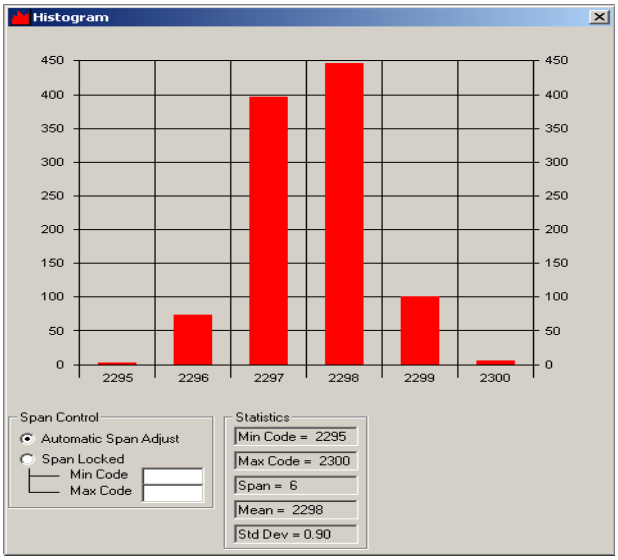
The resistors have been reduced by 10x. And the amplifier used in the instrumentation amplifier circuit is replaced with the lower noise version, the OPA 2335.

We have addressed the radiation issues by taking the loops out of the layout. In particular, the loop that went from the sensor to the amplifier to the ADC converter and then off the board has been stream line. We have also examined the board for areas where digital signals might couple across to analog traces. So let's look at the results of these changes on our new board.

Board #2 Test Results

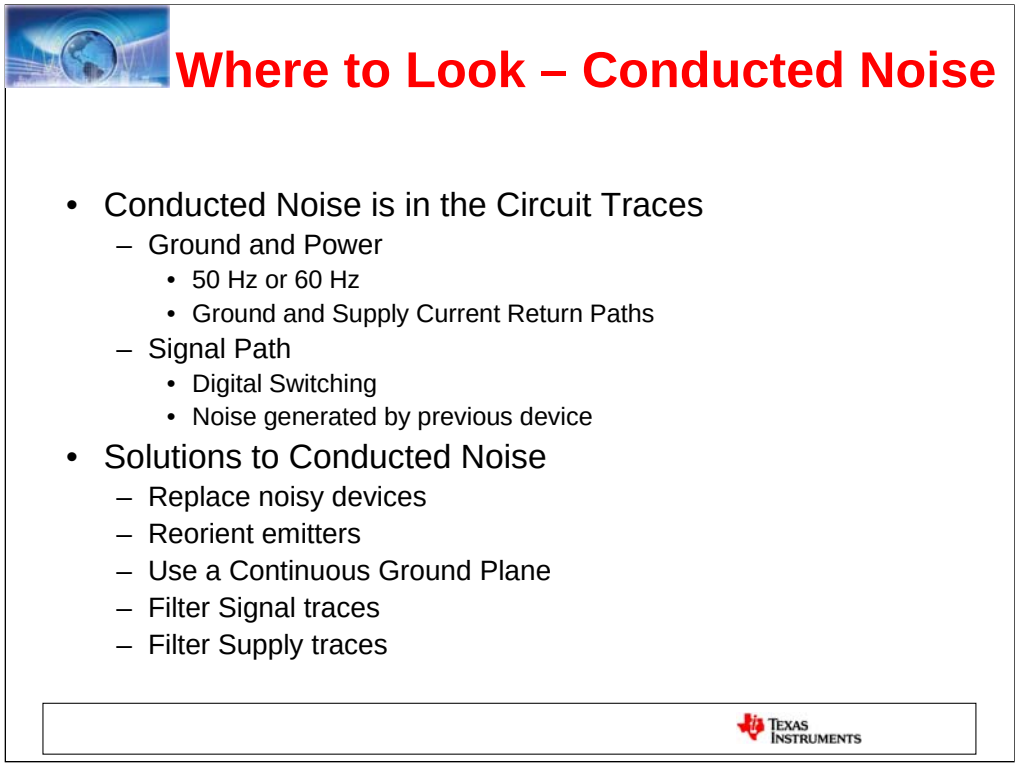
Code Width of Noise = 6

(total samples = 1024)



Texas Instruments

As this slide shows, the modified board has performed better than our first board. The code width of this histogram plot is six. Since these results reflect the noise of the system, the number of effective bits are now 9.4 bits (peak-to-peak).



So far, we have addressed the device noise and emitted noise issues on our board. Now let's talk about conducted noise and how it impacts our circuit.

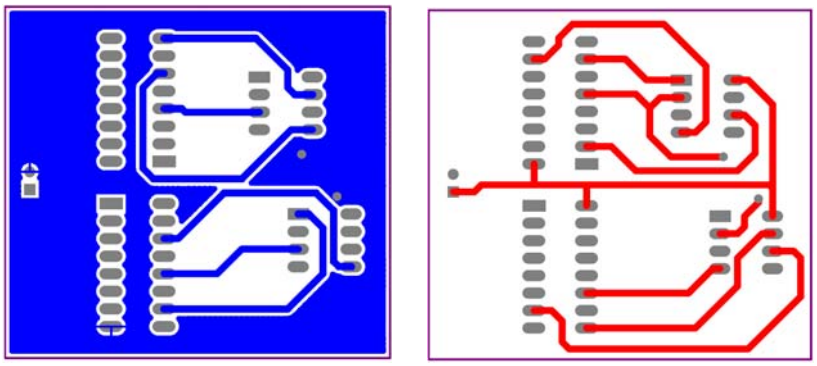
Conducted noise can be found in your application circuit traces. This noise originates as emitted or radiated noise as well as device noise.

Many times conducted noise problems can be corrected at the point of origin, whether it is replacing a noisy device or changing the environment in order to eliminate an emission problem. However, there are circumstances where this is impossible because of the primary purpose of a particular device or the nature of the environment.

For instance, an electrically isolated system needs isolated power that spans from one side of the barrier to the other. This type of isolation is provided with a DC/DC converter. A by-product of every DC/DC converter is switching noise on the power supply. Elimination of the DC/DC converter will remove the noise from the circuit but it will also remove the isolation barrier. Lower noise DC/DC converters are available on the market, however, the switching noise from this type of device is a standard by-product. Given this type of problem, there are techniques that can be used to minimize noise interference once it is present in the PCB traces.

Discontinuous Ground Plane

- Example of an Interrupted Ground Plane on the Back Side of the Board



bottom top

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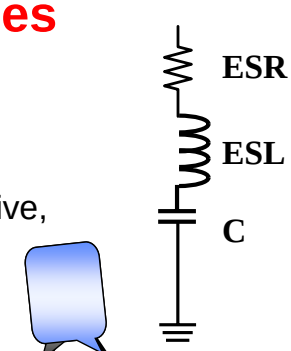
The definition and implementation of a ground plane and power supply strategy of a board layout is critical when designing low noise solutions. This is illustrated with the data presented so far. Both sets of data were taken with a board that did not have a ground plane. Assuming that a ground plane is not needed is a dangerous assumption in any circuit with analog and/or mixed signal devices. Ground planes solve problems such as offset errors, gain errors, and noise problems.

When determining the grounding strategy of a board, the task at hand should actually be to determine if the circuit can work adequately with just one ground plane or does it need multiple planes. If the circuit has a “minimum” amount of digital circuitry on board, a single ground plane and a single power plane may be appropriate. The board designer defines the qualifier “minimum”. The danger of connecting the digital and analog ground planes together is that the analog circuitry can pick-up the noise from the return currents which can couple into the analog signal path. In either case, the analog and digital grounds and power supplies should be connected together at one or more points in the circuit.

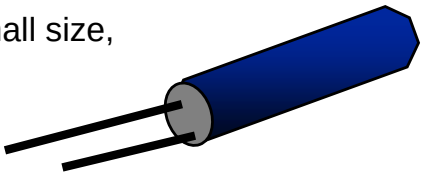
The inclusion of a power plane in a 12-bit system is not as critical as the required ground plane. Although a power plane can solve many problems, power noise can be reduced by making the power traces two or three times wider than minimum trace widths on the board and by using bypass capacitors effectively.

Bypass Capacitor Types



- Filters Noise at High Frequency
  - Ceramic - Small Case size, Inexpensive,
  - Good Stability, Low Inductance
    - C0G
    - X7R

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



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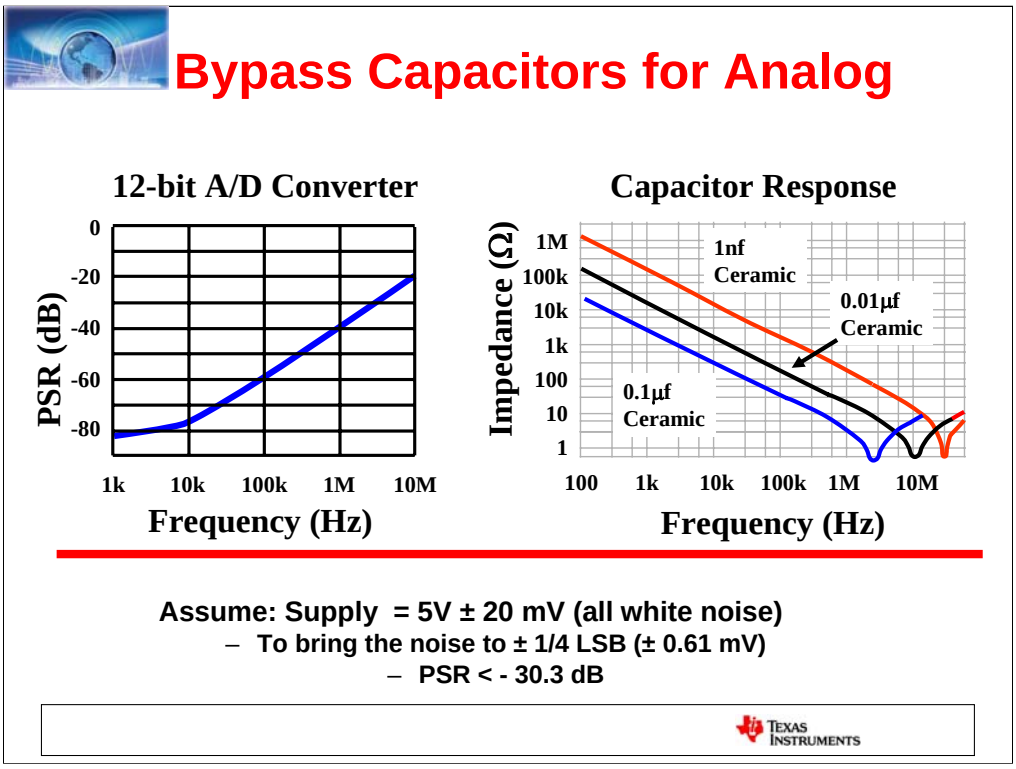
Regardless of the power supply source, good circuit design implies that bypass capacitors are used. This is true in all cases. For instance, a regulator, DC/DC converter, linear or switching power supply, can provide the power to the board. If the bypass capacitor is not included, the power supply noise may very well eliminate any chance for reliable circuit performance.

bypass capacitors belong in two locations on the PC board; one at the power supply (10μF to 100μF or both) and one on the power supply pin of every active device (digital and analog). The value of the device's bypass capacitor is dependent on the device in question. Generally speaking, if the bandwidth of the device is less than or equal to ~10MHz, a 0.1μF bypass capacitor will reduce injected noise dramatically. If the bandwidth of the device is above ~50MHz, a 0.01μF bypass capacitor is probably appropriate. In between these two frequencies, both or either one could be used. In all cases, it is best to refer the manufacturer's guidelines for specifics.

The leads of the device's bypass capacitor must be placed as close as possible to the power supply pin of the device. If two bypass capacitors are used for one device, the smaller of the two should be closest to the device pin. Finally, the lead length of the bypass capacitor should be as short as possible in order to minimize lead inductance.



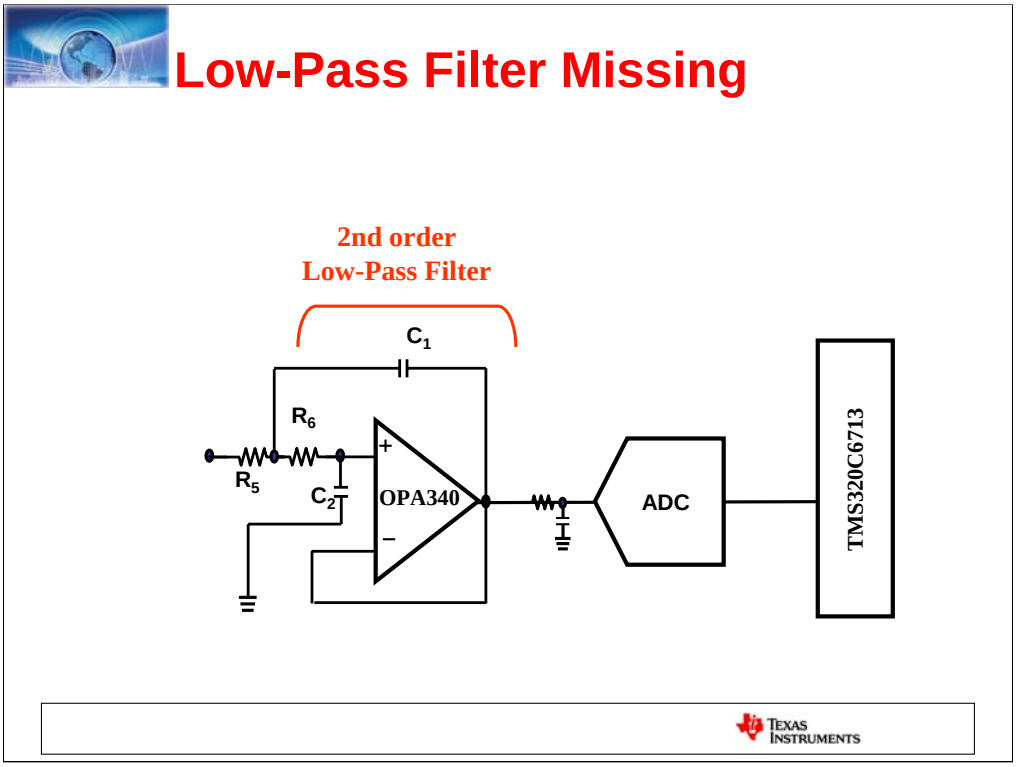
You should use the suggested bypass capacitor value per the product data sheet for your devices. If the device data sheet does not have a suggestion, these two graphs are helpful when you are selecting a proper bypass capacitor.

With the ADC graph on the left, the x-axis label is a log scale in frequency, ranging from 1 kHz to 10 MHz. Power Supply Rejection is plotted on the y-axis with units in decibels (dB). You will note that the power supply rejection capability of this 12-bit ADC at lower frequencies (1 KHz) is less that -80 dB. This is well below the ideal 74 dB Signal-to-noise Ratio (SNR) of this converter.

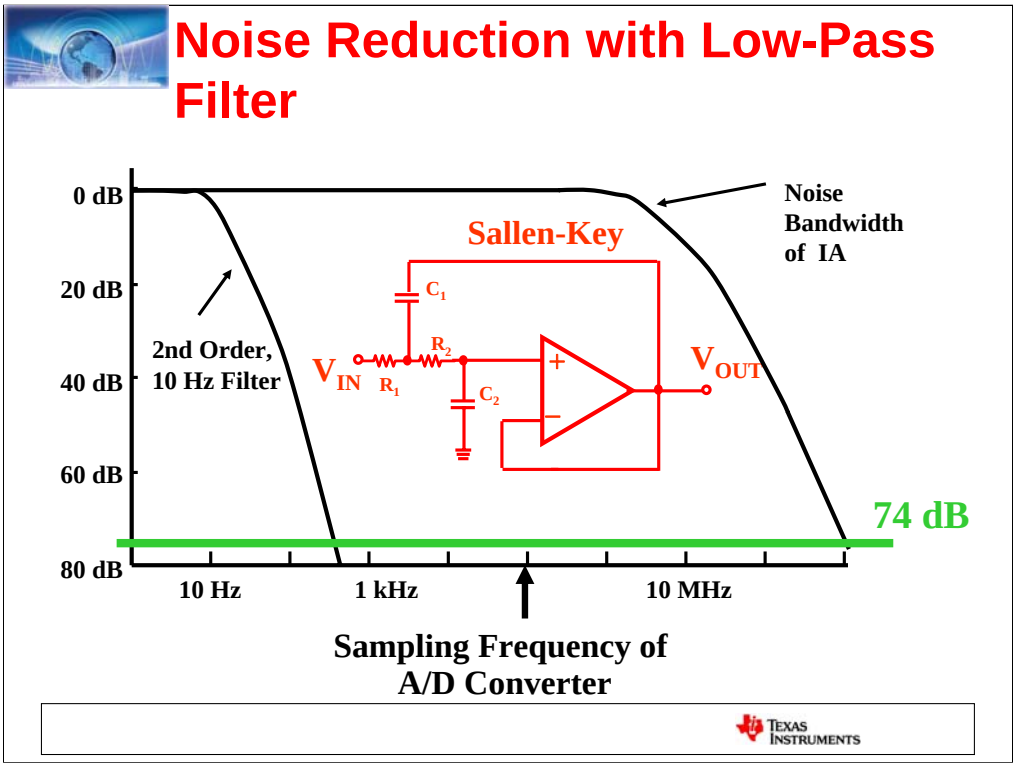
As frequency increases, the PSR moves towards 0 dB. At 10 MHz PSR is equal to -20 dB. From this graph you can read that a signal on the power supply line that has a frequency of 2 MHz will be attenuated by 30 dB as it goes into the ADC. For example, a 10 MHz, 5V+/-20 mV signal will appear at the output of the ADC as +/- 1.04 bits of noise. This noise can be reduced further by using a bypass capacitor on the power supply pin to ground.

The graph on the right side of this slide plots the impedance of various capacitors over frequency. Once again, the x-axis plots frequency (logarithmic) from 100 Hz to 30 MHz. The y-axis plots the impedance (logarithmic) in ohms of the capacitors from less than 1 Ω to 1 MΩ. You will notice in this graph that the 0.1 µF capacitor dips below 1 Ω at about 2 MHz and the 0.01 µF capacitor dips below 1 Ω at about 10 MHz. These are the frequencies where these capacitors are most capable of passing signals to ground.

If you match up these two plots you will find that an optimum capacitor value for our 12-bit ADC is 0.1 µF.



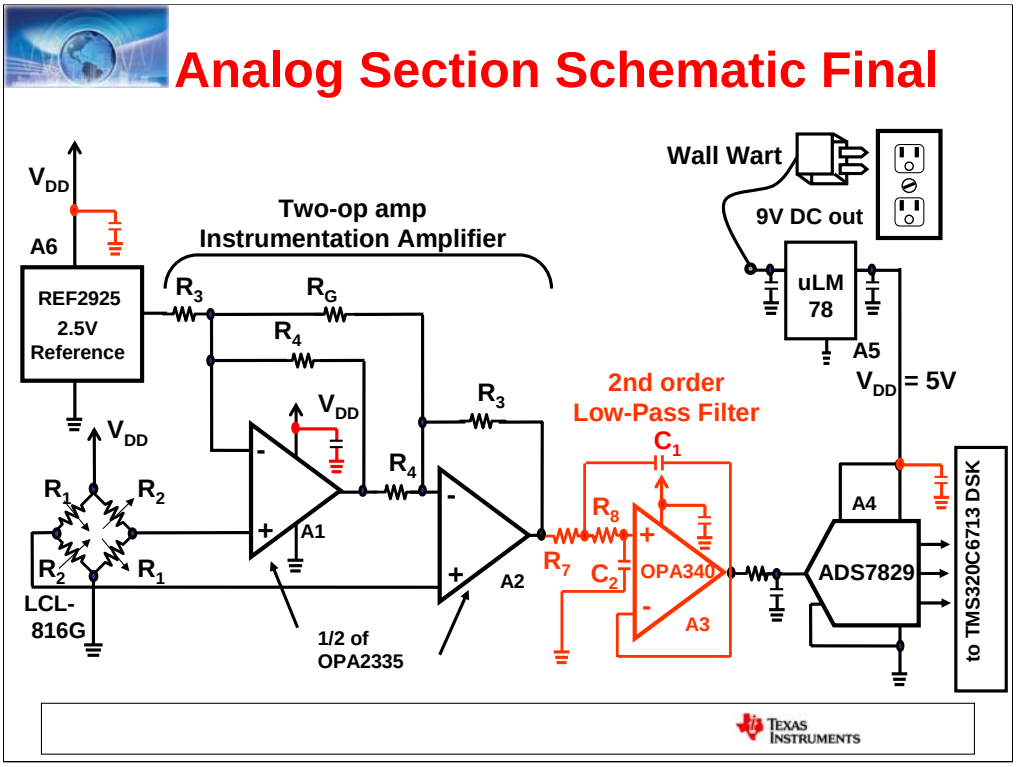
A system such as the one shown in our circuit must have an analog filter. The analog filter is always implemented in the signal path prior to the analog-to-digital converter.



The primary function of the low pass analog filter in this circuit is to remove the high frequency components of the input signal to the A/D converter. If these high frequencies pass to the A/D converter, they will contaminate the conversion data by aliasing during the conversion process. To illustrate this, a two pole anti-aliasing filter is added to the board.

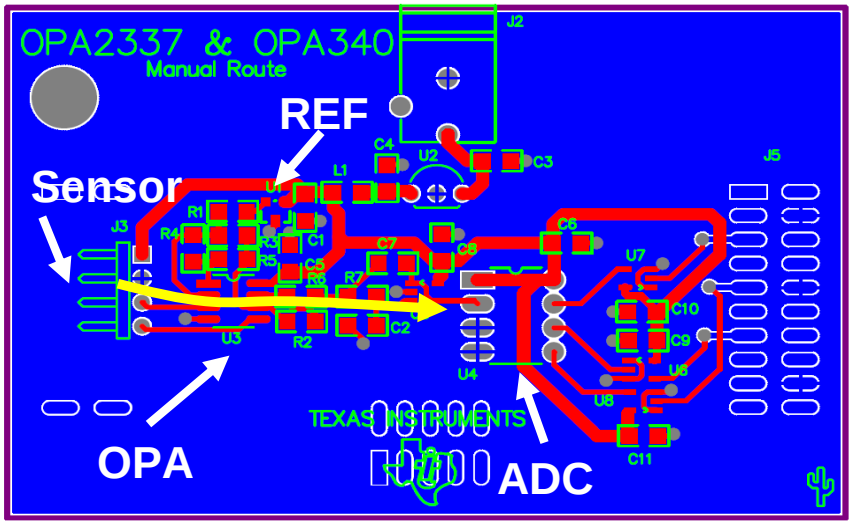
A second function of the analog filter in our circuit is to reduce noise that exists outside our bandwidth of interest. The load cell in our circuit operates near DC. Limiting the bandwidth with a 10 Hz lowpass filter further reduces the noise in our system.

Analog Section Schematic Final



In this second pass circuit, the bypass capacitors and the 2nd order low-pass filter have been added.

Analog Layout Final



The layout has been changed once more. The signal path is streamlined even further from previous board. The length of traces have again been reduced in attempt to have the traces connect even closer from device to device.

The ground plane is on the back side of the board and illustrated in blue in this diagram. Since these devices are in through-hole packages, the ground plane is interrupted, however, the power connector is at the top of the board in an attempt to stream-line the ground current return paths.

System #3 Changes

- 2nd Order Analog Filter Added
- Bypass capacitors included
- Has a Ground Plane
- Signal Path more Stream-lined
- Length of traces further reduced

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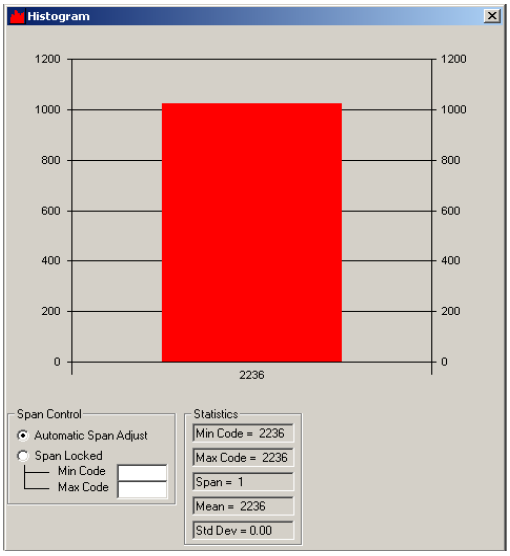
To summarize so far, the resistors around instrumentation amplifier circuit are R_3 = 40 kΩ, (+/-1%), R_4 = 10 kΩ, (+/-1%), and R_G = 533 Ω, (+/-1%).

The components in the 10 Hz, 2nd order filter are R_7 = 27.4 kΩ, R_8 = 196 kΩ, C_1 = 100 nF, and C_2 = 470 nF. Bypass capacitors are included and a continuous ground plane is added to the bottom side of the board.

Board #3 Test Results

Code Width of Noise = 1

(total samples = 1024)



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Eureka!

As this slide shows, the second modified board has performed better than our first two boards. The code width of this histogram plot is one. The number of effective bits are now 12- bits.

Noise in the Analog World

- The Noise will NEVER be Equal to Zero
  - Wise Layout Implementation
  - Devices Selection
  - Analysis of Environment
- Noise Reduction Rules of Thumb
  - Bypass all Components
  - Always use a Ground Plane
  - Current Return Path Evaluation

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In conclusion, it is important to realize that noise in your circuits and on your board is never equal to zero. You will always find that the devices on your board, such as passive resistors or semiconductors, generate noise which is deposited into the PCB traces. Additionally, you will find that your environment and PCB is capable of emitting and receiving noise.

The rules of thumb for avoiding noisy circuits is to bypass all of the components on the board, always use a ground plane, and spend some time thinking about the ground current return paths.

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Design Software

FilterPro Active Filter Design Software, www.ti.com

TINA , SPICE software, www.ti.com

Designing Mixed Signal Systems with Noise Reduction Techniques in Mind

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