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Dealing with Noise: A Practical Guide to Collecting Data in Harsh Environments

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Throughout the design process, experimentation and data collection are required to guarantee that a system is performing to desired specifications. In order to make informed design decisions, it is important to ensure that the quality of the data collected is high. Unfortunately, data corruption can occur in a number of ways that the intended recipient may not recognize. While a system redesign due to faulty data is costly and time consuming, preventing corruption can be simple and inexpensive. This paper presents a methodology for combating various forms of noise by performing a detailed sensor and acquisition system analysis, using proven hardware designs, and efficient post-processing techniques to remove sources of corruption while maintaining data integrity.

I. Introduction

THROUGHOUT the course of the Joint Precision Airdrop System (JPADS) Advanced Concept Technology Demonstration (ACTD), an instrumentation package and corresponding suite of sensors has been developed and matured by engineers at the Natick Soldier Research, Development, and Engineering Center (NSRDEC). It was the challenge of this instrumentation package to provide high quality data in the presence of harsh environments to include RF interference, extreme shock loading, widely varying temperatures, and tight space constraints. Over the last three years, an instrumentation box has been created that has proven utility, survivability, and repeatability over hundreds of drops. This paper discusses in detail some of the basic techniques used to protect and isolate test data from RF and EMI interference. The information presented here is just the very beginning of a complicated signal processing path, but it may help the reader in refining other data acquisition applications.

II. System Identification

A significant amount of time during data post processing can be saved if work is done up front to characterize the system during the test. What potential noise sources are present during testing? What operating procedures during test could contribute to noise or data corruption? How can noise in the system be characterized and isolated? If, for example, a military aircraft is being used to airdrop cargo, one can bet the radio frequency communications in the UHF band are in use along with GPS equipment. Without proper care, these common devices could cause significant distortion of the desired data.

The easiest way to answer the questions from above is to sample the desired data at a very high rate, then find the power spectral density (PSD) of the entire system. The PSD is a means of measuring the power of a signal per unit of frequency and is given in watts per hertz (W/Hz). Any known sources of interference will most likely be shown in the PSD. The radio frequency transmissions from the pilot of an aircraft or 802.11 data sent through a nearby network would be visible in the PSD and these frequencies can be isolated and filtered out or heavily attenuated, leaving the data uncorrupted.

Another factor to consider early in the design process is the sampling frequency during data acquisition. High sampling frequencies will require greater resources in terms of processing speeds and memory space, but will provide a clearer picture of what is happening during the experiment. Depending on the data acquisition components, sampling frequency may have to be limited. It is important to observe the Nyquist-Shannon sampling theorem which states that in order to properly reconstruct a signal from a set of samples, the sampling frequency used must equal or exceed the Nyquist frequency. The Nyquist frequency is equal to twice the highest frequency in the system under test. For example, if the system has a bandwidth of 200Hz, the Nyquist frequency is equal to 400Hz. Sampling must occur at or above this frequency. If the Nyquist-Shannon sampling theorem is not followed, aliasing will most likely occur. Samples reconstruction will occur in the wrong place and cause signal distortion.

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III. Filter Design

A wide array of filters exist that can be inserted into any circuit and made to work. Filters have a number of important characteristics that need to be considered before they are put into use in an experiment. Some of these considerations are given below.

A. Analog Filters

The very basic analog filter is constructed from a single-time-constant (STC) circuit that is composed of at least one reactive component (capacitor or inductor) and one resistance. These STC circuits are broken into two groups: high-pass (HP) and low-pass (LP). The HP circuit attenuates signals at low frequencies, passes signals at high frequencies, and ideally outputs zero at DC. Conversely, the LP circuit attenuates signals at high frequencies, passes signals at low frequencies, and ideally outputs zero as frequency approaches infinity.

Figure 1 shows two configurations of LP STC circuits. Both have resistive elements, but the first has a capacitor while the second has an inductor. The capacitor has an impedance of 1/jwC and can be thought of as an open circuit when frequencies are low and a short circuit when frequencies are high. The inductor has an impedance of jwL and can be thought of as a closed circuit when frequencies are low and an open circuit when frequencies are high.

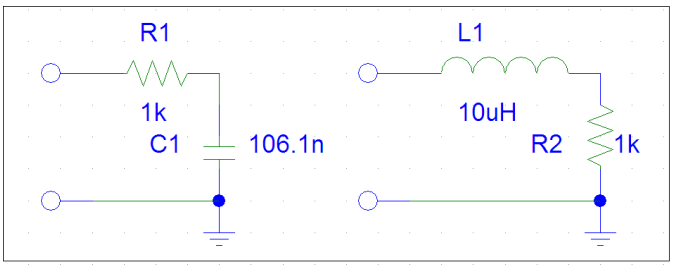

Figure 1. Low Pass filter STC circuits.

The transfer functions of these circuits are represented as Bode plots. Bode plots are extremely useful in determining the characteristics of the circuit. The cutoff frequency (fc) of the filter can be identified from the plot and can be specified as:

Fc = 1/2piRC or Fc = L/2piR

The cutoff frequency is the frequency at which attenuation reaches -3dB. After this frequency, attenuation will increase at a rate of -20dB per decade of frequency. When designing a filter of this type, select a convenient value for the capacitor or resistor, then calculate the value of the other component. A bode plot showing the magnitude and phase response for the capacitive LP STC circuit of Figure 1 is shown in Figure 2. A similar plot can be generated for the inductive circuit.

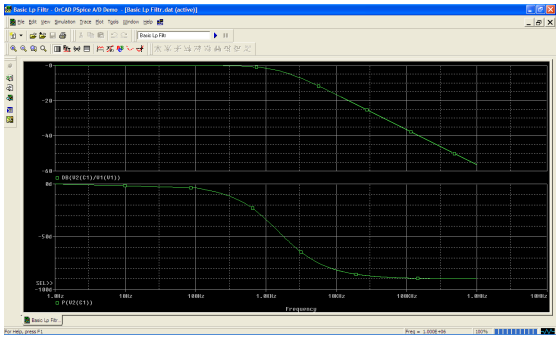

Figure 2. Magnitude and phase response for the capacitive LP STC circuit shown in Figure 1.

The same argument can be made for HP STC circuits. As shown in Figure 3, these circuits are again composed of a resistive element and a reactive element. Visualizing the capacitor and inductor as described above, it is clear that the circuits shown in the figure will both be open when frequencies are low and fundamentally resistive when frequencies are high.

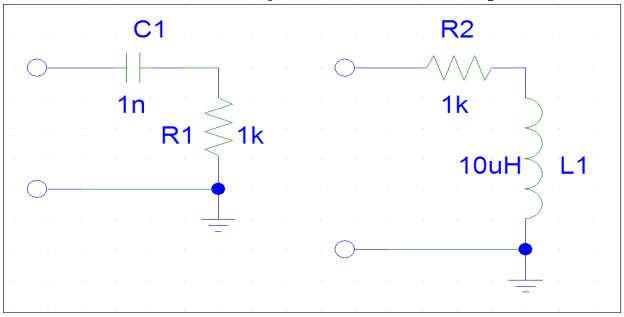

Figure 3. HP STC circuits.

It's interesting to note that cutoff frequencies for HP circuits are calculated with the same formula used with LP circuits as the time constants created by an RC or RL pair remain the same in either case.

Another interesting property of all four filters discussed so far is that each of the filters, whether HP or LP, RC or RL, induces a 90 degree phase shift in the output. This phase shift is due to the reactive nature of either the capacitor or the inductor. As proof, note the bode plot in Figure 4 the magnitude and phase response for the capacitive HP STC circuit in Figure 3. A similar plot could be created for the inductive STC circuit.

The filters presented in this paper are all first order filters, as they all will contain one reactive element. In order to achieve a faster roll-off rate, another STC circuit can be added to form a 2nd order filter. As a rule, each reactive element, properly arranged, will realize another -20dB/dec. Therefore, a 3rd order filter would roll-off at a rate of -60dB/dec. An ideal filter would have zero roll-off time; it would change from zero attenuation to maximum attenuation in zero seconds. Unfortunately, such filters are not physically realizable.

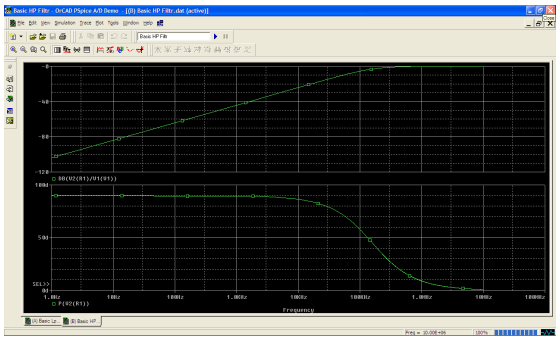

Figure 4. Magnitude and phase response for the capacitive LP STC circuit shown in Figure 3.

So far, the circuits discussed contain zero gain in the pass band. This can easily be adjusted so that the output is some scaled version of the input by using other components in the RC or RL networks. However, adding an operational amplifier (op-amp) to the circuit creates an active filter that is easily tunable with respect to both the cut-off frequency and the gain supplied to the output. As an example, take the circuit presented in Figure 5. The cut-off frequency equation from above still holds for this filter, but an added gain factor of R2/R1 must now be considered. In the case of the circuit in Figure 5, the output would be multiplied by 10. Some special considerations must be addressed when using active filters; details are given below.

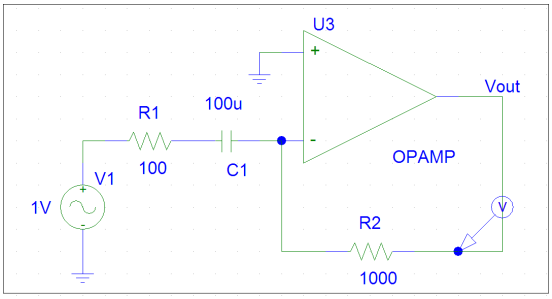

Figure 5. Active High Pass Filter.

Figure 6 is a bode plot displaying the magnitude and phase response. Because the filter is of 1st order, the roll-off rate is 20 dB/dec until the final value is realized. Note that the phase lag is a full 180 degrees due to the presence of the op-amp.

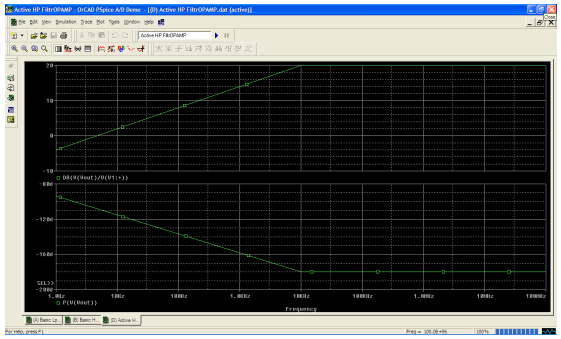

Figure 6. Magnitude and phase response of the active HP filter of Figure 5.

IV. Op-Amp Considerations

When using op-amps, several factors need to be considered. Failure to do so could result faulty operation of the amp and unnecessary loss of data. These considerations should be addressed in any op-amp application including instrumentation amplifiers, active filters and threshold detectors. Most of these op-amp characteristics will be specified on manufacturer data sheets.

A. Power Supply Rails

Op-amps will only amplify inputs up to the value of the op-amp power supply. If a 2 volt signal is input into an op-amp that provides a gain of 20 and is powered by +/- 10 volts, the output will saturate at 10 volts. In order to realize the expected 40 volts, a power supply of 40 volts must be used.

B. Slew Rate

An op-amp's slew rate (SR) is the maximum rate of change realizable at the op-amp output. If an input applied to the op-amp requires an output time response that is faster than the op-amp's SR, the output will still change, but it will take longer than expected. The output will be in a state known as slew-rated limited. If the output of the op-amp is being sampled by an A/D converter, it is possible that data points will be lost during slew limting.

C. Common Mode Rejection Ratio

A very important property of the op-amp which stipulates that if the positive and negative terminals are both at the voltage, the output should be zero. A low rejection ratio could become problematic especially when dealing

with higher frequencies. If one terminal picks up a small parasitic signal, it must be rejected, or it will show up in the output and cause distortion in the desired output signal.

V. Best Practices

Here are a few pointers that, when learned the hard way, can really destroy the data from an experiment and render all time spent basically wasted.

A. Grounding

Proper grounding is imperative to the collection of high quality data. The entire instrumentation suite, including the data acquisition system, must have a single point of ground. If multiple grounds exist, some may float, meaning they are not truly at ground.

Grounding is especially important when dealing with sensors that derive their value from a power source. Such sensors output a proportion of the power source

B. Output Buffering

Some applications require high input impedances in order to properly function. Many prepackaged instrumentation amplifiers need to drive high impedances at their outputs. Output buffering is a safe way to accomplish this. As depicted in Figure 6, a unity gain op-amp is added to the output of a circuit and acts as a buffer between the processed signal and any further actions on the signal.

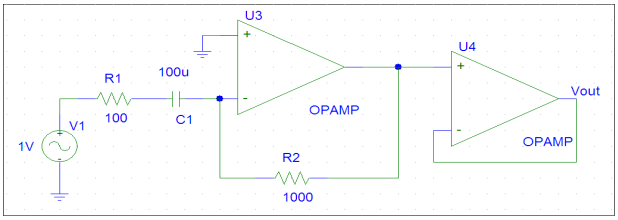

Figure 6. Active High Pass Filter with output buffer.

VI. Conclusions

As previously stated, this paper is really just the very beginning. The techniques mentioned above can be dramatically expanded upon to produce some fantastic results. It is the author's hope that the reader can use what was presented here, though elementary, to explore the signal processing possibilities that exist in every data acquisition application.

References

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