ANALOG SIGNAL ISOLATION TECHNIQUES*

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ABSTRACT

This paper discusses several techniques for isolating analog signals in an accelerator environment. The techniques presented here encompass isolation amplifiers, voltage-to-frequency converters (VFCs), transformers, optocouplers, discrete fiber optics, and commercial fiber optic links. Included within the presentation of each method are the design issues that must be considered when selecting the isolation method for a specific application.

INTRODUCTION

Signal isolation is a necessary feature of nearly every signal acquisition and processing system associated with an accelerator. This is in part because of the distributed nature of the signal collection. Signals are collected from the entire complex for monitoring at a single point which is typically the main control room. Without isolation, the grounds of several subsystems, each often with a different power feed and thus different ground potentials will be tied together to create ground loops. The loops will at best create noise in the processing electronics, and at worst render some systems completely useless. A similar situation occurs in distributing signals from a single point to multiple destinations. Again the danger of tying multiple grounds together exists. However, isolation is not solely limited to applications requiring the elimination of ground loops.

Isolation also has application where the desired analog signal is impressed on a common-mode voltage exceeding the systems supply rails. For example, at BNL's LINAC the signals used to monitor the operation of the ion source float at 35 kV relative to the local analog ground. In this case, the signals are coupled from the ion source using a combination of VFCs and digital fiber optic components, to a signal level compatible with standard analog processing systems. Rejection of common-mode high voltage can be accomplished for either single-ended or differential signal sources. However, differential applications offer the added benefit of noise suppression due to the common-mode rejection capability of the isolation device's front-end. Differential devices include baluns, some isolation amplifiers, and various optocoupler configurations.

For accelerators, the view of isolation can be broadened to include isolation from the effects of neutron and ionizing radiation. In the cases where electronic systems cannot be properly shielded or the systems must remain accessible during normal machine operation, it is necessary to transmit the analog sensor data to a location isolated from the radiation field. At BNL both optically

* Work performed under the auspices of the U.S. Department of Energy.

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presence of common mode signals is required. The common mode signals can be either potential differences across the input and output commons, or common-mode noise on a differential input. The second application is as a differential analog line receiver for low frequency signals. The third, and perhaps the most common, is breaking the ground loop between a sensor and its processing electronics.

In selecting an amplifier there are several key performance and isolation mode specifications that should be considered. The key performance specifications are nonlinearity, common-mode rejection (input to output), and both offset and noise referred to the input. The key isolation mode specifications include the barrier performance mentioned above and overload resistance.

In figure 1, the Analog Devices AD208 is shown. The AD208 is a 2-port isolated device with a bandwidth of 4 KHz and usable gains up to 1000 V/V. The front-end opamp shown is a TL062-type; it provides the AD208 with the flexibility of an opamp, and the functionality of an isolator. A unique feature of this device is the method for generating the isolated power. Most often the isolated power is achieved by internally chopping the DC supply rails and coupling the power to the input side via a transformer.

Figure 1. The Analog Devices AD208 (Courtesy of Analog Devices)

However in this case, the isolated power is derived from an external oscillator. This permits the use of a single oscillator to synchronize several channels at once, and minimize the possibility of beat frequencies in post-processing circuitry. The isolated power available on the input side is useful for driving either a transducer or high performance front-end amplifier. Although many isolation amplifiers supply isolated power, some do not. Providing isolated power off-chip can represent additional system cost and reduced channel density.

Other devices exist, such as the AD210 and 289, which are three port isolated. This means that the input, output and power ports are pairwise isolated and that isolated power is provided to the input and output ports.

pulse train of constant width and height, with a low duty cycle for small analog inputs. The duty cycle increases with increasing input level. The resistor R_{in} converts the input voltage to a current. The input current is then integrated by the feedback capacitor C_{int} , and causes the front-end amplifier output to decrease. When the amplifier output crosses the comparator trip point, an output pulse is triggered by the oneshot. The pulse duration is set by the capacitor C_{os} . During this pulse the integrator is reset to a positive voltage using the current source.

Figure 2. A Sample VFC converter configured for positive input.
(Courtesy of Analog Devices.)

When applying this technique, there are several important design considerations that must be balanced when selecting the component types and values. This is because in VFC and FVC circuits the linearity and drift performance are greatly influenced by the choice of the external component values and types, as well as the overall circuit parameters. Most manufacturers give simple algebraic equations for selecting the values of C_{int} , R_{in} and C_{os} as well as guidelines for the type of components to select. In selecting the component types most manufacturers recommend low tempco metal film resistors for R_{in} , low leakage capacitors such as silver-mica or polystyrene for C_{int} , and NPO type capacitors for C_{os} . Although for larger values, C_{os} can be silver-mica type and the circuit will most likely achieve adequate performance. In addition an output pull-up resistor, not shown in the figure, must also be chosen.

The other two VFC architectures available are the synchronous and astable multivibrator types. These two options differ from the charge balance type in the manner in which the pulse timing element is implemented. In the synchronous device, C_{os} and the one shot is replaced by an external clock and internal logic. Use of an external high stability clock removes the errors associated with the oneshot capacitor. An example of this type is the Analog Devices AD652. The

the materials and handling of the transformer during assembly of the circuit board. In addition the common mode AC isolation is limited by the parasitic capacitances of the transformer. Thus at higher frequencies, the rejection of common mode voltage will degrade, and the effects of such degradation should be considered during the design.

A less common application in instrumentation systems is the hum-bucker or longitudinal choke shown in figure 3b. In this application, the source signal appears differentially to the transformer but the common mode signals, such as ground transients or pickup on the cable, cannot pass through the transformer. This configuration is not useable when DC ground isolation must be maintained. To effectively use a transformer in this manner, the load and source impedances, including parasitics, must be balanced. Otherwise common-mode to differential-mode conversion can result, which may render the entire system useless.

Figure 3. Typical Transformer Applications.

LINEAR APPLICATIONS OF OPTOCOUPPLERS⁴

Linear circuits using optocouplers can be designed with passbands from DC to 20 MHz. The bandwidth and linearity achievable depend on the circuit configuration and the components selected. The two basic types of optocouplers suitable for analog systems are shown in figure 4.

SERVO TYPE

DIFFERENTIAL TYPE

VIDEO TYPE

Figure 5. Optocoupler Circuit Configurations
(Courtesy of Hewlett-Packard Co.)

precision connectors, fusion splicing, and high radiance sources. The wider core multimode fibers relax all of these requirements. Thus a trade-off between cost and performance must be made.

The intramodal dispersion is caused by the fiber's refractive index varying non-linearly across the spectral width of the source. This is often referred to as material or chromatic dispersion. The chromatic dispersion can be minimized in two ways. One way is to use lasers, either Fabry-Perot or distributed feedback (DFB), rather than LEDs in order to minimize the spectral width of the source. Laser diodes are several times more expensive than LEDs, and DFB lasers are more expensive still. However, the initial expense is offset by the wider bandwidth achievable due to the decrease in chromatic dispersion. The second method to decrease chromatic dispersion is, to select a transmitter operating in the 1330 nm region. This region provides the minimum chromatic dispersion for any transmitter type.

As a waveguide, fiber compares very favorably with coax in the areas of bend radius, size, and weight. Even the cost of fiber is very competitive with coax when purchased in similar quantity.

However, the doping of the fiber responsible for grading the index of refraction, providing zero dispersion at 1330 nm, and creating the minimum attenuation window at 1550 nm causes the fibers to be radiation sensitive. The fibers typically are doped with Boron, Fluorine or Phosphorus. These elements serve to improve the performance of pure silica fibers so that they can be used in telecom applications requiring both low loss and high bandwidth. However, in radiation fields, these same dopants cause the fibers to become sensitive to radiation. Not all dopants cause problems however. In some cases dopants are used to enhance the transient and long-term recovery of fibers exposed to radiation. Generally speaking though, for the best overall performance in a radiation environment, a pure silica fiber should be selected. At BNL we have used the Ensign-Bickford Optics HCS 200 micron core step index fiber in the AGS Booster. The fibers have been tested in the AGS at BNL to withstand an estimated 10 year dose in the Booster radiation environment.⁷

Selection of the receiver type also has an impact on system performance and cost. There are basically two types of photo detectors, the avalanche photodiode (APD) and the pin photodiode. In general APD circuits are much more complicated than pin circuits, and thus are more costly. This is due to the stabilization that must be performed for APD to provide reliable and stable high gain operation. APDs are generally used only where the received power is too low for adequate detection by PIN circuits.

Complete fiber optic links as well as separate components are available from many sources. Bandwidths of up to 12 GHz can be accommodated, albeit at very high cost. Therefore the option exists to either buy complete point-to-point fiber links as dedicated communication channels or to integrate subsystem components in house to meet the requirements of a specific application. In addition to single channel links, companies offer fiber optic multiplexing systems where many analog data channels are transmitted along the one fiber.

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