Design Brief 210

Using the Anadigm® TransferFunction CAM

Introduction

The Anadigm devices provide libraries of "Configurable Analog Modules" (CAMs), one of which is the TransferFunction CAM. This allows the user to define an arbitrary transfer function for the voltage-in, voltage-out block, and is intended for applications such as sensor linearization (thermocouples, LVDTs etc) and general waveform "shaping".

Transfer Functions

Figure 1 shows the "transfer function" of a simple amplifier, or gain stage. The block has an input voltage and an output voltage.

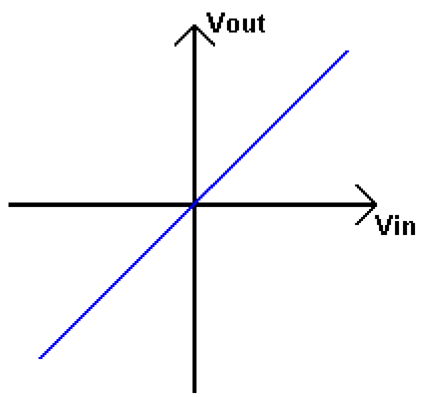

Figure 1: Transfer Function of an Amplifier

The transfer function here is a simple straight line (it is "linear"), and the gradient of the line represents the amplifier's gain.

The TransferFunction CAM may be used to provide non-linear transfer functions such as that shown in Figure 2.

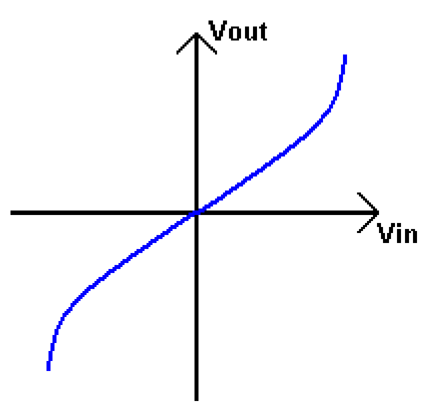

Figure 2: A Non-Linear Transfer Function

In this example, the transfer function is actually an "inverse sine", and may be used to convert a sine wave into a triangular wave i.e. it converts a sine wave into a straight line wave as shown in Figure 3.

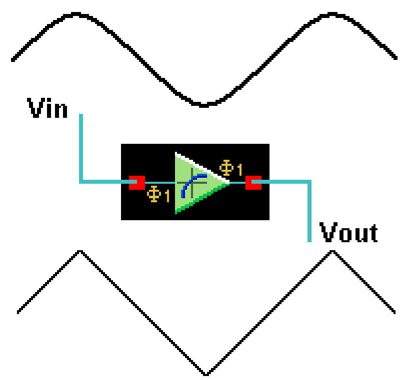

Figure 3: Effect of "Inverse Sine" Transfer Function

Block Diagram

The TransferFunction CAM works by digitizing the input voltage, and using the resulting digital word as the address for a "Look Up Table" (LUT - 256 x 8-bit RAM). The data word from the LUT is then converted back to an analog output voltage. The analog/digital conversions are carried out by an 8-bit ADC and 8-bit DAC as shown in Figure 4.

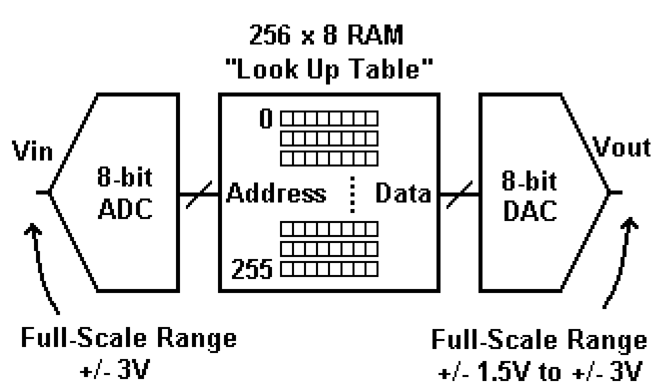

Figure 4: Block Diagram of TransferFunction CAM

The 8-bit ADC on the front-end has a full-scale range of +/-3V i.e. as the input voltage is swept from -3V to +3V the LUT address sweeps from 0 to 255 (decimal).

The content of the LUT (the data) is completely arbitrary and user defined. The data is converted to an analog output voltage with an 8-bit DAC whose full-scale range is flexible between +/-1.5V and +/-3.0V.

Defining the Transfer Function

The transfer function is stored in the LUT, and consists of 256 floating-point numbers. These numbers may be input manually, or loaded from a file ("CSV" format – numbers separated by commas) via the AnadigmDesigner2 schematic as shown in Figure 5.

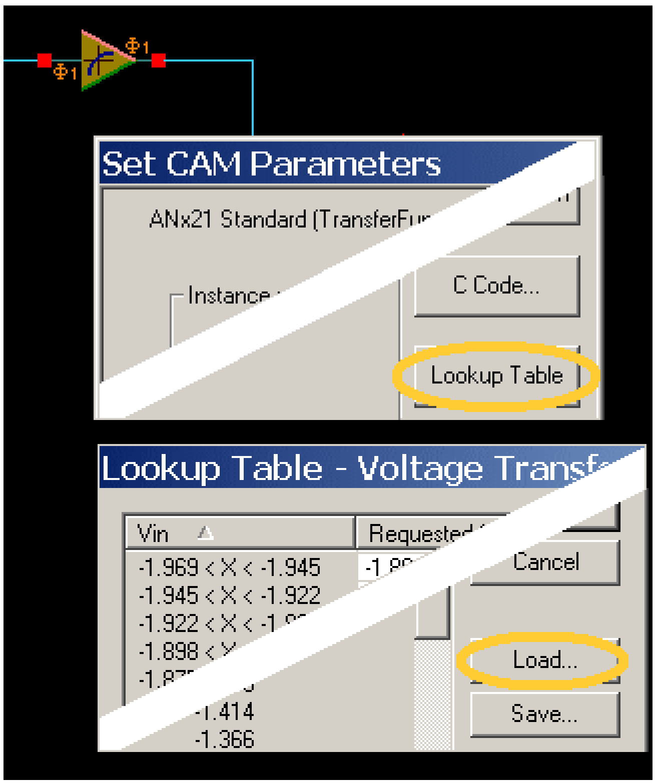

Figure 5: Loading the Transfer Function from a File

It is usually possible to create a CSV file from a spread-sheet program (use "Save As…"), or it may be more convenient to generate it with some sort of script. When it is "Loaded" into the TransferFunction CAM, the data is then stored in the schematic and the CSV file is no longer needed.

As Figure 5 shows, the CSV file is "Loaded" by double-clicking the CAM, pressing the "Lookup Table" button on the resulting form, and then pressing the "Load" button. If the transfer function needs to be changed, then the CSV file should be modified, and the loading sequence repeated.

Input and Output Quantization

The 8-bit ADC on the front-end "quantizes" the input voltage into 256 discrete levels – the levels are spaced between -3V and +3V as shown in Figure 6.

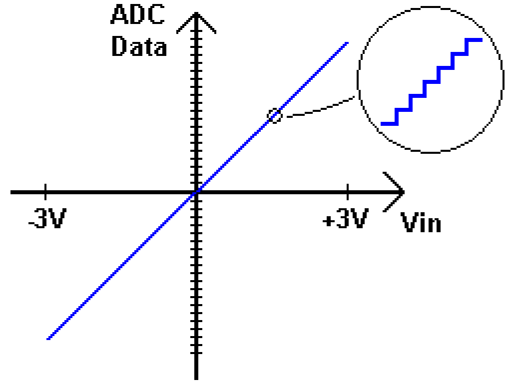

Figure 6: Quantization of the Input Voltage

Quantization of the signal introduces distortion and noise. It is important to arrange for the input signal to use as much of the +/-3V range as possible i.e. scale the signal so that it has a maximum amplitude of +/-3V. This allows the full 256 quantization levels to be used, and achieves the optimum signal-to-noise-and-distortion ratio (SINAD). The SINAD performance is that of an 8-bit converter, and is only moderate – with maximum signal amplitude the SINAD will be approximately 50dB.

The 8-bit DAC on the back-end of the CAM also introduces quantization errors. The DAC has some flexibility in the full-scale range of the output voltage – this means that the 256 quantization levels can stretch between +/-1.5V and +/-3.0V as shown in Figure 7.

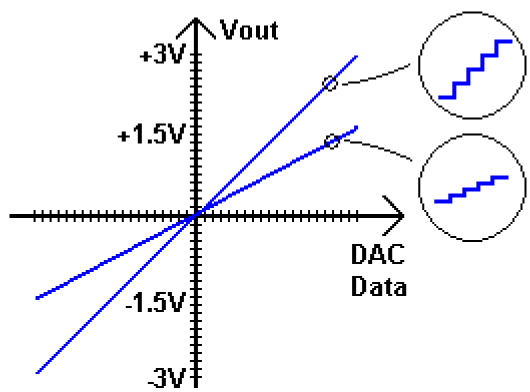

Figure 7: Quantization of the Output Voltage

It is important to arrange for the output signal to have as large a range as possible. A range less than +/-1.5V will not exercise all 256 quantization levels, and will not achieve the optimum signal-to-noise-and-distortion performance.

Minimizing Quantization

In addition to making sure that the input and output signals are as close as possible to the maximum, the performance can be significantly improved by using the TransferFunction CAM to create “delta” information rather than “direct”. Consider the example shown in Figures 2 and 3 which used a “direct” transfer function to convert a sine wave to a triangular wave.

Since the “inverse sine” transfer function contains a strong linear component (“it’s almost a straight line”), then it is beneficial to create that straight line component with a simple amplifier, and to use the TransferFunction CAM to generate the difference (the “delta”). The circuit is shown in Figure 8.

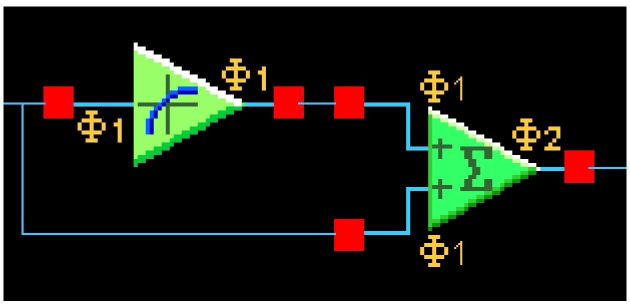

Figure 8: Straight Line Plus Delta

In this circuit, a “straight line” transfer function is provided by the lower input of the “summer” block, and the TransferFunction CAM provides the required perturbations from the “straight line”. In this case, the transfer function of the TransferFunction CAM is as shown in Figure 9. The optimum quantization performance is achieved by setting the TransferFunction output range to be at least +/-1.5 V, and then by scaling that signal down by setting the gain of the upper input of the “summer” block to be less than unity.

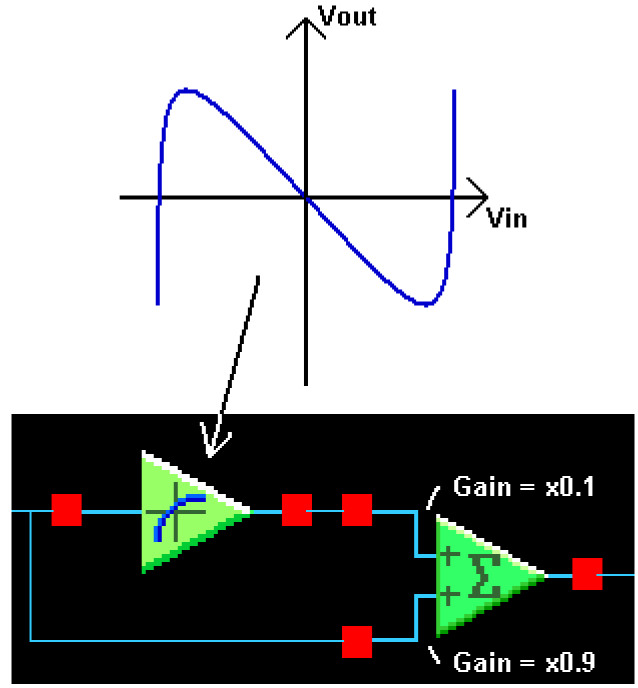

Figure 9: “Delta” Transfer Function and Summer Gains

In the example of Figure 9, it can be seen that quantization effects from the TransferFunction CAM are approximately 10 times less than they would be in the “direct” approach. This is due to the fact that the quantizing “steps” in the output waveform of the TransferFunction CAM are attenuated by a factor of 10 (the gain of the “summer” input is x0.1).

The reduction in quantizing effects is illustrated in Figure 10 which shows a section of the triangular waveform as it would be for a “direct” and “delta” transfer function circuit.

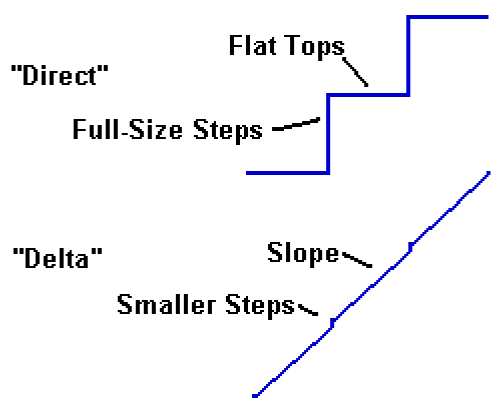

Figure 10: “Direct” Versus “Delta” Quantization

Linearization - Example Circuit

The TransferFunction CAM is typically used to create a non-linear transfer function for the purpose of compensating the non-linearities in a signal such as that from a thermocouple, LVDT, thermistor etc. In effect, the two non-linearities cancel each other out to provide a linearized signal e.g. voltage "exactly" proportional to temperature, or displacement etc.

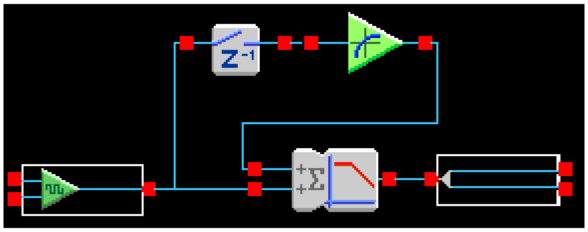

Figure 11: Example "linearization" circuit

The circuit in Figure 11 may be used to linearize the signal from a thermocouple for example. The signal voltage from a thermocouple is not exactly proportional to temperature, and comes with the additional challenge of being very small (e.g. 40 uV/degC).

In this circuit, the signal is first boosted by a chopper-stabilized amplifier in the input cell. It is then passed to the output via a summing stage (the CAM shown here happens to have some "free" low-pass filtering). The TransferFunction CAM is programmed with the "delta" information to compensate for the thermocouple's non-linear response, and this is summed into the output signal of the circuit. The TransferFunction CAM has a special requirement on its input signal – this must be stable or "held" during the CAM's sampling phase. This is accomplished here by the use of the Sample & Hold CAM which precedes the TransferFunction CAM, though many other CAMs will perform the same task.

Summary

The TransferFunction CAM allows the user to define an arbitrary transfer function, and is intended for applications such as sensor linearization (thermocouples, LVDTs etc) and general waveform "shaping".

The key points to remember when using the TransferFunction CAM are:

1. TransferFunction is a quantizing CAM which uses 8-bit analog/digital converters.
2. Scale the input signal to use the full input range.
3. Choose output values (LUT values) which utilize the full output range.
4. When the required transfer function is "almost a straight line", use the TransferFunction CAM to generate the "delta" information rather than the whole transfer function "directly".
5. The CAM input needs a stable/held input signal during its sampling phase.

For more product information, please visit Anadigm® at: www.anadigm.com

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