SUBSYSTEMS FOR DATA ACQUISITION – #39

Analog-to-Digital Converter (ADC) Function Card
ADC Function Card
Project Scope

- Design an ADC function card for an IEEE 488 interface box built by Dr. Robert Kolbas.

- ADC card will add capability to the current interface box.

- ADC card, in conjunction with the IEEE 488 interface box, will be used to communicate to a computer-based spectrum analyzer.
ADC Function Card
Product Appearance
ADC Function Card
Project Requirements

- Communicate with the computer via the IEEE 488 communication protocol.

- Accept IEEE 488 commands from the computer to set the sampling rate and transmit sampled data.

- Acquire a predefined number of 16-bit samples (8192).

- Accept analog input signals to sample in the range from 10 Hz to 25 kHz and to sample with a voltage range of +/- 10V.

- Sample the input signal with 16 bits of precision (15 bits + sign bit) and output the sampled data over the IEEE 488 interface to the computer, byte-by-byte.
ADC Function Card
Project Requirements – Cont.

- Be implemented using the wire-wrap technique.
- All integrated circuits on the ADC card will be mounted in sockets.
- Operate on the +15/-15 V and +5 V power supplied by the internal cabinet bus.
- Be reproducible for less than $250.
- Have a connector to which the analog input signal may be supplied
- Have an LED status indicator (ready/currently sampling/data acquired).
## ADC Function Card Design Alternatives – Summary

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<th>Multiple LP Time-Continuous Filters</th>
<th>Adjustable Switched-Capacitor LP Filter</th>
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<td><strong>Butterworth</strong></td>
<td>Bessel</td>
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<td><strong>ADC Chip</strong></td>
<td>Custom Circuitry</td>
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<td>x16 RAM</td>
<td><strong>x8 RAM</strong></td>
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<td>Pure Hardware</td>
<td><strong>Microcontroller</strong></td>
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<td><strong>PIC</strong></td>
<td>M16C</td>
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<td><strong>C</strong></td>
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<td>PCB</td>
<td><strong>Wire-Wrap</strong></td>
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<td>Soldering</td>
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<td>IEEE488 w/software</td>
<td><strong>IEEE488 Circuitry</strong></td>
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</table>
ADC Function Card
Design Alternatives

- Lowpass Filter (s): **Multiple Time-Continuous** vs. Adjustable Switched-Capacitor
  - Switched-capacitor filter can produce an artificial signal
  - “Multiple” in our case is only 2

- **Butterworth** vs. Bessel vs. Chebyshev
  - Butterworth gives best performance for simplest circuit
  - Chebyshev has too much ripple in passband
  - Bessel stopband attenuation is too low
  - Sponsor does not expect much high-frequency noise
    - (hi-freq noise would be a problem for Butterworth)

- **ADC Chip** vs. Custom Circuitry
  - Variety
  - Why reinvent the wheel?
  - Reliability
  - Easier to debug
ADC Function Card
Design Alternatives

- RAM width: x16 vs. x8
  - x16 chips aren’t free
  - IEEE488 bus only supports byte-at-a-time
  - ADC chip can output bytes separately

- Hardware vs. Microcontroller
  - Easier to debug
  - Familiarity with microcontrollers
  - Timing implementation

- PIC vs. M16C vs. AVR
  - M16C is 16 bit – too much power
  - Already have PIC development environment
  - Sponsor has experience with PICs
ADC Function Card
Design Alternatives

- **Assembly vs. C**
  - C first for ease of programming
  - Finer points/debugging in Assembly

- **PCB vs. Wire-Wrap**
  - PCB is difficult to rework
  - Research (not commercial) product
  - Easier for sponsor to modify

- **Sockets vs. Soldering**
  - May need to replace chips
  - Microcontroller will be replaced often (for reprogramming)

- **IEEE488: Software vs. Circuitry**
  - Handshaking = tedium
  - Consistency
  - Circuitry already designed and implemented
ADC Function Card
Sampling Rate Alternatives

#1 – **Fixed sampling rate (100 kHz) w/ 8K (8192) data points**
- Pros: easy; bus can handle data; good resolution (samples/period)
- Cons: at low frequency input signals, very few periods obtained

**100 kHz sampling rate and 8K data points**
- @ 25 kHz input signal
  4 samples per period (unavoidable, but not a big deal)
  2048 periods captured
- @ 1 kHz input signal
  100 samples per period
  ~82 periods captured
- @ 10 Hz input signal
  10000 samples per period
  **0.8** periods captured
ADC Function Card
Sampling Rate Alternatives

High sampling rate + fixed number of data points + low frequency input signal = bad stuff (incomplete sample)
ADC Function Card
Sampling Rate Alternatives

#2 – Fixed sampling rate (100 kHz) w/ 32K (32768) data points
Pros: good resolution; captures 3 periods of 10 Hz signal; easy
Cons: bus can't handle so much data

#3 – Fully-adjustable sampling rate w/ 8K data points
Pros: user can adjust sampling rate according to needs
Cons: tricky, need switch-capacitor filter (artificial signal)
ADC Function Card
Sampling Rate Alternatives

#4 – Two sampling rates (100 kHz & 10 kHz) w/ 8K data points
Pros: easy to implement (need only two LP filters), two choices of resolution, captures enough periods

100 kHz sampling rate and 8K data points:
@ 25 kHz input signal
  4 samples per period
  2048 periods captured

@ 1 kHz input signal
  100 samples per period
  ~82 periods captured

@ 122 Hz input signal
  ~820 samples per period
  10 periods captured
10 kHz sampling rate and 8K data points

@ 122 Hz input signal
~82 samples per period
100 periods captured

@ 10 Hz input signal
1000 samples per period
~8 periods captured
ADC Function Card
Sampling Rate Alternatives

# of Periods Captured vs. Input Frequency

![Graph showing the number of periods captured vs. input frequency for different sampling rates. The graph has two lines: one for 100 kHz and one for 10 kHz. The number of periods captured increases linearly with the input signal freq (Hz).]
ADC Function Card
Sampling Rate Alternatives

Sampling Resolution vs. Input Frequency
Much 60 Hz noise in the IEEE 488 box
Sponsor would like to distinguish 60 Hz + harmonics on spectrum
Computer performs DFT:

\[ \Delta f = \frac{f_s}{M} \]

- \( \Delta f \) = frequency spacing, \( f_s \) = sampling rate, \( M \) = # of samples
- 100 kHz sampling rate, 8192 samples: \( \Delta f = 12.2 \) Hz
- 10 kHz sampling rate, 8192 samples: \( \Delta f = 1.22 \) Hz
- Sufficient frequency resolution to distinguish 60 Hz harmonics on the spectrum
## ADC Function Card Cost Estimate

<table>
<thead>
<tr>
<th>Item</th>
<th>Qty</th>
<th>Price</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Pass Filter</td>
<td>3</td>
<td>12.58</td>
<td>37.74</td>
</tr>
<tr>
<td>Op-Amp</td>
<td>2</td>
<td>5.45</td>
<td>10.90</td>
</tr>
<tr>
<td>Op-Amp</td>
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<td>1.90</td>
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<td>Analog-to-Digital Converter</td>
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<td>34.35</td>
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<tr>
<td>Memory Chip</td>
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<tr>
<td>Microcontroller</td>
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<tr>
<td>PUM</td>
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<td>30.00</td>
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<tr>
<td><strong>Estimated Cost</strong></td>
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<td><strong>143.01</strong></td>
</tr>
<tr>
<td><strong>To-date Cost</strong></td>
<td></td>
<td></td>
<td><strong>30.00</strong></td>
</tr>
</tbody>
</table>
ADC Function Card
Block Diagram

- Status LED
- Analog Input
- Lowpass Filter
- PIC Microcontroller
- ADC Chip
- Bus Circuitry
- RAM Chip(s)
- IEEE488 Bus Interface
- Data
- Control
ADC Function Card
Schematic – Version 2

- **Status LED**
- **PIC18 microcontroller**
- **32Kx8 RAM**
- **7805 ADC**
- **5KHz circuitry**
- **50 KHz circuitry**
- **Relay**
- **UAF42 filter**
- **IEEE 488 bus interface**

Connections:
- **Analog Input**
- **Control**
- **Data**
ADC Function Card
PIC State Diagram

1) Wait for sampling rate from bus
2) Set LP filter frequency
3) Enable RAM/ADC

1) Supply sampling signal to ADC
2) Clock data into RAM chip(s)
3) Disable ADC
4) Setup RAM for output
5) Wait for TALK assignment
6) Set RAM chip to drive bus
7) Send data using DAV/NDAC/NRFD handshake

1) Reset everything
2) Setup RAM for output
3) Wait for TALK assignment
4) Disable ADC

1) Receive TALK assignment
2) Transfer Data
3) Transfer Done
4) Receive TALK assignment

ADC Function Card
Questions/Comments?