VLA / VLBA Interference Memo #7

Digital Spectrometer / Autocorrelator for Monitoring RFI

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Introduction

Dick Thompson wrote in a proposal for improved RFI monitoring, August 1994, that "monitoring of interference at radio astronomy sites is ... becoming steadily more important ... as the radio spectrum becomes more densely packed with man-made signals. In the past it was often sufficient to make surveys of interference when bringing new equipment into operation or when tracking down some particularly troublesome signal. It is now becoming increasingly desirable to monitor some observing bands during their use to provide improved efficiency in the subsequent editing of the astronomical data and to enable the observer to change frequency if serious interference is present." As part of his proposal, Thompson recommended the development of a digital spectrometer / autocorrelator to achieve optimum sensitivity for detection of weak interference. Thompson's spectrometer would take advantage of the large increase in capacity offered by the "Canaris chip," designed by J. Canaris of the University of New Mexico for use in new correlators at Green Bank and Arecibo [1]. To reduce costs, Thompson proposed using early Canaris chips that fall short of full bandwidth design value, and using boards already designed for the GBT correlator.

Interference monitoring at the VLA has proved useful. Randy Jones, an NMIMT coop student, put into service in December 1994, an RFI monitoring system at the VLA which uses a PC and a swept frequency spectrum analyzer to find interference in the IF of a single antenna [2]. The system has been used to document over 50 incidents of interference within a protected radio astronomy bands in the 5 month period starting in January 1995, where until that time, only a handful of operator reports of interference in a protected band are available for the previous ten years. Having been documented, identification and mitigation of the interfering signals can proceed. In addition, monitoring in the adjacent bands since January 1995, has led to improved dialog with the DOD Area Frequency Coordinator at White Sands Missile Range.

The IF monitor proves the efficacy of monitoring, but falls short in two important areas: 1) monitoring in the IF is subject to the vagaries of the observing schedule so that data are incomplete, and 2) monitoring with a spectrum analyzer limits the measurements to strong interference -- that appearing above the noise floor of the spectrum analyzer. Using the autocorrelator would permit looking at lower level interference, and with the addition of a frequency down converter, would permit monitoring low level signals directly on the output of the antenna front ends to correct both of the shortcomings. The purpose of this document is to outline initial plans for the spectrometer, and to serve as a design review.

The Spectrometer Design

The autocorrelator is a single input multi-channel digital spectrometer. The primary difference from a swept frequency spectrum analyzer is that all frequencies in the band being analyzed are measured simultaneously instead of sequentially, giving a larger (~500 times) effective integration time, and therefore a higher signal-to-noise ratio (SNR). The digital spectrometer offers a wider bandwidth than a typical Fourier spectrum analyzer [3]. The spectrometer consists of the following elements: 1) The autocorrelator, 2) A frequency down converter, 3) A controlling PC, and 4) Data analysis.

1. The Autocorrelator.

The autocorrelator is lag-type in that it finds the product of the input signal and the input signal with fixed time delays. The hardware configuration consists of 2 sampler analog cards, 1 sampler wirewrap card, 1 multilayer autocorrelator card, and a digital control card. Most of the card designs have been completed for the GBT correlator [4]. At the input to the autocorrelator is a Sony CXA1896D/K 8-bit 200 MHz flash A/D converter (Figure 1) which will accept an input signal power of 0 dBm and provide data for either 2-bit 3-level sampling or 4-bit 9-level sampling. The maximum sample rate is 125 MHz. The Sony sampler is selected because the design is complete and available. Level control must be provided for the input to the sampler. For use without a frequency down converter, level control may already be available at baseband monitor points at the VLA and VLBA. No phase quadrature is offered so that the correlation is "real" as opposed to "complex."

The GBT correlator boards use the UNM Canaris chip. The Canaris chip compares favorably with other correlator chip designs [5], but more importantly for this project, the design has been completed and verified and the cost is modest, especially for the early generation with limited bandwidths. Both 2-bit 3-level sampling and 4-bit 9-level sampling are available. 9-level quantization provides a ~15% improvement in signal-to-noise ratio [5] and 10 dB improvement in dynamic range [6] while 3-level would permit up to 4-channel operation and simpler design. The design selected is 4 channel in order to get the widest possible simultaneous bandwith. Since the initial bandwidth will be limited to 25 MHz by the Canaris chips, initial resolution bandwidth is then 25 MHz / number of lags or 25 MHz / 2048 or 12.2 KHz. 16 is the full complement of Canaris chips for the correlator board and would provide, 4 channels, 4096 lags and 12.2 KHz resolution with 50 MHz chips.

A bandwidth of 25 MHz requires a clock of 50 MHz; and a bandwidth of 50 MHz, a 100 MHz clock. If a frequency down converter is provided, the correlator clock could be generated from the same oscillator source as the converter LO. The clock must have sufficient accuracy for meaningful and stable frequency identification, < 1/10 x RBW, but phase locking to a time standard may not be necessary. An internal oscillator would be more convenient.

For the purpose of defining the interface from the correlator card into the PC, we assume all 16 Canaris chips are in use on the card. In order to work around the "ground bounce" problem, integration will be inhibited during the interval of time required to read the 1024 32-bit results from each chip. The maximum shift-out rate is 20 MHz transfers on the parallel 32-bit output bus or 50 nsec per transfer. 50 ns times 1024 transfers per chip times 16 chips =

0.8192ms or approximately 1 msec lost for each integration cycle. A FIFO buffer 16,384 deep by 32 bits wide will buffer the transfer from the chips to the PC. The transfer rate into the PC can be determined by multiplying 1024 results per chip times 16 chips times 4 bytes per result for 65,536 bytes per integration time. A block diagram of the correlator is shown in Figure 2.

The correlator is to be housed in a portable box. Room could be provided for the optional frequency down converter which, according to L. Beno, should take up a volume equivalent to a "loaf of bread." The cards could be sandwiched with hinges to permit scoping access rather than using a bin. Although the autocorrelator is proposed for use in monitoring at a shielded building, the high-speed digital circuitry and clocks up to 100 MHz are likely to generate interference in 4, P, and possibly even L band. As well, the LO must be prevented from coupling back into the receiver system. Hence, RFI shielding of the correlator cabinet and PC seems strongly indicated.

2. The Frequency Down Converter [7].

The input to the correlator must be baseband or passband and less than the analog bandwidth of the sampler. To extend the use of the autocorrelator to monitoring at the IF or the direct output of 4, P, and L band receivers, conversion to a lower frequency is necessary. The frequency range is 1300 - 1700 MHz for the VLA IF, though monitoring IFA and IFB only from 1300 - 1450 MHz would be adequate. IF frequency range at the VLBA is 500 - 1000 MHz. For monitoring receiver outputs, P band for the VLA is 300 - 345 MHz, and for the VLBA is 300 - 345 MHz and 608 - 614 MHz. L band at the VLA is 1155 - 1734 MHz and at the VLBA is 1260 - 1840 MHz. Also to be considered is "4" band at the VLA, 72.9 - 74.7 MHz.

Bandwidth of the correlator will vary from 25 MHz to 50 MHz as a function of the Canaris chip generation in use. The LO frequencies should be selected so that the bandwidth can be "slid" along the band to be converted. Assuming 4 channel operation the steps for single channel would then nominally be 200 MHz to permit conversion in sequence of the entire band being investigated. The steps should be slightly less than 200 MHz to permit an overlap. Although 5 MHz is commonly available at both VLA and VLBA, the frequency standard may be generated internally for convenience.

Automatic level control must be provided to keep the correlator input at 0 dBm, so that a square law detector may also be necessary. Control and monitoring of the converter will be via the parallel port on the controlling PC. For convenience, housing the converter in the same box with the correlator would be convenient. A block diagram of a conventional baseband converter is shown in Figure 3.

A digital IF processing technique called under sampling would permit Nyquist sampling over a range of frequencies offset from DC where the bandwidth is ½ of the sampling frequency [9]. The technique performs part of the down conversion task, and requires anti-aliasing filters and an A/D converter with a fast sample and hold.

3. The PC.

A full-size computer is proposed for the spectrometer because of the additional I/O slots available over a lap top. Initially, only a parallel port or printer port is necessary, but additional I/O to be provided later may include an IEEE 488.2 port for use of a spectrum analyzer in tandem with the autocorrelator, and a TCP/IP port for remote control, to transfer data to a "virtual instrument" controller at the AOC, and to access antenna pointing and receiver frequency tuning at the VLBA sites. Incidentally, antenna pointing, receiver frequency tuning time, and date are available from the station computer at both VLA and VLBA.

Since the autocorrelator will be lag-type, the FFT can be done in the PC. Chuck's benchmark software shows that a 4k FFT on 2K lags with overhead for system operations can be done in 160 ms and an 8K FFT 4096 lags in 300 msec on an Intel Pentium 66 MHz platform machine so that a hardware FFT may not be necessary. Comparable results may be attainable on an Intel 486 platform.

The PC must receive initially 2048 lags or 2048 32-bit data words times the number of channels from the autocorrelator every integration period. The autocorrelator will be expandable so that 4 channels, each with 4096 lags, may become available. At the low end, the integration period is limited by the time needed for downloading data and by the FFT; and at the high end by the accumulators which overflow after a few minutes. 1 second seems a nominal integration period for a starting point, though the integration time may have to be increased to 2-3 seconds for 4 channel operation. The PC should be able to read any status registers in the correlator or baseband converter. Also to be considered: a diagnostic read-back feature allowing the PC to write data to the correlator and read it back for operational verification.

Although the autocorrelator design will permit upgrading of the original 25 MHz bandwidth to 50 MHz, there does not appear to be any need for PC control of bandwidth. For use with a frequency down converter, the PC should have control of the LO. Total power and gain from the converter automatic level control should be readable. Resolution bandwidth is a function of the number of lags. Though the number of lags available initially is fixed at 2048 lags, 4096 may become available. There does not appear to be any need for lag selection under PC control.

Each integration can be processed by the PC much as a spectrum analyzer scan is processed now by the IF monitor; that is, the PC will maintain a running average in one buffer, and a "peak hold" in another. Peak hold is computed by saving the peak amplitude for each channel. The average data will show signals present during the majority of a measurement period, and peak hold will show the maximum signal level that occurred during the same period. The average and peak hold buffers can periodically be written to disk and/or transmitted to a host computer via a TCP/IP connection, if available. Though the average and peak buffers for the current IF monitor are saved every 15 minutes, that interval is dictated by a balance between the length of a "typical" observing run versus the desire to minimize the number of data files to process. For the autocorrelator, the accumulation period should be adjustable from every integration period up to at least 1 hour in minimum increments of a few seconds.

A monitor display should be sufficient to permit manual control of the autocorrelator/spectrometer and verification of the operation. The "control panel" for the existing IF monitor (Figure 4) can serve as a guide. For example, the current panel includes plots of the current span, the average buffer, and the peak hold buffer as well as a display of date and time, filter, center frequency, and file name in progress. For the autocorrelator panel, the results of the readback diagnostic and status registers should be added. Software buttons and/or fields for entry of parameters should also be provided. A comment field is required for entering external parameters such as attenuation, gain, location, antenna pointing, total power input data from the BBC, and receiver noise cal sync data. Most of the parameters are available via TCP/IP.

The current IF monitor was written in National Instruments LabVIEW, software intended to simplify and shorten the development of a "virtual instrument". Though canned drivers in LabVIEW are available for many test instruments, drivers would have to be developed for both the baseband converter and correlator for this application. As well, remote accessibility to the PC via the TCP/IP port for software and file maintenance may be limited with LabVIEW. A Unix-based operating system such as Solaris or Linux may provide greater versatility. Solaris is to be available on all the AOC Suns soon, but Linux is in common use on the NMIMT/NRAO campuses and uses less memory. A deciding factor may be the availability of software drivers for the hardware required.

4. Data Analysis.

Without the frequency down conversion, use of the autocorrelator will be limited to a 50 MHz baseband at the VLA and a 16 MHz baseband at the VLBA. In any case, two data buffers will be produced every second to every few minutes, so that the amount of data from the autocorrelator will be overwhelming without careful planning. For long term surveys such as the P and L band VLA survey, the data must be reduced automatically. For instance, graphical analysis software, such as PVWAVE, could automatically present the data from the autocorrelator PC in 3D representations. Two possibilities come to mind: 1) a "waterfall" plot in which the x axis would be frequency, y axis power flux-density, and an "isometric" axis time, or 2) a color plot in which the x axis is time, y axis frequency, and color the power flux-density. Power flux-density implies knowledge of antenna gain, which for many cases can be assumed to be 0 dBi, but may not always be known. Total power input data from BBC and/or receiver noise cal sync data may also be necessary to calibrate the amplitude of the spectrum, at least relative to the system noise temperature. These parameters are available at the VLA and VLBA via the station computer.

Separate plots would be necessary for peak and average. Each plot would be annotated with date, time, location, frequency range, RBW, and delimiters for protected bands. An accompanying plot showing antenna position might be useful. The period covered for each plot should be at least a day to save space. The plots could be accessible via the NRAO home page on the World Wide Web (WWW) for use by observers in planning observations.

Interference in the long term survey should be automatically detected and the results entered in a database. From the database, the probability can be determined for interference at a given frequency for different power flux-densities as a function of time-of-day, day-of-week, day-of-year, and antenna position. Antenna position, time and date can be accessed via the TCP/IP. Again, the information is to be made available on the WWW.

Short tests imply manual manipulation of the data. The data can be saved on disk and read back later into reduction software. The reduction software, like the long-term plotting, would also produce a graphical representation, but in this case, parameters must be changeable to accommodate, for instance, frequency conversion from IF to sky frequencies. For maintenance and short term monitoring at remote sites, a "virtual instrument" LabVIEW style, accessible via zia would provide remote control and operational verification of the autocorrelator.

Use of the Autocorrelator

Without the frequency down converter, the autocorrelator can be used to monitor a 50 MHz baseband signal at the VLA T5 module. A question that needs to be answered is if AGC is provided before or after the monitor point. At the VLBA, the autocorrelator can be used to monitor baseband output of one of the BBCs, which would have 16 MHz or less bandwidth depending on observing.

The addition of a frequency down converter opens up the possibility of monitoring on the output of 4, P, and L band receivers and of monitoring the IF. A separate proposal calls for installation of a transmission line from the antenna at pad DW8 to the VLA control building (CB) to permit continuous monitoring of interference entering the sidelobes of the antenna at DW8. All array configurations include an antenna at that location. Using splitters, amplifiers, and a coupler, the line will carry the outputs of both 4, P, and L band receivers so that the bands 73-75 MHz, 300 - 345 MHz, and 1155 - 1734 MHz can be monitored at the CB continuously and independently of the observing schedule. The signal line can be connected to the autocorrelator for RFI analysis. Since the dynamic range of the autocorrelator may limit its measurements of strong RFI, a spectrum analyzer monitor like the IF monitor system may also be connected to the signal line to look for strong interference; in fact, the autocorrelator and spectrum analyzer control can be combined in a single full-size PC.

A typical operating scenario with the frequency down converter calls for performing a scan over the bandwidth of the autocorrelator, shifting the LO to scan the adjacent observing band, and so on until the entire band is covered, then repeating the cycle. This requires 2 data buffers per channel times the number of scan bandwidths in the band to be measured.

Task Assignments, Schedule, and Costs.

The Correlator Group will design the correlator, procure the parts to include the PC, and develop sufficient software to prove the operation. As many as 6 units may be built.

The Interference Protection Group (IPG) will plan, procure materials for, and install the transmission line from DW8 to the AOC and the spectrum analyzer for 4, P, and L band monitoring. Software for the spectrum analyzer-based monitor will be developed on a full-size PC separate from the autocorrelator PC; software developed by the Correlator Group will be incorporated on the IPG PC when the autocorrelator becomes available. IPG will also add to the Correlator Group software as necessary to control the baseband converter and provide the operational features described earlier. Finally, development of the graphical and statistical presentation of the data falls on the IPG.

Development of the frequency down converter requires additional specification, and for budgetary reasons will be a follow-on project.

The target date for testing a prototype of the autocorrelator is 31 December 1995. Cost of the autocorrelator and computer is estimated at $10k, not including upgrade to 50MHz Canaris chips (Figure 5).

Conclusion:

The autocorrelator will permit measurement of low level interference in the baseband at both the VLA and VLBA and at other radio telescopes. With the addition of a frequency down converter, it would also be possible to monitor the outputs of 4, P, and L band receivers and to monitor in the IF. Though the initial bandwidth and resolution bandwidth of the correlator will be 25 MHz and 24.2 KHz, respectively, upgrades can increase the number of channels to four, each with a bandwidth of 50 MHz and resolution bandwidth of 12.2 KHz. Data can be gathered on disk or via a TCP/IP connection, the latter providing a remote control capability. The final result of the surveys will be graphical and statistical information on interference; the information will be available to the astronomical community via the World Wide Web.

References:

[1] High performance CMOS correlator, Preliminary Product Specification, University of NM, Albuquerque, NM, Aug. 18, 1993.
[2] The VLA IF Interference Monitor, VLA / VLBA Interference Memo #8, C. Janes, R. Jones, D. Jenkins, June 1995.
[3] An Interference Monitor with Real-Time FFT Spectral Analysis for a Radio Observatory, D. Romalo, P. Dewdney, M. Ito, and T. Landecker, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 4, August 1989.
[4] The Proposed GBT Correlator, GBT Memo 108, Carl Heiles, September 1993.
[5] A Survey of Digital Correlation Spectrometers, Robert Hayward, Herzberg Institute of Astrophysics, Proceedings of a Workshop on New Generation Digital Correlators, NRAO, Tucson, AZ, February 1993.
[6] Private Communication, D. Bagri, July 20, 1995.
[7] Cross-correlators, preliminary draft, Larry D'Addario, June 5, 1995.
[8] VLBA Baseband Converter Module T122, VLBA Technical Report No. 36, Alan E. E. Rogers, October 1988.
[9] Digital IF Processing, C.Olmstead and M. Petrowski, RF Design, Vol. 17, No. 10, Sept. 94.

Preferred Sampler

SONY

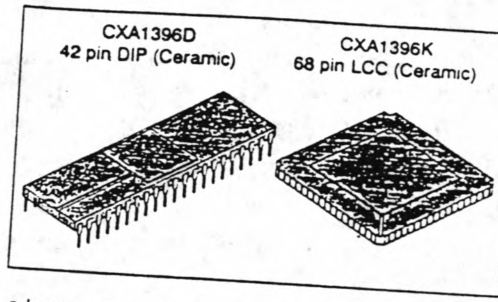
CXA1396D/K

8-bit 125 MSPS Flash A/D Converter

Description

The CXA1396D/K are 8-bit ultrahigh-speed flash A/D converter ICs capable of digitizing analog signals at the maximum rate of 125 MSPS. The digital I/O levels of these A/D converters are compatible with the ECL 100K/10KH/10K.

The CXA1396D is pin-compatible with the earlier model CX20116, and the CXA1396K with the CXA1066K. They can replace the earlier models respectively, without any design changes, in most cases. Compared with the earlier models, these new models have been greatly improved in performance, by incorporating advanced process, new circuit design and carefully considered layout.



Features

- Differential linearity error: ±1/2 LSB or less
- Integral linearity error: ±1/2 LSB or less
- Built-in integral linearity compensation circuit
- Ultrahigh-speed operation with maximum conversion rate of 125 MSPS (Min.)
- Low input capacitance: 17pF (Typ.)
- Wide analog input bandwidth: 200MHz (Min. for full-scale input)
- Single power supply: –5.2V
- Low power consumption: 870mW (Typ.)
- Low error rate
- Operable at 50% clock duty cycle
- Good temperature characteristics
- Capable of driving 50 Ω loads
- 2 types of packages for selection according to applications

Structure

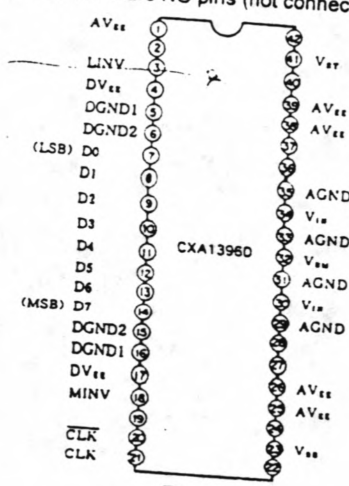
Bipolar silicon monolithic IC

Applications

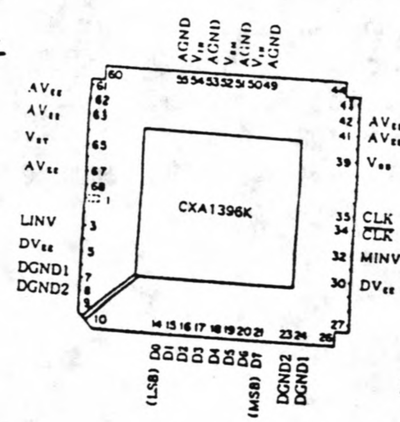
- Digital oscilloscopes
- HDTV (high-definition TVs)
- Other apparatus requiring ultrahigh-speed A/D conversion

Pin Configuration

Pins without name are NC pins (not connected).



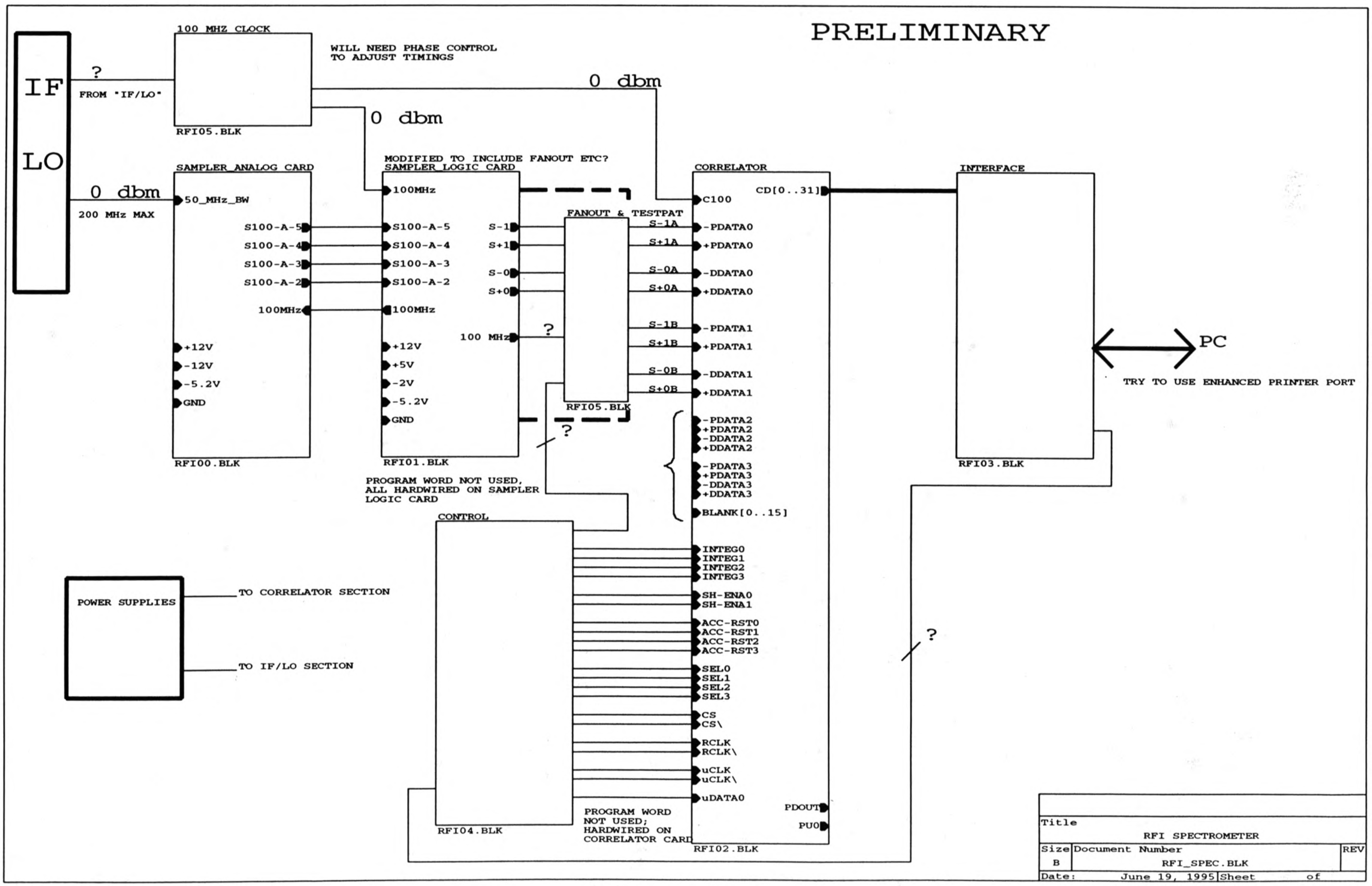
(Top View)



(Top View)

4

FIGURE 2



PRELIMINARY
IF
LO
?
FROM "IF/LO"
0 dbm
200 MHz MAX
100 MHZ CLOCK
RFI05.BLK
WILL NEED PHASE CONTROL
TO ADJUST TIMINGS
0 dbm
0 dbm
SAMPLER_ANALOG CARD
50_MHz_BW
S100-A-5
S100-A-4
S100-A-3
S100-A-2
100MHz
+12V
-12V
-5.2V
GND
RFI00.BLK
MODIFIED TO INCLUDE FANOUT ETC?
SAMPLER_LOGIC CARD
100MHz
S100-A-5
S100-A-4
S100-A-3
S100-A-2
100MHz
+12V
+5V
-2V
-5.2V
GND
S-1
S+1
S-0
S+0
100 MHz
RFI01.BLK
FANOUT & TESTPAT
?
RFI05.BLK
?
PROGRAM WORD NOT USED,
ALL HARDWIRED ON SAMPLER
LOGIC CARD
CORRELATOR
C100
CD[0..31]
S-1A
S+1A
S-0A
S+0A
S-1B
S+1B
S-0B
S+0B
-PDATA0
+PDATA0
-DDATA0
+DDATA0
-PDATA1
+PDATA1
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INTEG3
SH-ENA0
SH-ENA1
ACC-RST0
ACC-RST1
ACC-RST2
ACC-RST3
SEL0
SEL1
SEL2
SEL3
CS
CS\
RCLK
RCLK\
uCLK
uCLK\
uDATA0
PDOUT
PU0
RFI02.BLK
INTERFACE
RFI03.BLK
PC
TRY TO USE ENHANCED PRINTER PORT
?
CONTROL
RFI04.BLK
PROGRAM WORD
NOT USED;
HARDWIRED ON
CORRELATOR CARD
POWER SUPPLIES
TO CORRELATOR SECTION
TO IF/LO SECTION
Title
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Size
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RFI_SPEC.BLK
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Date: June 19, 1995
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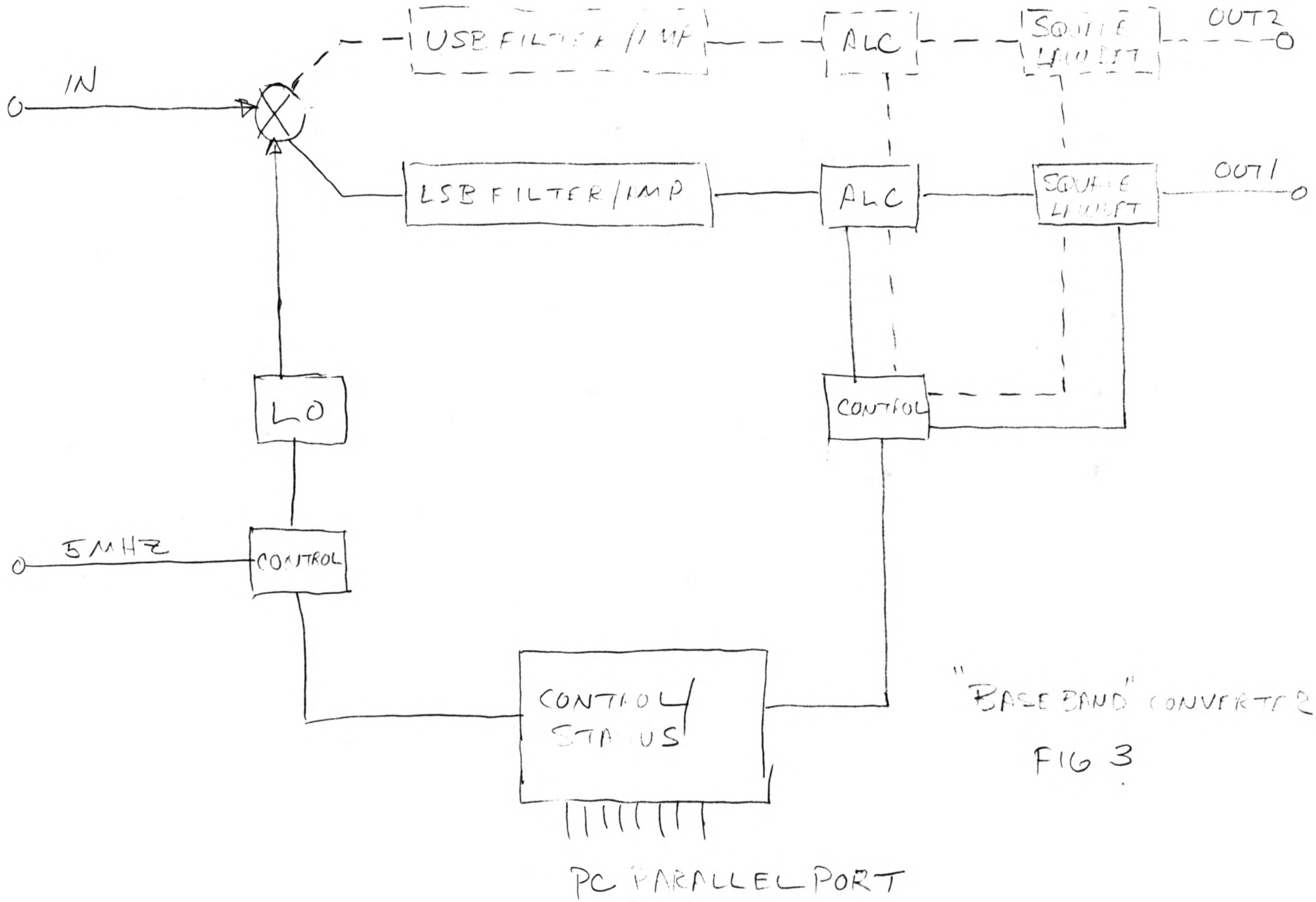


"BASEBAND" CONVERTER

FIG 3

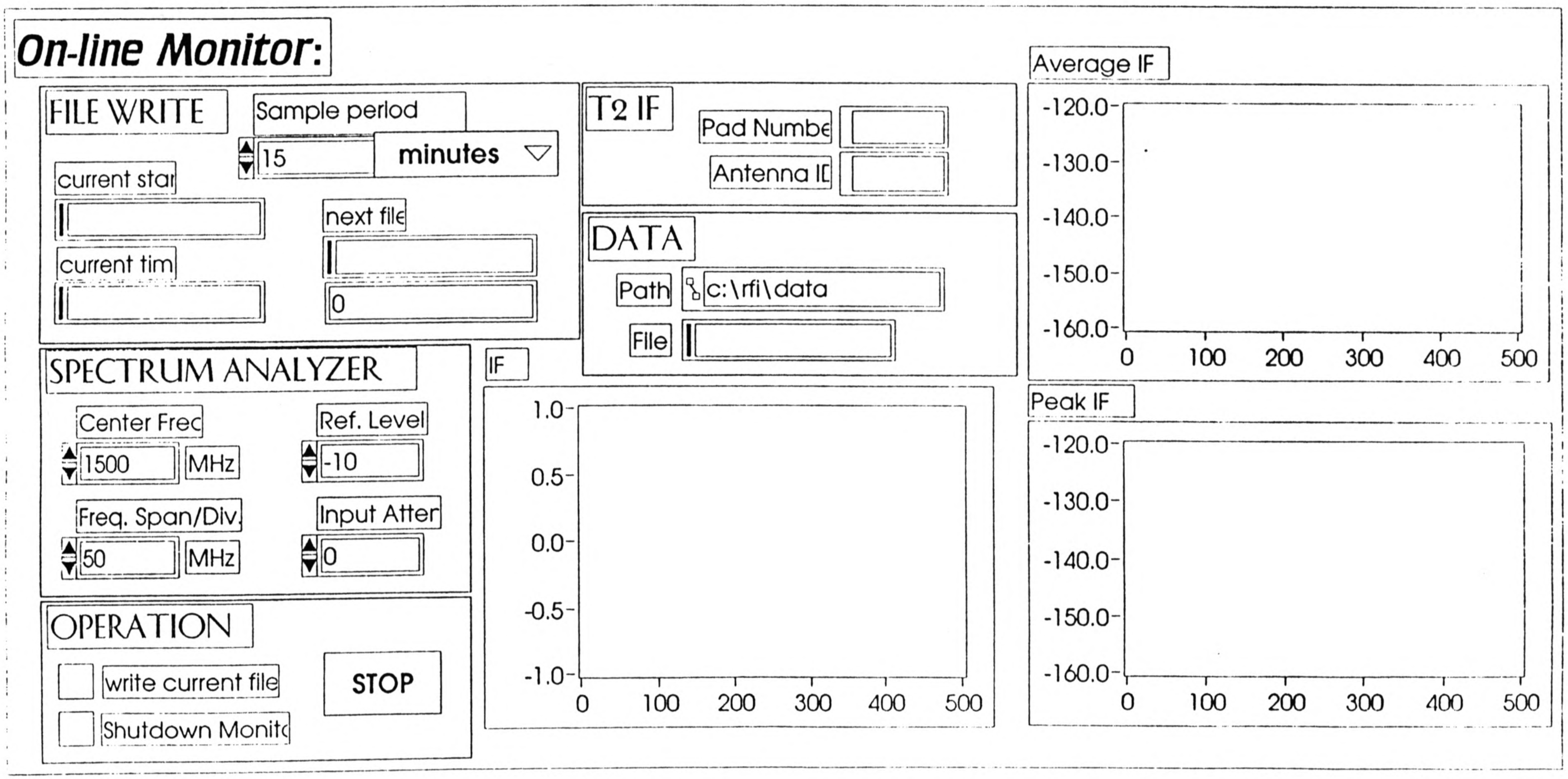
Monitor.vi
1/5/95 3:38 PM

Figure 4: LabVIEW Front Panel

Connector Pane

Monitor.vi

Front Panel



Budget for Autocorrelator — Figure 5

Already purchased from NRAO and NAIC:

10 GBT chips @ $100 each		$1000.00
6 GBT correlator cards @ $320.70 each		$1924.20
6 GBT sampler wirewrap cards @ $169 each (4 channel operation will require 2 sampler cards per autocorrelator)		$1014.00
	sub-total	$3938.20

NOTE: The purchase of cards above are for 6 systems.

Purchase requisitions ready to submit:

ICs and other parts for cards		$1576.50
	sub-total	$5514.70

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Future requisitions:

Full-speed GBT chips required for 50 MHz BW per channel:

4 channel, 4K lags = 16 chips per card @ approx $250.00 — $4000.00
(half as many channels = half as many chips; same for lags)

OTHER:

PC(not defined yet)	($2000.00)
DSP card for fast FFTs (?????)	($1000.00)
Power supplies (not defined yet)	($500.00)
Packaging (not defined yet)	($500.00)