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LIGO-T1100062-v4 *Advanced LIGO* 1 April 2011

aLIGO I&Q RF Demodulator Test Procedure

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Distribution of this document:

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# Overview

This test procedure applies to I&Q demodulator circuit board LIGO-D0902745-v3 contained within chassis assembly D0902796. There are two variants of the demodulator chassis, one for LSC photodetectors, and one for ASC (WFS) type photodetectors. A block diagram of the I&Q RF demodulator circuit board common to both variants is shown in Figure 1. Four such demodulator cells are packaged in one chassis. Refer to LIGO-T1000044 for principles of operation.



Figure I&Q Demodulator Circuit Block Diagram

# Testing

Each production chassis must be functionally tested and the results recorded in Section 4. Unless otherwise noted, the local oscillator level applied to the rear of the chassis is set to +10dBm, +/-0.2dBm for all RF measurements. It is assumed that the person using this procedure is familiar with RF Network Analyzers, Dynamic Signal Analyzers, and rudimentary test equipment including oscilloscopes and multimeters.

**Serial Number Data**

* Record all serial number data in Table 1

**DC Tests**

* Apply +/- 18, +/-200 mV Volts DC to the chassis under test and record front panel LED operation, total positive and negative power supply current, internal regulator output voltage and individual circuit board power supply currents as required in Table 2.

**RF Tests**

* Using a calibrated and normalized RF network analyzer, measure the insertion loss from each of the four front panel RF inputs to the respective RF monitor ports. Record the insertion loss at each frequency required in Table 4.
* Apply an RF or LO input at the prescribed frequency in accordance with Table 5. For each combination, record the DC value of each of the four RF and LO level detector responses.
* Apply an RF or LO input at the prescribed frequencies in accordance with Table 6. For each combination, record the amplitude of the differential IF beat note as required in Table 6.

**IF Tests**

* As detailed in Section 4.7, use the cross correlation setup in an SR785 and measure the I&Q balance at the front panel BNC outputs and record the results per Table 7 through Table 10.
* Use an SR785 to measure the IF output noise, with the associated RF input terminated in 50 ohms. Record results as required in Table 11 through Table 14.
* Using a pair of RF signal generators and an oscilloscope, measure the -3dB bandwidth of the IF chain. Record the results in Table 15.

# Reference for chassis front and rear panel layout

Figure , Demodulator Front Panel



Figure , LSC Demodulator Rear Panel



Figure , ASC Demodulator Rear Panel



# Test Data Tables

## General Information

Table , Serial Number Data

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Chassis Serial Number** | **ASC or LSC version?** | **Ch.1 PCB Serial Number** | **Ch.2 PCB Serial Number** | **Ch.3 PCB Serial Number** | **Ch.4 PCB Serial Number** |
|  |  |  |  |  |  |

## DC Power Supply Data

Total chassis and individual circuit board quiescent current draw is recorded in Table 2. For the individual circuit boards, unplug all but one board at a time and record the chassis current draw of the +/- 18VDC supply. Use caution in believing the digital readouts of laboratory triple output power supplies. Their meters are not highly accurate. When in doubt, use a multimeter on the appropriate scale in series with the supply to be measured.

Table , Record of DC Test Data

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Typical Value** | **Allowable Range** | **Measured Value** |
| Front Panel +/- 15VDC Power LEDs | All Lit, front and rear | N/A |  |
| +18VDC, +/-0.25VDC **TOTAL** supply current | 890mA | +/- 50mA |  |
| -18VDC, +/-0.25VDC **TOTAL** supply current | 300mA | +/- 50mA |  |
| Regulated Internal DC Voltage under full load (all four boards) | +15VDC, -15VDC | +/- 0.5VDC |  |
| +18VDC, +/-0.25VDC supply current (Board 1) | 240mA | +/- 20mA |  |
| -18VDC, +/-0.25VDC supply current (Board 1) | 80mA | +/- 20mA |  |
| +18VDC, +/-0.25VDC supply current (Board 2) | 240mA | +/- 20mA |  |
| -18VDC, +/-0.25VDC supply current (Board 2) | 80mA | +/- 20mA |  |
| +18VDC, +/-0.25VDC supply current (Board 3) | 240mA | +/- 20mA |  |
| -18VDC, +/-0.25VDC supply current (Board 3) | 80mA | +/- 20mA |  |
| +18VDC, +/-0.25VDC supply current (Board 4) | 240mA | +/- 20mA |  |
| -18VDC, +/-0.25VDC supply current (Board 4) | 80mA | +/- 20mA |  |

## DC Offsets on Each IF Output

As a general measure of the health, the DC offset at the differential outputs for each channel must be measured. Apply LO of 45MHz, 10dBm +/- 0.2dB to the channel under test. Using a multimeter, measure the DC offset at each differential output on the associated rear panel D-sub connector. Record the results in Table 3.

Table , IF Output DC Offset

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Differential DC Measurement Point*** | ***Typical DC Offset*** | ***Allowable Range*** | ***Measured DC Offset*** | |
| **I** | **Q** |
| Channel 1 | 0VDC | +/- 10mV |  |  |
| Channel 2 | 0VDC | +/- 10mV |  |  |
| Channel 3 | 0VDC | +/- 10mV |  |  |
| Channel 4 | 0VDC | +/- 10mV |  |  |

## Coupling Factor for Front Panel Monitors

Using a calibrated and normalized RF network analyzer, measure the insertion loss from each front panel SMA RF input to its respective RF monitor. Use a drive level of 0dBm +/- 0.2dB at each of the required frequencies. Record the test data in Table 4.

Table , RF Monitor Test Data

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Parameter** | **Typical Value** | **Allowable Range** | **Measured Values** | | |
| **9 MHz** | **45 MHz** | **100 MHz** |
| Chan.1 RF In to RF Monitor Gain | -23dB | +/- 1dB |  |  |  |
| Chan.2 RF In to RF Monitor Gain | -23dB | +/- 1dB |  |  |  |
| Chan.3 RF In to RF Monitor Gain | -23dB | +/- 1dB |  |  |  |
| Chan.4 RF In to RF Monitor Gain | -23dB | +/- 1dB |  |  |  |

## RF Level Detector Calibration Data

Apply a signal of the indicated magnitude to the RF or LO input on the front and rear chassis SMA connectors as specified in Table 5. Using a multimeter, record the DC voltage as measured differentially at the differential RF monitor outputs on the rear of the chassis (see Section 3, Reference for chassis front and rear panel layout). The presence of a four way power splitter on the LO input to the ASC version of the demodulator chassis is the reason for the second typical value shown for the LO detected level. Utilize the typical value dictated by the chassis type under test.

Table , RF Level Detector Response

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **RF Freq/Level** | **LO Freq/Level** | **Typical Value LSC or ASC Version** | | **Allowable Range** | **Measured Value** | | | |
| **CH1** | **CH2** | **CH3** | **CH4** |
| 45 MHz  (-20dBm) | 45 MHz  (-20dBm +/- 0.2dB) | **LO** | 7.9VDC (LSC)  7.2VDC(ASC) | +/-0.25VDC |  |  |  |  |
|  |  | **RF** | 6.2VDC | +/-0.25VDC |  |  |  |  |
| 45 MHz  (-10dBm) | 45 MHz  (-10dBm +/- 0.2dB) | **LO** | 9.1VDC (LSC)  8.4VDC (ASC) | +/-0.25VDC |  |  |  |  |
|  |  | **RF** | 7.4VDC | +/-0.25VDC |  |  |  |  |
| 45 MHz  (0dBm) | 45 MHz  (0dBm +/- 0.2dB) | **LO** | 10.3VDC (LSC)  9.6VDC (ASC) | +/-0.25VDC |  |  |  |  |
|  |  | **RF** | 8.6VDC | +/-0.25VDC |  |  |  |  |
| 45 MHz  (10dBm) | 45 MHz  (10dBm +/- 0.2dB) | **LO** | 11.5VDC (LSC)  10.8VDC (ASC) | +/-0.25VDC |  |  |  |  |
|  |  | **RF** | 9.8VDC | +/-0.25VDC |  |  |  |  |

## IF Beat note Measurements

Using a pair of RF signal generators, apply the indicated amplitude and frequency signals to the chassis under test as detailed in Table 6. There is a single rear panel LO input for the ASC (wavefront sensor) variant of the demodulator chassis simplifying the test setup. For the LSC version, the LO cable must be moved from channel to channel as needed. The presence of a four way power splitter on the LO input to the ASC version of the demodulator chassis is the reason for the second typical value shown for the IF Beat Note. Utilize the typical value dictated by the chassis type under test.

The IF beat note is measured differentially at the rear panel D-sub outputs for each channel under test using an SR785. Be sure to set the dynamic signal analyzer FFT window function to “flat top” during this amplitude measurement in order to accurately measure the peak to peak voltage at each beat note frequency.

Table , IF Beat Note Amplitude vs. Frequency Measurement Data

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **RF Freq/Level** | **LO Freq/Level** | **IF Beat Note Typical Value LSC or ASC version** | **Allowable Range** | **Measured Value (p-p)** | | | |
| **CH1** | **CH2** | **CH3** | **CH4** |
| **I** | **I** | **I** | **I** |
| **Q** | **Q** | **Q** | **Q** |
| 45 MHz  (0dBm, +/-0.2dB) | 45.0001 MHz  (10dBm, +/-0.2dB) | 100Hz @ 6.9Vp-p (LSC), 6.8Vp-p (ASC) | +/-0.2Vp-p |  |  |  |  |
|  |  |  |  |
| 45 MHz  (0dBm, +/-0.2dB) | 45.001 MHz  (10dBm, +/-0.2dB) | 1kHz @ 6.9Vp-p (LSC), 6.8Vp-p (ASC) | +/-0.2Vp-p |  |  |  |  |
|  |  |  |  |
| 45 MHz  (0dBm, +/-0.2dB) | 45.01 MHz  (10dBm, +/-0.2dB) | 10kHz @ 6.9Vp-p (LSC), 6.7Vp-p (ASC) | +/-0.2Vp-p |  |  |  |  |
|  |  |  |  |
| 45 MHz  (0dBm, +/-0.2dB) | 45.1 MHz  (10dBm, +/-0.2dB) | 100kHz @ 7.2Vp-p (LSC), 7.1Vp-p (ASC) | +/-0.2Vp-p |  |  |  |  |
|  |  |  |  |

## IQ Amplitude and Phase Balance

When measuring the IF beat note, the I and Q IF outputs should ideally be exactly equal in magnitude, and 90 degrees out of phase. Section of this document has a printout of the settings file for the SR785 Dynamic Signal Analyzer used to perform an I and Q balance measurement. These settings can be restored to the machine by obtaining the machine setup file from the DCC and loading them onto the SR785 via a floppy disk. LIGO Document T1100087 is actually this file.

Once the settings file is loaded into the SR785, apply an LO and RF signal at the indicated frequencies shown in Table 7. The LO signal level should be 10dBm +/- 0.2dB, and the RF signal level should be 0dBm +/- 0.2dB.

On the front panel of the I&Q demodulator are two BNC monitoring jacks per channel. These are IF monitors of the I and Q demodulated outputs. Apply the I monitor signal to the SR785 Channel 1, A input. Apply the Q monitor signal to the SR785 Channel 2, A input. Record data as needed in Table 7 through Table 10.

Table , Channel 1 IQ Balance

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Channel 1 RF Input and LO Frequency** | **Typical Amplitude Balance** | **Allowable Range** | **Typical Phase Balance** | **Allowable Range** | **Measured Amplitude Balance** | **Measured Phase Balance** |
| 9MHz & 9.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 36MHz & 36.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 45MHz & 45.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 100MHz & 100.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |

Table , Channel 2 IQ Balance

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Channel 2 RF Input and LO Frequency** | **Typical Amplitude Balance** | **Allowable Range** | **Typical Phase Balance** | **Allowable Range** | **Measured Amplitude Balance** | **Measured Phase Balance** |
| 9MHz & 9.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 36MHz & 36.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 45MHz & 45.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 100MHz & 100.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |

Table , Channel 3 IQ Balance

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Channel 3 RF Input and LO Frequency** | **Typical Amplitude Balance** | **Allowable Range** | **Typical Phase Balance** | **Allowable Range** | **Measured Amplitude Balance** | **Measured Phase Balance** |
| 9MHz & 9.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 36MHz & 36.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 45MHz & 45.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 100MHz & 100.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |

Table , Channel 4 IQ Balance

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Channel 4 RF Input and LO Frequency** | **Typical Amplitude Balance** | **Allowable Range** | **Typical Phase Balance** | **Allowable Range** | **Measured Amplitude Balance** | **Measured Phase Balance** |
| 9MHz & 9.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 36MHz & 36.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 45MHz & 45.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |
| 100MHz & 100.01MHz | 0dB | +/- 0.5dB | -90 Deg. | +/- 5 Deg. |  |  |

## IF Output Noise Spectra

With an LO of 45MHz, 10dBm +/- 0.2dB applied; terminate each of the RF inputs under test in 50 ohms. Measure the IF output referred noise differentially at the rear panel D-sub output for each channel as required. Record the results in through .

Table , Channel 1 IF Noise

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **IF Measurement Frequency** | **Typical Amplitude (dBVrms/√Hz)** | **Allowable Range** | **Measured Amplitude dBVrms/√Hz** | |
| **I** | **Q** |
| 100Hz | -145 | <-143 |  |  |
| 1kHz | -147 | <-143 |  |  |

Table , Channel 2 IF Noise

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **IF Measurement Frequency** | **Typical Amplitude dBVrms/√Hz** | **Allowable Range** | **Measured Amplitude dBVrms/√Hz** | |
| **I** | **Q** |
| 100Hz | -145 | <-143 |  |  |
| 1kHz | -147 | <-143 |  |  |

Table , Channel 3 IF Noise

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **IF Measurement Frequency** | **Typical Amplitude dBVrms/√Hz** | **Allowable Range** | **Measured Amplitude dBVrms/√Hz** | |
| **I** | **Q** |
| 100Hz | -145 | <-143 |  |  |
| 1kHz | -147 | <-143 |  |  |

Table , Channel 4 IF Noise

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **IF Measurement Frequency** | **Typical Amplitude dBVrms/√Hz** | **Allowable Range** | **Measured Amplitude dBVrms/√Hz** | |
| **I** | **Q** |
| 100Hz | -145 | <-143 |  |  |
| 1kHz | -147 | <-143 |  |  |

## IF -3dB Bandwidth

Apply a fixed 45MHz RF generator at 0dBm +/- 0.2dB as the front panel RF input, and a variable frequency LO starting at a frequency of 45.001MHz and a fixed level of 10dBm +/- 0.2dB applied to the LO input on the rear of the chassis under test. Use a dual channel oscilloscope with a pair of probes to view the IF beat note differentially on the rear panel D-sub for the channel under test. Increment the LO frequency until a 3dB decrease in the IF beat note is observed. Record the frequency corresponding to the -3dB frequency in

Table , Channel 2 IF Bandwidth

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Channel** | **Typical -3dB Bandwidth** | **Allowable Range** | **Measured -3dB IF Bandwidth** | |
| **I (kHz)** | **Q (kHz)** |
| 1 | 370kHz | +/- 30kHz |  |  |
| 2 | 370kHz | +/- 30kHz |  |  |
| 3 | 370kHz | +/- 30kHz |  |  |
| 4 | 370kHz | +/- 30kHz |  |  |

# Appendix

The SR785 Settings associated with the I and Q phase and magnitude balance measurement.

|  |  |  |
| --- | --- | --- |
| **Input** | **Ch 1** | **Ch 2** |
| Source | Analog | Analog |
| Config | Dual Chan. | Dual Chan. |
| Mode | A | A |
| Ground | Float | Float |
| Coupling | AC | AC |
| Range | 6 dBVpk | 6 dBVpk |
| AA Filter | On | On |
| A-Wt Filter | Off | Off |
| Auto Range | Up Only | Up Only |
| Auto Offset | On | On |
| EU | Off | Off |
| EU Label | m/s | m/s |
| EU/Volt | 1 EU/V | 1 EU/V |
| User Label | EU | EU |
| Tachs/Rev | 1 | 1 |
| Tach Level | 0.00 V | 0.00 V |
| Tach Trigger | TTL | TTL |
| Tach Slope | Rising | Rising |
| Tach Holdoff | Off | Off |
| ShowTach | Off | Off |
| Xdcr Convert | m/s | m/s |
|  |  |  |
| **Measure** | **Display A** | **Display B** |
| Measurement | Cross Spec. | FFTUsrFn1 |
| View | Phase | Log Mag |
| Units | deg | dB |
| dB Units | Off | On |
| Peak Units | pk | off |
| PSD Units | Off | Off |
| Phase Units | deg | deg |
| dBm Ref | 50 | 50 |
| Base Freq | 102.4 kHz | 102.4 kHz |
| Span | 400 Hz | 400 Hz |
| Start Freq | 9.8 kHz | 9.8 kHz |
| Lines | 800 | 800 |
| Window | BMH | BMH |
| Force | 3.90625 ms | 3.90625 ms |
| Expo | 50.00% | 50.00% |
|  |  |  |
| **Average** | **Display A** | **Display B** |
| Comp. Average | Yes | Yes |
| Type | Exp. / Cont. | Exp. / Cont. |
| Display | RMS | RMS |
| Number | 20 | 20 |
| Time Incr | 100.00% | 100.00% |
| Reject | Off | Off |
| Preview | Off | Off |
| Prv Time | 2 s | 2 s |
|  |  |  |
| **Display** | **Display A** | **Display B** |
| Ymax | 250 | 50 |
| Y/div | 50 | 10 |
| Xcenter | 2.86479 k | 50 |
| X/div polar | 572.958 | 10 |
| Ycenter | 2.86479 k | 50 |
| Y/div polar | 572.958 | 10 |
| Pan | 0 | 0 |
| Zoom | x1 | x1 |
| Format | Dual | Dual |
| X Axis | Linear | Linear |
| Grid | On | On |
| Grid Div | 10 | 10 |
| Grid Type | Rectangular | Rectangular |
| Phase Suppress | 0.00E+00 | 0.00E+00 |
| d/dx Window | 0.5 | 0.5 |
|  |  |  |
| **Marker** | **Display A** | **Display B** |
| Marker | On | On |
| Mode | Normal | Normal |
| Seeks | Mean | Mean |
| Width | Spot | Spot |
| Relative | Off | Off |
| X Relative | Off | Off |
| X Rel | 0 | 0 |
| Y Rel | 0 | 0 |
| # Harmonics | 1 | 1 |
| Display | Fundamental | Fundamental |
| Readout | Absolute | Absolute |
| Sideband Sep | 0 | 0 |
| # Sidebands | 10 | 10 |
| Band Exclude | none | none |
| Band Ratio | / | / |
|  |  |  |
| **Waterfall** | **Display A** | **Display B** |
| Wfall Display | Normal | Normal |
| Wfall Storage | Off | Off |
| Storage Mode | All | All |
| Total Count | 253 | 253 |
| Skip | 30 | 30 |
| View Count | 10 | 10 |
| Trace Height | 70% | 70% |
| Angle | -26 | -26 |
| Fast Angles | Off | Off |
| Threshold | 0% | 0% |
| Hidden Lines | Invisible | Invisible |
| Paused Draw | Normal | Normal |
|  |  |  |
| **Source** |  |  |
| Source | 0 | [0=Off, 1=On] |
| Type | 0 | [0=Sine, 1=Chirp, 2=Noise, 3=Arb] |
| Sine Freq 1 | 10.24 kHz |  |
| Sine Amp 1 | 500.0 mVpk |  |
| Sine Freq 2 | 51.2 kHz |  |
| Sine Amp 2 | 0.0 mVpk |  |
| Sine Offset | 0.0 mV |  |
| Chirp Amp | 1000.0 mV |  |
| Chirp Burst | 100.00% |  |
| Source Display | Display A |  |
| Noise Amp | 1000.0 mV |  |
| Noise Type | BL White |  |
| Noise Burst | 100.00% |  |
| Arb Amp | 100.00% |  |
| Arb Rate | 262.1 kHz |  |
| Arb Source | Arb. Buffer |  |
| Arb Start | 0 |  |
| Arb Length | 4 kPts |  |
|  |  |  |
| **Trigger** |  |  |
| Arming Mode | Auto Arm |  |
| Trigger Source | Cont |  |
| Trigger Level | 0% |  |
| Trigger Slope | Rising |  |
| Delay1 | 0 s |  |
| Delay2 | 0 s |  |
| Source Mode | Continuous |  |
| Start RPM | Off |  |
| Start RPM | 50 |  |
| Delta RPM | Abs. Change |  |
| Delta RPM | 10 |  |
| Time Step | 100 ms |  |
|  |  |  |
| **Capture** |  |  |
| Capt Channels | Ch1+Ch2 |  |
| Capt Mode | 1 Shot |  |
| Capt Length | 2024 kPts/ch |  |
| Capt Rate | 262.1 kHz |  |
| Auto Pan | On |  |
| Playback Start | 0 |  |
| Playback Len | 2024 kPts/ch |  |
| Playback Mode | 1-Shot |  |
| Playback Speed | Normal |  |
|  |  |  |
| **Memory** |  |  |
| Capt Memory | 2025 Blks |  |
| Wfall Memory | 2024 Blks |  |
| Arb Memory | 2 Blks |  |
|  |  |  |
| **System** |  |  |
| Output To | RS232 |  |
| GPIB Address | 10 |  |
| Overide REM | Yes |  |
| Baud Rate | 9600 bd |  |
| Word Length | 8 bits |  |
| Parity | None |  |
| Key Click | Off |  |
| Alarms | On |  |
| Alarm Vol | Noisy |  |
| Done Vol | Noisy |  |
| Audible Ovld | On |  |
| Screen Saver | On |  |
| Saver Delay | 10 m |  |
| Freq Format | Exact Bin |  |
| Node Info | No |  |
|  |  |  |
| **Output** |  |  |
| Print Screen Key | ASCII Dump |  |
| Printer Type | PCX 8 bit |  |
| Bitmap Area | Graphs |  |
| Plotter Type | PostScript |  |
| Destination | Disk File |  |
| GPIB Control | SR785 |  |
| Plotter Address | 2 |  |
| Print Bright | 12% |  |
| Print Dim | White |  |
| Print Black | Black |  |
| Print Graph | Black on White |  |
| Text Pen | 1 |  |
| Grid Pen | 1 |  |
| Trace Pen | 1 |  |
| Marker Pen | 1 |  |