W-Band Measurement Apparatus

The apparatus is shown in the attached drawing. After turning the instruments on there are several instrument settings must be done by hand and/or auxiliary computer program before starting measurements. These are:

1. Set E&M synthesizer frequency to 835.2 MHz. This is done with SYNTHESIZER.VI that is described below. The LED on the front of the module will light if the synthesizer is phase locked. The frequency should be checked with a frequency meter,
2. Set HP 83620 power to +18 dbm which is the highest power available with leveling.
3. Set SR830 lock-in amplifier. Current settings being used are: input AC coupled; floating ground; 24 db/octave filter roll-off; normal reserve; line and 2×line notch filters; channel 1 display = R; channel 2 display = θ. The Gain and phase are initially set with the AUTO controls on the front panel. (The filter time constant is now controlled by the programs.)
4. Set the SR560 amplifier. Current settings are 3 kHz high-pass, 30 kHz low-pass, gain = ×50, low noise.

There are LabView programs available for running the apparatus. They are located in

C:\LABVIEW\USER.LIB\W-BAND

GPIB instrument libraries are located in libraries with the appropriate instrument name in

C:\LABVIEW\INST.LIB

Subroutines specific to W-band are located in

C:\LABVIEW\USER.LIB\W-BAND\W-BAND.LLB

Subroutines specific to synthesizer operation are located in

C:\LABVIEW\USER.LIB\W-BAND\SYNTHLIB.LLB

1. As of revision 8, local oscillators were wired to get reference 10 MHz from HP8673D synthesizer.
2. The reference (forward) signal amplitude is measured with an HP3457A multimeter. This meter should be calibrated before use. see CALIBRAT.VI below
3. The phase and amplitude of the signal which can be either transmitted or reflected power (depending on the configuration) are measured with the SR830 lock-in.
4. There are three numbers that control data taking with the lock-in. The first is the "filter time constant", τ, which is the time constant on the lock-in internal low-pass filter. The second is the "rate", f, at which the lock-in data buffer is updated, and the third is the length of "time", t , over which data are taken. The signal amplitude and phase are the averages of the readings in the data buffer. For the averaging to make sense, $f\tau < 1$. The number of measurements that are averaged, N, is $N \sim ft$.
5. There is a choice of whether the amplitude is leveled internally (Internal Level Control) or through a feedback loop based on the reference arm (System Level Control).
6. In all cases the W-band frequency(ies) compatible with the desired W-band frequency(ies) and the first stage LO frequency(ies) of ~5 GHz produced by HP 83620 synthesizer are calculated and used.

7. Programs use the convention that quantities in BLACK are input variables, quantities in BLUE are the results of calculations, and quantities in RED are measurements.

8. Details of amplitude and phase measurement corrections.

    The amplitude calibration requires reference and signal intercept files. They are in **C:\matlab\toolbox\rhsfun\w-band**. They are ref62897.txt (which replaced ref51597.txt on 6/28/97) for the reference arm and sig32397.txt for the signal arm. These are the defaults, and the intention is to keep defaults up to date in the future.

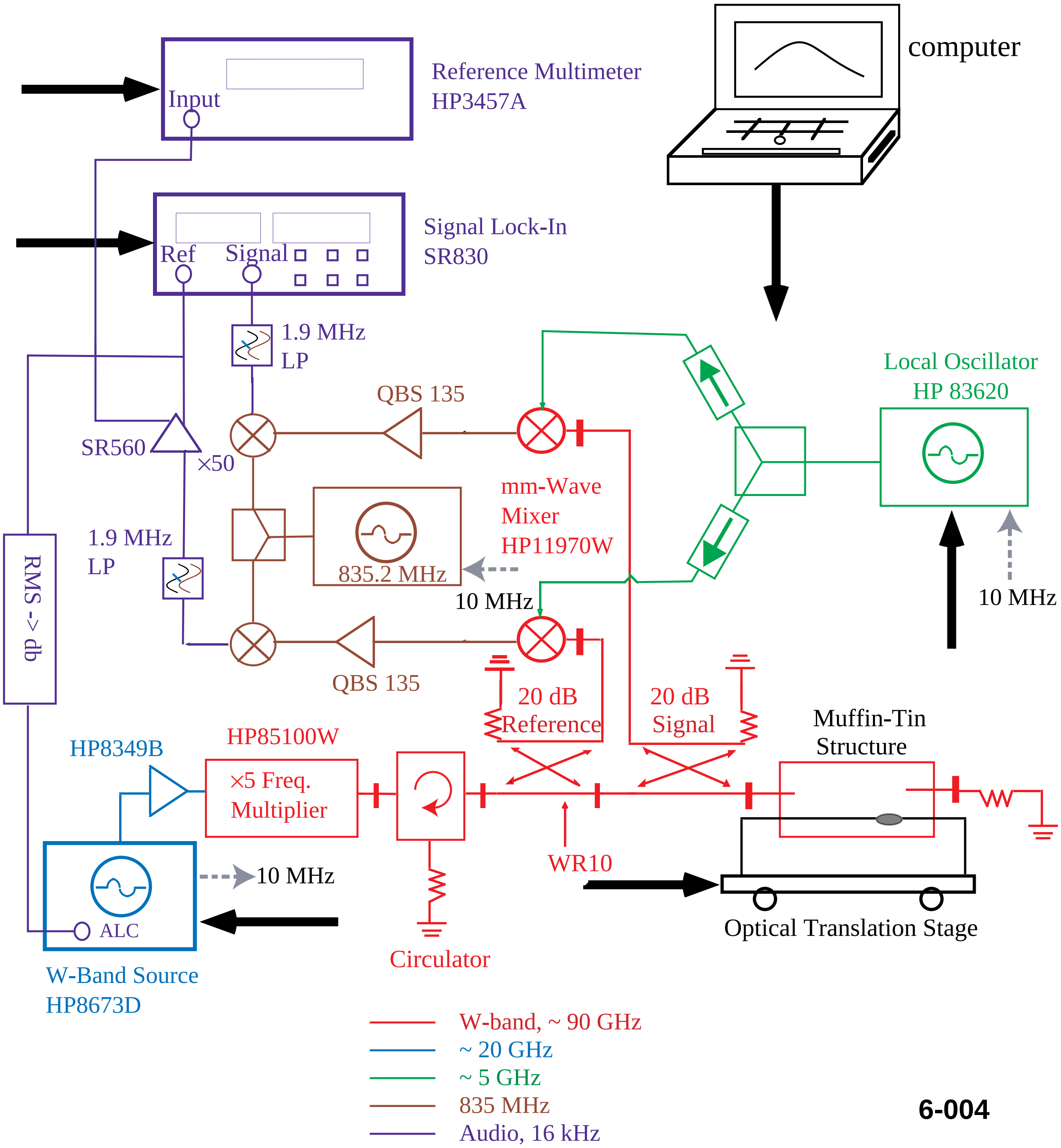
    The phase correction requires a phase offset file. The present one is fphs4797.txt in **C:\matlab\toolbox\rhsfun\w-band**. This is the default which will be kept up to date in the future.

9. Two different W-band sources are available. If the source is the HP85100W, the frequency multiplication is $\times 5$, and if it is the HP83558A the frequency multiplication is $\times 6$. The programs must be informed about the source being used. Use W-BAND MULTIPLIER.vi to do this.

LabView Programs in C:\LABVIEW\USER.LIB\W-BAND		
Program	**Description**	**Output**
CALIBRAT	Zeros and calibrates the HP3457A (reference) multimeter & HP437B power meter. Follow directions about disconnecting and/or turning-off before running VI.	None
BEADPULL	Beadpull perturbation measurement. The S_{11} measurement uses the amplitude correction files discussed above.	ASCII array with data in the following order: Translation stage position, signal phase, magnitude of S_{11}, signal amplitude, reference amplitude, frequency (recorded for convenience)
COMPARISON	Image acquistion VI used to align structure parallel to beadpull fiber and to measure distances. Description follows later in these notes.	None
DOWNMIX	Repeated measurements at a fixed frequency.	ASCII array with data in the following order: signal phase, signal amplitude, reference amplitude
FREQSCAN	Frequency scan with option of calibrating the measurements after the data are taken. This latter function used to be performed by ABSOLUTE.VI. Reference arm multimeter should be calibrated by using CALIBRAT.VI. There needs to be a description of the apparatus entered also. This description can be entered through the controls and includes whether the signal coupler is set up for a forward or reflected measurement, the number of inches of WR10 waveguide and the number of E-bends, H-bends, and Twists in the apparatus. The lengths and attenuations described in ARDB-45 use this information to account for losses and correct for phase shifts in the waveguide.	ASCII array with either four or six columns of data in the following order: *IN ALL CASES:* W-band frequency, Signal phase, Signal amplitude, Reference amplitude. *ADDITIONAL IF CALIBRATION PERFORMED:* Corrected amplitude, and Corrected phase

LabView Programs in C:\LABVIEW\USER.LIB\W-BAND		
Program	**Description**	**Output**
MOTOR	Performs MM2000 functions including: 1) Returning to the home position set by a switch in the translation stage, 2) Defining the origin of the encoder coordinate system. 3) Stopping the motor. 4) Reading the present position. 5) Setting and enabling soft limits. 6) Disabling the soft limits. 7) Translating to an absolute position. 8) Making a relative change in position.	None
POWER	For calibrations using power meter. The amplitudes of the two lock-ins together with power meter are read (Power meter should be zeroed and calibrated first using CALIBRAT.VI.)	ASCII array with data in the following order: W-band frequency, Signal amplitude, Reference amplitude, Power Meter Reading
SNAP IT	Program to acquire and record images. Images are acquired until STOP is pushed. Gain, Black and White levels of data acquistion can be adjusted. Image is calibrated in mm if lens magnification is entered.	Image can be output in TIFF format.
SPD1	Frequency scan designed for rapid data taking. Only the signal amplitude is readout. The apparatus should be in system mode to regulate the input power.	ASCII array with data in the following order: W-band frequency, Signal amplitude
SYNTHESIZER	Sets the frequency of the second (835.2 MHz) Local Oscillator. Run the VI in continuous mode to see changes in frequency as N and A are changed. (R should be left fixed at 400.) Push the "load" button when the desired frequency is reached. Stop the VI once the frequency is loaded and the synthesizer locked.	
THREAD ALIGNMENT	Image acquistion VI used to align the bead pull fiber with respect to the axis of translation of the mover stage. Description follows later in these notes.	None

W-BAND MULTIPLIER	Tells programs the multiplication factor of the W-band . HP85100W => $\times 5$ HP83558A => $\times 6$	Writes to file WMULT.TXT. Respond that the file should be replaced when asked.


computer
Reference Multimeter
HP3457A
Input
Signal Lock-In
SR830
Ref
Signal
1.9 MHz
LP
Local Oscillator
HP 83620
QBS 135
SR560
×50
mm-Wave
Mixer
HP11970W
1.9 MHz
LP
835.2 MHz
10 MHz
10 MHz
RMS -> db
QBS 135
20 dB
Reference
20 dB
Signal
Muffin-Tin
Structure
HP8349B
HP85100W
×5 Freq.
Multiplier
WR10
10 MHz
ALC
Optical Translation Stage
Circulator
W-Band Source
HP8673D
W-band, ~ 90 GHz
~ 20 GHz
~ 5 GHz
835 MHz
Audio, 16 kHz

6-004

Choice of Frequencies for W-Band Measurements

The W-band measurement apparatus has 4 frequencies:

f_W The W-band frequency. This is produced by an HP8673D multiplied by a frequency multiplier. The frequency 8673D resolution is 3 kHz between 12.3 – 18.6 GHz and 4 kHz for 18.6 – 26 GHz. Originally the output of the 8673D was multiplied ×5 in an HP85100W mm-wave source module. With this multiplier and for W-band frequencies up to 93 GHz the minimum frequency step is Δf_W = 15 kHz, and above 93 GHz it is Δf_W = 20 kHz. Later we acquired an HP 83558A that is a ×6 multiplier. The minimum frequency step in its range of operation is Δf_W = 12 kHz

f_1 The first local oscillator frequency derived from an HP83620 synthesizer. The minimum step size is Δf_1 = 1 kHz, and this frequency is multiplied by ×18 in the mm-wave mixer. f_1 should be chosen to make the IF frequency in the range 824 - 849 MHz which is the frequency range of the Q-bit QBS 135 amplifier.

f_S The E&M Research synthesizer that operates in the range f_S ~ 824 to 850 MHz and can makes frequency steps Δf_S = 25 kHz.

f_{LI} The lock-in amplifier frequency that is limited to $f_{LI} < 100$ kHz.

The frequency f_1 is chosen to keep f_{LI} constant with constant f_S when f_W is varied. The possible step sizes affect the possible values for f_W. The relationship between frequencies is

$$f_W - 18 f_1 - f_S = f_{LI}.$$

Require that f_S be divisible by each of the minimum step sizes, Δf_S, Δf_W, and $18\Delta f_1$. The lowest common frequency is 450 kHz, so restrict

$$f_S = m_S \times 450 \text{ kHz}.$$

where m_S is an integer.

The lowest common multiple between the three values of Δf_W and $18\Delta f_1$ is 180 kHz, so restrict Δf_W to be a multiple of 180 kHz.

$$f_W = m_W \times 180 \text{ kHz}.$$

With this restriction the minimum step size is ~ 2×10^{-6} which is much less than 1/Q, so this does not place a limit on the measurement.

With these two restrictions the frequency equation becomes

$$f_1 = \frac{90 m_W + 450 m_S - f_{LI}}{18} = 5 m_W + 25 m_S - \frac{f_{LI}}{18}.$$

f_1 will be an integer multiple of 1 kHz if f_{LI} is a multiple of 18 kHz

$$f_{LI} = m_{LI} \times 18 \text{ kHz}.$$

The present measurements have been done with f_S = 835.2 MHz (m_S = 1856) and f_{LI} = 18kHz.

Operation of E&M Research 830 MHz Synthesizer

This synthesizer is mounted in a single width NIM module.

INPUTS:
1) The 10 MHz reference output from the HP8673D synthesizer attenuated by ~10 db to increase the lock range.
2) DB9 (Serial port) connection to data taking PC for frequency control.

OUTPUTS:
1) Monitor signal from 10 db direction coupler for frequency measurement.
2) Output with ~ 12 dbm power.
3) LED on front panel that is lit when synthesizer is phase locked to reference.

FREQUENCY:
1) The range is roughly 824 to 850 MHz.
2) Step size 25 kHz.

The output frequency is

$$\boxed{f_{out} = \frac{f_{ref}}{R}\{64N + A\}}$$

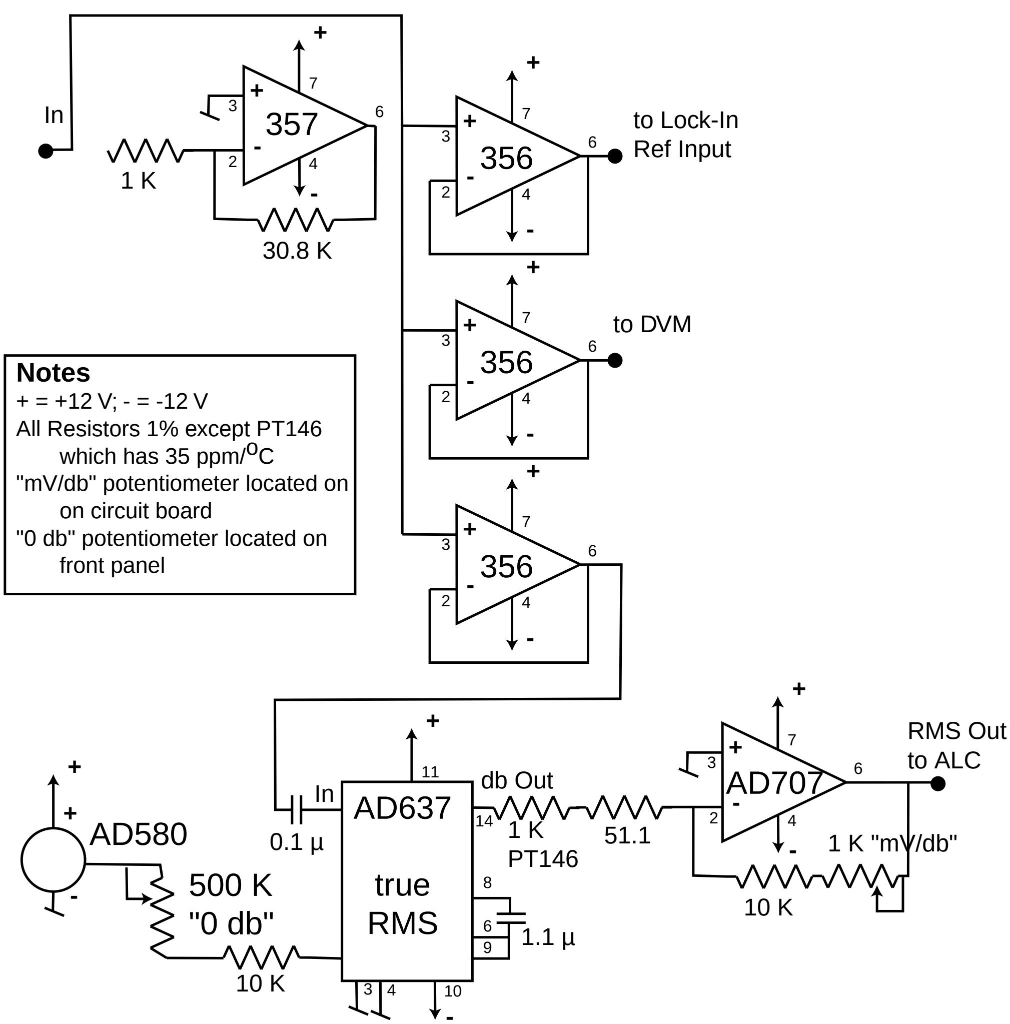
where f_{ref} = 10 MHz.

The frequency is controlled by the LabView VI named SYNTHESIZER described earlier in this note.

Audio Amplifier and RMS -> db Conversion

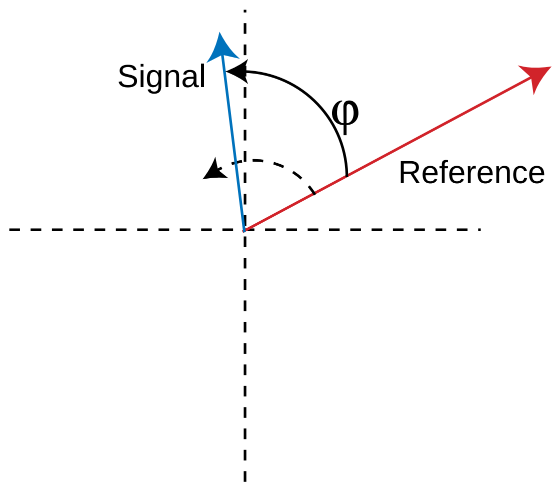
In the original incarnation this circuit was needed to bring the reference arm signal up to a level sufficient for the lock-in reference input. A 357 op-amp with gain = -30.8 was used. An SR560 low noise preamplifier is now being used for this, so the only remaining function is that of performing the RMS -> db conversion that levels the HP8673 W-band synthesizer. This is done using an AD637 circuit from Analog Devices wired as they suggest including temperature compensation. There are two adjustments. The first, “mV/db” sets the gain. The AD637 output is - 3mV/db, and the HP8673 requires 30 mV/db, so a gain = -10 amplifier is used. The potentiometer is located on the circuit board and was adjusted using a signal source. The second adjustment, “0 db” is located on the front panel. It needs to be adjust to match the HP8673 which requires an input signal of 0 V for 0 dbm output. It has been adjusted by setting the source to 90 GHz, measuring the power directly after the reference coupler and making that power equal to -10 dbm when that was the power called for.

Audio Amplifier & RMS -> db Conversion



Lock-in Phase Convention

The lock-in measures the phase that the signal ***leads*** the reference. In the figure below phasors are rotating in the counter clockwise sense, and the signal leads the reference. The angle φ is the angle by which the signal leads and is positive for the figure.



MM2000, UTM100CC.1, Bead Pull LABVIEW Applications

LABVIEW Programs have been written for control of the Newport UTM100CC.1 translator driven by their MM2000 drive unit. The device has an encoder with a 0.1 μm/count resolution; the encoder count is converted to/from mm in all the high level programs. The origin of the coordinate system can be lost when power is lost, so if that happens the device should be returned to the "home position" defined by a switch in the middle of the stage. The sign convention is that the positive axis points in the upward direction.. These programs and a brief description are

in C:\LABVIEW\USER.LIB\INST.LIB\DRIVERS\RSMM2000.LLB	
Absolute Position	Moves the translator to a specified absolute coordinate in a set length of time. There is the option to return to the starting point. Position is measured and plotted during the motion
Relative Position	Moves the translator a specified amount from the present location in a set length of time. Position is measured and plotted during the motion
Motion	The VI used in the position changing programs
Scale	Converts to/from encoder counts to distance including factors need to satisfy the sign convention that a positive change in coordinates is in the upward direction.
Motor Control	Allows miscellaneous functions to be performed including: 1) Returning to the home position set by a switch in the translation stage, 2) Defining the origin of the encoder coordinate system. 3) Stopping the motor. 4) Reading the present position. 5) Setting and enabling soft limits. 6) Disabling the soft limits.

Alignment of Bead Pull Apparatus using Image Acquistion VI's

The procedure for alignment is to first align the fiber relative to the translation axis of the moving stage using **Thread Alignment.vi** and then align the structure relative to the fiber using **Comparison.vi**.

CAUTION The National Instrument image acquistion vi's hang up and may force you to reboot the computer if you disconnect a camera or if you switch the video monitor from channel A to channel B during data acquistion.

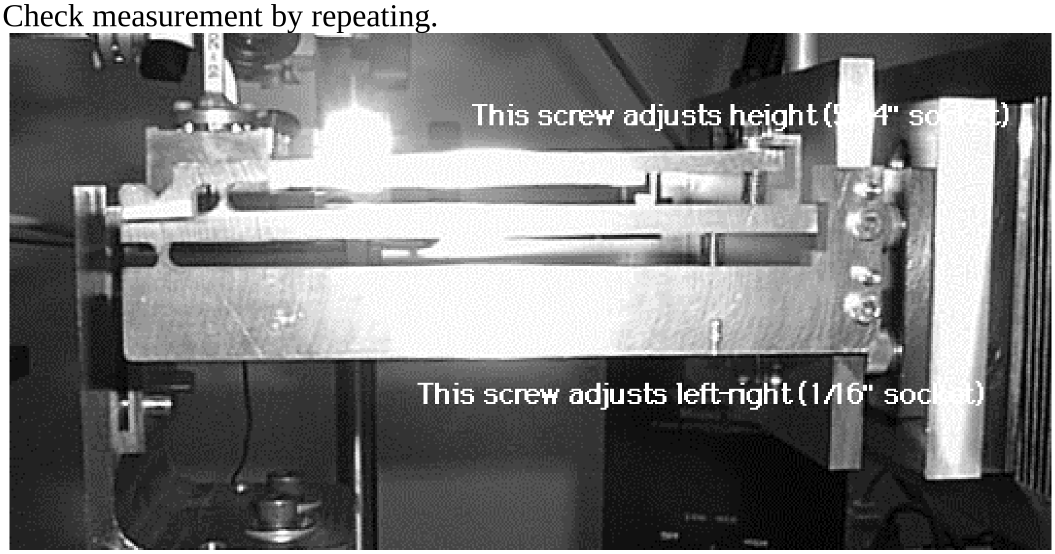
Thread Alignment.vi

Preliminaries

1) Run translation stage to home position and set this as the coordinate origin using **Motor.vi**.
2) Measure and enter *"L0"* which is the distance from the front face of the structure to the rear face of the front arm.
3) Using **Motor.vi** determine the coordinates corresponding to the rear arm near the structure and the front arm near the structure. Set the soft limits to prevent travel beyond those points.
4) Set microscope magnification = 3.0
5) Run **Thread Alignment.vi** without worrying about moving the thread. Use the final image (which is live) to adjust the camera Black, White and Gain.

Procedure The procedure that follows needs to be <u>repeated</u> for both horizontal and vertical thread alignment

1) Set microscope up to look in the appropriate dimension without parallax.
2) Run the stage such that the rear arm is near the structure.
3) Run such that the front arm is near the structure.
4) Align the cursor on the "Initial Image" to the center of the thread. Align the cursor on the "Final Image" to the center of the thread.
5) Choose the arm to be adjusted. The vi indicates the one that will allow the most sensitive adjustment, but the one you use is up to you. The target (red) cursor shows where the center of the thread should be located. Adjust the chosen arm to put it there. The location of the adjustment screws is summarized in a picture below.
6) Check measurement by repeating.



Socket sizes are not clear. Vertical takes 5/64" socket and horizontal takes 1/16" socket

Comparison.vi

Preliminaries

1) It is assumed that two cameras are in use. One at the front of the structure and the other at the back. The correspondences assumed are
   Front <=> Video monitor channel A <=> IMAQ camera #0 <=> Initial Image
   Back <=> Video monitor channel B <=> IMAQ camera #1 <=> Final Image
   Please observe the caution about disconnecting and switching video channels when running those VI's.
2) Set the cameras up to both be looking horizontal or both be looking vertical.
3) Set both microscope magnifications equal to 3.00, and enter this magnification in the VI
3) Use **Motor.vi** to roughly center the structure by going to the "home" position.

Remarks about ***Comparison.vi***

1) The *"horizontal fiber to structure"* and *"vertical fiber to structure"* distances are measured in the FINAL image
2) The *"calculate target"* switch calculates the location that the structure should take in the FINAL image to remove the angle between structure and fiber
3) There must be a left-right interchange for doing the horizontal measurements. There are two choices
   A) You look at the same edges on both the INITIAL and FINAL images (i.e. you look at the left edges on both images or you look at the right edges on both images). If you do that you must tell the vi that this is what you are doing, so set the *"Invert Horizontal"* switch to YES.
   B) Alternatively you look at the left edge on one image and the right edge on the other image. Then to tell the vi that this is what you are doing, set the *"Invert Horizontal"* switch to NO.

Procedure

The procedure that follows must be repeated for the horizontal and vertical directions.

1) Start the vi and adjust the appropriately labeled cursors in the INITIAL and FINAL images.
2) Rotate either the rotation stage (horizontal) or the goniometer (vertical) to position the structure at the target to remove the angle between the structure and fiber.

Other Features of ***Comparison.vi***

1) This vi can also be used to measure distances. One possible use is to center the fiber. The FINAL image gives the distances between the red and yellow cursors in millimeters provided you have entered the lens magnification. The magnification should be set to the maximum (3.00) for nulling angles, but can be lowered for distance measurements.

ARDB-37 Revision History

Revision #	Date	Description
6	4/15/97	Description of ABSOLUTE.VI added
7	5/15/97	**MAJOR REVISION** 1. Program locations (including libraries) changed 2. Lock-in frequency removed from output arrays. 3. FREQSCAN.VI and ABSOLUTE.VI combined. 4. Reference channel switched from HP multimeter to SR830 lock-in. 5. Reference channel calibrated. ref51597.txt is now the reference intercept file replacing ref32397.txt. 6. System level power has been calibrated at 90 GHz and -10 dbm which is now the suggested operating level. 7. An SR560 preamp has been substituted for the home made ×31 amplifier. 8. A general motor control VI, MOTOR, has been added to the applications.
8	6/14/97	1. Possible values of W-band frequency changed from multiples of 180 kHz 2. LO's changed to get reference 10 MHz from W-band source
9	6/30/97	1. Returned to using multimeter for reference 2. new reference calibration ref62897.txt 3. CALIBRAT.VI written for easy calibration of HP3457A multimeter and HP437B power meter.
10		1. Lock-in phase convention description added
11	1/19/98	**MAJOR REVISION** associated with moving programs from the original Windows 3.1 computer (ARDBW13) to the WINDOWS NT computer (ARDBW21).
12	1/24/98	835 MHz synthesizer control changed to SYNTHESIZER.VI
13	7/8/98	Description of the image acquisition VI's added
14	12/12/98	Description switching between times 5 and times 6 multiplier added.
14a	12/15/98	Modifications to procedure for switching from x5 to x6 multiplier