Introduction to the VSRT Interferometer

A detailed discussion of the mathematical theory behind how the VSRT Interferometer works, and how it simulates a modern cross-correlation interferometer that professional radio astronomers use, is given in "HowtheVSRTWorks.pdf." The discussion there, in general, is not intended for students. Instructors are advised to read this other document and decide for themselves whether their students would benefit from such a discussion. The labs discussed in "VSRTlabs.pdf" can be conducted without a discussion of the mathematical theory and the students will still attain an intuitive understanding of how aperture synthesis data leads to images of radio sources.

The discussion in "HowtheVSRTWorks.pdf" is, in fact, designed primarily for instructors who have some familiarity with aperture synthesis, although we do provide a very quick synopsis of the basic idea. The VSRT Interferometer is different, and simpler, than a professional radio astronomy interferometer, and so the purpose of "HowtheVSRTWorks.pdf" is to provide an explanation of how the VSRT interferometer produces (mostly) the same kind of data.

The discussion in this document, below, is helpful for both instructors and students in getting comfortable with the equipment and software.

A. Getting Familiar with the VSRT Interferometer

1. The Antennas (the LNBFs or Feeds) and the Detection Process

The radio signals are first collected by two satellite-TV feeds, known as "Low-Noise Block down-converter Feeds" or LNBFs or feeds, for short, which are shown in Figure 1. The VSRT comes with two assemblies each containing *three* LNBFs. However, only one of the feeds in each assembly is used; when viewing the LNBF with the feeds facing you and at the bottom (and the connectors above them) the leftmost feed is the active one, as shown in Figure 1. The frequency of radiation to which the feeds are most sensitive is ~ 12 GHz (or 2.5 cm).

After entering the feeds the radio signals are then "mixed down" (as is said in radio astronomy) to lower frequencies and then the signals are *added* together. The added, mixed-down signal is then fed into the computer. However, the signals in the different feeds are mixed down to slightly *different* lower frequencies, and so when the signals are added a
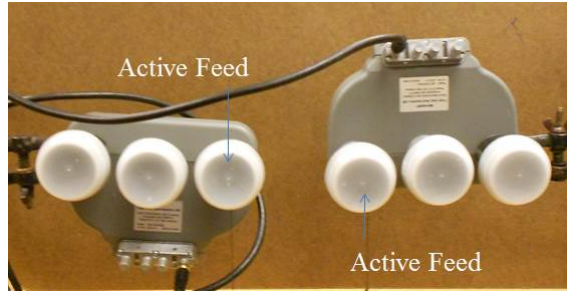
FIG. 1: The Low-Noise Block down-Converter Feeds. Three feeds come per assembly, but only one feed is used with the VSRT set-up.

"beat frequency" results. For those readers who have not learned of "beat signals", it is a common phenomenon when adding sine waves of slightly different frequency. Musicians are familiar with the slow oscillating sound that occurs when two instruments are slightly out of tune relative to each other and the same note is played – that slow frequency is a "beat frequency." With regards to the VSRT interferometer, it is the power in this beat frequency signal that is measured with the software. The VSRT interferometer, therefore, is different from a normal radio astronomy interferometer in two ways: (a) the different mix-down frequencies and (b) the fact that the signals are added, rather than cross-correlated.

2. The Laboratory Radio Sources: Compact Fluorescent Light Bulbs

Of course, these labs also require radio-emitting objects to observe with the VSRT interferometer. Fortunately, simple compact flourescent light bulbs (CFLs) do the trick. In addition to visible light, these light bulbs emit microwaves, which can be detected by the LNBFs. When electric current is applied to the "gas discharge" tubes, many electrons are freed from the atoms and then emit radio-frequency radiation in collisions, primarily with the walls of the tube. These light bulbs are inexpensive, easy-to-manipulate in the lab, and detectable with the LNBFs.

The radio-frequency emission occurs primarily in the direction perpendicular to the walls and so the most intense radio-frequency signals are emitted by CFLs that have straight tubes, such as the model given in the VSRT parts list (GE Bias 27 Watt, Part No. FLE27QBX/2/SW), in the direction of the tubes (i.e. with the tubes aimed at the LNBFs). However, for these labs we recommend that the equipment involve one straight-tubed CFL

and two large helical CFLs, such as the 55W GE (Part No. FLE55HT5/2/SW/BX). Some of the labs involve moving the CFLs to different positions and if using a straight-tube CFL then the necessity of turning the CFL to re-aim it at the LNBFs introduces another source of error in the labs. Additionally, these labs are simpler for the student to understand if the sources have simple rectangular profiles (as seen from the direction of the feeds) and the large helical CFLs emit more radio-frequency radiation out their sides than the straight-tubed CFLs. The radio emission from the sides of the 55W helical CFL is about one half as intense as that from the 27W straight-tube CFL in the direction of the tubes but about twice as intense as that emitted out the sides of the straight-tube 27W CFL.

When conducting these labs, be sure to turn the CFLs on in advance and *allow 30 minutes* or so for them to settle to a steady state. The radio emission is more variable when they are first turned on.

3.   How to Use the VSRT Interferometer for These Labs

1. Mount the LNBF assemblies on ring stands using proper clamps so that the two active feeds can be firmly and easily arranged to point in the same direction. Attach plumb bobs to the feeds and then lay a meter stick on the table to measure the distance between the centers of the active feeds.

2. Place a single CFL in line with the midpoint between the feeds and at a distance of two meters. To prevent reflections, place the feeds and CFL at the edges of different tables, as shown in Figure 2, and make sure that there is no wall close behind the CFL.

3. Insert the USB connector of the feed assembly into the computer USB port and plug the VSRT power adapter into a power strip.

4. On the computer, click on the SRT/vsrt icon (with an image of a radio telescope). (like that shown in Figure 3. After a few seconds a display window like that shown in Figure 4 should appear. In the window, note the pair of similar looking panels side-by-side at the top. These two panels each show a spectrum and in each panel you should see a single sharp peak. This peak is the beat signal (discussed above). The

FIG. 2: Set up with the CFL in the foreground and the LNBFs, connected to laptop, 2 meters away.
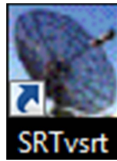

FIG. 3: SRT/vsrt Icon to open the VSRT data acquisition software.

panel on the right shows the spectrum detected in the last 0.5 seconds, and the panel on the left shows an averaged spectrum.

5. Now note the numbers at the bottom of the averaged-spectrum panel.

   (a) The first number indicates the antenna temperature (in Kelvin) of the beat signal, which is proportional to the detected power and hence a measure of the desired response of the VSRT interferometer. In Figure 4 the measured antenna temperature is 34.7 K.

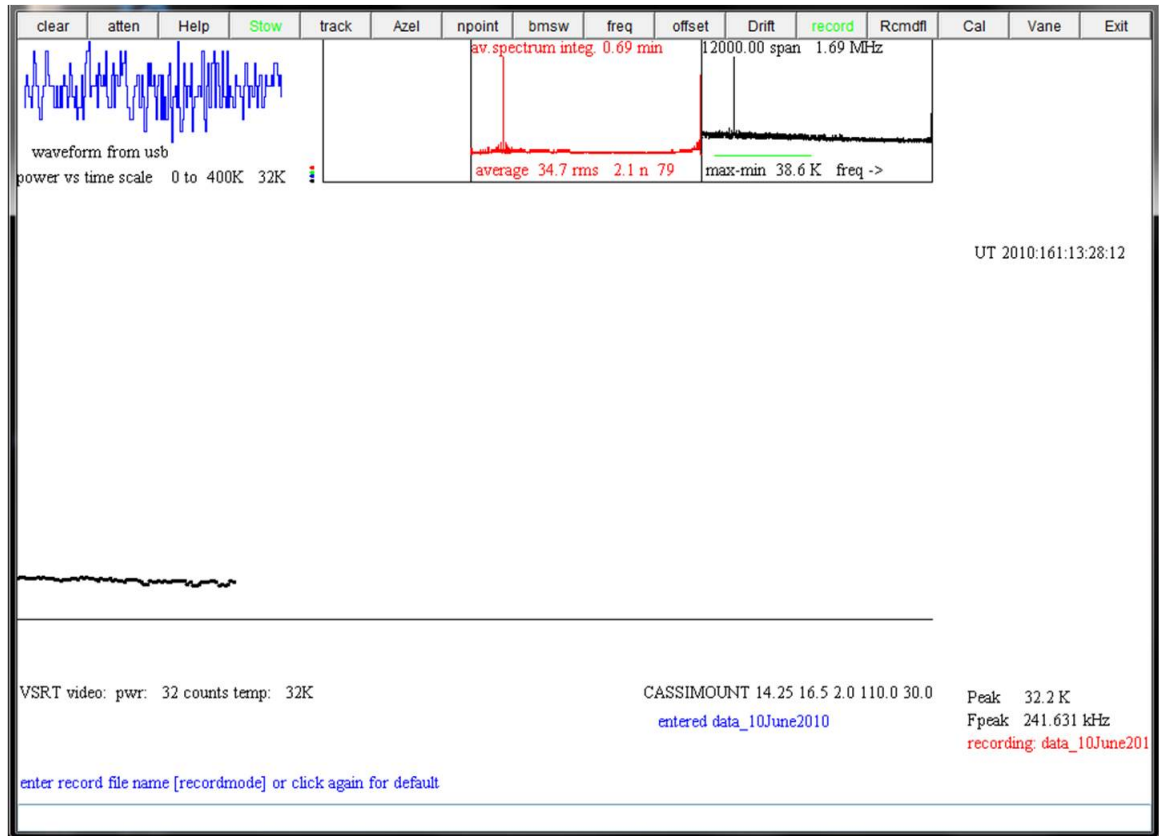   (b) The second number gives the rms in the average spectrum. In Figure 4 the rms is 2.1 K.

FIG. 4: Screen shot of a VSRT interferometer observation.

(c) The third number, "n," indicates the number of detections (or "integrations") used in the average. In Figure 4, n = 79.

(d) The uncertainty in the measured antenna temperature, which is "the uncertainty in the mean," is the rms divided by the square root of n. In Figure 4, then, the measured antenna temperature is 34.7 ± 0.24 K.

6. Use the mouse to click on the averaged-spectrum panel and note that the first click stops the average (the value for n stops increasing) and the second click starts the average over again. This will be useful in the labs for knowing how long you integrate your data for.

7. Place a second CFL at the same distance from the first but in a slightly different direction (but at the same height) and note the antenna temperature. Move the second CFL to other positions in different directions and note that the detected antenna temperature changes as the second CFL's position changes.

8. When conducting the labs, turn off the room lights.

4. Recording Data

For easy processing of the data, you will need the data to be written into data files. When ready to make a measurement of the VSRT interferometer response for a given arrangement, click on the **record** button (fifth button from the right end of the tool bar at the top of the display). Then move the mouse to the text box at the very bottom of the window and type in a file name. In order to use the VSRT_Plotter package for processing your data, it is very important that type in a file name that *contains a pair of single quotes with the value of the independent variable inside the quotes* – the lab instructions state what parameter is to be put inside the quotes. For example, when doing the beam-pattern lab, in which you will measure the detected power vs. angular position of a CFL, the file name for the data set when $\theta = 10^o$ could be beamlab'10'_15Sep12. The VSRT software will automatically add ".rad" to this file, so that the entire file name will be beamlab'10'_15Sep12.rad. The VSRTI_Plotter program then will look for the single quotes to read in the independent variable value. With the Plot Beam lab, for example, there is no way for the program to know where you placed the CFL, so inserting the value of θ inside the quotes is essential.

Then, when you're done recording data for that configuration, and before you touch or move anything, click on the **record** button again to stop the recording. (Note: the averaged spectrum window will continue to integrate, but don't be concerned though – that window is separate from the recording into a file.) You can then find these data files in the C:\SRTvsrt folder. In general, it is good practice to move these files to your own flash drive.

After you've written data files for every arrangement needed for the lab, you can read these files into VSRTI_Plotter package, as we discuss next.

B. Getting Familiar with VSRTI_Plotter

1. Click on the "VSRTI_Plotter" icon. A small rectangular window like that in Figure 5 should appear. This window gives you a choice of programs to run. The instructions for each lab will tell you which one you need for that lab. For now, select the "Plot Beam" program. You should see another window pop up, like that shown in Figure 6.

FIG. 5: The first window to appear in the VSRTI_Plotter package.

2. Reading in VSRT Interferometer data files: When you have a full set of data files for a lab, to read in the data, simply highlight and select all the relevant data files and drag and drop them into the empty "Data Files" box on the right side of the VSRTI_plotter display. You can add and delete data files at any time. DO NOT use the "Open file" button. Files to be input with this button have a different format from the raw VSRT data files. This button is explained below. Even if you don't have any data yet, continue with the following instructions.

3. The boxes below the Data-Files box contain parameters which affect the display, and which you can adjust.

4. The "Show ... " button displays a theoretical curve for that lab. The curve depends on some of the input parameters and so will change when you adjust these parameters and then click "Update." This curve can be used both to fit your data by eye, leading to conclusions regarding the values of the input parameters, and to demonstrate the concept for those without data. For now, for example, click on the "Show Beam Pattern" button, note the display on the left, and adjust the numbers for "D" and "λ" (clicking "Update" after each change) and note how the beam pattern changes.

5. When you get a plot that you'd like to save, you can right-click on the graph and save the image either as a JPEG file or an eps file.

6. At any point, you can click "Save File," which will save the data into a three-column ascii file. This file will have a different format from the .rad file written by the VSRT Interferometer software. Files saved by any VSRTI_Plotter program can be read back in using the "Open File" button. DO NOT drag and drop VSRTI_Plotter saved files into the data files box – that box is strictly for data files written by the VSRT Interferometer software.
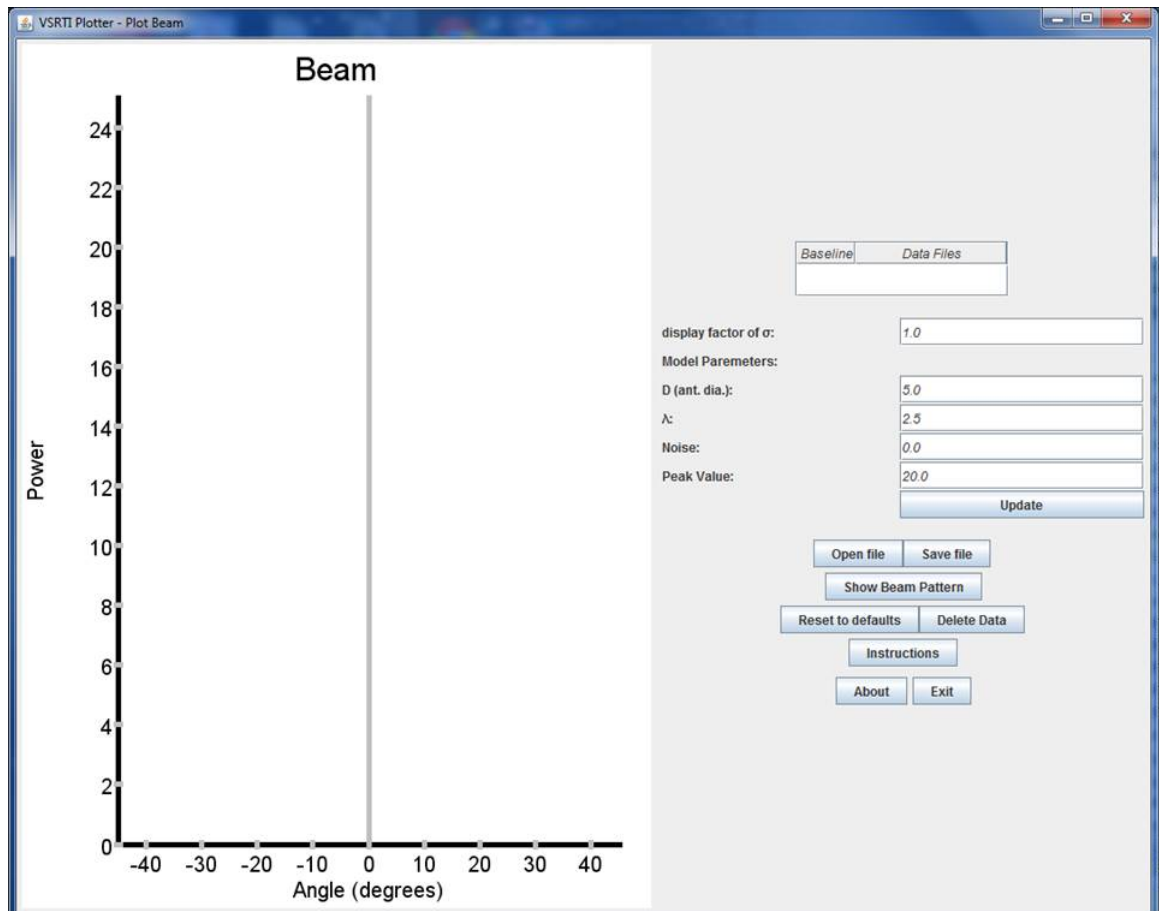
FIG. 6: The display when running "Plot Beam" in the VSRTI_Plotter package.

7. The size of the displayed error bars is equal to the uncertainty in the data multiplied by the "display factor of σ". (The uncertainty is calculated as $\text{rms}/\sqrt{N}$, where rms is the measured root-mean-square of the deviations in the data file and N is the number of values in the average). The rms values tend to be small with the VSRT interferometer and so the errors bars will generally be too small for the display without the display factor. You can change the display factor of σ using the input box.

8. To delete a data point, click on the appropriate data file in the "data files" box and hit the "delete" key.

9. Comments about units: The equations used for the models in "Plot Beam" and "Plot Fringe Pattern" assume the user has calculated the position angles of the CFL in units of *degrees*. However, in "Plot Visibilities," the angle input parameters (angular sizes of sources and angular position of second source) are in units of radians. (The

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expectation is that students would more naturally measure angles in degrees in the first two labs, while in the Visibilities lab inferring the angles in radians is more meaningful in terms of understanding the relation between the Visibility function and the intensity distribution of the light source.)

Also, the default setting for the wavelength of the detected radiation is in cm, and so all other distance values (such as the diameter of the feed, or the distance between feeds) is in cm. If one wishes to measure these distances in another unit, then the setting for the λ input box should be changed accordingly.