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Sharjah five-meter radio telescope

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Abstract: The project aims at building the first-ever 5-m SPIDER 500A radio telescope in the United Arab Emirates with an observing frequency of 1420 MHz. This is one of three telescopes that will be used to simulate a 40-m radio interferometer. This interferometer will be the first of its kind in the Gulf Cooperation Council (GCC). The location, construction, and the first observations of the Orion nebula and the Sun with the 5-m single-dish are described in this paper.

Keywords: Antennas; Interferometry; Image processing

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Contents

2020 JINST 15 P01033

1 Introduction

Radio Astronomy studies the natural radio emission from different celestial sources at the lower end of the electromagnetic spectrum [1]. The radio band in the EM Spectrum contains a broad range of frequencies that can propagate through the Earth's atmosphere [2]. This range of frequencies that lies between 10 MHz up to 300 GHz (or 30 m down to 1 mm) is called the *radio window* [2]. Compared to dust grain sizes, radio wavelengths are much longer and can easily pass through Earth's atmosphere [1]. Radio observations can then be performed during day or night.

Observing the radio sky requires radio telescopes which are designed to receive radio waves from any celestial object. These radio signals tend to be very weak, so a large effective area is necessary [3]. A radio telescope consists of an antenna, feed horn, mount, and pier. The antenna receives the pre-amplified signals from the radio source in the sky and transfers them to the receiver, which detects and amplifies the signals.

Radio telescopes are located all over the world and come in all shapes and sizes, such as the Five hundred meter Aperture Spherical Telescope (FAST) in China (the largest non-steerable telescope),[1] the Arecibo Observatory radio telescope in Puerto Rico,[2] the Green Bank Telescope in West Virginia in the US,[3] and Effelsberg in Germany.[4] Such telescopes can be combined to produce an interferometer like the Very Large Array (VLA) in New Mexico.[5]

This work will introduce the Sharjah 5-m radio dish that will be a new addition to these telescopes. The telescope is located at the Sharjah Academy for Astronomy, Space Sciences, and Technology (SAASST) in the United Arab Emirates. It is the first radio telescope of this size in the Gulf area. The system operates at the frequency of neutral Hydrogen emission of 1420 MHz.

This paper is organized as follows: section 2 explains the reason behind choosing the location of the radio telescope. Section 3 introduces the different components of the system. The installation process, mounting, and operation of the radio dish are provided in section 4. Section 5 describes the main features of the RadioUniversePRO 1.4.6 Software and how it is used to perform the different radio observational tasks. In section 6, we report the preliminary observations of Orion A and the Sun as the first targets of the telescope. Details on the future 40-m radio interferometer are mentioned in section 7. The last section describes the importance of the telescope in SAASST's educational program and the future use of the radio interferometer in observing large radio sources.

2 Radio telescope location

The location of the 5-m radio telescope was chosen on the eastern side of Sharjah's building (figure 1) for easy access and control of the telescope. To check for any possible radio interferences at the chosen location, a portable spectrum data analyzer was used to scan the radio window centered at the telescope operating frequency of 1420 MHz with a bandwidth of 50 MHz. The analyzer detected no significant artificial interference around 1420 MHz. The exact geographical latitude and longitude coordinates of the radio telescope are $25^\circ\ 17'\ 05.21''$ and $55^\circ\ 27'\ 50.28''$, respectively.

3 Radio telescope components

The four primary functional components of a radio telescope are the reflector dish, the antenna, the radio receiver, and the amplifier. All are used to detect radio-frequency radiation that can be emitted by the Sun, Moon, planets, or any other celestial body. Since radio wavelengths are much longer than those of visible light, the radio dish has to be large enough to match the angular resolution of a similar optical telescope.

The sensitivity of a radio telescope, i.e., the ability to detect the emission of weak radio sources depends on four major factors: (1) the total collecting area of the dish, (2) the efficiency of the dish, (3) the type of receiver in terms of its sensitivity to amplify and detect the radio signals, and (4) the length of the observation. The receiver bandwidth is also crucial for broadband continuum emission. Some radio telescopes can be huge (the Chinese five hundred meters aperture spherical telescope

[1] "Science." *FAST*, fast.bao.ac.cn/en/Science.html, [Accessed] 8th Oct. 2019.

[2] "The Arecibo Observatory." *The Arecibo Observatory*, www.naic.edu/ao/landing, [Accessed] 8th Oct. 2019.

[3] "Green Bank Telescope." *Green bank Observatory*, greenbankobservatory.org/science/telescopes/gbt/, [Accessed] 8th Oct. 2019.

[4] "Radio Telescope Effelsberg." *Max Planck Institute for Radio Astronomy*, www.mpifr-bonn.mpg.de/en/effelsberg, [Accessed] 8th Oct. 2019.

[5] "The Karl G. Jansky Very Large Array." *Science Website*, science.nrao.edu/facilities/vla/, [Accessed] 8th Oct. 2019.

2020 JINST 15 P01033

Figure 1. Satellite view of the preferred SPIDER 500A telescope location at the Sharjah Academy for Astronomy, Space Sciences, and Technology (SAASST).

or FAST [4], or the 100-meter NRAO Green Bank Telescope) since some radio sources are feeble, and a large collecting area is necessary. The use of sensitive radio receivers to detect these weak signals becomes then mandatory to avoid the masking of these signals by terrestrial human-made radio interference.

The Sharjah 5-m radio telescope is a SPIDER 500A made by PrimaLuceLab [5]. The telescope has a motorized altitude-azimuth mount that allows the radio dish to move from 0°–90° in altitude and 0°–360° in azimuth. The main characteristics of our radio system are summarized in the coming sub-sections.

3.1 5-m prime focus parabolic dish

The 5-m parabolic dish (WEB500-5) is made of a fine metallic mesh to provide a large collecting area with a low overall weight. The telescope uses unique rear supports to maintain the rigidity of the whole parabolic dish on the mount. This is necessary to avoid any bending and ensure the effectiveness of the pointing system. The perfect parabolic shape provides a maximum error of less than the twentieth of a wavelength.

3.2 1420 MHz optimized feed horn

The H-FEED feed horn has specifically been developed for the 1420 MHz SPIDER 500A radio telescope. It is designed for maximum illumination of the primary reflector to allow high gain while

2020 JINST 15 P01033

minimizing side lobes and spillover effects to have the best performance from the 5-m parabolic antenna. Two Low Noise Amplifiers (LNA) for the 1420 MHz frequency are installed to allow the reception of dual-polarization. At the point of focus of the antenna, the feed horn is maintained through a rigid structure of four supports to minimize obstruction. This setup allows the radio telescope to focus correctly and also maximize the performance.

3.3 Alt-Az waterproof computerized mount

Radio telescopes are used around the clock, even when it is cloudy, since the 1420 MHz radio waves are transparent to clouds. To capitalize on this, the new WP-400 mount has been designed to be utterly weatherproof without the use of a protecting dome. The software is equipped with an automatic GoTo system controlled by the radio telescope software. With a 400 kg load capacity, the WP-400 mount allows very high precision pointing and tracking with a read resolution of 5.4 arcseconds. Our system is equipped with a unique electronic system that parks the antenna toward the zenith if the wind exceeds 50 km/h. This vertical position permits the lowest resistance to the wind.

3.4 High load capacity pier

The 5-m web dish can generate a lot of pressure on the surrounding ground. With the WP-400 mount, a very stable and robust anchoring platform is necessary. The C400-Heavy pier system is designed to keep SPIDER 500A radio telescope very stable. The SPIDER 500A and its massive pier are designed to be installed on a reinforced concrete base, as explained above.

3.5 1420 MHz receiver

The H142-One receiver of the SPIDER 500A is unique. It has special characteristics such as a 1420 MHz superheterodyne type radiometer/spectrometer, a double conversion (up/down) with a 50 MHz bandwidth (RF = 1395–1445 MHz) and a 14-bit analog to digital converter. The spectrometer has 1024 channels (each 61 kHz) that are displayed and processed in real-time by the telescope operating system. Because of the high gain and low electronic noise of the receiver, radio sources can be observed with a theoretical flow of at least 5 Jy [6]. The RCPU-400 remote control and power unit with the receiver can be hosted in a one single 19” rack (figure 2) or even placed on a table close to the control computer.

3.6 Other additional components

The SPIDER 500A comes with a radio astronomy flux calibrator to perform absolute radio flux calculations. This is a necessary tool for real professional radio observations to calibrate the data. We have also installed an ultrasonic wind sensor (RCPU-USWIND) well integrated with the radio telescope control software to monitor the wind speed. If it exceeds 50 km/h, the radio dish goes to a “PARK” mode facing the zenith to minimize the wind force. An All-sky camera with 180 degrees lens was also installed to remotely monitor the radio telescope from the control computer room.

Other features were also installed, like the Multimedia module that permits the RadioUniversePRO to be used in museums. For educational purposes, the user can listen to an audio signal produced from the signal acquired by the radio telescope. He will also have the ability to point to

Figure 2. The H142-One radio astronomy receiver, the RCPU-400 remote control and power unit, and the RCPU-USWIND were all mounted inside a 19” computer rack.

several radio sources, including the Sun and the Moon, to highlight the differences in the brightness temperature at the operating frequency of the radio telescope.

4 Installation

The SPIDER 500A radio telescope was assembled and installed at SAASST on April 25, 2019, with the help of the PrimaLuceLab team from Italy [7].

A mounting base plate was used to install the C400-HEAVY pier on a reinforced concrete base using high strength bolts (figure 3). After completing the assembly of all the elements of the WEB500-5 dish along with the H-FEED feed horn, the system was then mounted on the WP-400 alt-az mount (figure 4). To make sure that there were no mechanical errors in the movement of the telescope, the system was rotated 360 degrees along the azimuth and 90 degrees along the elevation. This was performed after connecting the mount to the software. This procedure was also executed to make sure the cables attached from the feed horn to the receiver do not cause any hindrance in the antenna movement. The computerized mount was then aligned along the North direction for the precise location of sources during observation. Another method of calibration was performed by pointing the telescope towards the Sun and making sure the shadow of the feed horn was near the center of the dish. This is to assure that the telescope is precisely pointing at the radio source. After calibration of the mount and antenna, the telescope was connected to the H142-One superheterodyne receiver. All of the telescope’s controlling elements (receiver, power control unit, and computer) are placed inside a 3-m underground bunker to minimize any surrounding radio interferences.

2020 JINST 15 P01033

Figure 3. Foundation and mounting plate of the SPIDER 500A.

Figure 4. SPIDER 500A radio telescope.

5 RadioUniversePRO 1.4.6 software

The RadioUniversePRO software [8] is specially designed for the SPIDER 500A radio telescope. It shows all the parameters of the telescope, as well as allows the operation and the record of all the observations. At SAASST, it is installed on a computer with a Windows operating system. The graphical interface provides a comfortable reading in a simple mode through an integrated planetarium system that permits real-time control of all the different functions of the telescope. The position of the radio source under observation is continuously displayed. The software has an advanced interface that adds many options, customizations, and typical functions similar to professional radio telescopes. It allows the user to create scripts to automate the radio telescope to capture and save the raw data into FITS format for post-processing.

The main interface of the software is divided into four sections (figure 5):

Section One (Mount Control): connects the telescope to the mount and displays all the data related to it, such as the Actual Antenna Coordinates and the Commanded Antenna Coordinates, the coordinate system, and the pointed object.

Section Two (Software Features): consists of 11 different tabs that allow full access to all the telescope features, such as:

1. **User Data:** enables the user to enter the location of the radio telescope, the elevation, and the time zone.
2. **Source visibilities:** includes a list of the most powerful radio sources in the sky that the user can choose from to conduct the observation.
3. **Intermediate Frequency (IF) Monitor:** permits to view the data received by the telescope in the form of a power spectrum and Fast Fourier Transform (FFT) Waterfall for left and right polarization.
4. **Base Band Converter (BBC) Tools:** displays the uncalibrated real-time power spectrum of the input signal in the Intermediate Frequency (IF) monitor tab for left and right polarization. The system consists of a group of 16 filters (1u to 16u) for each polarization, which can be activated or deactivated to remove unwanted signals at 1420 MHz.
5. **Mapping:** creates radio maps of the sources with pre-set parameters.
6. **Total Power Plots:** visualizes and records the variation of the radio signal flux overtime for every BBC filter used.
7. **Offset Alignment:** is used to synchronize the radio telescope with the radio source.
8. **ON/OFF:** allows the radio telescope to collect the data while pointing towards a source (ON position) and then at a point away from the source (OFF position), this is known as a "cycle". Data obtained from the OFF position helps the telescope reduce the background radio noise and the effect of external components like the Earth's atmosphere.
9. **Spectrometer:** displays the spectra obtained in every cycle and the total average spectra of the source during the ON/OFF and Cross Scan.
10. **Gain Calibration:** executes Total Power measurements on a set of radio sources with a known radio flux.
11. **Weather Control:** continually displays the wind speed and monitors the sky through the All-sky camera.

Section Three (Receiver and Data Acquisition Control): connects the telescope to the receiver, controls the data acquisition and allows choosing proper receiver settings.

2020 JINST 15 P01033

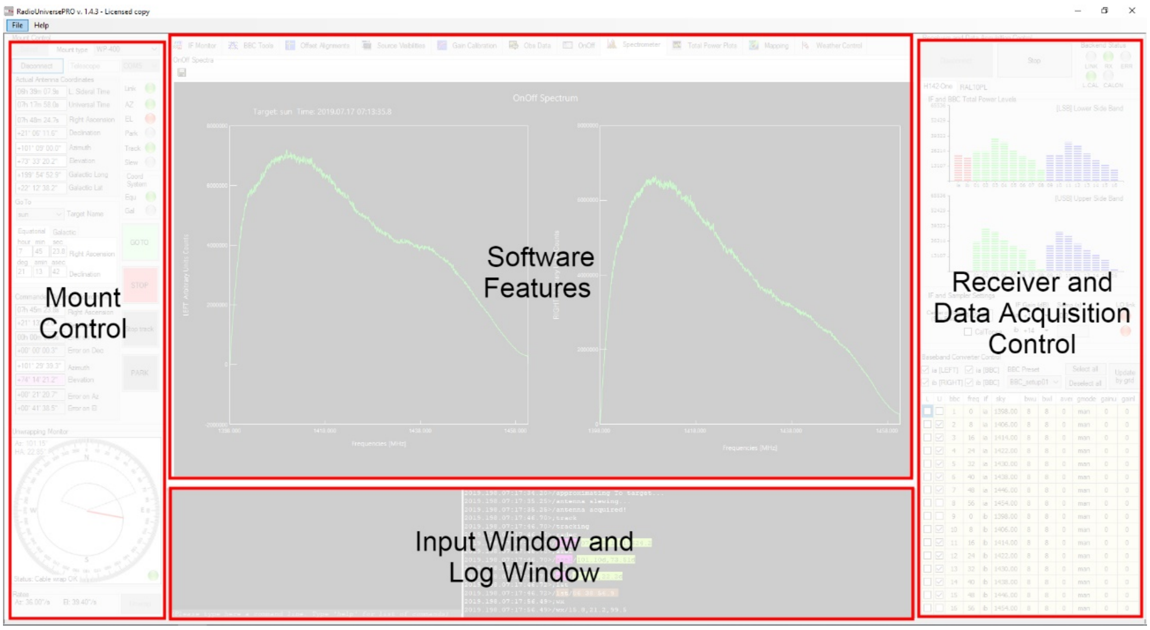


Figure 5. RadioUniversePRO Software showing the Mount control (left), Software features and Observed data (center top), Logs (center bottom), and Receiver control (right).

Section Four (Input Window and Log Window): controls the telescope manually and displays the status of the telescope.

6 Radio maps

Radio telescopes can observe a broad range of radio sources, from the most energetic objects such as pulsars and quasars to other objects such as galaxies, nebulae, and even planets. Radio maps are thus essential to know the overall morphological structure of a radio source. For observational studies, these radio maps will serve as a basic data set for any astronomical research.

6.1 Mapping using RadioUniversePRO software

Once the radio receiver is powered and connected with the control computer, the RadioUniversePRO software is ready to perform any observation. From the Source Visibilities list, there are more than 30 radio sources already implemented in the telescope database. If a source is not listed, its coordinates can then be manually typed in for the telescope to point at directly. Once the "Start Acquisition" button is selected, the IF monitor will display the data coming from the radio telescope to the receiver in the form of a power spectrum and FFT Waterfall, both for Left and Right polarization. The power spectrum is the graphical representation of the electromagnetic power distribution in the operative band through the RF chain. The spectrum graph shows for every channel the signal spectral power, that is, the levels are proportional to the square of the input signal of the FFT execution. The power spectrum is then used to calculate the total power use through an integral part of the entire bandwidth on the left and right channels. Total power values are reported on the right column graph "IF and BBC Total Power level" with the labels "ia" and "ib" that indicates the values "Intermediate Channel A" and "Intermediate Channel B" (IF left and IF right).

2020 JINST 15 P01033

The BBC tool window is an essential tool of the RadioUniversePRO software. It allows the visualization in real-time of the uncalibrated power spectrum of the input signal in both IF left and right. In some observations, we can find interferences in the IF or, more simply, there may be parts of the spectrum that we do not want to consider during measurements. The software allows the use of a group of filters (16+16) fully tunable on the 2 Intermediate Frequencies. Every filter can be set in frequency (starting frequency in baseband in the IF), and in bandpass (the width of the filter band that will define its radiometric sensitivity and the exposition to RFIs). You can also choose the IF to which to associate the filter to. As an example, BBC02 and BBC10 can be associated with the IF left and right, by using the options in the lower part of the BBC Tools window.

Creating a radio map, a total power plot, or performing offset alignments on a radio source or the gain calibration, can be done on a precise BBC set up in order to optimize the used bandwidth by excluding RFIs in-band or centering one or more filters on a particular region of the spectrum for the Hydrogen observation. Since the SPIDER 500A antenna has high directivity, we need to check the BBC filters and the absence of artificial signals every time we move the radio telescope to a new object, before capture.

The BBC Tool is also important to correctly set the gain value for the left (ia) and right (ib) polarizations especially when observing not so strong radio sources like Cassiopea A, Cygnus A, or Taurus A. We must increase the ia and ib digital gain in order to better match with the system dynamic.

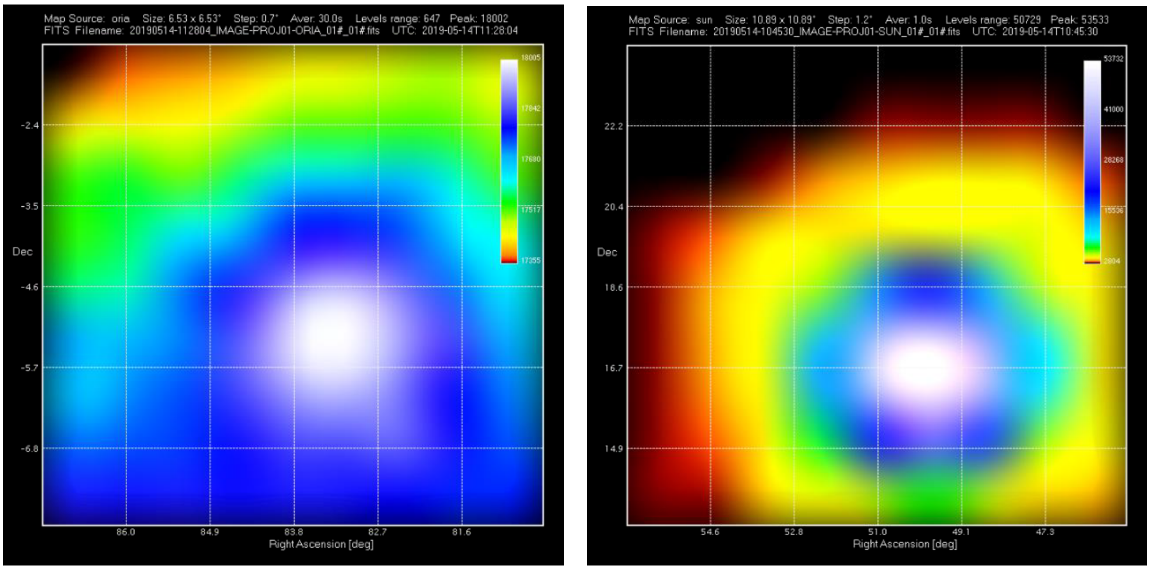
6.2 Observations

The Sharjah 5-meter radio telescope saw first light on May 14, 2019, with the observations of the famous Orion nebula (M42) and the Sun. Table 1 shows the properties of the two radio sources. These sources were selected as the primary targets for the telescope through the Source Visibilities database. BBC filters from 2u to 7u for left polarization and 10u to 15u for right polarization were activated to remove surrounding radio interferences at 1420 MHz. Table 2 includes the parameters that were used to map the Orion nebula and the Sun. After the measurements are completed, the RadioUniversePRO calculates the average of the data and displays the radio map. Figure 6 (a and b) shows the radio maps obtained where the region of maximum radio emission is shown in white color.

Table 1. Properties of Orion A and the Sun.

Properties	**Orion A**	**Sun**
Object Type	Nebula, HII	Star
Right Ascension (h m s) (J2000)	05 35 17.3	03 38 54.3
Declination (d m s) (J2000)	−05 23 28.0	+19 29 19.0
Elevation at the time of observation (Deg)	+70.2295	+50.18463
Flux (Jy) at 1420 MHz*	520	40000

*These values are obtained using RadioUniversePRO Software.



(a) (b)

Figure 6. Radio maps obtained using SPIDER 500A for (a) Orion A and (b) the Sun.

Table 2. Mapping Parameters of Orion A and the Sun.

Map Setup	Orion A	Sun
Width × Height (Deg)	5×5	10×10
Delta*	0.3	0.5
Average (s)**	30	1

*Distance from pixel to pixel in the radio map.

**Number of seconds the antenna must track every pixel.

7 Future 40-m radio interferometer

The installation of the first SPIDER 500A at SAASST took into consideration our aim to build a 40-m radio interferometer. A multi-element interferometer (with N radio telescopes) produces (N*(N-1))/2 unique responses, so a three-element interferometer produces three responses that are the arches in the (u,v) plane of the generated high-resolution map [9]. We need to avoid the installation of more SPIDER 500A radio telescopes at the same distance from each other since this would produce a “visibility” redundancy of several pairs of antennas. For this reason, the three SPIDER 500A will compose the base interferometer at the top of a rectangular scalene triangle, with distances (sides of a scalene triangle) of 30, 40, and 50 meters, as shown in figure 7. This array will be able to simulate the resolution of a 40-m diameter single-dish antenna, with a collecting area equal to an antenna of 8.7 meters in diameter. The synthesized beam in this configuration will measure about 0.36° (21.6 arc minutes).

To upgrade the single SPIDER 500A radio telescope to a three-element interferometer (composed by 3 SPIDER 500A units), the following points will be taken into consideration: (1) upgrade the RF cables to fiber optics to avoid signal losses and uncertainties in the timing of the signal com-

2020 JINST 15 P01033

ing from every radio telescope; (2) add the multi-million channel backend to every SPIDER 500A receiver; and (3) add the interferometer correlator that will allow you to create the high-resolution map from the interferometer.

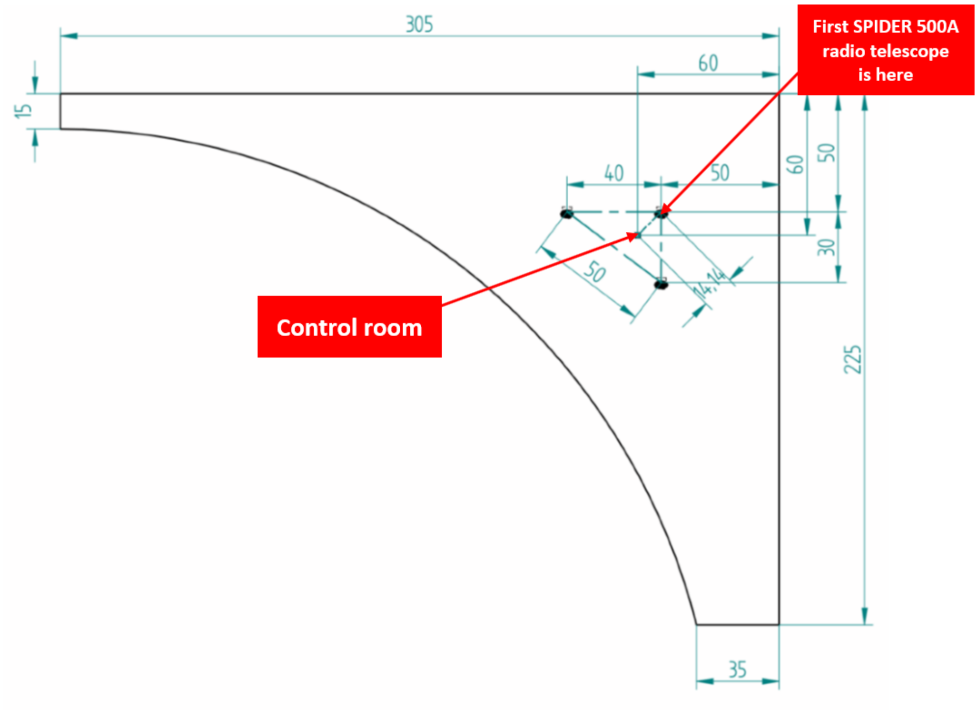


Figure 7. Proposed design of the 40-m Sharjah radio interferometer.

8 Conclusion

Besides our SAASST optical observatory, the 5-m SPIDER 500A has opened for us a new window of observation: the radio window. It will help the Sharjah Academy for Astronomy, Space Sciences, and Technology in the promotion of its academic program especially the new MSc in Astronomy and Space Sciences. Our 5-m radio telescope is a real professional one with a straightforward visual interface, where the user has a better control of all the functions of the telescope. The high gain and directivity parabolic antenna, the weatherproof alt-az computerized mount, the spectrometer and radiometer low noise receivers, and remote control capabilities, all of these make the SPIDER 500A an ideal tool for radio astronomy. With the future completion of the 40-m radio interferometer, the system will have an angular resolution of about 0.36°. Hundreds of extended radio sources can then be observed with greater details, and this will help to build better models to understand large radio sources.

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2020 JINST 15 P01033