



Design strategies for antenna array to monitor the sun in low-frequency range

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Radio signal wavelengths typically range from centimeters to meters, so the waves themselves are not nanometers. The connection to the nanoscale lies in the materials and manufacturing processes within the telescope system, the design of antenna arrays and their orientation toward the observed object are among the most important considerations in communications systems and the construction of modern radio telescopes, particularly low-frequency telescopes. This paper addresses a fundamental methodology for optimizing the design and placement of antenna arrays to enhance performance metrics, including key design considerations in terms of element spacing, array geometry, and feed network structure. Advanced techniques, such as adaptive beamforming and digital signal processing, are being investigated to improve the signal-to-noise ratio and mitigate interference. Several common geometries are used in antenna array design, each with its advantages and characteristics depending on the application. A special array system is used to monitor the sun on top of the Astronomy and Space Department building at the College of Science at the University of Baghdad, which is the subject of our research. This system is a linear array, with antennas arranged in a straight line. This type of antenna is the most common in astronomical studies. A dipole antenna with a length of $\lambda/2$ is designed, and two antennas are made with the same specifications in terms of wire length and material to receive the same signal at the same frequency. The system determines the position of the sun based on time and date, tracking the sun throughout the year without moving the antenna. The phase shift angle is calculated, and from there, different wire lengths are made to obtain different resistances compatible with the phase shift angle. The results underscore the need for a tailored approach to antenna array design to maximize the observation of most astronomical phenomena originating from the sun,

Keywords: Antenna array; Interferometry; Sun tracing; Phase shift; Linear antenna array.

1. INTRODUCTION

Radio telescopes are indirectly linked to nanotechnology: nanoscience contributes to improvements in materials, coatings, thin-film components, and receiving electronics, which in turn improve sensitivity, efficiency, and interference resistance, one of the most important features of the LOFAR (Low-Frequency Array) telescope is its ability to offer several advantages that enhance its astronomical research capabilities [1,2]. Its wide field of view allows it to quickly scan vast areas of the sky, making it ideal for large-scale surveys [3]. Its high sensitivity is achieved through its design at low radio frequencies, enabling it to detect faint astronomical signals that other telescopes might miss [4,5]. This low-frequency range enables unique observations, including the study of the early universe and cosmic structures often difficult for high-frequency telescopes to access [6,7]. These advantages make LOFAR a powerful tool for advancing our knowledge of the universe. For solar observations, LOFAR offers unique benefits, including its low-frequency sensitivity, as it can observe the sun at low radio frequencies and capture emissions from solar flares and other solar activity that are difficult to observe at higher frequencies [8, 9]. LOFAR's high temporal resolution and its ability to observe solar events in real time enable researchers to study the dynamics of solar activity, such as coronal mass ejections (CMEs) and solar flares, as they occur [10,11]. It also enables researchers to image solar structures. LOFAR's interferometric capabilities allow detailed imaging of solar structures, including sunspots, solar prominences, and coronal holes, providing insights into the solar magnetic fields and solar wind [3,12]. By observing the sun's interactions with the solar wind, LOFAR contributes to our understanding of how solar activity affects space weather and Earth's magnetosphere [13,14].

These features make LOFAR a valuable asset for solar research, contributing to our understanding of solar dynamics and its influence on the solar system [6]. However, we have been able to design a miniature array with which we can conduct a wide range of astronomical observations, particularly those related to radio emissions from the sun at low frequencies [15]. The Array's design allows for high sensitivity to weak radio signals, making it effective for studying faint solar activities such as solar flares and coronal mass ejections (CMEs) [8,16].

One of the most important reasons and key features of the LOFAR telescope, which made it an important tool for observing the sun, is the primary reason for choosing this research topic. LOFAR operates in a wide frequency range between 10 and 240 MHz, allowing it to capture a variety of solar emissions often overlooked by other telescopes [17,18]. LOFAR's high sensitivity and imaging capabilities enable it to produce high-resolution images of the sun, revealing fine details of its structures and dynamics [19]. LOFAR also detects solar radio bursts, which contribute to understanding solar magnetic fields and plasma processes [20]. One of the most important features that made solar observations essential is coronal mass ejections, which can be observed to reveal their origins and potential effects on the solar wind [21]. Real-time monitoring of the telescope enables the observation of solar activity in real time, providing valuable data for understanding space weather phenomena that may affect Earth [22]. As for imaging and mapping, LOFAR can create detailed images of solar activity, helping scientists visualize and analyze phenomena occurring on the sun's surface and in its atmosphere and solar events and their impact on space weather and Earth systems [23,24].

One of the most important technologies LOFAR relies on is a technique called Interferometry, which combines signals from multiple antennas to create high-resolution images, improving the quality of astronomical object imaging [25]. The basic principle of Interferometry involves combining signals received from various antennas (or dishes) to simulate a much larger telescope [26]. This technique exploits the wavelike nature of radio signals, allowing the phase differences between them to be measured [27].

Then, Interferometry relies on the interference of waves, typically radio waves, in the context of antennas. When signals from multiple antennas are combined, they produce an interference pattern that can reveal information about the source of the waves [28,29]. The second important parameter is phase shift, where the key concept in Interferometry is the phase difference between the signals received by different antennas. By measuring this phase difference, one can deduce the direction and characteristics of the incoming waves [30].

2. METHODOLOGY

LOFAR's LBA and HBA dipole antennas are primarily affected by nanoscale material and surface conditions, rather than by the dipole geometry (which is macroscopic at the wavelength level). Designing an omnidirectional antenna array system to detect the sun requires it to be capable of directing its beam at the time of day when detections are to be undertaken. This study considers the sun's average direction and the elevation of the sun at mid-day (noon) at the capital of Iraq, Baghdad (latitude 33°, longitude 45.35°), at noon every month of the year, as illustrated in Table 1.

Table 1 Average location of the sun at midday for each month.

Month	Elevation Angle (degrees)
January	33.68°
February	39.39°
March	49.24°
April	61.48°
May	72°
June	78.87°
July	79.68°
August	74.44°
September	64.75°
October	53.23°
November	41.97°
December	34.79°

In this Table, the elevation angles are taken from an online solar location resource (<http://kiesan.casio.com>), which provides this data for any given location at any required time, where the elevation is an angle that is formed between the horizontal line and the line of sight if the line of sight is upward from the horizontal line.

3. RESULTS AND DISCUSSION

At these frequencies, antenna performance is less sensitive to very fine geometry, but surface/material effects remain important because they alter loss. nanoscale impact low-band (LBA) antennas in changing the position of the sun during the year, the monthly average is taken to calculate the change in phase shift for calculating the wire length in phase shift design, as shown in Table (2).

Table 2 The relation between direction pattern and wire's length.

Θ (degree)	L (m)
0	0
15	0.410447761
25	0.684079602
30	0.820895522
40	1.094527363
60	1.641791045
70	1.915422886
90	2.462686567
sum	6.019900498

To design the receiver system, a single antenna must first be designed to operate at a specific frequency, where this work has chosen a dipole antenna as an inverted-V antenna type. This type of antenna features simplicity and compact size compared to a standard dipole antenna, and the influence of external factors is less. This antenna contains two copper wire arms. The wire forms an angle with a metallic ground of area m^2 . Our design process utilises a simulation program called EZNEC, a popular antenna modelling tool based on the "Numerical Electromagnetics Code" (NEC). With an NEC-based antenna modelling program, it is possible to design antennas by modelling their geometry and connections, and then simulating parameters like radiation pattern gain and SWR. The purpose of arranging the antennas in this way is to cover the sky and eliminate ground effects. Additionally, the study utilised the following feature: single wire loss. This allows each wire to have a different loss, if desired, and ensures the best alignment for optimal gain. As shown in Figure 1.

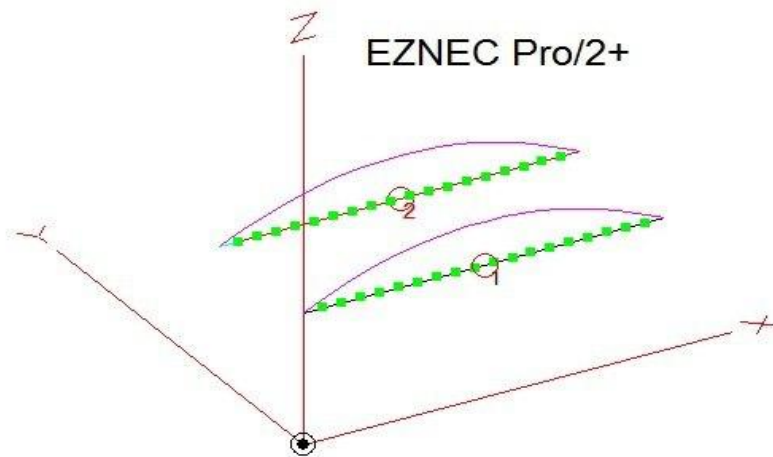


Figure 1 Simulation design for antenna array.

To design a linear Array in which the array elements are placed in a straight line with a single-phase shifter. Even though the antenna arrangement is simple, the beam steering is limited to a single plane. The vertical arrangement of several linear arrays forms the flat antenna. To create an antenna array circuit as shown in Figure (2) which involves several key components and concepts, focusing on the principles. To design the sample, the basic components include a minimum of two antennas. The preferred type is a half-wave dipole antenna, which is configured linearly and has a baseline or spacing between antennas that is typically half the wavelength ($\lambda/2$) for optimal performance.

Additionally, the Feed Network requires transmission lines, utilising either coaxial cables or microstrip lines, to connect antennas to the power divider and phase shifters, thereby steering the beam from astronomical objects, such as the sun. The other concept involves using a power divider to split the signal from the transmitter to the individual antennas, as well as connectors and cables used for connecting the antennas to the feed network. We finally need Oscilloscopes or signal analysers to measure performance, such as software programs (SkyPipe, Audacity) and devices (HSA2000 series spectrum analysers).

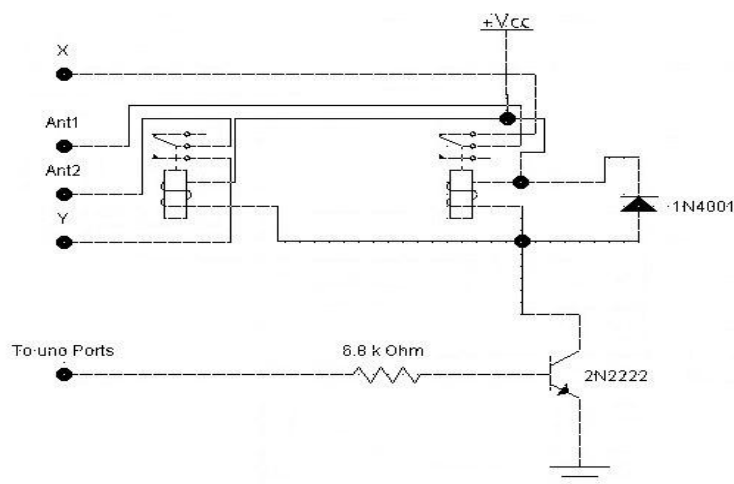


Figure 2 Circuit diagram for linear antenna design.

Since celestial objects are moving, not stationary, and antennas are fixed to the Earth, a phase shift must be added to the signal received from each antenna in the antenna array. In contrast to the individual antennas in the Array, this enables the combined signal of these distinct antennas to function as a single antenna signal with a very different performance. Since the combined signal is the sum of the signals from each individual antenna, combining numerous antennas results in increased power. Additionally, compared to a single antenna, the combined antennas' beamforming pattern may be far thinner. It is not necessary to mechanically adjust the individual antennas to change the direction of the beam, which represents the direction of the collective antenna's maximum sensitivity. The beam position of an array with variable phase shifters can be altered just as fast as the phase shifts.

Additionally, a phased array weighs less than a single gimbal antenna with quick steering. Cost is a crucial factor since huge antennas move more slowly, and a very large mechanically guided antenna can be swapped out for a series of smaller, less expensive antennas without losing accuracy. Even if building an array is more costly than developing a single antenna, it is challenging to compare costs when specific system needs are not taken into account. In contrast to individual antennas, this method enables antenna arrays to attain higher gain and improved signal reception.

The scanning angle, which shows the object's position in relation to the horizon, is an important consideration for orienting an array. The entire aperture gathers the signal, and the mechanical antenna must be slanted if the target is low on the horizon. A phased array's effective collection area is decreased when its phase is increased toward the signal in that direction. At the same time, the aperture's physical layout (such as parallel to the ground) remains unchanged. However, the Array is positioned at the target's edge and only picks up a very tiny signal if the target is on the horizon.

The second consideration is bandwidth; the majority of phase shifters are made to offer a steady phase shift over a variety of frequencies. The secret is to use the phase shift of the signal to approximate its delay. The phase shift of a delayed signal increases linearly with frequency. In phased arrays intended for narrow beamwidth and signals with a wide instantaneous bandwidth, the phase-shifted beam squints, or changes direction with frequency. This may be enough to entirely divert the beam from the

target, which would drastically lower the amount of signal that is picked up. Cross-coupling is the last component; even when surrounded by other antennas, each one functions identically. To reduce the impact of cross-coupling, the design needs to be adjusted.

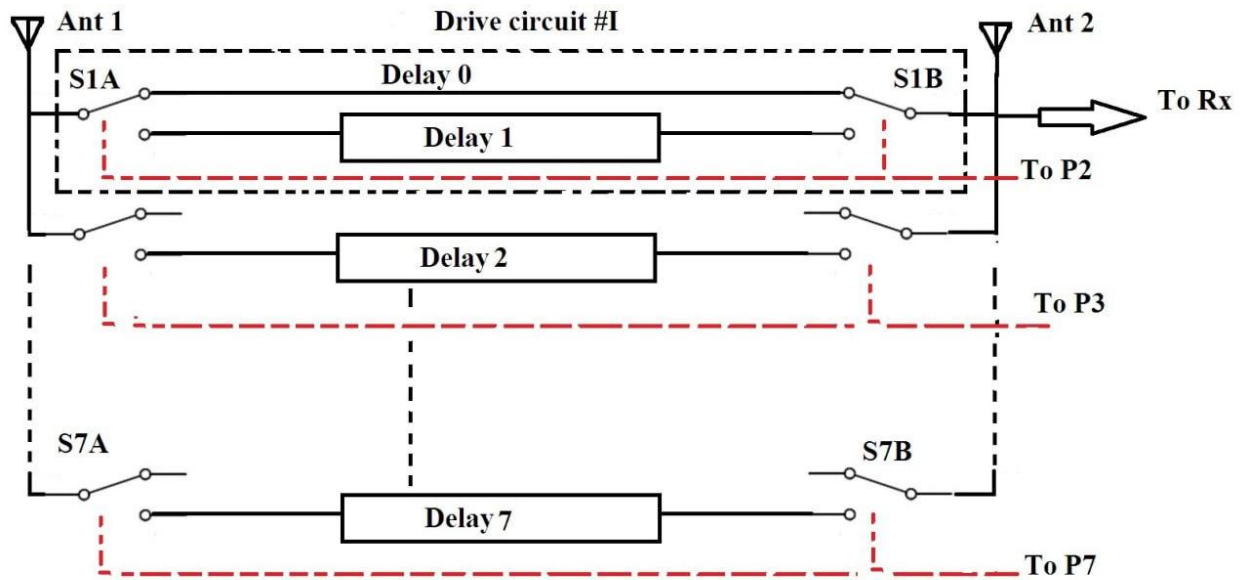


Figure 3 Diagram of electric circuit of phase shift.

Analyzing wave interference, building circuits, and enhancing communication systems all require an understanding of phase shift. It has a significant impact on how signals interact with one another, which influences everything from wireless transmission quality to audio fidelity. However, through interference and signal strength, phase shifting degrades the radio transmission's quality: A radio signal can combine constructively (in phase) to strengthen it or destructively (out of phase) to weaken or even cancel it out when multiple copies of the signal arrive at a receiver with different phase shifts (often as a result of reflections or multipath effects). This results in a loss of signal strength and quality degradation, such as noise and distortion. For wave alignment before combining, the phase shift is $2\pi(d/\lambda) \sin \theta$, where d is the matrix element spacing, λ is the wavelength, and θ is the signal direction. Keep in mind that the wavelength is a frequency-dependent property. If a delay instead guides the beam, the necessary delay is $(d/c) \sin \theta$, where c is the propagation speed of light. The pattern is no longer frequency-dependent.

To achieve this, a manual phase shifter is developed, which uses parts that enable manual signal phase adjustment. We require the parts listed in the Figure, including a breadboard for circuit assembly, a variable resistor (potentiometer) for resistance adjustment, capacitors for phase shift creation, an optional inductor for additional phase adjustment, and an oscilloscope or signal generator for output testing. As illustrated in the schematic design in Figure (3), the construction procedures involve connecting the resistor and capacitor to the breadboard to assemble the components. To enable manual adjustment, a potentiometer is employed in place of a set resistor. After that, the circuit is connected to the input signal. Lastly, the output is quantified: To see the phase shift, connect the output to an oscilloscope. Changing the capacitors' values to alter the phase: Changing the resistor (i.e., the wire

length) alters the resistance, which alters the phase shift and the time constant ($\tau = RC$). Phase adjustments can be made instantly with this manual phase shifter.

4. CONCLUSIONS

Some advanced radio systems use engineered structures to precisely control the waves. These structures can be built with features down to the nanoscale or sub-wavelength, depending on the design and target frequency as following:

1. nanoscale impact low-band (LBA) antennas in - Surface roughness and oxidation on the metal: can slightly alter conductivity, affecting ohmic loss and efficiency. Thin protective coatings/films (if present): Their thickness (down to the nanometer to micrometer range) affects the stability of conductivity/impedance in open air.
2. The possibility of many astronomical phenomena reaching Earth from the sun, especially at low frequencies, is particularly challenging for other types of telescopes to monitor, as it requires the use of multiple antennas simultaneously.
3. From the practical design of fresh antennas, the phase difference depends partly on the position of the sun, as many other elements participate in it, such as the orientation of the antenna itself towards the position of the sun, as well as the difference in the height of the sun, which enables the radiation pattern, as we note that the solar radiation is exposed to many refractions during the exhibition.
4. It was noted that using more than one antenna at the same time and studying the final results using the interference principle greatly affects the accuracy of the results and significantly increases the coverage range.
5. Using two identical antennas in terms of design and specifications (length, size, height, and directivity) greatly enhances the accuracy of the results.
6. Practical observation revealed that the phase difference angle directly affects the length of the wire used, as experience has shown that the relationship between them is directly proportional; consequently, the larger the phase difference angle, the longer the wire used.
7. The phase difference between the antennas is set so that we can track the position of the sun throughout the whole day.

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