



Publication Year	2019
Acceptance in OA	2020-12-14T15:37:56Z
Title	1933: Radio Signals From Sagittarius [Historical Corner]
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Publisher's version (DOI)	10.1109/MAP.2019.2920050
Handle	http://hdl.handle.net/20.500.12386/28835
Journal	IEEE ANTENNAS & PROPAGATION MAGAZINE
Volume	61

1933: Radio Signals From Sagittarius

Renzo Nesti

The title of the front-page left headline of the 5 May 1933 issue of the *New York Times* (Figure 1) was “New Radio Waves Traced to Centre of the Milky Way.” This was the world-wide announcement of Karl Guthe Jansky’s (Figure 2) discovery of radio waves apparently coming from the center of our galaxy.

Today, this announcement is celebrated as the birth of a new science, radio astronomy. But at that time, it was not known that celestial objects could emit radio waves detectable from Earth, and this particular kind of radio detection was not the purpose of Jansky’s experiments. The first detection of radio waves coming from outside Earth was an event made possible by a mixture of luck, technological capabilities, and human abilities along with Jansky’s skill, persistence, and deep curiosity in investigating the new.

Besides the papers by Jansky, the key references for this landmark in astronomical research are the book by W.T. Sullivan (1984) [1] and the paper by W.A. Imbriale (1998) [2]. The originality of the present work is mainly to revisit the electromagnetic modeling of the Jansky antenna with modern software tools, present some crucial pictorial views of the sky seen by Jansky during his experiments, and focus

EDITOR’S NOTE

This issue’s “Historical Corner” column is about the first-ever detection of radio signals of extraterrestrial origin. It is focused on the Holmdel measurement campaign in the 1930s, highlighting the technological background leading to Jansky’s detection of that hiss-type signal being celebrated as the birth of radio astronomy. What would have been a detailed report of a successful experiment on the characterization of thunderstorm static, it has the flavor of a happy-ending fairy-tale chapter of a book on a branch of science whose writing is in continuous progress.

We are almost necessarily led to increase our interest in every minute detail of that historical campaign if we let our mind recall all the discoveries made by radio astronomers, improving our knowledge of the universe. The very last of these has

(Continued)



Giuseppe Pelosi

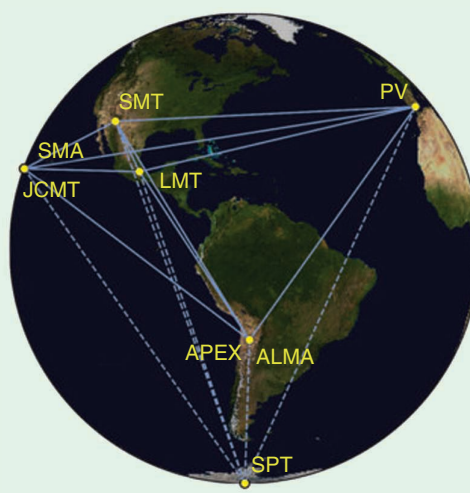


FIGURE S1. A map of radio telescopes across the world contributing to the Event Horizon Telescope. [Source: Event Horizon Telescope Collaboration/*Astrophysical Journal Letters*, 875(2019) L1/CC BY 3.0.]

EDITOR'S NOTE (CONTINUED)

been recently announced: the first image of a black hole has been captured using an interferometry observational technique at a frequency of about 230 GHz. This image, resulting from two years' elaborated data, taken by a set of radio telescopes distributed worldwide (Figure S1), in the framework of the Event Horizon Telescope project. It is a realistic portrait unveiling the most elusive object in the universe and is another confirmation of Einstein's theory of general relativity.

"It is wonderful to see the nearly circular shadow of the black hole. There can be no doubt this really is a black hole at the center of M87, with no signs of deviations from general relativity," commented astrophysicist Kip Thorne, winner of the 2017 Nobel Prize for the discovery of gravitational waves from colliding black holes.

Incidentally, the observed black hole is in the center of our Milky Way galaxy, exactly in the region originating the hiss-type signal observed by Jansky in his experiments. There is no better way, in my opinion, to introduce this contribution to the "Historical Corner" column than by recalling when the *New York Times* announced the captured image of the black hole (Figure S2) on their Thursday, 11 April 2019, front page, exactly as they did almost 90 years ago for Jansky's discovery.



FIGURE S2. The first radio image of a black hole. (Source: Event Horizon Telescope Collaboration.)

in a slightly different way on the historical steps and results.

BACKGROUND

Jansky was born in 1905 in Oklahoma; his father was a professor of electrical engineering and was of European origin, his father's parents having emigrated from Czechoslovakia to the United States in the 1860s. In 1927, Jansky obtained his bachelor of arts degree in physics, and after an extra year of graduate studies in physics, in the summer of 1928 he joined Bell Labs in New York. He first worked on long-wave noise, focusing on the characterization of static disturbances of overseas radio-telephone services [2], a crucial research activity at Bell Labs in those days. He was assigned to study the incoming direction of thunderstorm static, starting with the refinement of receivers by using all improvements available at that time to optimize signal-to-noise ratio. His main achievement was the minimization of receiver noise and improving long-term gain stability. He developed a receiver able to output an energy-averaged noise signal incorporating a calibration system that allowed both accurate amplitude measurement and smooth curves recorded on paper.

His extraordinary contribution was the fabrication of his antenna, the so-called Jansky's merry-go-round (Figure 3). Free to rotate on a circular track with four wheels, the antenna was able to scan the full-width 360° horizon in about 20 min, pointing toward a narrow region in the azimuth direction. These antenna features turned out to be very useful in the localization of thunderstorm static and fundamental in the unexpected radio-astronomical discovery Jansky made.

After tuning his receiving system, he started one of the most famous measurement campaigns in the history of science, in Holmdel, New Jersey, to search for static and to determine its predominant direction of arrival.

THE HOLMDEL MEASUREMENT CAMPAIGN

The Holmdel measurement campaign started in late 1930. The experiment



FIGURE 1. An photocopy of the *New York Times* front page from Friday, 5 May 1933. The announcement of the discovery of interstellar radio waves is outlined in red.

setup and the very first results were published by Jansky in 1932 [3]. In that publication, he described the detection of two different types of disturbances: 1) local and distant static (Figure 4), with the latter mainly coming from the south, and 2) a hiss-type disturbance (Figure 5), the origin of which he initially said to be unknown, but which was capturing more and more of his attention.

He recognized that the term *static* did not quite fit what he called *hiss-type static*, since it was a very steady, continuous signal whose incoming direction changed gradually throughout the day, going around the compass in the course of a day. He continued the measurement campaign for the entire year of 1932 with the aim of unraveling the nature of the mysterious hiss-type signal and its origin. At the end of one year of measurements, he had the required data to present the solution to the puzzle.

SOLVING THE PUZZLE

The hiss-type signal seemed to have a fixed position in the sky, as the recordings clearly indicated: the signal peak was synchronous with the 20-min period of the antenna azimuth rotation, as is evident from the record given in Figure 6, taken in September 1932.

It is important to note a potential trap that could have led to a wrong conclusion: in December 1931, when measurements started, the hiss-type signal peak was in the direction of the sun. Today, the ever-faster race to publish early results would make a modern engineer in the

same hypothetical situation as Jansky distribute a preprint of a paper announcing something incorrect, such as “New Radio Waves Traced to the Sun.” This was not the case for Jansky, whose meticulousness and persistence gave him the time required to determine and publish the correct conclusion in his first paper.

About a month of continuous examination was enough to observe that the hiss-type signal peak was not directly coming from the sun, since he noticed a continuous shift in the peak anticipating the sun. Early in 1932, he detected about an hour shift between them, and he thought initially that

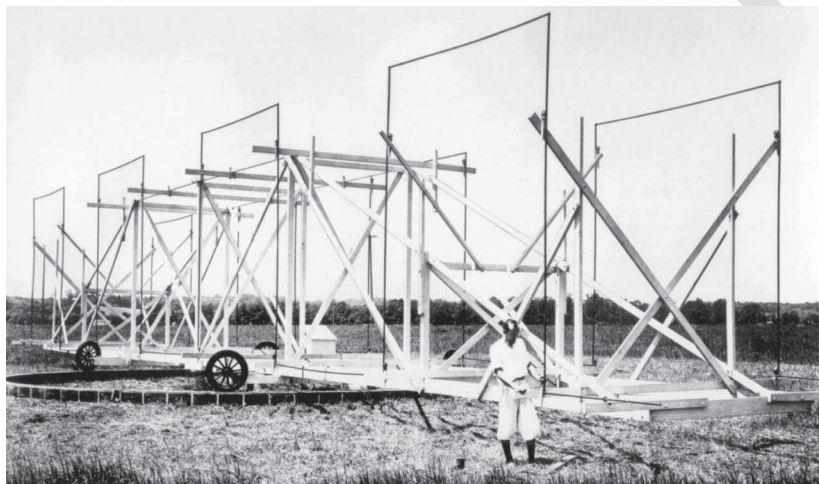


FIGURE 3. Jansky at the Holmdel, New Jersey, site in front of his merry-go-round antenna.

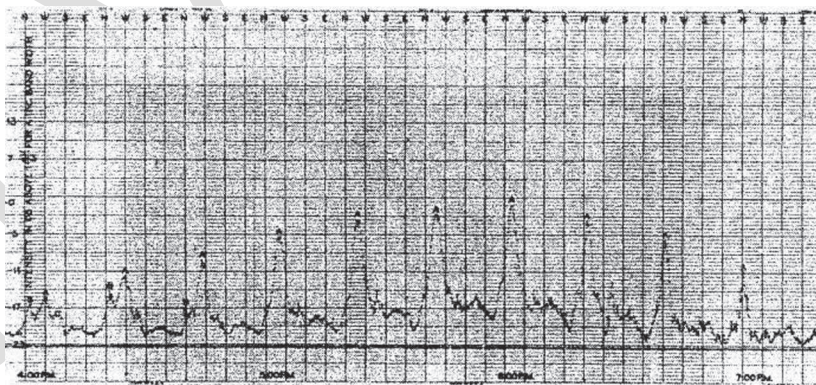


FIGURE 4. An example of a static signal from a thunderstorm.

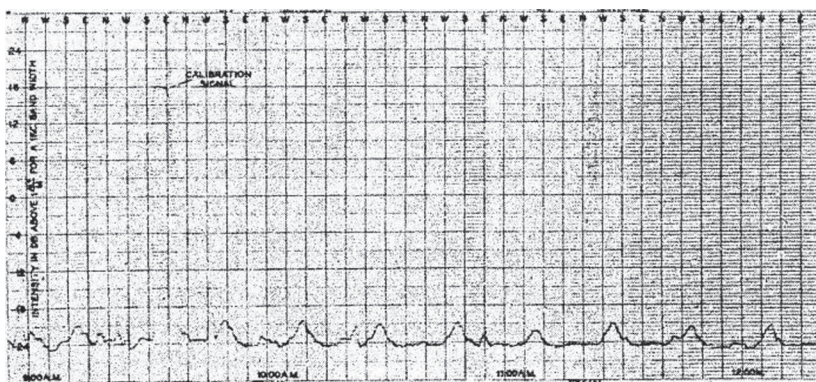


FIGURE 5. An example of the hiss-type signal of unknown origin.

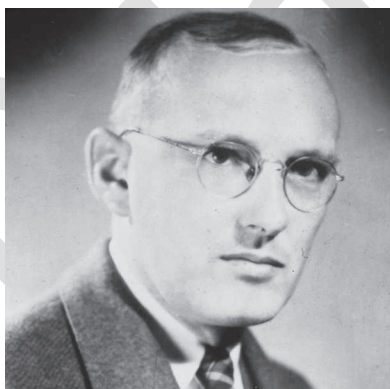


FIGURE 2. Karl Guthe Jansky (born Norman, Oklahoma, 22 October 1905; died Red Bank, New Jersey, 14 February 1950).

the peak was still somehow linked to the sun (the interval between sunrise and sunset increases by about one-half hour from December to January at the 40° latitude of Holmdel), and he was quite curious about what would happen at the summer solstice. Maybe, he supposed, an inversion would occur in the relative shift between the peak and the sun, and this gave him reason to continue to observe and record data until after June 1932. When, at the end of August, he clearly did not notice the expected inversion of the relative shift but, conversely, the hiss-

Jansky concluded that the hiss-type source was synchronous with sidereal time, not solar time, thus being fixed in the sky in the same fashion as are all the stars.

type signal peak continued shifting ahead of the sun's position, he decided to continue and complete a full

year of measurements. In December 1932, the hiss-type signal peak and the sun returned to share the same position in the sky. After an accurate study of the entire year's data, he organized the results on a single long-term plot (Figure 7), giving the time of the day versus the azimuth arrival direction of the peak. It was the key to

solving the puzzle, as he caught fully the astronomical aspect of the experiment: the hiss-type signal always lies in a plane fixed in space, meaning that its right ascension is constant.

Observing a 2-h shift per month in the curves in Figure 7, he concluded that the hiss-type source (HTS) was synchronous with sidereal time, not solar time, thus being fixed in the sky in the same fashion as are all the stars (except the sun). He used the phrase "of interstellar origin" to describe that fixed-in-space disturbance, whose direction he calculated to be at 18 h right ascension and -10° declination, pointing to the Sagittarius constellation, which is close to the center of our Milky Way. Jansky also estimated the error in the localization of the HTS, mainly associated with the antenna half-power beamwidth (HPBW), to be as much as about $\pm 7.5^\circ$ in azimuth and $\pm 30^\circ$ in elevation.

It is interesting to have a pictorial view of the sky seen by Jansky at the Holmdel site at some periods during his experiment. In Figure 8, four sky maps, focusing on times and regions of interest, are given to better appreciate the motion of the Sagittarius constellation with respect to the sun: on a monthly scale, by comparing Figure 8(a) with (b), and (c) with (d); on a yearly scale, by comparing the first two maps with the last two. It is interesting also to notice, highlighted in every map, the HTS position and the antenna pointing error as estimated by Jansky.

Jansky described his results in technical [4] and popular [5] papers, both fundamental to the birth of radio astronomy: it was after reading those papers that Grote Reber became increasingly fascinated with celestial radio emission,

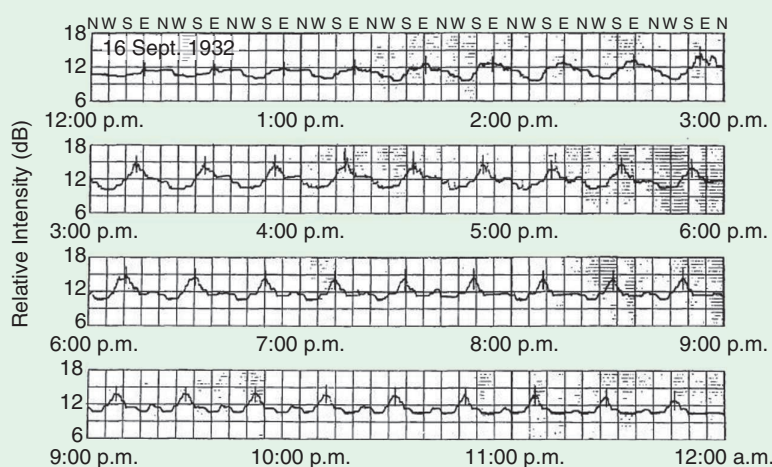


FIGURE 6. A daytime record of the mysterious hiss-type signal from September 1932. The 20-min periodicity of the antenna azimuth rotation is evident.

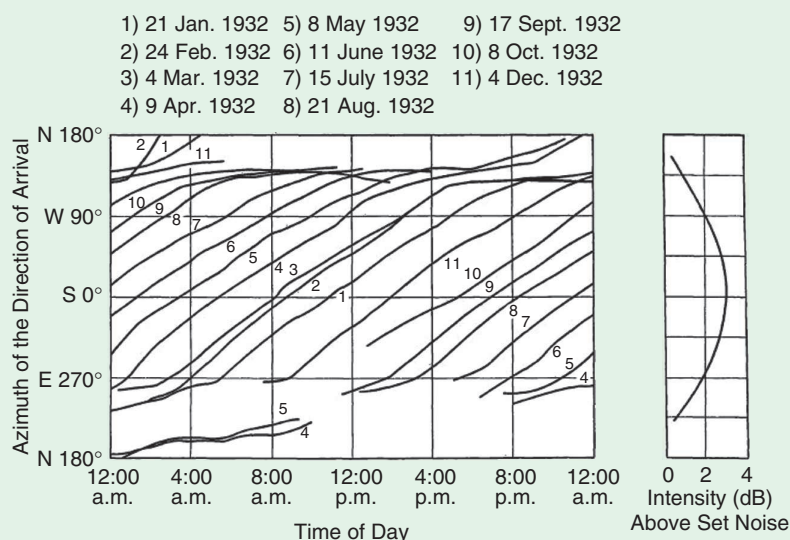


FIGURE 7. A graph of the azimuth of the direction of arrival of hiss-type waves plotted against time of day.

built the very first radio telescope to purposely make a radio map of the Milky Way, and took the second step in the development of radio astronomy.

JANSKY'S ANTENNA

The basic element of the Jansky merry-go-round was a Bruce-type array [6], developed shortly before the Jansky experiments by Edmond Bruce (a U.S. radio engineer) for transoceanic radio communications when Bruce was working in the group of Harald Trap Friis (a Danish radio engineer) at Bell Laboratories. The Bruce array is a vertically polarized broadside array, which Jansky used as both active monopole element and as passive reflector over a bandwidth of about 26 kHz centered at about 20.5 MHz. Each element was made of 7/8-in brass pipes, supported by glass insulators on a fir lumber frame (Figure 3). The active array element (Figure 9) was a four-period, half-wavelength-amplitude square-wave, with one-half duty cycle and half-wavelength period width, starting (and terminating) with an open-ended, eighth-wavelength-long, low-level section. The passive element was almost identical to the active element, except 15% taller and separated by one-quarter wavelength.

At the design frequency, the part of the antenna concerned with radiation is limited to the vertical wires only, where standing wave currents oscillate in phase. The presence of the passive array makes the antenna beam pattern unidirectional, in the direction from the passive to the active element. The earth below the antenna behaves like a ground plane, and the effect is to raise the main beam above the horizontal plane. Those were exactly the ideal features for a receiving antenna scanning for static on a ground-based platform, as already discussed. Today, about 85 years after Jansky's experiment, due to the availability of electromagnetic software packages and highly efficient computer hardware, it is possible to carry out a sort of time-reversed engineering and simulate the performance

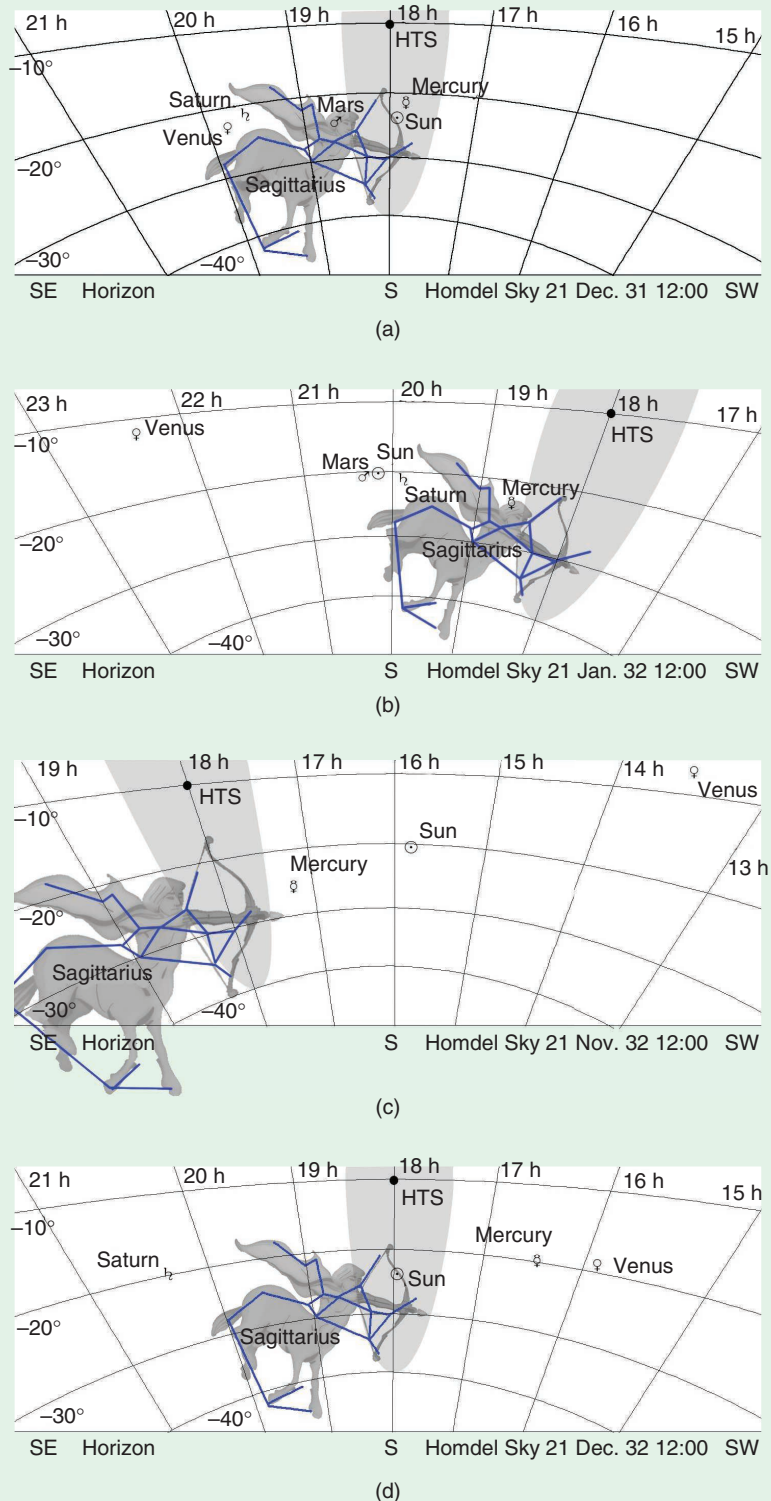


FIGURE 8. Holmdel sky maps centered on the south (S) direction and taken at noon on some particular days during the Jansky experiments. Maps (a) and (b) are from the beginning and (c) and (d) from the end of the year-long experiment. The positions of planets, the sun, and the Sagittarius constellation are indicated on the equatorial grid giving right ascension and declination. The HTS position, as estimated by Jansky, is centered on the HPBW spot of the Jansky antenna. SE: southeast; SW: southwest.

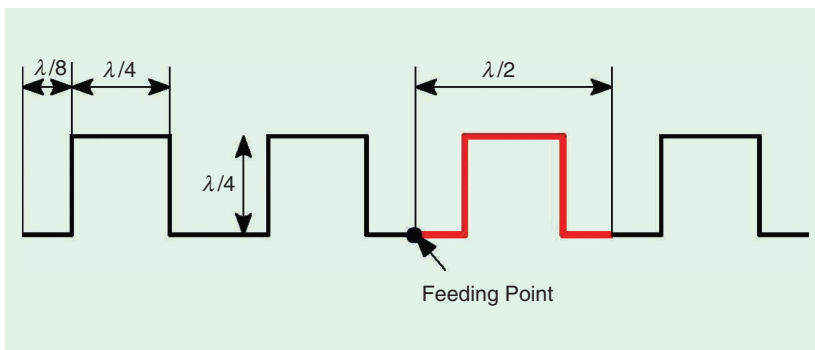


FIGURE 9. A sketch of the active element of the Jansky merry-go-round antenna. In evidence are the period and the feeding point.

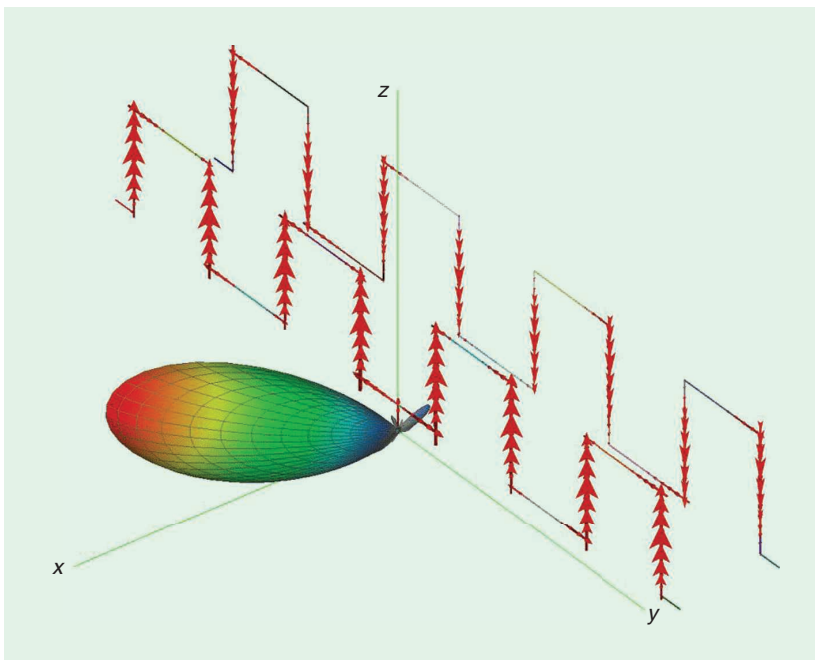


FIGURE 10. An electromagnetic model of the Bruce-type array used by Jansky obtained using the FEKO software package. The current peak distribution along the wires and the antenna 3D radiation pattern are shown.

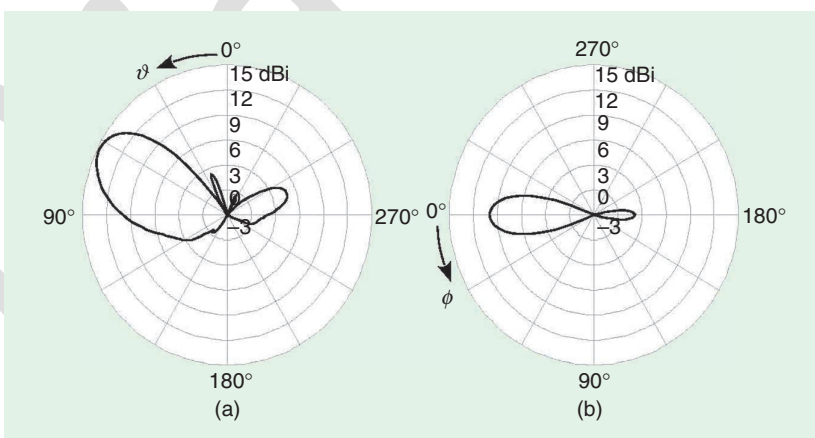


FIGURE 11. Polar plots of the principal plane cuts of Jansky's antenna. (a) E-plane (elevation) and (b) H-plane (azimuth).

of an accurate electromagnetic model of Jansky's antenna.

The Bruce array is basically a wire antenna, and method of moments (MoM)-based software [7], [8] is able to accurately characterize the current distribution in the wires, taking into account the effects of finite wire diameter. Also, the effect of the earth, modeled in the simulations by a circular four-wavelength-diameter perfect electric conductor ground plane, can be taken into account. Finally, a voltage source placed from the center of the active element to the ground is used to excite the antenna.

The electromagnetic model and some analysis data at 20.5 MHz are given in Figure 10. The simulated current distribution is superimposed on the wires, and, from the arrow directions, phase matching on the vertical wires can be clearly observed. A 3D pattern with a maximum above-the-ground level in the positive x -axis direction (Figure 10) is also plotted and superimposed on the geometry.

A more precise characterization of the antenna beam at 20.5 MHz is given in the beam principal plane cuts, plotted in Figure 11. Jansky's antenna has a directivity of about 15 dBi, a HPBW of about 24° in the azimuth plane (H-plane) and about 30° in the elevation plane (E-plane). The direction of the maximum in the elevation plane is about 30° above the horizon. Variables ϕ and ϑ used in the polar plots in Figure 11 correspond to the angular coordinates of a spherical system referenced to the x , y , and z axes in Figure 10.

The MoM numerical model also allows us to characterize the input

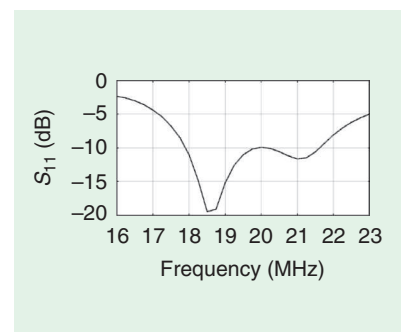


FIGURE 12. A graph of the input matching of the Jansky antenna to a 50- Ω line.

matching of the Jansky antenna. Using a 50- Ω reference impedance, the simulated input matching over a quite broad band (16–23 MHz), including the Jansky-experiment central-frequency of 20.5 MHz, is plotted in Figure 12. The simulation shows a –10 dB reflection coefficient bandwidth of about 3.5 MHz (18–21.5 MHz).

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