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Technical Considerations on Using the Large Nançay Radio Telescope for SETI

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The Nançay decimetric Radio Telescope (NRT) in Nançay, France, is described, and its potential use for SETI (Search for Extraterrestrial Intelligence) observations is discussed. The conclusion reached is that the NRT is well suited for SETI observations because of its large collecting area, its large sky coverage, and its wideband frequency capability. However, a number of improvements are necessary in order to take full advantage of the system in carrying out an efficient SETI program. In particular, system sensitivity should be increased. This can be achieved through a series of improvements to the system, including lowering the ground pickup noise through the use of ground reflectors and more efficient feed design, and by using low-noise amplifer front ends.

I. Background

The Nançay Radio Telescope (NRT) is a large astronomical telescope located in Nançay, France, 200 km south of Paris. Figure 1 shows an aerial view of the instrument. The telescope has been in operation since 1964. Administratively, it is operated by the Observatoire de Paris, Départment de Radioastronomie Décimetrique.

The configuration of the NRT derives from the concept formulated by J. D. Kraus and used in the construction of the Ohio State University Radio Telescope (OSURT) in the United States, but the NRT is much larger and has better tracking capability. It is made of two reflecting surfaces, one fixed and one movable. The movable surface is a plane, and can be rotated about a horizontal east-west axis to move the telescope beam in declination. The tiltable surface is 40 m × 200 m (east-west), made up of ten independent elements, each 40 m × 20 m. The fixed reflector is curved in the shape of a portion of a sphere, with a radius of 560 m. Its dimensions are 35 m (vertical) × 300 m (east-west). The spherically shaped reflector facilitates the tracking of radio sources. In its present design, the reflector can follow a zero-degree declination source for about one hour (± 30 minutes) around its meridian transit by moving the focal feedhorn along a track from west to east. Tracking time increases in proportion to the secant of the declination. (The OSURT has a parabolic-shaped fixed reflector; it can track radio sources only about half the time that the NRT can.) The mobile feed is implemented by mounting the feedhorn and low-noise amplifiers in a small building, or shed, that rides on the track. The building is called a "chariot."

To limit spherical aberration in the system, the center of curvature of the spherical reflector has been set at a distance of 100 m behind the plane reflector. Furthermore, the spherical mirror is only illuminated over 200 m in the east-west direction. Also, the four outermost elements in the movable reflector are displaced slightly backwards to increase the electric path for rays striking the edges of the spherical reflector. This correction is analogous to the Schmidt correction used in optical systems.

The surfaces of the reflecting elements are made of 1.2 cm of welded mesh fixed on stretched cables. The root-mean-square accuracy of the surface is ± 0.5 cm from the nominal surface. The movable reflector can be positioned within ± 0.1 minutes of arc from a fixed reference.

Table 1 gives various parameters for the telescope and some pertinent information on the presently available receivers and back ends. Figure 2 shows the current sensitivity of the telescope in circular polarization receive mode at 21 cm wavelength.

II. Potential Use of the NRT for SETI Observations

The general problem of searching for signals originating from extraterrestrial intelligence involves choosing search directions, frequencies, modulations, and sensitivities. Detailed studies carried out by several science working groups in the United States [1,2] reached the consensus that (1) the microwave window (1–10 GHz) is a logical and promising spectral region for interstellar communications, (2) both directed (target) searches and wide-area sky searches should be used, and (3) high-sensitivity telescope systems equipped with high-resolution multimillion-channel spectrum analyzers should be employed in the searches. Heidmann [3] suggested that the Nançay radio telescope could be successfully used with the NASA megachannel spectrum analyzers currently under development. The use of the NRT for SETI was considered with these factors in mind.

The NRT is the third largest radio telescope (after Arecibo, in Puerto Rico, and just after Effelsberg, in Germany) in existence; its effective area is equivalent to a circular aperture of 94 m. Table 2 compares the sensitivity of the NRT with other radio telescopes that have been considered for use by NASA: Arecibo, Green Bank, Ohio State, and all of the Deep Space Network 70-m and 34-m antennas. The sensitivity is given relative to that of Arecibo.

The NRT can track radio sources over approximately 80 percent of the sky, extending from $-38°$ declination up to the north pole. The telescope is able to track radio sources for an hour or more, and to scan large areas of the sky.

The NRT is inherently a broadband design, with an upper frequency cutoff near 5 GHz, determined by the accuracy of the reflecting surfaces. The primary operational frequency range of the telescope, 1–3 GHz, is in the frequency range considered to be ideally suited for SETI searches. Figure 3 shows the spectral utility function for SETI, which represents the frequency for maximum utility for interstellar communications. This function is the reciprocal of the free-space and quantum-noise temperatures of the background, multiplied by the square root of the frequency, to account for the minimum allowable bandwidth (see Figure 1.1, page 3 in [2]). The normal range of operation of the NRT is at the very best part of the entire microwave spectrum. As a result, the NRT shows great potential for use in SETI observations.

The NASA SETI program consists of a target-search mode and a sky-survey mode. This bimodal strategy is intended to cover a wide range of possibilities. The target mode assumes that other solar systems are similar to ours, and that intelligent life may form on planets around solar-like stars. The target-search strategy is to apply the highest possible sensitivity to detect putative radio signals coming from the direction of the nearest solar-type stars. The NRT is well suited to carrying out a target search because it has access to a large number of solar-type stars and it can track sufficiently long to enhance sensitivity. It has been estimated that over 500 F, G, or K stars within 100 light-years from the Sun can be examined with the NRT. Special galactic and extragalactic objects can also be included in a target search program.

The utility of the NRT for targeted search work has already been demonstrated. A collaborative search program these last years carried out by two of the authors (F. Biraud and J. Tarter) has concentrated on solar-type stars that lie beyond the declination limits of the Arecibo telescope. These observations have used the existing 1024-channel autocorrelator to achieve a spectral resolution of 50 Hz over a bandwidth of 3 MHz centered around the molecular hydrogen (HI) line and lines of the hydroxal radical (OH). Real-time reduction of the signals has not been possible, but efficient software has been written for the off-line computing system to allow the data taken on a given star to be completely analyzed before that star rises again. This capability and the generally favorable environment at Nançay within the protected radio astronomy bands enhance the efficiency of the observations. Previous non-real-time targeted searches required the antenna to be directed "off-source" for significant amounts of time to guard against false identification of interfering signals. At Nançay the percentage of time spent off-source can be reduced.

The sky-search mode allows for the possibility that intelligent life may exist in directions that we are not able to identify at the present time. The strategy is to search for radio signals over large areas of the sky. The small beam size of the NRT makes this strategy difficult, but not impossible, to carry out. Used as a transit instrument, the NRT can map approximately a 1/3 degree strip of sky in 24 hours at 21 cm, and can map the entire sky at a single frequency in 270 days. This is prohibitively long for the NRT, which is primarily devoted to astronomical work. The time required to map the sky in a specified frequency range can be shortened by

(1) raster scanning the telescope beam in the sky

(2) employing a multifrequency feed system

(3) enlarging the telescope beam by underilluminating the primary mirror

Raster scanning can be achieved by rapidly moving the chariot (which holds the feedhorn) along the hour-angle scan track and/or by moving the flat reflector in a stepped or continuous motion. Raster scanning can easily reduce the survey times by factors of from 2 to 3, and perhaps up to 10.

The spherical reflector of the NRT permits a multibeam feed to be used with different declinations. Its availability on the NRT should allow timesharing of a large spectrum analyzer with several different feeds to speed up a search. Using this approach, survey times could probably be decreased by factors of from 2 to 3.

Increasing the size of the telescope beam defeats the purpose of using the large collecting area of the NRT; therefore, it is not an attractive alternative. However, there may be interesting combinations involving multiple beams and receivers and a single-spectrum analyzer that permit the NRT to perform a sky survey at sensitivities that exceed those contemplated by the NASA SETI program. These possibilities are especially attractive at frequencies around 1.0 GHz, and deserve further studies.

Note that the NRT is particularly well suited to carry out surveys limited in space or frequency for which high sensitivity is desired. Particularly interesting examples are high sensitivity searches in the galactic plane, and searches in the water-hole region (1.4–1.7 GHz). The high-sensitivity galactic plane searches could be associated with searches for interesting galactic objects such as fast pulsars.

Finally, the NRT is very well suited for mounting an off-axis focal feed and receiver system. Such an off-axis system could be used 24 hours a day without interference to ongoing astronomical programs. While the declination of the search would be restricted by the astronomical program in progress at the time, the choice of frequencies could be freely determined by the requirements of SETI. This approach may not be the best use of the large NASA spectrum analyzer, but it could be implemented with other, less expensive, automated signal processors. This "commensal," or parallel detection strategy, is very attractive and has already been implemented to some degree with the SERENDIP system at the National Radio Astronomy Observatory (NRAO) [4]. SERENDIP is more restricted than what is proposed here for the NRT, because that system must accept not only the direction on the sky but, in addition, the frequency that has been chosen by the principal telescope user. Nevertheless, the project has been judged to have scientific merit, and has received funding from NASA. If it can be demonstrated that the parallel search at Nançay could significantly increase the volume of multidimensional space that can be investigated (e.g., in some interesting parameters such as frequency coverage, sensitivity, or repetition period for pulsed signals) there is a good possibility of obtaining NASA funding.

III. Potential Upgrades for the Nançay Radio Telescope

While the NRT itself has significant potential for SETI observations, a number of improvements are necessary in order to take full advantage of the system in carrying out an efficient SETI program. In particular, an efficient SETI search must operate with the highest sensitivity available, and with the largest multichannel spectrum analyzers available. NASA has designed and built prototype spectrum analyzers for SETI with upwards of one million channels. These analyzers increase the search speed that is possible over existing analyzers by a factor of more than 10,000.

The discussion that follows focuses on a number of potential improvements to the NRT that will make it compatible with the new class of spectrum analyzers with up to ten million channels which will become available over the next five years. This discussion is not intended to be exhaustive. It is the result of several meetings held between the authors of this article and the engineering staff at the NRT. Additional work is necessary to define and prioritize the upgrades.

A. Aperture Efficiency

The current peak aperture efficiency of the telescope, operating in circular polarization at 21 cm wavelength, is only 45 percent. This yields a sensitivity of 1.1 K per jansky (1 Jy = 10^{-26} W/(m^{2}Hz)). It should be possible to increase the efficiency to 55 percent or more. Some work will need to be done to determine where the losses are originating from. Potential sources of losses are the reflecting surfaces, the illumination pattern on the primary surface, or possibly losses in the feedhorn that show up as aperture efficiency losses because of the calibration procedures that are being used. Preliminary discussions indicated that the Schmidt correction was optimized for 9 cm wavelength, but could be changed for longer wavelengths, to provide a maximum in the aperture efficiency of between 18 and 21 cm.

Additional increases in aperture efficiency can also be accomplished if the optics of the telescope are transformed from prime focus to a system employing a carefully shaped secondary reflector. In addition to providing increased bandwidth, a Gregorian reflector might also improve aperture efficiency by altering the illumination pattern of the primary mirror. Increased bandwidth and aperture efficiency cannot be achieved independently, but some optimum can be found that offers improvement in both parameters.

B. System-Noise Temperature

Current system-noise temperatures in the 18- to 21-cm band are between 40 and 50 K. It should be possible to lower these temperatures by 25 percent or more by using lower noise receivers while decreasing the ground spillover using well-designed feeds, and by lowering the apparent temperature of the ground using reflecting screens. Plans already exist to erect additional rows of screen mesh on the ground in front of the spherical reflector.

The parameters, system-noise temperature and aperture efficiency, are not independent, and they should be optimized in such a way as to give the maximum sensitivity for the telescope. This condition implies that the ratio of system temperature to aperture efficiency should be minimal.

C. Broadband Focal-Plane Feeds

A focal-feed system that spans 1–3 GHz is needed for SETI observations. The feeds should have an instantaneous bandwidth of at least 40 MHz to take advantage of the NASA target-mode spectrometer, and 30 MHz to take advantage of the NASA sky-survey spectrometer. The current feed system is limited to narrow ranges (~150 MHz) around 21, 18, and 9 cm wavelengths. A Gregorian feed mounted a few meters behind the present feedhorn might facilitate the construction of a wideband feed system.

D. Broadband RF and IF Receivers

Broadband, low-noise receivers to cover the 1–3 GHz spectral range will be needed.

E. Spectrometers

Large multichannel spectrometers will need to be used in conjunction with the NRT in order to make efficient searches. Spectrometers currently under development in the United States for the NASA SETI program have more than 10,000 times the number of channels used in conventional radio astronomy spectrometers, such as those with 1,000 channels currently in use at the NRT. The possibility of using such a NASA spectrometer at the NRT should be investigated.

F. Chariot

Since SETI instrumentation would compete for space in a chariot, it is necessary to consider the ways in which a chariot can be used. There are a number of possibilities for SETI.

First, it seems reasonable that SETI could share a chariot with radio astronomy by providing its own receivers. A disadvantage to this approach is that installation time would probably be needed to switch back and forth between radio astronomy and SETI.

A second concept is for SETI to provide a chariot dedicated to SETI observations to be parked out of the way when not in use. This dedicated-chariot concept would alleviate most interruptions to the radio astronomy operation.

A third concept is to use a stationary chariot for SETI, located either at one end of the track or elsewhere (e.g., above the track). This concept is interesting because the telescope could be used on a noninterference basis, nearly full time; however, it would at the same time greatly restrict the types of SETI programs that could be pursued. In particular, the fixed-chariot concept would rely on other programs for determination of the flat-mirror position, and hence the declination of the scans. As a result, target-mode observations could not track radio sources and would be restricted to those sources which pass through the declination setting. Similarly, the sky-survey observation would be restricted in declination. A further drawback for the fixed-chariot concept is that the receivers would not be available for radio astronomy.

An existing chariot, formerly used by the Centre National d'Etudes des Télécommunications (CNET) for ionospheric research, could possibly be used for either the movable, dedicated system, or a fixed system.

G. Telescope Tracking

Probably no modifications will be necessary to the tracking or pointing system. However, if a fast declination scanning mode of SETI observations were contemplated, it would be necessary to evaluate the limits set by mechanical and electrical aspects of the system.

H. Computer System

The current computer system is adequate to drive the telescope for SETI observations; however, it is somewhat out of date and there are plans to require funding to replace it. Additional computers will be needed for on-line data analysis. These will be provided as part of the NASA spectrometers, and will be connected to the on-line NRT computer via a standard serial port.

IV. Radio-Frequency Interference

As at any other radio astronomical site, the radio-frequency interference (RFI) level is a matter of concern. It should be monitored in order to track its possible origins, and hard-copy records should be kept for use in negotiations with the corresponding transmitter operators. In this respect, it is interesting to note that the Nançay Observatory has already started such monitoring with a dedicated dish. This should be strongly supported.

As a matter of fact, SETI, with its sophisticated signal-recognition procedures for data analysis, has the potential to reject most RFI; one way is to use Doppler shifts which extraterrestrial sources would not share with most terrestrial or even orbital transmitters.

Unfortunately, an increase in RFI level is expected; if it does occur, more efficient ways to distinguish RFI will have to be contemplated. One powerful way is to differentiate between Doppler shifts created by nearby moving transmitters (e.g., airplanes and satellites) and extraterrestrial sources. In the case of the NRT, a second element is currently being considered for conventional radio astronomy work. It may be a single dish, at least 30–40 m in diameter, located about 1 km from the NRT itself. Its interest for SETI RFI problems is plain. The need to use an interferometer for SETI may prove so compelling that some funds will need to be invested to make this possible.

References

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[3] J. Heidman, "Le MegaSETI, une étape majeure en bioastronomie," *Journal des astronomes français,* no. 29, p. 11, 1987 (English translation in *New Ideas in Astronomy,* F. Bertola, B. Madore, and J. W. Sulentic, eds., New York: Cambridge University Press, 1988).

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Table 1. Nançay radio telescope features

Physical parameters		
Plane reflector:	Width	40 m
	Length	200 m (east-west)
	Height of elevation axis above ground	21 m
Spherical reflector:	Height	35 m
	Length	300 m (east-west)
	Radius of curvature	560 m
Distance between reflectors	460 m	
Total weight	7000 tons	
At focal plane	100 m = 20°	
Latitude	47° 22′ 48″ N	
Longitude	8 min 47.4 sec E	

Performance parameters	
Declination coverage	−38° to + 90°
Hour-angle coverage	±35 min × secant (declination)
Collecting area	7000 m^2 maximum (decreasing north of 35° declination)
Aperture efficiency	45% at 21 cm; 20% at 9 cm; 10% at 6 cm
Beam width	~20 × 4′ at 20 cm
Tracking speed	2 cm/sec nominal
Pointing accuracy	±0.5′
Sensitivity	1.1 K/Jy at 21 cm; 0.5 at 9 cm; 0.25 at 6 cm

Instrumentation

Receivers

Wavelength, cm	Frequency, GHz	Bandwidth, MHz	System temperature, K
21	1.4	150	40
18	1.6	150	45
9	3.3	300	65

Back ends	
Autocorrelator[a]:	
Channels	1024 (4 × 256, 2 × 512, or 1024)
Bandwidth	6.4 MHz maximum
Resolution	Down to 50 Hz
Digitization	7-level (2 bits + sign) with weighting table

[a] Designed by F. Biraud and D. A. Cesarsky.

Table 2. Relative sensitivities of radio telescopes

Radio telescope	Diameter, m	System noise temperature, K	Aperture efficiency	Sensitivity
Nançay (now)	94	40	0.45	0.131
Arecibo	213	30	0.50	1.000
Green Bank	93	70	0.47	0.077
Ohio State	53	200	0.45	0.008
DSN 70 m	70	21	0.50	0.129
DSN 34 m	34	21	0.48	0.035

Notes: Sensitivity equals diameter squared times efficiency, divided by temperature, relative to Arecibo.

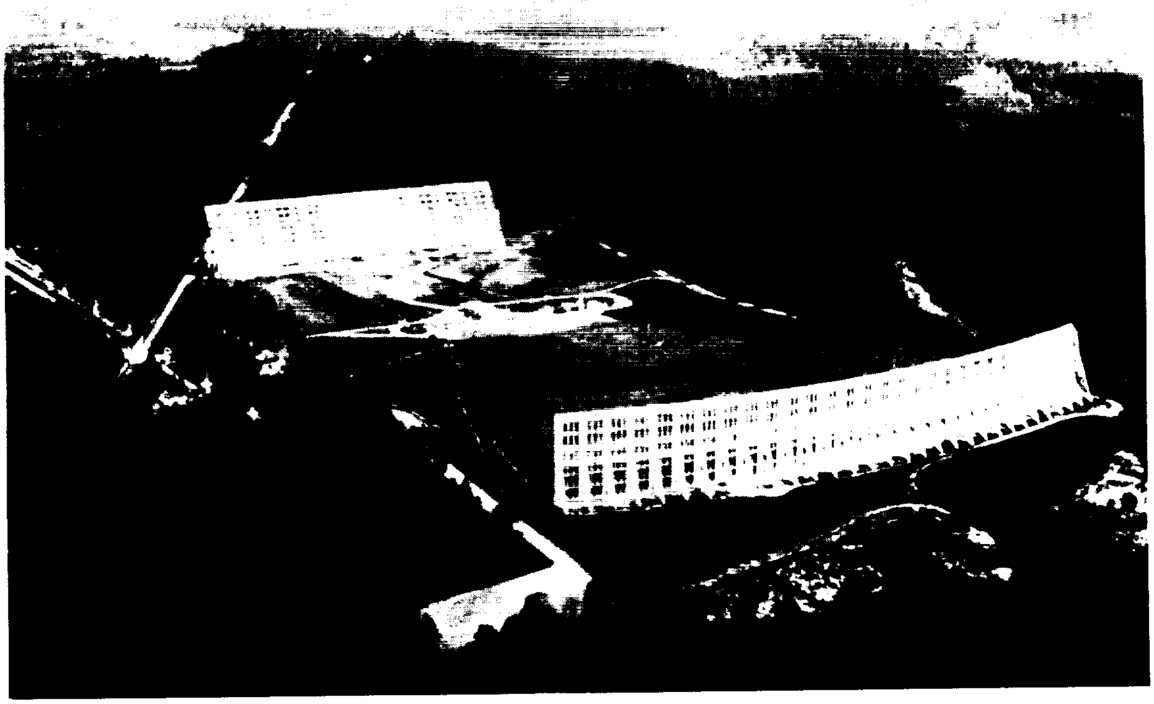

Fig. 1. Nancay Observatory.

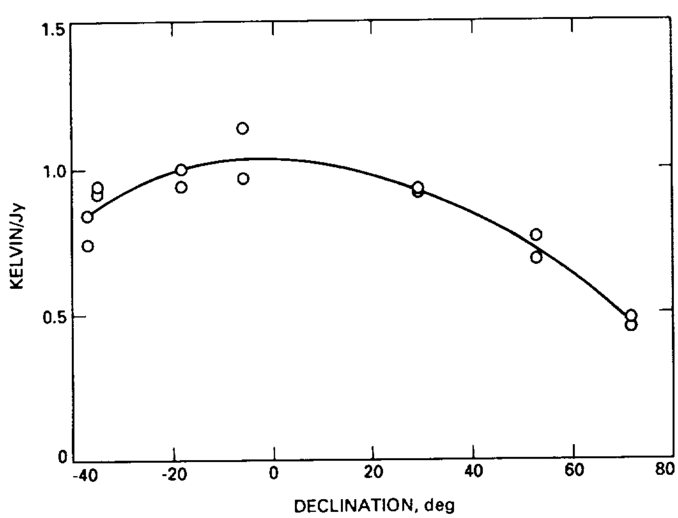

Fig. 2. NRT sensitivity in K/Jy versus declination in degrees.

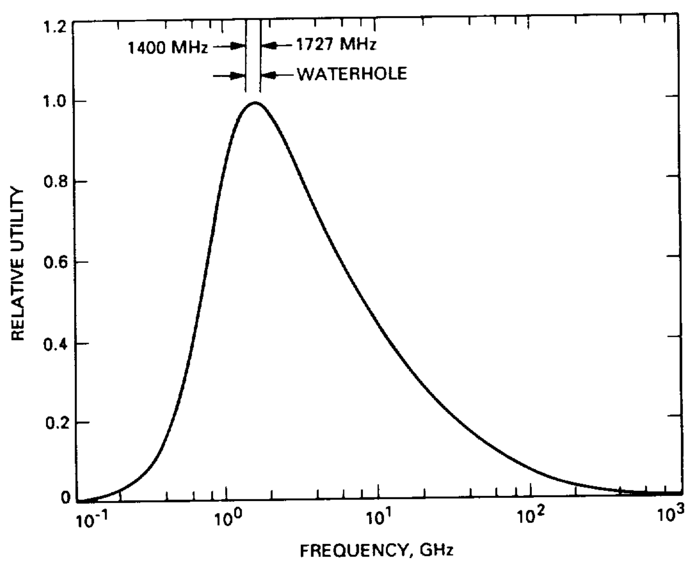

Fig. 3. Relative spectral utility function for SETI versus frequency in GHz.

Referees

The following people have refereed articles for *The Telecommunications and Data Acquisition Progress Report.* By attesting to the technical and archival value of the articles, they have helped to maintain the excellence of this publication during the past year.

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