NEW 45M RADIO TELESCOPE AND FOURIER-TRANSFORM TYPE SPECTROMETER AT NOBEYAMA RADIO OBSERVATORY

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ABSTRACT. The 45m radiotelescope of Nobeyama Radio Observatory (NRO) is now in operation. It has a surface accuracy of 0.2 mm (rms) and a pointing accuracy of 0.001 degrees. Two types of spectrometers were designed for the telescope. One type is an Acousto-Optical-Spectrometer (AOS) with a 16,384 channel, 2000 MHz full-bandwidth spectrometer, and a 8192 channel, 160 MHz full-bandwidth spectrometer. The other type is a direct Fourier transform type spectrometer called "FX". One FX is designed for a 10 meter, 5 element supersynthesis interferometer and another for the 45m radio telescope. The "interferometer FX" is a spectro-correlator that processes 5 inputs of 320 MHz bandwidth signals into correlations with 1024 frequency channels. The "45m FX" has 4 sets of 10 MHz bandwidth, 1024 channel spectrometers.

It has been pointed out by Morimoto, Hirabayashi, and Jugaku (1978) that formaldehyde anti-maser absorption lines in the direction of dark clouds would be suitable for SETI (Search for Extra-Terrestrial Intelligence). The Nobeyama 45m radiotelescope is suited for such targeted deep SETI.

1. 45M RADIOTELESCOPE

The 45m radiotelescope (Morimoto, 1981) of Nobeyama Radio Observatory (138° 28' 32.4"E, 35° 56' 29.5"N), which had been under construction for several years, is now in operation. The radiotelescope is a general purpose type for open use and is designed to work down to the mm wave region. The required surface accuracy is 0.2 mm rms; this accuracy has been achieved.

1.1. Main Reflector

To meet the required accuracy, the main reflector structure uses a so-called "homologous deformation" design. As a result of the use of the homology deformation design, the deviation from the best fit paraboloid is 0.08 mm (rms), including the effects of inaccuracies of

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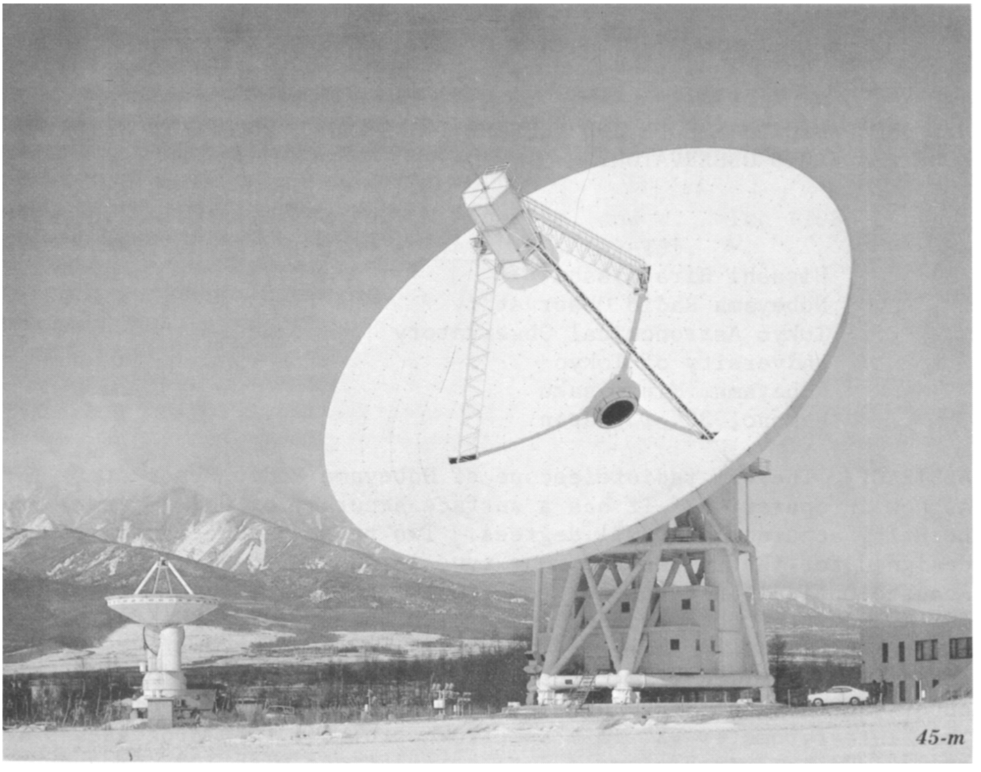

Photograph 1. 45m radio telescope of Nobeyama Radio Observatory with a 10m antenna of the supersynthesis array.

member weights, etc. The rear structure is covered with heat insulating panels, and the air inside is circulated to reduce temperature differences within the structure to less than one degree C.

The reflector surface is made up of about 600 honeycomb sandwich panels. These aluminum foil honeycombs provide efficient heat transfer between the skin material in the two sides and reduces the temperature gradient. For the inner 33 meters, CFRP (carbon fiber reinforced plastic) skin is used because of its very small thermal expansion. The accuracies of these panels is about 60 microns (rms). The panels are supported by a motorized adjusting mechanism for convenient remote adjustment.

For surface measurements, a special laser ranging laser ranging theodolite was developed. It sends a parallel beam modulated at 1200 MHz to reflecting corner cubes mounted at each corner of the panels. The phase of the modulated component of the return light is measured to determine the distance. Angle is measured by sending diverging rays and the theodolite autocollimates to the return light.

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1.2. Pointing

Because the telescope has a half power beamwidth of about 17 arcseconds at 115 GHz, a very high pointing accuracy is required. The specified pointing accuracy is 1/1000 degrees for winds of less than 7 m/sec. A master collimator angle readout and various monitors are provided for accurate pointing of the telescope.

The master collimator is placed at the intersection of the azimuth and elevation axes on a tower with a foundation independent from the telescope. The collimator sends a parallel beam of light to a plane mirror attached to the back of the main reflector. The reflected light is used to autocollimate the telescope. As the collimator is a small, very precisely finished instrument, a very accurate angle readout is possible.

1.3. Optical System and Feeds

For ferquencies below 8 GHz, the prime focus is used, while for frequencies above 8 GHz the signal is transmitted to ground level through a beam transmission system. Feed horns and low noise front ends are arranged at the coude focus in the lower cabin. This arrangement provides good access to the receiver front ends and convenience in changing the observing frequency.

The system configuration of observing frequency is changed easily by inserting or removing beam switching mirrors. For the 80 and 120 GHz bands, Small diagonal horns illuminated by concave mirrors are used; the horns are located in the dewar.

All of the front ends are low noise, cryogenically cooled, dual channel devices that can handle two polarizations simultaneously.

2. SPECTROMETERS OF THE 45M RADIOTELESCOPE

Two types of spectrometers are used at NRO for analyzing atomic and molecular line radiation. They consist of two sets of acousto-optical spectrometers (16,384 channels for 2000 MHz bandwidth and 8,192 channels for 160 MHz bandwidth) and a Fourier-transform type spectrometer (4,096 channels for 40 MHz to 600 kHz bandwidth).

2.1. Acousto-optic spectrometer (AOS)

Two banks of AOS are used, that is, wideband AOS and high resolution AOS. The wideband AOS covers a 2 GHz instantaneous bandwidth with a resolution of 260 kHz, and can be divided into four 0.5 GHz bands. With the help of the versatile IF system, it can pick various frequency bands from various front ends. It uses eight acousto-optic modulators with 250 MHz bandwidth each. The total number of frequency channels is 16,385. The high resolution AOS uses four

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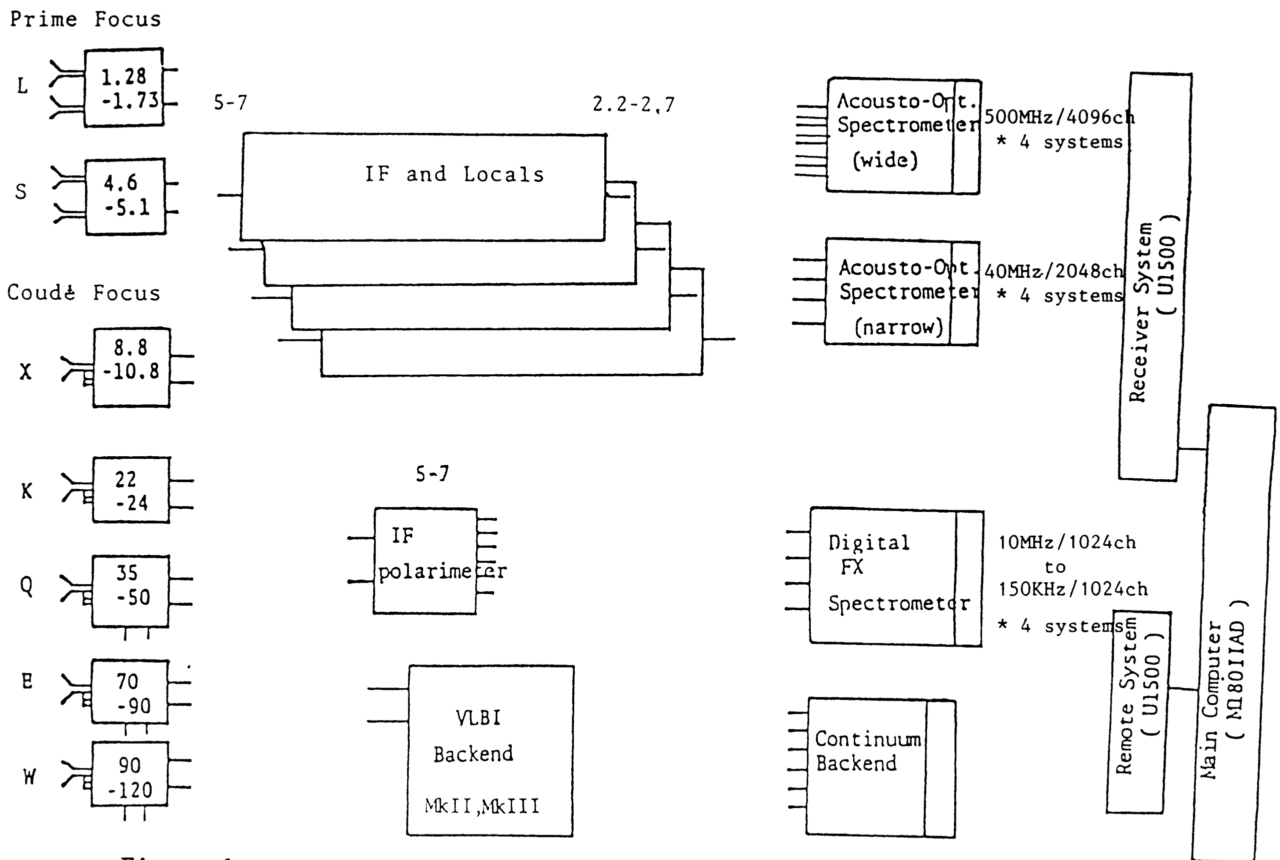

Figure 1. Block schematics of 45 m radiotelescope receiving system. Frequencies are in GHz if not specified.

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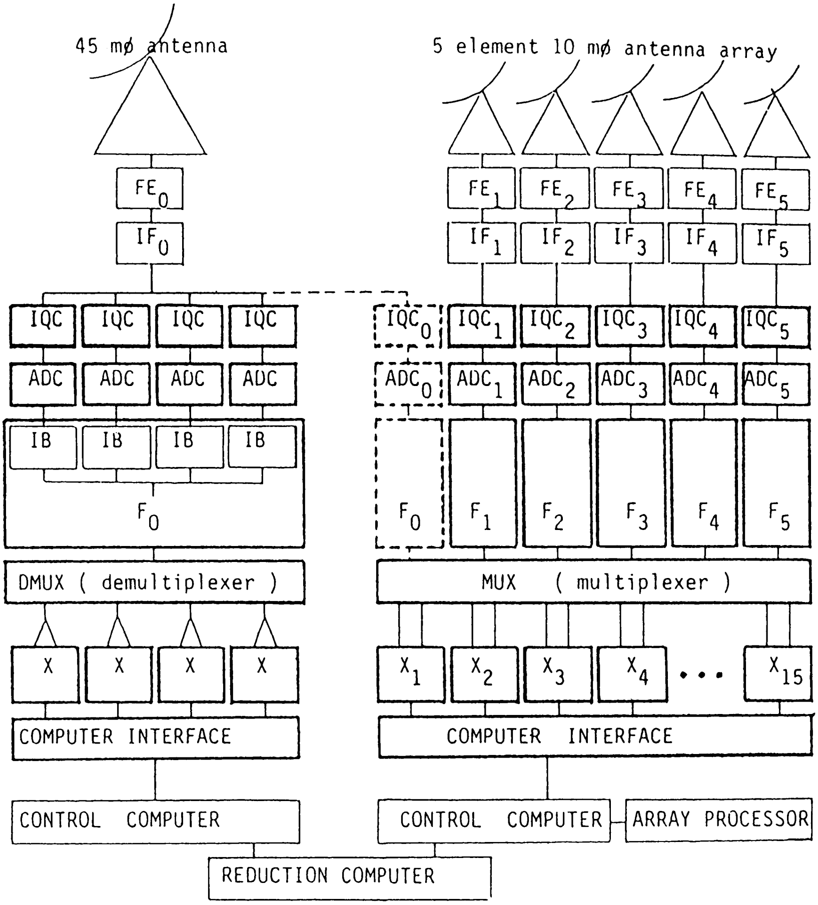

FE : Receiver front-end.
IF : Intermediate frequency amplifier.
IQC : In- and quadrature-phase frequency converter.
ADC : Complex analog-to-digital converter.
F : FFT processor.
IB : Input signal buffer (the first corner turner).
DMUX : Demultiplexer.
MUX : Multiplexer.
X : Correlator in frequency domain.

Figure 2. Block schematics of the 45m radiotelescope and the supersynthesis telescope, which is related to the "FX" backends.

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modulators of 40 MHz bandwidth and 40 kHz resolution, each with 2048 channels, for a total of 8196 channels. They can also be used as four independent spectrometers.

Both systems are now complete and have been used for spectroscopy of interstellar molecules.

2.2. FX

The Fourier transform spectrometer of the 45m radiotelescope, called "FX" (Chikada et al., 1983), has the same architecture as the FX digital spectro-correlator used in the 5-element supersynthesis interferometer (Ishiguro, 1981) of Nobeyama Radio Observatory. The IF signal is converted to video frequency and A-to-D converted, then Fourier-transformed using an FFT algorithm (Cooley and Tukey, 1965), and detected and integrated in digital form. Almost all of the digital circuits are made up of four kinds of custom ICs (16x16 bit corner turner, 7 bit complex butterfly, 6x6 bit complex multiplier, and 9 bit 32 word complex accumulator) that are made by CMOS gate array technology. These ICs can operate up to a 10 MHz clock rate. A maximum bandwidth of 320 MHz for 1024 channels is made possible by using pipeline and parallel processing schemes.

The 45m telescope FX is made up of four sets of 1024 channel, 10 MHz bandwidth spectrometers. The total bandwidth and related frequency resolution can be altered by varying the video bandwidth and the related clock frequency. Resolution currently installed varies from 100 kHz to 153 Hz.

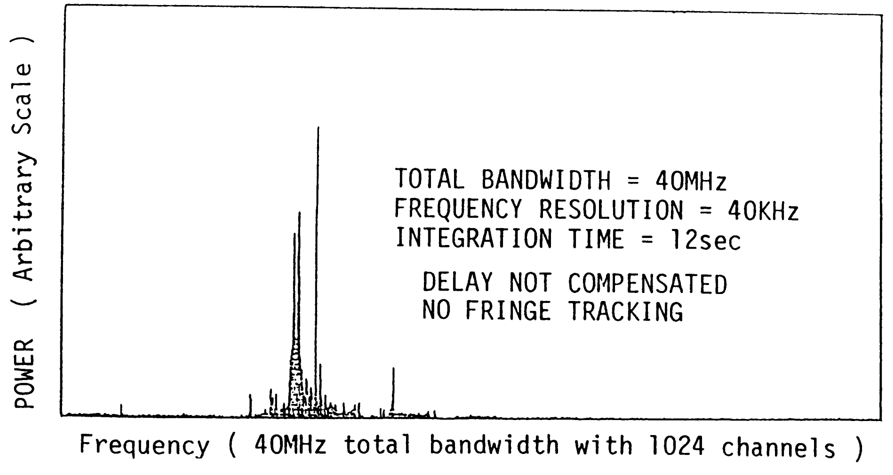

Figure 3. Cross-power spectrum obtained by the "Interferometer FX". W49 H_2O maser spectrum at 22 GHz on Aug. 24, 1983 is shown. This is a raw data output from the "FX" and is not calibrated.

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Although performance tests and tuning have not yet been completed, some preliminary results have been obtained. The digital FFT processors ('s) and the correlators (X's) were tested for their processing speed, and proved to function correctly at the maximum bandwidth of 320 MHz. They were also tested for their logical validity, and gave an output identical to that of a simulator in a computer. The NSR (noise-to-signal ratio) of the FFT processor was measured at the output of the simulator to be less than 3 percent.

3. FORMALDEHYDE LINE FOR TARGETED SEARCH

Morimoto, Hirabayashi, and Jugaku (1978) proposed the use of formaldehyde anti-maser absorption lines toward dark clouds for interstellar communication. The formaldehyde line exhibits a very low excitation temperature through the anti-maser effect of the source, and consequently the background temperature in the direction of dark clouds is below the 3 K cosmic background temperature. If a search is made at this frequency, we would get a lower noise temperature than at any other frequency band. A civilization on a star that is seen by us in front of a dark cloud would know this advantage and would tend to send signals to us at this frequency, knowing that we, too, would be aware of the same advantage. The absorption line is itself much narrower than other known lines. The distinguishing property is that the transmission signal can use the frequency determined by the absorption minimum by the observation, and and we need not bother about the ambiguity of the Doppler shift. When considered from the standpoint of frequency ambiguity and background noise temperature, the formaldehyde line strategy has the best figure of merit compared with other proposed strategies.

There are many dark clouds in the sky, a substantial fraction of the sky is covered by such clouds, and there are many stars that are seen in front of such clouds. One may argue that the number of candidate stars is limited and that this is a drawback. But I recognize just this point as an advantage because we can specify not only the frequency but also the directions to be searched. Thus we can concentrate ourselves to a high sensitivity targeted survey. An example of a concise list of candidate stars of suitable spectral type is found in Morimoto et al. (1978). Fred Hoyle created hydrodynamic intelligence in his "Black Cloud" from scientific fiction basis. Our proposal is to detect closer neighbourhoods towards black clouds.

Our 45m telescope, including the FX spectrometer, is capable of performing such SETI activity. Kardashev (1979) emphasized the importance of the millimeter wave region for interstellar communication. The 45m telescope is suited for that purpose, as well.

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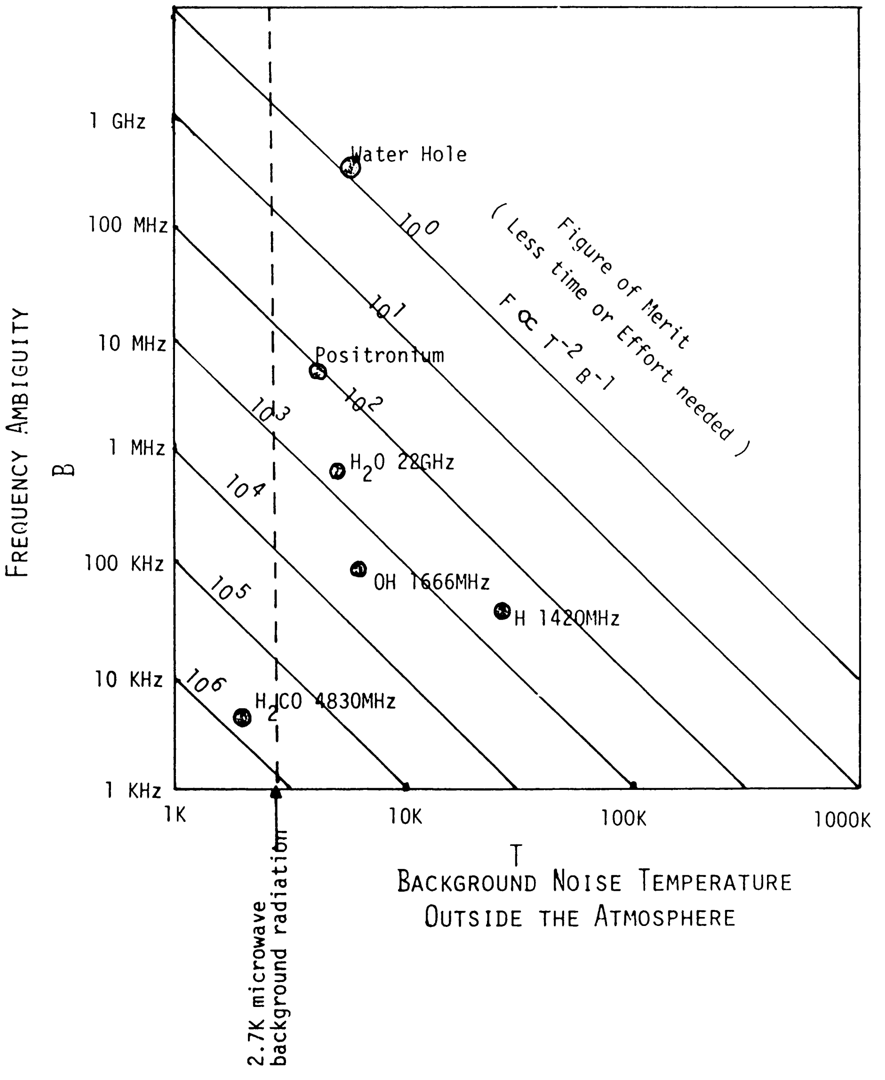

Figure 4. Frequency ambiguity versus noise temperature for various magic frequencies. Note that 4830 MHz line of formaldehyde has less noise temperature than that of any other frequencies and is less than cosmic background temperature. The frequency ambiguity of frequencies except formaldhyde and the "water hole" is proportional to the ambiguity due to the Doppler shift. For an amibiguity of transitter movement for them, the random velocity of 10 km/s is assumed. The range of the figure of merit is 10^5 for various proposed magic frequencies.

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