Internet Antenna Elements

Abstract

We propose construction of a pair of elements of antenna array, to test the design of a distributed network of antennas to be used individually as educational tools for high schools and colleges and as a combined array for scientifically motivated research. The basic design concept is similar to the Low Frequency Array (LOFAR) design except that the infrastructure costs are reduced by use of existing internet connections for transmission of array data to correlators. The array would operate in the 100 to 300 MHz range, and antenna elements would consist of phased up arrays of dipoles. Each element would also consist of a number of DSP based processors for phasing of elements to point the antenna and for data averaging, pulsar dispersion and auto correlation for production of spectra.

Background

A large number of scientifically interesting experiments have been proposed for the Square Kilometer Array (SKA) and Low Frequency Arrays (LOFAR), but the system model for these instruments has been oriented towards a dedicated facility with special high speed data links and a technical staff to support these activities.

We propose a system to achieve similar science goals as LOFAR and SKA, but via a more distributed development program, with each element of the Internet Antenna array to be hosted by a high school or university. Very important collaboration and research skills can be effectively disseminated by this program.

Our first step in development of the Internet Array is the implementation of a pair of elements of this array. Our goals are that these first elements would be distributed over a small geographical area and have only a few low cost components. Later projects would have a larger number of antenna elements.

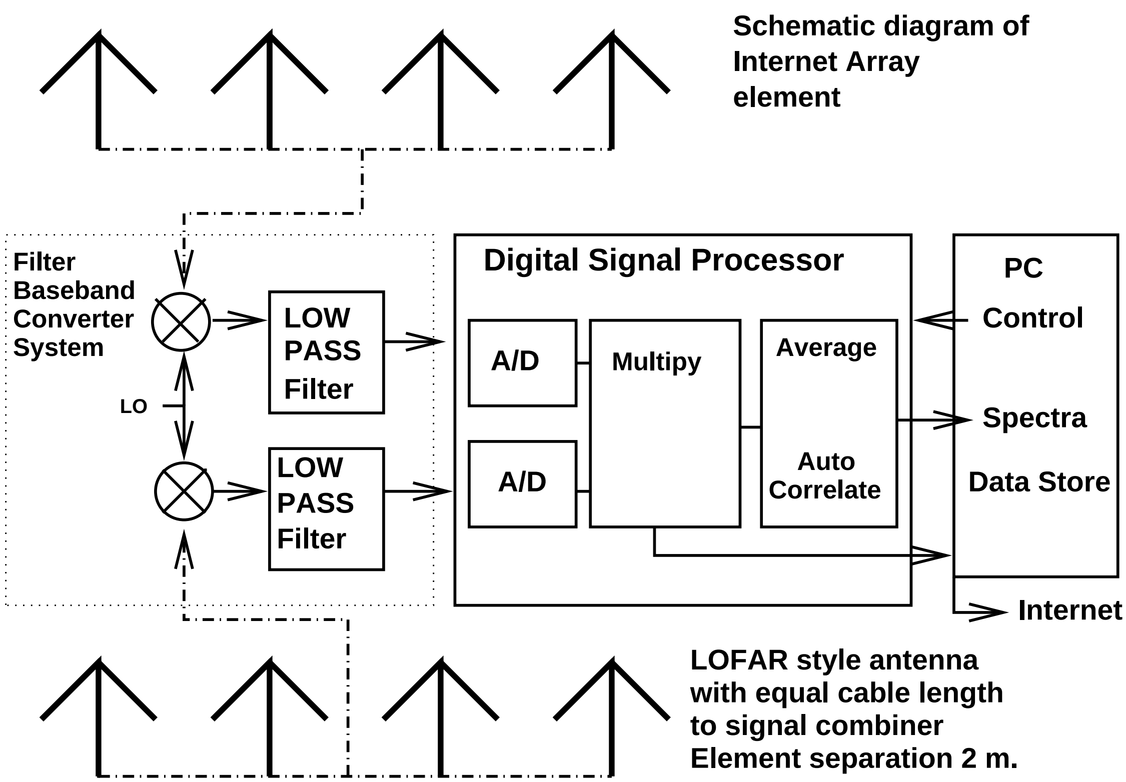

Fig 1: Schematic design of one element of Internet Antenna

Simple Element Design

The simple antenna system design is shown in figure 1. To achieve reasonable sensitivity requires a number of signals form dipole antenna elements to be added together in phase. One simple approach is to build a pair of sets of 4 dipoles. Each of the 4 dipoles would be arranged in an east-west line. (See Kraus for a discussion of dipole phased arrays). The dipole elements will be separated by 2 λ at the highest frequency. This will yield a beam for the dipoles with 15 Degree width in the narrow direction. This array would be used as a transit instrument, with a 1 hour view of individual objects. This angular resolution matches the size of the galaxy reasonably well at these wavelengths.

Pairs of dipoles would be connected to a mixer and LO system so that the pair of baseband signal would be fed into digital signal processor Analog to Digital Converters. Tan and Rohner (Ref 1) have shown that a simple dipole design with active BA-LUN can achieve antenna temperatures smaller than 100 K in this frequency range.

A number of design choices are possible for the Filter/Base Band Converter system. Recently high speed samplers and Field Programmable Gate Arrays (FPGAs) have come to market that allow the analog implementation of this subsystem to be replaced with a very flexible digital implementation of the filters. Using these FPGAs could also allow steering the antenna single element beam.

Gain calculations

The usefulness of the single element as a telescope is discussed next. The antenna will have an effective area of $A_e = \eta \times 2 \times 4 \times \lambda^2$, where η is the efficiency of the single element dipole. Assuming $\eta = 0.5$ and $\lambda = 1m$ then the effective area of the elements of the antenna is 4 m^2.

The sensitivity to a source with flux density S (in Jy) is

$$\frac{T_A}{S} = \frac{A_e}{2k} = \frac{4 \times 10^{-26}}{2 \times 1.38\ 10^{-23}} = 0.0014K/Jy.$$

The rms noise level (Kelvins) for an observation of duration t (sec) with bandwidth B (Hz) is $\Delta T = T_{sys}/\sqrt{Bt}$, where T_{sys} is the system temperature.

Note that the sensitivity of the elements could be increased in a number of straight forward manners. Addition of dual polarization elements and increasing the number of phased dipole elements could be done at low cost.

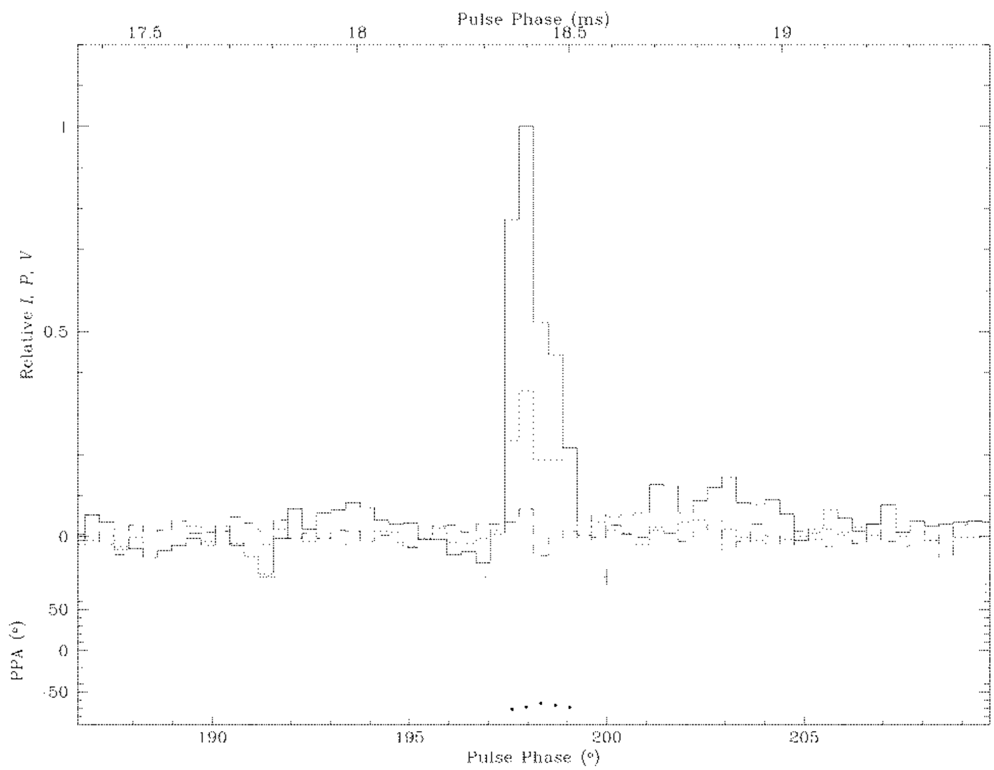

Fig 2: Single Crab pulsar pulse (from Ref 2), taken at 600 MHz with the 85-3 telescope in GB West Virginia. Peak intensity of this pulse was greater than 7000 Jy.

Candidate Targets

A primary target for a single element of the internet array is the galactic plane.

In the galactic plane, pulsars are good targets due to their increasing brightness at low radio frequencies. A notable target is the Crab pulsar which exhibits giant bursts (Ref 2), with brightness > 7000 Jy in individual pulsar pulses. The mechanism creating these giant pulses is not understood, but the giant pulses are occur approximately once every 1000 pulses The crab pulsar period is 33 milliseconds and the giant pulse duration is slightly greater than 1 millisecond. The giant pulses occur about every 30 seconds.

The antenna temperature for such a pulse is $T_A = 7000 \times 0.0014 \sim 10$ K. The required bandwidth to achieve a signal to noise ratio of $T_b/\Delta T = 10$ for an individual pulse is of the Crab is

$$B \times t = \frac{100 \times T_{sys}^2}{T_A^2}.$$

For t = 0.001 seconds, $T_{sys} = 100$ K, $T_A = 10$ K, then

$$B = \frac{100 \times 10,000}{100} \times \frac{1}{.001} = 10 \times 10^6 \ Hz$$

This bandwidth is achievable with existing DSP technology. The bandwidth requirements for an individual DSP processor can be reduced by having a number of DSP processors working in parallel. Producing a pair of systems with orthogonal polarizations would immediately reduce the bandwidth requirements.

Note that the DSP/PC system should be capable of buffering a few seconds of data at the highest data rate, so that processing to detect the pulses could complete before the data are lost. The computer system must be able to accurately time tag data samples to better than 0.1 micro seconds accuracy.

A second area of scientific interest is in monitoring the sky for transient events (Ref 3). This type of observation can bring discovery of exotic new phenomena and is of interest to a broad community. With addition of processor systems, the individual elements could be combined to give good monitoring coverage to a large fraction of the sky. By linking the separate elements, immediate confirming observations could be made, with much greater sensitivity.

Interferometer Challenges

The great scientific promise of this type of antenna will be achieved by bringing the signals of many independent internet antennas to a common correlator. The scientific promise justifies the work required to overcome a number of technical challenges. Some issues which must be addressed are:

1 High data rate communications. This may be solved by the market, as the internet communications rates have steadily increased.

2 Distribution of phase stable oscillators. Current inexpensive clock oscillators do not have the required phase stability required for coherent averaging of the data. This challenge may be overcome by use of special phase stable GPS based frequency standards or development of systems to track pulsars timing. Pulsars provide more phase stable signals than any Terrestrial standard, but no system has yet been built to transfer the pulsar phase to a locked local oscillator system.

3 Large data processing requirements. Since the field of view of each of the individual elements is large, correlated signals will be visible over a large field of view, requiring powerful, 3 dimensional mapping capability.

Conclusions

An Internet Antenna Array is now possible with existing technology, although a number of technical challenges must be met. Scientific, education and engineering skills must be combined to develop an new instrument with many important uses.

References

1 Gie Han Tan and Christof Rohner, 2000 “The Low Frequency Array active antenna system”

2 Shauna Sallmen, D.C. Backer, T. H. Hankins, D. Moffett, and S. Lundgren, “Simultaneous Dual-Frequency Observations of Giant Pulses from the Crab Pulsar”, *Ap. J.*, **517**: 460.

3 Katz, C. A.; Hewitt, J. N.; Moore, C. B.; Ellithorpe, J. D., 1994 “The STARE Project: A Search for Transient Astronomical Radio Emission”, *Bull. Am. Astro. Society*