Random Phase Antenna Combining for SETI

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ABSTRACT: Since the direction from which the first ETI signal will arrive is not known in advance, it is possible to relax the phasing requirements of a small (up to 3 antennas) SETI array without reducing the detection probability. Possible ways of combining two and three antennas are discussed and analysed regarding their relative performance and signal processing requirements. Different baseline sizes and orientations are compared in terms of beam shape and possible limitations on integration time they produce. The possibility of multiple simultaneous beam sets is also considered and suggested as the best way to exploit a multiple antenna setup.

1. Introduction

In conventional interferometry, as used for astrometry, imaging etc.[1], the positions of the individual antennas, including the movement of their phase centers when tracking, have to be known to a fraction of the wavelength. The phase of the feeding lines, local oscillators etc., must be precisely controlled and calibrated. One of the reasons for these requirements is the need for accurate pointing of the synthesized beams. In the BC era of SETI (Before Contact), this need for precise pointing is absent, since we are simply looking for a signal from ANY direction. So at least until we reach the AD era (After Detection), the phasing requirements can be somewhat relaxed.

2. Two antennas

There are at least three ways how to increase search space / detection probability by using two dishes instead of one [2]: a simple additive interferometer gives an 41% improvement, two independent receivers a 2X improvement and two receivers with synthesis of interlaced beams 2.83 times.

2.1 Beam pattern

If the mutual coupling is neglected (which is a safe bet with dishes), the directional pattern of two equal antennas pointing in the same direction and connected together is a product of the pattern of a single antenna and the pattern of the combination of two isotropic radiators placed in the phase centers of the antennas [3].
The second part is a pattern with multiple lobes, the number of them being approximately four times the spacing in wavelengths. These lobes are usually called 'grating lobes'. In the direction perpendicular to the baseline (a virtual line connecting the phase centers of the two antennas) their width is approximately wavelength divided by baseline radians. In other directions it increases as 1/cos(x), being proportional to the projected baseline. The exact direction of these lobes depends on antenna positions and

feeding phases. Since we do not want to loose efficiency by overlapping apertures, the projected baseline will always be larger than individual antenna diameter, so the grating lobes will always be smaller than the main lobe of the individual dishes, and there will always be at least one grating lobe maximum within the main beam. Because all grating lobes have the same amplitude and we don't care about their exact direction, the feeding cable length is irrelevant. Fig 1 shows a typical beam pattern.

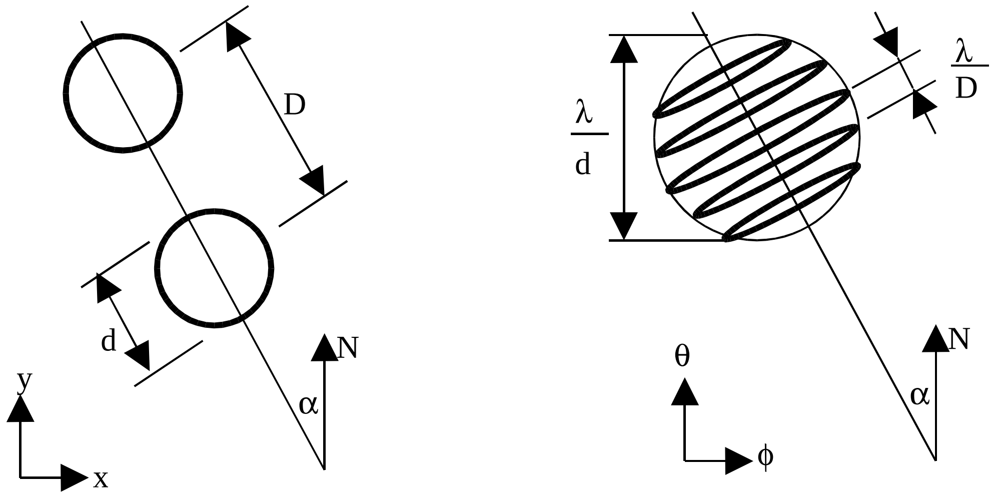

Fig 1. Dual aperture and corresponding directional pattern

2.2 Consequences for signal processing

Fig 2 shows the transit of a sidereal source through the beam pattern and the corresponding signal amplitude, the typical interferometer fringes. Obviously, there is some reduction of the possible maximum integration time. One way to avoid this reduction is a strictly north-south baseline, and another to insert a time-variable delay in one of the arms (fringe stopping).
On the other side, the distinct fringe pattern offers a good opportunity for sifting out terrestrial interference - a task for the analysis software.
The time that a source spends inside a single grating lobe is approx. one half of the fringe period:

6900*wavelength/Dew [sec]

where Dew is the east-west component of the baseline.

2.3 Antenna pointing

The antennas must point exactly (to a fraction of their 3dB beamwidth) in the same direction, so this poses some requirements on the positioner's angle readouts. The simplest solution are of course fixed mounts for the drift-scan mode.
Changing the direction of the antennas will change the projected baseline and in most cases the position of the antenna phase centers. Changed phase center positions will add a random free space delay, which simply adds to the random cable delay and is not a problem in this mode of operation. A different projected baseline will change the width of the fringes, which a smart analysis program might want to take in account.

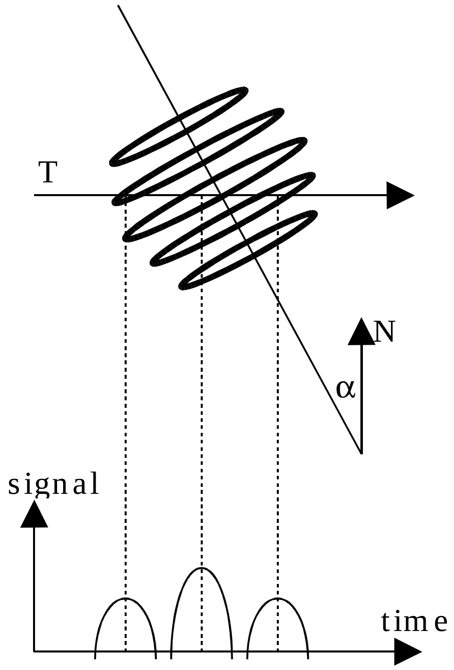

Fig 2. Transit of a source

2.4 Interlaced beams

With two antennas, it is easy to synthesize two exactly interlaced sets of beams using a simple hybrid circuit, as shown in fig 3. The interlaced beams are available at the sum and difference ports of the hybrid, and feed two receivers. The random cable lengths are not a problem, since only the phase difference is important.
The processing software could be independent in both channels, however a more sophisticated solution would be to track sources as they alternate between the two patterns.

2.5 Amplitude balance

For best S/N, the signals from equal dishes (in terms of G/T) must be combined with equal weights. This means that the sums of the preamplifier gains and cable losses must be equal in all arms. One way to check this is to observe a transit of a suitable source (like the Sun) in each arm separately and adjust for equal amplitudes. (Point the antennas at least 3..4 beamwidths apart in right ascension and not more than 0.2 beamwidth apart in declination and compare the peaks.) Checking the fringe visibility of an unresolved source would be OK too, but there aren't many suitable (strong) sources available. The Sun can be too big - it will start to be resolved at about 20m or less of baseline on 1400MHz. Maybe a non-geostationary satellite signal could be used.
When combining different size dishes, their signals must be combined proportionally to their individual G/T ratios. However, it doesn't make much sense to combine dishes of significantly different sizes. For example, a 3m and a 2m dish together have the area of a 3.6m dish, giving only 1.6dB more gain than the 3m dish alone.

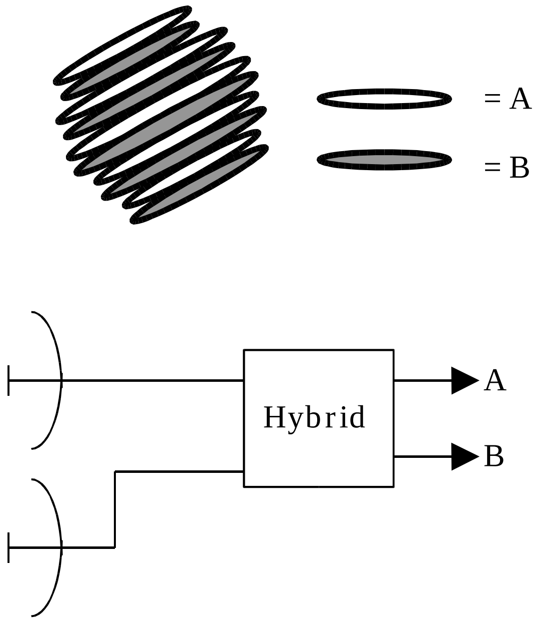

Fig 3. Interlaced beams with two antennas

2.6 Combining later in the pipeline

Synthesizing multiple beams is a task that can be very well done in software, if all the preceding processing of the parallel channels is done coherently. Since here we are working with random phase it would be even theoretically possible to work with independent LO's and sampling clocks, but in practice any differences in frequency would cause the beams to 'sweep' across the sky and severely limit possible integration time. To get one second of integration, the frequencies must be within less than 0.5Hz.

2.7 VLBI

The most demanding aspect of VLBI is the requirement for extremely accurate time/frequency standards and calibration. The random phase technique would significantly relax these requirements, making it attractive for VLBI - but it is questionable if a very long baseline would bring any advantage in a 'general search' SETI situation - more likely the extremely narrow lobes would represent a drawback.

3. Three antennas

Since it is always possible to put a plane through three randomly chosen points, connecting three antennas with random cables will always give a grating maximum (A direction, from which contributions from all three antennas add in phase).
Synthesizing a single beam set would increase the search space / detection probability by 73%, and three beam sets more than 5 times. Of course, three independent dishes give a 3X improvement. The three beam sets must be synthesized in such a way to evenly and efficiently 'tile' the theta-phi plane of the pattern. This can be done by feeding the three antennas with (0,0,0), (120,0,-120) and (-120,0,120) degrees of phase shift, like a 3x3 Butler matrix.
After suitable amplitude-balanced preamplification the simplest way to realize this is by six one-to-four symmetrical power dividers and nine phasing cables, the six unused ports simply terminated with dummy loads. Again, only relative phases are important. Fig 4 shows

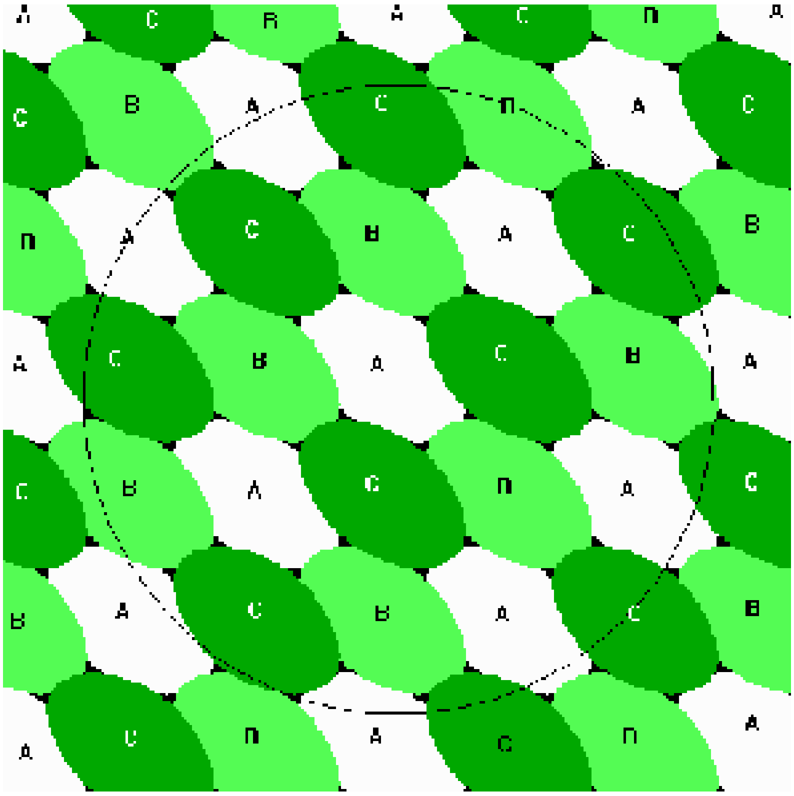

Fig 4. Simulated beam contours of a three dish random phased array

simulated 3dB contours of the three beam sets of a three antenna array fed this way, with antennas located in a horizontal plane at (0,0), (10,5) and (5,-5) meters, looking straight up and operating on 1400MHz. The thin black circle represents the beam of a single 3m dish.
The maximum possible integration time depends mostly on the east-west dimension of the array, similar as above. However, it is not advisable to put three random phased antennas close to a single line, since this can produce very big grating lobes, which could fall outside of the individual antenna beams. The lateral dimension of the array should at least equal the individual aperture diameter. This can also become a problem when targeting sources low on the horizon, as the projected baselines are reduced in one direction.

4. More than three antennas

Three antennas is the maximum for random phasing, since four or more randomly chosen points are not likely to lie in a single plane. It is not possible to work around this by dividing the antennas into subgroups, for example 2+2, since the two sets of grating lobes will not match in general. In a group of N antennas, the phase must be adjustable in at least N-3 antennas.

5. Conclusion

Since the price of surplus dishes is usually much lower that that of SETI-capable receivers, even the simplest multi-dish setup - just connecting up to three antennas together and feeding a single receiver - may well make sense. On the other hand, adding a second or third receiver and some simple RF components can produce a much improved system, all without the need for accurate positioning and phasing of the antennas.

6. References

[1] IRAM interferometry summer school, available online at http://www.iram.fr/IRAMFR/IS/archive.html

[2] Marko Cebokli S57UUU: Upgrading your argus station – where to put the money? Proceedings of the SETIcon 02, ARRL 2002

[3] Jasik, Johnson: Antenna Engineering Handbook, McGraw-Hill 1992 ISBN 007032381X