Major National Research Facility Upgrade of the Compact Array Local Oscillator Reference System

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Abstract: The Compact Array at Narrabri, N.S.W, is a six-element earth rotation aperture synthesis radio telescope. New receivers are being installed at the telescope array with frequency response up to 115GHz. A down-converting local oscillator derived from the current 160.05MHz centrally distributed reference will have inadequate phase noise for high frequency operation.

On completion of the upgrade a microwave reference frequency, and the existing 160.05MHz reference, will be distributed from the central site using analogue fibre optic links. Local oscillators derived from the new microwave reference will have less than 3.5 degrees r.m.s. phase noise at 100GHz.

Introduction: Compact Array Background [1]

Earth rotation aperture synthesis telescopes require repetitive observations with different antenna spacing, or baselines, to effectively map a source.

Five 22-metre antennas, CA01 to CA05, are mounted onto a 22-metre gauge rail track allowing the antennas to be periodically relocated. The 3km long rail track is aligned east to west. Thirty-five stations are spaced in integer multiples of an array unit spacing equal to 15.306 metres. A sixth antenna, CA06, is mounted on a short section of track, 3km to the west of the western end of the 3km track.

New stations have been added as part of the high frequency upgrade bringing the total number of stations to forty-four. Three standard east-west stations have been added and a spur fourteen array units long has been added in a north-south alignment. On the north-south spur six stations have been added including a station on the main track and spur intersection.

Each compact array antenna currently provides dual frequency operation in the observing band, with orthogonal polarized outputs available for each frequency. The observing bands from 1.25 to 1.75GHz and from 2.2 to 2.5GHz are available simultaneously. By changing receivers the bands from 4.4 to 5.1GHz and from 8.0 to 9.2GHz are available. Four intermediate frequencies are sampled at the antenna and are available in bandwidths of 256MHz, 128MHz and 64MHz.

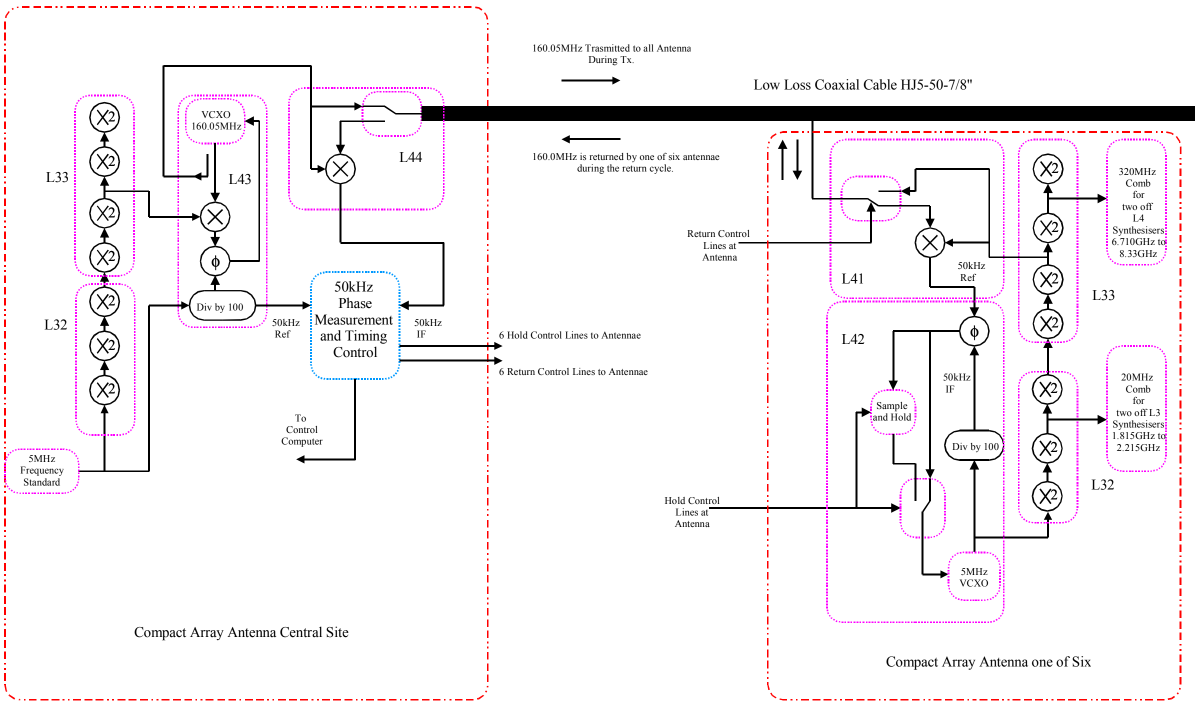
1: Co-axial Cable Reference Distribution Scheme

Two 7/8" inch dry nitrogen filled coaxial cables are directly buried at the central site and after crossing beneath the rail track one cable runs to the east the other west. The coaxial cable enters and exits the base of each old station posts, allowing a normally connected jumper to be replaced by a coupler in the antenna pedestal room if an antenna is on station. The cable to the east is approximately 2km long; the western cable is over 1km in length.

As shown in Figure1, at the central site an offset Phase Lock Loop (PLL) utilizing a multiplier chain locks a 160.05MHz Voltage Controlled Crystal Oscillator (VCXO) to a 5MHz reference supplied by a hydrogen maser. The 160.05MHz VCXO tone is used as a reference frequency by the remote antennae.

The 160.05MHz VCXO output is passively split three ways, two ports being used to drive the co-axial cables, the third being used to directly modulate a 1310nm Fabry Perot laser diode. An Avalanche Photo Diode (APD) detector mounted in the antenna vertex room completes the 4.5km single mode fibre optic link to CA06.

Figure 1: Local Oscillator Reference Distribution on Low Loss Coaxial Cable at Compact Array



At the antenna an offset PLL locks a 5MHz VCXO to the 160.05MHz reference distributed from the central site. The 5MHz tone is then multiplied up to 640MHz by the antenna 'reference chain'.

Two custom synthesizers use a Step Recovery Diode multiplier driven by the 320MHz output from the reference chain, and an offset PLL to provide a down conversion local oscillator with frequencies in the range of 6.710GHz to 8.33GHz in 320MHz steps. A second pair of synthesizers utilizes 20MHz from the reference chain to produce a local oscillator in the range of 1.8GHz to 2.2GHz with 20MHz steps. Various other frequencies produced by the reference chain are used to produce UHF variable phase down conversion local oscillators, and variable phase 512MHz sample clocks.

Systematic phase offsets in the distribution system are measured by a round trip phase measurement scheme.

For antennas CA01 to CA05, phase offsets are periodically measured by briefly disconnecting the 160.05MHz VCXO at the central site from the co-axial cable. Each antenna sequentially connects the 160MHz output of the antenna reference chain to the co-axial cable for a short interval. A sample and hold circuit in the PLL allows the antenna VCXOs to "freewheel" whilst the antenna reference is removed.

At CA06, the antenna VCXO PLL is locked permanently to the 160.05MHz reference supplied by the analogue fibre optic link. To implement the round trip phase measurement a 1310nm Fabry Perot laser diode is directly modulated by the 160MHz output of the antenna reference chain. An APD detector at the central site can be switched to the round trip phase measurement circuitry.

Phase offsets and corrections for each antenna are applied in the following manner. Phase difference is measured between the 50kHz reference produced from the maser, and a 50kHz mixing product of the 160MHz antenna return and the central site 160.05MHz VCXO output. During a previous calibration interval a reference phase difference for each antenna is measured, if there has been a relative phase shift a correction is applied to the antenna via the UHF phase rotated synthesizer and the sampler phase rotated clock.

2: Proposed Photonic Reference Distribution Scheme

The upgraded reference distribution scheme attempts to address several deficiencies in the existing distribution scheme.

The co-axial cable "daisy-chain" architecture translates any fault in the cable. For example a co-axial jumper with low return loss will affect to all antennae along the cable.

During the return of the 160MHz signal from each antenna, the antenna reference offset PLL is unlocked and allowed to "free-wheel". Additionally twisted pair control lines are run from the central site to each station post to control the PLL sample and hold circuit and the 160.05MHz and 160MHz transmit/receive switch. The twisted pair control lines have proved to be susceptible to lightning damage and are high maintenance items during summer.

The antenna VCXO determines short-term phase noise of the antenna synthesizers. To derive a 100GHz local oscillator from a 5MHz VCXO requires a multiplication of the order of 20,000. Phase noise of approximately seven degrees r.m.s is theoretically possible for a 100GHz local oscillator derived from a low noise VCXO at the antenna. Introducing high Q filters in the multiplication chain to limit phase noise increases synthesizer sensitivity to thermal effects.

Long-term phase offsets are measured by the round trip phase measurement at 160.0MHz. Extrapolating instrumental phase offsets to 100GHz is impractical due to the high multiplication ratio required. The current round trip phase measurement system uses a time interval counter and is resolution limited to 0.036 degrees of phase at 160.0MHz. The resolution at 100GHz of the old system would be 22.5 degrees.

The proposed scheme will replace the co-axial cable in the reference distribution system with a pair of single mode optic fibres run from the central site to each antenna. In figure 2 overleaf, two laser sources are Wavelength Division Multiplexed (WDM) onto a single fibre. The output of the WDM is split seven ways; six fibres are run to the antennas via the patch panel at the central site.

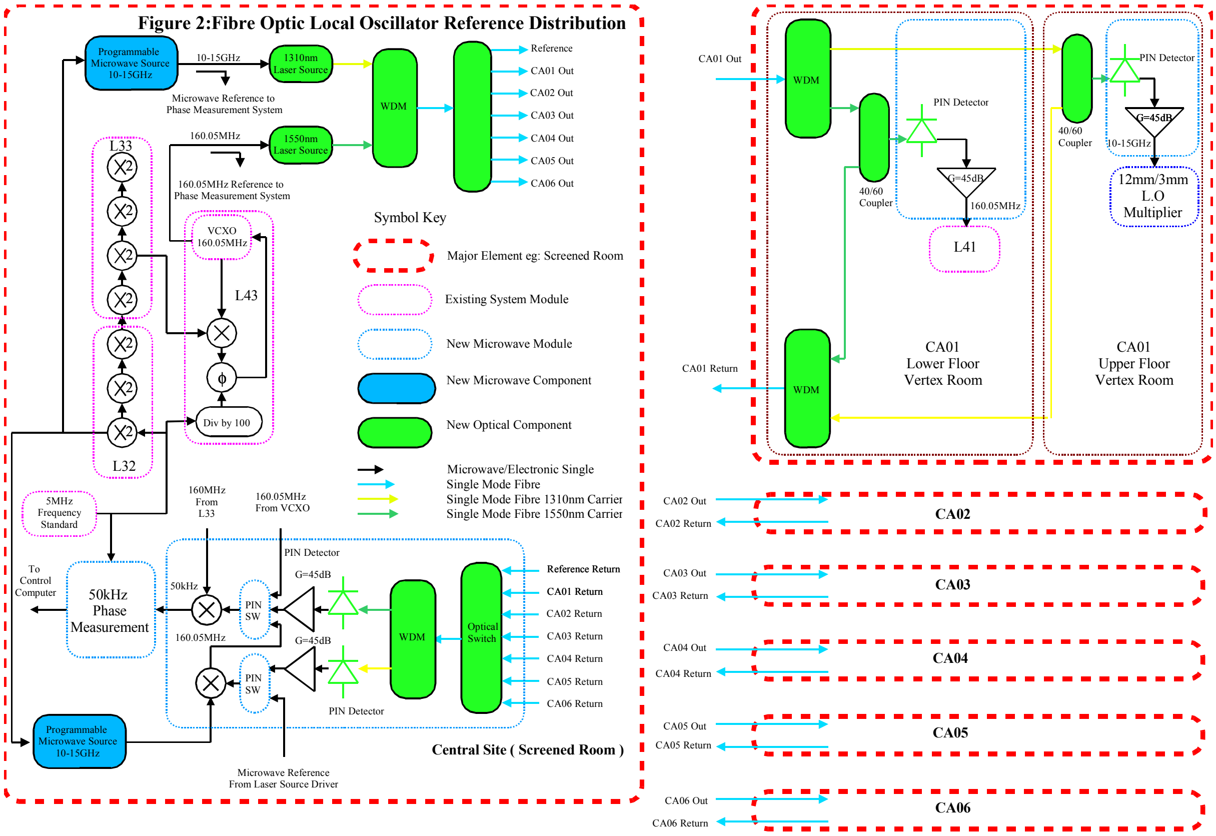


Figure 2:Fibre Optic Local Oscillator Reference Distribution

The 160.05MHz reference has been maintained to minimize the impact of the upgrade on the operation of the array. The 160.05MHz reference is transmitted by a directly modulated 1550nm distributed feedback laser source.

A high frequency reference directly modulates a1310nm Ortel laser source at a microwave frequency between 10 to 15GHz. An externally modulated link, driven by a continuous wave Diode Pumped Solid State Nd:Yag laser is also being evaluated. The externally modulated link would have lower loss, and a lower noise floor.

At the antenna a WDM separates the two incident light wavelengths onto different fibres. On the 1550nm fibre a portion of the incident light is coupled to a detector in the lower floor of the antenna vertex room. Link loss of 46dB at 1550nm is expected at the antenna. The detected output from the link will lock the antenna VCXO to the central site VCXO continuously. Output from the other coupler port is WDM onto the return fibre to the central site to implement a round trip phase measurement.

On the fibre carrying the wavelength at 1310nm, power will be coupled to a microwave detector in the upper floor of the antenna vertex room mounted on the high frequency receiver. The other coupler port is WDM multiplexed onto the return fibre to the central site. Multipliers following the detector gain stage will generate the high frequency local oscillator signals. An active doubler will multiply the detected signal by two, producing a local oscillator in the frequency range of 26 to 30GHz. This local oscillator will be used to down convert the receiver band covering 15 to 26GHz. A four times multiplier following the doubler is expected to provide a local oscillator in the range of 80 to 120GHz. The high frequency local oscillator will be used for down conversion of the receiver band covering 85 to 115GHz.

An eight to one optical switch will select the antenna return fibre for the round trip phase measurement. The output of the switch is WDM onto a 1310nm-wavelength fibre and a 1550nm-wavelength fibre. Link losses are expected to be 55dB for the 1310nm round trip link and 58dB for the 1550nm round trip link to the central site.

A second local oscillator locked to the 1310nm-laser diode modulating frequency, down converts the output of the 1310nm-microwave detector to a 160.05MHz tone. A high isolation pin switch selects the 160.05MHz intermediate frequency, derived from the microwave detector, the VCXO or the low frequency detector. The selected 160.05MHz source is down converted to 50kHz, phase shift from the reference 50kHz is measured by a time interval counter.

The new reference system is planned to be operational by mid 2001.

In the laboratory a 2km and 4km link were established using the Ortel laser directly modulated at 14GHz, see figure 3. A r.m.s phase noise of 0.45 degrees r.m.s between the 2km and 4km detectors was measured over a period of 16 hours, after correcting for detector temperature. A local oscillator at 100GHz derived from this reference would have r.m.s phase noise of 3.2 degrees r.m.s.

3: Conclusions

The upgrade allows a high frequency reference to be distributed to the compact array antennas. Short time scale phase noise should be reduced by a factor of at least two, compared to a system multiplying the antenna VCXO. Further the accuracy of the slow time scale phase offset corrections should be vastly improved by the reduction in the multiplication ratios between reference and local oscillators.

Inclusion of a reference fibre allows central site phase offsets to be measured and corrected.

Serviceability of the array should increase due to the robust star distribution configuration adopted and removal of twisted pair control signals.

The scope of the upgrade could be increased to include the photonic distribution of the four antenna synthesizers from the central site. This could be achieved by using four separate International Telecommunications Union (I.T.U) grid lasers, modulated by separate synthesizers and WDM multiplexing the lasers onto the reference fibre.

Developments in coherent fibre optic technology suggest the possibility of introducing a truly photonic high frequency local oscillator distribution will become viable within the next decade.

References:

[1] Journal of Electrical and Electronics Engineering, Australia Volume 12, No.2 June 1992