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# THE MERLIN – PHASE 2

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ABSTRACT The Jodrell Bank MERLIN is currently being upgraded to produce higher sensitivity and higher resolving power. The major capital item has been a new 32m telescope located at MRAO Cambridge which will operate to at least 50 GHz. A brief outline of the upgraded MERLIN and its performance is given.

## INTRODUCTION

The MERLIN (Multi–Element Radio–Linked Interferometer Network), based at Jodrell Bank, was conceived in the mid-1970s and first became operational in 1980. It was a bold concept; no one had made a real–time long–baseline interferometer array with phase–stable local oscillator links before. Six remotely operated telescopes, controlled via telephone lines, are linked to a control computer at Jodrell Bank. The rf signals are transmitted to Jodrell via commercial multi–hop microwave links operating at 7.5 GHz. The local oscillators are coherently slaved to a master oscillator via go–and–return links operating at L–band, the change in the link path–length being taken out in software. This single–frequency L-band link can transfer phase to the equivalent of $<$ 1 picosec ($<$ 0.3 mm of path length) on timescales longer than a few seconds. A detailed description of the MERLIN system has been given by Thomasson (1986). The MERLIN has provided the UK with a unique astronomical facility, one which has made important contributions to extragalactic radio source and OH maser studies. In addition the images show how well one can do with an array of only six telescopes when the data quality is high – this has had a major impact in the VLBI community.

However, in order to keep the MERLIN at the forefront its sensitivity, its resolution and its frequency range had to be improved. The sensitivity of the original system only allowed for self–calibration, and this limited the flux density of sources which could be observed to $>$ 50 mJy. The resolution of the MERLIN for continuum observations could be matched by the VLA at a frequency only four times greater and no systematic observations had been made with the MERLIN above 5 GHz. Starting in 1985 the UK SERC provided funding, in two phases, to provide for upgrades. These will allow the MERLIN to remain competitive throughout the 1990s.

## THE TECHNICAL DEVELOPMENTS

The receivers: Cryogenically cooled receivers are now available at L-band and at 5 GHz. Cooled 22 GHz receivers will soon be available. At L-band (a broadband system covering the range 1350–1750 MHz) the system temperatures will be 35–40K; at 5 GHz the system temperatures are 25–30K.

The microwave links: The microwave links in MERLIN are commercial items built by the UK firm Ferranti. Up till now they have been operated in FM mode giving a bandwidth of $\sim$ 9 MHz. In order to increase the bandwidth with the existing links and the 50 MHz channel width, they will be changed to AM (independent double sideband) operation. This is accepted practice in the telecommunications industry. Operation with AM will allow two 16 MHz channels to be transmitted back from each outstation; usually one for each hand of circular polarisation.

The correlator: A new $2 \times 2$ bit XF correlator has been designed by Bryan Anderson which will enable MERLIN to operate much more flexibly than before. It is based on a custom VLSI chip (a 2020 CMOS gate array from LSI Logic) and produces only real cross–correlations, the quadrature channels are produced in software. All pairs of circularly polarised inputs from the home and out–stations will be correlated, enabling full polarisation information to be obtained. At the full bandwidth, data from 32 delay channels per baseline will be produced for each of the four polarisation combinations. For line work recirculation is used to increase the number of channels to 2048 per baseline over a bandwidth of 250 kHz.

The 32m telescope at Cambridge: The most obvious enhancement in the new MERLIN is the new 32m telescope at MRAO, Cambridge. It is a fortunate happenstance that Cambridge is an almost ideal location for the first additional telescope in the array. Fig 2. in Thomasson (1986) shows that Cambridge is located well to the East of the existing array of telescopes. This not only increases the maximum baseline to 218 km from 135 km, it enhances the coverage of the synthetic aperture plane, particularly at low declinations. The location of the new telescope also provides baselines which link the MERLIN with the European VLBI Network and thus facilitates joint MERLIN–EVN observations.

The prime contractor for the telescope was MAN GHH of Germany. The design was based on that of an existing MAN satcom antenna but significant changes, made in close consultation with NRAL staff, were required to produce a state-of-the art radio telescope capable of working to 50 GHz and beyond. The design of the optics uses the best current practice from around the world. The prime and sub–reflectors are both shaped to optimise the aperture efficiency at L–band and above. A decision was made to mount receivers on-axis; frequency flexibility is achieved by mounting them on a rotatable carousel in the vertex cabin, following the Australia Telescope design. Low frequency ($<$ 1 GHz) operation will be at prime focus; the feeds will be mounted in front of the sub–reflector, following the NRAO design. Sufficient travel is provided in the sub–reflector drive mechanism to place the low frequency feed at the prime focus. The sub–reflector drive mechanism is a complex arrangement, in part based on the design of the IRAM 30m telescope on Pico Veleta. It allows for 0.1mm motions of the sub–reflector in 3–D as the figure of the telescope changes with elevation under gravitational loading and the position of the focus changes.

The telescope is now (November 1990) being commissioned. Following optical measurements and setting by MAN the surface accuracy of the telescope is now $\sim$ 300 microns rms. It is hoped that holographic measurements, using a satellite beacon at 20 GHz, will enable us to reach a surface accuracy of $\sim$ 200 microns rms at the set angle ($\sim$ 30°) and in optimum observing conditions. The pointing accuracy of the telescope in optimum conditions is better than 5 arcsec rms. It may therefore be possible to use the telescope for observations at 90 GHz.

Phase referencing: The sensitivity of the upgraded MERLIN (typically 2–3 mJy per minute per baseline) will enable it to make phase referencing observations routinely. This will enable the coherence time of the array to be increased from a few minutes to 12 hours and more, with a resulting increase in sensitivity of over an order of magnitude. At 5 GHz phase referencing observations, using one of the VLA calibrators, have already yielded interesting astronomical results on a Wolf–Rayet star (Moran *et al.* 1990). However test observations at 1.6 GHz (where the phase changes are dominated by the ionosphere) have shown that the calibration source must be within a few degrees of the target source for succesful phase transfer. We have therefore begun a series of VLA measurements (see Patnaik *et al.*, this volume) to measure the positions of a denser network of calibrators.

## PERFORMANCE

The resolution and the estimated senstivity of the upgraded array at its primary operating frequencies is given in Table I; a 12 hour integration period has been assumed.

TABLE I The Upgraded MERLIN Performance

| Frequency (GHz) | Thermal Noise ($\mu$Jy beam$^{-1}$) | Resolution (milliarcsec) | Jodrell antenna |
|---|---|---|---|
| 0.408 | 210 | 500 | Mk2(25m) |
| | 100 | 500 | Lovell(76m) |
| 1.66 | 50 | 150 | Mk2 |
| | 25 | 150 | Lovell |
| 5.0 | 40 | 50 | Mk2 |
| 22.0 | 150 | 11 | Mk2 |

Note that: i) all Stokes parameters will be observed as a matter of routine. ii) At a given frequency the resolution of the extended MERLIN will be $\sim 6$ times that of the VLA in 'A' configuration. iii) A brightness temperature of 10,000 K corresponds to 400 $\mu$Jy beam$^{-1}$; thermal emission will, therefore, be readily detectable at 1.6 GHz and above. iv) The MERLIN will operate at a single frequency for periods of 6 months or more before changing to another frequency.

## STATUS

Full operation at 5 GHz is expected to begin in Spring 1991. The observing frequency will not be changed during the first nine months of operation. The MERLIN is being operated by Jodrell Bank as a UK 'National Facility'; applications for observing time are considered by a Time Allocation Committee linked with the SERC PATT committee structure. Applications should be sent to the Director, NRAL; the deadlines are September 30 and March 30 each year. For further information contact Dr. T.W. Muxlow (SPAN 19739::TBM; FAX 44–(0)477–71618.)

## HISTORICAL AND PERSONAL NOTES

The MERLIN grew directly out of a series of interferometers conceived and constructed at Jodrell Bank since $\sim$ 1950. In the early days the driving force was undoubtedly Hanbury Brown and with students of the calibre of Roger Jennison and Dick Thompson the intensity interferometer and the 'rotating lobe' interferometer were developed and used for pioneering observations. The idea of what we now call 'closure phase' and the discovery that Cygnus A was a double source were early successes. In the late–1950s and 1960s Henry Palmer led the push to longer and longer baselines. The fact that some of the most intense sources had angular sizes less than a few arcsec led to the search for optical identifications and hence to the discovery of quasars. Henry Palmer it was who first suggested the idea of the MERLIN, following the demise of the 500–foot 'Mark 5' telescope project in the early 1970s. The MERLIN project revitalised Jodrell at a low point in its fortunes. John (J.G.) Davies then played a vital role in the development of the on–line software for the new instrument. Both died prematurely; 'J.G.' in September 1988 and Henry in May 1990. Henry was my supervisor; he was held in great affection by all his students not least because of his endearing love of food in all its guises. When an interferometer was being most irritatingly unreliable he would lighten the mood.. 'Look on the bright side Peter, it'll soon be coffee–time!'.

## REFERENCES

Moran, J. P., Davis, R. J., Bode, M. F., Taylor, A. R., Spencer, R. E., Argue, A. N., Irwin, M. J. and Shanklin, J. D. 1989, *Nature*, **340**, 449.
Thomasson, P. 1986, *Q.J.R.A.S.*, **27**, 413.

**T. Daishido** : Is the proper motion of pulsars you showed obtained by interferometric or timing measurements? Is the origin of the velocity distribution understood?
**Peter Wilkinson**: The motions are measured by interferometric measurements with some of the MERLIN telescopes (at Jodrell Bank), Knockin (60 km away) and Defford (127 km away). The motion is measured with respect to point sources which fall within the primary beam. As for the origin of the velocities, I have no idea!

**Richard Simon**: Is there a smooth connection in baseline lengths between MERLIN and the EVN?
**Peter Wilkinson**: Yes! There is when we include the new 32m at Cambridge.