# Beam-former & Data processing system for the Mexican IPS Array

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Technical Report : **MxA/TR/2k3–02**

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## 1 Introduction :

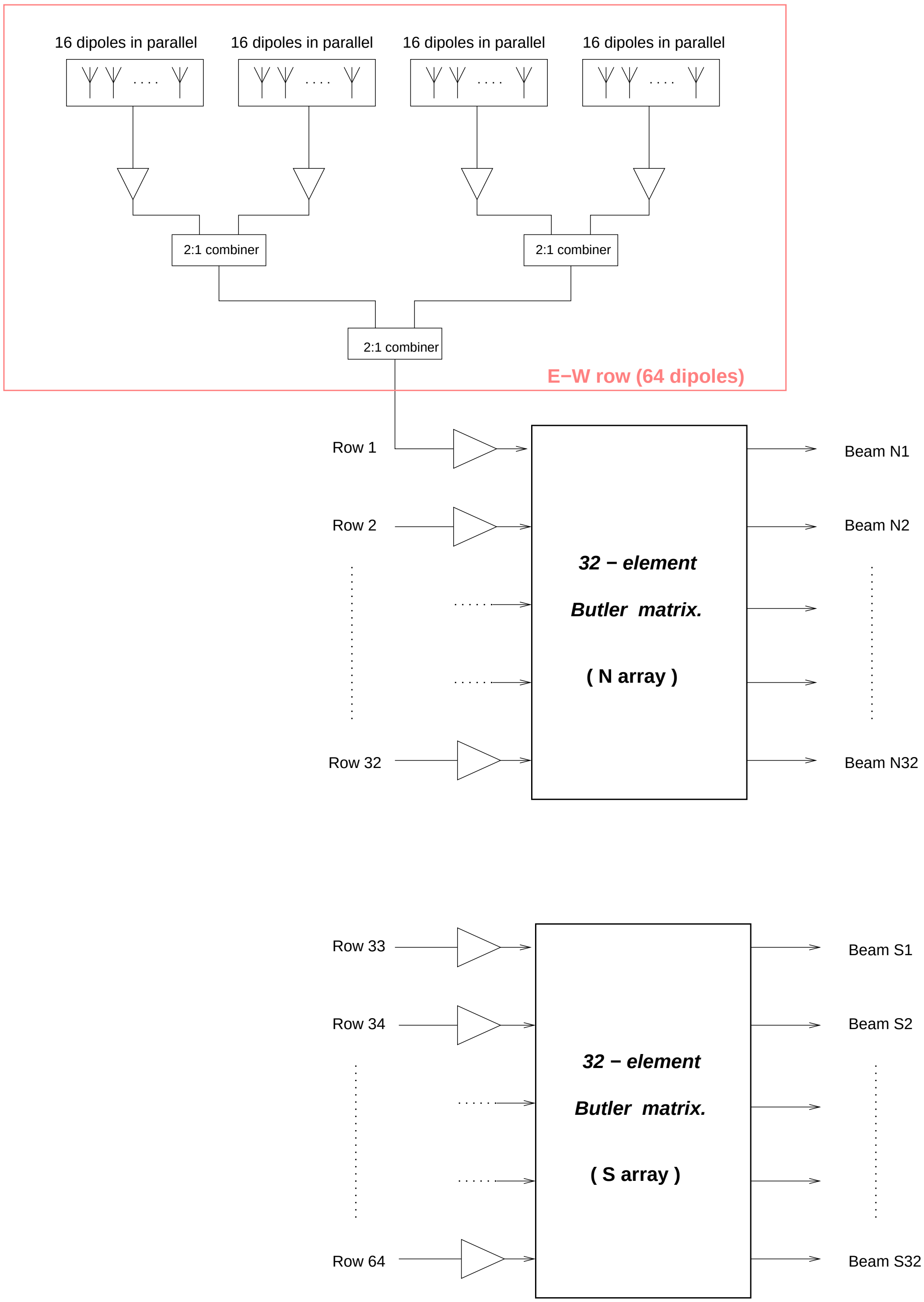
The Mexican IPS array is a planar array comprising of an Ease-West row of 64 nos. of full-wave dipoles and a North-South column of 64 rows. Dipoles are spaced $1\,\lambda$ apart and the E-W rows are spaced $0.5\,\lambda$ apart. The Project document of the Instituto de Geofisica,UNAM,Mexico mentions about Butler Matrices for beam-forming and yet is silent about the data capture/recording/analysis after beam- formation. Fig.1 is a re-drafted block diagram of the UNAM's document.

## 2 Beam-forming Techniques :

Beam-formers are complex networks used to precisely control the phase and amplitude of RF power passing through them. In receiving systems, similar to the Mexican IPS Array, they are constructed between the antenna arrays and the receiver to shape the relative spatial sensitivity of the system to RF signals originating in its field of view. The result is to effectively 'focus' the receiver system on a specific region of space.

### 2.1 Butler–matrix :

In a phased-array construction,similar to the Mexican Array, the Butler–matrix can generate mulitiple simultaneous beams covering a large sector of space. For the same beam-pointing direction, each beam has the gain of a single-beam array of the same size and illumination. A separate beam terminal is provided for each beam of the Butler–matrix output.
This network uses quadrature couplers (viz.,directional couplers that have a $90^\circ$ phase-shift property) and fixed phase shifters. A signal injected at any one of the beam input terminals excites all the radiating elements equally in amplitude with phase differentials of odd mulitples of $\pi/N$, where N is the total number of radiating elements or beam terminals. A Butler–matrix requires $2^{n-1}$ couplers at each of its $n$ levels, where $N = 2^n$. Thus the total no. of couplers will be,


16 dipoles in parallel
16 dipoles in parallel
16 dipoles in parallel
16 dipoles in parallel
2:1 combiner
2:1 combiner
2:1 combiner
E−W row (64 dipoles)
Row 1
Row 2
Row 32
32 − element
Butler matrix.
( N array )
Beam N1
Beam N2
Beam N32
Row 33
Row 34
Row 64
32 − element
Butler matrix.
( S array )
Beam S1
Beam S2
Beam S32

$n \cdot 2^{n-1}$ or
$N/2 \cdot \log_2(N)$ .
For a 32- element matrix of Mexican array, $n = 5$ and 80 nos. of quadrature couplers will be required.

## 3 Beam-forming + Acquisition :

Here, a balance is struck between the conventional anlog method with the modern DDC blocks. Fig.2 shows the overall block diagram. As conceived earlier, two Butler matrices of 32 -element each are employed. The complexity of building a 32-element matrix is minimised by selecting off-the-shelf products, as illustrated in the following section.

- North and South array Butler matrices are the first blocks. The dipoles rows 1 to 32 form the inputs to the N-array matrix, while rows 33 to 64 are the inputs to S-array matrix.

- The 32-beam simulataneous beams are coupled to a RF switch, such that any one beam from N-array and another from S-array can be correlated. The 32-to-1 RF switch is the 2nd block. The switches are interfaced with a Fibre-optic Receiver to facilitate beam-selection. Based on the Mex.Array site's topogrphy, the Fibre-optic Receiver was chosen; an RF interface will require amplifiers/IF mixers.

- The selected beam-output from the switch is band-pass filtered next; a pair of filters are required.

- Through a low-loss RF cable the beam outputs are brought to the Rx/Control room.

- A combined block of DDCs and DAS, follows next; The device identified for this DDC operation is a Dual Channel (analog inputs) Reconfigurable Digital Receiver – Model 304 FlexReceiver PMC of Red River Inc.,TX.. The architecture features a dual channel digitizer tightly coupled to a Xilinx FPGA and a PCI Bus Master supports 64-bit ( 66 MHz) data transfer.

  If we were to implement this, an additional IF block must be introduced in Fig.1 - between the BPF and DDC blocks. Since this device/ card handles a maximum data sampling rate of 105 Msps, a down-conversion from 140 MHz to less than 50 MHz is mandatory.

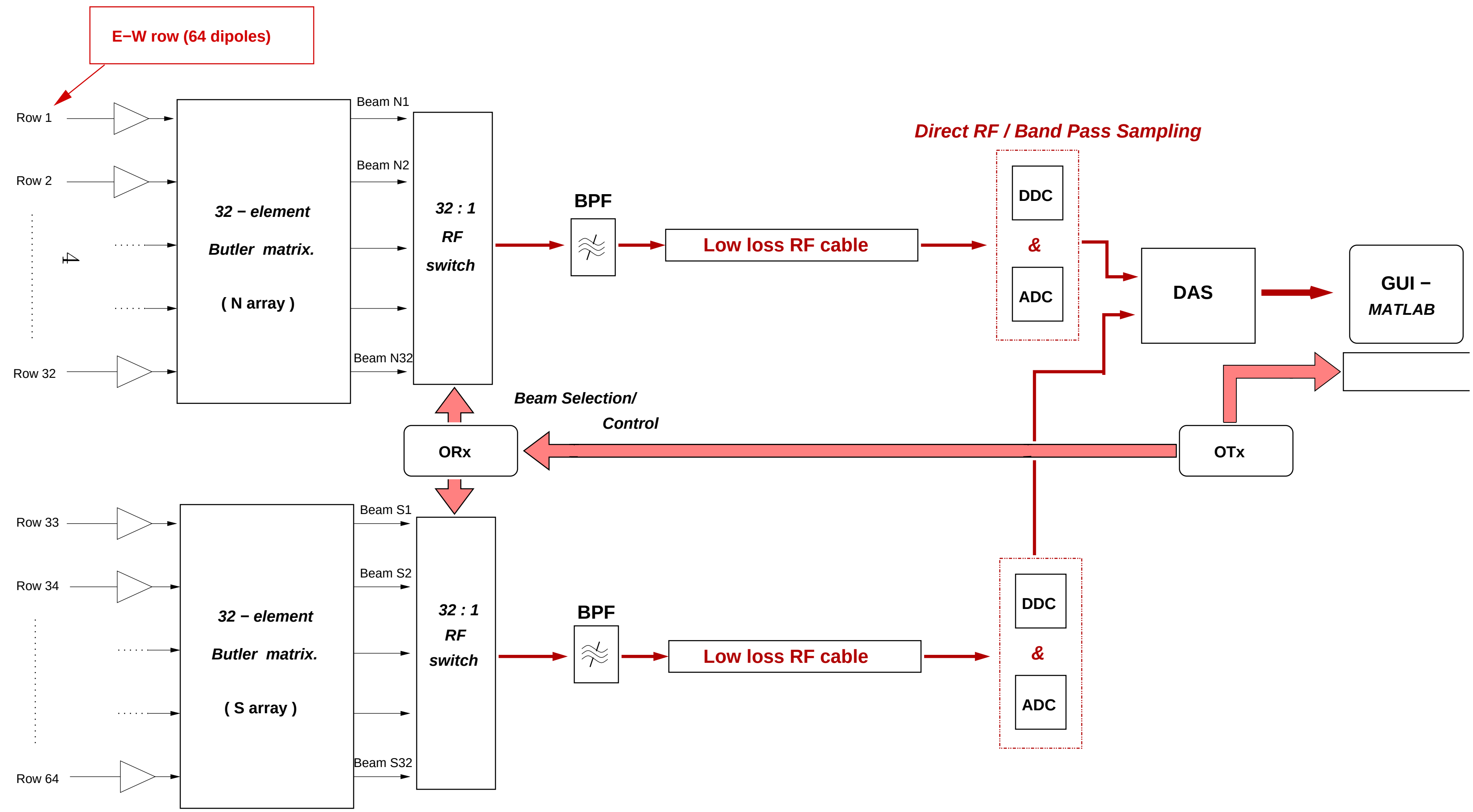



**Fig.2 Analog Beam Forming Scheme for Mexican IPS Array.**

- PC + MATLAB is the final block. Beam selection/control info. is passed on to a Optical Transmitter. Data acquisition is simpler from the PCI bus outputs of the FlexRx.PMC 304 card.

- A plastic fibre to link the OTx and ORx circuits. The length of fibre can be ~ 200 m. and 1310 nm. wavelength will be used for communication.

# 4 Butler Matrix Construction :

The 32-element Butler matrix will require 80 nos. of quadrature couplers and 64 nos. of fixed phase-shifters, as shown in Fig.3. Passive Quad.couplers are available which can be soldered to a PCB. MACOM's JHS-121 is one-such coupler. Similar PCB-mountable phase shifters (like trim pots) are also available - viz., Merrimac's PSS-2B Series. The Ref.links as indicated by '0' phase-shift in Fig.3 can be custom-made by semi-rigid cables of equal electrical length and 64-nos. of coaxial connectors (SMAs/N-type) would complete one full-matrix for 32 elements.

The required beam formation can be easily realised as per the above construction plan, since reliable products are identified and minimal help is required from skilled-technical hands while fabricating the unit.

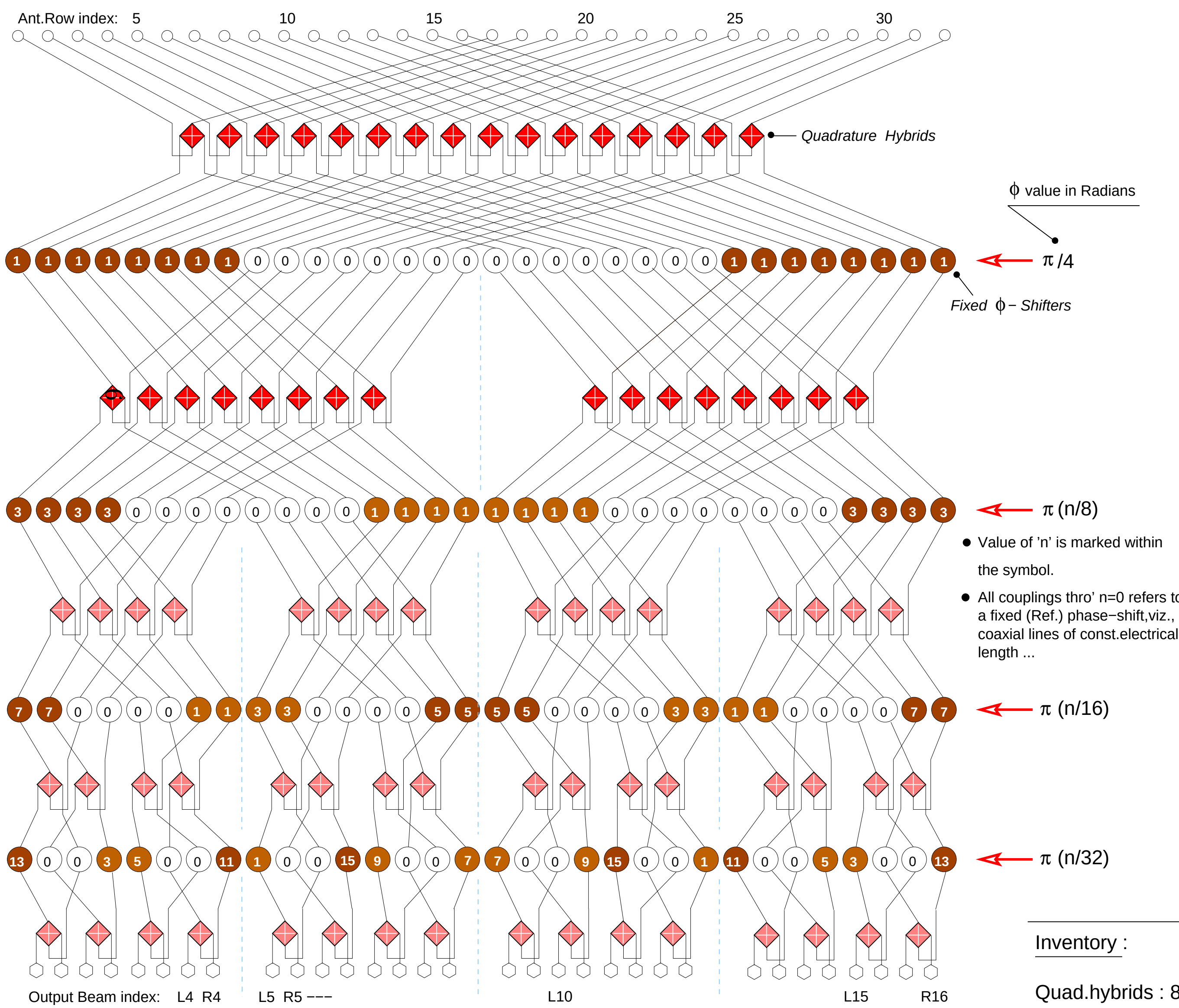
## 4.1 Cost Estimates :

Refer Fig.2. The cost for a single Butler matrix must be estimated first.

`32-element Butler matrix` - Components

| No. | Functional Blocks | No.of units | Cost/ unit | Net Cost |
|---|---|---|---|---|
| 1 | Quad.couplers | 80 | 10 $ | 800 $ |
| 2 | Fixed phase shifters | 64 | 5 $ | 320 $ |
| 3 | Connectors | 128 | 7 $ | 896 $ |
| 4 | Semi-rigid cables | 64 | 1.5 $ | 96 $ |
| 5 | PCB,Chassis,Misc. | — | 200 $ | 200 $ |
| 6 | Labour,Overheads etc. | — | 1150 $ | 1150 $ |
| | Total cost | | | 3462 $ |

Coming back to the overall system,




Inventory :

Quad.hybrids : 80 Nos.

Phase shifters : 64 Nos.

**Fig.3 32−Element Butler Matrix.**

| No. | Functional Blocks | No.of units | Cost/ unit | Net Cost |
|---|---|---|---|---|
| 1 | Butler Matrix | 2 | 3462 $ | 6924 $ |
| 2 | RF switch blocks | 2 | 130 $ | 260 $ |
| 3 | BPFs | 2 | 10 $ | 20 $ |
| 4 | Low-loss RF cable | 2 | 600 $ | 1200 $ |
| 5 | Accessories of (4) | 1 | 670 $ | 670 $ |
| 6 | DDC+DAS+Software | 1 | 6500 $ | 6500 $ |
| 7 | Fibre,OTx,ORx | 1 | 200 $ | 200 $ |
| 8 | Labour,Overheads etc. | — | 5000 $ | 5000 $ |
| | Total cost | | | **20774 $** |

The above figure takes into consideration that the Butler matrices and the back-end electronics would be fabricated,tested and installed at Mexico itself. (*If it were to be fabricated at India, the cost of packing,insurance and air-cargo charges are to be taken into account*).Similarly the cost of air-travel of either Mexican/Indian Engineers is **not** considered.

## 5 Project Schedule :

The table below shows the tentative schedule of building and commissioning the Butler matrices and back-end electronics systems at the Mexican IPS Array.

| No. | Jobs | Time(in Weeks) |
|---|---|---|
| 1. | Procurement of Components,devices etc. | —(10)— |
| 2. | Wiring,testing & Assembling | —(5)— |
| 3. | DDC testing,coding & installation | —(10)— |
| 4. | Integration of subsystems | —(4)— |
| 5. | Commissioning tests | —(4)— |

On the whole, this work would take 28 weeks, i.e. 7 months from the start.Any unforeseen delays could make it extend upto 30–32 weeks.At the end of this perios the IPS Array should be ready for test observations by any radio astronomer, with the active backup of the trained technical team of UNAM,Mexico. As shown in the table above the Mexican team will involve in all activities of Sl.No.3 onwards.

## 6 Future improvements :

Arrays employing **digital beam-forming** has a distinct advantage of multi-functionality with programmable interfaces while compared to analogue methods. All the amplitude and phase-shifting functions, as well as beam-forming are done digitally. True time-delay for steering the beam can also be implemented. This technique offers a single beam which can be steered to any region on the celestial sphere (for Mexican Array).

Yet the hardware components increases in numbers (even discarding the Butler matrices,RF switches and Optical beam-selection blocks as shown in Fig.2) so that the Project cost will increase by a factor of 5 or more.
The key advantages despite the high costs are:

- There would be no 'blind-spot' regions on the celestial sphere; the beam can scan in all possible directions.

- Any interfering signal can be filtered out by pre-computed positioning of the nulls along the interfering signal's propagating direction.

- Multiple-beam operations are achievable with **no** additional hardware; the FPGA-part of the DDC card (viz.Model 304 – FlexReceiver PMC) can be reprogrammed such that any desired numbers of simultaneous beams can be generated and data acquired.

The usefulness of the array can thus be extended further if one goes the digital way at a later stage.

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