
You can't design what you can't conceive
- Bob Frater's Theorem
What can we learn from history?


You can't design what you can't conceive
- Bob Frater's Theorem
What can we learn from

Summary

- How do the multidisciplinary knowledge and skills come together under a "system thinker" to produce something so far ahead of its time?
- I consider the work of some of the radio astronomy pioneers
- I look at the environment in which they produced breakthrough ideas
- overwhelming conclusion:
- ***similar conditions must have existed at the time the Antikythera mechanism was devised and built***

Formation of Australia's Radio Astronomy Group after WW2 in 1950

- Part of CSIR (now CSIRO) under the then chairman Sir David Rivett
  - *"The famous Rivett philosophy was to determine the field of study that you want to do, find the best man in the world you can get to lead the group, and then give him his head."* - Paul Wild
- Radiophysics was led by (Edward) Taffy Bowen
  - Established a Radio Astronomy group led by Joe Pawsey
  - Pawsey was an absolute believer in the Rivett philosophy
- Radiophysics became a major Radio Astronomy centre housing some great pioneers in the field
  - Along with the UK and Netherlands

The Backgrounds of Those in the new Radio Astronomy Group

- Degrees in physics, mathematics and engineering
  - No astronomers
- A variety of wartime and early post-war roles
  - Radar development
  - Operational navy radar
  - Communication antennas - AWA
  - air navigation
  - early computing
- Breadth of experience and training allowed cross fertilisation

The Radiophysics culture

- Joe Pawsey – a key player in Radiophysics
- The group had developed a can-do, must-do attitude during their WW2 development of radar
  - This carried over into the radioastronomy era and beyond as the people moved on to other roles
  - Pawsey was very much part of this – a proponent and practitioner of the need for System thinking and Physical understanding

System thinking and Physical understanding

Pawsey understood the need for people who can think at both the system level and the component level so that they are able to work from the system level to detailed design and component assessment

He knew that without that you can't subdivide a big system into parts that will integrate properly later

And so to Frater's theorem-

You can't design what you can't conceive

(*Feynman had strong views in this space*)

What are the Ingredients for Success in bringing new ideas to fruition?

- An existing or emerging need- ***necessary***
- A champion ***- necessary***
  - Someone with fire in their belly and a clear view of the goal
- Mentors ***- desirable***
  - People providing example and guidance
- A supportive environment ***- desirable***
  - Availability of necessary resources – material and intellectual
  - People with system thinking ability and physical understanding
- A sponsor ***- desirable***
  - Someone in a position to help who appreciates and supports the goal

There are, of course, many examples of people who have succeeded "against the odds"

The Astronomers

- Chris Christiansen
  - Design of Rhombic antennas
  - 2D images of the Sun through Rotational Synthesis
- Bernie Mills
  - Positioning nulls on interfering sources in his interferometer to reduce confusion
  - Concept of Cross
- Paul Wild
  - Mechanism of solar bursts
  - H line in the solar bursts
- Ron Bracewell
  - Transform concepts
  - Seeing the Pott's Hill scans as convolutions

This first four all cited Joe Pawsey, a true system thinker, as a mentor

- Hanbury Brown and Richard Twiss
  - Post-detector correlation

All had aspirations beyond the technology of the time

They were able to conceive their new analysis, approach, design

An observation

- My mentors and their mentors had the capacity to hold and manipulate a complex image or concept in their head. They were “System thinkers”
- They had the authority to implement decisions flowing from their deliberations on these concepts and were not blocked by people who were unable to grasp the broader issues
- They contributed to my and others’ development by their advice, encouragement and their maintenance and defence of those aspects of the work environment necessary for the development of new leaders

Joe Pawsey's leadership and mentoring - 1

- Bernie Mills comments capture other key elements of the Pawsey approach:
  - *"Joe Pawsey was in charge of the general development . . . . .work and I learnt a great deal from him. He was always available . . . . I attended a short course of lectures which he gave on transmission lines and antennas which was a real eye-opener. The highly mathematical approach to which I had been exposed during my last year in Engineering was replaced with a physical understanding . . . . . . which stood me in good stead thereafter."*

Joe Pawsey's leadership and mentoring - 2

- Ron Bracewell worked with Pawsey before going to Cambridge in 1946 to study with Ratcliffe, Pawsey's PhD supervisor, who stimulated his interest in the Fourier Transform. He returned and worked with Pawsey's group.
  - Pawsey asked him to be coauthor of the book ***Radio Astronomy (1955)*** and Bracewell surmised that this was partly a device to get him more interested in the subject. Pawsey also asked him to produce a pictorial dictionary of Fourier Transforms, which later led to Ron's most important book, "***The Fourier Transform and its Applications***".

The Ideas that come from my Mentors

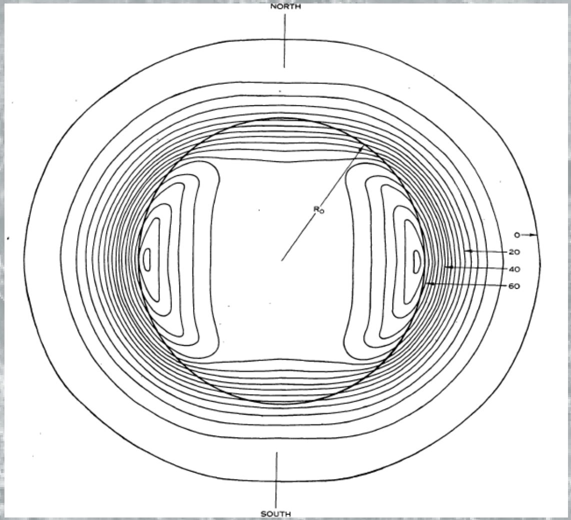
- Each of these people came up with ideas and solutions that required them to step outside simple problem solving approaches and bring together concepts, analysis and technology
- All were stimulated by those around them and by their work environment
- To have a real appreciation of achievement, we must think of these examples against the backdrop of the technology of the time – key ideas came up way before the modern “solid state devices” era and years before the zero point of Moore’s Law
- The examples I’ve chosen were **big** steps at the time

Christiansen
1955

- Conceived an approach to 2D images of the Sun
  - Understanding of properties of a grating array where you get 1D scans of source as it drifts through successive lobes
  - Recognising that the angle of the scan changes with the rotation of the Earth
  - Recognising that the angle of the scan changes with the rotation of the Earth
  - Understanding that a 2D image could be recovered from drift scans of the sun as the earth rotated

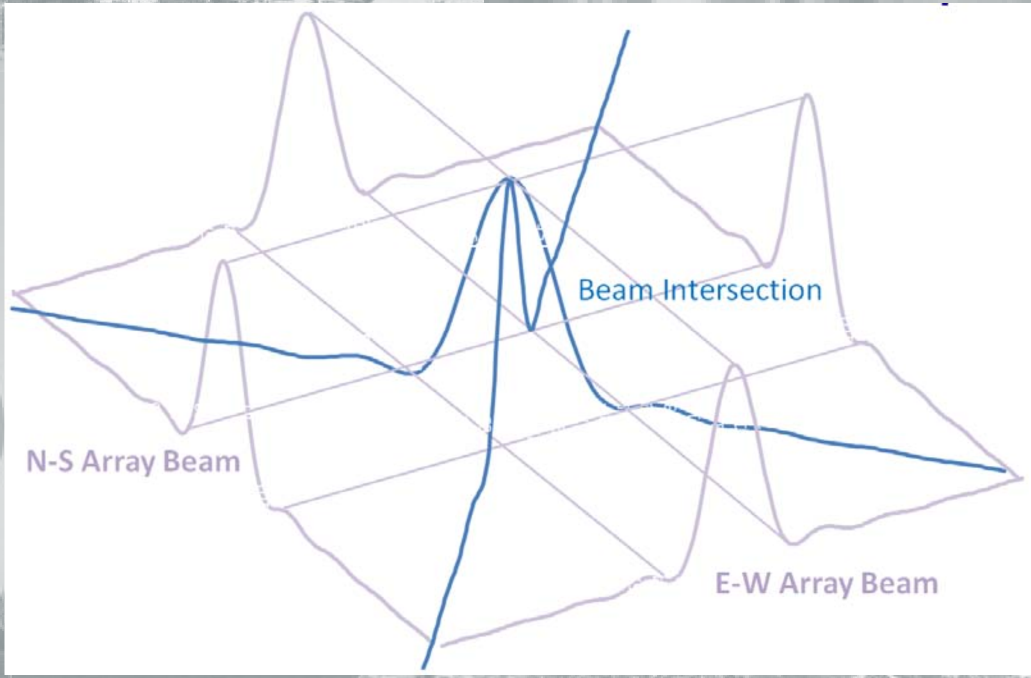
Christiansen
1955

- *"The way in which a 2D radio brightness distribution may be derived from a number of 1D scans is not obvious. However rather similar 2D problems have arisen in crystallography and solutions for these problems, using methods of Fourier synthesis have been found"*
  - Chris then takes the 1D FT of each strip, combines these radial distributions in Fourier space, reweights and does a 2D FT to form the 2D image



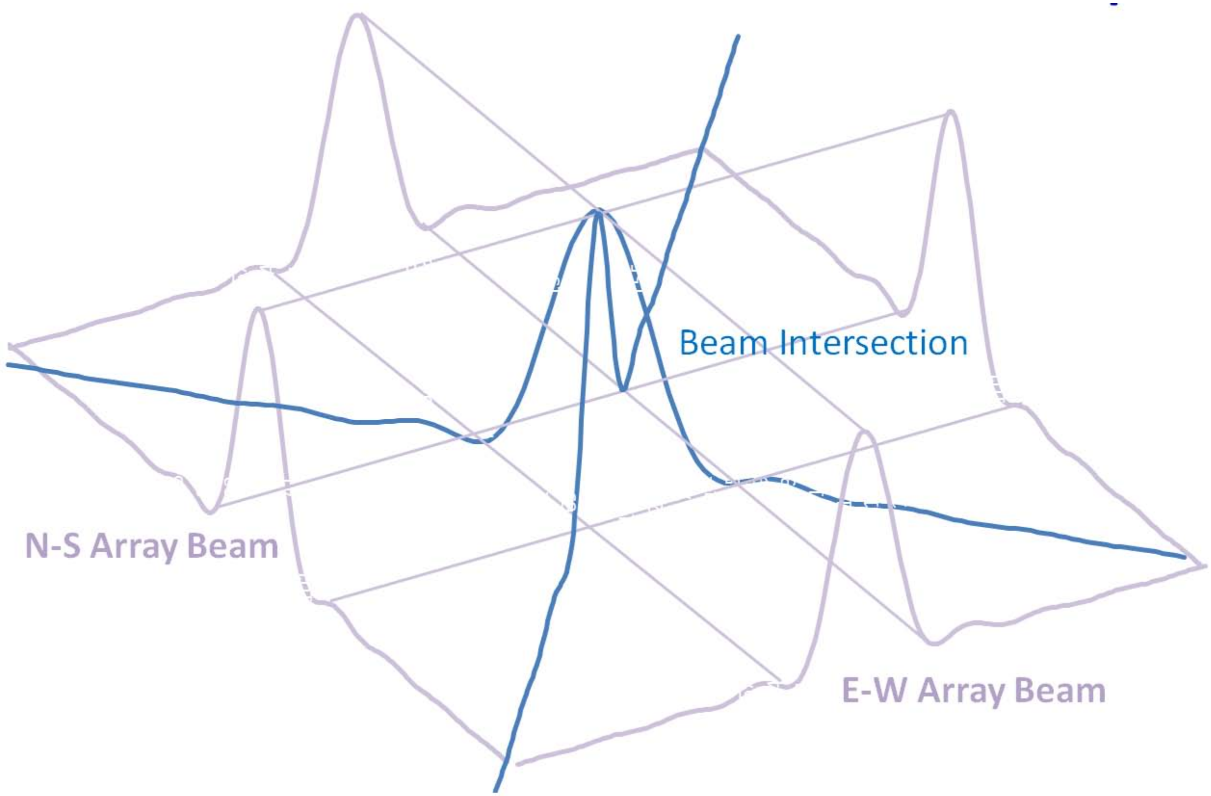
Bernie Mills
1953

- Concluded (correctly) that by positioning nulls on interfering sources in his interferometer work he could reduce the confusion that plagued the early Ryle observations in Cambridge
- Conceived of a Cross having a pencil beam corresponding to the overlap of the fan beams
- First catalogue of southern radio sources



The Mills Cross Concept

Question: How do you obtain the information in the fan beam overlap area?



Answer: Multiple the signals from the two arms by phase switching one, adding them and passing them to a square law detector:

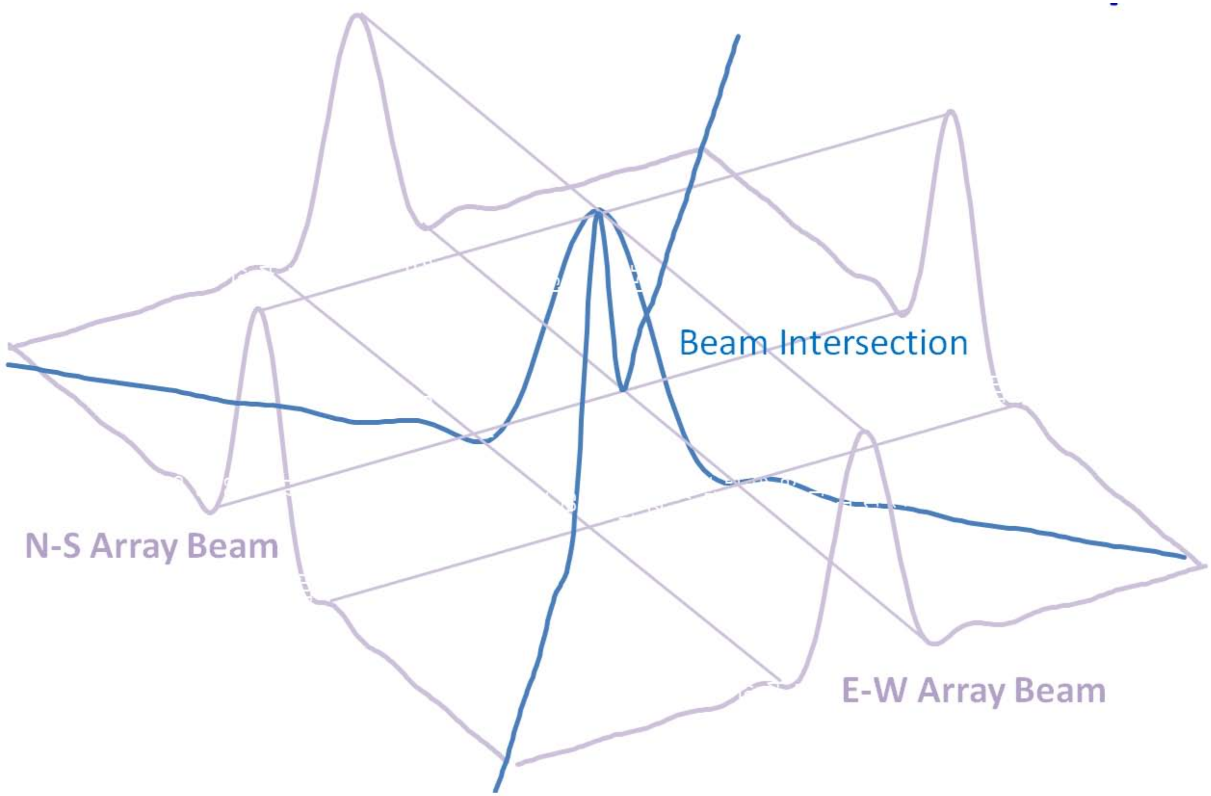
$$((E\text{-}W) + (N\text{-}S))^2 = (E\text{-}W)^2 + (N\text{-}S)^2 + 2(E\text{-}W)X(N\text{-}S)$$

This component appears as a square wave that can be demodulated to obtain the product.

The squared components add noise

The Mills Cross Concept - 2

Question: How do you obtain the information in the fan beam overlap area?



Answer: Multiple the signals from the two arms by phase switching one, adding them and passing them to a square law detector:

$$((E\text{-}W) + (N\text{-}S))^2 - ((E\text{-}W) - (N\text{-}S))^2 = 4(E\text{-}W)X(N\text{-}S)$$

This component appears as a square wave that can be demodulated to obtain the product.

The squared components cancel – reducing noise

Paul Wild
1965

- Conceived the use of dynamic spectra as a path to understanding the physics of solar bursts leading to the now accepted classification
- The circular array heliograph – a radio-frequency simulation of an optical device

Kevin Sheridan’s footnote: The good thing about a circle is you can’t extend it

Bracewell
1955

- Conceived the mechanism of the Pott's Hill scans as being convolutions:
  - explained the scanning of a source by an antenna as a convolution of the brightness function and the point-source response of the antenna. By using the convolution theorem it was clear that in the process the Fourier components of the source profile are filtered by the Fourier spectrum of the antenna response.
- Showed the transform relationships involved in reconstructing two-dimensional images from one-dimensional scans
- Concept of the "aerial smoothing" and the "principal solution"(with Jim Roberts)
- Pawsey's promptings for a pictorial dictionary of transforms led to his classic book (1965)

Hanbury Brown (with Richard Twiss)

- Conceived the principles of the intensity interferometer - Post-detector correlation
  - Successfully demonstrated it in a climate of absolute disbelief using search-light mirrors to observe Sirius
  - Hanbury constructed the Stellar Interferometer in Narrabri and measured 32 stellar diameters over an eight year period (Hanbury Brown, Davis, Allen 1973)
  - Now commonly used in quantum optics as the HBT effect

A couple of my own examples

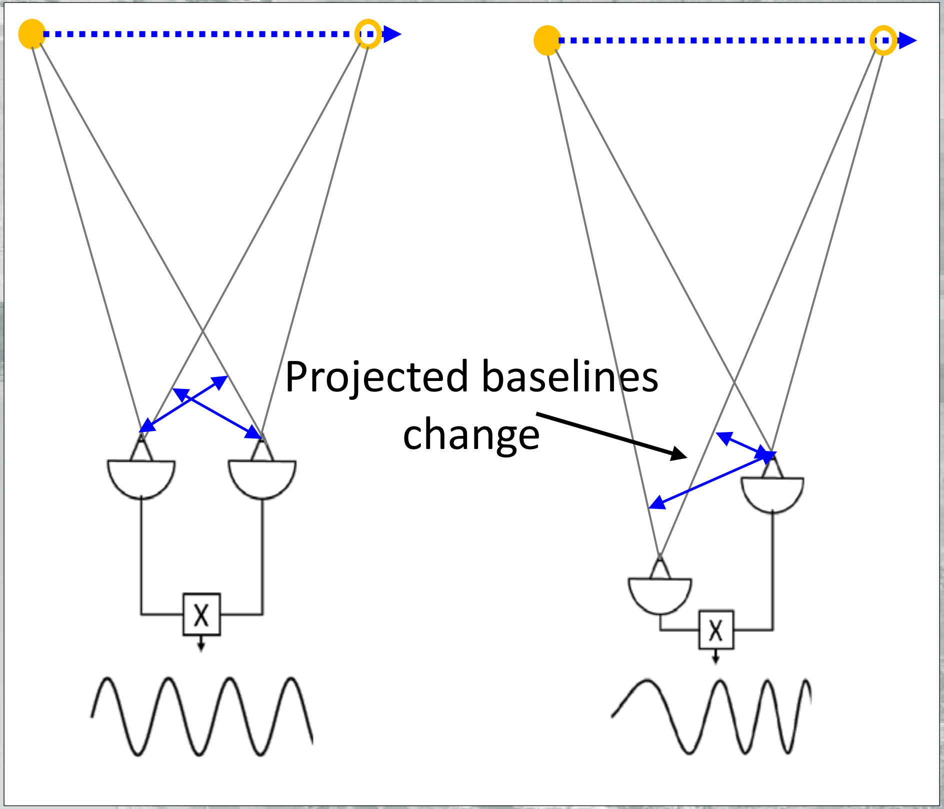
Both examples represent “physical understanding” influenced by my mentors and bring together ideas from different areas

- Representing 3D data in 2D
  - A convolution approach for reducing 3D data to 2D
  - Came from applying modulation theory to “spatial” frequencies
- The ColFet
  - An active circuit that looks like a cold resistor
  - Came from a confronting system realisation and the application of bipolar transistor analysis approaches to a FET circuit

- Both are the product of having had the opportunity to work and gain experience across a large system

Representing 3D data in 2D

- Off E-W spacings give frequency change across field as the projected baseline changes
- This is Frequency Modulation and the off-axis spacing can be represented by a central on-axis spacing with the equivalent of FM sidebands
- A convolution function can be derived to achieve this



The ColFet

It suddenly dawned on me that if we have a low noise amplifier with a matched resistive input, the input resistance must look "cold".

In an approach developed with FET amplifiers, an inductor was used in the source lead of the FET. The input capacitance (capacitive reactance) of the FET effectively gave it a complex current gain so that the impedance seen at the input was this current gain times the inductive reactance - resistive.

This resistance was produced entirely by reactive components so that no noise was contributed other than from losses and intrinsic resistances in the FET itself. The input impedance looked like a cold resistor.

And after me . . . . .

- I always tried to teach with a combination of a "physical understanding" approach and a more formal analytical approach.
- I carried this across into the research arena and in the way I operated in Radiophysics
- I've seen it carried on by those I taught

- For the future?

And after me . . . . .

- I always tried to teach with a combination of a "physical understanding" approach and a more formal analytical approach.
- I carried this across into the research arena and in the way I operated in Radiophysics
- I've seen it carried on by those I taught
  - Tasso Tzioumis
  - David Skellern
  - John O'Sullivan
- For the future?

The Ancients!

- The environments I have described must have existed in various places in the ancient world
- In the era before printed books, places like the Library of Alexandria must have played a critical role in the dissemination of the knowledge of the time
- Something like the Antikythera mechanism was not the product of an individual working in isolation
- Let’s look at the background science of the era

The Ancients

Thales of Miletus. **~585 BCE**	Predicted solar eclipse 28 May 585BC
Aristarchus of Samos **310-230 BCE**	Deduced that the Sun was larger than Earth and that it's the Earth that's moving
Eratosthenes of Cyrene **275-192 BCE**	Method to calculate prime numbers Calculated circumference of the Earth
Hipparchus of Nicaea **162-128 BCE**	Discovered precession of the Earth Calculated the distance of the moon
Antikythera designer **~100 BCE?**	Integrated understanding of work of Thales, Aristarchus, Eratosthenes and Hipparchus, levers and waterwheels into a new mechanism?

The Ancients timeline

		600-	500-	400-	300-	200-	100-
Thales of Miletus.	solar eclipse 28may585						
Democritus of Abdera	atoms						
Hippocrates of Cos,	physician						
Aristotle of Stagira	Logic, Student of Plato						
Euclid	Mathematician						
Aristarchus of Samos	It is the earth that is moving! - size of the Universe						
Archimedes of Syracuse	"Archimedes Principle", Pi, Levers, War Machines						
Eratosthenes of Cyrene	Prime numbers and circumference of the Earth						
Hipparchus of Nicaea	Discovered precession an calculated the distance of the moon						
Library of Alexandria	Major centre of scholarship in the ancient world						

Antikythera Mechanism

What are the lessons?

- My mentors and their mentors had the capacity to hold and manipulate a complex image, concept in their head. They were "System thinkers"
- They had the authority to implement decisions flowing from their deliberations on these concepts and were not blocked by people who were unable to grasp the broader issues
- The Antikythera Mechanism is surely an example of this!

The Future?

- The Radiophysics environment and those following from it were excellent ones for allowing new ideas to blossom
- Similar situations existed in many other places – other radio astronomy groups, Bell labs etc.
- Something similar must have existed for the Antikythera mechanism to be developed
- Are we working to have such environments exist in the future?
- Are we identifying and developing the next generation of “system thinkers”?
- How do we protect our system thinkers in the future in an increasingly bureaucratic world?