
You can't design what you can't conceive
A Theorem
What can we learn from history?

My mentors

- I have been greatly honoured to be a co-author on the memoirs of a group of pioneers who were my mentors
  - **Chris Christiansen**
  - **Bernie Mills**
  - **Paul Wild**
  - **Ron Bracewell**
- **Hanbury Brown** was another key mentor
- It has provided a great opportunity to ponder on the factors that contribute to success
- Today, I am considering the work of these people and some other mentors and look at the environment in which they produced breakthrough ideas
- I look at the benefits that flowed through for radioastronomy and to me as an individual.

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

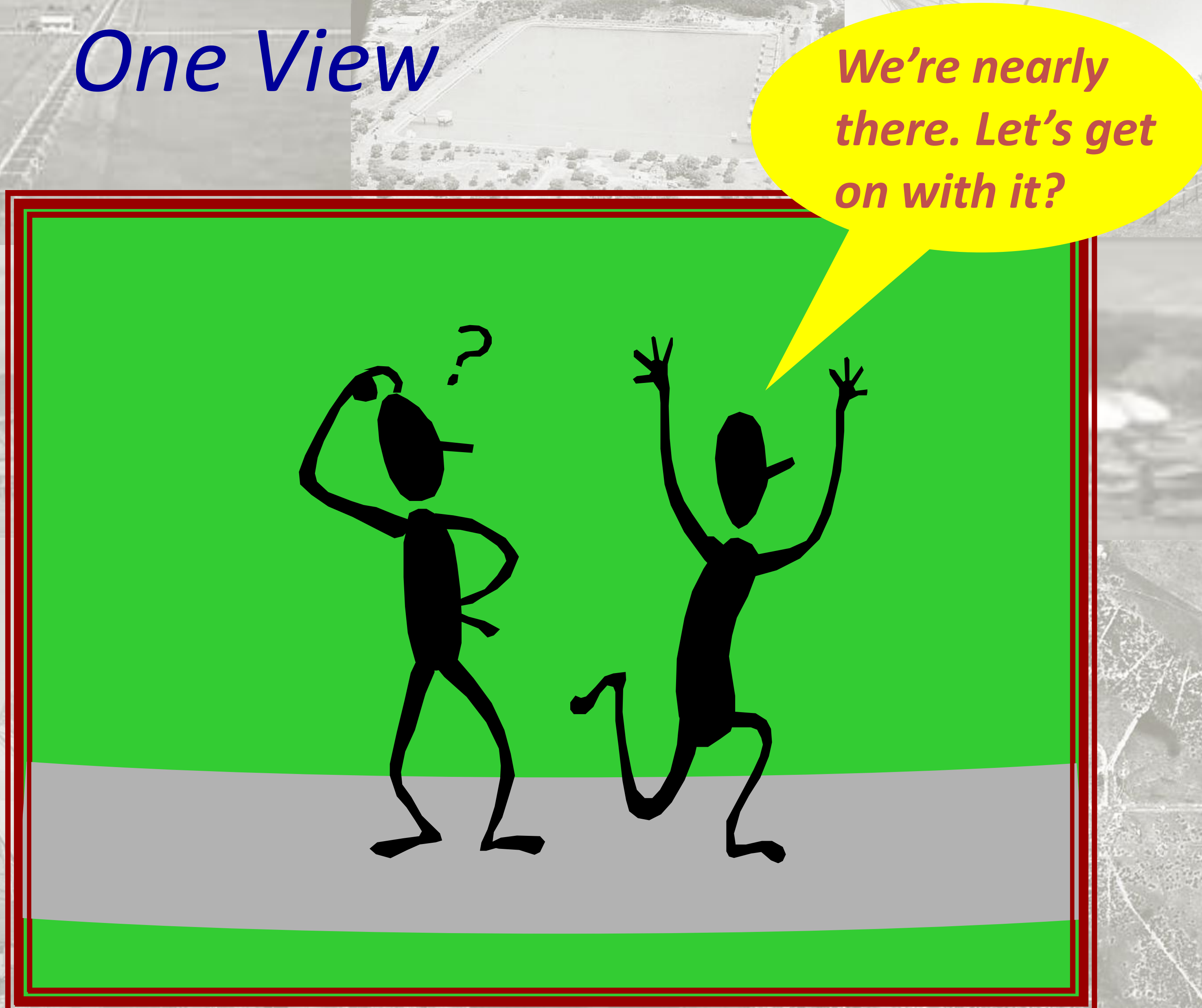
To have all of these is a great gift

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

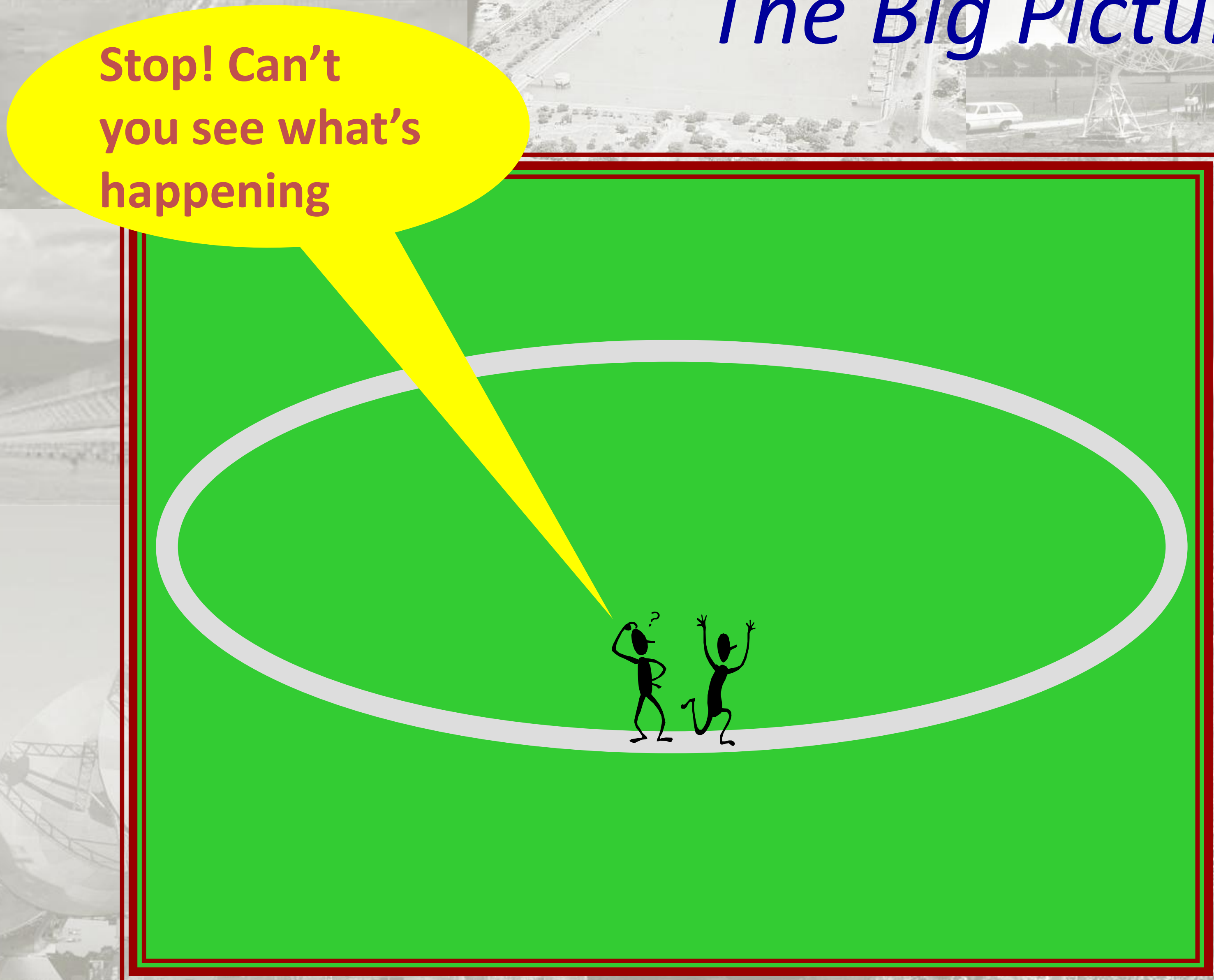
Other key ingredients

- Physical understanding
  - A feeling and sense of "how things work"
- System thinking
  - The ability to comprehend the complexities of the system or situation
  - Seeing the Big Picture
    - We all know people who can't see beyond the next step. . . . .

One View



The Big Picture!



The Radiophysics Division after World War 2

- 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
  - Joe was an absolute believer in the Rivett philosophy
- Radiophysics became a major Radio Astronomy centre housing some great pioneers in the field

The Backgrounds of Those in the new Radio Astronomy Group

- Degrees in science and engineering
- 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

Joe Pawsey - A key player in Radiophysics

- A great leader, described by Chris Christiansen as a man in the mould of David Rivett, the first Chief Executive then Chairman of CSIR mentioned earlier.
- The Radiophysics culture
- 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
  - Joe was very much part of this – a proponent and practitioner of the need for System thinking and Physical understanding

System thinking and Physical understanding

Joe understood the need for people who can think at both the system level and the component level

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

And so to my theorem-

You can’t design what you can’t conceive

(*Feynman had strong views in this space*)

Some of my Mentors
– From Electronics and Astronomy

- Electronics and Electroacoustics
  - Ron Aitchison - Sydney Uni EE - Electronics
  - Cyril Murray - Sydney Uni EE - Electronics

  Ron and Cyril were involved with the Molongolo Cross

  - Neville Thiele - ABC - Electroacoustics
- Radioastronomy
  - Christiansen - Sydney Uni EE
  - Paul Wild - Radiophysics
  - Bernie Mills - Sydney Uni Physics
  - Ron Bracewell - Stanford – frequent visitor to Sydney Uni Physics
  - Hanbury Brown - Sydney Uni Physics

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**
  - Swept frequency machine at Penrith –
  - classification of solar bursts
  - H line work
- **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** (with Richard Twiss)
  - Post-detector correlation

All had aspirations beyond the technology of the time

They conceived practical approaches to analysis and 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

Contributions from Astronomy

Astronomy has contributed strongly to wide areas of modern technology

- For example:
  - Telecoms – Paul Vanden Bout's paper,
  - DSP – Fourier transform work
  - medicine - rotational synthesis to CAT scans?
- Makes a strong argument for "Open Innovation"

Joe Pawsey's leadership and mentoring - 1

- Chris came in from antenna development in AWA to a senior role in Radiophysics. Joe rapidly made him lead researcher for the solar research program. His own practical approach made for easy communication with Joe and he strove to emulate him in his own career.

- 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

- After a year in Radiophysics Paul Wild was delighted to be able to join Pawsey's group and was given the task of developing a solar spectrograph:
  - "Joe just provided ideal conditions, an ideal environment to allow everyone to use their own initiative".
- 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 contributions of my Mentors

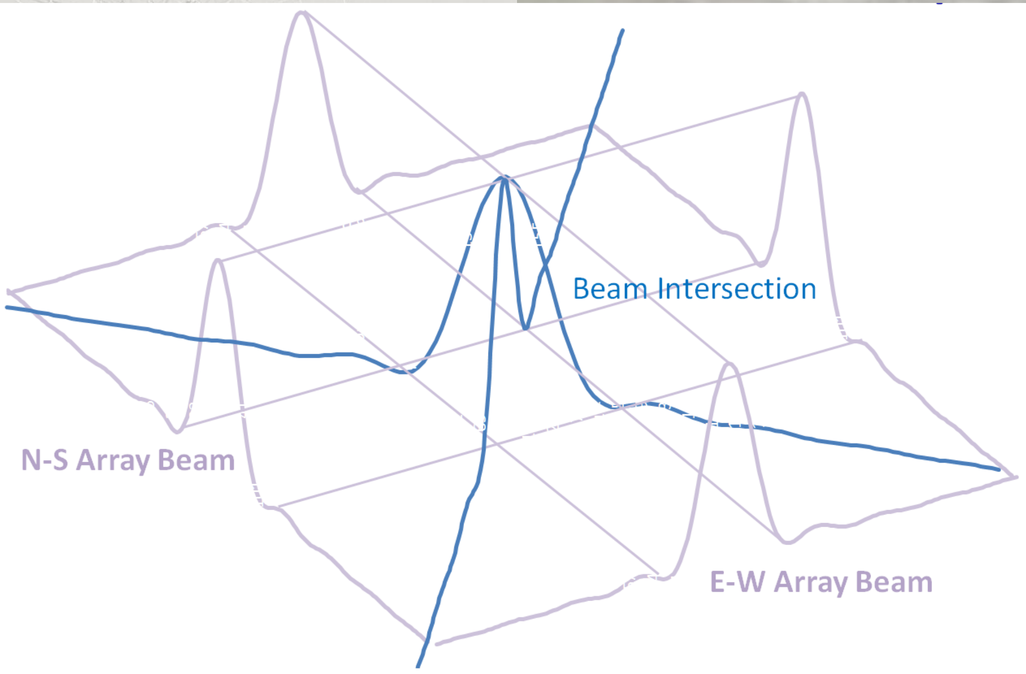
- Each of these people came up with ideas and solutions that required them to step outside simple problem solving approaches and bring together concepts, analysis and technology
- All were stimulated by those around them and by their work environment
- We view these examples against the backdrop of the technology of the time – way before the “solid state devices” and “microchip” eras and years before the zero point of “Moore’s Law” and not that measurement techniques and equipment were very basic
- The examples I’ve chosen were **big** steps at the time

Chris Christiansen

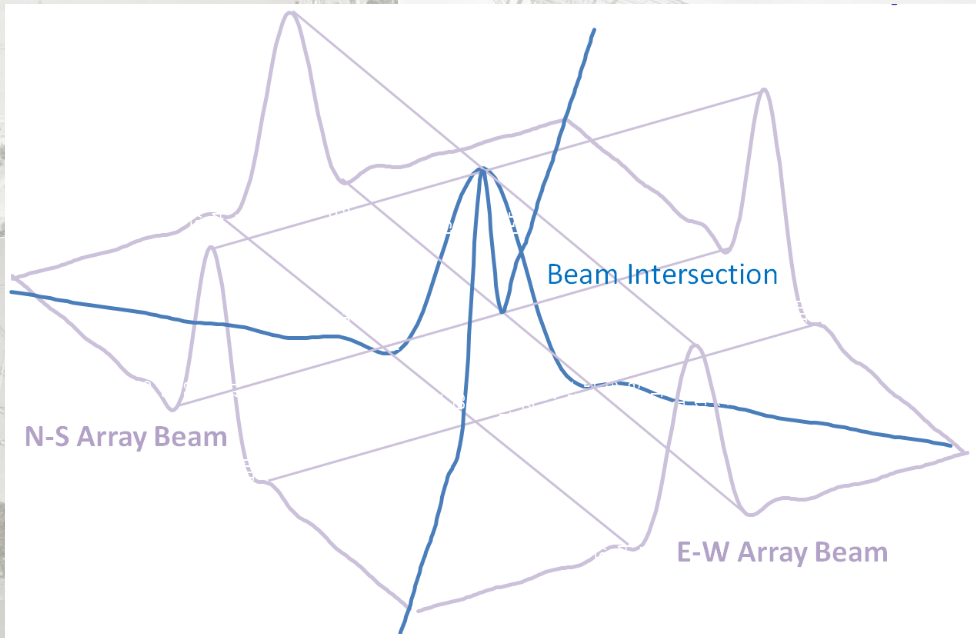
- Conceived ways to formalise and extend the design of Rhombic Antennas for telecommunications in the AWA Beam Wireless section – the fore-runner of Overseas telecommunications Commission (OTC)
  - *As a young engineer in OTC, I used his design approach*
- After observations of two solar eclipses during sunspot activity in 1948, Chris saw the need for regular observations of the sun and developed the grating array at Pott's Hill for this purpose
- Conceived an approach to 2D images of the Sun
  - *Understanding of properties of a grating array where you get 1D scans of a source as it drifts through successive lobes*
  - *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*

Bernie Mills

- Concluded (correctly) that by positioning nulls on interfering sources in his interferometer work he could reduce confusion
- Conceived of a Cross having a pencil beam corresponding to the overlap of the fan beams achieved by multiplying the two beams



The Mills Cross Concept



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

1. Phase switch the signal from one arm
2. Pass the sum and difference of the two arms to square law detectors
3. Subtract the outputs of the detectors and demodulate

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

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

The squared components cancel – reducing noise

Paul Wild

- Conceived the use of dynamic spectra as a path to understanding the physics of solar bursts leading to the now accepted classification system
- H line in the solar bursts
  - Paul suspected that there were spectral lines in the solar bursts they were observing, became interested in the radio spectrum of hydrogen and wrote an internal report.
  - After the Ewen and Purcell 21 cm line detection in 1951, Paul generalized his report to include the hyperfine structure of hydrogen, and
  - Paul published the first detailed theoretical paper on the hydrogen lines – a classic in the field.
- 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

- Conceived the mechanism of the Pott’s Hill scans :
  - 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)
- Followed Pawsey’s promptings for a pictorial dictionary of transforms to write his classic book

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

Where do I come in?

- I had worked at AWA, OTC - our overseas Telco of the time and Ducon. At AWA and Ducon I worked on radio and TV design.
- I was reputed to be "good at electronics"
- Ron Aitchison invited me back to Sydney University Electrical Engineering Department to work on electronics for Mills Cross at Hoskinstown.
- I was faced with requirements for the receiver and correlator system that couldn't be met with available technologies
- ***I was working for people who really believed in me in the best sand-pit I had ever been in!***

Some of my own examples

These examples represent "physical understanding" influenced and encouraged by my mentors and bringing together ideas from different areas

- The Transconductance Multiplier
- The Synchronous Integrator
- The ColFet
- Representing 3D data in 2D

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

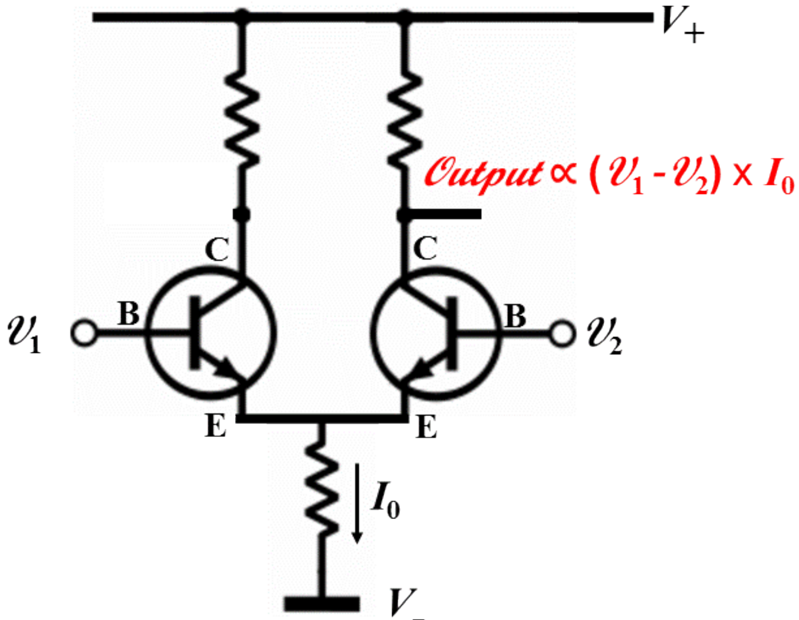
My question: Is Direct Multiplication Possible?

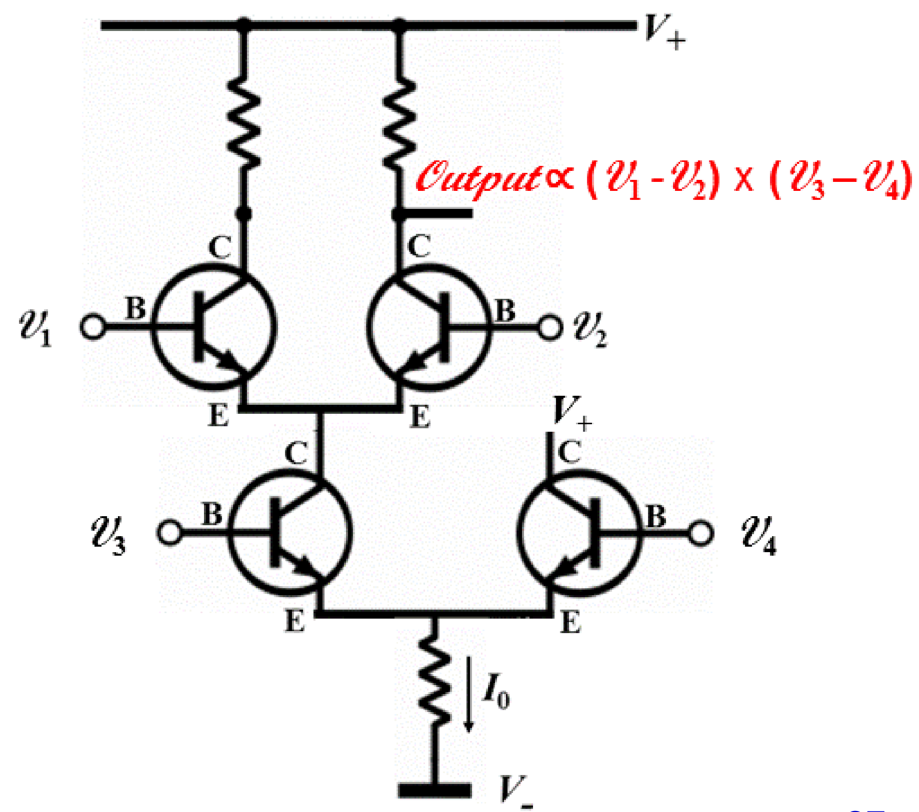
- **Issue:** Existing systems were based on the “quarter squares” approach with square law detectors
  $\mathbf{(A + B)^2 - (A - B)^2 = 4AB}$
- Dynamic range was a big issues with square law detectors
- **Conjecture:** There must be a way of harnessing the fact that gain is proportional to current in a transistor to give **A x B** directly

Differential Amplifier

to

Transconductance Multiplier



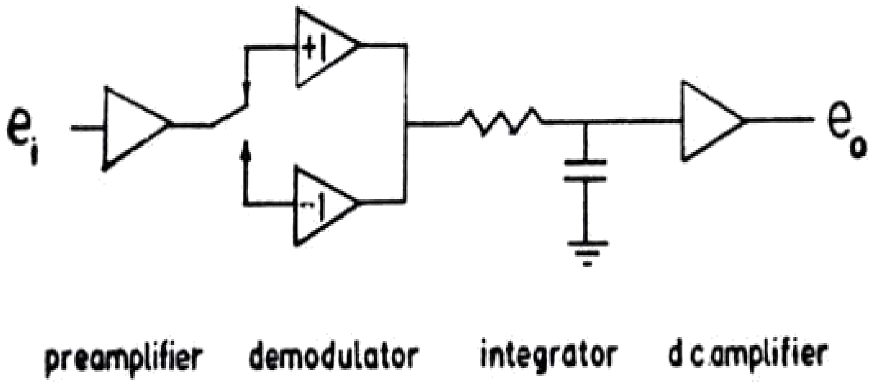


My question: Synchronous Demodulation – is there a better way?

Issue: Demodulating systems were subject to substantial drift, reducing the dynamic range to a level unacceptable for both Bernie Mills and Hanbury Brown

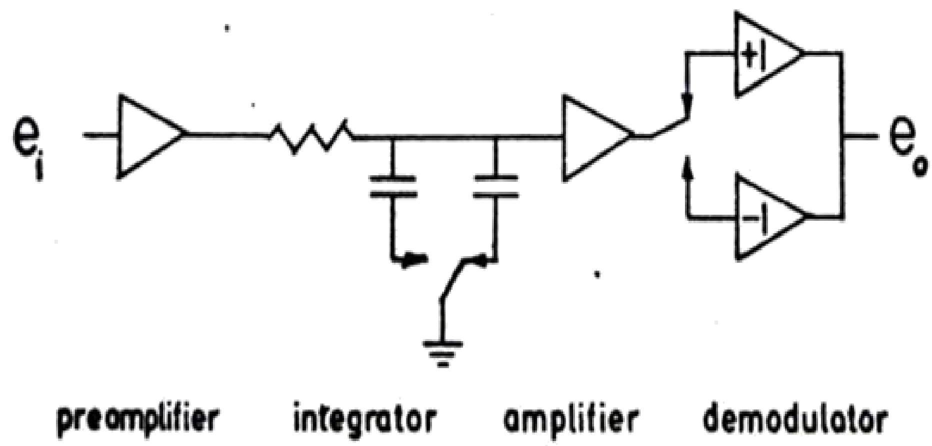
Conjecture: Perhaps you could integrate before you demodulated, reducing the dynamic range requirement on the demodulator

From Synchronous Demodulator/ Integrator



to

Synchronous Integrator/ Demodulator



A switched capacitor system "The Synchronous Integrator" added orders of magnitude to the dynamic range – *achieved 80dB*

This became a common part of "lock-in Amplifiers"

My question: Are room temperature Low Noise Resistors possible

- in spite of the second law of thermodynamics

Issue:

Measuring noise entails comparisons of noise with a room temperature resistor and a (liquid nitrogen) cooled resistor

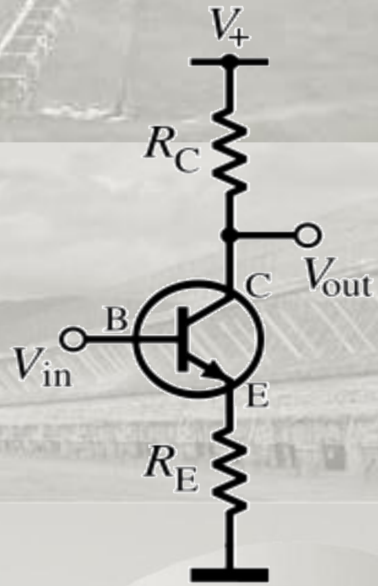
Conjectures:

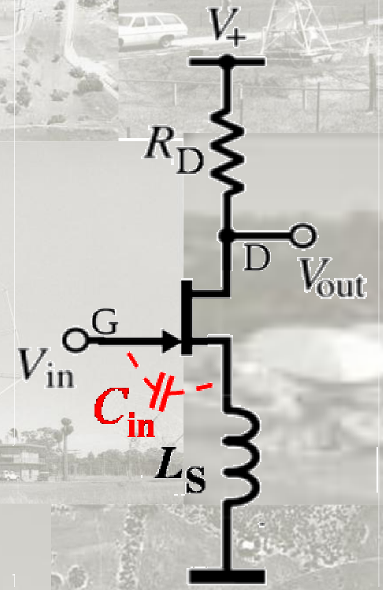
1. If a low noise amplifier has a resistive input impedance, the resistance has to be "cold"
2. A device with a reactive input impedance has a complex β.

A "real" resistance in the *"GaAsFET with source inductance"* case results from the product of two complex impedances and must be a "lossless" resistor

GaAsFET amplifier– a Bipolar Analogy

What happens if we add a inductance L_S?





Remember the bipolar transistor – no R_E

$\beta = g_m \times Z_{in}$

Input impedance with R_E = $\beta(1/g_m + R_E)$

$\approx \beta R_E$

GaAsFET input impedance - no L_s

$\beta = g_m \times Z_{in} = g_m / j\omega C_{in}$

Input impedance with L_s, $\approx \beta \times j\omega L_s$

$\approx g_m \times j\omega L_s / j\omega C_{in}$

and so the GaAsFET $Z_{in} \approx g_m \times L_s / C_{in}$

A lossless resistance we called COLFET!

The COLFET

We called this COLFET in our paper:

An active 'cold' noise source (using GaAs FET circuit)

FRATER, R H | WILLIAMS, D R

IEEE Transactions on Microwave Theory and Techniques.

Vol. MTT-29, pp. 344-347. Apr. 1981

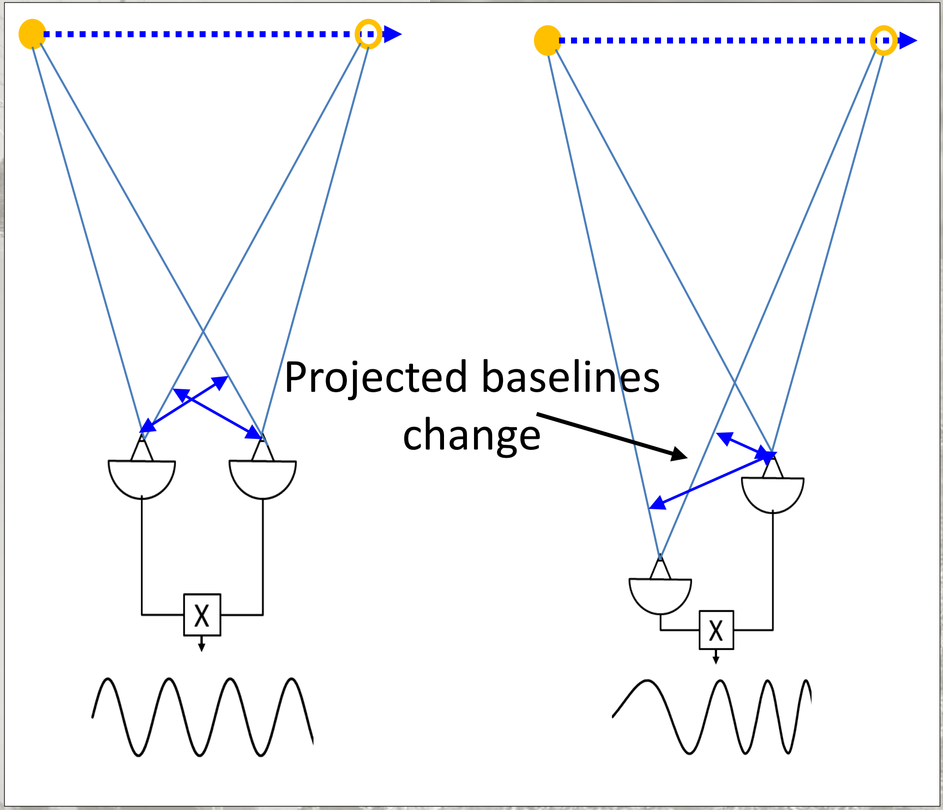
Spacek Labs sells a system under the same name!

Spacek Labs Model CS-K
Low-Noise COLFET

My question: If we think of an interferometer spacing in a plane in terms of its spatial frequency, can we think of an off-plane spacing as spatial frequency modulation

Off plane spacings give a frequency change across the field as the projected baseline changes

1. This is Frequency Modulation and the off-axis spacing can be represented by a central on-axis spacing with the equivalent of FM sidebands
2. A convolution function can be derived to achieve this



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 and since
- I've seen it carried on by those I taught
- For the future?

What are the lessons?

- My mentors and their mentors and I had the capacity to hold an manipulate a complex image, concept in their head. They were “System thinkers” and they ***were able to conceive, design and implement***
- Physical understanding was key for all of them
- My ingredients for success: needs, a champion, mentors, a supportive environment, a sponsor were broadly present for these people at various stages of their work
- 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 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 – in groups in Cambridge, Jodrell, etc and others like Bell labs.
- 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?