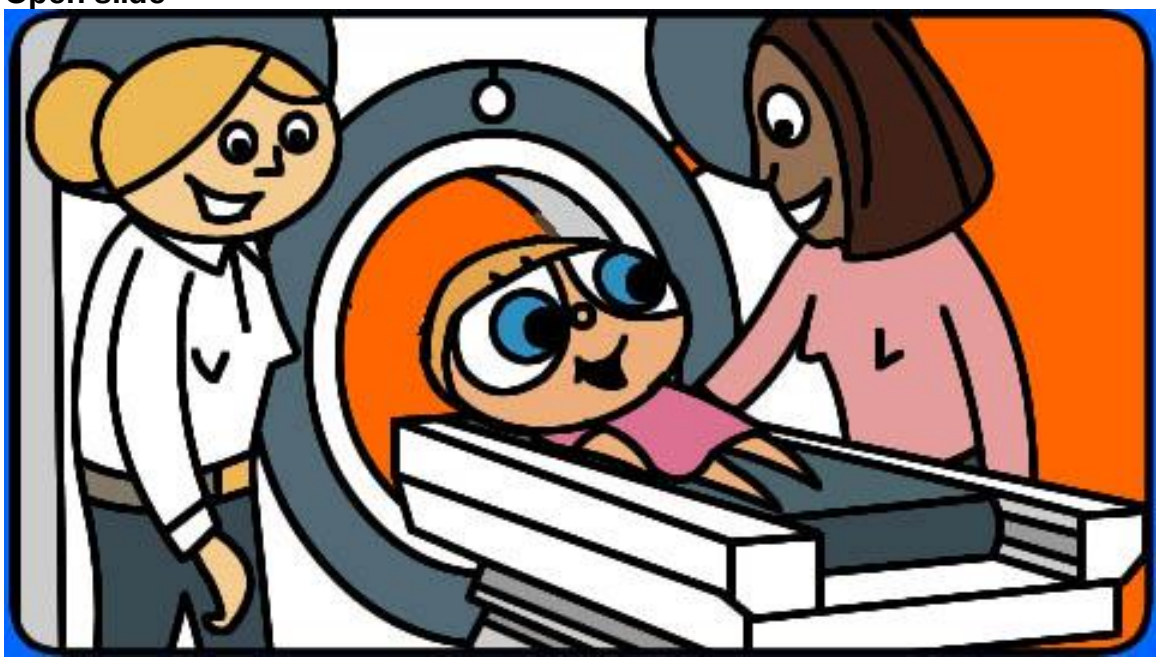
Invention of Computerized Tomography.

Introduction

When last year I had the misfortune to need a diagnosis in a CT Scanner, I was very pleased that in 1968 Godfrey Hounsfield and I had bludgeoned the Department of Health into supporting Godfrey's then rudimentary idea with some seed money!

Open slide

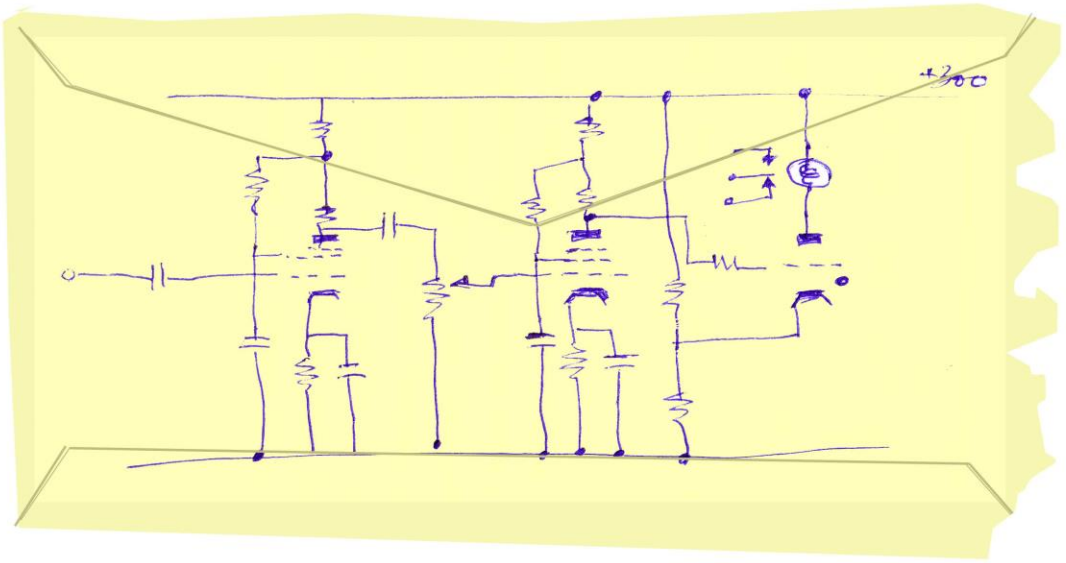


Tut

I started my Engineering career as an Electronic engineering trainee working for EMI Electronics. At that time there was an engineer also working there called **Godfrey Hounsfield**.

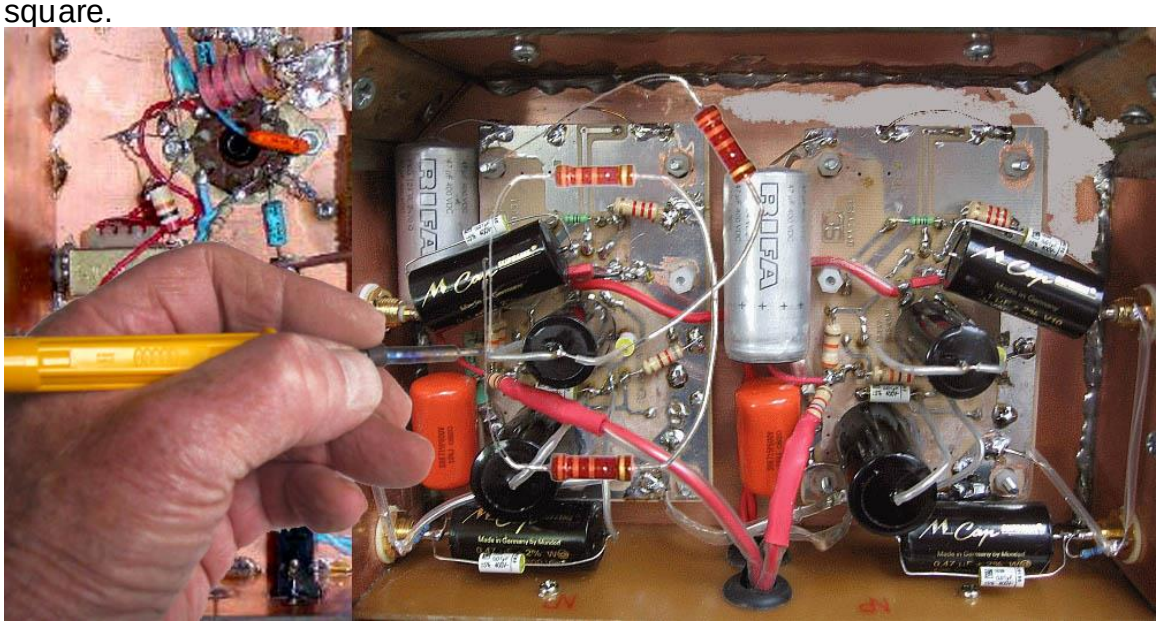
He was a typically long haired, moustached and rather eccentric genius. Like many clever people he was anxious about his work, suffered from stomach trouble and took indigestion pills.

I had an assignment as his assistant in those early days when he was designing the display system of a military radar called Red Indian.
He would **sketch out a circuit**



for his latest bit of invention and it was my job to solder the resistors, capacitors and inductors together with, in those days, some valves or vacuum tubes and then to try to adjust the values to make it all work.

Typical of the way Godfrey worked was the environment we worked in. In those days parts of the bare circuit were up at plus 300 volts while others were down at minus 300 volts. All this was often on a little **circuit board** of a few inches square.



So as you adjusted the values (of course while it was all switched on) your

fingers were often low down in the bare terminals and many a time got their richly deserved shock and sometimes much remembered holes in the skin.

I lost track of Godfrey after that for a few years while he was **developing computers**

the 1100, for EMI Electronics.

Godfrey was a graduate of a London Institute called **Faraday House** an institution I personally had never heard of until Godfrey told me about it.

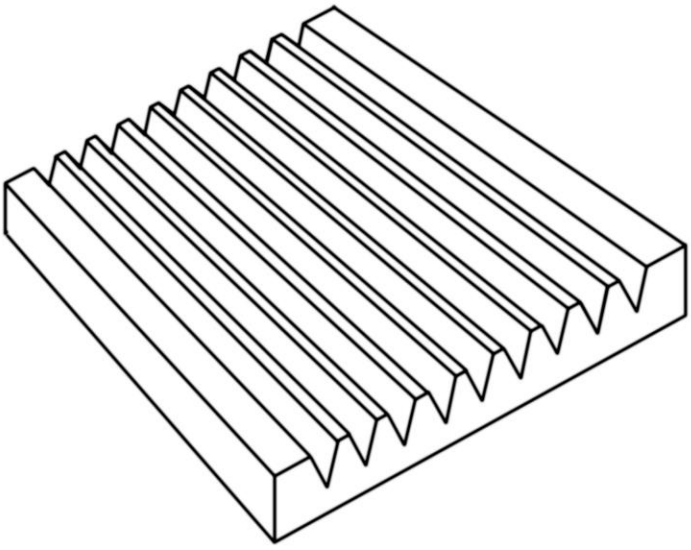
The next time we met was after EMI had sold its computer interest. Godfrey had been transferred to **EMI's Central Research Laboratory**
and I was deputy to the Director of Research there and responsible for reporting progress on all projects and trying to obtain finance for whatever we wanted to do, in particular making sure that we did not spend money that we had not got.

The building where so many things had been invented, was knocked down a few years ago and some colleuges of mine rescued some of the documents in this lecture from the archive then found.

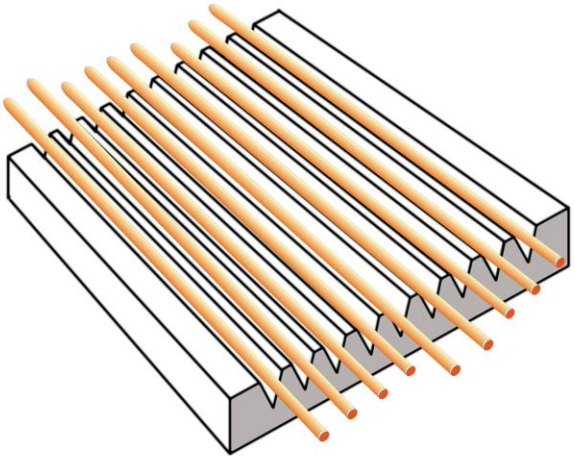
The Director, **Len Broadway**,

had been recruited by EMI when it was developing the British Television System. He came from the atom splitting Cavendish Laboratory where he got his doctorate on developments in cathode ray tubes.
Len was really only interested in the science so he was more than happy to rely on me to deal with staff levels and particularly the overspends.

Since the EMI group was no longer interested in computers, a research Project, led by Godfrey Hounsfield, which was bleeding our money away, was a real problem. Godfrey was all fired up on developing his then **novel computer storage system.**



A thin ferromagnetic plate had grooves cut in it.



In these were laid copper wires. Two of these plates, one on top of the other and laid at an angle could form a host of tiny torroidal transformers which could be wired up as a RAM computer store.

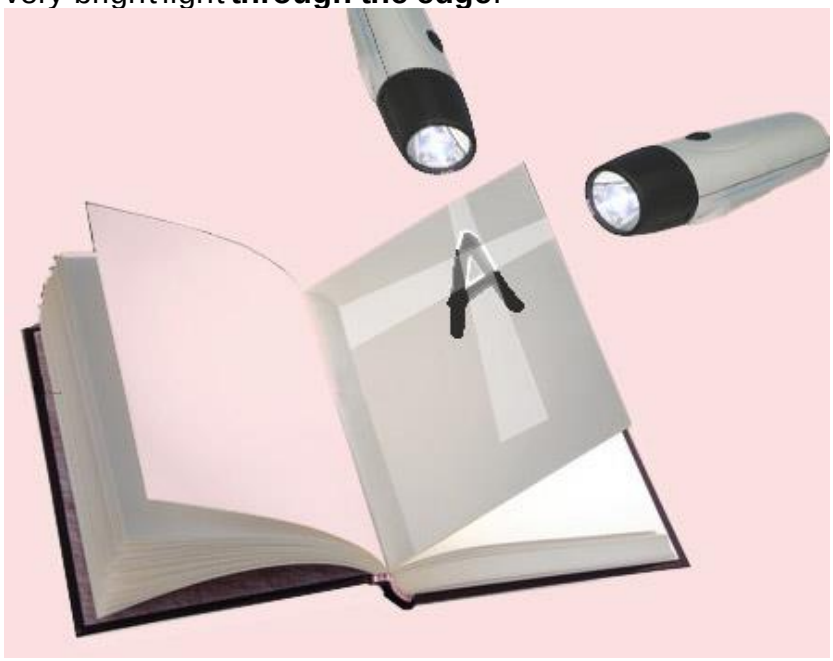
But little girls in Hong Kong were threading wires through tiny bits of ferrite and so making computer stores for next to nothing. So there was no profitable future in this computer storage system anyway.

Len and I discussed our problem. We had already told Godfrey to stop the computer job but the costs kept going up. He clearly needed another interest. He had not taken any holiday for a year or two and looked a bit pale so we sent him on six weeks holiday break, and told the **policeman on our gate** not to let him in if he came to work.

He went to stay on his brother's farm. Taking long **walks in the countryside**.

Six weeks later he returned to work and came and sat in my office for a chat.

"You know Don," he said, "I've been thinking of an interesting idea." "Suppose you took a single page of a book and imagined that is was possible to shine a very bright light **through the edge**.



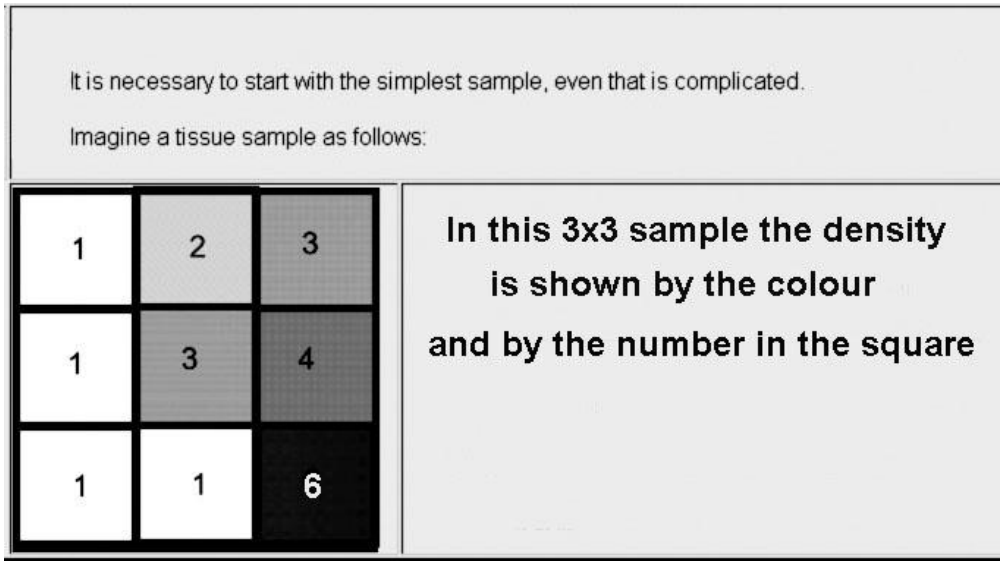
Then you collected the light that came out from each position across the bottom of the page. And suppose you did the same thing along the side from one side to the other, and then from the brightness values that came though the edge of the page, given enough readings, you could calculate what was written on the page!"

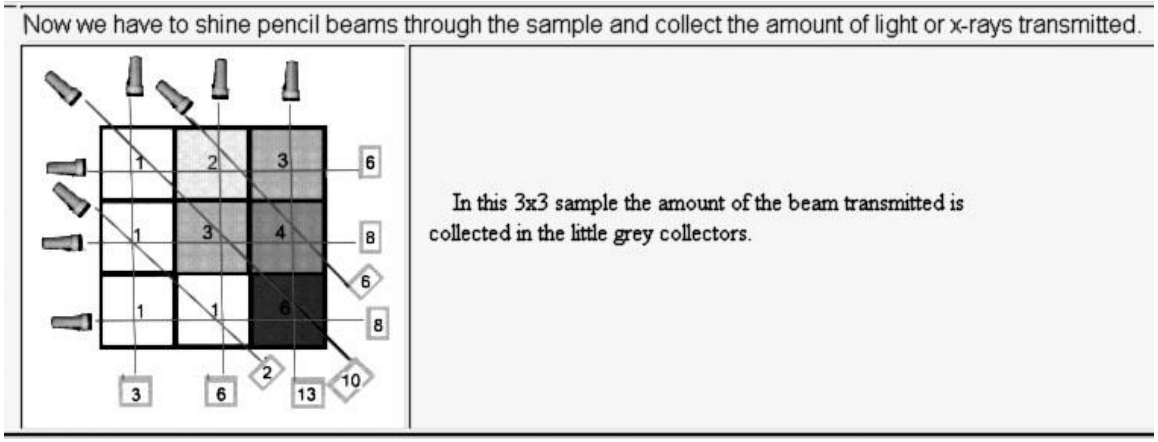
Of course Godfrey was a good mathematician and I had no doubt that he could have set up the necessary mathematical matrices to solve such multiple

equations as necessary. At that time it was just a concept and so far as I remember we did not, in that first chat, even discuss an application. But it was something to get a new line of thinking going, -- anything to steer Godfrey away from those wretched computer stores!

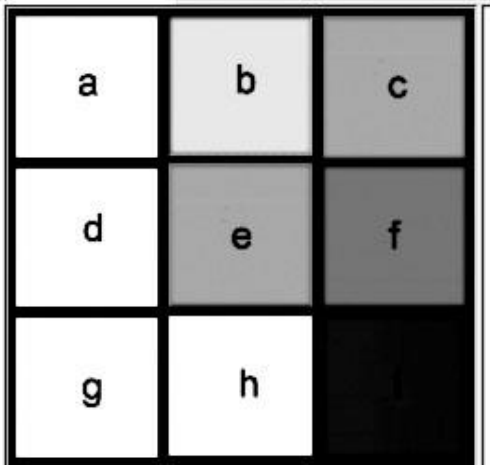
The principle he then described in those first thoughts worked like this.

How it works





At this stage the densities in the nine squares are unknown.



There are nine squares so in this case we need nine simultaneous equations to find the nine unknowns.

Referring back to the picture with the torches, we can see the following:

1. a+b+c=6
2. d+e+f=8
3. g+h+I=8
4. a+d+g=3
5. b+e+h=6
6. c+f+i=13
7. b+f =6
8. a+e+i=10
9. d+h =2

Nine unknowns and nine equations. Now these equations can either be solved longhand or by means of the Excel "Solver" function which can be found under the Excel "tools" tag. If you don't have this on your Excel you can download it. Help can be found at http://www.dslimited.biz/excel_tutorials/simultaneouslinearequations.html

But if you don't want to go to all the trouble to solve the simultaneous equations you can take it from me that they do solve back to the original values which I show at the beginning.

The one thing this does show is that even for a tiny little 3x3 sample there are a lot of equations. So you can just imagine how much calculation would be involved for a high definition sample. It is no wonder that the CT scanner got better over the years as computer power gradually increased.

(*My long time colleague has reminded me that the simultaneous equation route is only by way of illustration. In practice it had to be done differently because the presence of noise in the readings meant that there wasn't a perfect solution and so an "iterative" approach was used and generated a picture much more speedily than the conventional way of solving the equations. Later even this was improved by a what he called a "filtered back projection" that was even more efficient!* >

Not long after that Godfrey came up with the medical application that we all know about today.

Len Broadway's

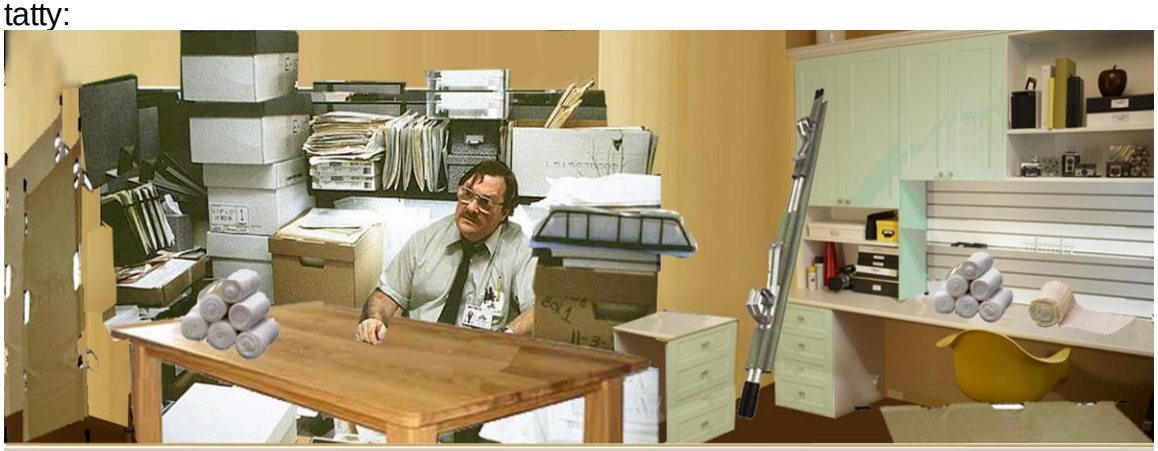
first reaction was that EMI had absolutely no interest in the medical market so there would be no group company money to fund it. Our Central Research Laboratory was supported by projects for subsidiary companies which they funded. However, there was a small group levy on all the operating companies, of which in those days the Record Company's was only a small part.

This group levy was spent at the discretion of the Director and monitored on a quarterly basis by the main EMI Board, and later by a Research Committee of Board directors..

So we kicked this new project idea of Godfrey's around for a while and eventuallyLen Broadway said, "I'll tell you what I'll do. You two go up to the Department of Health head office in London with Godfrey's idea. If you can persuade them that the idea is good enough to give you any money for research I will authorize you to open a project on company funds.

So up we went **by train**

from Hayes where we were based, just dodging the rail strike of that year!.
The **London office of DHSS** in those days - 1968 was a bit tatty:



My recollection of the DHSS office in 1968

I remember it a bit like a kitchen table with lots of samples of equipment littered around. I think there were some new designs of stretchers in the corner. Godfrey did a great presentation but all by word of mouth, no props, and I did my bit. Somehow or other the discussion gravitated down around a sum of **£2,500**.

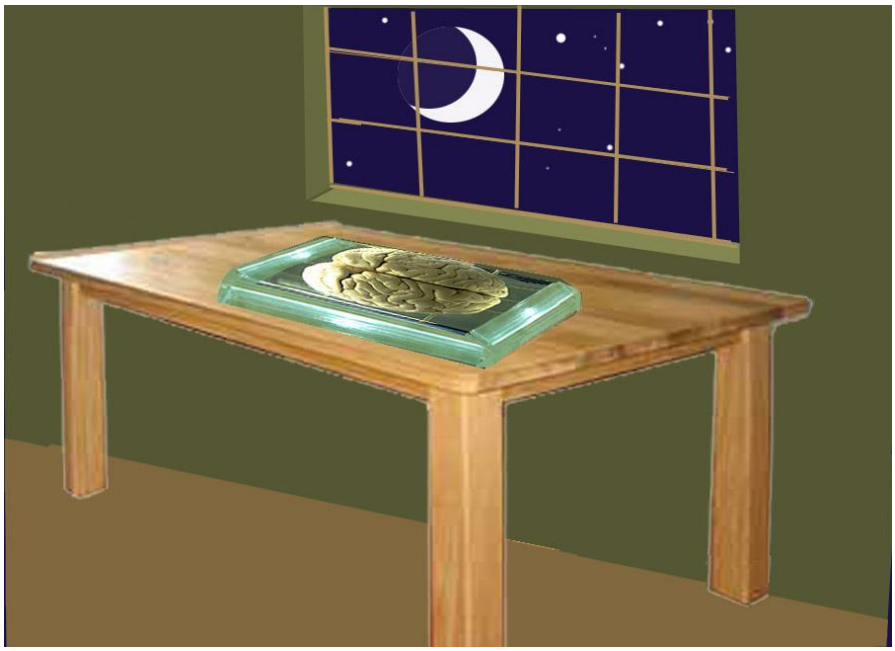
I don't really remember the negotiations to that figure but I do remember the DHSS officer saying in his words, "We'll have to forego a hell of a lot of bandages and stretchers for that!"

We came back to Hayes not realizing that we had made such a momentous achievement.

Next day Len Broadway called me in, "Well? Get anywhere?"
"£2,500 ", I said.

There was a silence, and then, "Oh well I did say I'd authorize it if you got **any** money I suppose!"

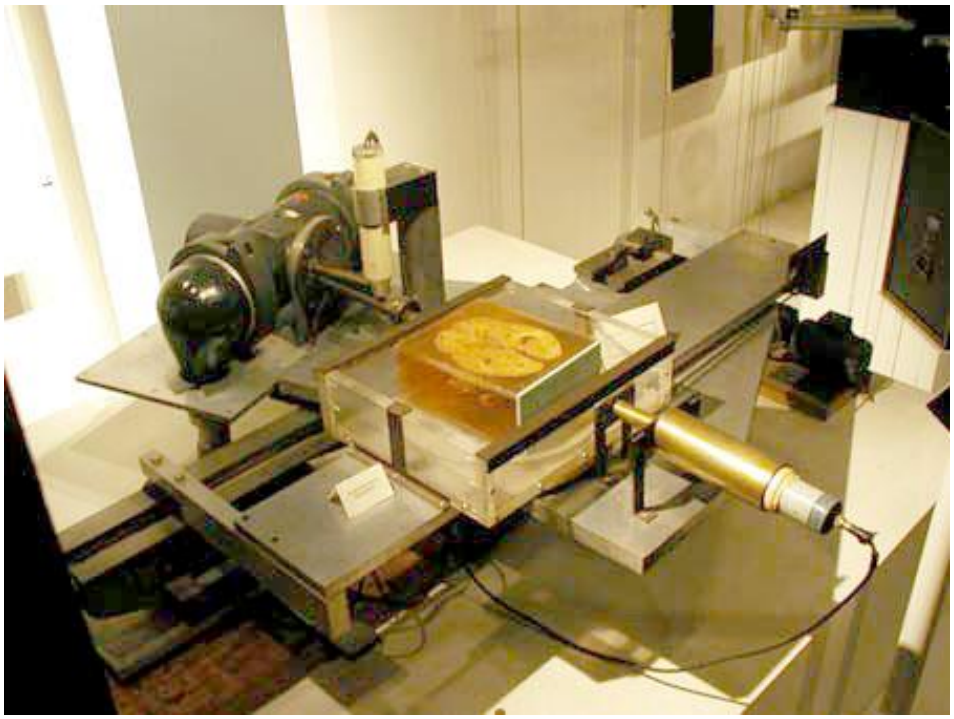
So that was it. We opened a works order and for a few weeks Godfrey worked alone and then with a young assistant. A month or so later I was going home late one night and noticed Godfrey's lights on near 8pm. So I went up to his lab to try to persuade him to go home and take a rest. On the bench was **a Perspex box full of formaldehyde**.



“What’s that in there Godfrey?”
“Oh it’s just a human brain[1].”
“And what’s the lump in it?”
“Oh that’s a tumour!”
It was all so casual. (I never did find out how he managed to get someone to lend him a human brain!)

Godfrey’s obituary says he used pig’s brains, but I am sure he told me that evening he had borrowed a human brain.

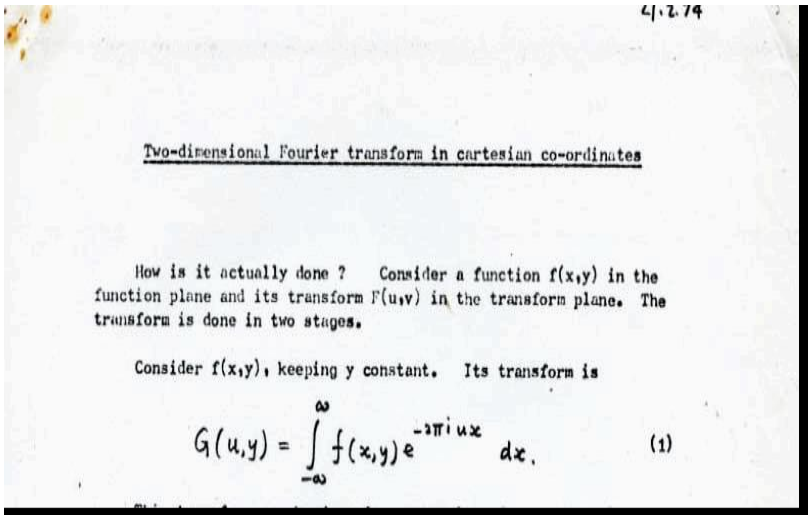
Spread around the bench were an X-ray tube source, scintillation counters, photocells and photomultipliers. All good things that might come in handy for such a series of experiments.



God knows in those days whether all the proper safety precautions were being followed. I think Godfrey was sensible and knowledgeable enough to use the necessary shielding but he was also very keen to make progress.
From that point a great deal of work was needed to get the project from the concept to a working model that could be demonstrated with safety. Large quantities of transmission data through the sample were contained in the surrounding detectors all of which needed mathematical computation.

Matrix equations were an established branch of mathematics but computer power was not as great as it is today. Godfrey spent a long time improving his handling of the matrices. Of course the Laboratories had one or two very clever mathematicians who could help if needed.

Godfrey dreamed up a way around all these simultaneous equations and came up with a guessing method called his **iterative method**. He tried to explain it to me, but I could never understand it. Later they used another approximation referred to as **convolution**.



4.2.74

Two-dimensional Fourier transform in cartesian co-ordinates

How is it actually done ? Consider a function f(x,y) in the function plane and its transform F(u,v) in the transform plane. The transform is done in two stages.

Consider f(x,y), keeping y constant. Its transform is

$$G(u,y) = \int_{-\infty}^{\infty} f(x,y)\, e^{-2\pi i u x}\, dx. \qquad (1)$$

I think the method consisted of calculating a few widely spaced angular readings and then filling in others subsequently for the fine detail.

The doubters in our management board needed to be kept convinced that it would all work.

As a result of the DHSS involvement Godfrey got some medical supervision and advice from a neurosurgeon **James Ambrose** at Atkinson Morley's Hospital, Wimbledon.

He was a great enthusiast and was also honoured for the invention. What I did not know till later was that the money we had been promised by DHSS was not actually paid until at least a year later. The DHSS did very well out of their investment and **subsequent contract** with EMI.

BENEFITS TO DHSS ACRUING FROM THE EMI-SCANNER

Total Orders to Date -	167 (then)
@ £145K each	£24,215K
Deduct Sales to DHSS	£ 528K
	£23,687K
Royalty at 3% on the above SALES TO DHSS	= £711K
List Price	£ 814K
DHSS Paid	£ 528K
Benefit from special price	£ 286K
TOTAL BENEFIT	£ 997K
ORIGINAL CONTRIBUTION FROM DHSS	£ 37.4K

I left the Central Research lab around this time for a promotion, but we had done enough and the group Central management in the form of **John Powell** had noticed and been convinced of the potential.

Dr John Powell: Managing Director, Joined EMI in 1971 from Texas Instruments.

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Rumours exist that the money from the **Beatles** funded all this. It's a good story but certainly it did not up to the point when I left.

By this point the machine was undergoing successful clinical trials with the DHSS. It was a great decision for John Powell, an embryo product of completely unknown potential in a market in which EMI had no presence and no experience. The patent position was thought to be strong. EMI possessed a **very good patent** department for its background. The possibility of licensing was considered.

EMI Patents and published applications in the field of computed tomography

UNITED KINGDOM

1 283 915
1 407 528
1 430 088
1 430 089
1 462 861
1 462 862
1 464 864
1 468 021
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1 474 685
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1 478 121
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1 493 148
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1 518 086
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USA

3 778 614
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3 881 110
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3 924 129
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3 936 636
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3 937 963
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3 996 467
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4 034 224
4 035 647
4 035 651
4 038 551
4 039 807
4 041 315
4 044 260
4 048 503
4 048 505
4 052 618
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CANADA

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GERMANY

P 19 41 433
P 24 12 658
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P 24 24 753
P 24 26 343
P 24 27 418
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P 24 39 847
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P 24 62 509
P 24 62 564
P 25 03 978
P 25 03 979
P 25 03 980
P 25 06 686
P 25 13 137
P 25 20 539
P 25 21 230
P 25 25 270
P 25 32 716
P 25 51 322
P 25 59 427
P 26 04 662
P 26 11 532
P 26 11 706
P 26 17 974
P 26 23 965
P 26 25 312
P 26 30 961
P 26 31 516
P 26 44 889
P 26 48 503
P 26 49 492
P 26 49 499
P 26 55 000
P 27 02 009
P 27 04 784
P 27 05 925
P 27 09 599
P 27 09 600
P 27 13 839
P 27 21 712
P 27 22 964
P 27 24 244
P 27 30 324
P 27 37 566
P 27 38 045
P 27 38 047
P 27 41 865
P 27 41 874
P 27 50 651
G 76 00 207
G 76 37 786
G 76 09 805
P 28 04 732

HOLLAND

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FRANCE

69 29 050
74 14 031
74 18 993
74 25 208
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74 28 268
74 29 537
75 02 912
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77 28450
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JAPAN

66,087/69
(1274/77)
26,114/74
47,032/74
49,619/74
57,773/74
60,165/74
62,451/74
63,812/74
73,788/74
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83,729/74
94,561/74
99,443/74
9,653/75
13,911/75
13,912/75
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34,180/75
53,073/75
65,977/75
87,788/75
136,127/75
3,713/76
8,858/76
29,034/76
30,739/76
41,747/76
54,243/76
67,021/76
68,608/76
80,789/76
82,424/76
118,910/76
128,139/76
132,257/76
145,165/76
1,403/77
10,594/77
13,470/77
23,247/77
23,248/77
33,935/77
55,909/77
57,539/77
63,906/77
78,440/77
98,157/77
99,396/77
101,480/77
102,508/77
112,098/77
114,466/77
132,422/77

SWEDEN

7405528

SPAIN

458137

AUSTRALIA

455 162
486 427

SINGAPORE

43/77
411/77
412/77
471/77
519/77
520/77
521/77
197/78

BELGUIM

850233
850234
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HONG KONG

193/77
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576/77
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611/77
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337/78

ITALY

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MALAYA

152/77
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RUSSIA

576011

Courageously however, Powell decided that EMI should create a completely new business.

In five years, he directed the effort which resulted in the manufacture and sale of over 700 scanners worldwide, selling at a peak rate £100M per annum, and generating some £38M of profit for the company.

From virtually a zero base, EMI Medical Electronics had grown to employ 2,500 people and were represented in over a dozen countries.
Of course there were many who challenged the originality of the invention. One Cormack, who, although he never managed to make any machine, still got a Nobel prize for his theoretical work.
Cormack had his **champions**

Pioneering medicine

FROM DR T. R. HENNESSY

Times August 25, 2004

Sir, Alan Cormack, of the University of Cape Town (later Professor of Physics at Tufts University, US), made a seminal contribution to the development of the CT scanner (Sir Godfrey Hounsfield's obituary, August 18).

After a few years on a research scholarship at the University of Cambridge, Cormack returned to the Department of Physics at the University of Cape Town (where he had obtained his first degree) and, stimulated by the needs of colleagues in the University of Cape Town Medical School, solved the problem of how to reconstruct an unknown object embedded in a mass of biological tissue, given only the data obtained from a series of X-ray images taken at different angular positions around the periphery of the inaccessible object.

He did this quite independently of Hounsfield's pioneering work to construct an electro-mechanical device that was able to take X-ray images at different angular positions around a target site.

Cormack's mathematical modelling and analysis led directly to the encoding of the CT scanner's computational engine. He and Hounsfield were jointly awarded the Nobel Prize for Medicine in 1979.

The members of the design team sent a refutation. Saying that nothing came from Cormack's work.

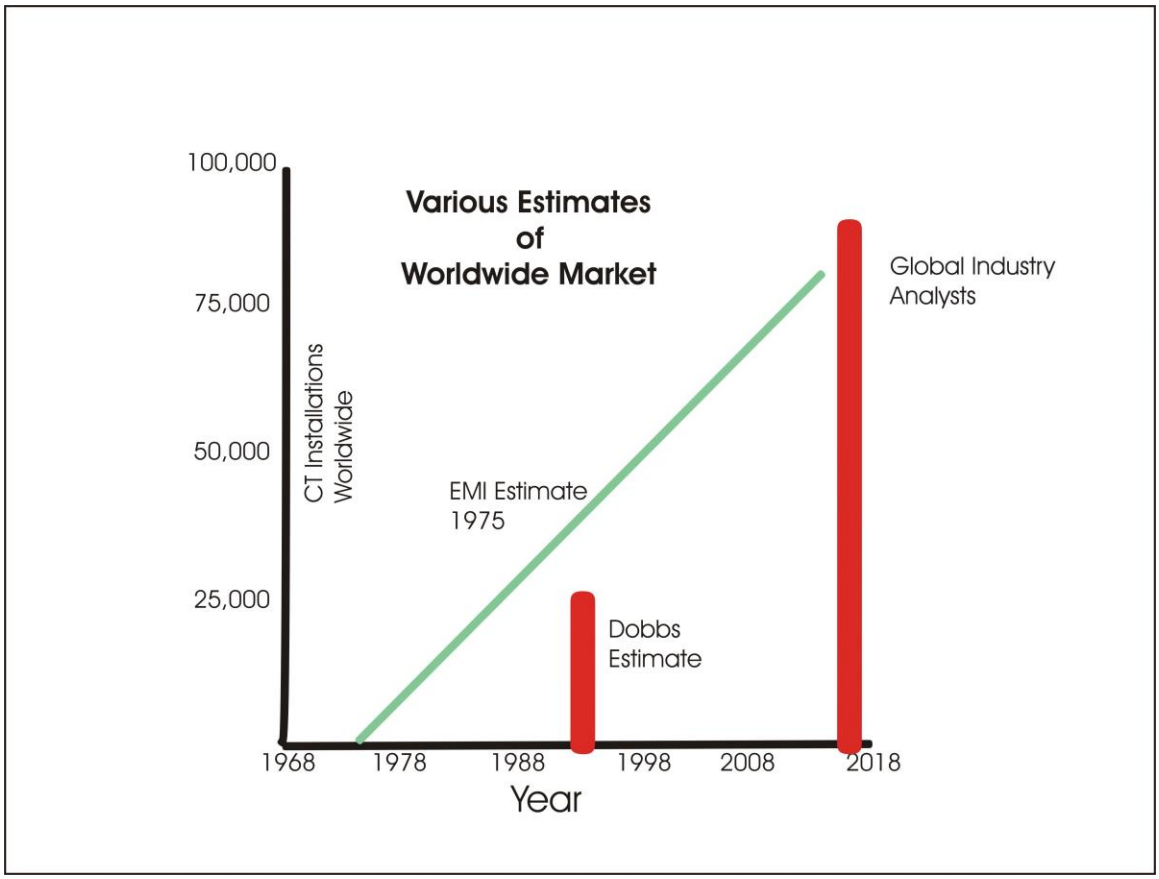
Pioneering medicine

From Stephen Bates, Mac Gollifer, John Ryan

Sir, In response to Dr Hennessy on the contribution of Alan Cormack to the development of the CT Scanner it is well known that, although he and Sir Godfrey Hounsfield shared the Nobel prize, they worked independently and had never met. However, the impression created that Cormack's mathematical modelling method led directly to the computational method used for CT Scanners is incorrect with respect to Hounsfield's EMI Scanner. The first prototype scanner installed at Atkinson Morley's Hospital for clinical trials in 1971 used a three-pass iterative feedback method proposed by Hounsfield himself, working from first principles. Later scanners used a one-pass convolution method developed entirely by Hounsfield's research team. Neither method was based on Cormack's work.

The fact that Hounsfield's work was original was proved by the fact that the US Examiner failed to find anything and when all the lawyers of Ohio Nuclear and GE combined also failed to find any relevant prior art which led to those companies settling their infringement suits and paying substantial patent licence fees.

USA that home of free trade found that so many of these machines were being purchased that President Carter introduced a special certificate of need for which any American organization wanting to purchase one had to seek permission from the authorities. This temporarily strangled EMI's USA export market. By this time there were at least 18 companies trying to compete for this juicy market. Here are some forecasts of the time.



As the competition grew EMI could not maintain its market leadership with its manufacturirg base several thousand miles away. Hospitals worried about servicing and the supply of spares. There was a marketing advantage in being able to put a "**Made in America**" badge on scanners for the American market.

There were obstacles to this; the two main ones were the lack of a superior product and the right management leadership to establish an American factory. The **new body scanner** solved the first problem,

EMI-Scanner CT 5005 installation at the Rigshospitalet, Copenhagen.

and an old colleague of John Powell's from Texas Instruments solved the second.

Norman Provost had run TI's European operation. In 1976 he was working for American Plessey, and approached Powell with an offer to establish a scanner factory in America. He was exactly the right man for the job. EMI built an American factory at Northbrook to assemble parts manufactured in Britain and later help develop a new generation of scanners.

Google did not have a picture of Provost!

EMI's plans were dealt a devastating blow when, while on a visit to EMI in England in May 1976, Provost dropped dead from a heart attack. American operations never recovered from this.

Powell recalled, "*I lost a lot of time ...From then onwards, we suffered many delays, and could find no way of overcoming them."*

The growth of the scanner business had been so fast that these delays proved fatal. Work on the new 7000 series was stuck at Northbrook. They were simply **unable to get the technology to work**.

These delays saw GE take the lead in the American market, which because of President Carter's restrictions on health capital spending had slumped to a quarter of its previous size. EMI had invested heavily in a new factory but was beset by delays, and suffered a reduced share in a reduced market.

What had been a hugely profitable venture suddenly became a **black hole**

down which vast sums of money disappeared.

The whole rags-to-riches-to-rags story had taken less than a decade.

The rise of EMI's medical business had been spectacular, but its collapse was more so.

£Millions	1973	1974	1975	1976	1977	1978	1979
EMI Sales	321	400	503	671	851	873	869
Medical	0.32	5	20	42	93	67	44
Medical %	0.10	1.30	4.10	6.30	11.00	7.70	5.10
EMI Profits	32	41	43	65	75	38	29
Medical	-0.07	1	9.00	13.00	15.00	-13	-13
Medical %	-0.2	3.1	21.0	19.0	20.0	-35.0	-45.0

Godfrey Hounsfield's scanner was a brilliant invention, well worth his Nobel Prize for Medicine in 1979.

Godfrey Hounsfield's scanner was a brilliant invention, for which he was awarded the Nobel Prize for Medicine in 1979.

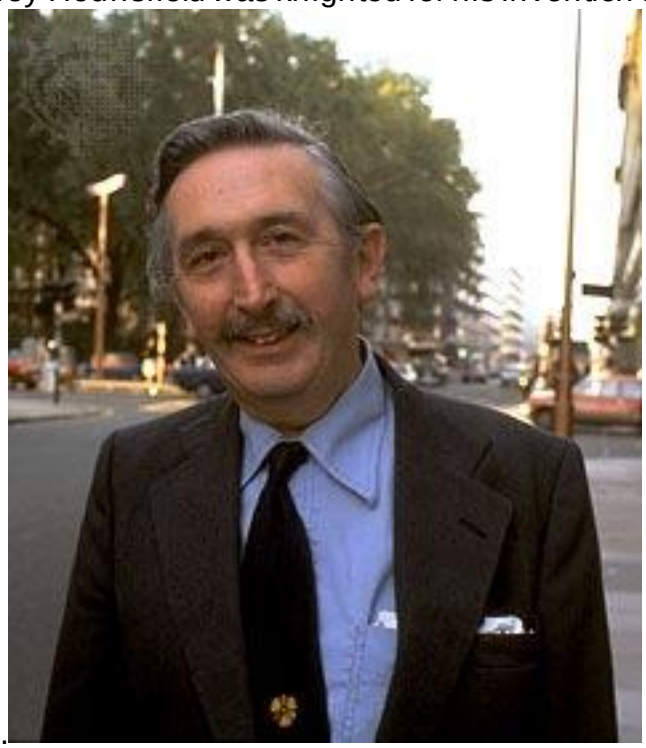
From a commercial point of view it was a disaster that virtually bankrupted EMI.

Within eight years the company was driven out of the industry that it had created, selling its medical electronics business to GE. Reasons for this, were the death of Norman Provost, the intervention of Jimmy Carter and the endless delays at the American factory.

The rapid expansion of the company in a new industry threw up many problems.
"The whole growing up of the scanner business, and the scanner organisation, was like a plant in a hothouse.
We had grown a plant with a long **slender stalk** whose roots were not properly developed.

The main competition did not suffer from this. While companies like GE took a few years to catch up with EMI's technology, medical electronics was an industry that they were already well established in. They had strong and deep roots. When the gale of rationalisation blew they could withstand the pressure and EMI could not.

Godfrey Hounsfield was knighted for his invention and awarded the Nobel Prize.



Strangely there is an **invoice** in the archive showing that a recipient had paid for the medal!

MYNTVERKET

FAKTURA
Fakturadatum
1980-03-18

7937

Vår beteckning
A 447
Er beteckning
B Wijkander
Nobel Foundation

Handläggare
P Helander

Dr Godfrey N Hounsfield
EMI Limited
Shoenberg House
Trevor Road
GB-Hayes Middlesex UB3 1HH
England

Betalningsvillkor	Leveranssätt	Leveransdatum
kontant netto	post	1980-03-18

Beskrivning	Antal	Pris per enhet	Belopp
Nobel-medal in goldfilled bronze	1 pec	100:-Skr	100:-Skr
Package and postage			50:-Skr
			150:- Skr
			Paid in advance

Fraktkostnader . . . . . .
Expeditionsavgift . . . . . .
Summa . . . . . .
Mervärdeskatt . . . . . .
Summa att betala →

Kvittens vid kontantbetalning
Ort och datum
Kvittenss . . . . .

Postadress	Gatuadress	Telefon	Telex	Postgiro
Box 631 103 08 ESKILSTUNA	Smedjegatan 13	016-120300	46008 svemint s	76 22 15 - 2

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So if you are expecting to get one soon be ready to pay up!

Don Tyzack