

60 Years of Precision Circuits

(Fun in Metrology! John Pickering)

Scope of Talk, may depend on time!

- * History of the learning process and early career.
- * The founding and early development of Datron
- * Datron through 17 years, good and bad times!
- * The start of Metron Designs Ltd & “why”.
- * Early contracts
- * CERN to the present.
- * Some technical discussions & answers to questions.

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- * Hobby...building Hi-Fi, then Test Instruments
- * County Grammar with Elton, “A” levels (not very good)
- * Careers advice: “Not too bright, better do applied Science”!!! (turned out EEs did Physics ++)
- * Imperial College, scraped an “Honours” BSc Eng. (Was great at Electronics and playing Bridge though)
- * Vacation Job Hewlett Packard, became permanent. MUCH learned at HP. Met Bill and Dave!
- * Six months in California at Dana Labs.
- * Co-founded Datron Electronics Ltd Norwich...17 years.
- * Co. sold, set up contract design Metron Designs Ltd
- * Took contract to design magnet reference for the LHC
- * Still working with CERN and now GSI

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Learning A LOT at HP & Meeting with Bill & Dave!

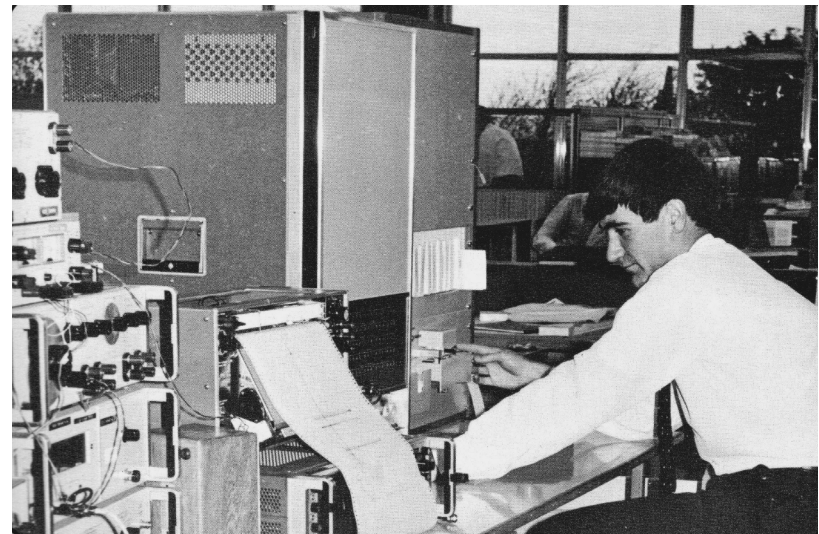
HEWLETT-PACKARD JOURNAL

<<The 3721A Correlator



NOVEMBER 1969

Me, pretending to
program the HP2116A



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- Hewlett Packard, South Queensferry

- Joined in 1967 as a vacation job....and stayed to work on an instrument “HP 3721A” to measure correlations between signals.
- Met Bill and Dave, Bill sat down with me and discussed my work in some detail....how motivating is that?
- Consider the technology changes to come:
 - - I proposed to design in a memory using silicon chips of **2500 “bits” (not even bytes!) at 10 cents per bit**, predicting the cost would eventually drop to 1 cent per bit.
 - I just bought a silicon chip memory of over **1000,000,000,000 bits for about \$30**.
 - This is a real **reduction in cost of 3 billion times**, in fact 30 billion relative to general inflation. Has anything else got anywhere near to this?

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- Dana Labs California....then Datron

- After a brief and very fruitless period with GEC, joined Dana Laboratories in Luton and Newport Beach California.
- 6 months in Newport Beach, that was more like it!
- However, Dana got into financial trouble so the UK Managing Director and I founded Datron Electronics Ltd:
- Total startup, we wrote business plan and hawked it around the City.
- Company to be a UK owned Electronic instrumentation house to take on the likes of Solartron, Fluke, Hewlett Packard.
- Founded in Luton 1971, moved to Norwich in 1973, USM IPO in 1985, bought out by Wavetek in 1988.
- Now owned by TEK/Fluke but Norwich still employs about 200 people

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1971-1973 First Premises, 75a Crawley Road Luton
(Sepia Tone after Bill & Dave's Garage!)



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THE BUSINESS PLAN MARK 2



Cash Required 1973:

Cash Needed:	£66,766
Equity:	£20,000
Bank Overdraft:	£15,000
Long term Loan:	£31766

Additional Cash Required 1974:

Cash Needed:	£24,197
Equity:	
Bank Overdraft:	£10,000
Long term Loan:	£14,197

Also Forecast:

Long term Loan and Bank Overdraft to be fully repaid by beginning 1976. Ha Ha!!

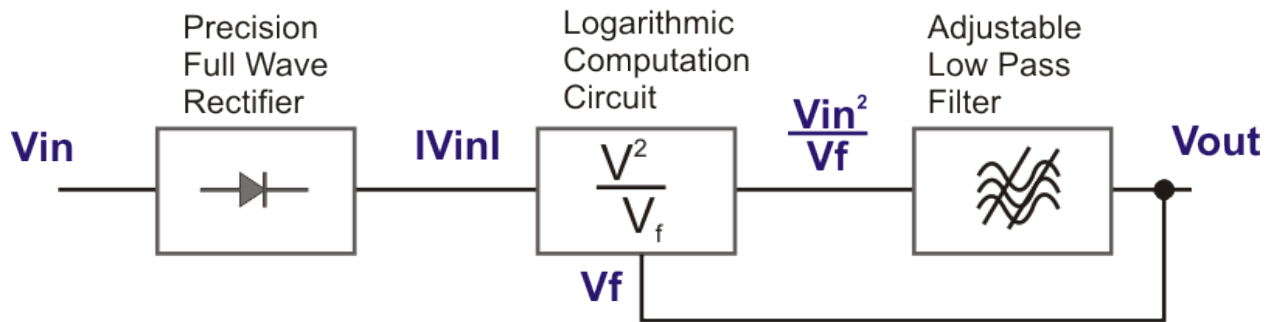
(In the event TDC put in ~£8,000 in Equity (~29%) and £35,000 in long term loan: at very high interest rates)

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- The Datron Years: Core Technology.

THE FEEDBACK (Log feedback) RMS CIRCUIT



$$V_{out} = \overline{\frac{V_{in}^2}{V_f}} \quad (\text{Bar Notation for Average})$$

But: $V_{out} = V_f$ (Same Point!)

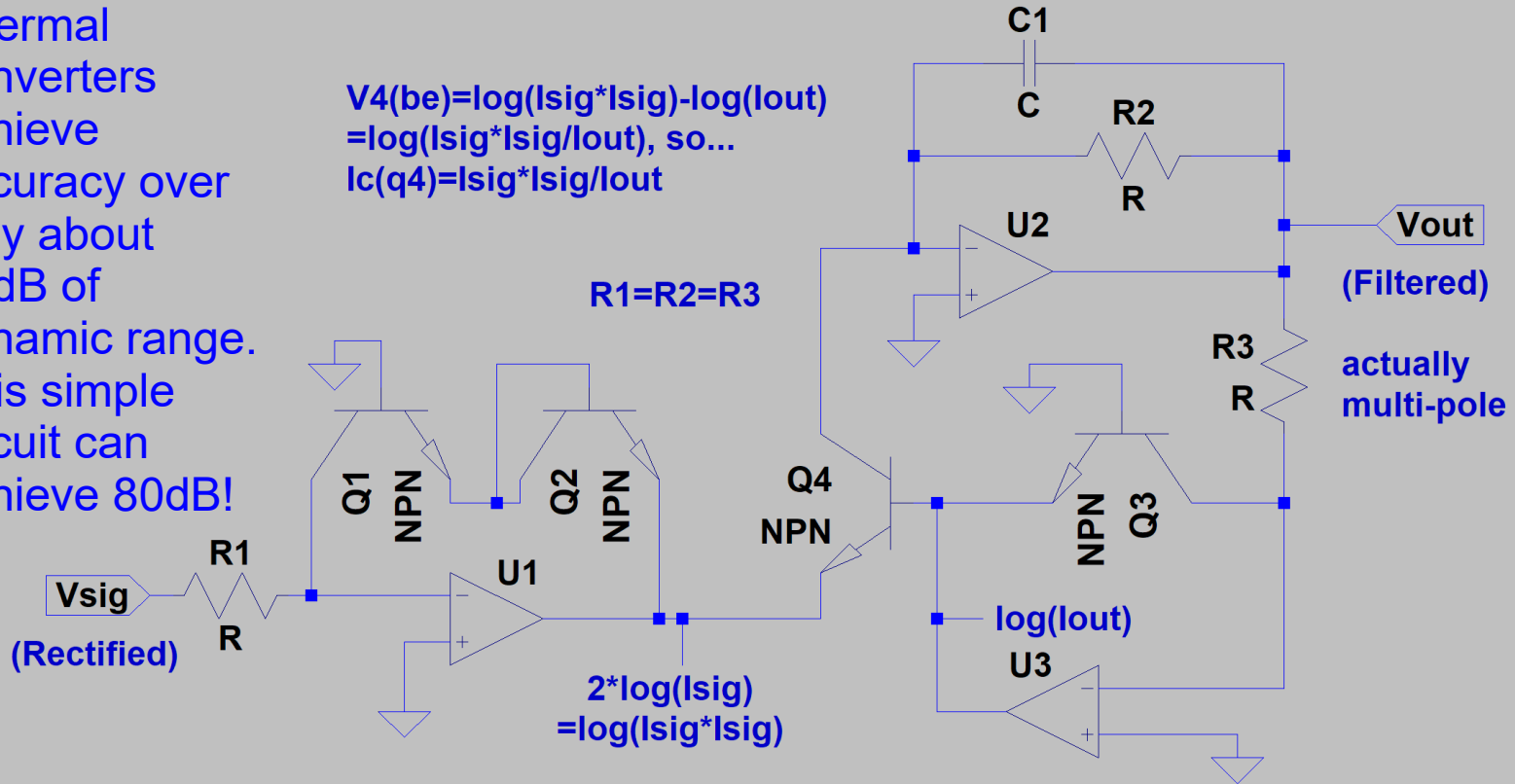
Therefore: $V_{out} = \overline{\frac{V_{in}^2}{V_{out}}}$

And..... $V_{out} = \sqrt{\overline{V_{in}^2}}$

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Thermal converters achieve accuracy over only about 20dB of dynamic range. This simple circuit can achieve 80dB!

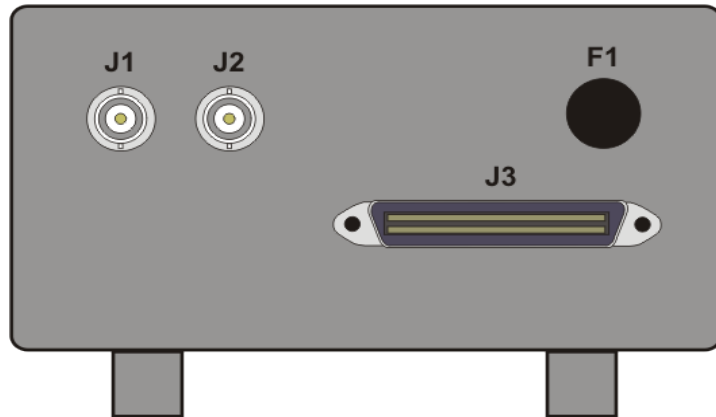


Square Law from a 1\$ Transistor Array!

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- The Datron Years: 1st products.

The Attractively Packaged ST5689
(from memory!)



Key Spec: RMS Accuracy 3% from .1Hz to 8Hz

MODEL 1030 True RMS Voltmeter.

Specifications

Ranges 0.000V - 0.000V 1.000V
0.00V - 0.00V 1.000V

Overrange 200% on all ranges except 0.00V (0.00V over range)

L.F. Capability Maintains full accuracy down to selected frequency

Input 1 lead, 2-lead, 4-lead, 6-lead, 8-lead, 10-lead, 12-lead, 14-lead, 16-lead, 18-lead, 20-lead

Resolution 0.1% of full scale

Accuracy ±0.5% of full scale

Power 100W

Dimensions 100mm x 100mm x 100mm

Weight 100g

Accuracy ±0.5% of full scale

Resolution 0.1% of full scale

Power 100W

Dimensions 100mm x 100mm x 100mm

Weight 100g

Key Spec: RMS Accuracy 3% from .1Hz to 8Hz

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- The Datron Years: Premises

1973-1974, Hotblack Road
aka Hat Block Road!

(Down the back: Beware of the Dog!)

The Product Planning Department
from 1973 until 1980



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Later Datron products Pre-Wavetek

AutoCal DVMs, the Fruit of the Ten Bells!

The autocal DVMs (1061, 1071,) used a 6800 μ Processor

Fluke had already done this but really doing little more than adding a calculator so we decided to use the capability to handle the calibration control and corrections....our marketing theme was to do this under lock & key!

We also added "Spec. Readout" which took the datasheet specifications (in ROM) to calculate the DVM's uncertainty on any particular measurement in any part of its scale. Unfortunately, some of our US sales reps and competitors took this as correcting the uncertainties....never our intention.

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- The Datron Years: USA

Datron Instruments Inc.

Gee! How does it work?!

The 1071 at the IEEE show:



**Works just
Great!!**

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Later Datron products Pre-Wavetek

4700 Series Calibrators and then the 1271/1281!

The calibrators, 4000 (DC only), 4200 (AC only), 4700/7 AC_DC

A major development for a small company....and sold too soon putting on terrific pressures. We had over one hundred 4200s in order backlog with another year of development to go. The problem was fitting 1000V AC capability into the single case. Tough!

The 12 series DVMs (1271, 1281,) used a 68000 μ Processor

The aim was to introduce an element of self calibration by installing a “drift free” inductive divider to “self calibrate” the range gains. During a horrendously difficult software development for this instrument the 3458A was released leaving us at an uncompetitive cost point, especially with our (better) hermetic VPG resistors installed.

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The Datron Years: Project Phases!

- **THE SIX PHASES OF EVERY PROJECT**
- **1. Enthusiasm**
- **2. Disillusionment**
- **3. Panic**
- **4. Search for the Guilty**
- **5. Punishment of the Innocent**
- **6. Praise and Honours for the Non-Participants**

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The Datron Years: Awards!

CELEBRATING THE QUEEN'S AWARD

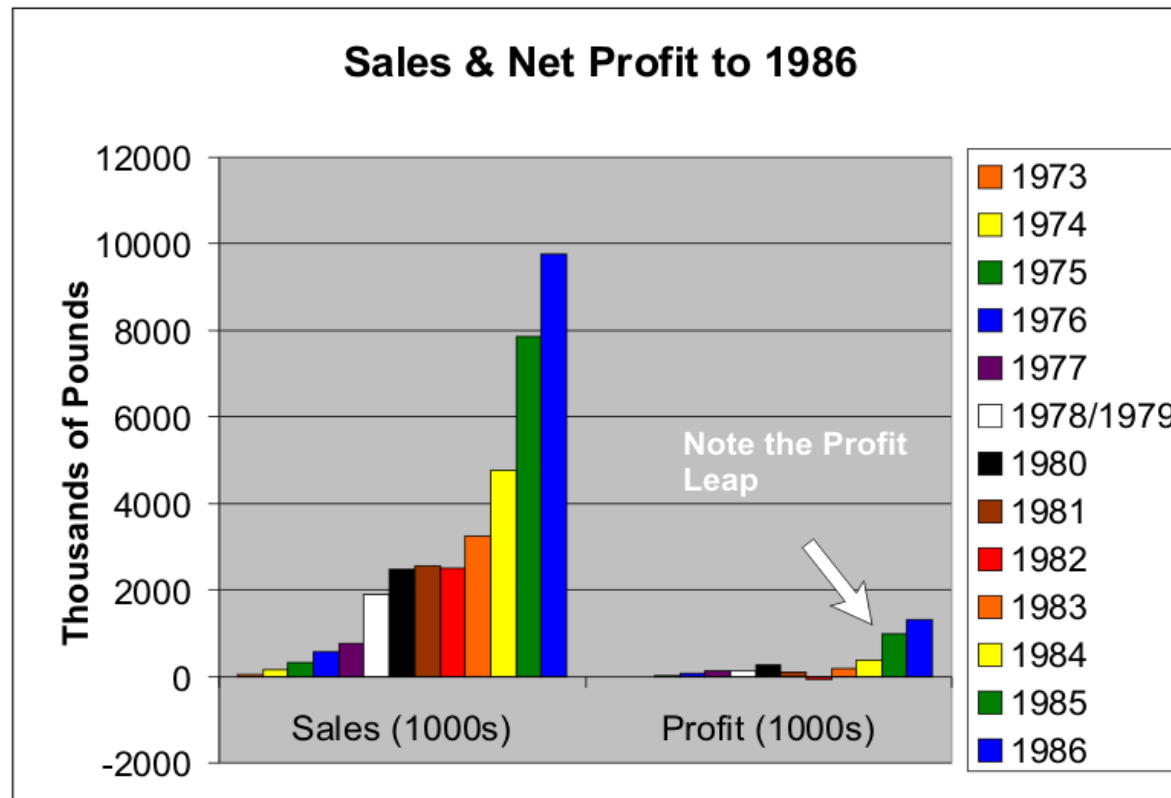


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The Datron Years: The figures?

THE EXCELLENT (??) PICTURE IN 1986, DATRON'S
LAST PUBLISHED ACCOUNTS



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(Fun in Metrology!)

And on to Metron Designs Ltd....:

- **Enough of Finance & Corporations**
 - What did I like doing?
 - **Electronic Designs!!**
 - What was I good at? Finance? Management?
 - No!! **Electronic Circuit Design!**
 - So started Metron Designs Ltd to provide contract design services in precision electronics, measurement & instrumentation

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Some Initial Metron Contracts:

- * Wavetek: The 7000 series 10V reference & system
- * NPL: A Hi Isolation DC-DC converter from the 7000 series.
Used for Josephson Array biasing. Now sold to NMIs mainly
- * NPL: a Self traceable Wattmeter for High Frequencies
Power = $[(V + I)^2 - (V - I)^2]/4$. All measurements RMS traceable
- * Aldel: An old fashioned DC DVM (non- μ P) for a VERY noisy environment!
- * Vishay (VPG): Evaluation of precision foil resistors with different foil coatings



CERN & the LHC needs 13kA to 1ppm.....



Evaluating the 22-bit $\Delta\Sigma$, The Iref-2

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And on to CERN up to the present

And MUCH more learning!

Cern were defining the LHC where the main calibration and control of the cryogenic magnets was to be in Current rather than Voltage and was targeted at 1ppm resolution and stability at 13,000 Amps. This involved many new special circuits, especially those concerned with DCCTs (Direct Current Current Transformers/Transducers). These DCCTs could divide down to 5A but measuring 5A to 1ppm is extremely difficult. Power Coefficient, $PC \neq \Delta T * TC$. !!

The first task was evaluation of the John Pett designed $\Delta\Sigma$at the time I thought that $\Delta\Sigma$ converters could not work to high precision.

The second task was to provide a 10mA current reference very nearly as stable as a 732 is in Voltage. It became a major project to design the Iref2_CERN based on the LTZ1000ACH.

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(Fun in Metrology!)

Current Control....13,000 Amps to 1ppm!

- Magnets Need 13,000 Amps
 - The magnetic strength has to be adjusted as the particles speed up
 - The control accuracy needed is a few parts in a million
 - The calibration accuracy is circa 1 part in a million
 - The reference current used for checking and calibration is the Iref2.

- Metron's tiny bit!
About 40 are used:



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(Fun in Metrology! Some technical answers)

Q: How do you get stability out of \$2 thin film arrays?

A: There's a history to this. At Datron we used to buy matched ratio resistors from top suppliers but their ability to test them and match them for TC was not good enough...They depended on their measurements to hit a ratio spec. This, together with problems from humidity in foil resistors (yes, even trapped humidity in hermetic resistors) caused us hours & hours of rework.

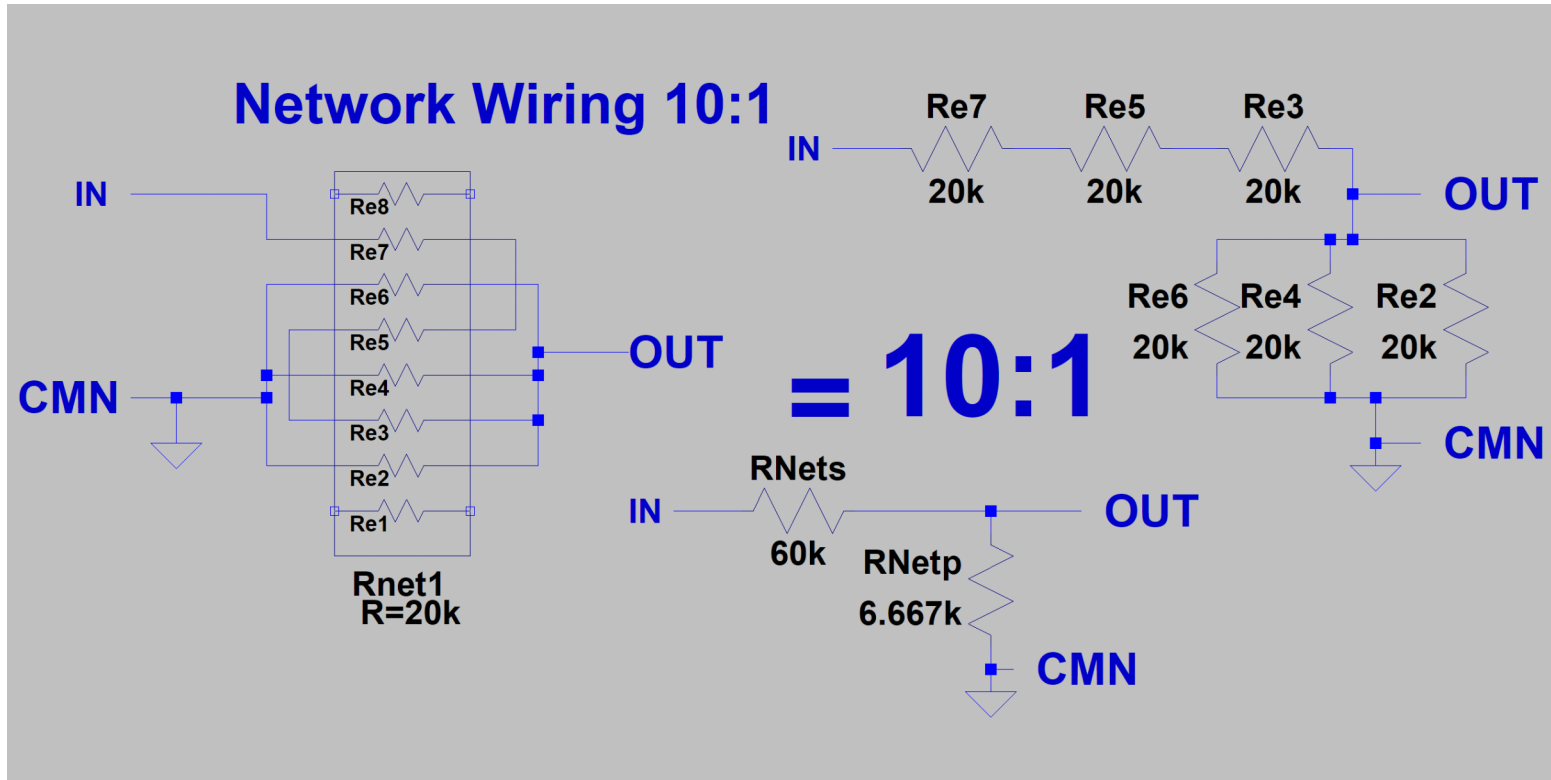
We took the view that we should look for manufacturing processes that would deliver ratio stability inherently. What better than a thin film process with a number of equal value resistors on a single chip if that number could be combined into different ratios through series/parallel arrangements?

Indeed, we could afford to use multiple resistor elements to give a statistical advantage too.

Finally, thin film does not have the humidity problems inherent in foil Especially if passivated NiChrome or Tantalum Nitride is used.

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(Fun in Metrology! Some technical answers)



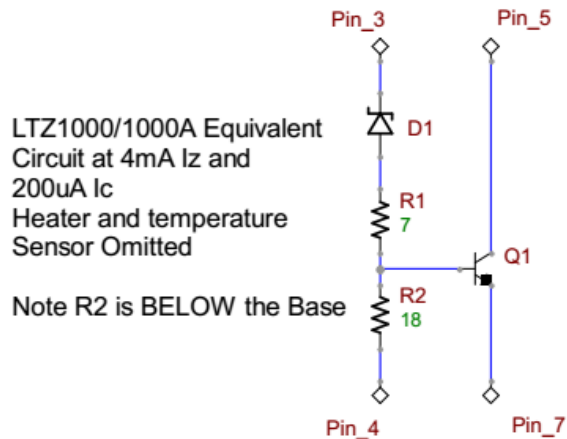
Using 3 networks in parallel the 7000 divides 10V down to 1V with:
 $<0.1\text{ppm}/^\circ\text{C}$, $<0.2\text{ppm}/\text{year}$ and negligible humidity coefficient.

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(Fun in Metrology! Some technical answers)

The LTZ1000 !!

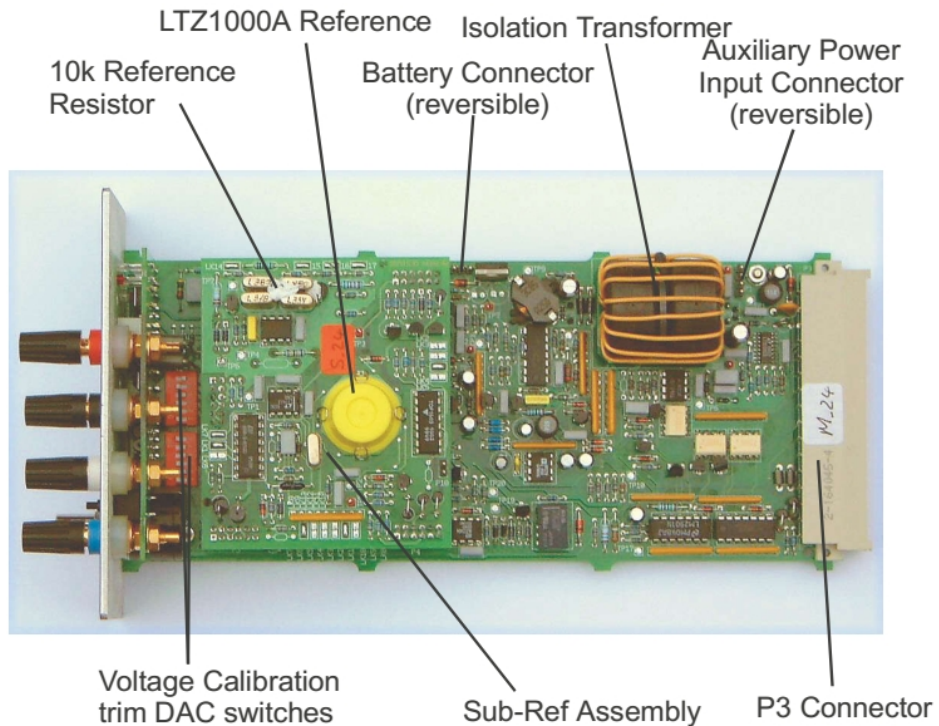
The CERN IRef2 10V & 10mA 1ppm source



D1 TC is about +2.4mV/degC
Q1 TC is about -2.1mV/degC
R1 and R2 are about +0.3%/degC
Pin 4 TC is about -2.3mV/degC
Pin3-Pin7 is about +300uV/degC!!

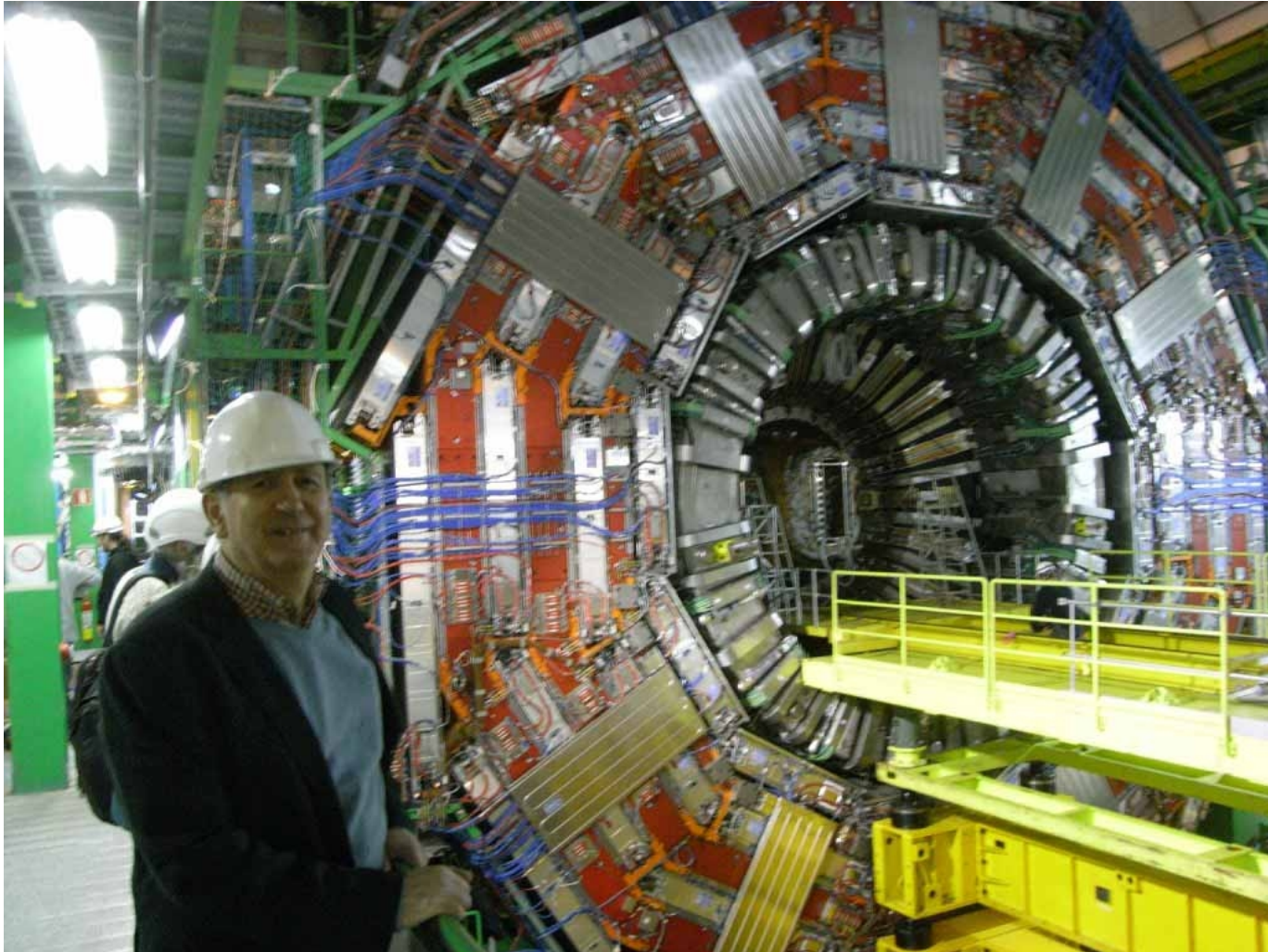
TC unbalance between D1 and Q1
Can be solved by making Q1 into
A V_{be}-Multiplier stage.

PCB Assemblies removed from module



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(Fun in Metrology! CERN CMS Picture)



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(Beware! The Scientific method)

“Science is the Belief in the Ignorance of Experts”*Richard Feynman*

Every theory should be questioned again and again. What we think we know may not be right. (That applies to analogue circuit de-bugging!!!)

Science (and engineers!) today would do well to remember this and keep an open mind.....

The End....JRP

Caution....The Scientific Method

- “Science is the Belief in the Ignorance of Experts”*Richard Feynman*
 - *Every theory should be questioned again and again. What we think we know may not be right. (That applies to circuit de-bugging!!!)*
 - *Science (and engineers!) today would do well to remember this and keep an open mind.....*
 - » *The End....JRP*