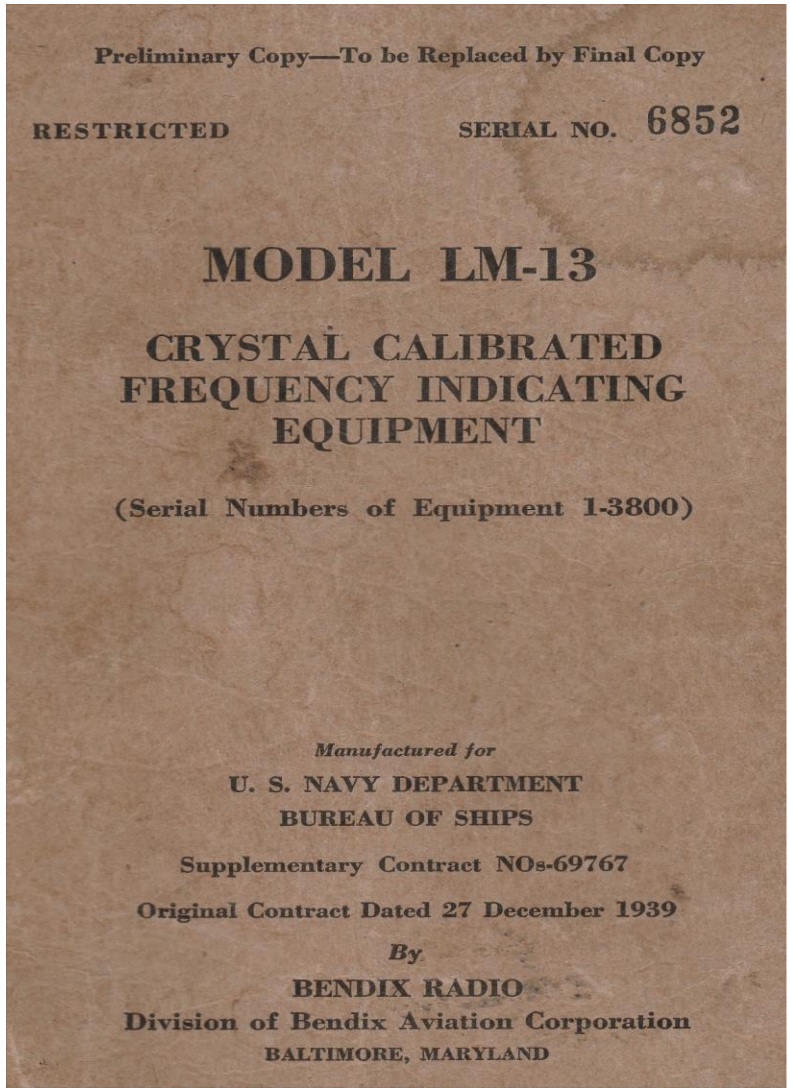
Electronics to Microwaves – some reflections

For me, school in the 1950's was quite an exciting time. I had a scientific bent and our Physics master was a bit of a radio ham and encouraged us to explore electronics. In those days ELECTRONICS was a mixture of "old" and "new". Lots of WWII equipment was surplus after the war and the Model LM-13 was a precision item for measuring frequency - accurate to 1 part per million.
This type of equipment was better than anything new and there were lots of components and kits that could be purchased for modest prices. Yes, the equipment was old but often it had been designed to very high specifications and usually(???) worked.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RESTRICTED SERIAL NO. 6852

MODEL LM-13

CRYSTAL CALIBRATED FREQUENCY INDICATING EQUIPMENT

(Serial Numbers of Equipment 1-3800)

Manufactured for
U. S. NAVY DEPARTMENT
BUREAU OF SHIPS

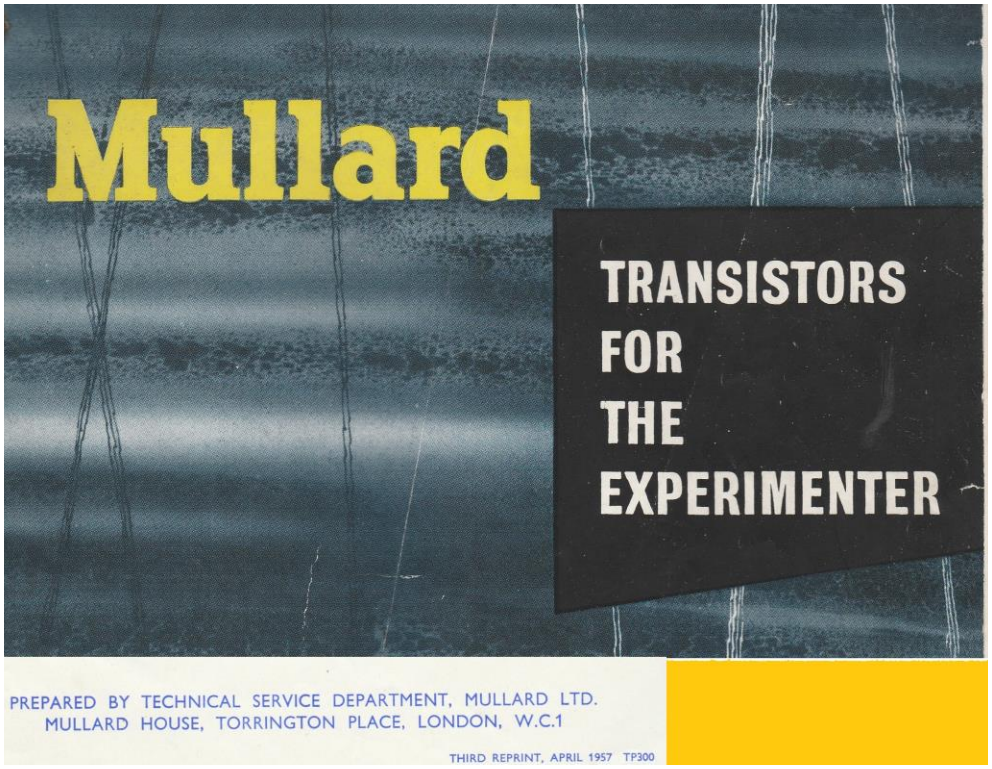
Supplementary Contract NOs-69767

Original Contract Dated 27 December 1939

By
BENDIX RADIO
Division of Bendix Aviation Corporation
BALTIMORE, MARYLAND

However transistors were now being marketed and this was the "new" area of electronics. The Mullard Company had a superb Educational Department at Torrington Place and they generously provided lots of FREE information.

The relief of building a transistor circuit compared to that using valves was enormous. No high voltages to bother about and no more holes to be drilled in aluminium bases to support the valves. It was a designer's dream to be leaving valves behind.



Moving onto University was a slight disappointment as the Physics Department only had a small part of the course devoted to electronics and this was very much the "old" electronics with not a single transistor in sight. Later, I did understand their philosophy as they were focused in detecting very fast cosmic ray pulses at their Observatory at Haverah Park. I'll explain - if one tried to detect a milli-second pulse with a moving coil meter then one may well fail. The meter may "twitch" but you would have to be very alert to notice this. Now, at the end of the 1950's valve circuits had a MUCH, much faster response then any transistor circuit so valves were the preferred option for electronics at Leeds University in the Physics Department. I'm sure they will have changed by now !!

Haverah Park experiment

From Wikipedia, the free encyclopedia

Coordinates: 53.9703417°N 1.6385028°W

The **Haverah Park experiment** was a cosmic ray air shower detection array consisting of water Cherenkov detectors distributed over an area of 12 km^2 on Haverah Park on the Pennine moorland near Harrogate, North Yorkshire. The experiment was operated by University of Leeds for 20 years, and was switched off in 1987.

Air showers of secondary particles generated from a primary cosmic ray hitting the Earth's atmosphere are spread over many kilometres when they hit the ground. An array allows for detection of secondary particles caused by a single cosmic ray at several detectors. The geographic spread of the detectors allows for calculation of the following:

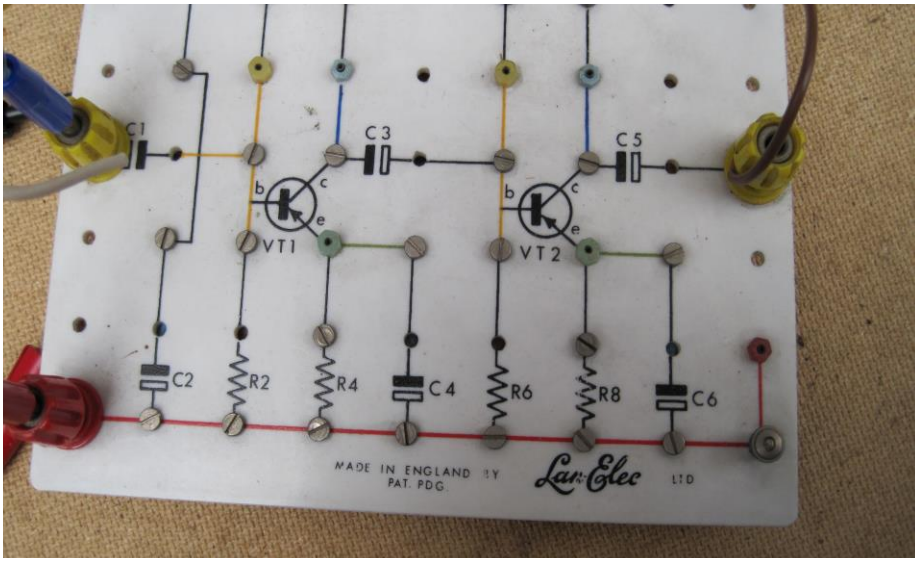
- The total number of particles detected can be used to estimate the number of particles in the air shower and from the model of the energy required to generate those particles, the energy of the primary cosmic ray.
- The difference in the time of arrival of recorded particles at multiple detectors can be used to estimate the arrival direction of the primary cosmic ray.

During its operation, many thousands of cosmic ray events were recorded including four exceptional events with energies over 10^{20} eV. These results were somewhat controversial because they are beyond the GZK limit. Such particles were since observed by other experiments, such as Fly's Eye (Oh-My-God particle) and AGASA.

The water Cherenkov detector array is one of two cosmic ray detection systems used by the currently operating Pierre Auger Observatory.

Instrumentation was basic – moving coil meters, an AVO if you were lucky and a Cossor oscilloscope if you were very lucky.

On teaching electronics, in the early 1970's, things had moved on. Typical Laboratory exercises most definitely used transistors:

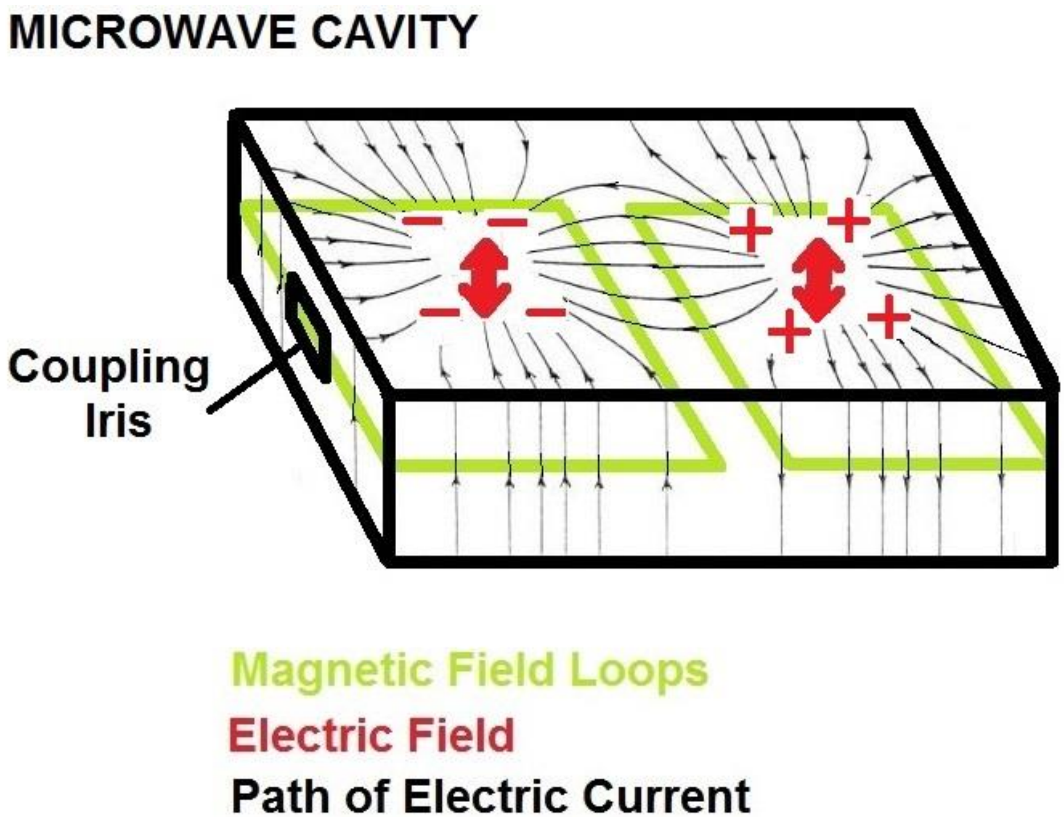


But then integrated circuits took over and the beloved OP AMP simplified the teaching approach to analogue electronics.

The story unfolds in a very rapid way in the 1960's, 70's and 80's and, if you wish, you may consult an article "100 years of Electronics 1904 – 2004" This is on the previous page. More details of how circuits are made is given on www.methodbook.net and go to electronics tab.

Now MICROWAVES started out as a different story.

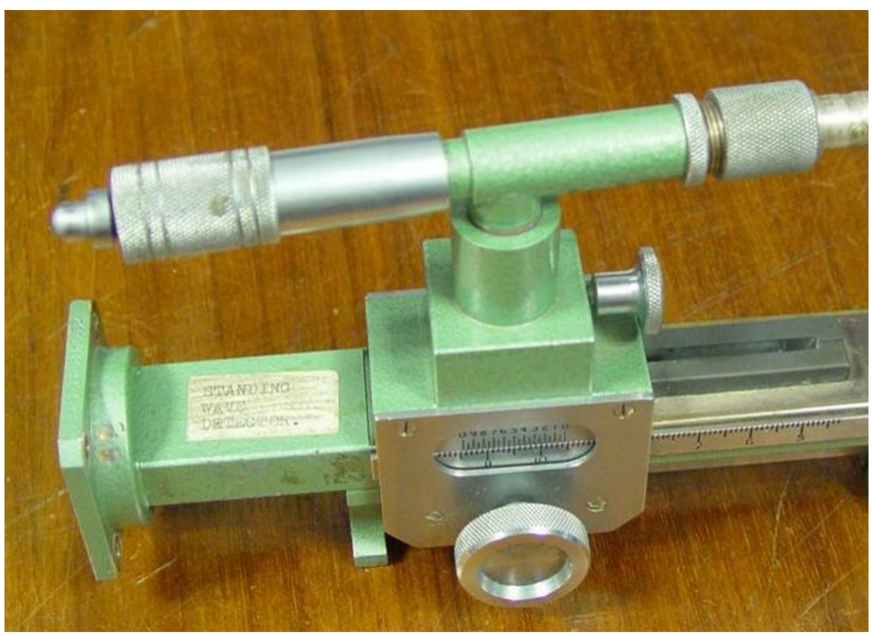
Radar had played such an important role in WWII and a great deal of information had been accumulated. The USA governments were very generous in allowed much of this material to be published and the 20 volume series from the Radiation Laboratory provided a starting point for anyone wishing to embark on a career in this area.
Lengths of waveguide were used to make circuits linking all the components together and it was more akin to plumbing then linking "normal" electrical components (resistors, inductors, capacitors, etc…)together with a soldering iron. Sources of radiation were mainly from Magnetrons or Klystrons though Gunn Oscillators were just beginning to appear. Amplifiers were a difficult item and rather specialist devices were used -- Maser (microwave amplification by the stimulated emission of radiation) and parametric amplifiers.
A resonant circuit at microwave frequencies does look very different from the resonant LC circuit used at lower frequencies:-



Electric and magnetic fields are contained in a metal box and the current flow in the box sides will cause accumulation of charge on the top and bottom surfaces. Energy is extracted from the hole at the end called the coupling iris.

A .T. Starr (Radio and Radar Techniques, Pitman, 1952) calculates, on page 178, a theoretical value of Q factor as 52,000 with measured values above 40,000. This value is far in excess of Q-factors achievable at low frequencies.

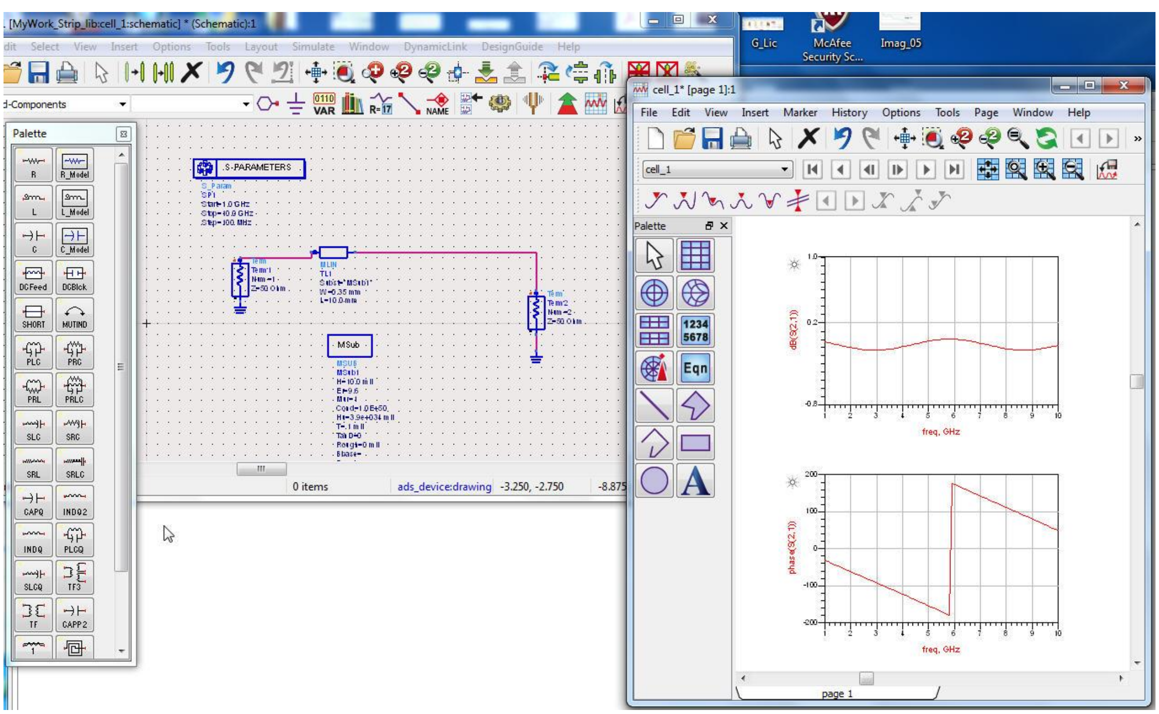
One of the most useful pieces of instrumentation up to the 1970's was the Voltage Standing Wave Ratio unit. This could test the reflection from a Device Under test, DUT, and ascertain if it was matched to the transmission line.



In our area of the UK (North West) Jodrell Bank Observatory had a big microwave dish which was doing it's bit to turn swords in to plough-shares. It was almost due to be moth-balled for lack of money in the late 1950's and then Sputnik was launched. Everyone could detect Sputnik as it was broadcasting
" I'm Here, I'm Hear…." at short-wave frequencies in the popular amateur bank. But Jodrell bank, in radar mode, detected the spent rocket shells as they plummeted to earth invisible to everyone else. Overnight our Observatory was a hit as we now had capabilities to detect incoming MISSILES which would ***certainly not*** be transmitting
" I'm Here, I'm Hear….". Sir Bernard no longer had money problems.

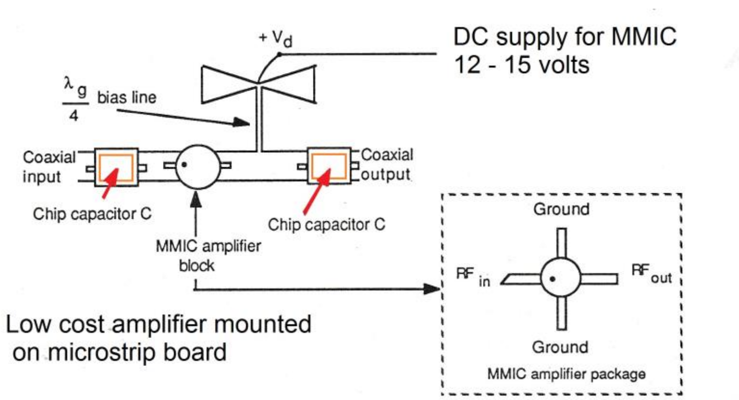
Space communications (plus Military and Industrial requirements) has driven microwave techniques forward at a very fast pace. Microstrip technology (please see "Foundations for Microstrip Circuit Design" by T. C. Edwards, Wiley 1981) and many subsequent texts – also Mike Hoshings presented a readable account in Electronics World (Wireless World) April 1994 p 276) moved the subject away from waveguides. It was noted previously that electronics had changed from valves to transistors and this was greeted with much relief. Perhaps the same can be said about Microstrip circuits replacing Waveguide circuits; it opened the doors to many commercial opportunities.
Microwave amplifiers using Gallium Arsenide transistors can operate happily in the GHz range and anyone knows that positive feedback applied to an amplifier will produce an oscillator.
Thus both active and passive microwave circuits were immediately possible with microstrip circuits. The varactor tuned oscillator was a relatively easy device to construct.

Simulation tools from Agilent/ Keysight have greatly simplified circuit design.



The very simple circuit above is a microstrip line with width 0.35 mm and length 1 cm. The top graph shows an attenuation of about 1 dB but that, with a rerun of the simulation with w = 0.2 mm we find a perfect transmission. The phase shift is about 360 degree at 10 GHz and this is to be expected. Although the free-space wavelength is 3 cm the strip-line board has a permittivity of 9.6 so wavelength will be compressed to about 1 cm. Thus a 1 cm strip will give about 360 degrees. (you can always check your calculations with the simple calculator on www.micowave101.com - this is a wonderful web-site with a vast amount of information about microwaves and many other topics)

Miniaturisation has been possible with MMIC's (monolithic microwave integrated circuit) and therefore the boundary from electronics to microwave has become blurred. A printed circuit board (pcb) in electronics has a lot in common with a Duroid microwave circuit board as given below.
A typical amplifier would be constructed as follows:



A 50 ohm microstrip line has three spaces – two blocking capacitors are soldered into two of these places, as shown. The MMIC amplifier is soldered into the middle space and ***through connections*** are made from to the ground pins to the earth plane on the underside of the board. The DC power is supplied using a high impedance quarter wavelength line which is terminated in a low impedance "butterfly stub. This bias technique prevents any signal being lost from the 50 ohm

Coaxial leads can be connected to the board using re-usable SMA to board clamps as illustrated in Figure 9.

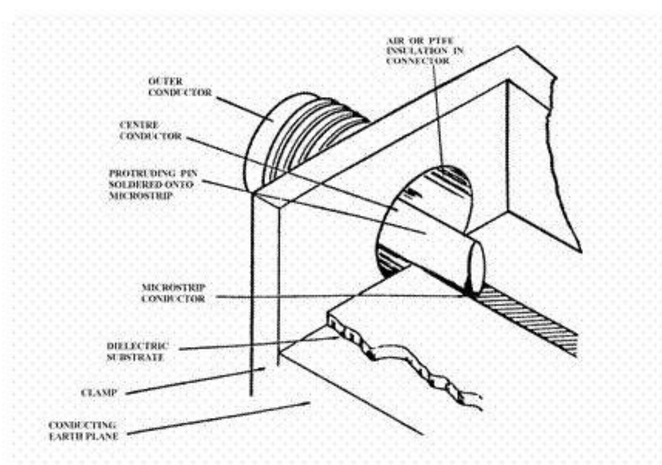
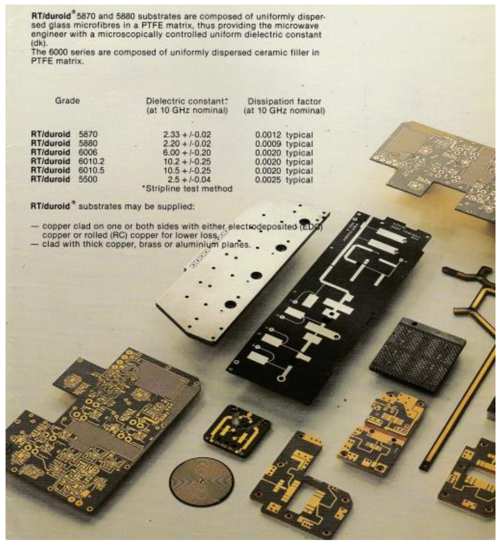


Figure 9. Coaxial to board clamps

line. Adaptors – coax to strip – are then solder onto each end of the line.

All manner of circuits can be laid out in this way and Duroid boards are frequently used as they have low losses (below, listed values of the dissipation factor is very low)


RT/duroid® 5870 and 5880 substrates are composed of uniformly dispersed glass microfibres in a PTFE matrix, thus providing the microwave engineer with a microscopically controlled uniform dielectric constant (dk).
The 6000 series are composed of uniformly dispersed ceramic filler in PTFE matrix.

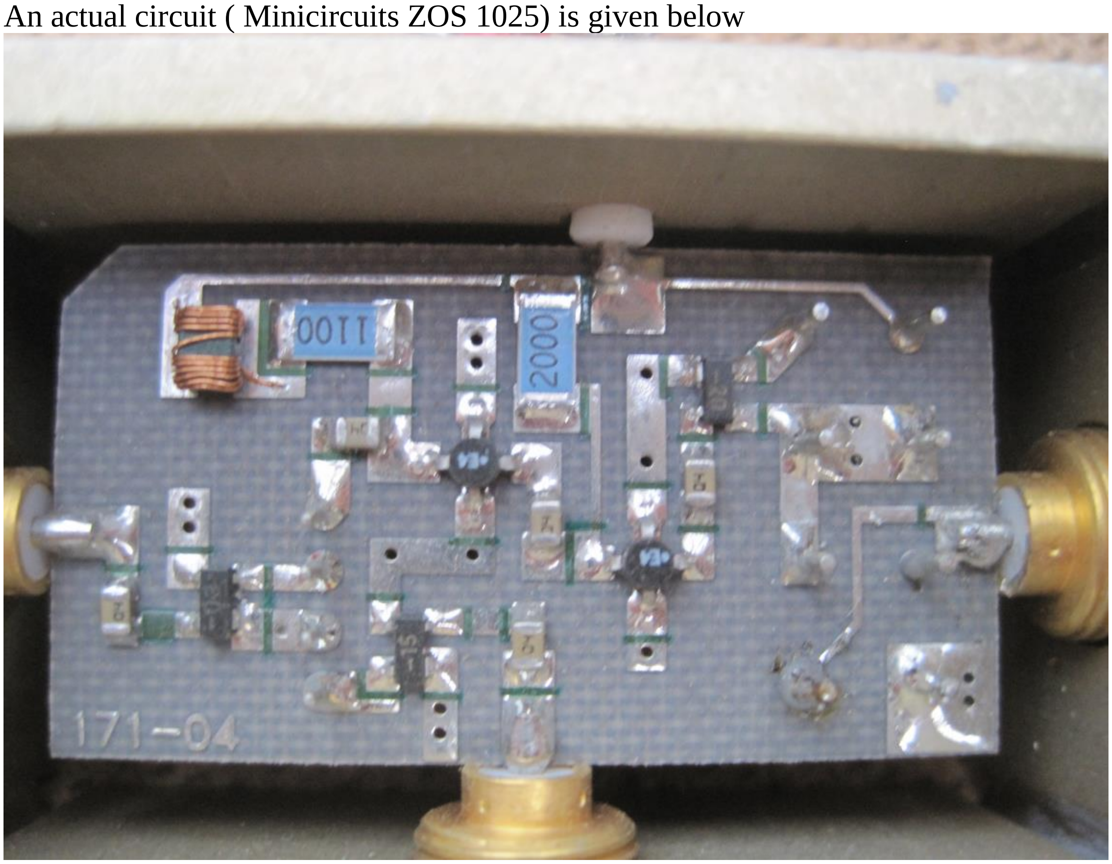
Grade	Dielectric constant* (at 10 GHz nominal)	Dissipation factor (at 10 GHz nominal)
RT/duroid 5870	2.33 +/-0.02	0.0012 typical
RT/duroid 5880	2.20 +/-0.02	0.0009 typical
RT/duroid 6006	6.00 +/-0.20	0.0020 typical
RT/duroid 6010.2	10.2 +/-0.25	0.0020 typical
RT/duroid 6010.5	10.5 +/-0.25	0.0020 typical
RT/duroid 5500	2.5 +/-0.04	0.0025 typical

*Stripline test method

RT/duroid® substrates may be supplied:

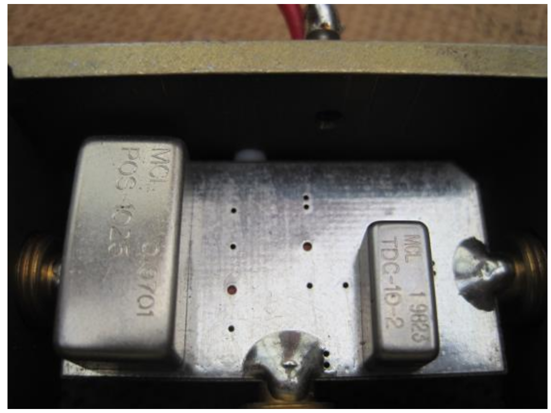
— copper clad on one or both sides with either electrodeposited (EDC) copper or rolled (RC) copper for lower loss,
— clad with thick copper, brass or aluminium planes.

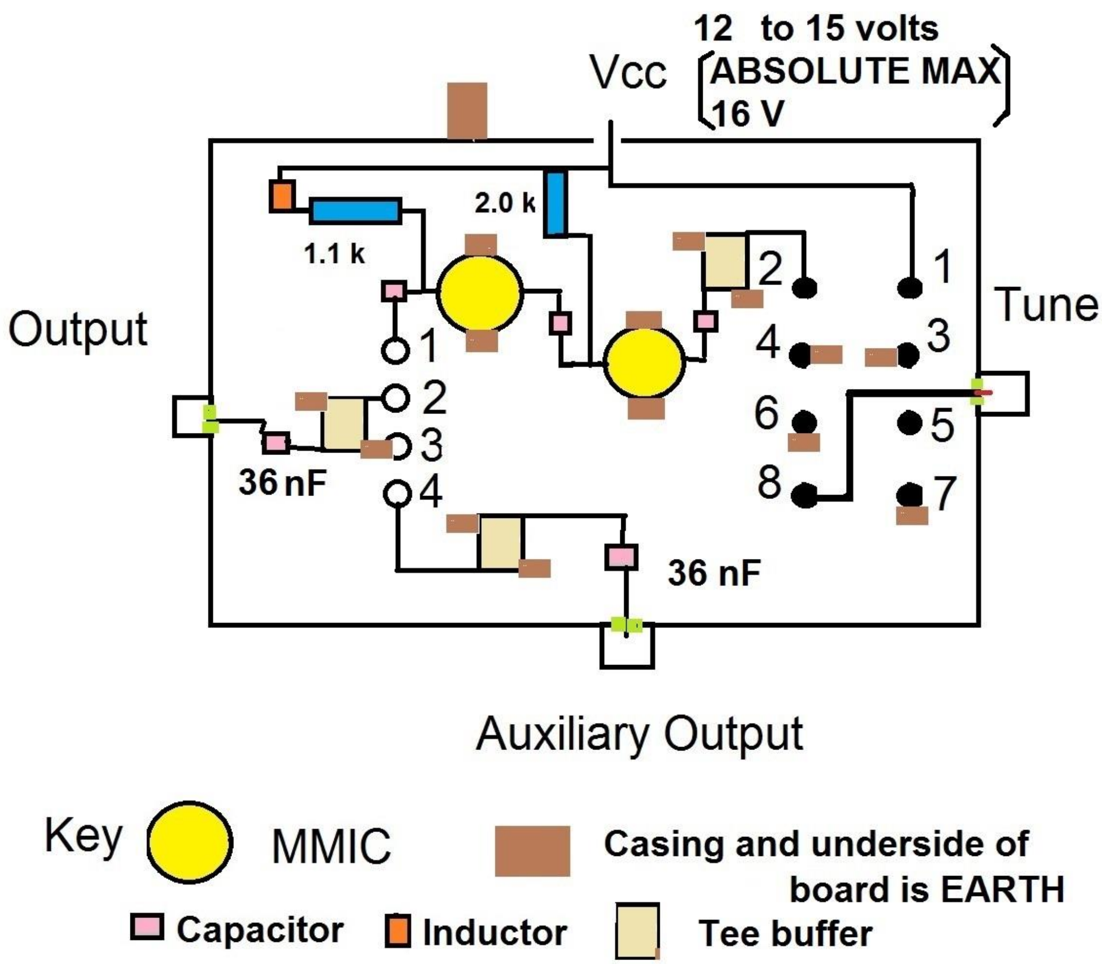
An actual circuit (Minicircuits ZOS 1025) is given below



This is based on a varactor tuned oscillator (VTO) POS 1025 with an amplifier stage and a directional coupler (DC) to give an auxiliary output. The underside of the board houses the VTO and the DC,

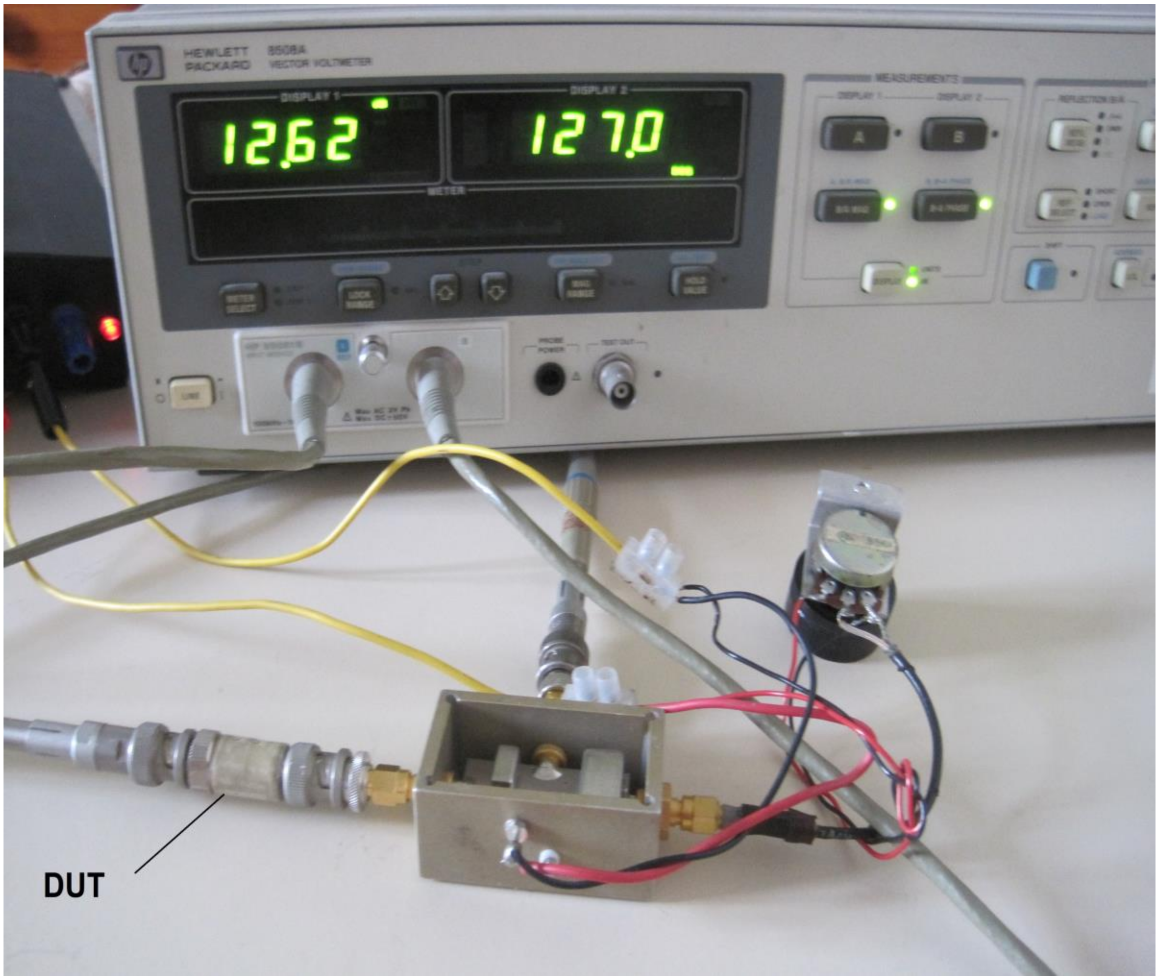
A circuit may be drafted out as follows





I was unable to obtain circuit details from MINICIRCUITS but the capacitors (which were measurable as they had one open terminal) were 36 nF so I assume they will all be the same. A Tee attenuator (perhaps 3 dB) is likely to be used for buffering. The Tee devices have good 50 ohm impedance characteristics and, should there be slight mismatch, then the standing wave is lessened by multiple passages through the attenuator. The two MMIC will be something like the MAR or MAV monolithic amplifiers. MMIC’s are devices where much of the troublesome matching has been done on the chip and therefore the MMIC can be placed directly onto a 50 ohm line.

The ZOS 1025 device has proved useful as it easily connects to a Hewlett Packard vector voltmeter, HP 8508, to give a vector analyser, ZOS has a good frequency range of 685 MHz to 1025 MHz which matches the top end of the vector voltmeter:



The auxiliary output is connected to channel A and then channel B is connected to the main output. Any component placed on the this output line is likely to cause attenuation and phase shift and the two display windows can record these parameters.

Instrumentation for electronics or microwaves has moved at an equally rapid rate. Several years ago I purchased this item as an add-on for a PC from PICO. "Your PC becomes an oscilloscope!" The company has gone from strength to strength largely because PC's have undergone astonishing advances in the last few decades. The Company now offers a large range of add-on and a Vector Analyser, VNA 106, for about £4000. This Analyser is capable of measurements up to 6 GHz. (www.picotechnology.com).

If one require only scalar measurements the SA44 and TG44 from Signalhound is very cost effective. (www.signalhound.com).
The Bode 100 is another excellent product from Omicron (www.omicron.com).
Countless other instrumental packages are available for attaching to a PC by the USB port and it is obviously a great advantage for the experimenter – a much better display, data storage and manipulation uses the immense power of the PC. National Instruments (www.ni.com) have even gone a stage further in that "virtual" instruments are supported ON the PC. We do always keep Keysight (etc..) in our minds www.keysight.com .

Over less than a lifetime the progress in electronics and microwaves has surpassed all expectations and this must be the same in many scientific, engineering, medical, metrological, aviation and space, etc….. fields. For many of these areas it is the display of REAL-TIME imaging that has helped to propel the disciplines to new heights

As a final thought, waveguides are still used for specialist instrumentation, for instance, Electron Paramagnetic Resonance relies on high-Q cavities so waveguides have to be used. Also, the Magnetron has found a niche as an energy source with Microwave cookers. However, the miniaturisation of microwaves has been important in consumer satellite TV and other areas and may well be needed if self-drive cars are to become commonplace on our roads.

There are exciting times ahead for electronics and microwaves.