76 GHz and above
Our experiences so far

Part 1

Roger Ray G8CUB
Chris Whitmarsh G0FDZ

What are the highest frequency millimetre wavebands?

76 GHz	4 mm
122 GHz	2.5 mm
134 GHz	2 mm
241 GHz	1.2 mm

How many UK amateur's are operational on these bands?

- 76 GHz there are six stations equipped
- No stations on 122 GHz (due to poor propagation conditions)
- On 134 GHz there are two of us and three more due very soon
- No one on 241 GHz (but hopefully two soon)

So what are the plus points of these bands?

- New microwave territory with largely unexplored frequencies, in particular above 100 GHz
- Use techniques some of which are unfamiliar at lower microwave frequencies
- Generally you have to build the equipment or modify commercial

And how about the negatives?

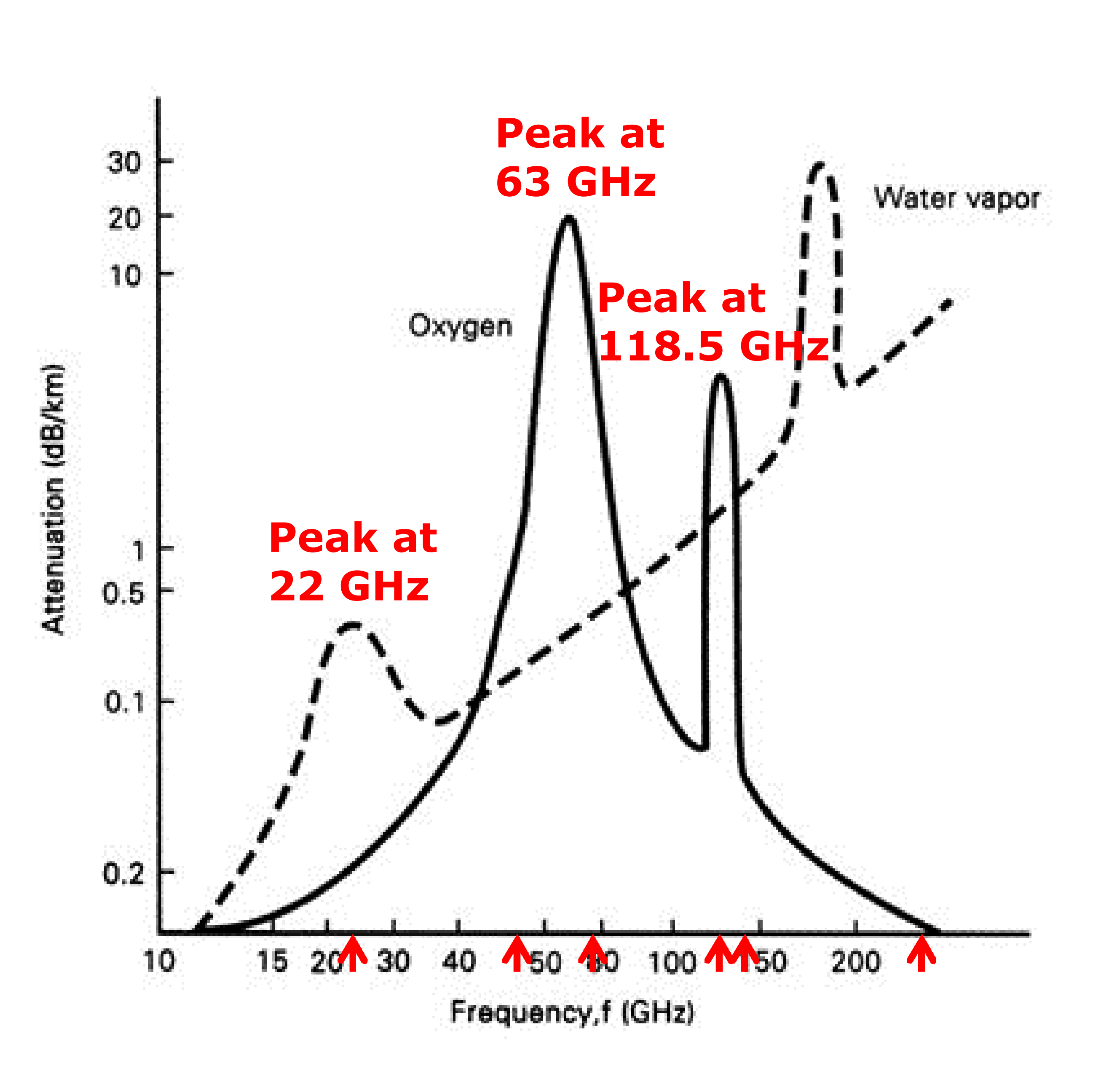
- Not a great deal of published info and designs available to the amateur for the highest frequencies
- Water vapour and oxygen atmospheric losses can be high at some frequencies
- Components can be difficult to acquire at times and can be expensive
- Need more stations to be operational
- Some experience on lower microwave frequencies is highly desirable

But…

- There is a great deal of personal satisfaction to be had from getting going on the millimetre wavebands and having a go at something new
- Much more to be learnt from the bands both with regard to equipment & propagation
- These high frequency bands will be a new area of the spectrum for upcoming technical developments – even above 300GHz

Propagation

- Propagation is very much 'line of sight' on the higher frequencies.
- Atmospheric water vapour and oxygen can have severe detrimental effects on propagation at some millimetre wave frequencies
- Much still to be discovered about propagation on these frequencies



Water and Oxygen losses at millimetre waveband frequencies

Amateur bands

What can you do about the path losses?

- With oxygen losses there is nothing that can be done
- Water vapour varies considerably and this can decide the best time for working long distances.
- The relative humidity varies by temperature and the method to determine the lowest loss is to use the dew point which can be calculated from the relative humidity and temperature.
- The dew point is always lowest in the winter

How can you measure the relative humidity and calculate losses?

Luckily, modern electronic hygrometer devices make measuring humidity easy these days.

These devices are all available from Maplins

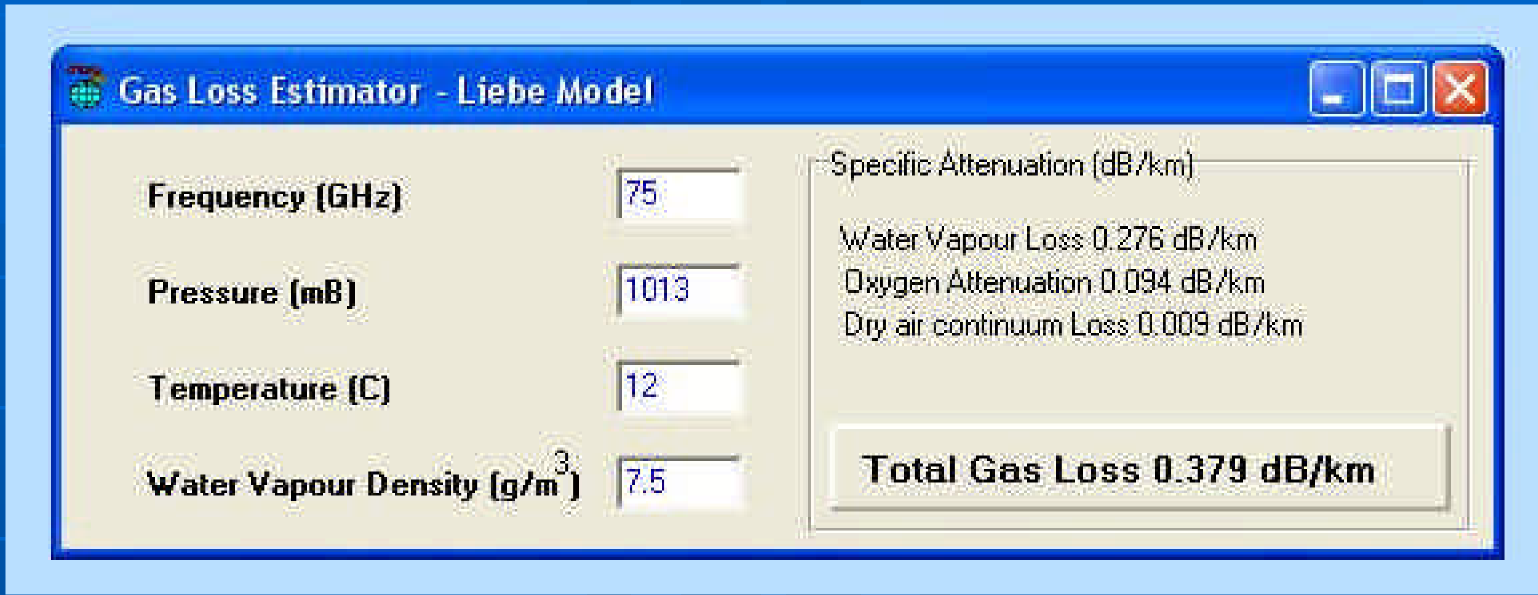
An Android mobile phone app is available to enable dew point to be quickly and easily determined

How can you calculate the path loss?

Computer programs such as G0MJW's 'Gas Loss' make the job of determining absolute humidity and ultimately the total path losses easy. It calculates the water vapour and oxygen losses and then the total path extra loss per km is given.

Total path loss (dB) = Free space path loss + oxygen losses + water vapour losses + extra water vapour losses due to rain or fog along the path.

How can you calculate the path loss?

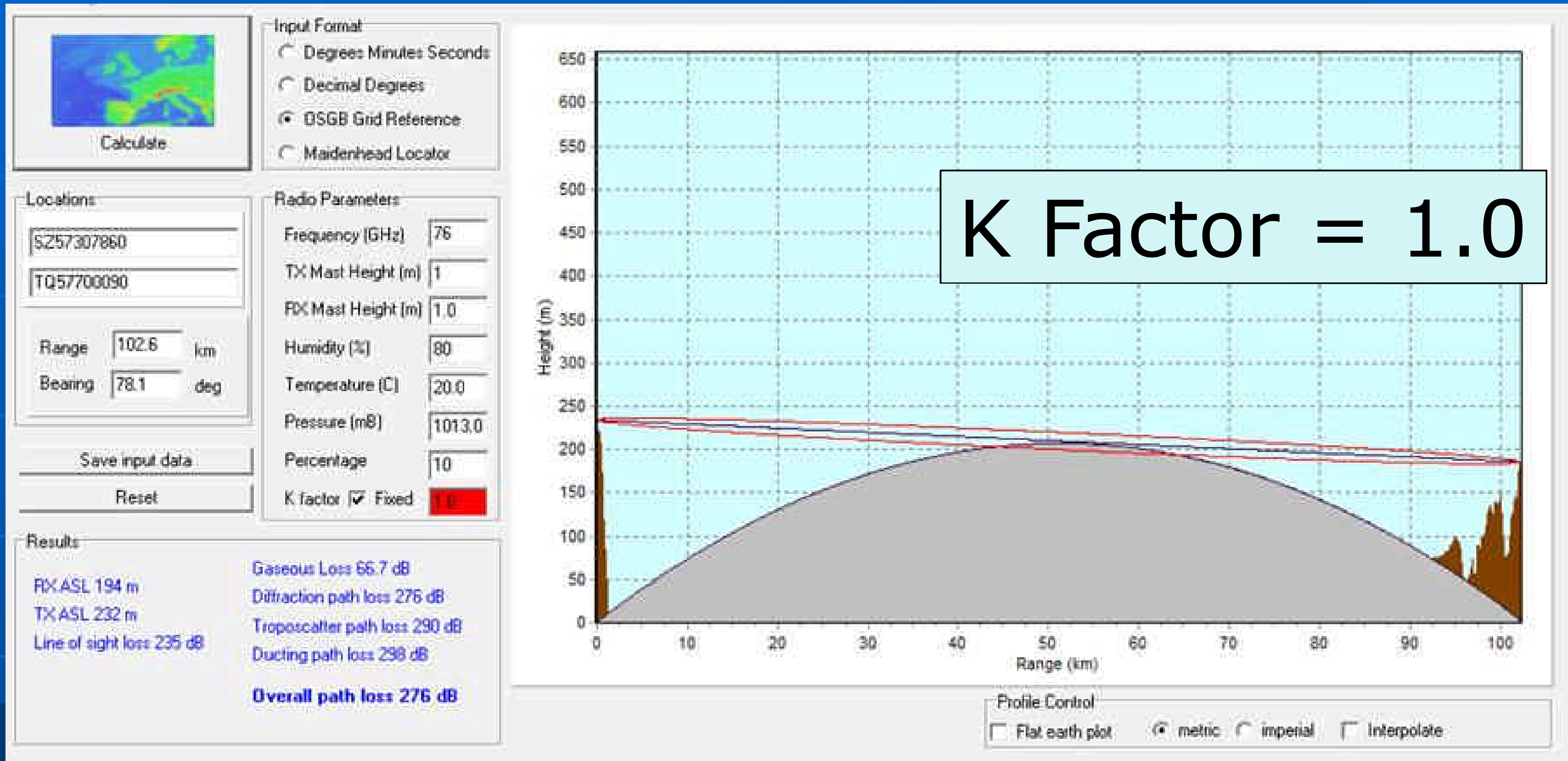


The absolute humidity (amount of grams of water per cubic metre of air) can be derived from the relative humidity (meaning relative to the temperature) by using conversion programs. Thus warm air can therefore hold more water vapour than cooler air so operating when it very cold is the best time for the lowest losses

K Factor of 1?

- For lower frequency microwaves it is safe to use a K Factor of 1.3 but, for the higher millimetre wavebands we certainly need to look at using a K Factor of nearer to 1.0 which is optical
- For the higher frequency bands we are therefore usually looking at true line of sight paths

Path Checking



We can use software such as G0MJW’s radio path checking package to see if we have sufficient clearance due to the curvature of the earth and obstructions such as hills. Here this 100 km potential path from Willingdon Hill to the Isle of Wight is very marginal on 76 GHz.

Any beacons to provide signals?

- There are proposals for UK beacons operating at 76 and 134 GHz from the Cheltenham area but neither are operational yet
- Highly desirable therefore to have some form of local signal source available for receiver and antenna checking

Talkback & Path Plotting

- Radio talkback is essential and for distances up to 50 kms a few Watts of 144MHz SSB and an HB9CV antenna is OK and for shorter distances the use of 144.775 MHz FM has been used
- The technique of path plotting on OS maps before the contact is tried, is very useful for the higher frequencies
- Enables land features to be recognised from the map and identified when viewed through a rifle sight fixed to the equipment and which is used to enable the correct alignment of the antenna

The high bands ?

- The highest frequency millimetre wavebands will use either direct (fundamental) mixers, sub-harmonic mixers or multipliers from lower frequencies
- The more power generated gives the highest chance of making long distance contacts, and also the use of CW over SSB will make equipment easier to construct and will offer longer range but FM can often provide a useful speech mode when signals are strong
- Often better to use the sub-harmonic or fundamental mixer for receive and have a separate multiplier for transmit, as higher power is more likely to be obtained than the power from a basic transverter

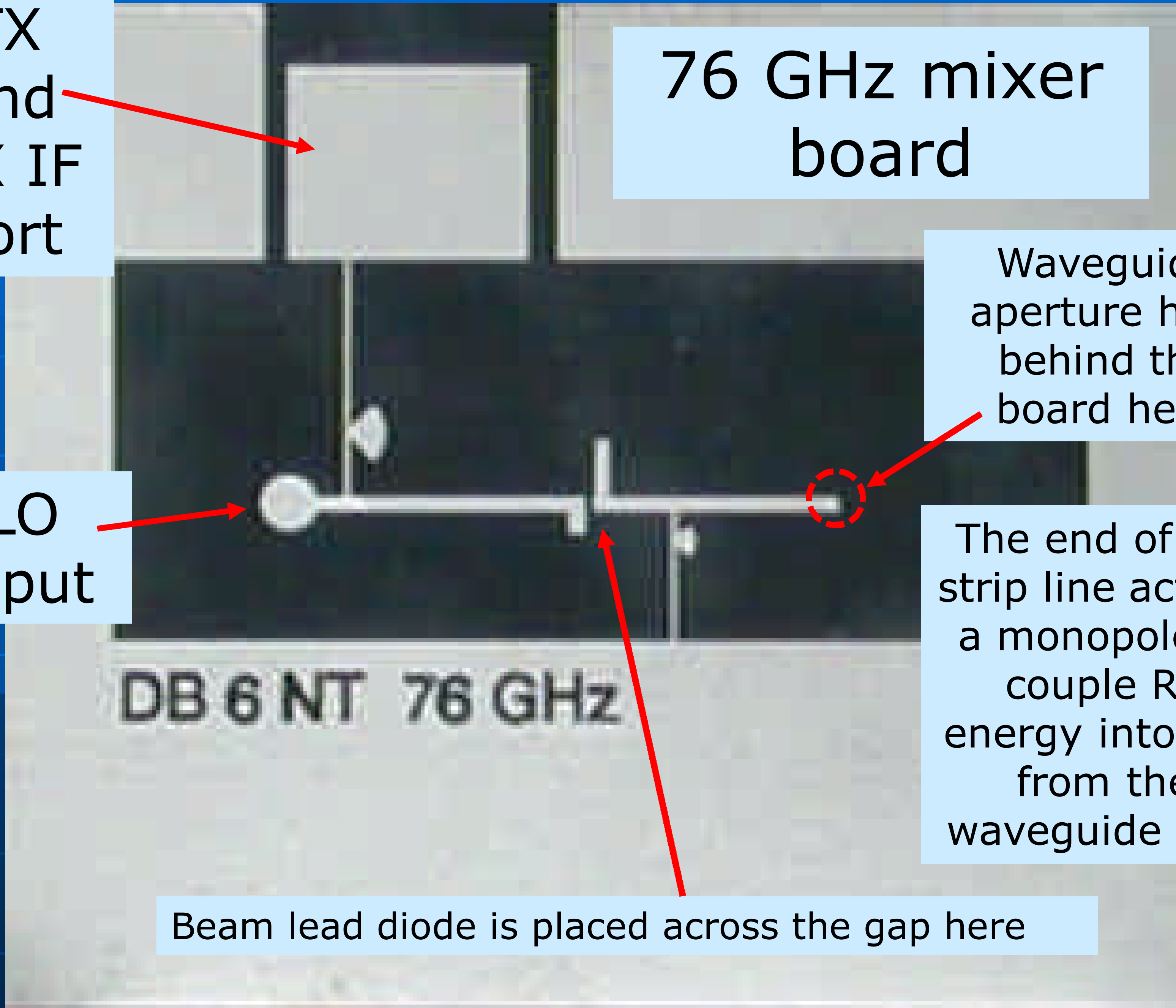
76 GHz - 4 mm

- Our typical equipment uses a DB6NT type sub-harmonic mixer design but output power is only about 250 µW at best
- We use the 2nd harmonic of a 38GHz LO for the mixer
- A nice x3 or x4 multiplier to 38 GHz is obtainable from Germany for a very reasonable cost and makes the LO much easier to construct than trying to built a 9.5 GHz to 38 GHz x4 multiplier from scratch
- Image rejection filter now obtainable from DL2AM for 118 Euro
- LO frequency accuracy, stability and jitter starts to become a real issue

76 GHz - 4 mm

- For antennas, some 50 & 60 GHz dielectric horns have been found to provide good performance at 76 GHz. One type was found to be just as good as the 76 GHz Procom dish and much cheaper!
- Also some 50 GHz link dishes have also been found to work well at 76 GHz
- Use of surplus RF commercial units for parts of the LO chain can make building a transmitter/transverter much easier
- However for a receiver IF, the choice of IF tuning range may be restricted (such as having to use 440 MHz instead of 432 MHz) when using these modules for the receiver LO or as a transmitter frequency generator
- 75.976 GHz is the UK sub band

76 GHz mixer board



TX and RX IF port

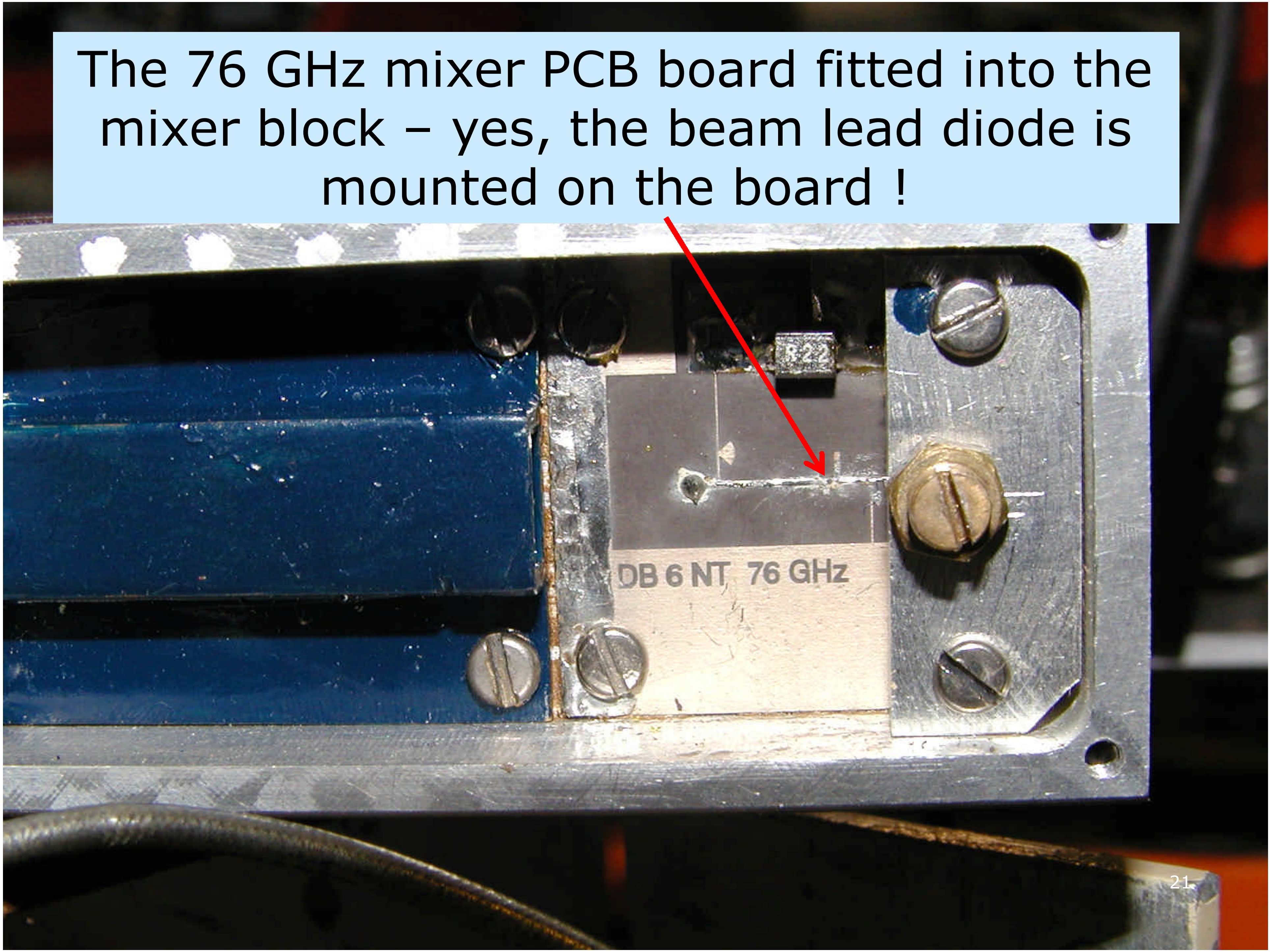
LO input

Waveguide aperture hole behind the board here

The end of the strip line acts as a monopole to couple RF energy into and from the waveguide hole

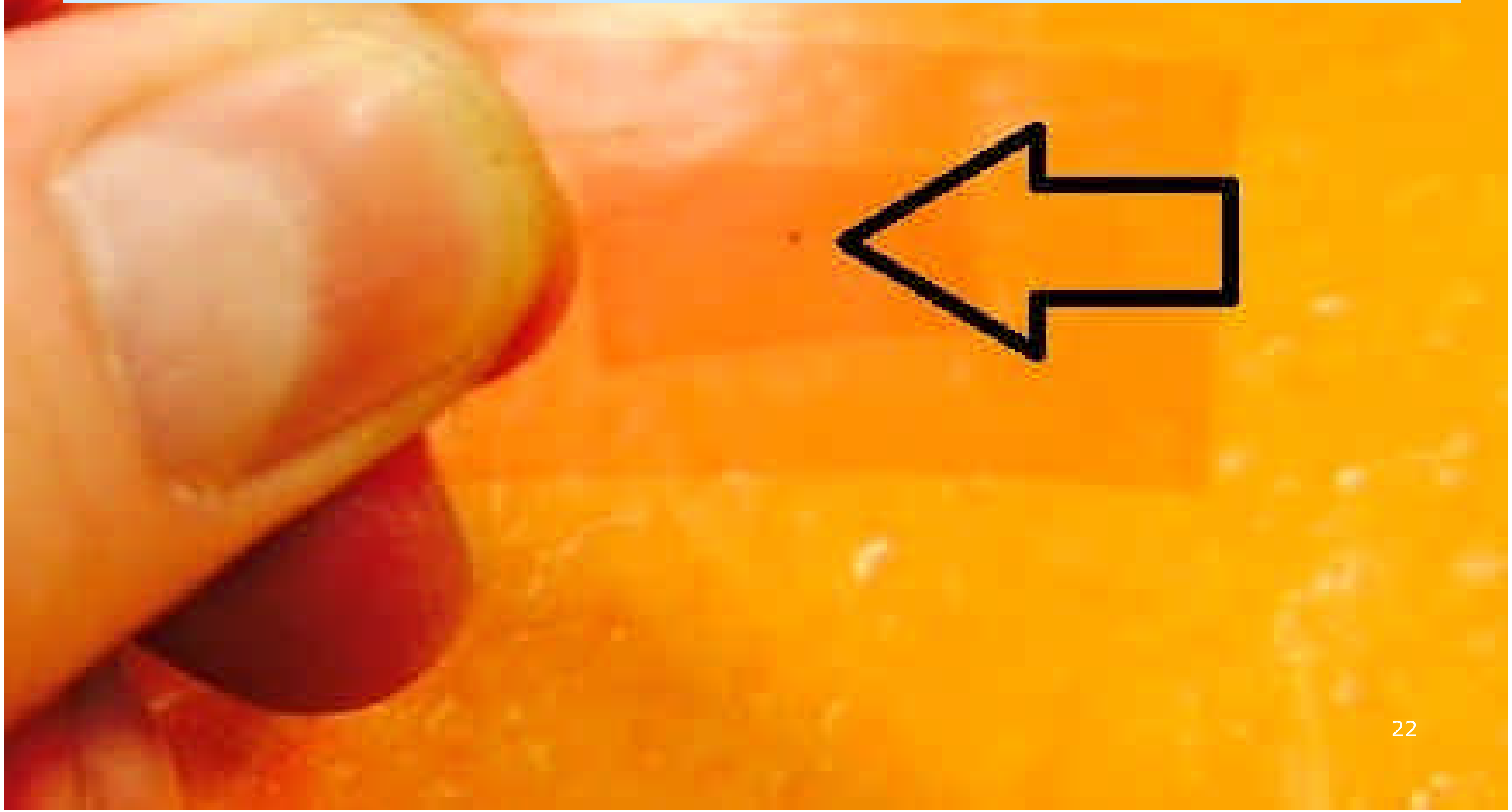
Beam lead diode is placed across the gap here

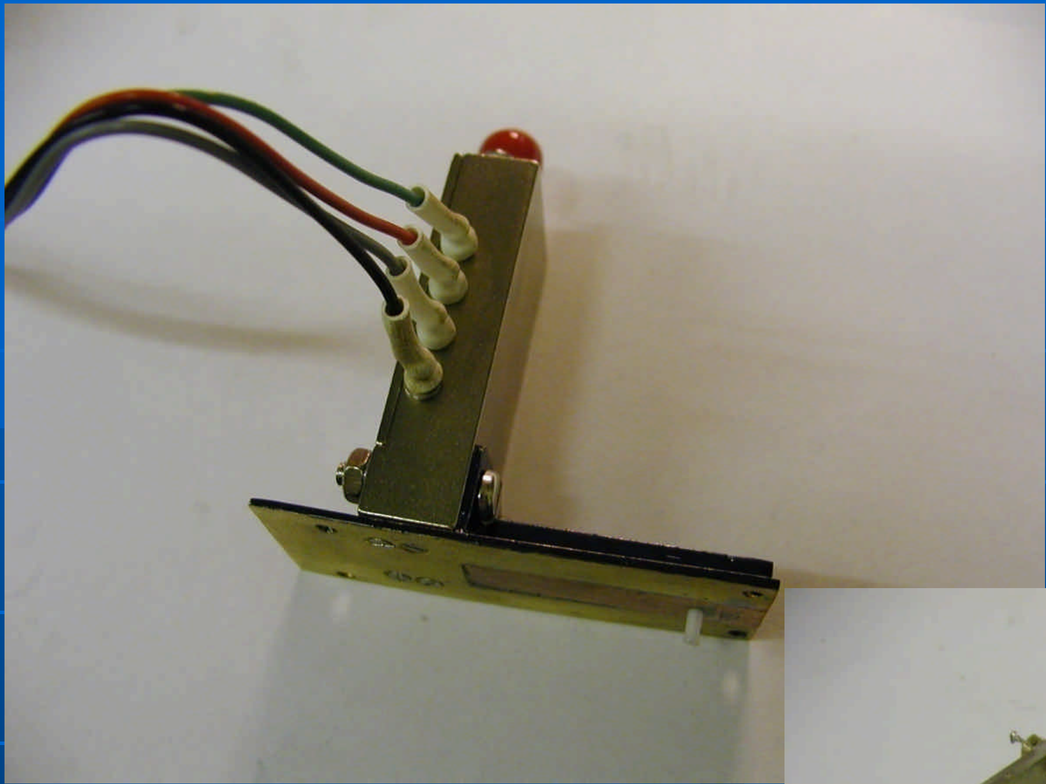
The 76 GHz mixer PCB board fitted into the mixer block – yes, the beam lead diode is mounted on the board !



Here is what it looks like – the sample shown is sandwiched between two sheets of anti-static plastic.

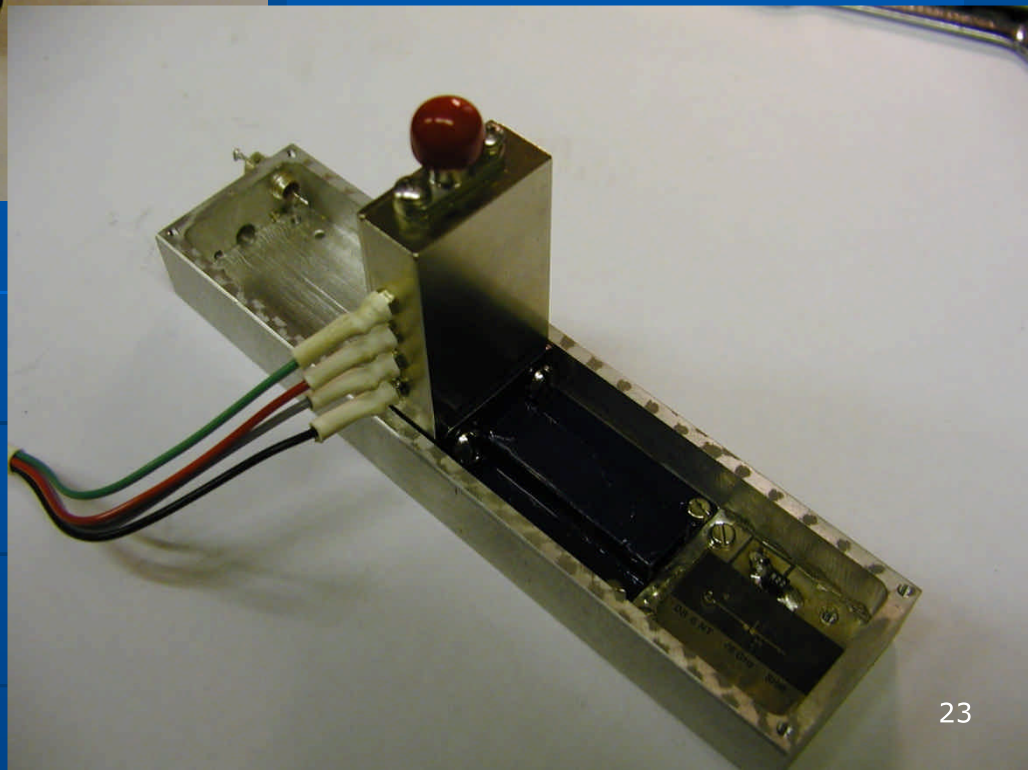
It's the size of a small full stop !!





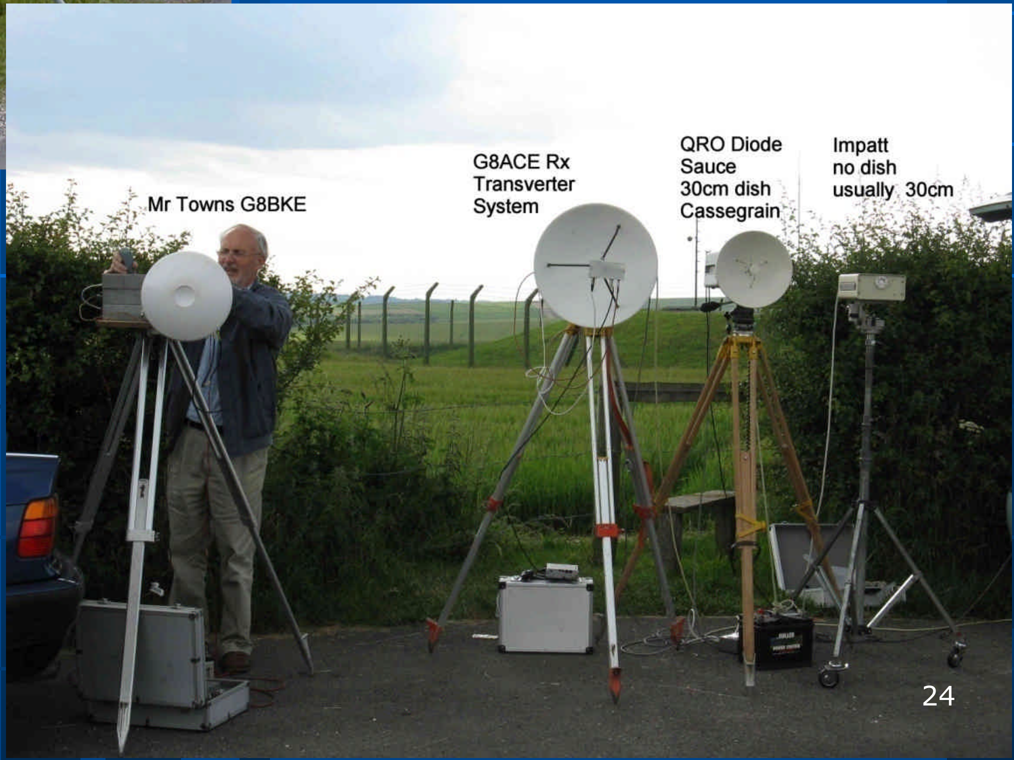
A 38 GHz LO multiplier fixed to a waveguide adapter

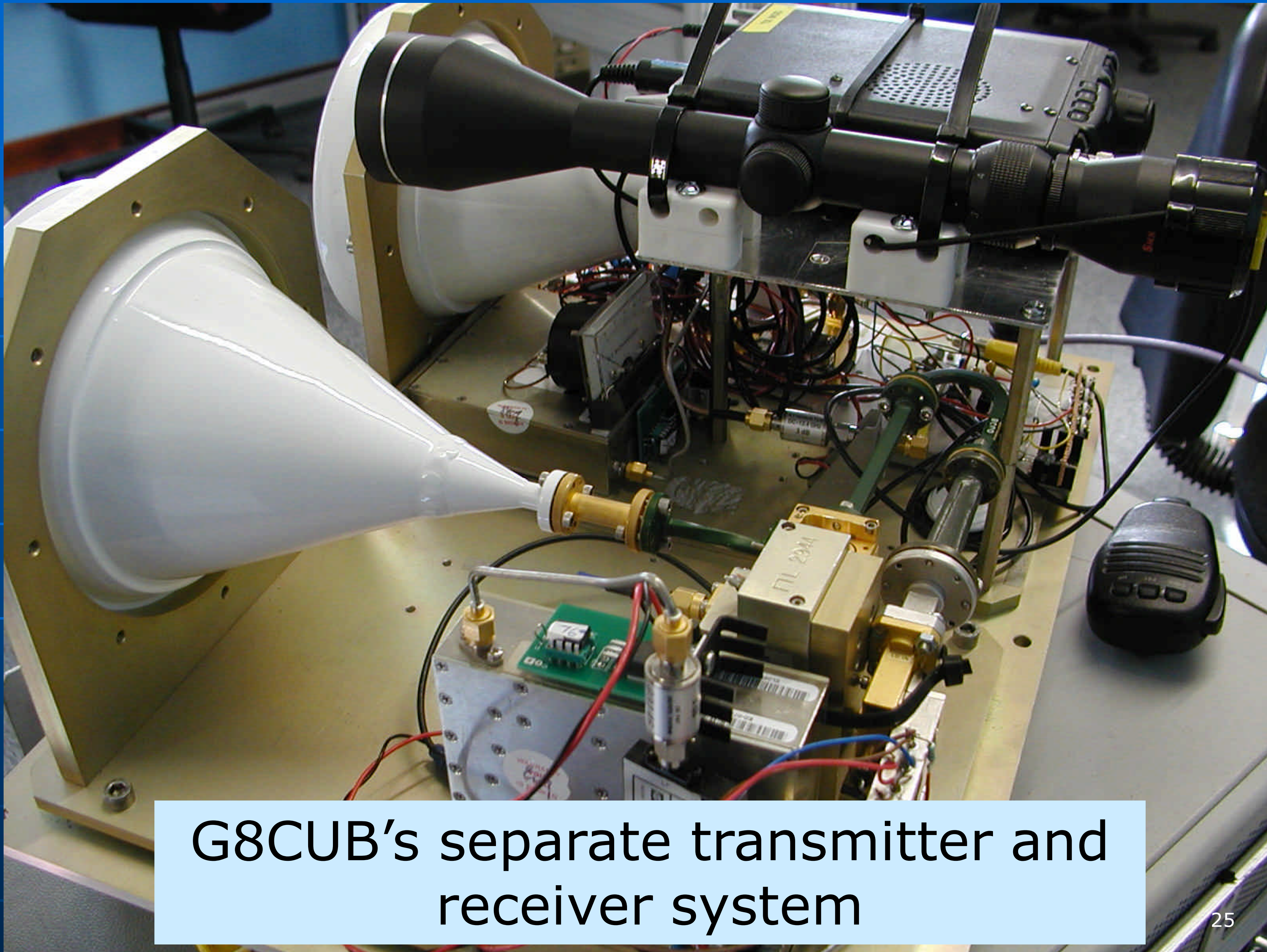
The 38 GHz multiplier fixed to the 76 GHz mixer



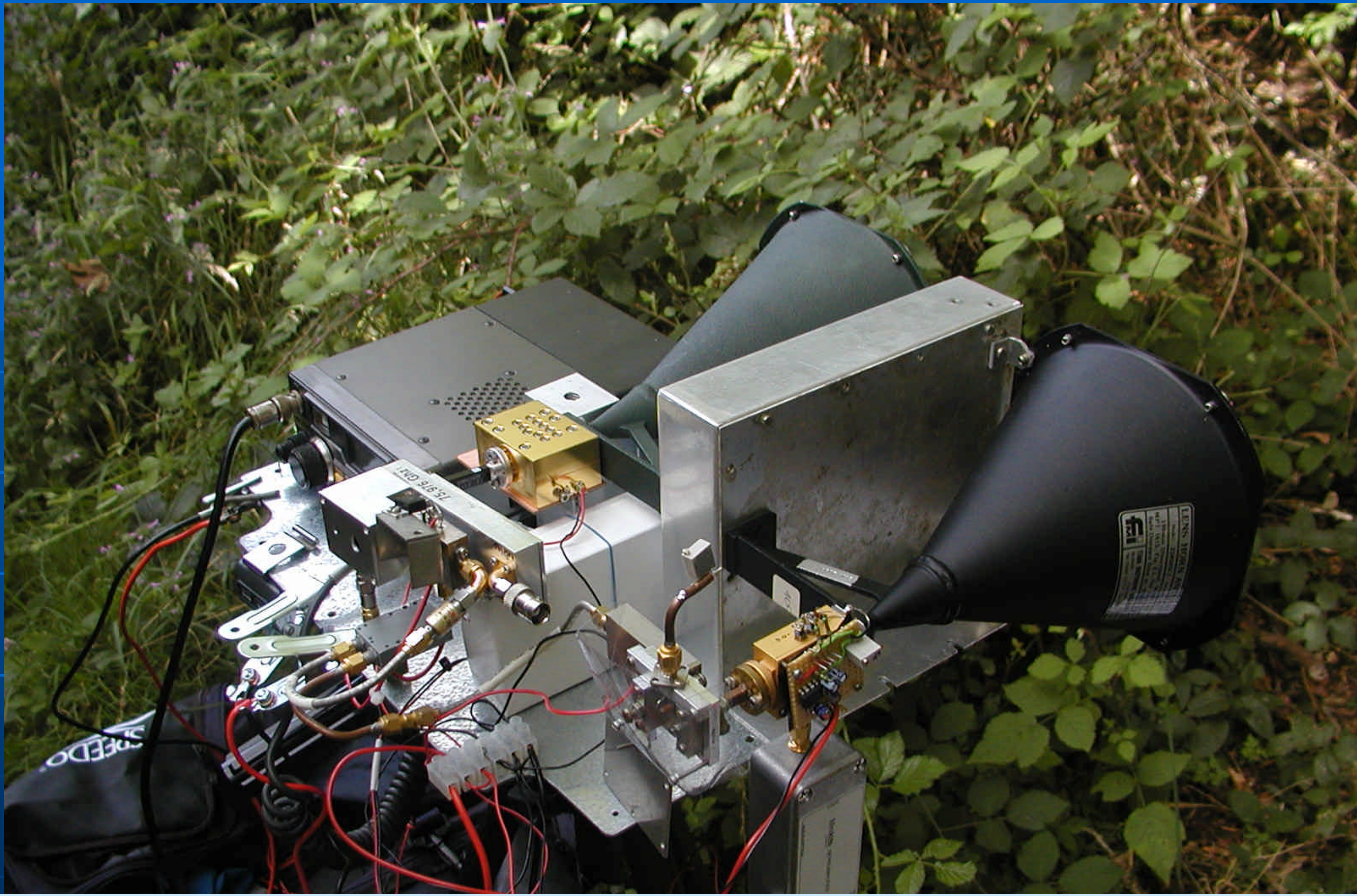
Joining up with Ian G8KQW for a first QSO at 19 kms

On that day G8ACE, and G8BKE were worked





G8CUB's separate transmitter and receiver system



G4EAT's separate beacon transmitter and transmitter/receiver combination

G4EAT's 76 GHz beacon transmitter set up at his home at Danbury and pointing due south enabling him to work G8CUB and G0FDZ at Wrotham over 48 kms.

Operating from Ditchling Beacon in 2013 to break the then UK distance record to the IOW

Increasing the record distance further to 94 kms from Firle Beacon and using CW

G8CUB’s 90 mW HPA and LNA 76 GHz system gave 59+ signals !

G4EAT’s 5mW 76 GHz system with adjacent 24 GHz beacon to aid antenna alignment

John G4EAT and Roger G8CUB on Winter Hill to break the UK record which is now standing at 129 kms

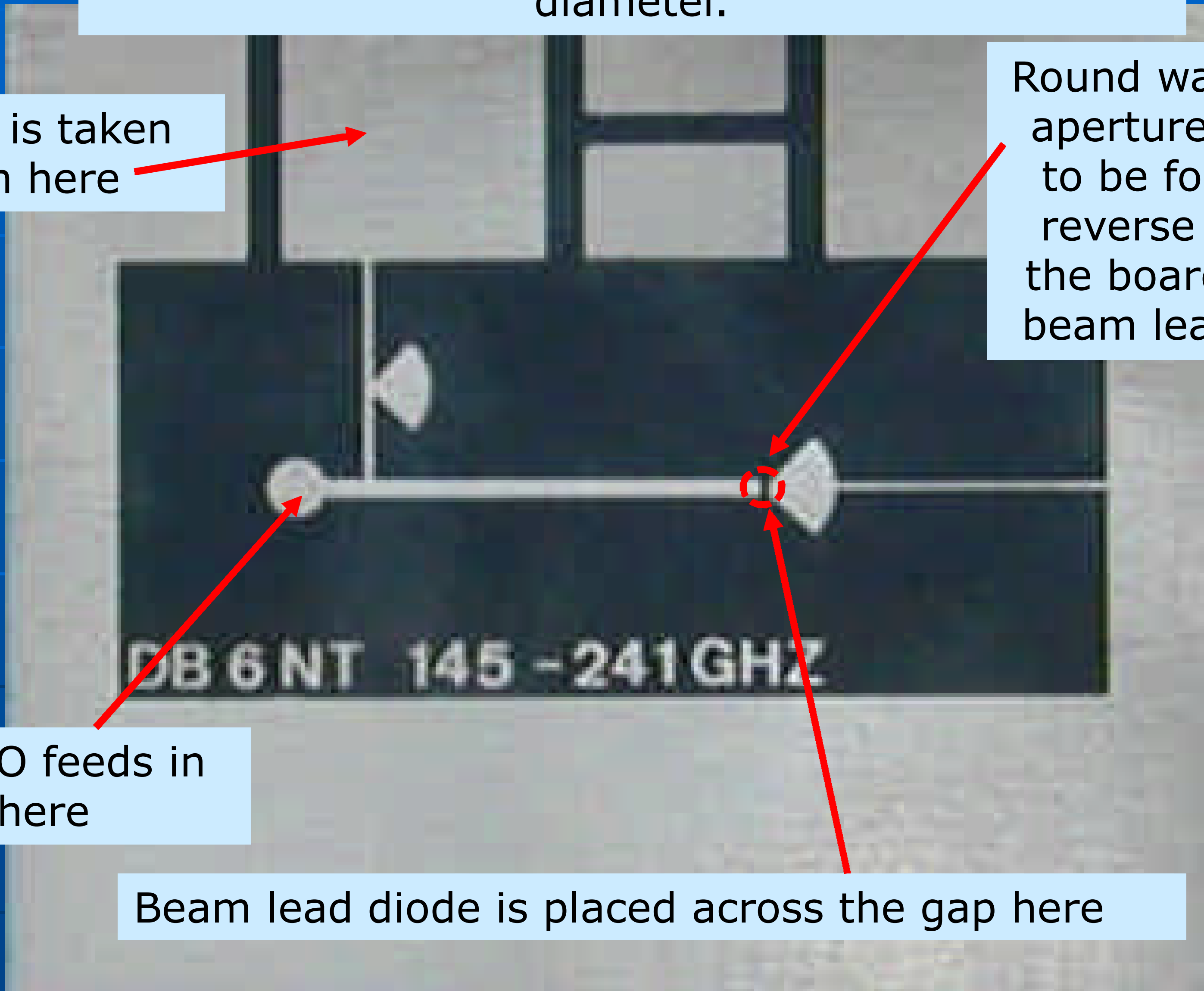
134 GHz - 2 mm

- The DB6NT sub-harmonic mixer design uses only a single mixer diode rather than anti-parallel types so output power can be much less than at lower frequencies – possibly less than 20 µW, and mixer PCB's are available from DB6NT
- Using higher frequency multiplier units make the mixer process more efficient as the mixer is driven from 34 or 44 GHz rather than 23 GHz. i.e. third or fourth harmonic instead of the 6^{th} harmonic in the original design
- Higher transmit power is likely to be obtained by straight multiplication from a lower frequency so the mixer could be used only as a receiver and a separate transmitter used
- 134.928 GHz is the IARU sub band

134 GHz - 2 mm

- LO frequency accuracy, stability and jitter is so bad with crystal sources that PLL 11GHz low noise sources are essential
- 1 mW is definitely QRO at this frequency !
- Procom 142 GHz (this band no longer available in the UK) dishes can provide a suitable antenna for this band but the beam-width is only 0.8 degrees!
- ProCom dishes are expensive !!
- Any future millimetre wavebands above 134 GHz are likely to be based on harmonic multiples of 134 GHz
- There is still very much to learn on the characteristics of these frequencies

The 145 GHz mixer board can be used for 134 GHz At this frequency the waveguide aperture round hole on the machined block is just 1.6mm in diameter.



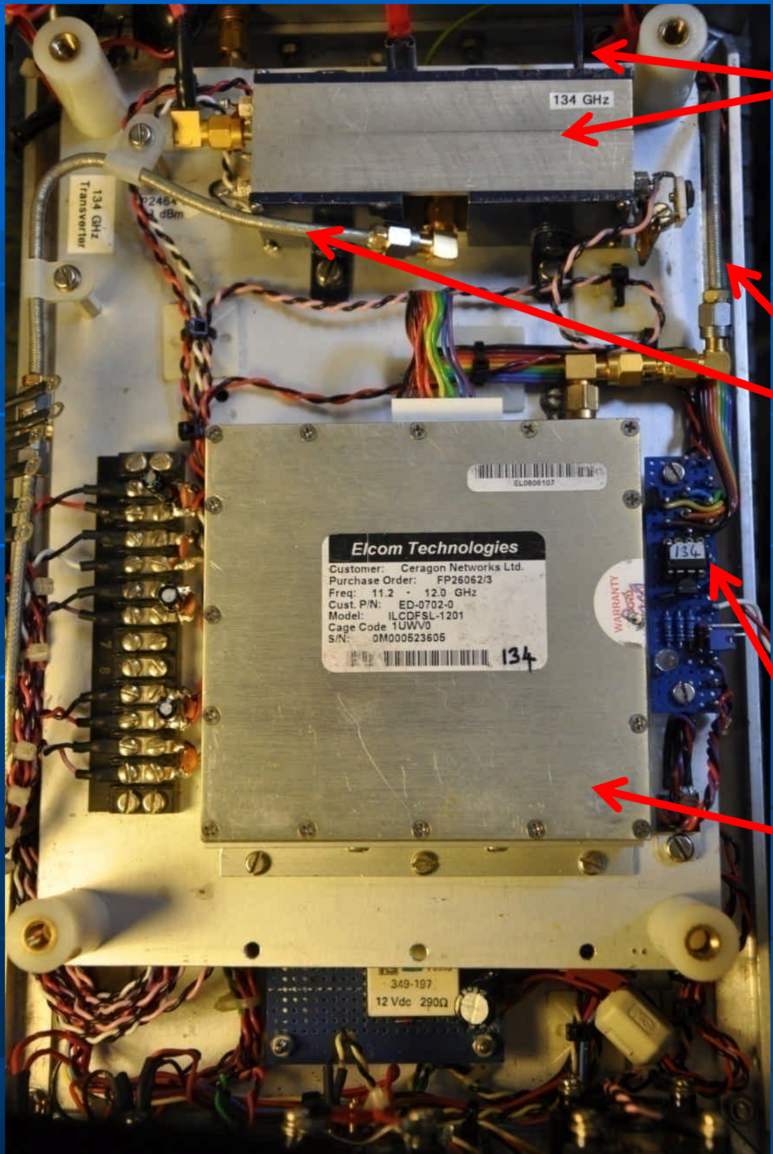
The IF is taken from here

Round waveguide aperture hole is to be found on reverse side of the board to the beam lead diode

The LO feeds in here

Beam lead diode is placed across the gap here

134 GHz - 2 mm



The 134 GHz mixer assembly with the output waveguide.

The 11 to 22 GHz doubler is underneath the transverter plate and connected to it using semi-rigid cables

Note the Elcom 11 GHz PLL unit with the PIC used to program the required LO frequency.

This sub harmonic mixer system uses the 6th harmonic of the LO frequency of 22 GHz

First QSO on the 134 GHz with Roger G8CUB over a 0.5 km path

Roger G8CUB checking that the systems are working OK before commencing tests across the Thames

Testing across the Thames from Allhallows to Canvey Island over a 5 kms path on both 76 & 134 GHz

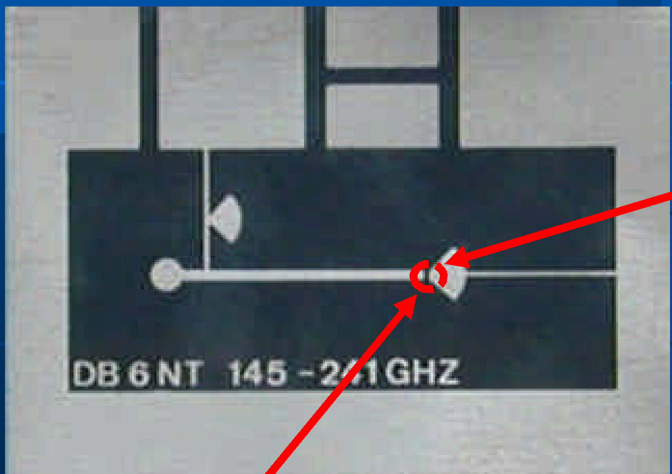
G0FDZ/P CW QSO on 134 GHz with Roger G8CUB/P over a 6.3 km path from Higham to West Tilbury. The rifle sights are essential to accurately align the antennas.

241 GHz - 1.2mm

- A DB6NT sub-harmonic mixer design is available but is very inefficient as it uses the 10^{th} harmonic of a 24 GHz LO frequency for the mixer
- The RF output likely to be very low – probably <10 μW at best !!
- We improved the mixer by using drive at 34 GHz as the 7^{th} harmonic is used
- LO frequency accuracy, stability and jitter is extreme at this frequency with a crystal source so a PLL 11.45 GHz low noise source for the LO is essential
- CW is the probably the easiest mode to use at this frequency

241 GHz - 1.2mm

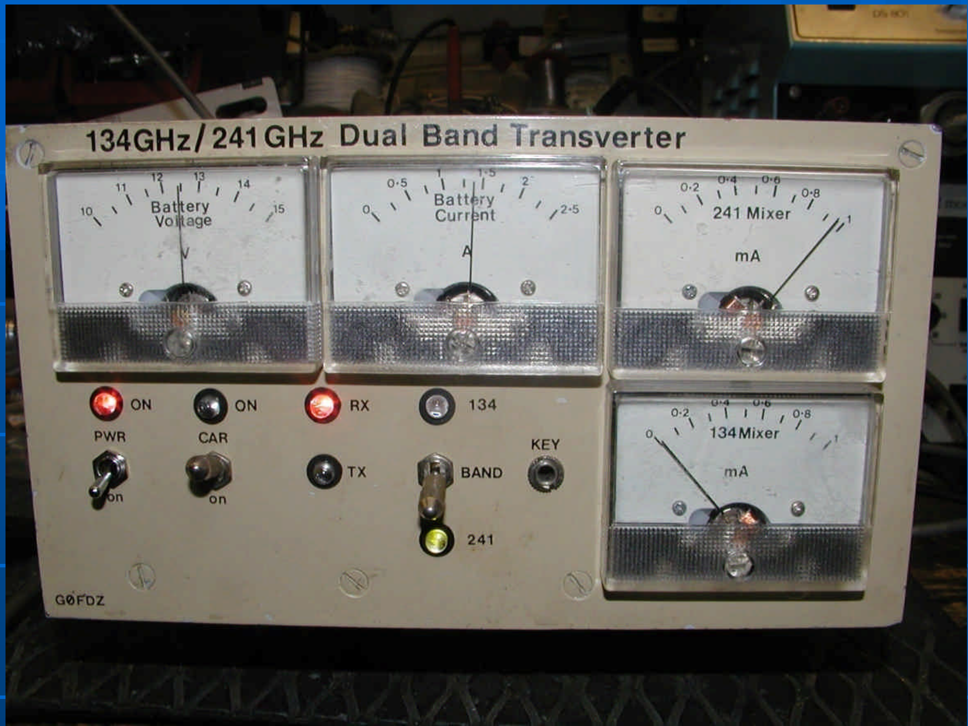
- Extremely small waveguide (WG30) is very hard to obtain in the UK. Round waveguide hole size is just 0.8 mm
- Antenna can be small horn (e.g. icing nozzle)
- Germany and USA have seen the first activity on this (top) band and Germany uses 241.920 GHz as the sub- band



The waveguide aperture hole that is positioned on the reverse side of the board is just 0.8 mm

Beam lead diode is placed across the gap here

241 GHz - 1.2mm



Testing is currently underway on our 241 GHz systems and signals have been exchanged across a few metres which is encouraging

Using SDR Techniques

- Recognising very weak signals on the millimetre wavebands can employ SDR techniques in addition to normal methods of finding signals
- It is easier to spot weak signals within the IF pass band but that maybe outside of the current receiver tuning frequency
- The wide availability of TV dongle devices that will tune over a wide range of frequencies can form the basis of a suitable SDR that can be used for many purposes
- We use FT817’s as tuneable IF and modified to provide an output of the 68.33 MHz wideband IF which feeds the SDR receiver and using HDSDR running on the PC

Distance records for the high bands

- 76GHz World – USA at 252.5 kms (AD6IW & KF6KVG)
- 76GHz UK at 129 kms (G8CUB, G8KQW, G4EAT & G8ACE)
- 122 GHz World – EU at 132 kms (OE5VRL & OE3WOG)
- 134 GHz – Uk at 17.7 kms (G4FRE & G7FRE)
- 241 GHz World - USA at 114.4 kms (WA1ZMS/4 & W2SZ/4)

76 GHz and above
Our experiences so far

Part 2

Roger Ray G8CUB
Chris Whitmarsh G0FDZ

Elcom Synthesiser

10 / 24 / 47 / 76 / 134 / 241Ghz

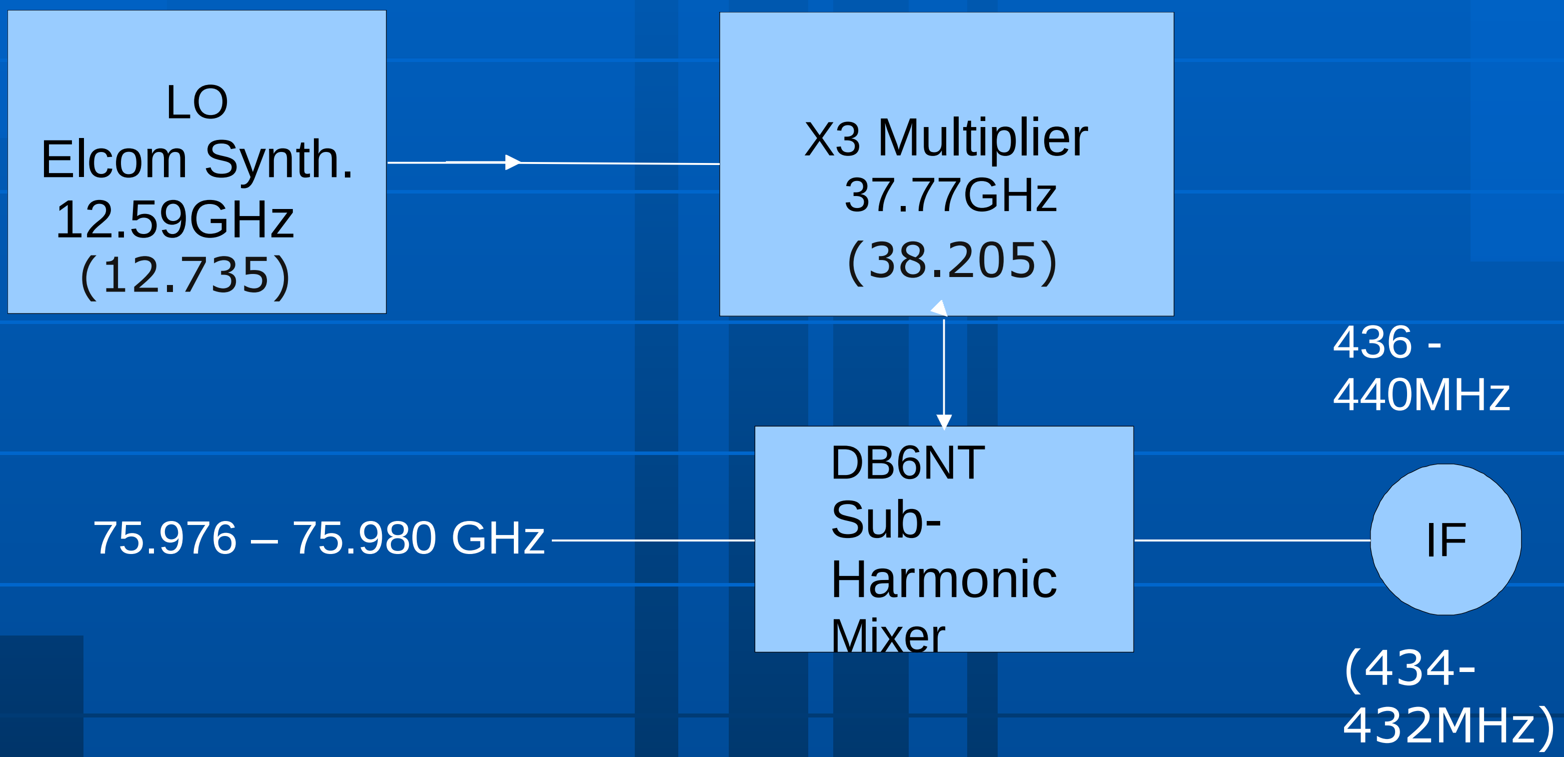
10.575 – 11.400 GHz 3.333M step
11.200 – 12.000 GHz 3.333M step
12.200 – 12.950 GHz 3.333M step
12.650 – 13.350 GHz 5M step

Elcom Synthesisers

- Complete robust block
- Simple to program
- Stable frequency
- Low cost
- Multiple frequencies
- Possible to GPS lock

- Limited frequency step
- No more 12.20 – 12.95GHz versions !

76GHz Transverter



- Sub-harmonic mixer in DL2AM housing

G4EAT 76GHz Receive

Synthesiser

12.6385GHz
(12.639)

X3 Multiplier

37.9155GHz

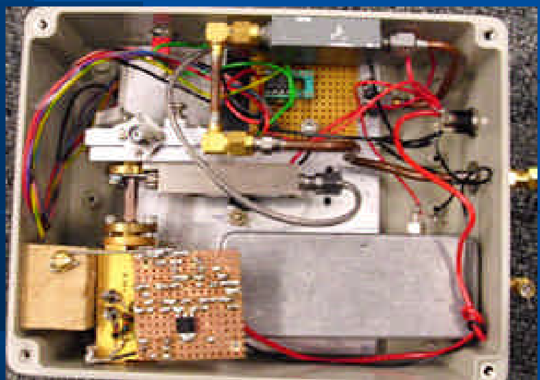
X2 Multiplier

75.831GHz

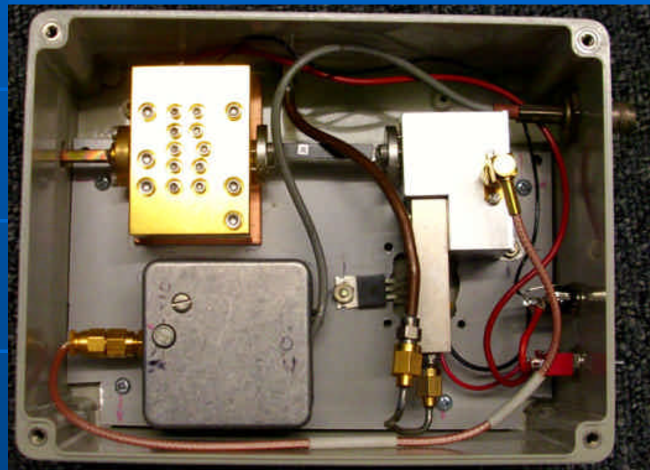
145 – 149MHz
(142-146)

Fundamental
Mixer

75.976-
75.980GHz



G4EAT 76GHz Transmit



From RX Conv.

X3 Multiplier

37.9155GHz

145M+

100mW

Atten

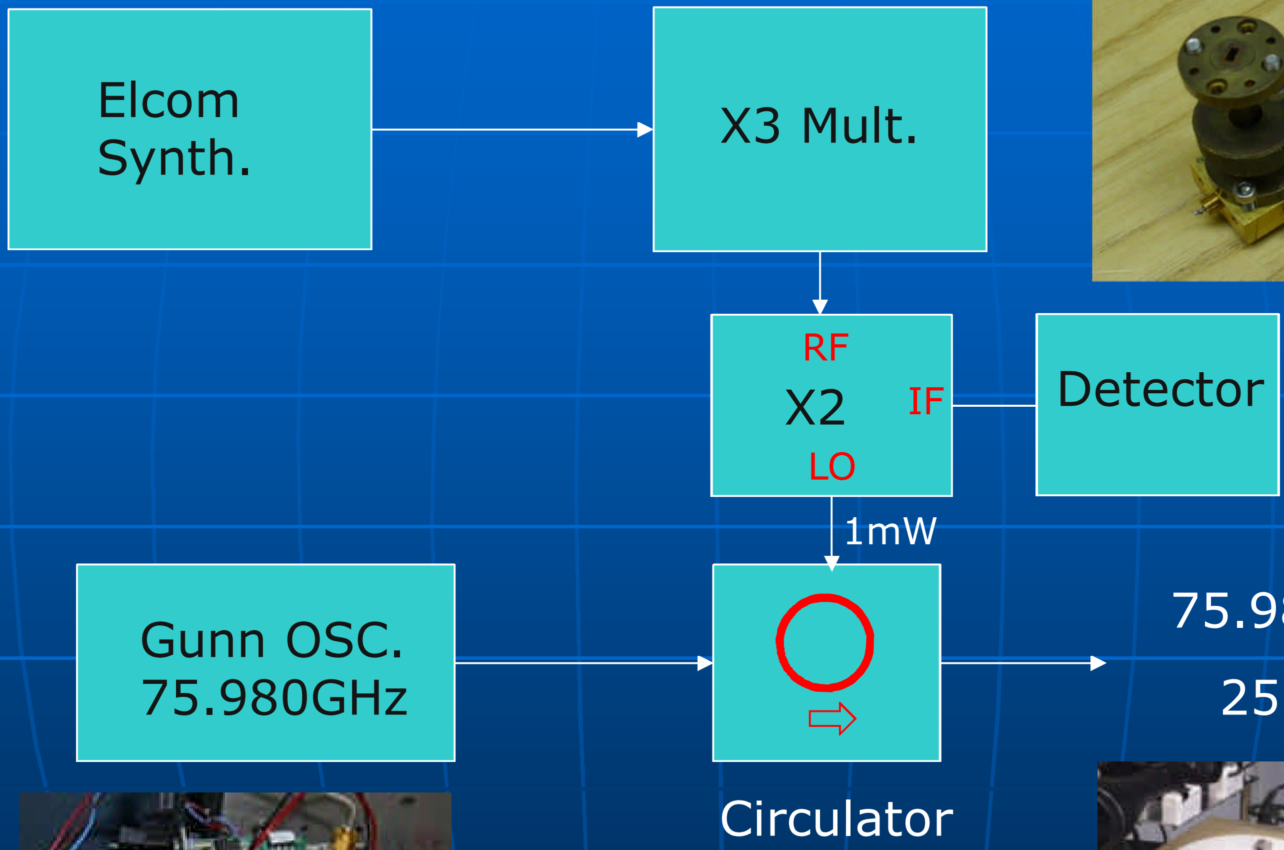
Sub-
harmonic
Mixer

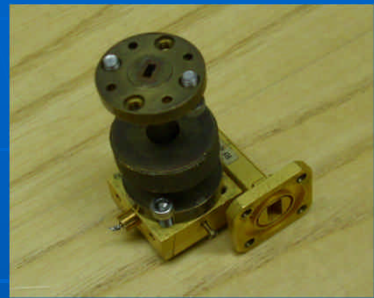
Amp

75.976+

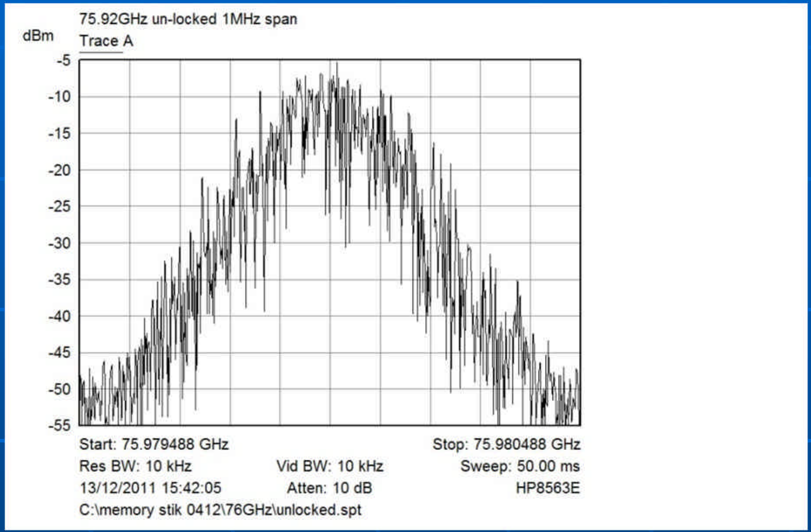
5mW

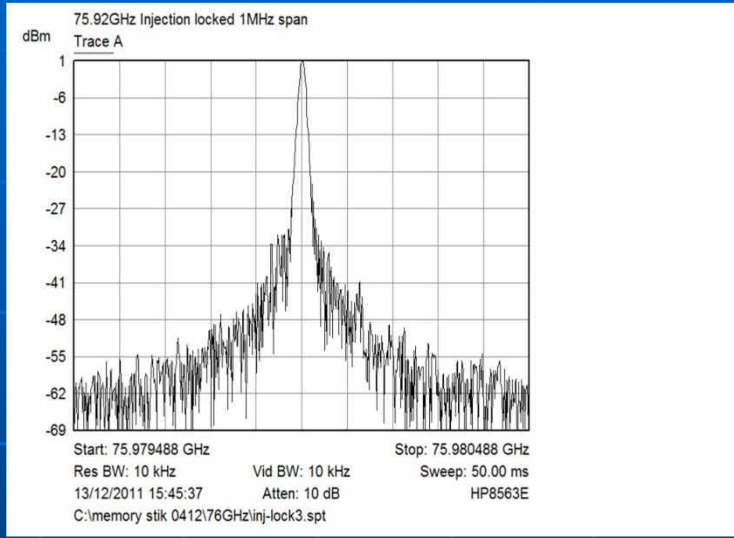
G8CUB 76GHz Transmit





Injection Locked

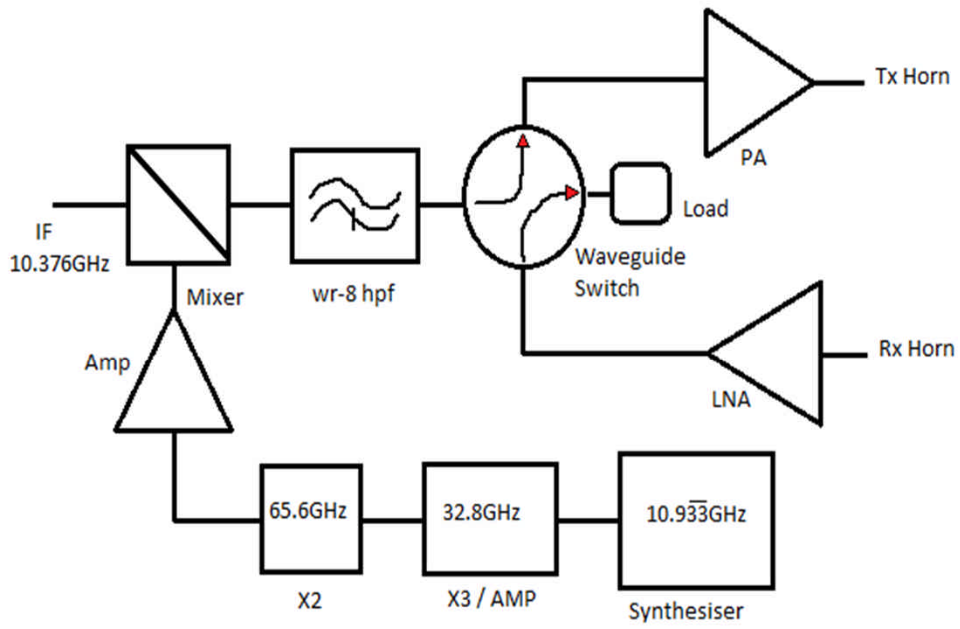




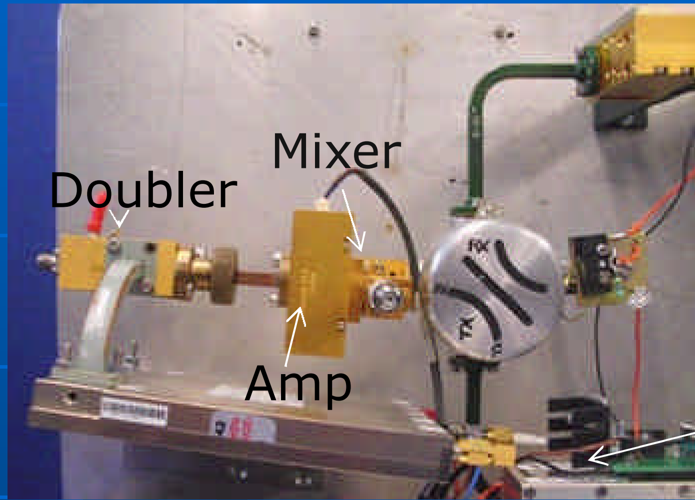
Un-locked

Locked

76GHz latest Transverter



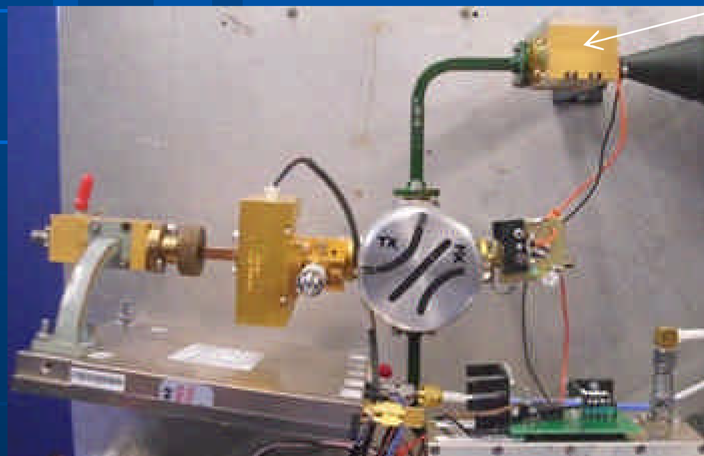
Receive



WA1MBA
Pre-amp
+30dB

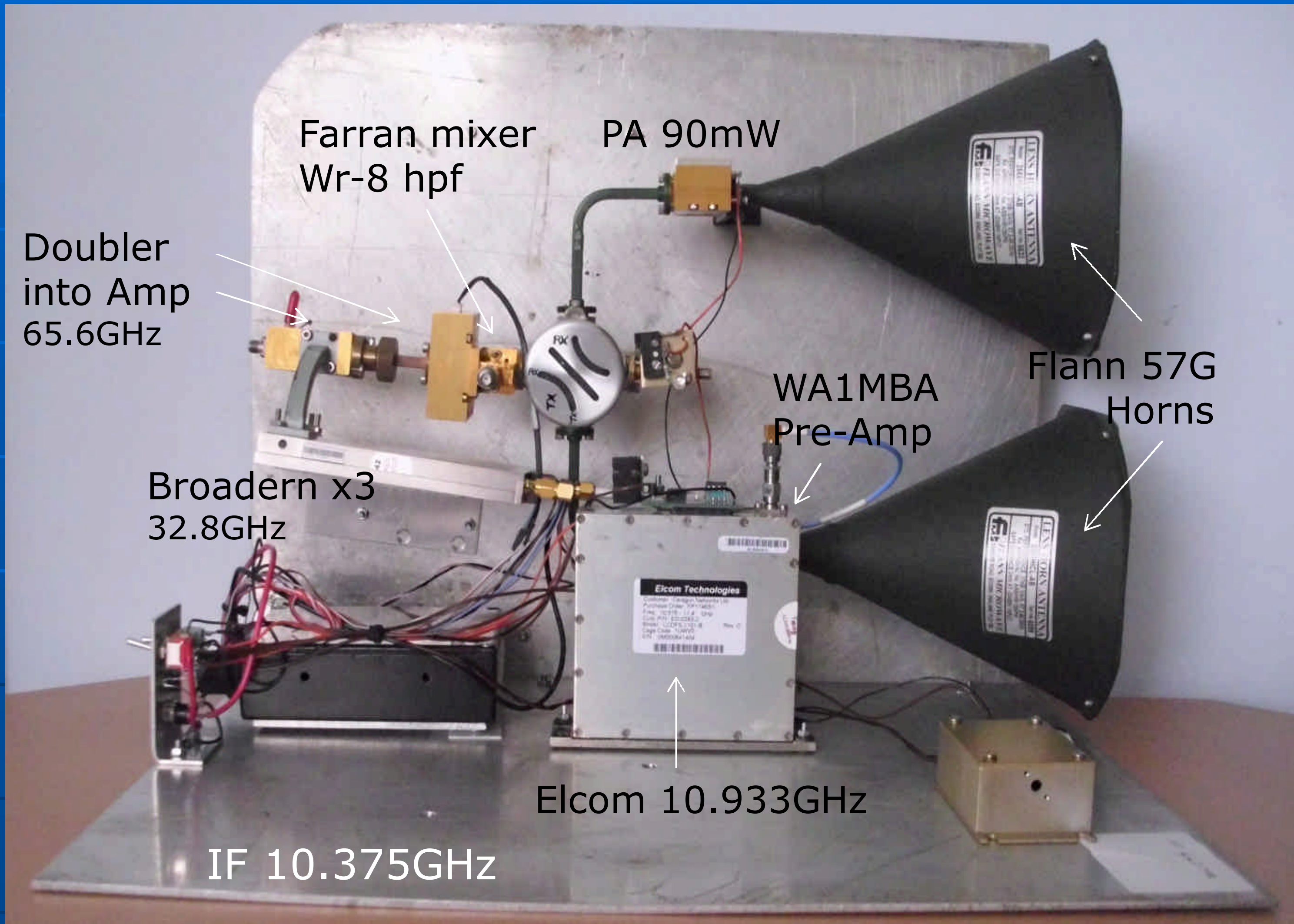
Transmit

PA



Broadern x3

76GHz transverter



134GHz Transverter

Building Blocks:
Elcom Synthesiser
X3 multiplier
Amplifier
Harmonic Mixer
Antenna

134GHz Band Plan

134.926 – 134.928GHz
Not synthesiser friendly
134.920 and 134.925 as Beacon / TX frequencies (X12)
LO 134.480 giving IF of 440 / 445 / 446-448MHz
Only 2 of us here!

Alternate frequency 134.400
High side LO 134.840 giving 440MHz IF
Lowest frequency with Elcom synth. 11.2GHz X 12
Why Not?

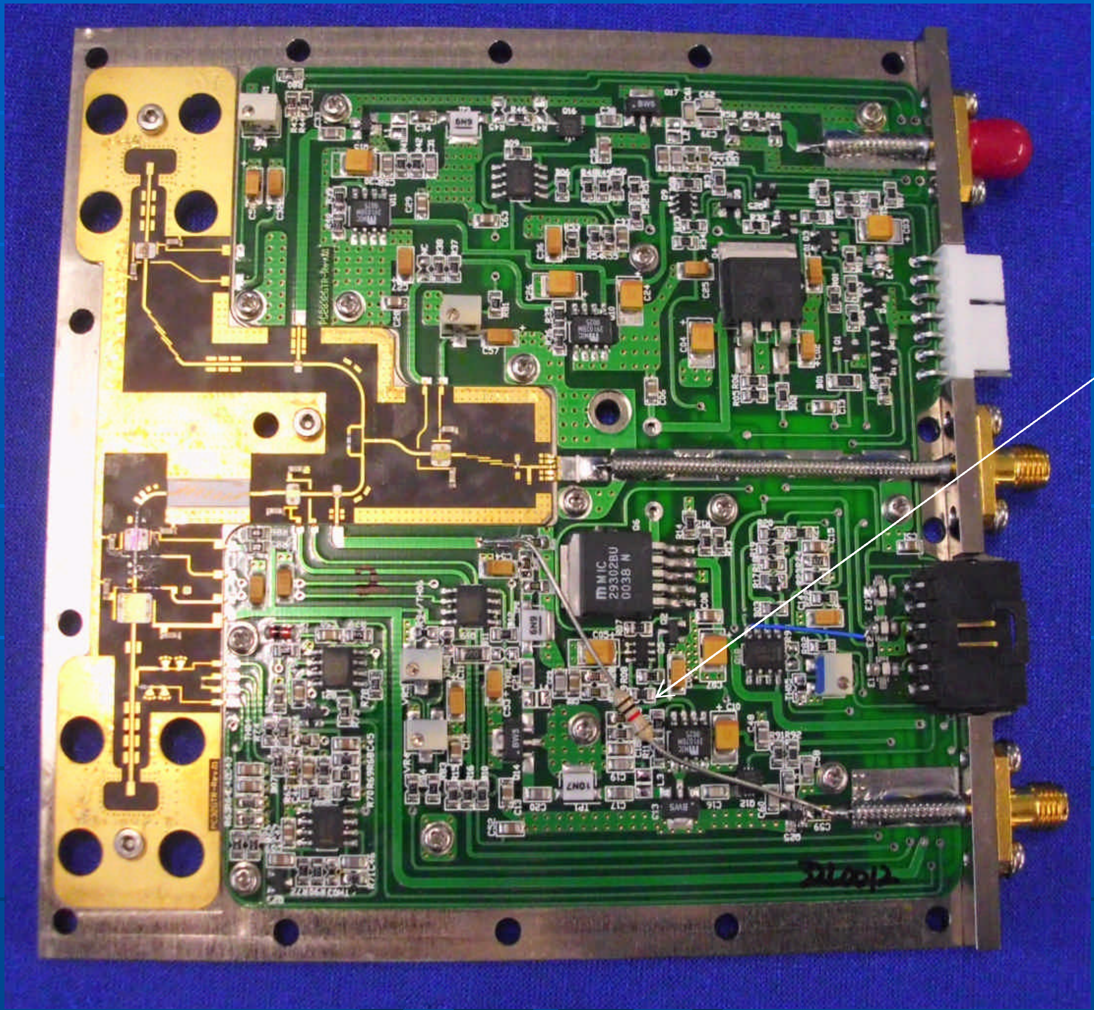
134GHz Transverter

11.2GHz X2 (22.4GHz) X6 – 134.4Ghz
11.2GHz X2 (22.4GHz) X2 (44.8GHz) X3 – 134.4GHz
11.2GHz X3 (33.6GHz) X4 – 134.4Ghz
11.2GHz X3 (33.6GHz) X2 (67.2GHz) X2 – 134.4GHz

44.8 / 67.2GHz limited by lack of amplifiers
33.6GHz helped by availability of modules

'Gold' mm-tech amplifier or Broadern module

Broadern Module



Mod
1 resistor

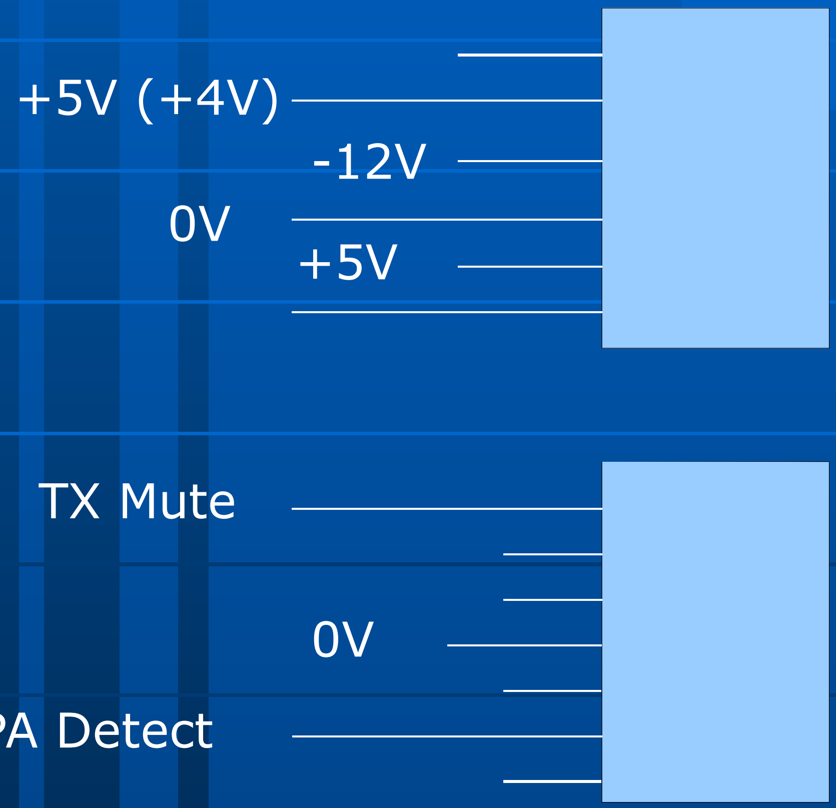
X3 Multiplier / Amplifier

- Broadern ED-0296-2

I A	dBm	Det V
.85	+20	2.6
.87	+22	2.7
.90	+24	2.9
.95	+26	3.1
1.0	+28	3.3

Control 0 – 1.5V

Drive +3dBm

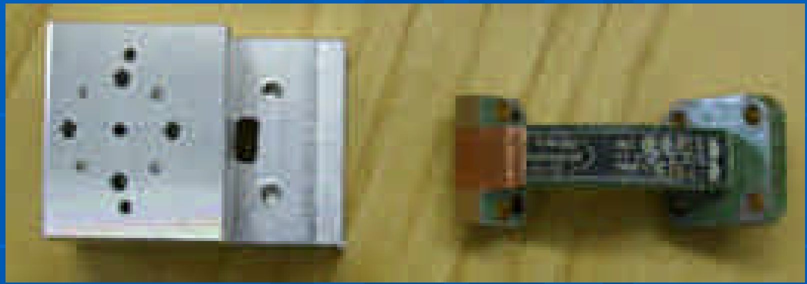


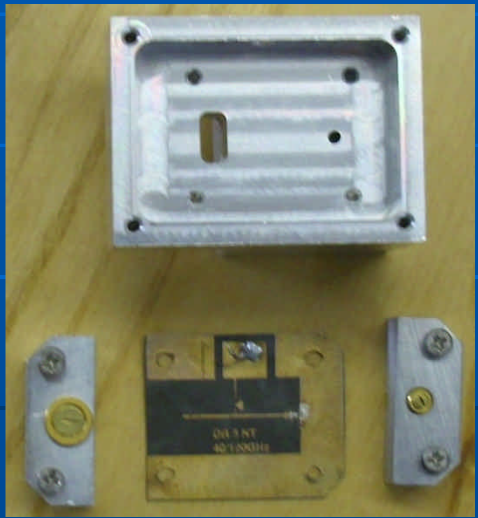
134GHz Mixer

- Care 1W destroys diodes very quickly!

- Choice of Diode:
- MA4E1317 RX + CW TX
- MA4E1318 RX
- HSCH-9161 RX
- HSCH-9101 RX
- DBES105A RX + CW TX

134GHz Mixer





134 GHz

DBES105A diode circa 250mW drive
Circa 3mA diode current

On receive diode current a few micro-amps

Separate TX / RX

Combined Transverter

Test Sources

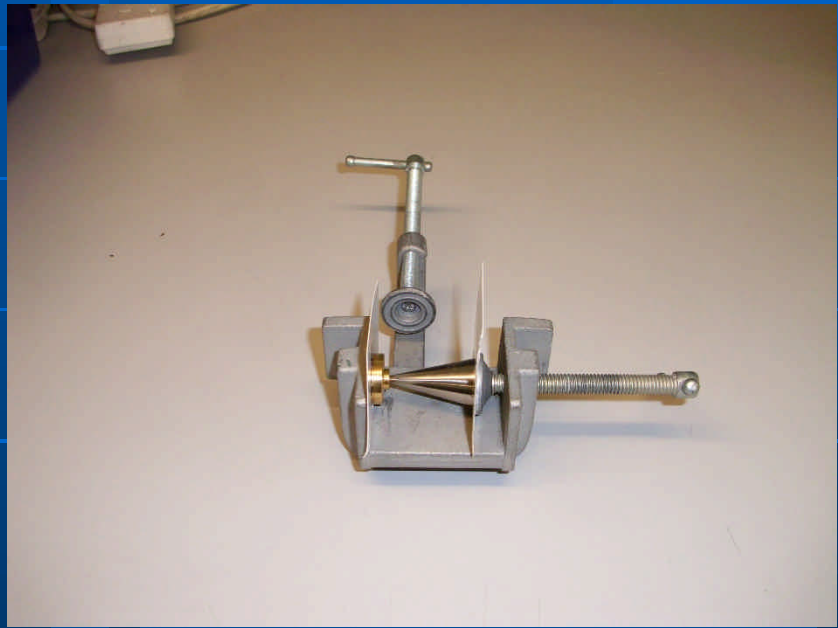
76 / 134GHz Test Beacons

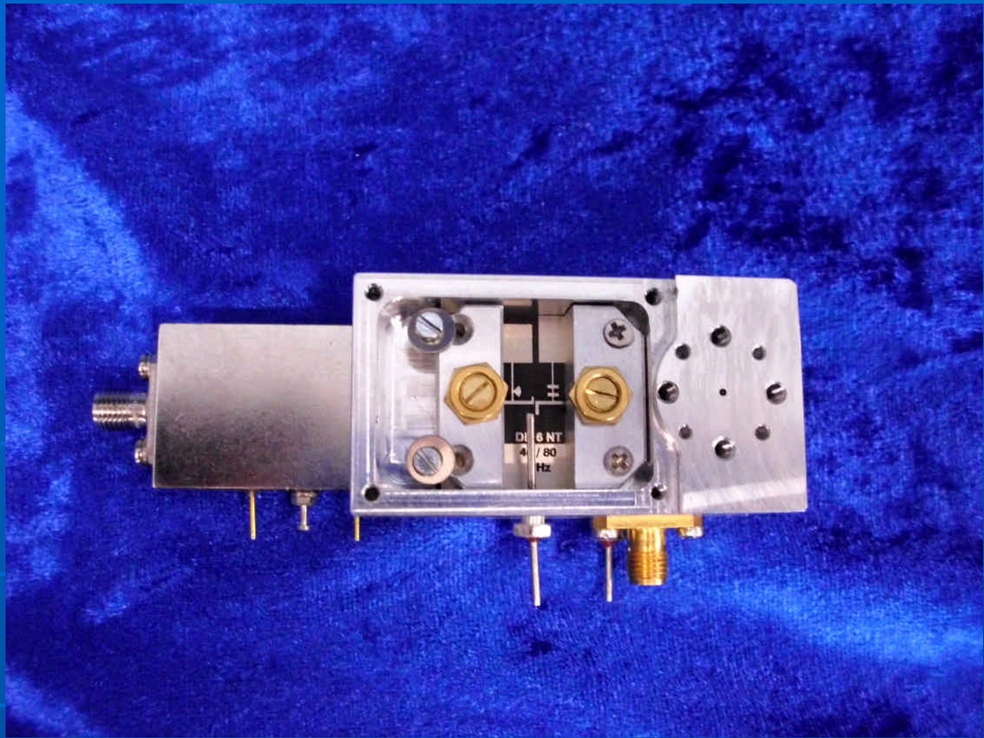
241 GHz - 1.2mm

- More difficult than 76 /135GHz
- A lot of test gear stops working at < 200GHz
- Waveguide very small WR-03 – 0.8mm hole
- High gain antennas required – very directional
- Project is on-going!

241 GHz Test Antenna

- Making a Horn Antenna

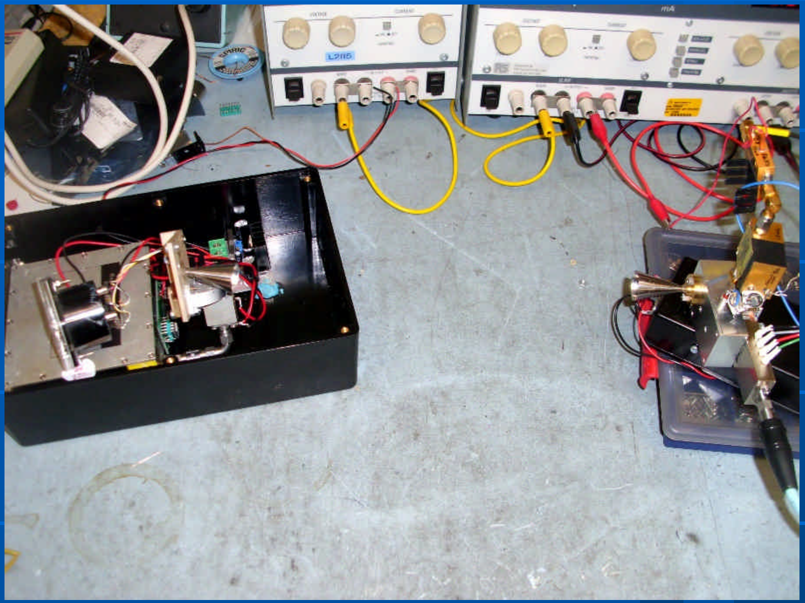




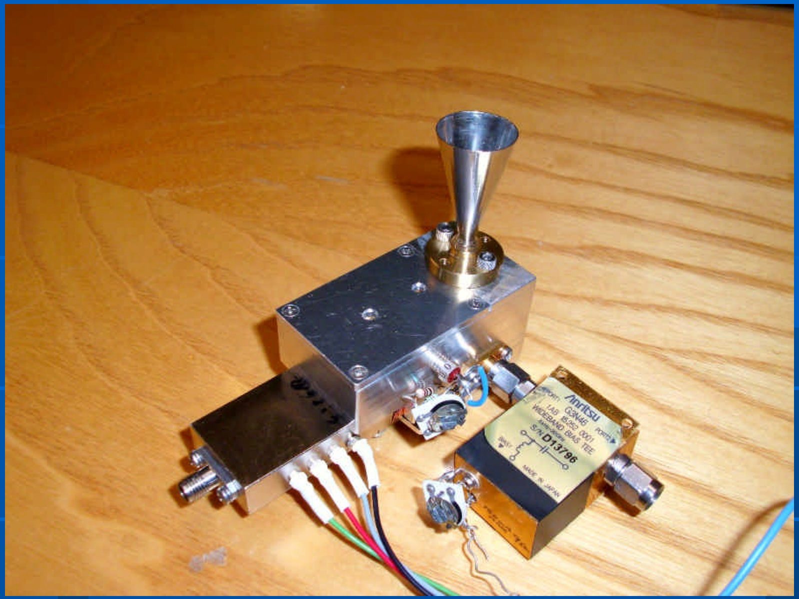
Circular waveguide 1.0mm

The 241 GHz mix

241 GHz - 1.2mm



Range 30cm



134GHz How to get more power?

Finline Multiplier

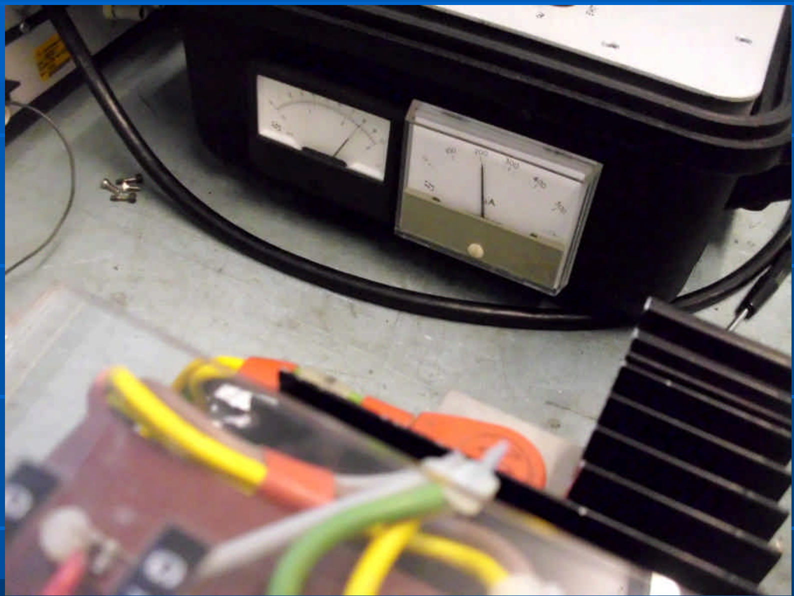
4 x DBES105A 5mW possible

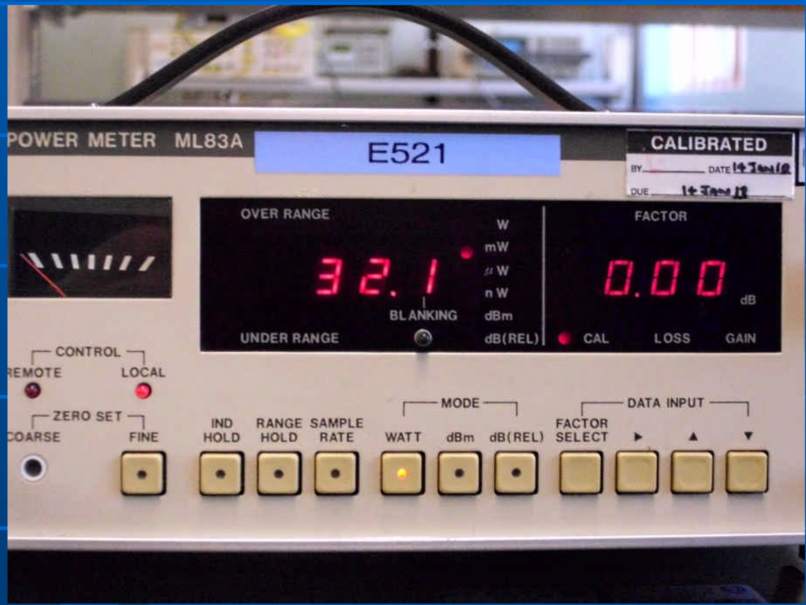
Klystron?

Varian millimetre Klystron

- VRT-2T23B14 2.5kV 30mA ....

30mW at 139GHz !





We both look forward to working you on these bands !!

Roger Ray G8CUB

Chris Whitmarsh G0FDZ