JT4 on 122 GHz

And the Continuing Evolution of a Portable System

G8KHU / G1TVL

Version 1v0 November 2024

This is a project that started during lockdown and that has taken quite some time to evolve.

It’s only really come to the point of fruition and our first JT4 QSO happened in August of this year

Some of the long timescale was due to family life and day job commitments - but the main delays were due to the inordinate number of “really interesting” rabbit holes we gleefully leapt down en-route :)

The presentation breaks down into several sections, The link budget, generating and decoding JT4, a brief overview of our SDR implementation, and then, fingers crossed, a live demo of JT4 across the room and a guided tour of the system functionality

A Systems Perspective

Link Budget

Version 1v0 November 2024

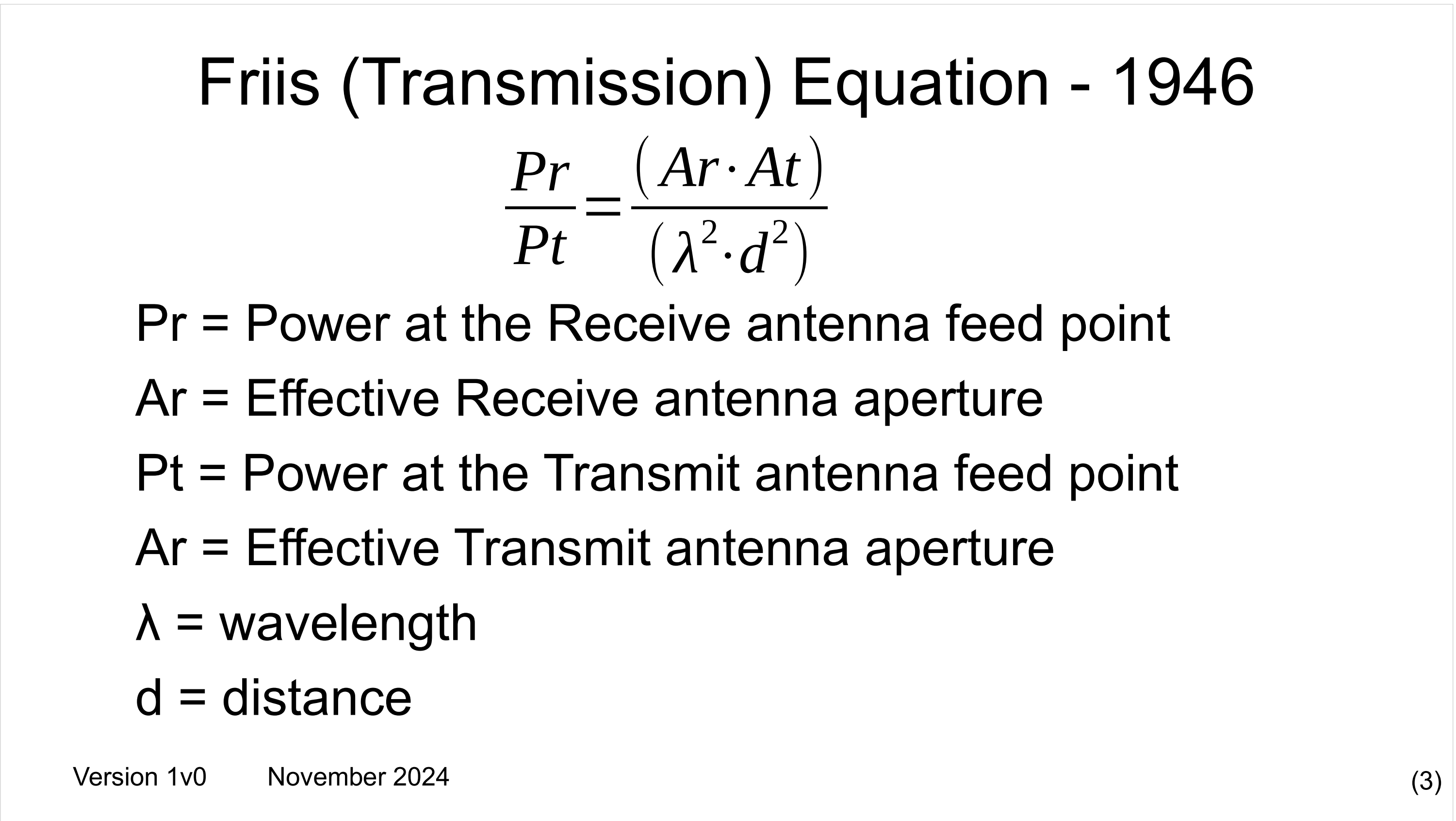
Andrew VK3CV published his article in Dubus which generated huge interest. Tim VK2XAX co-ordinated a crowd funded group buy of the boards, horns and Chaparral feeds

In the time between signing up to the group buy and receiving the boards we speculated about what could be achieved

The first thing we did was to estimate the possible range we could achieve so we worked out the provisional link budget. This was based on the limited data we had at the time but it gave us a feel for what might be achieved

Since then the Link Budget has been much refined as the worldwide 122GHz community has generously shared their results and insights on groups.io

So I can get a feel for how fast I go through this section may I have a show of hands please from those who are familiar with calculating a Link Budget



Friis (Transmission) Equation - 1946

$$\frac{Pr}{Pt}=\frac{(Ar\cdot At)}{(\lambda^2\cdot d^2)}$$

Pr = Power at the Receive antenna feed point

Ar = Effective Receive antenna aperture

Pt = Power at the Transmit antenna feed point

Ar = Effective Transmit antenna aperture

λ = wavelength

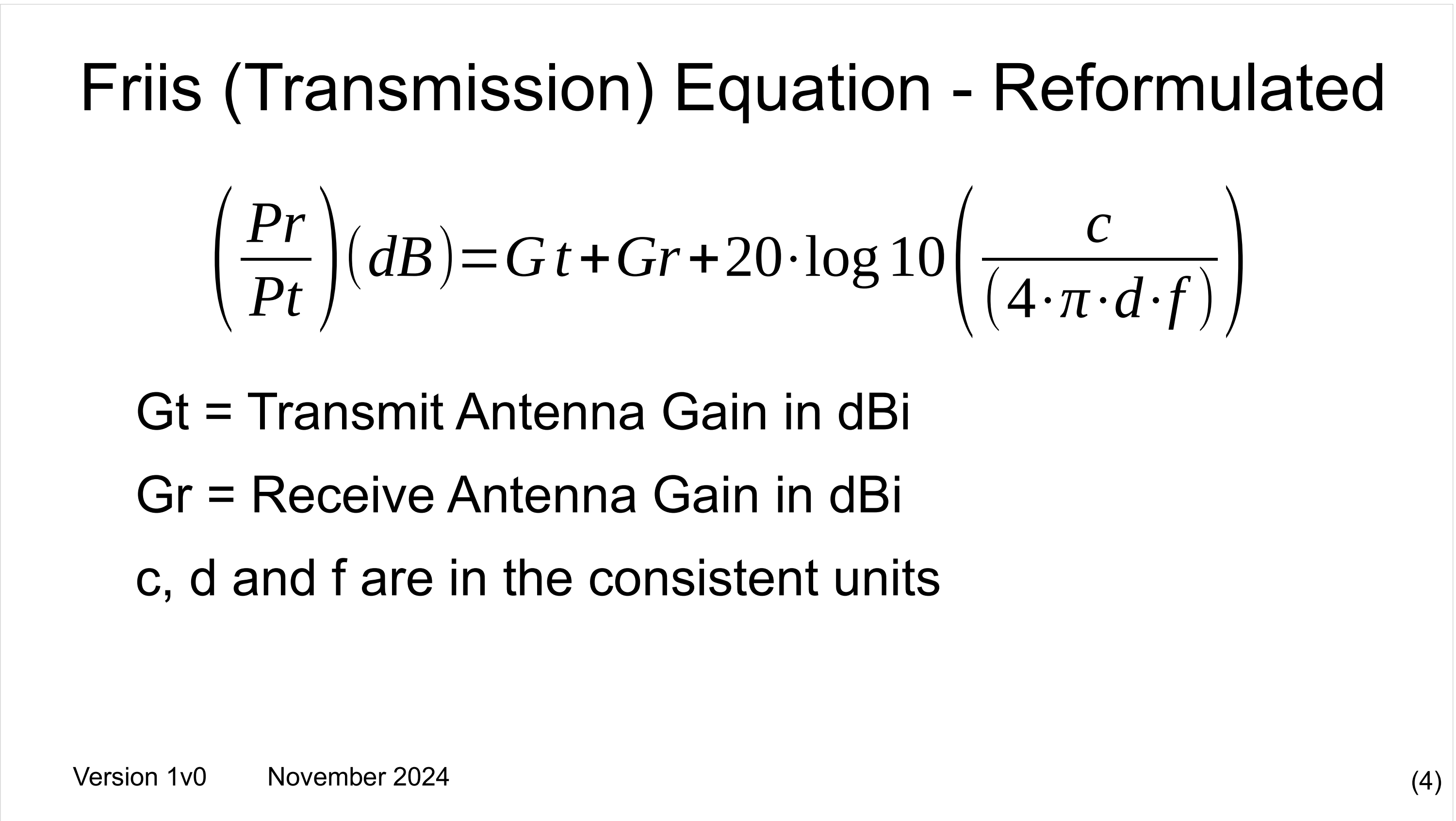
d = distance

The equation that underlies the link budget is the Friis equation – originally published by Harald Friis in 1946

Its pretty universally referred to as the “Friis Equation” but in this presentation I’ve called it the Friis TRANSMISSION equation as Friis also published the equation for cascaded S/N and noise figure.

I haven’t been able to pin down the date when the Noise equation was published but I’ve seen some references to 1944

The units and definitions he used seem somewhat dated nowadays but remember back in the forties wavelength was relatively easy to measure, frequency wasn’t



Friis (Transmission) Equation - Reformulated

$$\left(\frac{Pr}{Pt}\right)(dB) = G\,t + Gr + 20\cdot\log 10\left(\frac{c}{(4\cdot\pi\cdot d\cdot f)}\right)$$

Gt = Transmit Antenna Gain in dBi

Gr = Receive Antenna Gain in dBi

c, d and f are in the consistent units

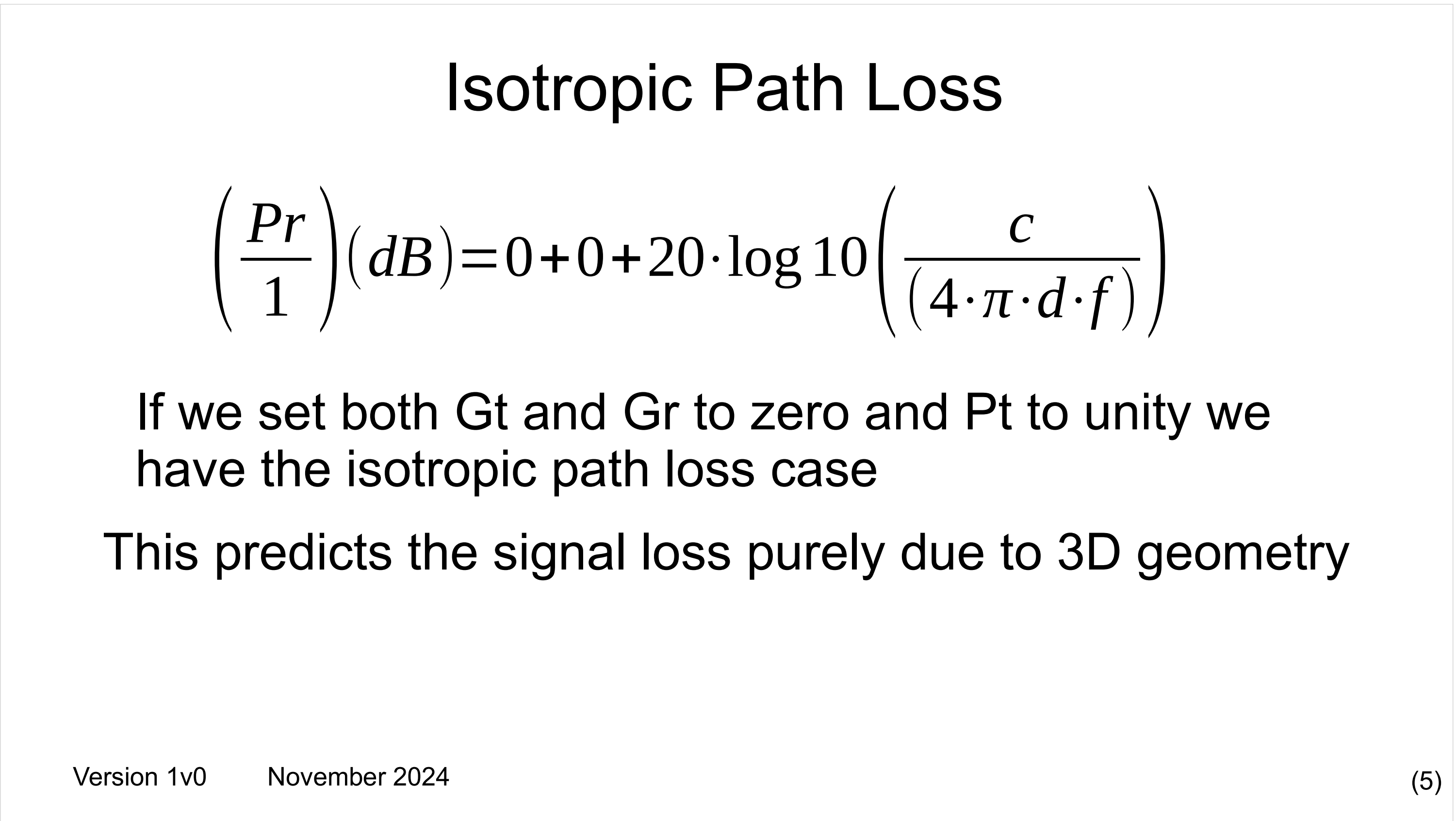
Currently the trend is to use logarithmic terms in the form of dBm and dBi.

Also frequency is now much preferred over wavelength

However - the amateur community does clings on doggedly to some traditions, for example in the designation of the HF bands 10 metres, 40 metres, 3 centimetres etc.

By means of simple rearrangement and substitution the Friis equation can be presented various forms -this slide shows the form I prefer, but choose and use the one that best suits you

To determine the maximum range we need to find Pr(d) at limit sensitivity



Isotropic Path Loss

$$\left(\frac{Pr}{1}\right)(dB)=0+0+20\cdot\log 10\left(\frac{c}{(4\cdot\pi\cdot d\cdot f)}\right)$$

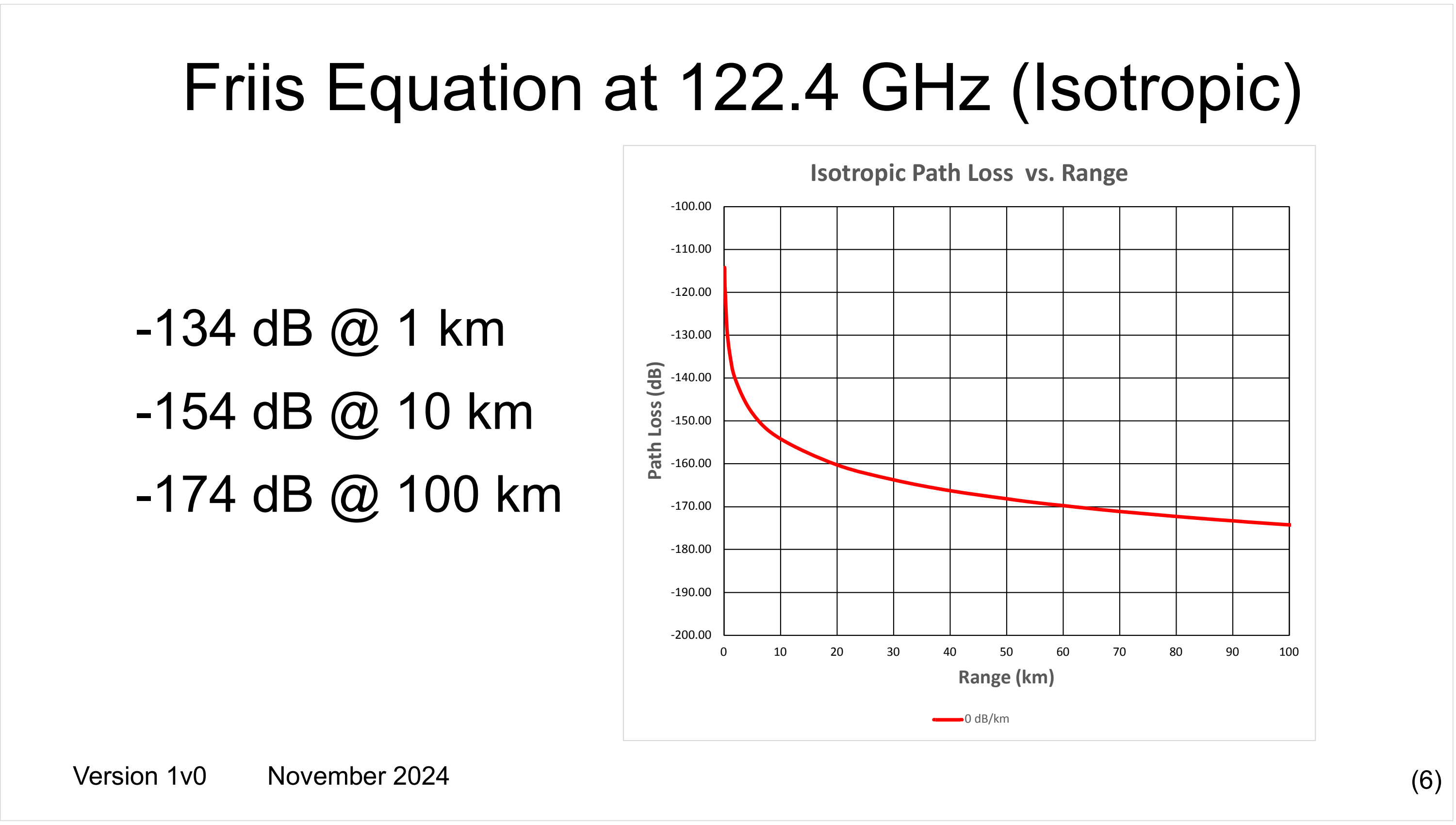
If we set both Gt and Gr to zero and Pt to unity we have the isotropic path loss case

This predicts the signal loss purely due to 3D geometry

If we zero the terms for antenna gains and then replace the power term with a dimensionless unity we end up with the free-space loss between the feed-points of an isotropic transmitter antenna and an isotropic receive antenna

This assumes 100% antenna efficiency, no other propagation losses, and is a function of distance (or range) and frequency

This is plotted on the next slide for the 122.4 GHz case



Friis Equation at 122.4 GHz (Isotropic)

-134 dB @ 1 km

-154 dB @ 10 km

-174 dB @ 100 km

The path losses for 1km, 10km and 100 km are -134, -154 and -174 respectively

We next need address the real life absorption losses

ITU-R P.676-13 (08-2022) - Annex 1

Standard

Temperature 15° C

Water Vapour 7.5 gm3

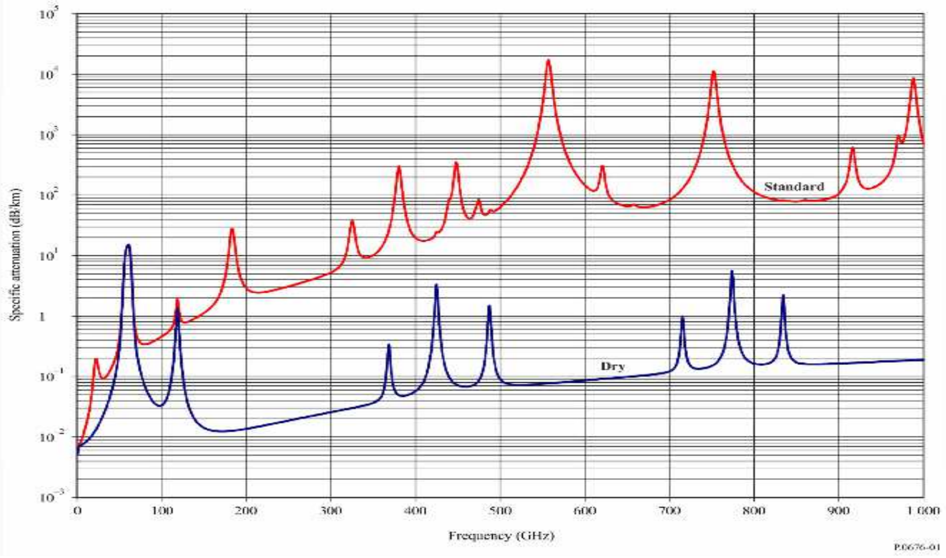
Pressure 1013.25 hPa

Dry

Temperature 15° C

Water Vapour 0 gm3

Pressure 1013.25 hPa

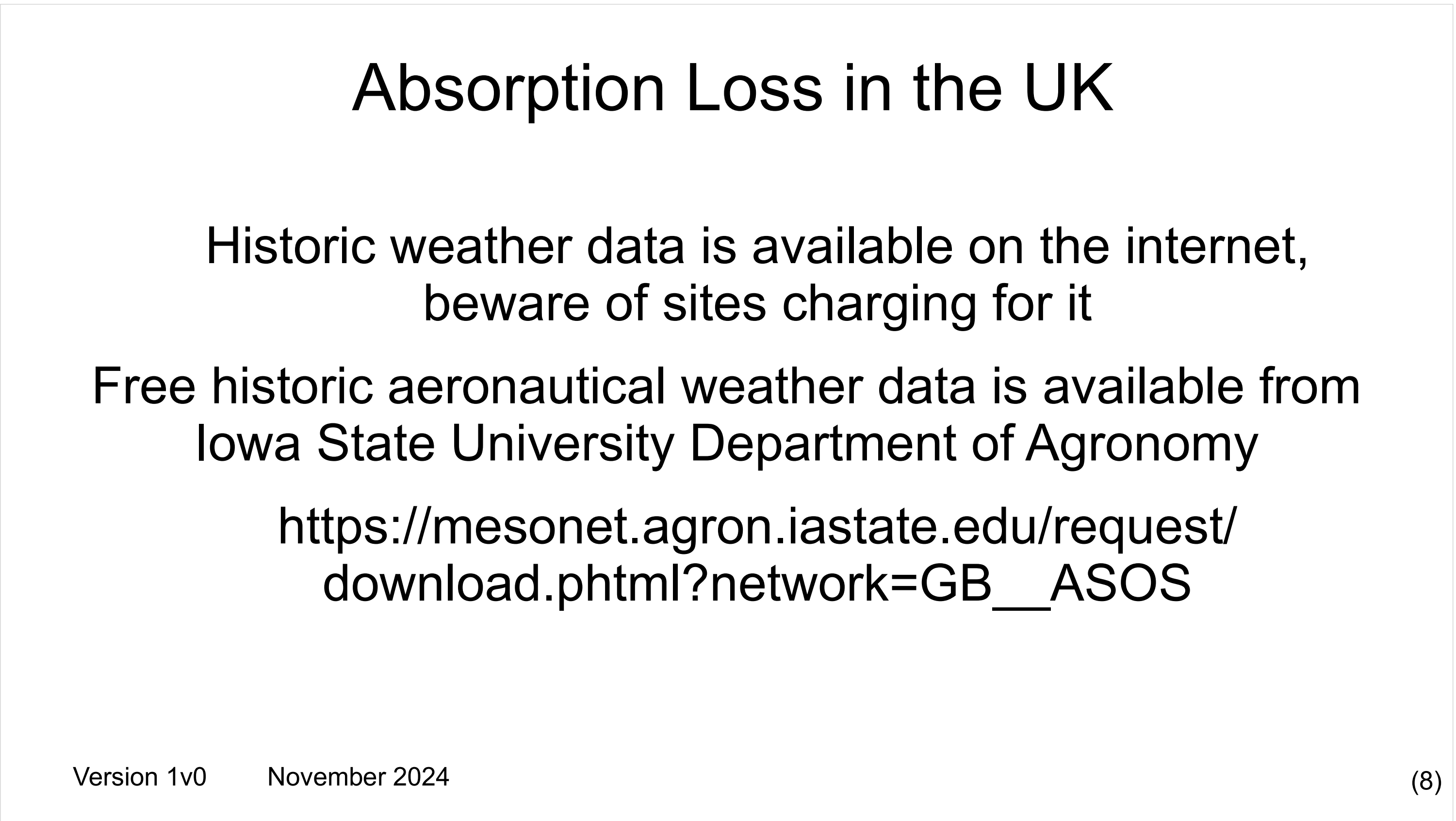


Most of you will have come across this plot from the ITU showing atmospheric absorption as a function of frequency

Those active on 122GHz are acutely aware of it

Annex 1 of the publication contains a line by line methodology to generate the plot from a set of tabulated absorption data

Barry G8AGN used the method to good effect in his Weather Box (Scatterpoint – January 2020 and February 2020). This inspired one of our rabbit holes forays (I’ll come onto this later in the talk)



Absorption Loss in the UK

Historic weather data is available on the internet, beware of sites charging for it

Free historic aeronautical weather data is available from Iowa State University Department of Agronomy

https://mesonet.agron.iastate.edu/request/download.phtml?network=GB__ASOS

The available data is worldwide, goes back decades, and is detailed, most weather site producing hourly updates continuously. That’s a lot of data and needs filtering so it’s not totally overwhelming

For this presentation we’ve taken the data from Army Aviation Corps Middle Wallop Airfield near Andover – as an aside this is the home of the Museum of Army Flying, which is well worth a visit if you’re passing

We’ve taken the hourly data for the full year 2023 and filtered it down to the noon report for each day

Although one of the available downloads is precipitation a lot of stations don’t seem to report this, Middle Wallop included

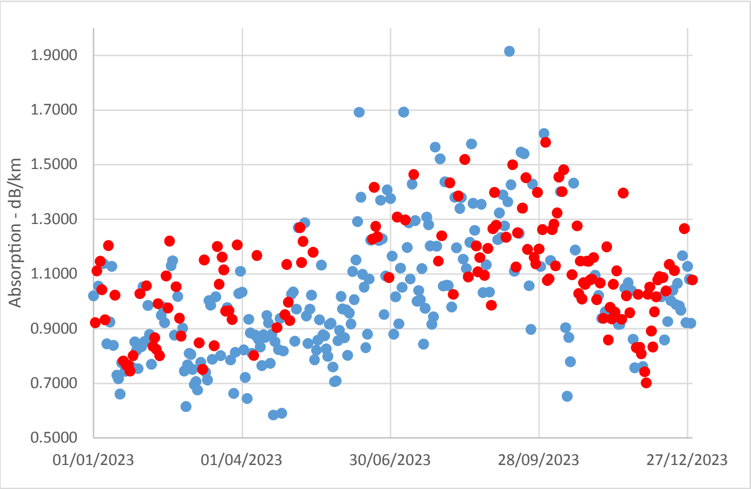
We have therefore inferred that it was a rainy day when the relative humidity was reported as 100% any time between 6 am and 6 pm on that day

Atmospheric pressure is given by altimeter setting for the location in inches of mercury (as this is what aircraft use), Relative Humidity and Temperature can be downloaded direct in % and degrees C

AAC Middle Wallop

Absorption

Min	0.585 dB/km
Mean	1.046 dB/km
Median	1.027 dB/km
Max	1.916 dB/km



From these we can calculate the atmospheric absorption and this we've plotted for full year 2023

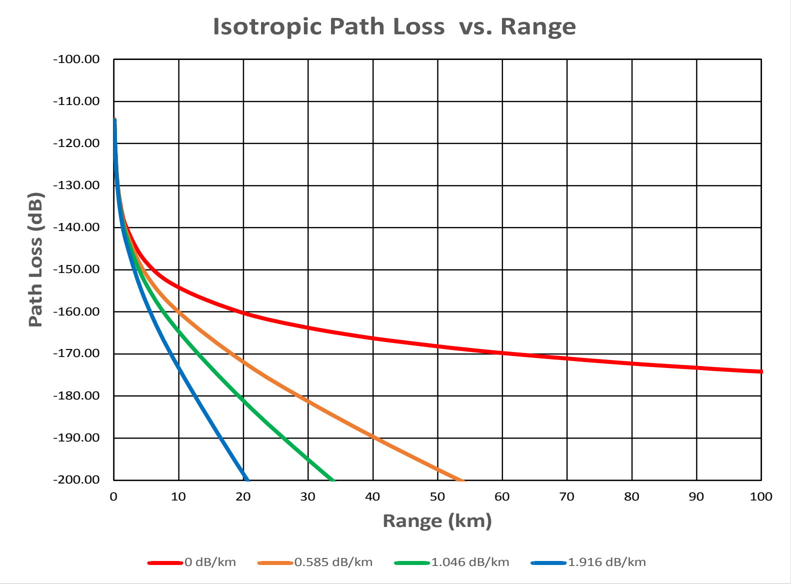
The red dots are dry days and the blue dots are rainy days (by my criteria)

In 2023 there were 225 wet days compared with 140 dry days - this is the UK – don't look surprised

It's interesting to note that the days which by my criteria are "Wet" have sometimes had a lower path loss figure (min 0.585) than days which I assigned as "Dry" (min 0.702)

So the moral here is to trust the Weatherbox and don't write off a day for brief periods of rain

122.4 GHz Isotropic case including 2023 Weather data



Here is the Isotropic Loss Graph now including the calculated historic absorption.

Things have gone down hill very rapidly indeed

However this is only part of the story so we next move on to transmitted power and antenna gains

Transmit Power

Datasheet:

-3dBm ± 4 dB

at die level and measured (?) / simulated (?)

WITHOUT the integral Antennas

Initially the only data that was available was the datasheet – which can best be described as “sparse”

This gives a figure of -3 dBm +/- 4dB for transmit power – whether this is measured or simulated is unknown as various iterations of the datasheet seem to use the two terms interchangeably. The one currently on their website says measured

Also its measured at the output of the die – presumably tested before assembling to the antenna and there are no details of the on-chip antenna gain or efficiency

Therefore any calculation we make using this data has to be treated with caution as we have to make several assumptions without much supporting evidence

Transmit Power

122GProject@groups.io: KG6OJI (message 2661)

KG6OJI used a TRG 980 calorimeter with a V981 head plus adaptors and the combiner cavity from the VK3CV Chapparal feed

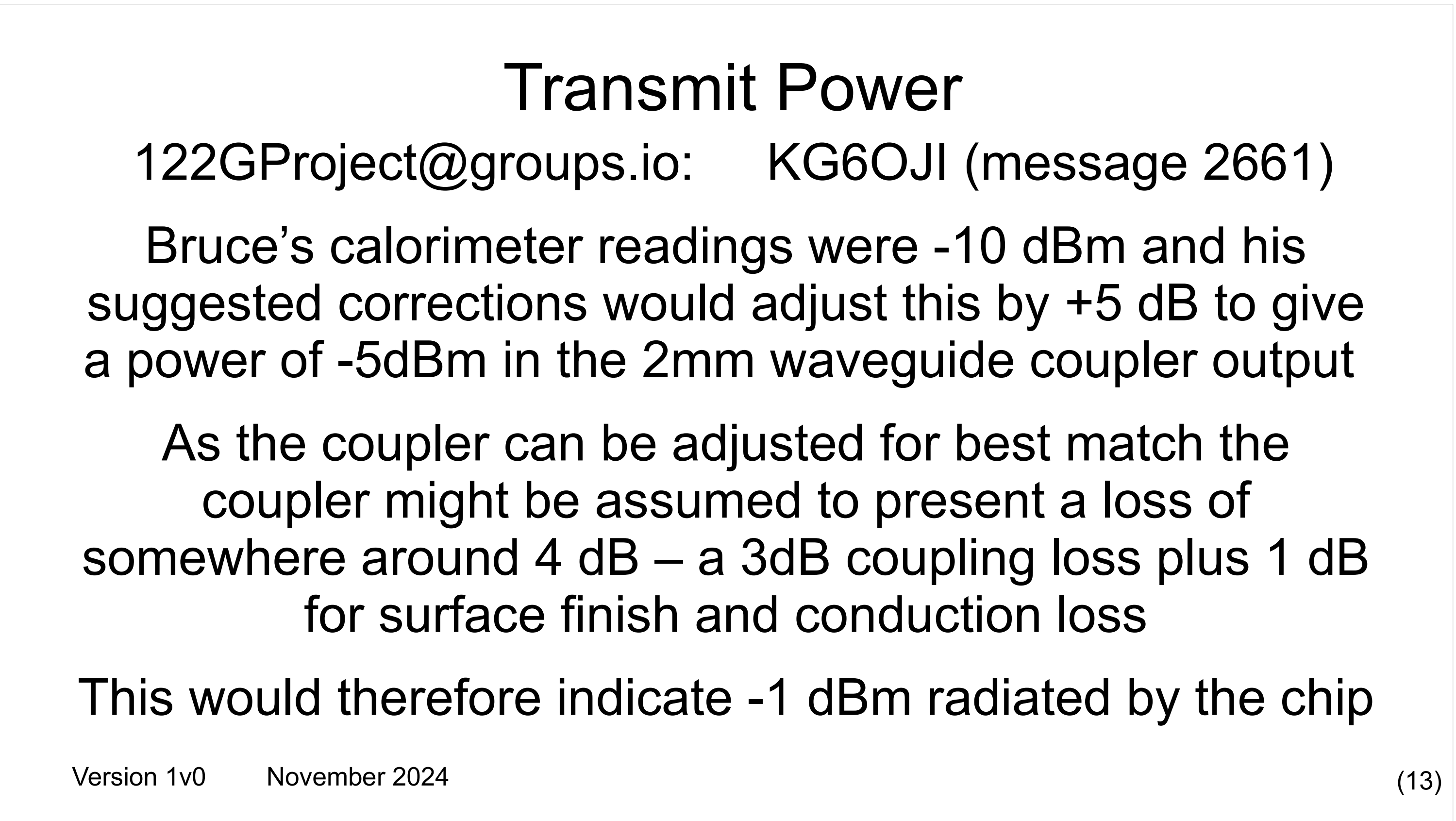
“*These power readings need to be corrected for the approximate 2.5 dB loss in the brass waveguide probe, perhaps 2dB more for the reflection at the 2mm circular guide to WR-10 interface and probably about 0.5 dB more for the WR-10 to WR-15 taper section.*”

A few amateurs have access to appropriate power measurement systems and have shared their results on the 12GHz group on groups.io.

Bruce’s email is comprehensive and his estimates appear very reasonable

The calorimeter used is capable of reading power to over 700 GHz, with the frequency limitation being the need to provide an accurate taper section to match the WR10 input of the V981 head to the system under test

The basic accuracy of the calorimeter is 2% to 5%



Transmit Power

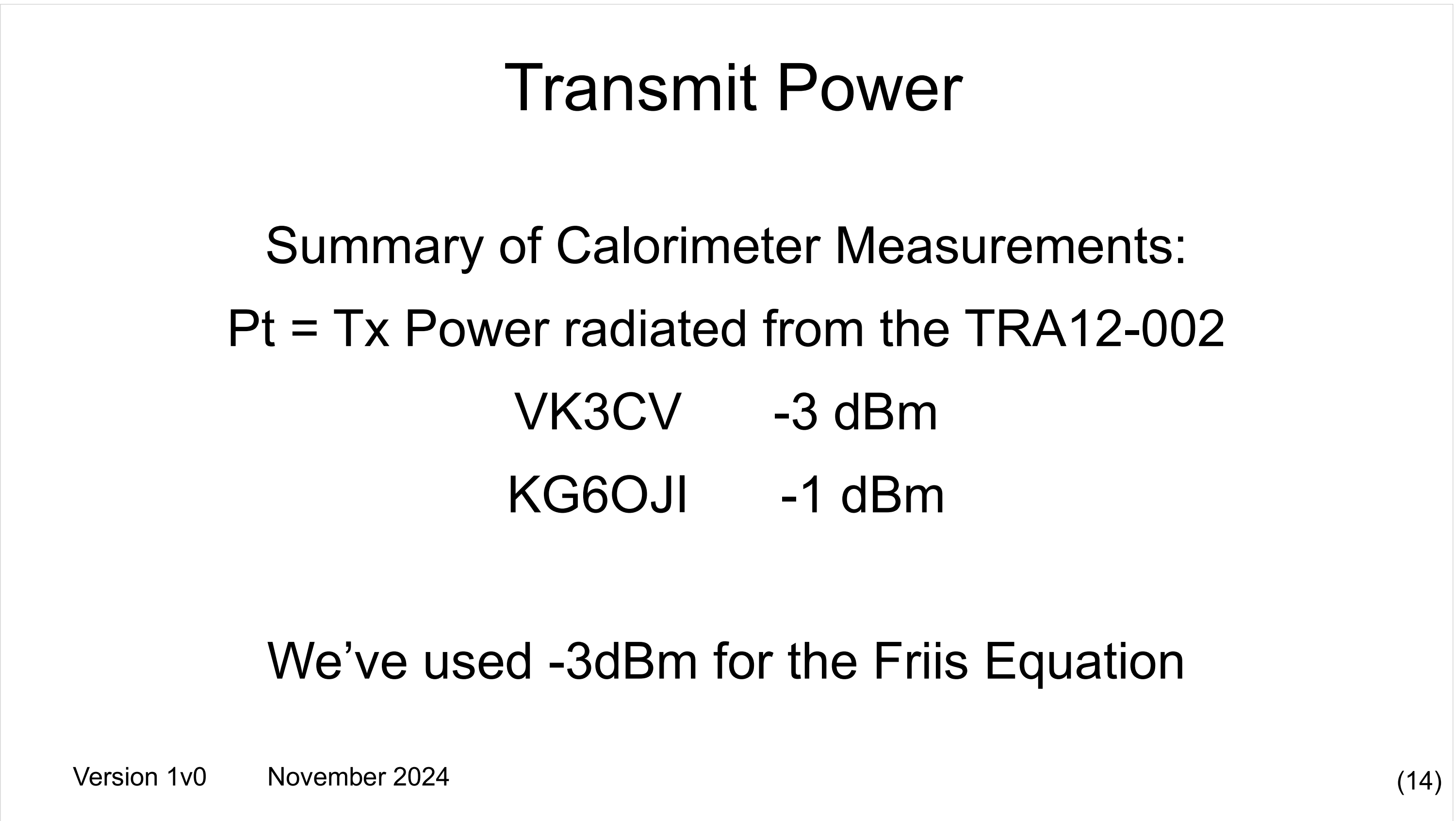
122GProject@groups.io: KG6OJI (message 2661)

Bruce’s calorimeter readings were -10 dBm and his suggested corrections would adjust this by +5 dB to give a power of -5dBm in the 2mm waveguide coupler output

As the coupler can be adjusted for best match the coupler might be assumed to present a loss of somewhere around 4 dB – a 3dB coupling loss plus 1 dB for surface finish and conduction loss

This would therefore indicate -1 dBm radiated by the chip

As we’re using the VK3CV horns which have an integral coupler I’ve worked this back to the power radiated from the surface of the chip



Transmit Power

Summary of Calorimeter Measurements:

Pt = Tx Power radiated from the TRA12-002

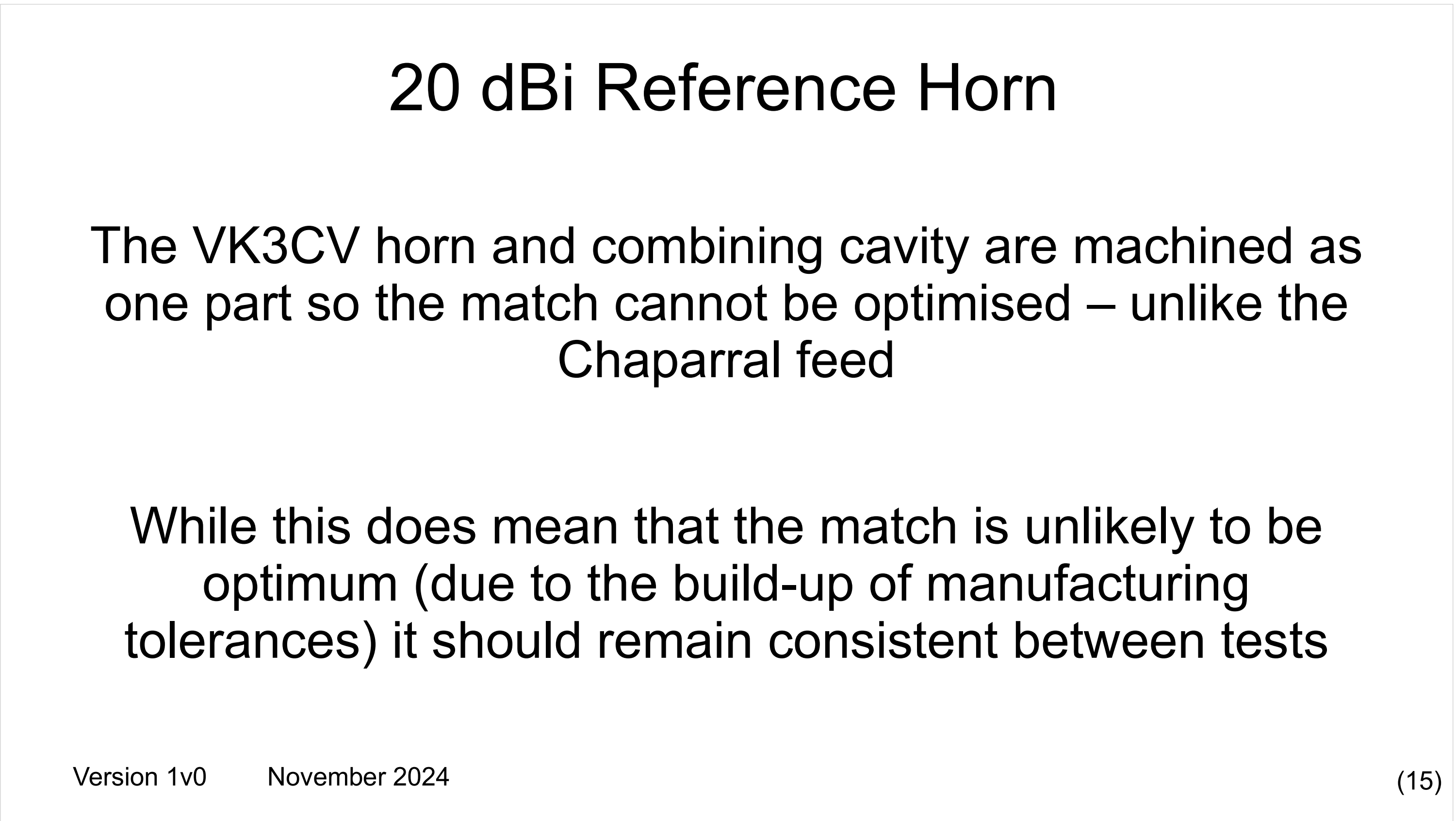
VK3CV	-3 dBm
KG6OJI	-1 dBm

We’ve used -3dBm for the Friis Equation

So we have 2 measurements which are in very good agreement with each other

For the rest of this presentation I’m going to use the -3 dBm figure to be slightly conservative

Bear in mind the datasheet suggests the power can vary by up to 8 dB



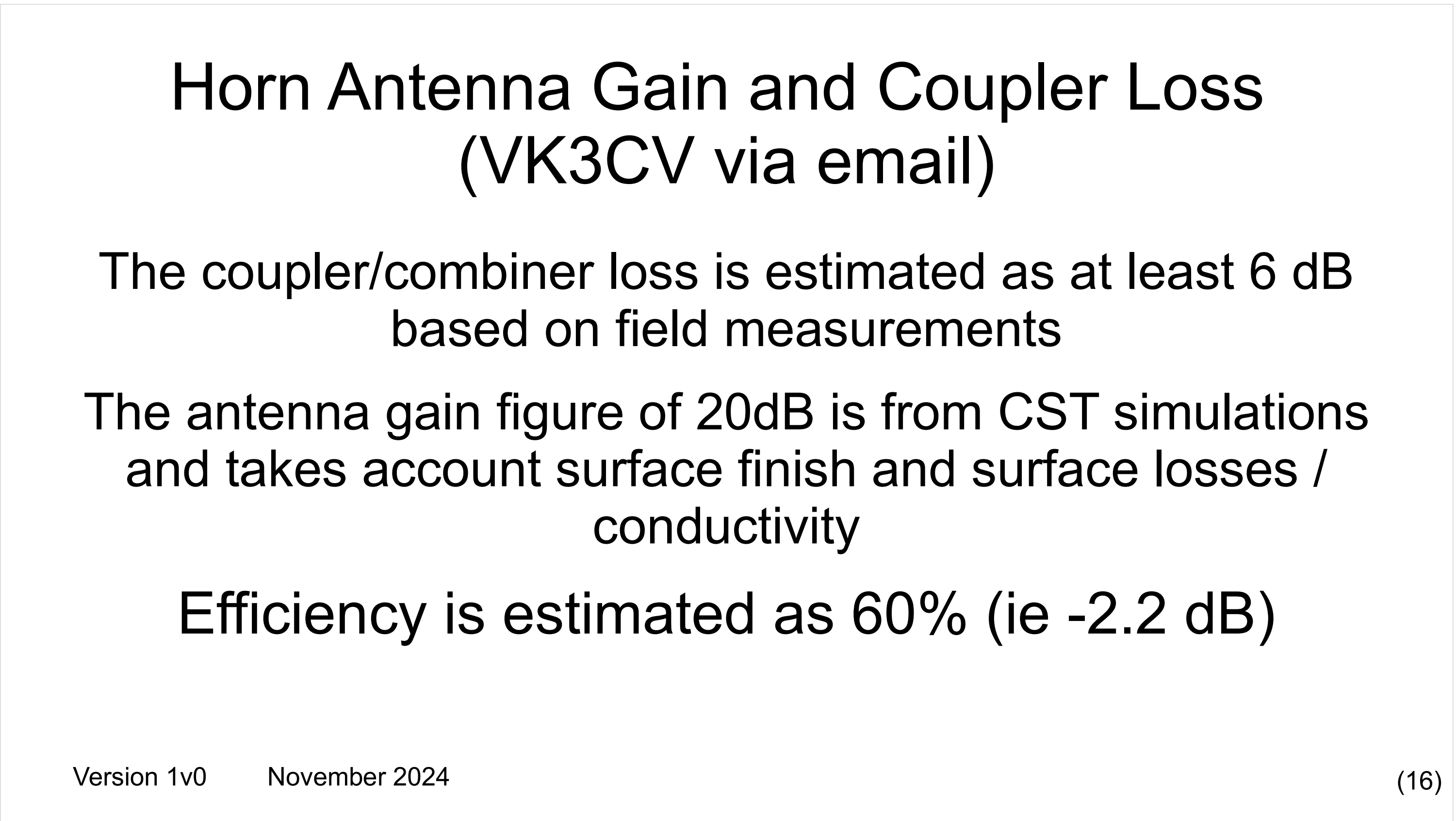
20 dBi Reference Horn

The VK3CV horn and combining cavity are machined as one part so the match cannot be optimised – unlike the Chaparral feed

While this does mean that the match is unlikely to be optimum (due to the build-up of manufacturing tolerances) it should remain consistent between tests

We’ve chosen to use the 20 dBi Reference Horn in our system as this allows us to test for limit conditions over reasonably short paths (in the 1km to 20 km range)

This should allow us to make several tests at different ranges in the course of a day while minimising path absorption loss changes



Horn Antenna Gain and Coupler Loss (VK3CV via email)

The coupler/combiner loss is estimated as at least 6 dB based on field measurements

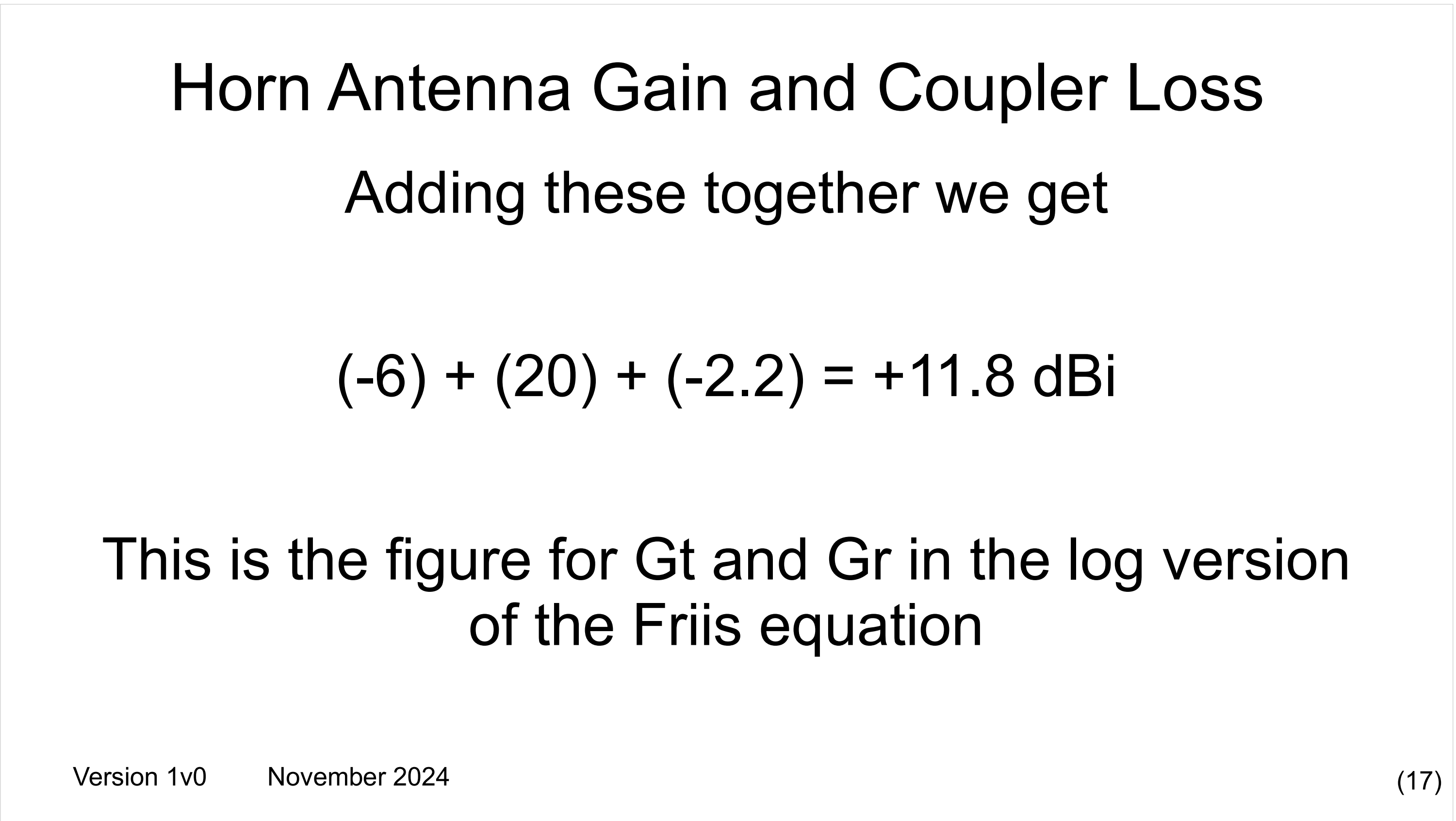
The antenna gain figure of 20dB is from CST simulations and takes account surface finish and surface losses / conductivity

Efficiency is estimated as 60% (ie -2.2 dB)

Based on measurements the horn coupler/combiner has a 6 dB insertion loss on transmit and receive – I.e. a 3dB coupling loss and a 3 dB loss of which a proportion is due to mismatch.

The VK3CV horn does not have the adjustment that the Chaparral feed has so we’re stuck with this loss when using these horns. The G4DBN version is however adjustable and should be capable of reducing the mismatch loss with careful adjustment

The horn gain is from CST simulations – a highly regarded (and very highly priced!) professional EM simulator – a free cut down student version is available for personal use



Horn Antenna Gain and Coupler Loss

Adding these together we get

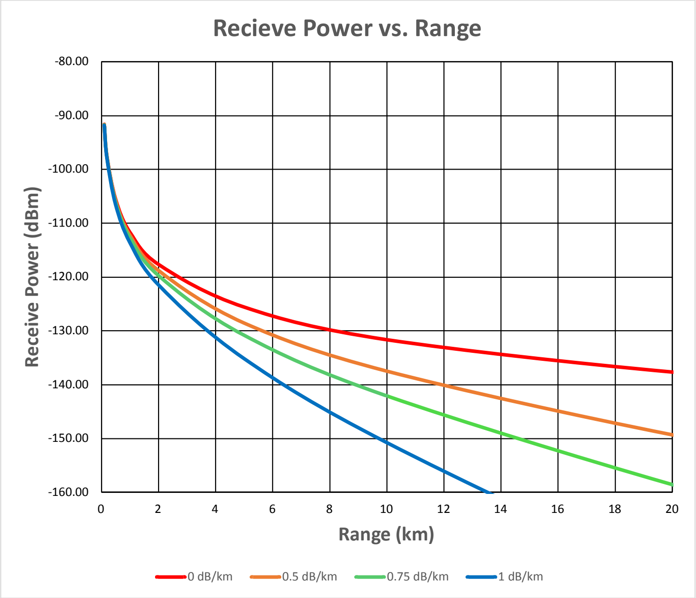
$$(-6) + (20) + (-2.2) = +11.8 \text{ dBi}$$

This is the figure for Gt and Gr in the log version of the Friis equation

Given a coupler loss of 6 dB, an isotropic gain of 20 dB and an efficiency loss of 2.2 dB we find that the real life isotropic gain of the horn/coupler system is 11.8 dBi

We can now plot the complete Friis equation to find Pr(d)

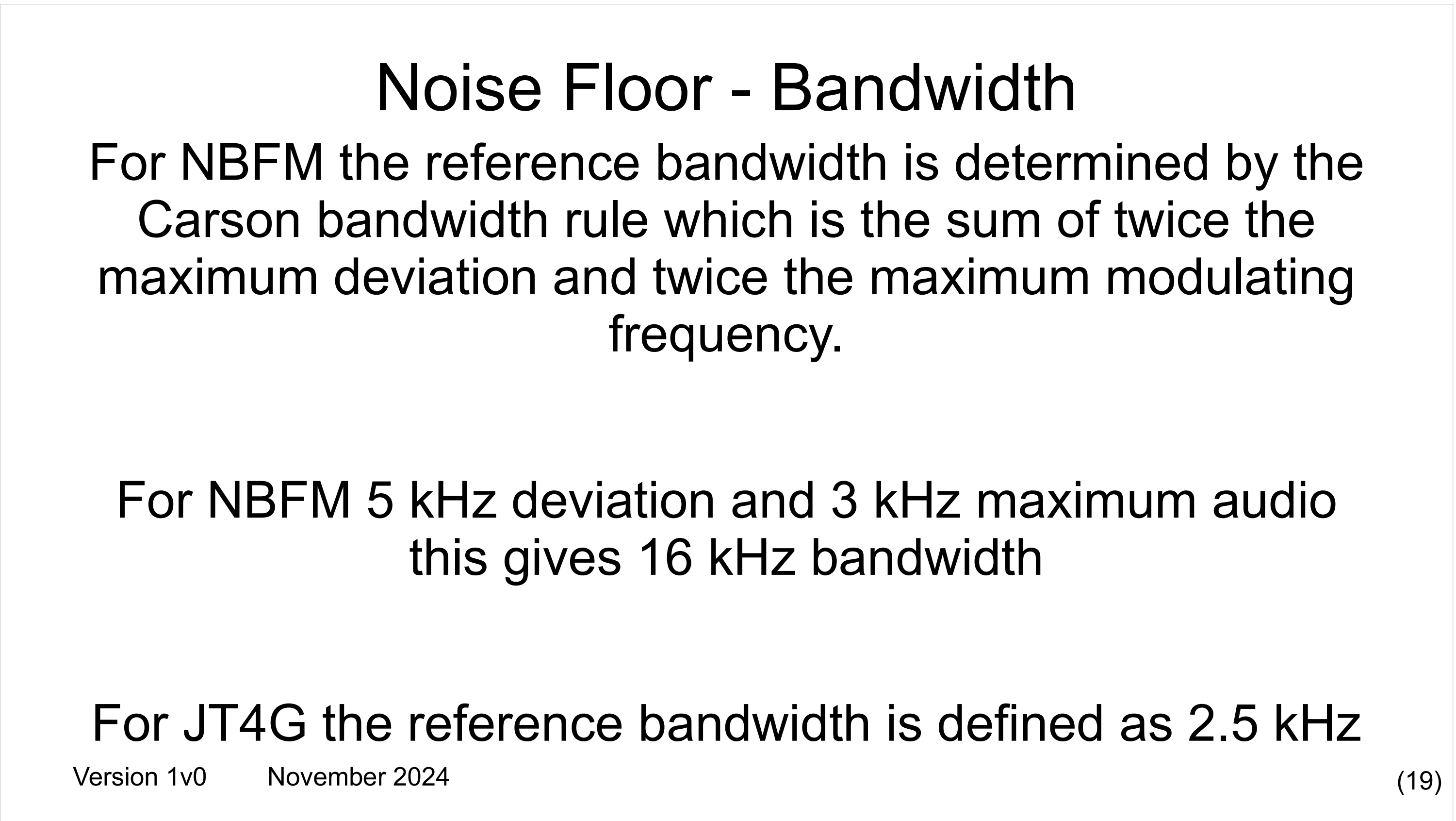
Received Power



Adding the figures for Transmitter power and the Transmit/Receive antenna/coupler gain into the Friis equation enable us to predict the theoretical received signal incident on the receiver TRA120 transceiver chip

So arbitrarily taking the -140 dBm received power case – and this is purely as an example - in the horn to horn system the best case estimate is a range of 6 km for worst case absorption, 9 km for the median case and 12 km for the minimum case

Finally for the link budget we need to determine the required signal to noise ratio for the modulation schemes used – in our case NBFM and JT4G



Noise Floor - Bandwidth

For NBFM the reference bandwidth is determined by the Carson bandwidth rule which is the sum of twice the maximum deviation and twice the maximum modulating frequency.

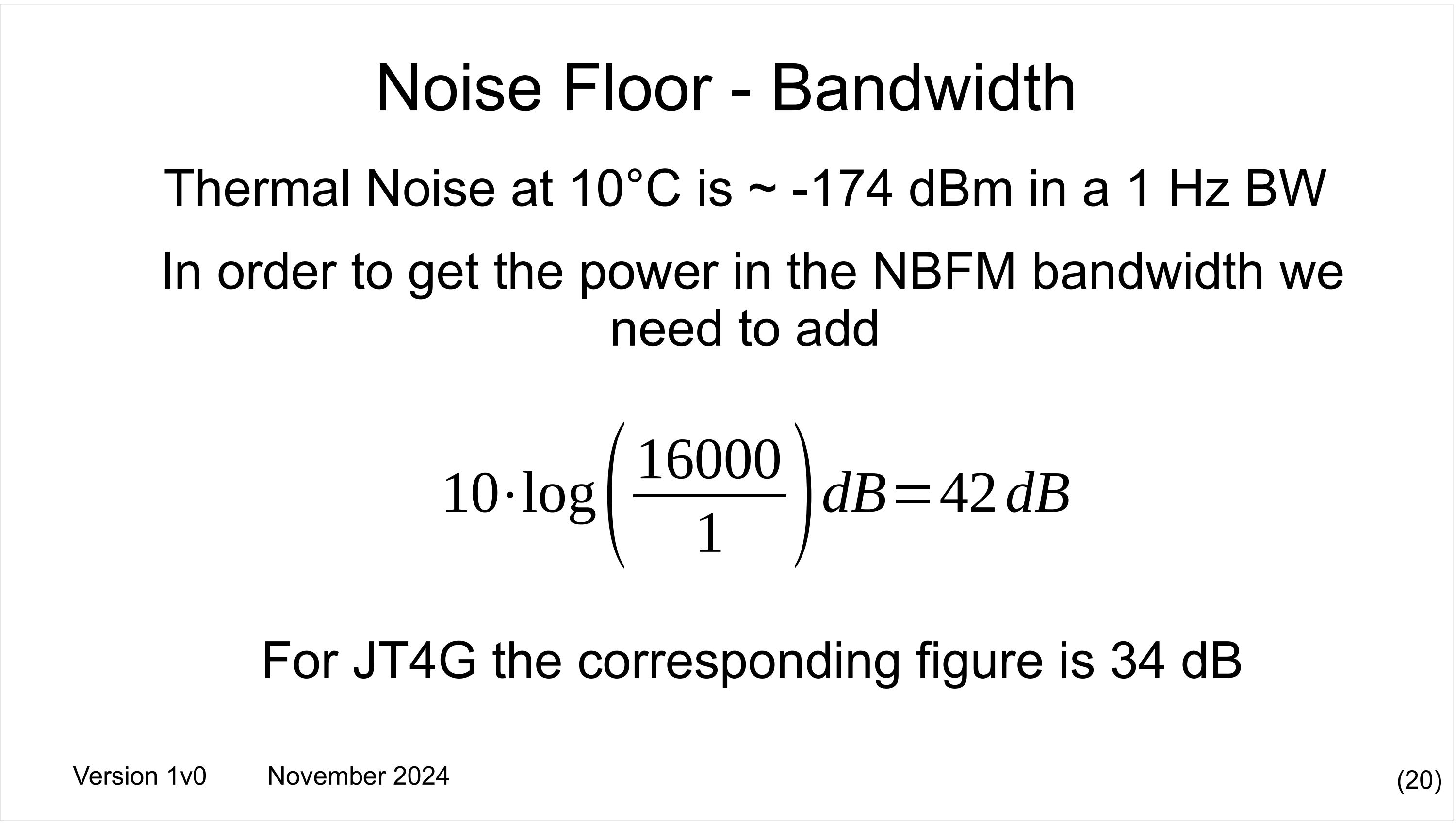
For NBFM 5 kHz deviation and 3 kHz maximum audio this gives 16 kHz bandwidth

For JT4G the reference bandwidth is defined as 2.5 kHz

To determine the noise floor of the receiver we need the reference bandwidth and the receiver Noise Figure

For NBFM Carson’s rule gives us a reference bandwidth of 16 kHz

For JT4G it is defined as being 2.5 kHz to align with the normal SSB filter bandwidth



Noise Floor - Bandwidth

Thermal Noise at 10°C is ~ -174 dBm in a 1 Hz BW

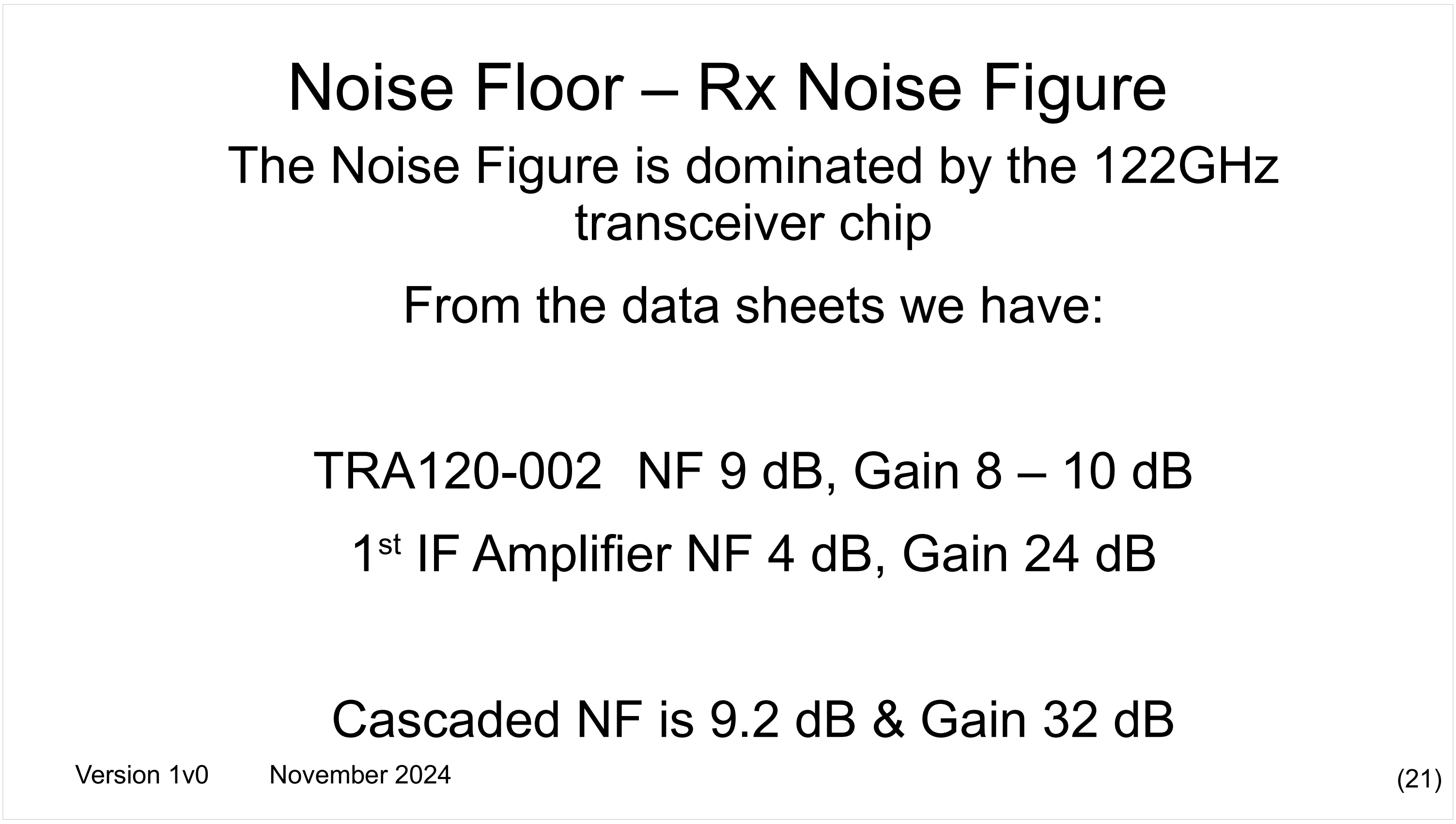
In order to get the power in the NBFM bandwidth we need to add

$$10 \cdot \log\left(\frac{16000}{1}\right) dB = 42\, dB$$

For JT4G the corresponding figure is 34 dB

For the 16 kHz reference bandwidth NBFM case then the multiplier from 1 Hz to 16 kHz is 10 log10 of the reference bandwidth (ie 16000 Hz) divided by 1 Hz and this comes out to 42 dB

For JT4G the corresponding figure is for 2500 Hz which gives a figure of 34 dB



Noise Floor – Rx Noise Figure

The Noise Figure is dominated by the 122GHz transceiver chip

From the data sheets we have:

TRA120-002 NF 9 dB, Gain 8 – 10 dB

1st IF Amplifier NF 4 dB, Gain 24 dB

Cascaded NF is 9.2 dB & Gain 32 dB

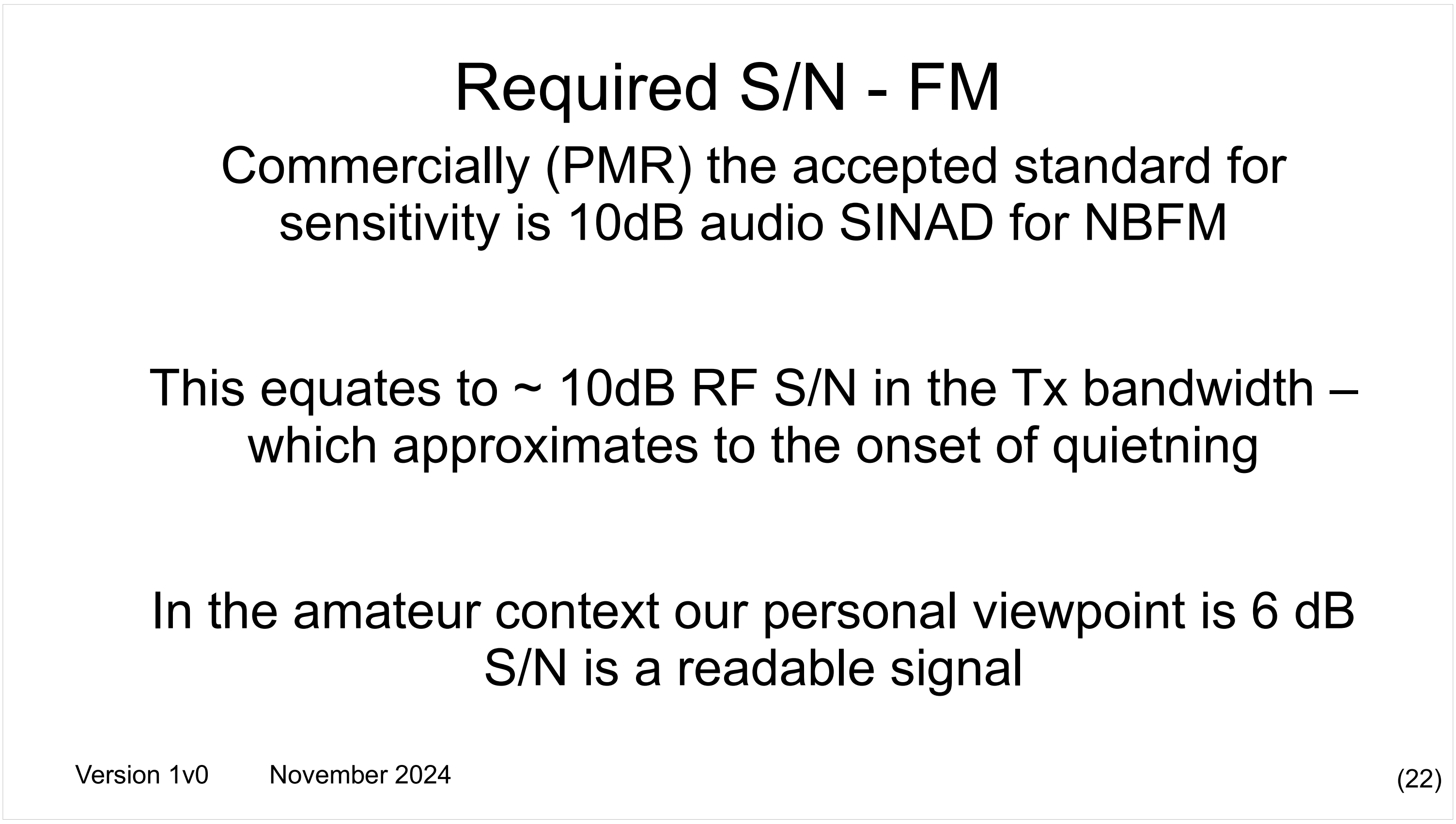
We have no measurements of the noise figure and gain of the RF head so we fall back on datasheet figures. These give us a NF of 9.2dB and a gain of 32 dB for the VK3CV board

BUT we have to treat these figures with a great deal of caution

The combiner cavity matching network is a 3 port system with no specific isolation between the Tx port and the Rx port other than a presumed 3 dB splitting loss and, possibly, up to 3dB or so matching loss

Even with a minimum output device, say -10 dBm radiated, this means that at least -16 dBm is incident on the Rx antenna. It could very easily be much. The Rx compression point is -20 dBm

The Rx is compressed and NF may be significantly degraded – we don’t know



Required S/N - FM

Commercially (PMR) the accepted standard for sensitivity is 10dB audio SINAD for NBFM

This equates to ~ 10dB RF S/N in the Tx bandwidth – which approximates to the onset of quietning

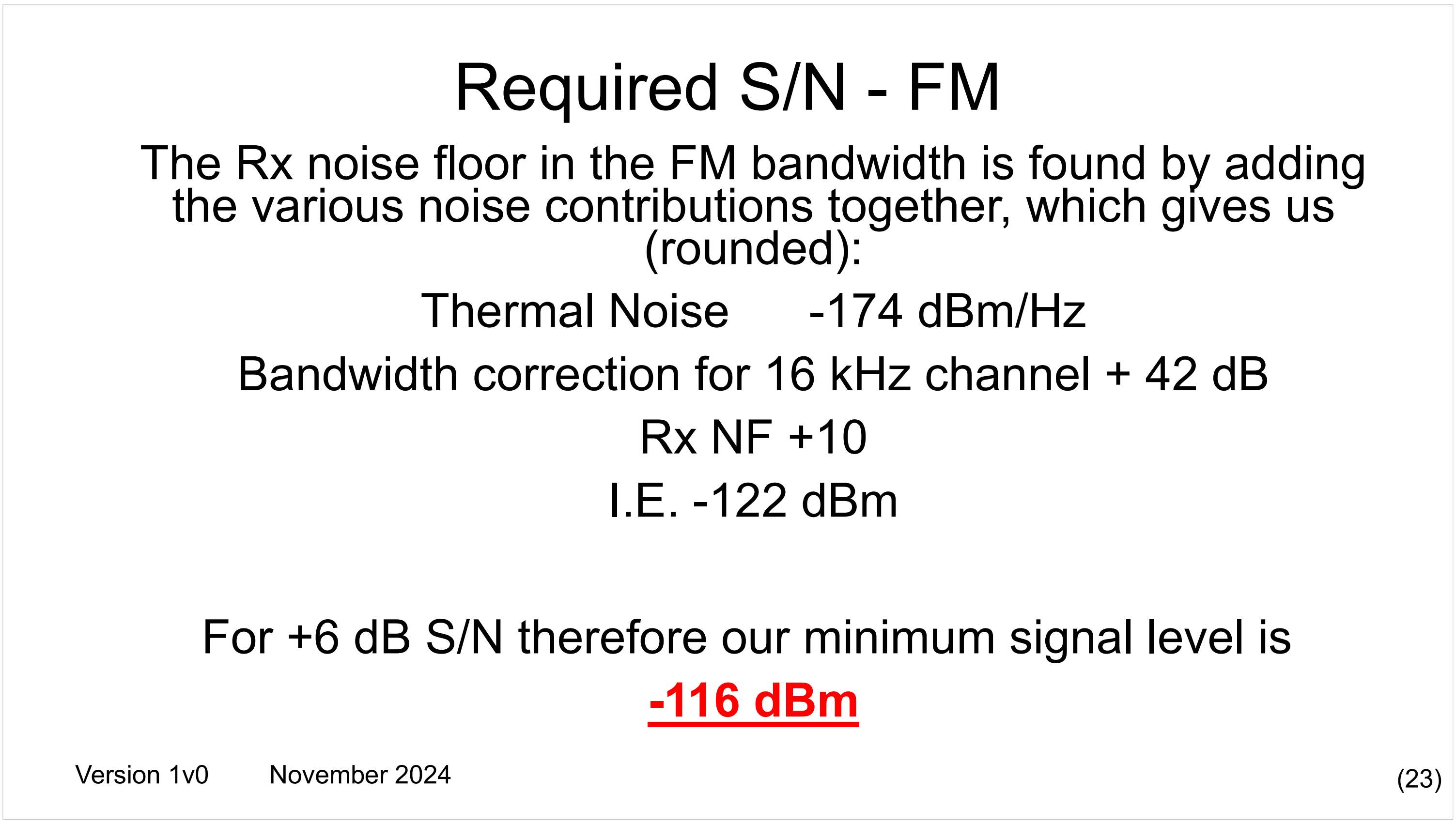
In the amateur context our personal viewpoint is 6 dB S/N is a readable signal

In PMR the SINAD is measured using a 1 kHz modulating tone at 60% of peak deviation, standardised in ETSI 301 166 (which was largely based on the original based on Ministry of Post and Telecommunications specification MPT 1301)

This gives a repeatable base standard for comparison of signals in the commercial sector

As amateurs we often operate below the standardised signal quality – in our case our personal definition of a barely readable signal is of the order of 6 dB RF S/N for FM

Your mileage may vary but for the purpose of our system calculation we’ve assumed 6 dB



Required S/N - FM

The Rx noise floor in the FM bandwidth is found by adding the various noise contributions together, which gives us (rounded):

Thermal Noise -174 dBm/Hz

Bandwidth correction for 16 kHz channel + 42 dB

Rx NF +10

I.E. -122 dBm

For +6 dB S/N therefore our minimum signal level is

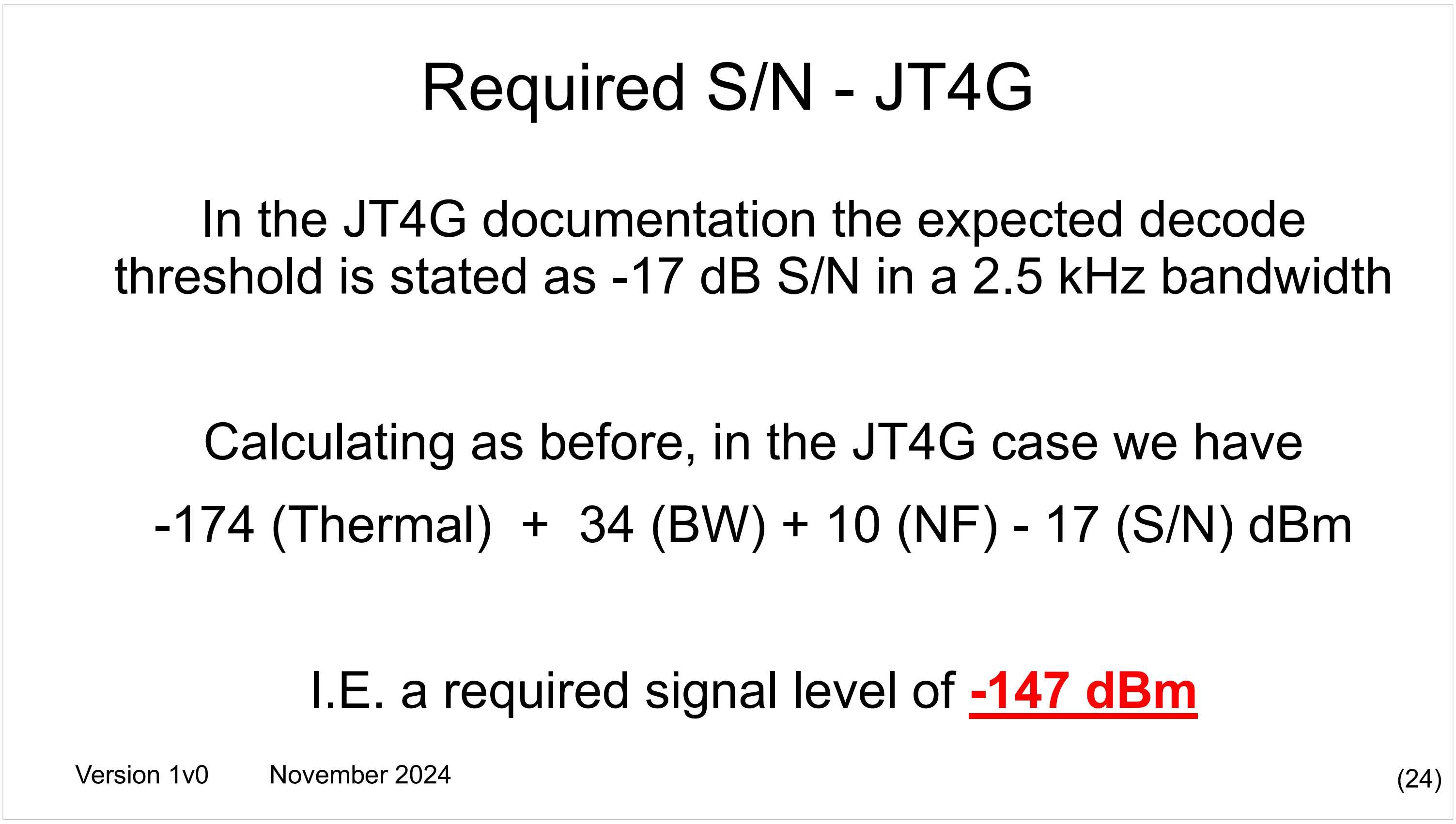
-116 dBm

We start with the standardised reference noise density of -174 dBm/Hz – which is pretty accurate for terrestrial point to point systems

We correct for the receiver bandwidth and noise figure to get the channel noise floor

We know our required S/N – which in this case is positive – and this gives us the required signal power incident at the receiver input of -116 dBm

Remembering that the datasheet specification for the TRA120 specifies its parameters at die level and neglects the antenna we will have to estimate the gain and efficiency of the on chip array



Required S/N - JT4G

In the JT4G documentation the expected decode threshold is stated as -17 dB S/N in a 2.5 kHz bandwidth

Calculating as before, in the JT4G case we have

-174 (Thermal) + 34 (BW) + 10 (NF) - 17 (S/N) dBm

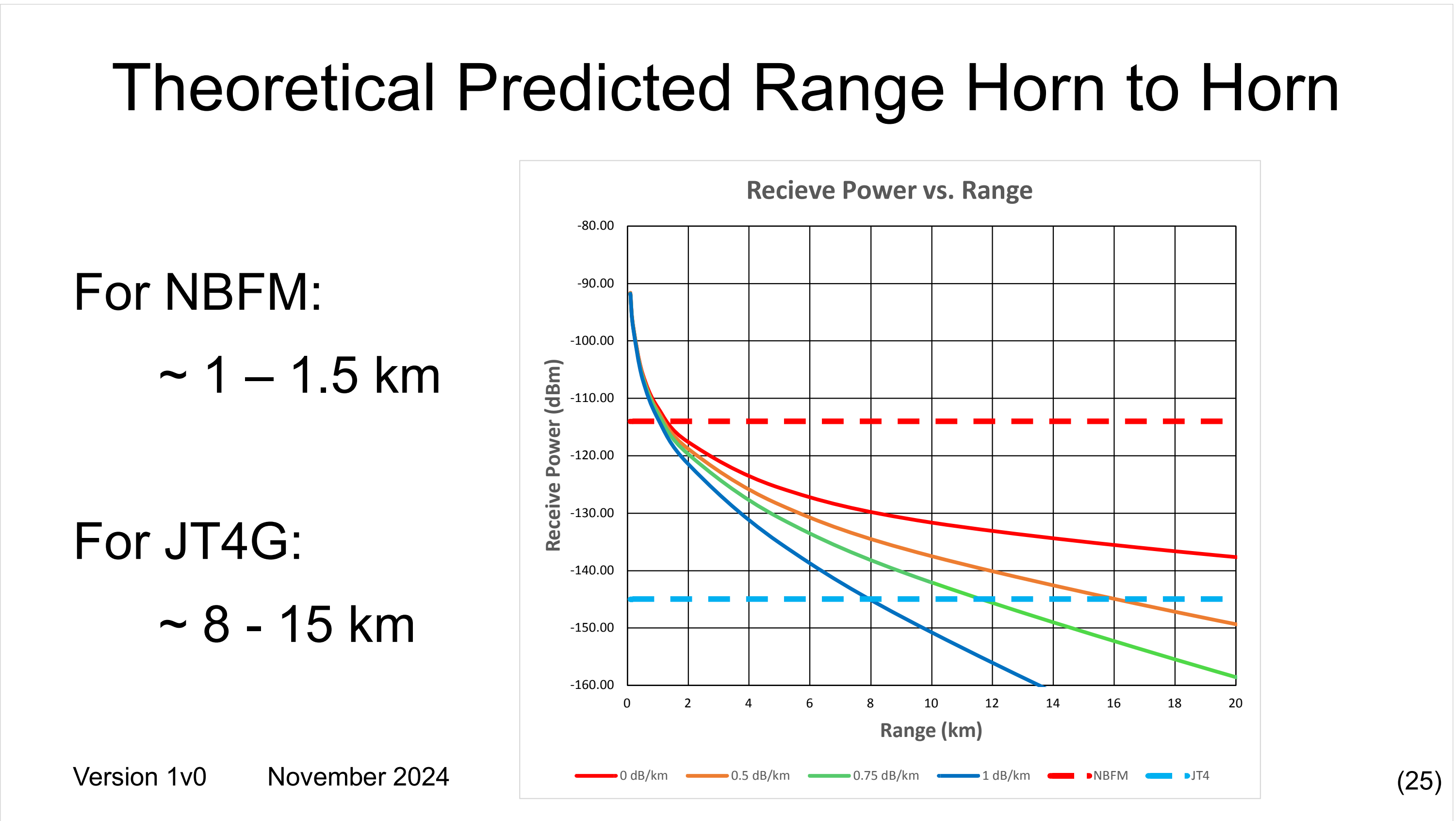
I.E. a required signal level of **-147 dBm**

A similar calculation for JT4G gives a signal level of -147 dBm

Again we we will have to estimate the efficiency of the on antenna chip array

In the absence of any real data here we’re going to assume a loss of 2 dB – this is most definitely a wet finger in the air estimate

The gain of the on-chip antenna array doesn’t come into the calculation as in our case its used as a coupling structure from the cavity to the chip die



Theoretical Predicted Range Horn to Horn

For NBFM:

~ 1 – 1.5 km

For JT4G:

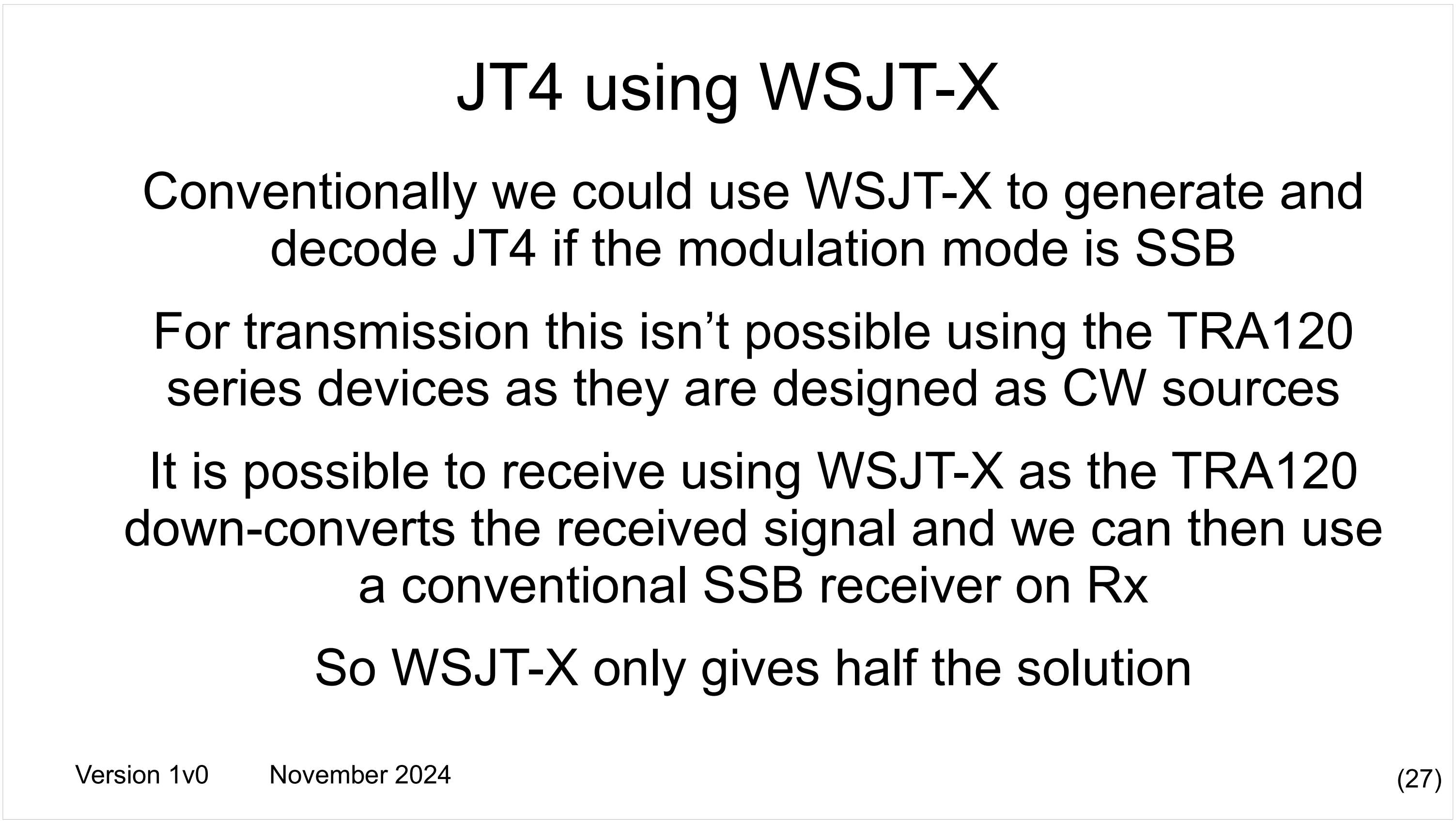
~ 8 - 15 km

Here is the final output of the link budget calculation and we've drawn on the thresholds for FM and JT4G having allowed 2 dB in each case for the on-chip Rx antenna efficiency so-116 becomes -114 dBm for FM and -147 becomes -145 dBm for JT4G

How to Implement JT4 ?

Version 1v0 November 2024

So how can we implement a JT4 system ?



JT4 using WSJT-X

Conventionally we could use WSJT-X to generate and decode JT4 if the modulation mode is SSB

For transmission this isn’t possible using the TRA120 series devices as they are designed as CW sources

It is possible to receive using WSJT-X as the TRA120 down-converts the received signal and we can then use a conventional SSB receiver on Rx

So WSJT-X only gives half the solution

On the lower bands transverters perform a transmission and reception up/down conversion and modulation and demodulation are carried out by the transceiver used at IF

TRA120 devices are CW in transmission so we have to be modulate the TRA120 VCO in some manner to generate the required modulation, ssb is ruled out – hence the VK3CV board is a designed as an FM system

So no means of generating JT4 directly from WSJT-X

On receive however the TRA120 devices simply down-convert and we can therefore use an SSB receiver and connect to a soundcard in the normal manner.

So – only half a solution

JT4 Tx – FSK

WSJT-X produces a series of tones which modulate an SSB driver to produce an FSK signal

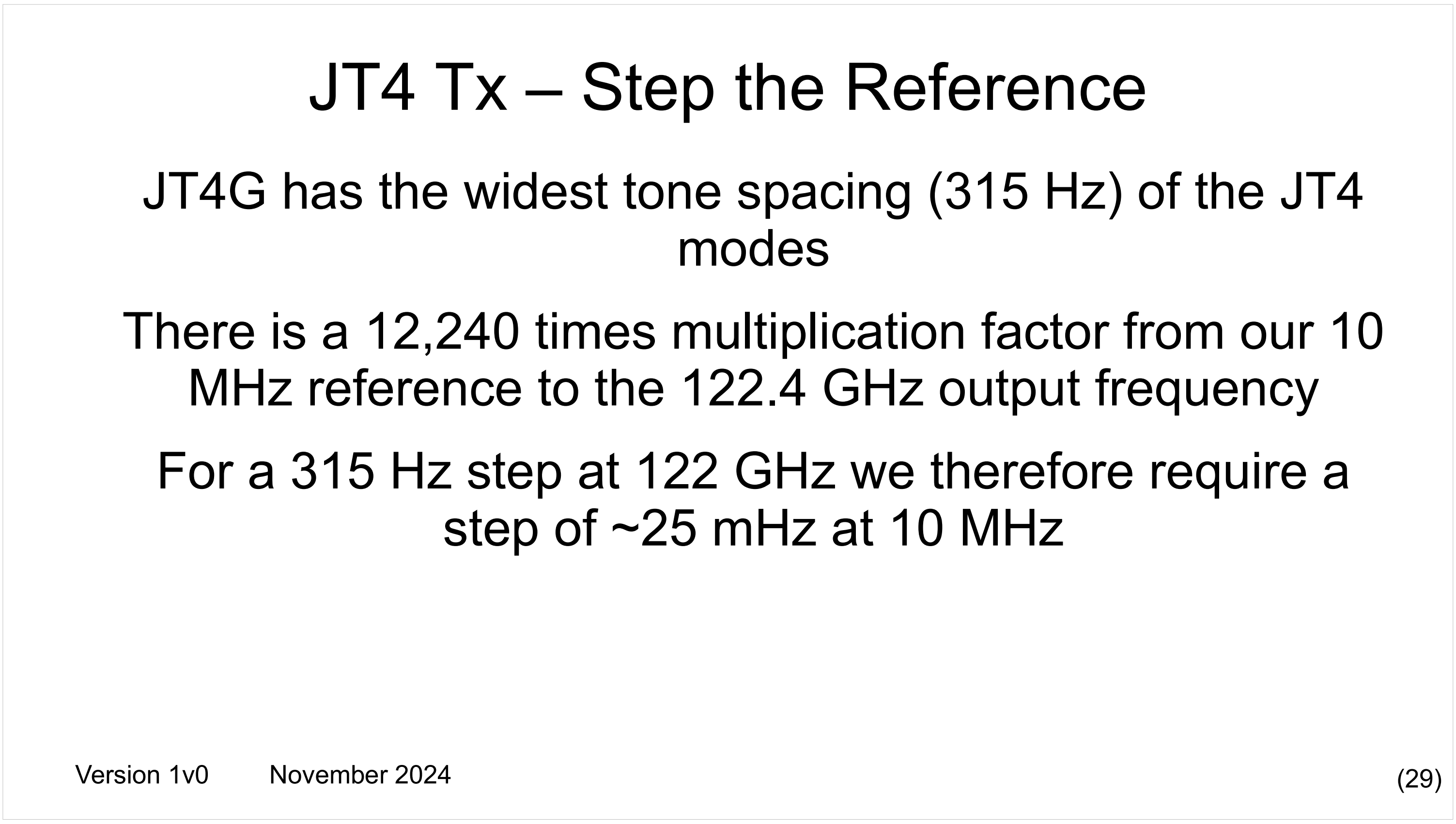
Generating FSK is something we can do with the TRA120 chips

We’ve implemented it by micro-stepping the 10 MHz reference VCOCXO using a waveform in which the different tones are represented by different voltages

WSJT-X produces a series of tones which modulate an SSB driver to produce an FSK signal

We can generate FSK in the TRA120 chips

If we have a voltage controlled frequency reference we can modulate the control voltage to generate FSK on the reference and, provided that the syllable rate of JT4 falls within the loop bandwidth of the TRA120 phase locked loop, it will track the frequency variations and so generate FSK modulation on the carrier.



JT4 Tx – Step the Reference

JT4G has the widest tone spacing (315 Hz) of the JT4 modes

There is a 12,240 times multiplication factor from our 10 MHz reference to the 122.4 GHz output frequency

For a 315 Hz step at 122 GHz we therefore require a step of ~25 mHz at 10 MHz

We want a tone spacing of 315 Hz at 122 GHz for JT4

The multiplier from our 10 MHz reference to the 122 GHz output is 12,240.

This means to generate tones separated by 315 Hz at 122 GHz we need tones separated by ~ 25 mHz at 10 MHz i.e. ~2.5 ppb

This has been well within the tuning capability of all the OCXOs we’ve tried.

JT4 Tx – Step the Reference

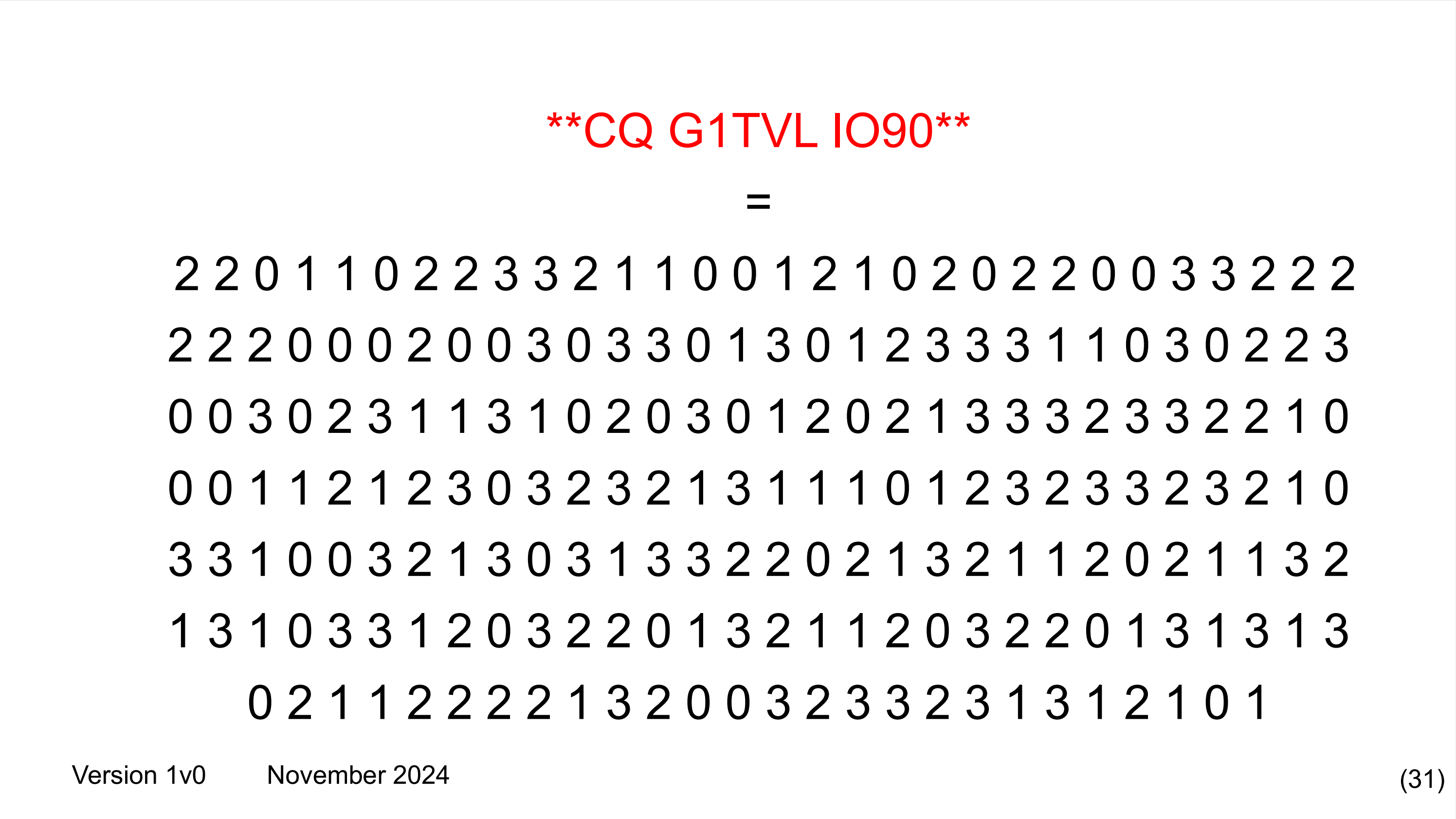
We use an 18 bit DAC to drive the Tune pin on the OCXO giving approximately 1.6 Hz per bit at 122 GHz

We store a “Tune” value (to get us on frequency) and then “Tone” value to step between the various JT4 Frequencies

To encode the message we pre-compose the message and then use the jt4code console utility from WSJT-X to generate a stream of tone codes

An 18 bit DAC gives ample resolution to tune the OCXO over its full range for frequency calibration while at the same time giving sufficient granularity to set each tone offset from the carrier with sufficient accuracy for JT4

We use the “jt4code” console utility to encode the message into a string of tone values in the format



CQ G1TVL IO90

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2 2 0 1 1 0 2 2 3 3 2 1 1 0 0 1 2 1 0 2 0 2 2 0 0 3 3 2 2 2
2 2 2 0 0 0 2 0 0 3 0 3 3 0 1 3 0 1 2 3 3 3 1 1 0 3 0 2 2 3
0 0 3 0 2 3 1 1 3 1 0 2 0 3 0 1 2 0 2 1 3 3 3 2 3 3 2 2 1 0
0 0 1 1 2 1 2 3 0 3 2 3 2 1 3 1 1 1 0 1 2 3 2 3 3 2 3 2 1 0
3 3 1 0 0 3 2 1 3 0 3 1 3 3 2 2 0 2 1 3 2 1 1 2 0 2 1 1 3 2
1 3 1 0 3 3 1 2 0 3 2 2 0 1 3 2 1 1 2 0 3 2 2 0 1 3 1 3 1 3
0 2 1 1 2 2 2 2 1 3 2 0 0 3 2 3 3 2 3 1 3 1 2 1 0 1

This sequence of symbols is used to generate a series of values to program a DAC which tunes the 10MHz reference oscillator.

We oversample the 206 symbols by 4 for practical reasons (giving a sequence of 824 symbols which only change every 4th symbol).

A short header is added to put the carrier out of the receiver passband for 1 second before transmission starts, and a similar footer puts the carrier out of band for a 1 second period at the end of transmission. This is emulate the ssb/audio card JT4 case where there is no carrier before/after transmission

Each value is multiplied by the tuning gain of the OCXO (bits per tone), and then add a small amount of filtering to the values so the frequency slews between tones rather than jumping).

Then, just as for the WSJT-X gui program, we wait for the top of the minute, then tune the OCXO at the required rate until the sequence is complete.

JT4 Rx

The VK3CV board outputs a 144 MHz IF

We’ve implemented an SDR using the FUNcube Pro+ dongle as the receiver with GNU Radio running on a Raspberry Pi Compute 4 module

This is a multimode AM/FM/SSB receiver with individual always available AM, FM, USB and LSB demodulated audio

Switching modes is simply by selecting the required audio stream

We used the FUNcube Pro+ dongles because we had them

Likewise we had the CM4 modules

The receiver is pretty straight forward, the only real item of note is that we chose a Weaver demodulator architecture rather than brute force filtering

JT4 Rx

After GNU Radio has demodulated the received RF the remainder of the system is implemented in Python using the PyGame library to provide a fast graphics and event scheduler – without the overhead of a full graphical desktop

The output of GNU Radio is the demodulated audio streams. The remainder of the system is written in Python. The main system tasks are:

Screen update (17.5 frames/second, divide this by 4 to get the JT4 syllable rate)

User Interface

Streaming data to the OCXO DAC in Tx mode

Interface to the GPS and LoRa modules

Interface to the environment sensor

JT4 scheduling

Map and path profile calculations and graphics

More on each of these in the hardware walk-around

A brief aside: JT9 Too !

As an aside JT9 is implemented in a similar manner to JT4.

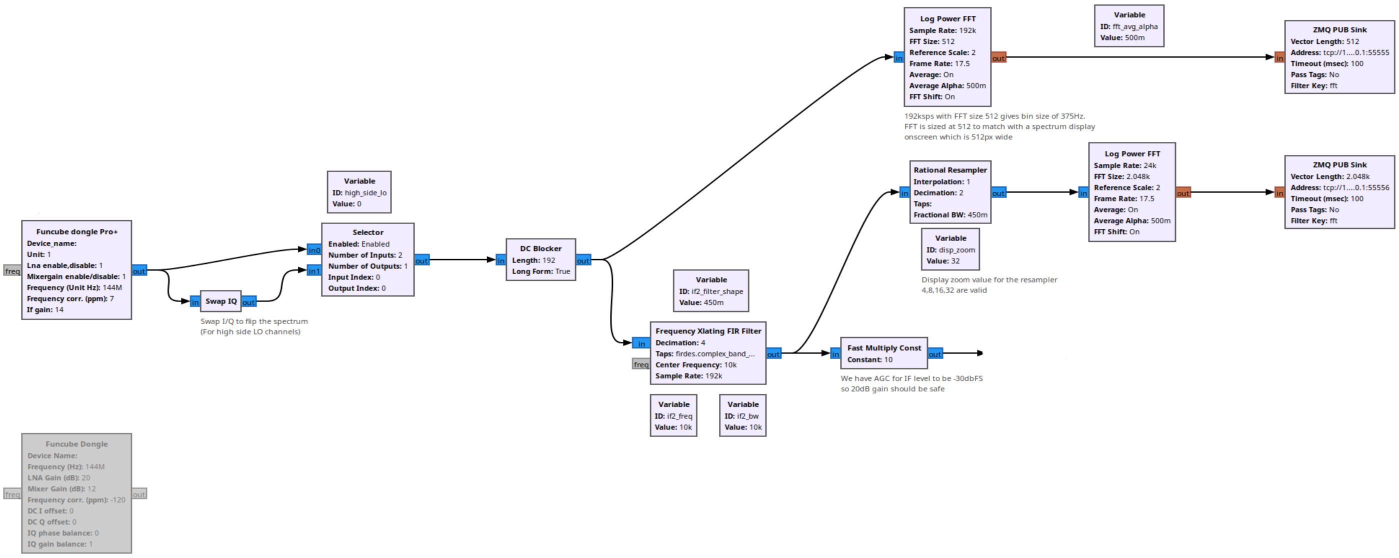
Transmission works as expected, and reception, at as far as saving the WAV audio files, which have been demodulated on a PC successfully.

Unfortunately when fed JT9 audio the JT9 decoder currently crashes while running on the Raspberry Pi even though it works fine on the PC

No time has been available to investigate this further.

Now on to the GNU radio SDR

JT4 Rx - 1



Funcube dongle Pro+
Device_name:
Unit: 1
Lna enable,disable: 1
Mixergain enable/disable: 1
Frequency (Unit Hz): 144M
Frequency corr. (ppm): 7
If gain: 14

Swap IQ

Swap I/Q to flip the spectrum
(For high side LO channels)

Variable
ID: high_side_lo
Value: 0

Selector
Enabled: Enabled
Number of Inputs: 2
Number of Outputs: 1
Input Index: 0
Output Index: 0

DC Blocker
Length: 192
Long Form: True

Log Power FFT
Sample Rate: 192k
FFT Size: 512
Reference Scale: 2
Frame Rate: 17.5
Average: On
Average Alpha: 500m
FFT Shift: On

192ksps with FFT size 512 gives bin size of 375Hz.
FFT is sized at 512 to match with a spectrum display
onscreen which is 512px wide

Variable
ID: fft_avg_alpha
Value: 500m

ZMQ PUB Sink
Vector Length: 512
Address: tcp://1....0.1:55555
Timeout (msec): 100
Pass Tags: No
Filter Key: fft

Variable
ID: if2_filter_shape
Value: 450m

Frequency Xlating FIR Filter
Decimation: 4
Taps: firdes.complex_band_...
Center Frequency: 10k
Sample Rate: 192k

Variable
ID: if2_freq
Value: 10k

Variable
ID: if2_bw
Value: 10k

Rational Resampler
Interpolation: 1
Decimation: 2
Taps:
Fractional BW: 450m

Variable
ID: disp_zoom
Value: 32

Display zoom value for the resampler
4,8,16,32 are valid

Log Power FFT
Sample Rate: 24k
FFT Size: 2.048k
Reference Scale: 2
Frame Rate: 17.5
Average: On
Average Alpha: 500m
FFT Shift: On

ZMQ PUB Sink
Vector Length: 2.048k
Address: tcp://1....0.1:55556
Timeout (msec): 100
Pass Tags: No
Filter Key: fft

Fast Multiply Const
Constant: 10

We have AGC for IF level to be -30dbFS
so 20dB gain should be safe

Funcube Dongle
Device Name:
Frequency (Hz): 144M
LNA Gain (dB): 20
Mixer Gain (dB): 12
Frequency corr. (ppm): -120
DC I offset: 0
DC Q offset: 0
IQ phase balance: 0
IQ gain balance: 1

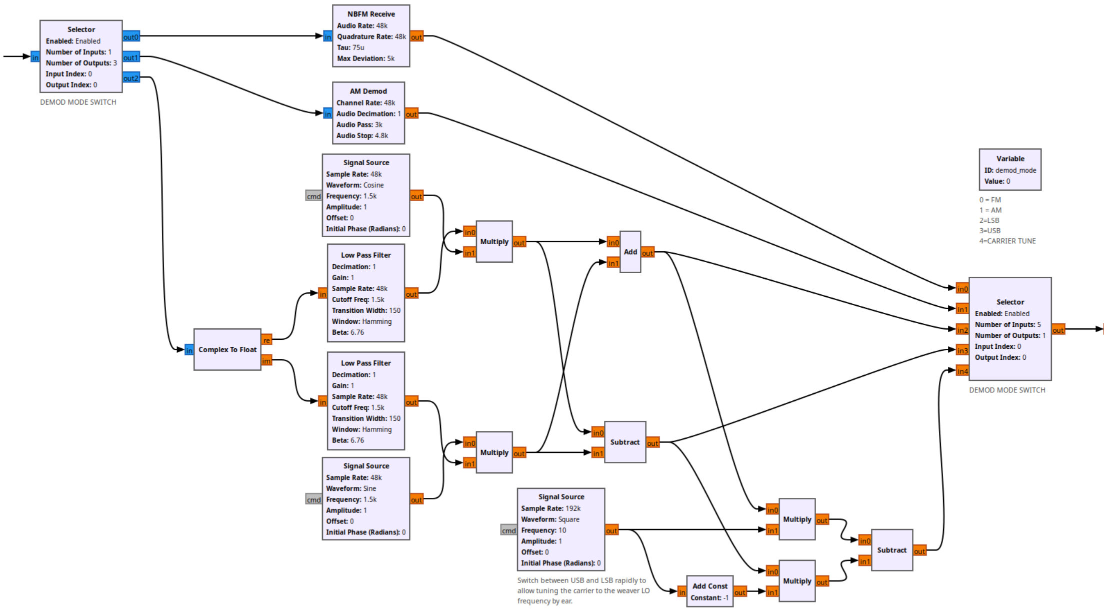
A simple multimode receiver (FM/AM/SSB) is constructed in GnuRadio, fed by a Funcube Pro+ SDR

This is the front end implementation

A 512pt FFT is run on the full 192kHz bandwidth constantly, and the output is always available.

After the first IF filter a second 2048pt FFT is run on a 24kHz bandwidth. This second stream output is also always available

JT4 Rx - 2



Selector
Enabled: Enabled
Number of Inputs: 1
Number of Outputs: 3
Input Index: 0
Output Index: 0
DEMOD MODE SWITCH

NBFM Receive
Audio Rate: 48k
Quadrature Rate: 48k
Tau: 75u
Max Deviation: 5k

AM Demod
Channel Rate: 48k
Audio Decimation: 1
Audio Pass: 3k
Audio Stop: 4.8k

Signal Source
Sample Rate: 48k
Waveform: Cosine
Frequency: 1.5k
Amplitude: 1
Offset: 0
Initial Phase (Radians): 0

Low Pass Filter
Decimation: 1
Gain: 1
Sample Rate: 48k
Cutoff Freq: 1.5k
Transition Width: 150
Window: Hamming
Beta: 6.76

Low Pass Filter
Decimation: 1
Gain: 1
Sample Rate: 48k
Cutoff Freq: 1.5k
Transition Width: 150
Window: Hamming
Beta: 6.76

Signal Source
Sample Rate: 48k
Waveform: Sine
Frequency: 1.5k
Amplitude: 1
Offset: 0
Initial Phase (Radians): 0

Signal Source
Sample Rate: 192k
Waveform: Square
Frequency: 10
Amplitude: 1
Offset: 0
Initial Phase (Radians): 0

Switch between USB and LSB rapidly to allow tuning the carrier to the weaver LO frequency by ear.

Add Const
Constant: -1

Variable
ID: demod_mode
Value: 0

0 = FM
1 = AM
2=LSB
3=USB
4=CARRIER TUNE

Selector
Enabled: Enabled
Number of Inputs: 5
Number of Outputs: 1
Input Index: 0
Output Index: 0
DEMOD MODE SWITCH

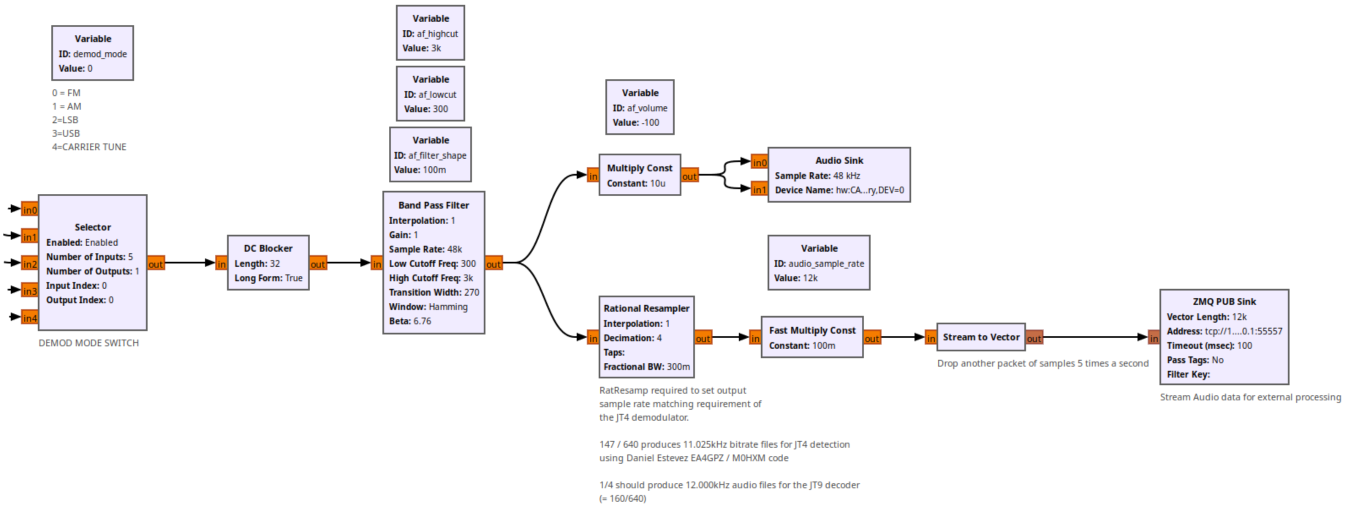
Here is the demodulation block

The output of the first IF filter is demodulated by AM and FM blocks, and also by the SSB Weaver demodulator, providing 4 possible audio streams to select.

A fifth audio channel is generated by rapidly switching between USB and LSB audio streams, and using the inherent frequency shift of the weaver demodulator to give an audio guide tone for carrier tuning.

Both FFT streams and the selected audio stream are made available to the python code as data streams.

JT4 Rx - 3



Variable
ID: demod_mode
Value: 0

0 = FM
1 = AM
2=LSB
3=USB
4=CARRIER TUNE

Selector
Enabled: Enabled
Number of Inputs: 5
Number of Outputs: 1
Input Index: 0
Output Index: 0

DEMOD MODE SWITCH

DC Blocker
Length: 32
Long Form: True

Variable
ID: af_highcut
Value: 3k

Variable
ID: af_lowcut
Value: 300

Variable
ID: af_filter_shape
Value: 100m

Band Pass Filter
Interpolation: 1
Gain: 1
Sample Rate: 48k
Low Cutoff Freq: 300
High Cutoff Freq: 3k
Transition Width: 270
Window: Hamming
Beta: 6.76

Variable
ID: af_volume
Value: -100

Multiply Const
Constant: 10u

Audio Sink
Sample Rate: 48 kHz
Device Name: hw:CA...ry,DEV=0

Variable
ID: audio_sample_rate
Value: 12k

Rational Resampler
Interpolation: 1
Decimation: 4
Taps:
Fractional BW: 300m

RatResamp required to set output
sample rate matching requirement of
the JT4 demodulator.

147 / 640 produces 11.025kHz bitrate files for JT4 detection
using Daniel Estevez EA4GPZ / M0HXM code

1/4 should produce 12.000kHz audio files for the JT9 decoder
(= 160/640)

Fast Multiply Const
Constant: 100m

Stream to Vector

Drop another packet of samples 5 times a second

ZMQ PUB Sink
Vector Length: 12k
Address: tcp://1....0.1:55557
Timeout (msec): 100
Pass Tags: No
Filter Key:

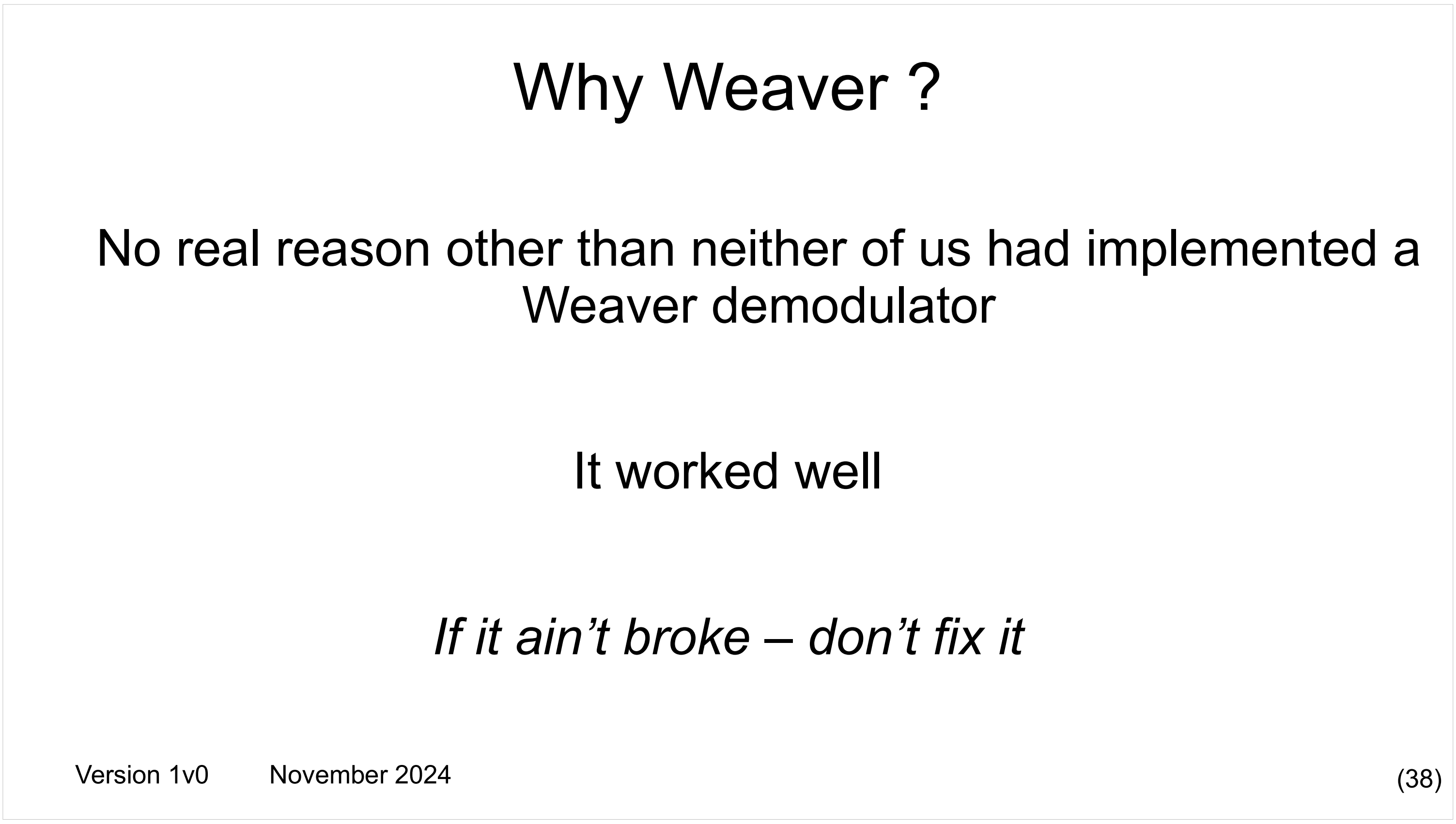
Stream Audio data for external processing

This is the final part of the GNU radio with a selector for whichever demodulation mode is required on the left

The selected audio stream is fed directly to the hardware sound card, amplifier and speaker.

The out put of the soundcard stream is saved into successive WAV files each with 1 minutes audio aligned to the top of the minute

These are then processed sequentially by the JT decoder utility and any received messages are presented on the GUI



Why Weaver ?

No real reason other than neither of us had implemented a Weaver demodulator

It worked well

If it ain’t broke – don’t fix it

Neither of us had used the Weaver method before

For good descriptions see

QST – September 1957

Hamradio.si

Panradio-sdr.de

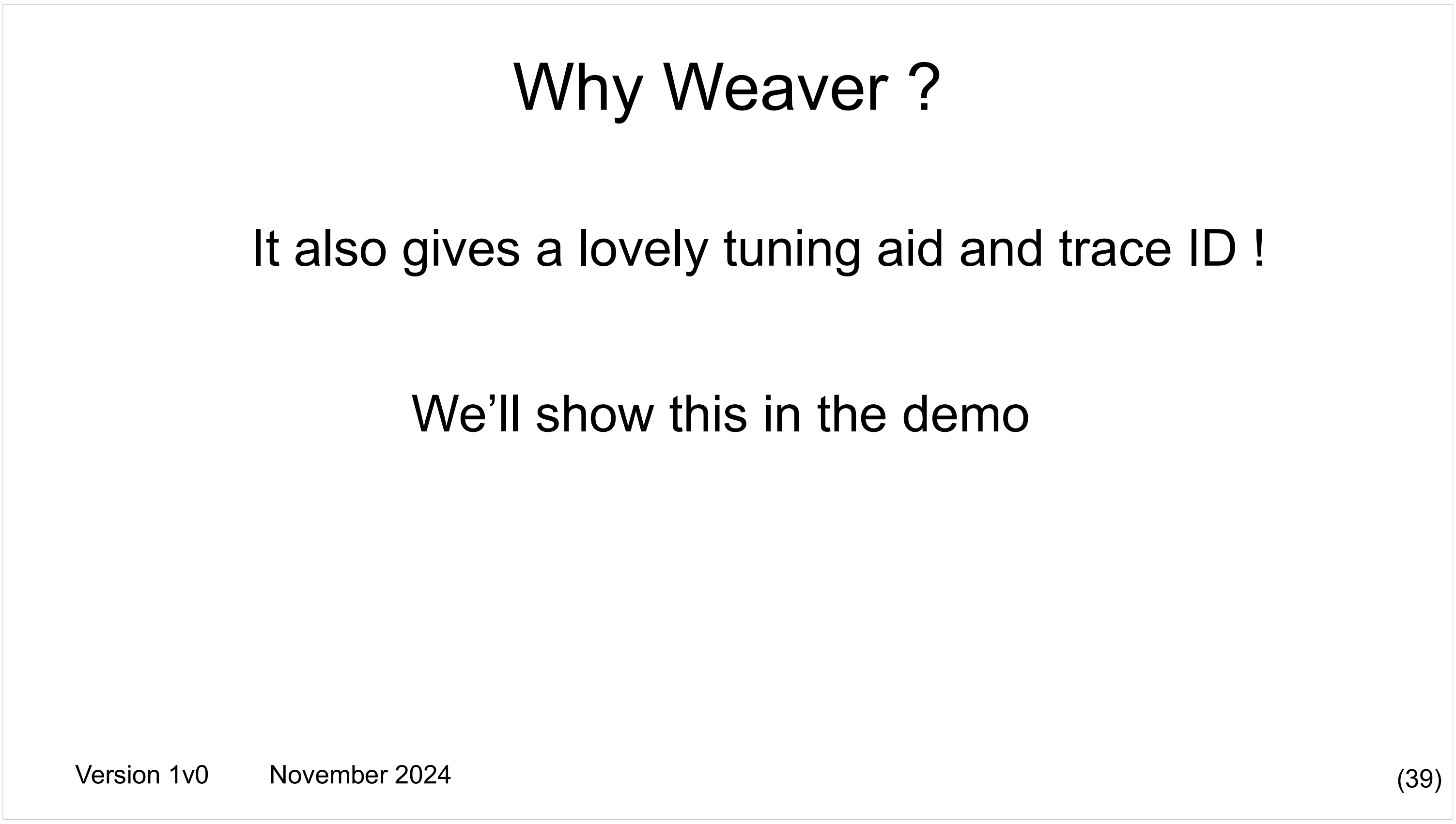
Radcom March 2020

QST September 1957 "The Third Method of SSB" Howard F. Wright W1PNB (https://www.hanssummers.com/images/stories/weaver/library/qst1957.pdf)

No-Tune Zero-IF Microwave SSB/CW Transceivers - Matjaz Vidmar S53MW (https://lea.hamradio.si/~s53mv/zifssb/block.html)

"SSB Demodulation" (https://panoradio-sdr.de/ssb-demodulation/)

"SSB - Weaver Method" Reinhard Weber DC5ZM - Radcom March 2020 (https://www.george-smart.co.uk/wordpress/wp-content/uploads/2020/06/ssb_weaver_method-DC5ZM.pdf)



Why Weaver ?

It also gives a lovely tuning aid and trace ID !

We’ll show this in the demo

In the Weaver method boath sidebands map into the same audio bandwidth wrapper around the Weaver frequency.

Switching repeatedly between LSB and USB the audio tone will be heard to 'Warble' either side of centre frequency.

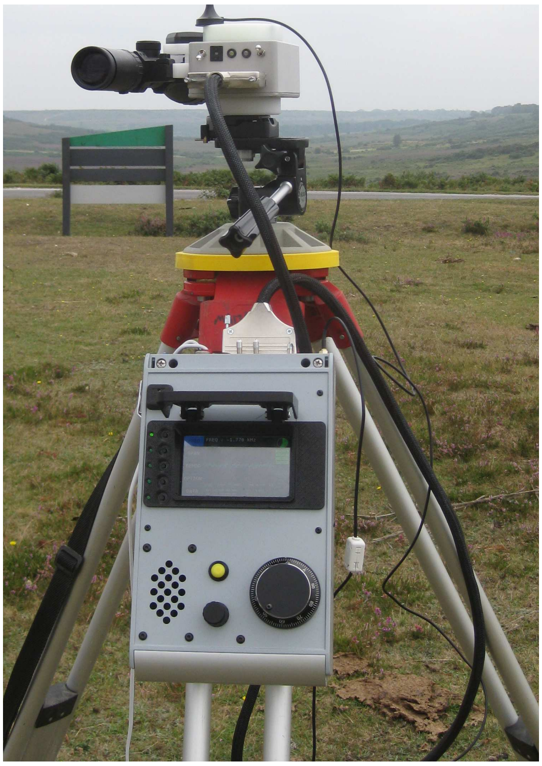
Echos here of the pre-WWII 'Lorenz' blind landing system system and the German WW2 Knickebein blind bombing system

Hardware Implementation

The hardware consists of two units joined by an umbilical

The main unit is mounted on the tripod leg is our SDR radio

Controls are sparse, a multipurpose tuning/selector encoder, a fast/slow button for the encoder, the volume control and 5 soft-keys to the left of the display



On to the hardware implementation

Hardware Implementation

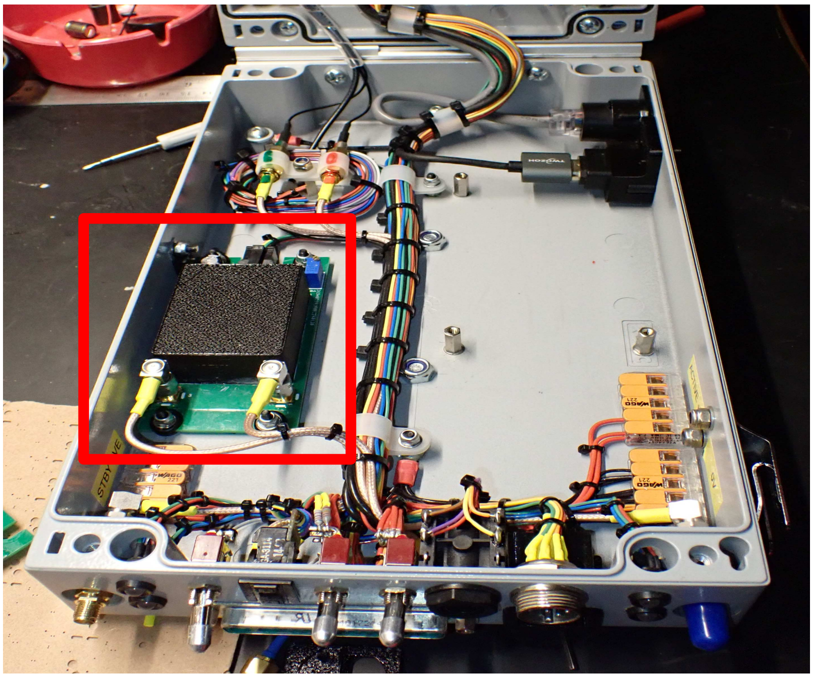
The RF head is simply the VK3CV board and horn mounted in a diecast box

This connects to the main unit via an umbilical which carries the discrete power and data signals and also has 4 coax interconnects for Reference, IF, GPS and Tx Audio

Hardware Implementation

This is the base section of the main unit

The Reference board is outlined centre left



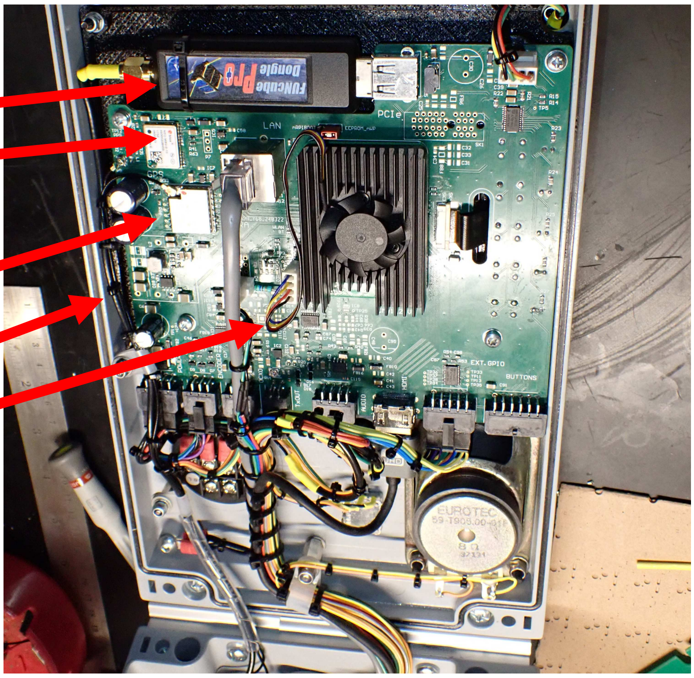
Looking inside the main unit base the main part of interest is the OCXO board, the OCXO is inside the 3D printed shield to prevent it being affected by air currents with the main unit – the OCXO only being a single ovened unit

The network and HDMI connections are top right and on each side at the bottom are 5 way Wago connectors for the Power Switched 12V supply (we can highly recommend these if you make a unit and are thinking ahead to future expansion)

The main switch powers the Reference board and RF head. It also routes to the Standby/On switch which powers the remainder of the system

The remainder is just wiring to the top panel umbilical and the panel switches and indicators

Hardware Implementation



This is the main board

Top left is the FUNcube

Underneath is the GPS module

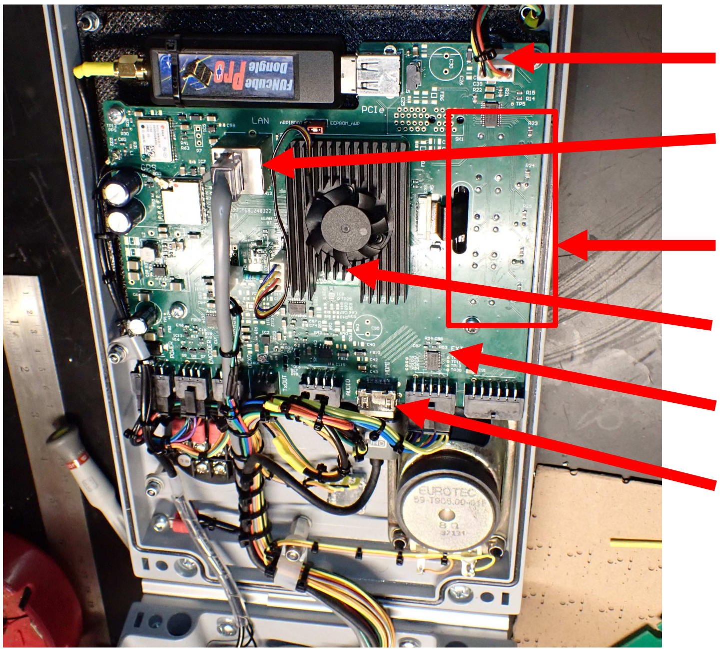
Then the LoRa module

Power Supply

Audio

This is the main PCB mounted on the underside of the lid showing the major items on the left side of the main board

Hardware Implementation



Environment sensor

Network

Soft-Keys and Indicators

Raspberry Pi CM4

GPIO

HDMI

And here are the remainder of the major blocks

We’ll come to the GUI when we do the JT4 demo

Results So Far

Version 1v0 November 2024

So, our results so far

Bear in mind that although we’ve made FM tests over the past couple of years the first out using JT4 was mere weeks ago

FM

Best FM contact to date was ~2 km early this year on a cold clear day

2km is a bit further than our predictions would indicate

This would tend to infer that some of our data is conservative

JT4

Best dx so far
with JT4 is 2.1 km

IO90DW27TL

to

IO90DX50VC

Map view from
streetmap.co.uk

We’ve only been out with JT4 on a couple of occasions, the weather and work/family commitments have been a bit against us

Hopefully both will improve in the new year

The weather conditions were far from ideal, it was fairly warm and humidity was medium – certainly not cold and crisp as we had for our FM tests

JT4

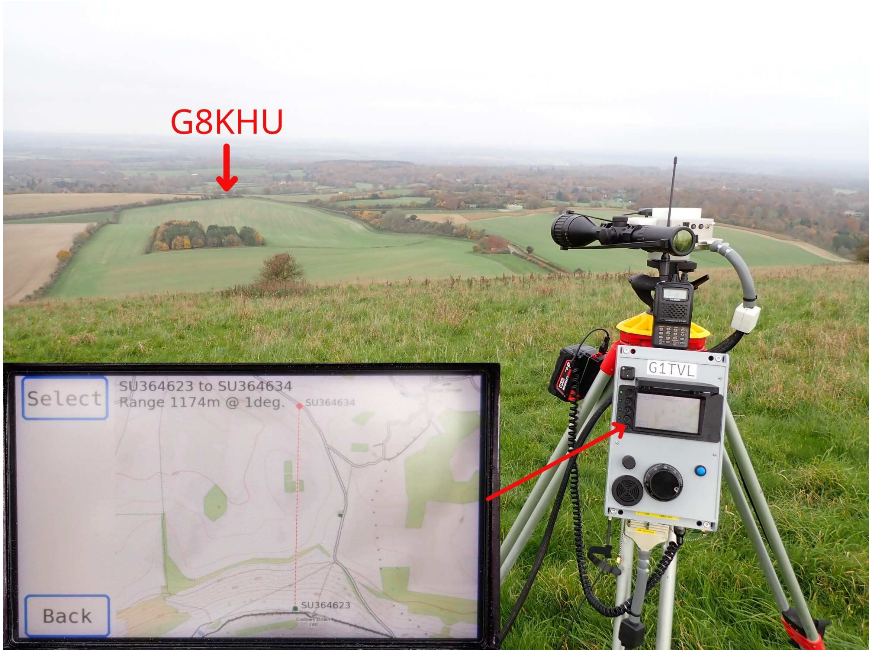
Most interesting

Combe Gibbet

to

North Road Gate

1.1km



SU364623 to SU364634
Range 1174m @ 1deg.

The most interesting path was a local one from Combe Gibbet. At 1.1 km it should have been a doddle - but it wasn’t

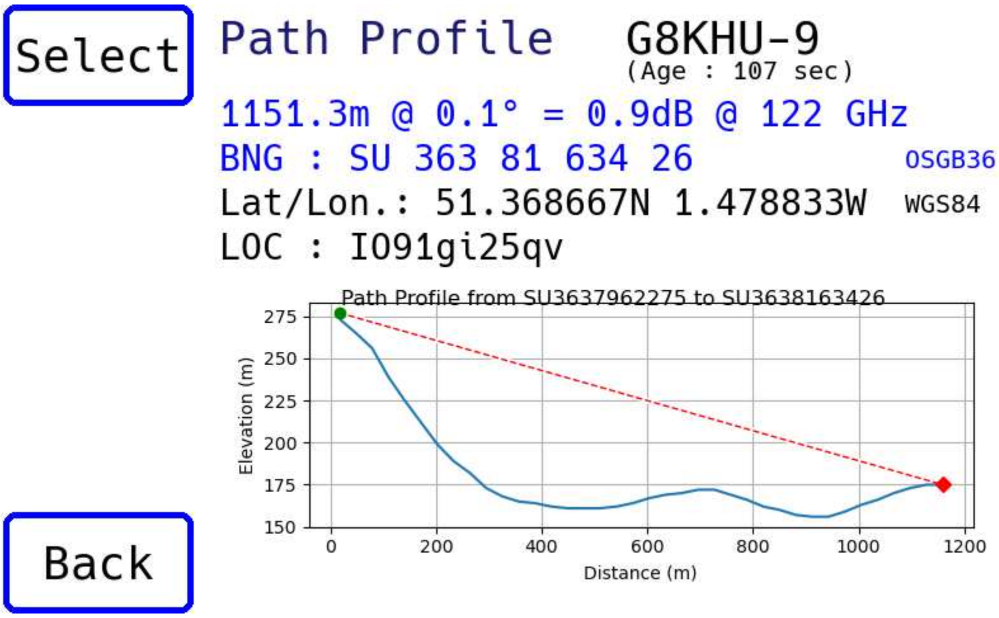
JT4

The path profile seemed ideal

It was dull and cloudy and visibility was good

The path loss was mediocre at 0.9 dB/km

BUT no signal ??



Path Profile G8KHU-9
(Age : 107 sec)
1151.3m @ 0.1° = 0.9dB @ 122 GHz
BNG : SU 363 81 634 26 OSGB36
Lat/Lon.: 51.368667N 1.478833W WGS84
LOC : IO91gi25qv

The most interesting path was a local one from Combe Gibbet. At 1.1 km it should have been a doddle - but it wasn’t

The path profile was good, atmospheric absorption was mediocre but it was only a 1.1 km path

It was dull with cloud cover and the sun wasn’t visible

The temperature was around 13°C and the dew point around 4°C

No signal was visible in either the spectrum display or the waterfall

As we chatted on the talkback channel the cloud cover started to break up and we watched the sun illuminating more and more of the path

JT4

The path profile seemed ideal

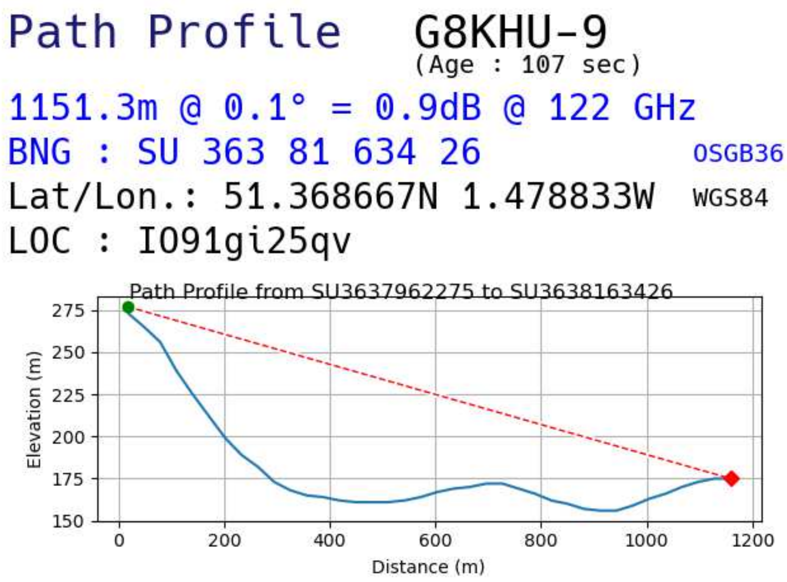
It was dull and cloudy and visibility was good

The path loss was mediocre at 0.9 dB/km

BUT no signal ??

Select

Back



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(Age : 107 sec)

1151.3m @ 0.1° = 0.9dB @ 122 GHz

BNG : SU 363 81 634 26 OSGB36

Lat/Lon.: 51.368667N 1.478833W WGS84

LOC : IO91gi25qv

As the sunlight spread across the field so a signal rose in the spectrum display and waterfall – peaking at about 7 dB above the noise in the spectrum display

The sun went behind a cloud and the signal sank back below the noise until nothing was visible

As the cloud cover finally dissipated this cycle repeated itself another 2 or 3 times

We just stood there and watched it …. to be honest neither of us wanted to mention it first ….

The variation was at the very least 10 dB and atmospheric absorption changes that would create such a change without the aparant visibility changing seems implausible

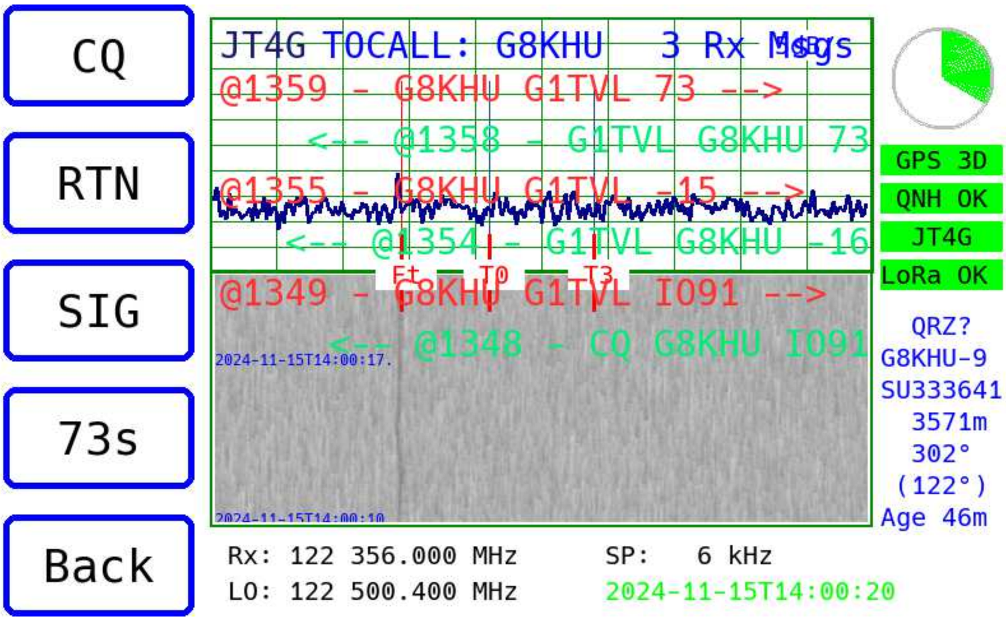
However a layer of mist rising and falling creating a mirror might explain it. Any ideas anyone ?

JT4

Bright sunshine, blue sky

Good signal

☺



```
JT4G TOCALL: G8KHU   3 Rx Msgs
@1359 - G8KHU G1TVL 73 -->
    <-- @1358 - G1TVL G8KHU 73
@1355 - G8KHU G1TVL -15 -->
   <-- @1354 - G1TVL G8KHU -16
@1349 - G8KHU G1TVL IO91 -->
      <-- @1348 - CQ G8KHU IO91
2024-11-15T14:00:17.
2024-11-15T14:00:10

GPS 3D
QNH OK
JT4G
LoRa OK
QRZ?
G8KHU-9
SU333641
3571m
302°
(122°)
Age 46m

Rx: 122 356.000 MHz        SP:    6 kHz
LO: 122 500.400 MHz        2024-11-15T14:00:20
```

Once the sun was fully out the path worked without a hitch and here is a mid QSO screenshot

The signal peak is obscured slightly by the G in my call-sign – a rather cluttered display as we try and combine the data from several screens into a summary on a small 5 inch LCD

JT4 - Demonstration

(note to self :- never do unrehearsed live demos in front of the customer)

Version 1v0 November 2024

The two stations are established here and at the back of the room

Just so the map and path displays are a little more interesting the station at the back of the room has had its GPS position spoofed so it thinks it is a few kilometres away rather than a few metres

Demonstration 1

Spectrum
and Waterfall
Displays

Demonstrate the Spectrum and Waterfall displays

Demonstration 2

JT4

Demonstrate JT4 displays and functionality

Demonstration 3

Screenshot

Screenshot saves the current screen to memory for later download

Demonstration 4

Where am I ?

GPS

Show the GPS screen – GPS is required for position and timing

The satellite mapping and statistics screen gives an indication of the reliability of the GPS fix

Demonstration 5

Where are you ?

LoRa

Position data is automatically exchanged between stations using LoRa, this enables range, bearing, and estimated excess path loss due to absorption to be calculated and displayed

Demonstration 6

Map

From the station positions we show the locations and path on the map

Mapping is from open street map, tiles are preloaded into permanent memory in the unit, any missing tiles are downloaded either live or later depending on the availability of an internet connection

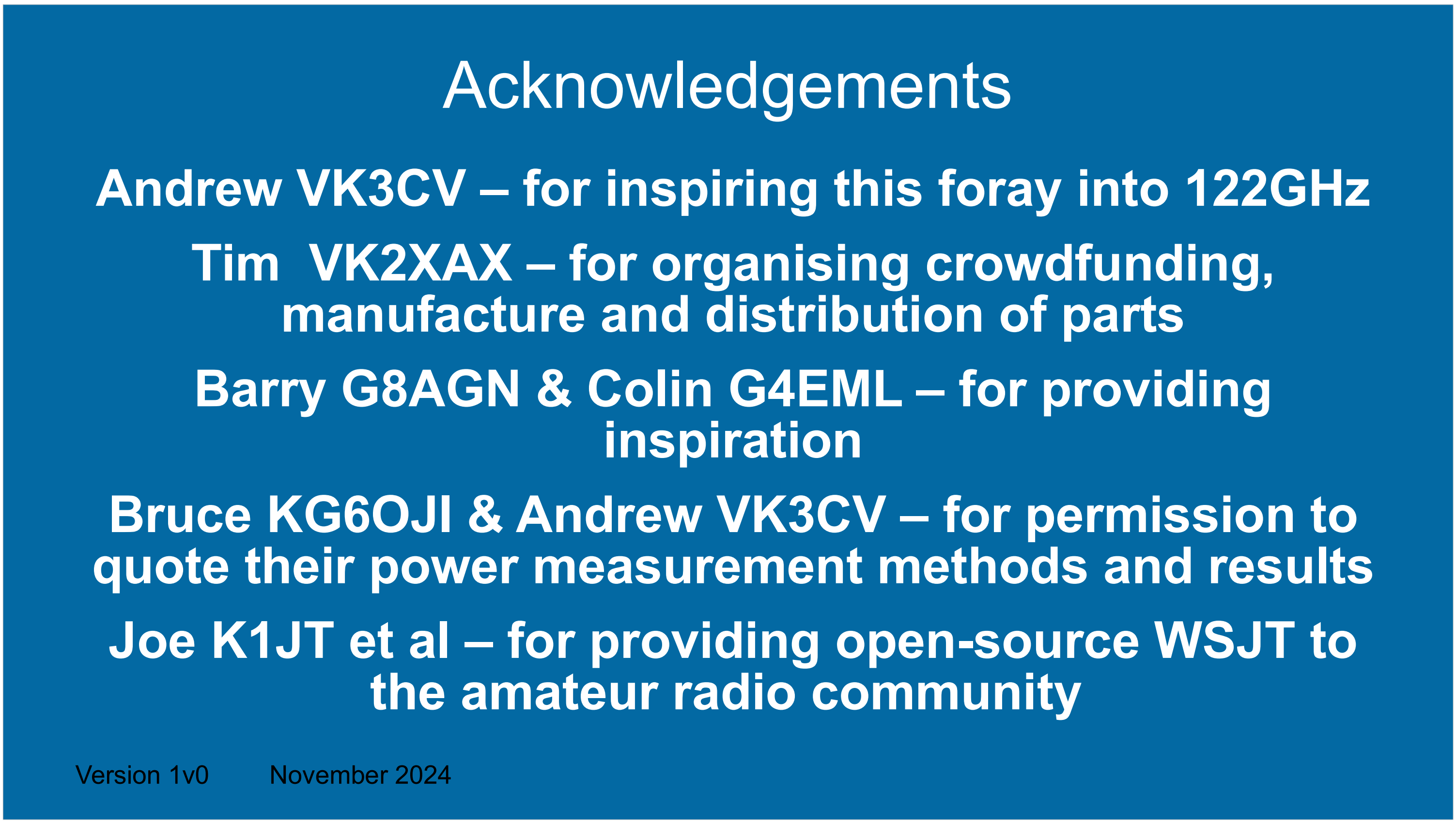
Again these are stored in memory for future use

We can also display the path imposed on satellite imagery but this requires a real time internet connection as the imagery data is far to large for the available storage

Demonstration 7

Path
Profile

Path profile is calculated from STRM data, again this is stored on the unit in permanent memory



Acknowledgements

Andrew VK3CV – for inspiring this foray into 122GHz

Tim VK2XAX – for organising crowdfunding, manufacture and distribution of parts

Barry G8AGN & Colin G4EML – for providing inspiration

Bruce KG6OJI & Andrew VK3CV – for permission to quote their power measurement methods and results

Joe K1JT et al – for providing open-source WSJT to the amateur radio community

Version 1v0 November 2024

Andrew and Tim obviously for the impetus to start this project

Barry and Colin’s published work were of huge interest and even though we haven’t used any of their code their work provided inspiration and many insights

Barry – Weather Box in Scatterpoint Jan and Feb 2020, and also analysis of non-differential GPS in Scatterpoint June 2022

Colin – Portsdown and Langstone on various websites BATC and Microwaves UK

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Any Questions ?

Or even

Any Answers :-)

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