21st October 2022

Radio Range Model (Guidance manual)

alastair john underwood, GW0AJU

Updated article

Introduction

The radio range model is an attempt to try to put some degree of light to the design criteria laid down for a radio communication system design. The criteria of the radio transceiver design and the antenna system used, go to all play apart within the eventual success of any radio communication system design layout.

On the whole radio signal propagation, is a subject that is not only talked about a great length by radio hams and shortwave listeners, but also, a subject of much debate by the many professionals of the engineering craft of radio, mostly refer radio as a black art, as well as the many applications related to topics of radio frequency engineering.

To any affect upon the radio propagation contact distance, it seems that the circumference of the planet earth, seems to be a closely guarded secret, perhaps for military reasons. This has led to many problems to relate together the radio distance pathway to hours of arc travelled.

In the end, I have depended upon an aviation flight distance measurement between London Heathrow to New York, in essence some 3500 miles in all, relating to some 5 hours of arc travelled around the earths circumference.

To add, an input variable for the coax and connector losses are also included. This allows also an individual Tx / Rx antenna's to be used and discovered, as well modelling the two radios used within the contact QSO, both the individual transmitter and receiver system profiles.

This is as best as I can do, so hopefully just as a guide to the time zones of the planet that can be reached, relating to distance able to contact. The additional path loss is an interesting variable, as an increase means a bad day for radio, while a lower figure a good day for radio. Any additional increases could relate to the propagation path hazards that surrounding your location QTH.

Regarding the inductive resistance of the antenna used, please refer to the PDF article "antenna suspects" or make some attention to the additional notes supplied on the display image for the programs use.

To reduce the radio front end bandwidth, an antenna pre-selector could be placed in circuit via Tx/Rx relay switching network. Varying the front-end bandwidth, changes the contact distance range for the Tx power, in effect reducing the Tx power for a reduced front-end RF bandwidth for a set contact distance.

In due regard to the transmitter power output, it may be best to relate this to your average power output, as the" Peak to Peak" power will only relate to the peak distance reached which may perhaps not give a simulated distance answer for a good solid QSO contact.

Relating to the use of a "Nano Spectrum Analyser", the nano spectrum analyser antenna has a calibration variable, given also with the programs calculated answers. With todays both RSGB and ARRL exposure limits with radio transmitters, as well as from your own countries regulations, the signal strength at a point of location can be correctly measured, to hopefully provide some degree of assistance to Radio Signal Exposure from a Radio Transmitter Antenna Emissions.

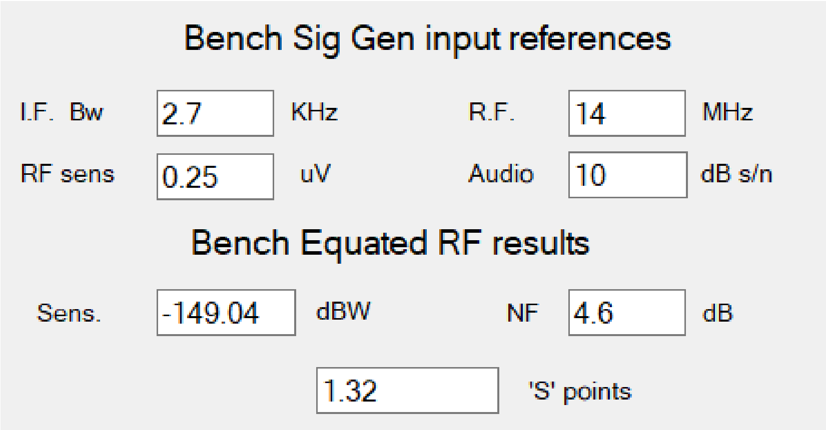
With the emission regulations in mind, technical notes can be made to hopefully satisfy the radio Regulators requests, both as a historical point, but with also as an "on the spot" transmitter test check with the radio regulator inspector during an inspection routine.

To conclude, a Nano Vector Analyser can be used to measure one's own antenna quality of match, as well as printing out upon one's own printer the results.

Shown as well, are the part listings of the program codes subroutines.

Radio design principles

Refer to the below image:



The above image bench tests are the reflection of the below image formulae:

The below program coding listings, using visual basic, examines the radio performance, calculating the radio receiver noise figure, as well as calculating the minimum signal of the radio receiver to a required audio signal to noise ratio. The signal meter value is also listed to give the complete picture of an RF bench test performance summary.

```
' ************** theory RF sens based upon used Bw of radio ********************

BaseFloorVoltage = Math.Sqrt(4 * (1.38 * 10 ^ -23) * 290 * Bw * 50)
' voltage value equation of theoretical noise floor Power = 4*K*T*Bw
BaseFloorPower = (BaseFloorVoltage ^ 2) / 50
BasefloordBW = 10 * Math.Log10(BaseFloorPower)  ' convert into dBW
BasefloorINT = Int(BasefloordBW * 10) / 10      ' limit decimal places
BaseFloorValue = BasefloorINT

' ************** noise figure of radio based upon RF gen sens dBW and theory floor dB ********************

RxNoiseFigure = (BasefloordBW + AFdB) - radio_sens_measure_dBW
RxNoiseFigure = Int(RxNoiseFigure * -100) / 100
TextBox12.Text = RxNoiseFigure           ' string answer  ----- Radio Front-end Noise Figure
```

The signal meter calculations relate to as follows:

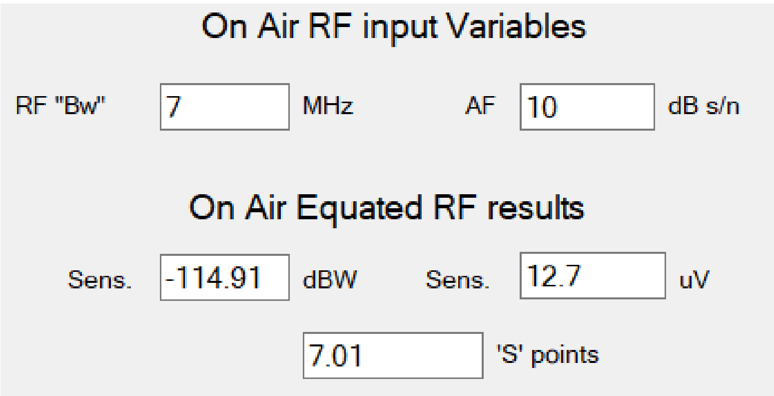
```
' ******************* sig gen test equated values ********************
' ***************  calculation of gen sens uV to dBW ********************

Dim radio_sens_measure_watts As Double = (RFsens ^ 2) / 50
Dim radio_sens_measure_dBW As Double = Int((10 * Math.Log10(radio_sens_measure_watts) * 100)) / 100
TextBox22.Text = Int(radio_sens_measure_dBW * 100) / 100

If Val(TextBox22.Text) >= -103 Then
    Dim dB_over As Double
    dB_over = Int((Val(TextBox22.Text) + 103) * 100) / 100
    TextBox9.Text = "9 +" & dB_over & "dB"
End If

If Val(TextBox22.Text) < -103 Then
    TextBox9.Text = Int((-157 - Val(TextBox22.Text)) / 6 * -100) / 100  ' S points of rx signal
End If
```

The next stage is the calculated capability of the radio once connected to an on-air test. The difference here is that the RF bench test only refers the radio to an RF signal generator, whereas the noise within the RF signal generator test signal, is of a minimal value.

With the radio receiver connected to an on-air antenna, the radio receivers front-end circuit bandwidth now comes into play, accumulating all the signal noise that the antenna can collect or pick up. It would be assumed, that the limiting bandwidth of the front-end circuit, would limit the bandwidth of antenna noise the radio would collect, and it is here where the radio receivers design can be affected to the overall on-air noise figure test of the radio receiver.

The RF signal generator noise floor bandwidth is limited, so the radio receiver would only experience the narrow noise from the signal generator, which is not the case when connected to an-air antenna. In days gone by, a parallel tuned circuit would be found within a radio circuit, namely within the front-end circuit design. Todays, this subject is more taken up by the use a high pass and low pass filters to limit the noise pick signal level, relating to the band plan in use.

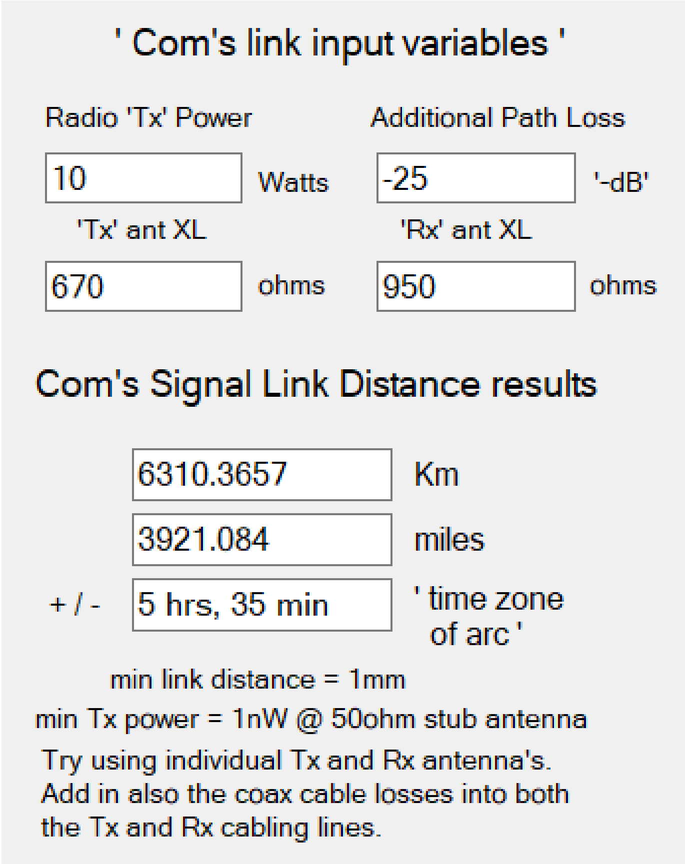
However, considerations need to be taken as to the bandwidth differences between the parallel tuned circuit, and the use of a high pass and low pass filter combination.



Notice the difference between the RF signal bench tests to the actual on-air experience.

```
Bw_front = Val(TextBox13.Text)
On_air_AFdB = Val(TextBox10.Text)
On_air_base_floor_volt = Math.Sqrt(4 * (1.38 * 10 ^ -23) * 290 * Bw_front * 10 ^ 6 * 50)
' voltage value equation of theoretical noise floor Power = 4*K*T*Bw
On_air_base_floor_watt = (On_air_base_floor_volt ^ 2) / 50
On_air_base_floor_dBW = 10 * Math.Log10(On_air_base_floor_watt)  ' convert into dBW
On_air_dBW = Int(On_air_base_floor_dBW * 100) / 100       ' limit decimal places

Dim gen_cal_Tx_dBW As Double = On_air_dBW + On_air_AFdB + RxNoiseFigure
gen_calculated_dBW.Text = Int((gen_cal_Tx_dBW) * 100) / 100
Dim sens_cal_watts As Double = 10 ^ (Val(gen_calculated_dBW.Text) / 10)
Dim sens_cal_volts As Double = Math.Sqrt(sens_cal_watts * 50)
gen_calculated_volts.Text = Int(sens_cal_volts * 10 ^ 6 * 100) / 100

If Val(gen_calculated_dBW.Text) >= -103 Then
    Dim dB_over As Double
    dB_over = Int((Val(gen_calculated_dBW.Text) + 103) * 100) / 100
    TextBox14.Text = "9 +" & dB_over & "dB"
End If

If Val(gen_calculated_dBW.Text) < -103 Then
    TextBox14.Text = Int((-157 - Val(gen_calculated_dBW.Text)) / 6 * -100) / 100  ' S points of rx signal
End If
```

The signal propagation losses, including the additional path losses, also come into play at this moment, allowing for terrain and signal propagation variables, such a signal lift of bad weather play.



The antenna specifications are listed as an inductive reactance, which is based upon the inductive reactance of a full wave wire antenna, irrespective of the radio signal frequency.

The effectiveness of an antenna design is then relative to the improvement or loss of the used antenna design, to the signal emissions or pick up relating to the full wave wire antenna performance. It transpires, that the inductive reactance of a full wave antenna, is that of 475 ohms inductive reactance.

The dipole antenna design, has a centre collective impedance of 50ohms, used for radio communications, while for commercial radio, this collective impedance value is more of 75ohms terminal impedance. The designed resonance of an antenna design, is thus the signal frequency upon which the antenna terminal impedance is matched, be this 50ohms or 75ohms, or even 300ohms.

Relating to the dipole designed terminal impedance of 50ohms, each ¼ wave section delivers a signal source to the coax cable. The antenna sections to provide a 50ohm current source, each ¼ wave section would be twice that of the coax terminal impedance, thus the dipole terminal impedance.

The ¼ wave sections would then be of a designed inductive reactance of 100ohms each, the combined parallel current source be then 50ohms effectively. The dipole antenna overall inductive reactance is then the combination of each ¼ wave section inductive reactance, 100ohms + 100ohms to a value of 200ohms.

As the full wave wire has a full signal emission of collection, the dipole with its 200ohms collective reactance, would inhibit a reduced signal performance over the full wave wire antenna. The calculated difference of the dipole antenna is a 7·5dB reduction of antenna performance levels, relating to the full wave wire antenna. Notice the difference with the Tx power to reach the same destination contact range.

Additional losses due to RF coax connectors losses can also be included within the additional path loss calculations.

Source Radio 'Tx' Antenna results

0	Tx Coax Loss '-dB'
10	Tx Coax dBW
2.987	antenna dB eff
12.987	dBW ' ERP '
19.8	Watts ' ERP '
31.5	Volts ' ERP '
9 +115.98dB	'S' points ' ERP '

Destination Radio 'Rx' Antenna results

30.372	Rx radio uV
-107.34	Rx radio dBW
0	Rx Coax loss '-dB'
6.02	antenna dB eff
-113.36	Etha Rx dBW
7.27	Etha 'S' points
10	Ant. RF 'Q' MHz
0	Ant. fading dB s/n

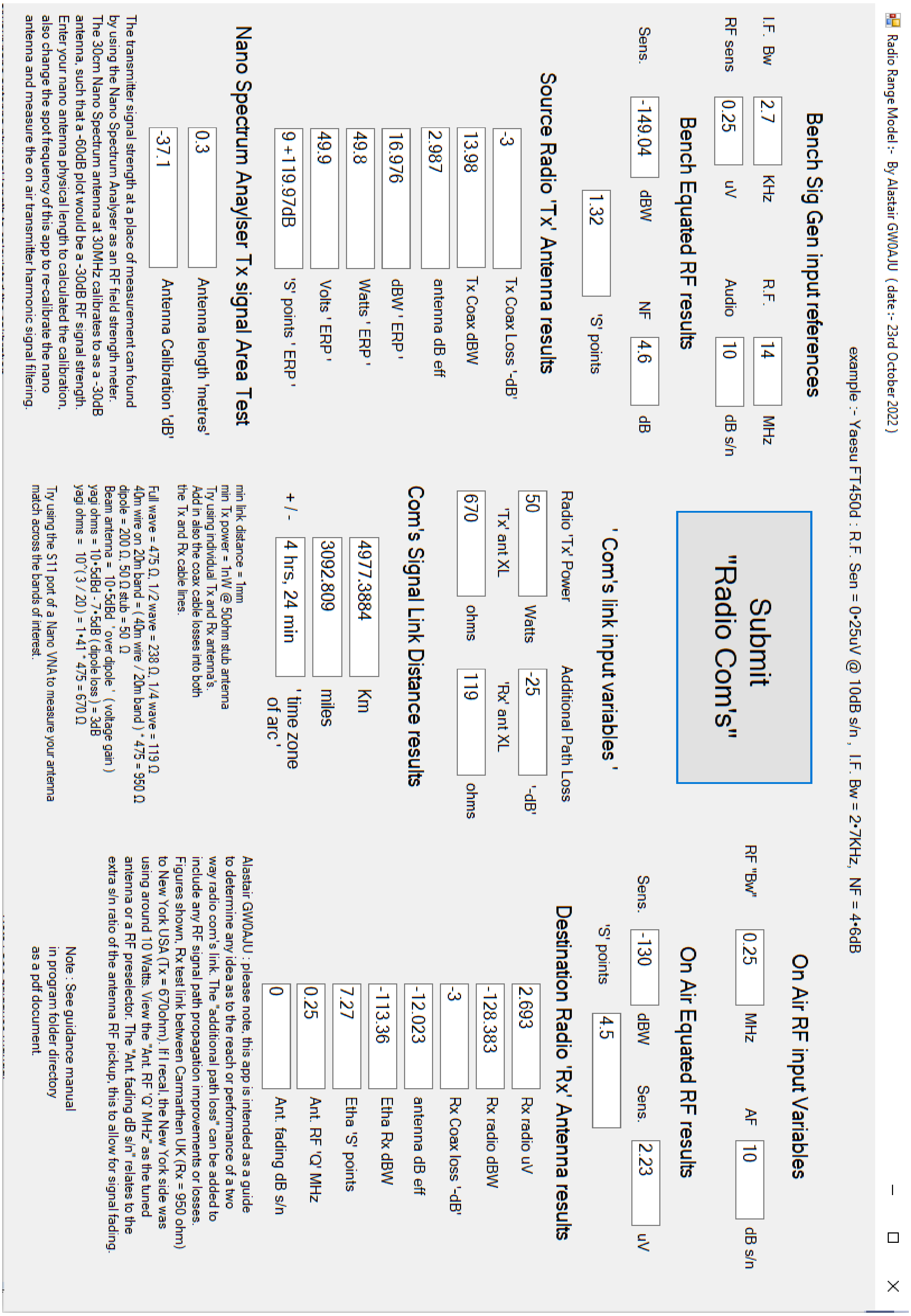
The variable listed on the "destination radio Rx antenna result", also lists two additional boxes. These are the "ant. RF Q MHz" and the receiver signal fading "Ant. Fading dB s/n". If the antenna 'Q' is les than the radio receiver, then the radio receiver frontend bandwidth would be adjusted to be equal to the antenna 'Q' MHz If a loaded coil antenna has a 'Q' RF bandwidth of 250KHz, then the box contents would be 0·25 MHz for also the radio front end bandwidth, of the "on air input variables".

The "ant. fading dB s/n" variables is to attempt to determine the transmitter power required to overcome signal fading conditions, such as say 18dB of signal fading which equates to 3 'S points'.

With the receiver antenna equal to a full wave wire (XL = 475 ohms), the "Rx radio uV" should match the "on_air _equated _values" radio sensitivity. With an antenna gain, the "Rx radio uV" would be greater than the "on_air_equated_value" of radio sensitivity.

However, if the antenna used is less than the full wave equivalent, then the "RX radio uV" falls below the radio sensitivity value. I have yet not been able to find a solution, but as the contact distance will alter, then corrected with perhaps the Tx power increase, then provided the contact distance is reached, then a QSO should perhaps be made.

Below is an image of a radio setup using a quarter wave load coil tuned vertical antenna.



The visual basic program code for the radio receiver parameters.

```
Dim Rx_ant_watt As Double

Rx_ant_watt = (Rx_ant_volt * Rx_ant_volt) / 50

dB_rx_gain = 10 * Math.Log10(Rx_ant_watt / 0.5)
dB_rx = (Int(dB_rx_gain * 1000)) / 1000
TextBox18.Text = dB_rx ' rx antenna eff dB

Dim Ant_floor_volt As Double = Math.Sqrt(4 * (1.38 * 10 ^ -23) * 290 * Val(TextBox10.Text) * 10 ^ 6 * 50)
' voltage value equation of theoretical noise floor Power = 4*K*T*Bw
Dim Ant_floor_watt As Double = (Ant_floor_volt ^ 2) / 50
Dim Ant_floor_dBW As Double = 10 * Math.Log10(Ant_floor_watt)  ' convert into dBW
Dim Ant_On_air_dBW As Double = Int(Ant_floor_dBW * 100) / 100      ' limit decimal places

' ant_bw_improve_s/n
If Val(TextBox13.Text) > Val(TextBox29.Text) Then     ' bw antenna < bw radio
    ant_sn_improve_dB = 10 * Math.Log10(Val(TextBox13.Text) / Val(TextBox29.Text))
Else
    ant_sn_improve_dB = 0
End If

ant_fading_sn_improve_dB = Val(TextBox31.Text)

Dim run_dB As Double = Ant_On_air_dBW + Val(TextBox12.Text) + Val(TextBox10.Text)
'Val(gen_calculated_dBW.Text) - Val(TextBox18.Text)
TextBox30.Text = run_dB ' etha dBW

'Dim run_dB_watts = 10 ^ (Val(TextBox5.Text) / 10) ' etha watts pick up
' Dim run_dB_volts = Math.Sqrt(run_dB_watts * 50)   ' etha volts pick up
'TextBox30.Text = (Int(run_dB_volts * 10 ^ 6 * 1000)) / 1000  ' etha uV pick up

Dim coax_rx_loss As Double = Val(TextBox28.Text)
TextBox5.Text = Val(TextBox30.Text) + Val(TextBox18.Text) + coax_rx_loss  ' Rx front end dBW signal
' Rx radio dBW = etha dBw + Rx antenna dB + Rx coax loss dB

Dim Rx_mim_watt As Double
Rx_mim_watt = 10 ^ (Val(TextBox5.Text) / 10)  ' power of rx signal (radio + antenna)
Dim Rx_mim_volt As Double
Rx_mim_volt = Math.Sqrt(Rx_mim_watt * 50)
TextBox6.Text = (Int(Rx_mim_volt * 10 ^ 6 * 1000)) / 1000  ' voltage of rx signal, mim 1/1000uV

'-------------------- not required text code, found to provide wrong answers although seem fine ok ---------
'Dim system_radio_sn As Double = 20 * Math.Log10(Rx_mim_volt / sens_cal_volts)
'TextBox29.Text = Val(TextBox10.Text) + Int(system_radio_sn * 10) / 10

'TextBox29.Text = Int((on_air_sens - Val(TextBox5.Text) - Val(TextBox10.Text)) * 10) / 10  ' rx s/n
'------------------------------------------------------------------------------------------------------------

If Val(TextBox30.Text) >= -103 Then
    Dim dB_over_link As Double
    dB_over_link = Int((Val(TextBox30.Text) + 103) * 100) / 100
    TextBox7.Text = "9 +" & dB_over_link & "dB"
End If
```

To calculate the distance reached, each doubling of the signal wavelength travelled distance is a 6dB drop. This can be explained by the following. If a 1m band signal travels one wavelength, then at the end would 6db down, at the end of the additional two wavelengths, the signal will be 12dB down. At additional four wavelengths, the signal is 18dB down, and at 8 additional wavelengths, the signal is 24dB down, and have travelled 15m in distance at the 1m band wavelength overall.

Which equates to as 1+2+4+8 = 15 wavelength @ 1m wavelength, at 20m band equals to 300 metres.

On the 2metre band, the 15 wavelengths would be just 30 metres distance at 24dB down.

The signal propagation is then relative to the wavelength of the transmission signal to as the distance travelled for a 24dB down signal at the Rx end.

In addition to this, is the impedance found by a radio signal to its travel through the etha which is relative to the radio frequency wavelength and conditions of the band at that moment.

Below are shown the calculation format for the com's link budget calculations:

From the above mentioned of a transmitter signals inverse square loss, to the radio signal illumination of the receiving station, looking back at the 18dB down signal of 16 wavelengths of the 20m band, your friendly radio ham next door at 300metres distance down the road, or street, then the inverse square loss is 24dB.

Now if then we divide the 24dB by 6dB, this the signal reduction at each doubling of the signal wavelengths:

24dB / 6dB = 4

The value 3 being the number of doubled distances, to check this is so, if we then do this:

Number of wavelengths between the Tx and Rx stations = (2^(24dB / 6dB)) -1 = 15 wavelengths

Should as in this example be the signal band of the 20m band, then the distance travelled by the radio signal is then :

Distance between Tx and Rx = wavelength * ((2^(24dB / 6dB)) -1)

Which equates too as :

Distance between Tx and Rx = 20m band * ((2^(24dB / 6dB)) -1)

Distance between Tx and Rx = 300metres

This calculation method is not one I found in any manual or online, but what I did find online that gave the clue to the calculation routine, was the 6dB value of loss over of signal loss for each doubling of signal distance. A while ago, I twigged that the double of distance was not such a in "km" or "miles" distance, but the answer hidden as the double of signal wavelengths as the distance.

Thus so, each doubling of the signal wavelength for the inverse square loss calculation, was in fact a 6dB loss each time the number of wavelengths was doubled. By including the band wavelength, the effects upon the signal frequency for signal propagation, can be found.

```
Dim Wave_length As Double
Wave_length = 300 / (Val(freq_test.Text))

' Dim radio_emf_dBW As Double = Val(TextBox5.Text)   ' dBW of rx signal (radio + antenna)

Dim travel_Path_loss_dB As Double
travel_Path_loss_dB = Val(TextBox11.Text) - Val(gen_calculated_dBW.Text) + Val(path_attenuation.Text) + Val(TextBox18.Text) + Val(TextBox28.Text)
' travel_Path_loss_dB = (Tx)dBW_ERP + (Rx)gen_calculated_dBW + additional_path_loss_dB + (Rx)antenna_dB  +  (Rx)coax_cable_loss_dB   ---  ( text form explanation )

Dim sq_law_factor As Double
sq_law_factor = travel_Path_loss_dB / 6

Dim m_value_distance As Double
m_value_distance = Wave_length * ((2 ^ sq_law_factor) - 1)

Dim KM As Double
KM = (m_value_distance / 1000)
Dim KM_range As Double
KM_range = Int((KM) * 10000) / 10000
TextBox19.Text = KM_range

Dim miles_km_scale As Double = 3461.34 / 5570.48  ' london - new york = 3,461.34 miles / 5570.48 km

Dim miles As Double
miles = Int((KM_range * miles_km_scale) * 1000) / 1000
TextBox20.Text = miles

' New Yor city USA is -74degrees longnitude, at 5570kM from London at in essence zero degrees longnitude.
' therefore, ( 360 / 74 ) * 5570 = 27097Km earth circumfence,
' which equates to ( 27097 / 24 ) = 1129Km / hr rotation of earth
' this summation does not include that New York USA is +40degrees latitude.


Dim Globe_cir As Double = 27097
Dim km_hour_arc As Double = 1129  ' earth rotation = 1114 Km/hour of arc
Dim range_hour_arc As Double = (KM / km_hour_arc)
Dim range_minutes_arc As Double = ((range_hour_arc) - Int(range_hour_arc)) * 60

TextBox8.Text = Int(range_hour_arc) & " hrs, " & Int(range_minutes_arc) & " min"
```

In addition, us radio hams with our long chats as to the suspected coax connector losses, as to many on air debates regarding this matter, can now be let us say, finally resolved to all concern.

Now for an interesting study, below is a signal strength chart.

The chart shows a monitored FT8 signal s/n dB to GMT, of a radio propagation path from UK to South Australia on the night of the 6th August 2022. The VK2 ham apparently is near an airport.

The chart was drawn up from using the WJST program, the Rx data just monitoring the signals, and the chart itself completed with MS Excel. Notice the near 6dB fluctuation within the FT8 signal s/n dB ratio.

It is interesting to see how for a period of a near 20 minutes, how the signal propagation various, related too through the FT8 s/n dB signal results. It maybe worth to mention that the antenna systems I was using, gave my radio an on-air sensitivity of some 1·6uV in signal level.