



EMF Pre-Assessed Configuration – Half-wave dipoles (160m to 40m)

1. Scope

This is a draft of the first Pre-Assessed Configuration guidance document (PAC-1). We welcome comments and suggestions on any areas that could be added or clarified.

This document provides guidance **for resonant half-wave dipoles from 160m to 40m** to support the demonstration of conformity with Ofcom EMF licence condition [1] for radio amateur licensees.

Specifically, it identifies regions near to the dipole where people should not be present when transmitting. This is a key part of performing an assessment see [4]. We show how mitigations can be applied in situations where the guidelines cannot be met, including monitoring to ensure no one is present in any exclusion zones. Examples are provided to illustrate the application of PAC-1 to assessments.

When transmitting all antennas produce EMFs which diminish with distance. Here we model some representative examples and summarise results, from which EMF compliance can be achieved. If your antenna is high enough to work well without local RF interference, then it will almost certainly comply with ICNIRP requirements as well. In the Annexes we provide more technical detail to help with your specific configurations, including worked examples.

For the antennas that are the subject of PAC-1, we show that compliance can be achieved at the full licensed RF power output of 400W PEP, provided that all parts of the antenna are more than 6 to 7 metres above ground level – which is already true in many installations. Compliance can be demonstrated at lower heights for example at lower power levels or subject to ground conditions and antenna configuration.¹

WARNING - CONDITIONS OF USE

PAC-1 presents “work in progress” on a complex subject that is still under development; details are subject to change and PAC-1 and referenced material may be updated or replaced.

This is preliminary information provided for evaluation purposes only, it shall not be used to claim compliance until it has been reviewed by Ofcom. Whilst RSGB and its volunteers takes all reasonable care in the production of its advice, we can accept no responsibility for errors, inaccuracies or omissions contained within that advice, or for misuse of that advice.

In no event will RSGB or its volunteers be liable for any loss or damage including, without limitation, indirect or consequential loss or damage, or any loss or damages whatsoever arising from use, or loss of use, of advice given in the pre-assessed compliance configurations. By quoting the advice from the PAC's, you agree to the above.

¹ Remember, this current edition of PAC-1 is still work in progress. These figures may change before compliance becomes necessary.

2. Pre assessed configurations

The ideal situation is to have a station that can be operated at the maximum permitted (or achievable if less) power with no locations where people may be expected to access that might result in them being exposed above the limits. The Ofcom EMF licence condition is satisfied if an assessment has been made to demonstrate this is the case and appropriate records are kept.

PAC-1 includes the results of several hundred assessments using advanced techniques. Each of these can be considered a pre-assessed configuration. If you can identify your station as being consistent with some of these configurations in Annex C (minimum height of wires) and Annex D (minimum separation from wires), then you can refer to PAC-1 as the technical justification for your assessment in your compliance record.

Where PAC-1 identifies locations in which it has not been possible to demonstrate compliance, you have the option of applying alternative assessment methods, redesigning your antenna system, reducing your maximum power, or establishing access or no-transmit controls to prevent any member of the public being exposed above the exposure limits when you transmit.

Key parameters

Accurately understanding your station configuration is key to selecting the closest model.

The following parameters are needed for each band and antenna:

- Transmit Power – The maximum transmit peak envelope power (PEP) at which you wish to demonstrate compliance (no reductions are made for mode or duty cycle for frequencies below 10 MHz see [7])
- The minimum height AGL or platform of any radiating part of the antenna (see Figure 1)
- The V angle of the dipole (see Figure 1) – [If unknown, assume 90°]
- The ground classification (see Table C.1) – [If unknown, assume “Rich soil” unless operating on a marine vessel or salt marsh then assume “Sea”]

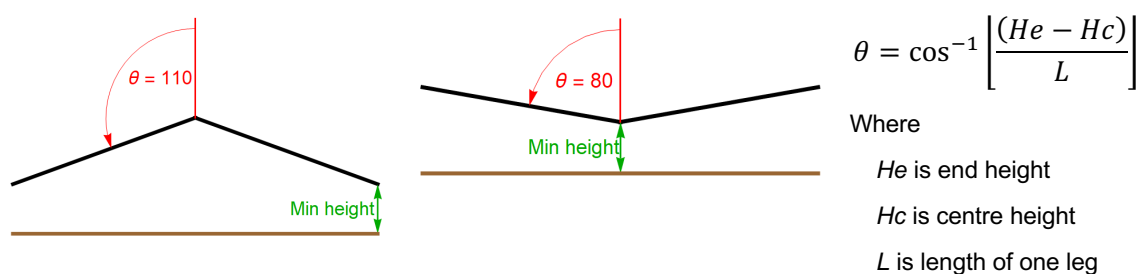


Figure 1 – Defining the V angle θ and minimum height

Generic configurations

In Annex C, data is plotted for over 2600 modelled cases covering over 140 combinations of band, ground, and V angle at a range of minimum heights.

A simple approach is just to take the “worst case” of all of these and create a single recommendation that is applicable to all of your cases. However, such a restriction would not be necessary for the majority of cases and may unduly limit the ability to demonstrate compliance.

A better approach is to consider the patterns in the data and identify the conditions that are most restrictive – in this case lower minimum heights. You can then define more-limited sets of configurations that exclude these and thereby provide less restrictive minimum heights that are valid for a useful subset of real-world situations.

Table 1 is the generic guidance for all PAC-1 pre-assessed configurations. The minimum height AGL data is critically dependent on the input parameters so additional “configuration” tables in this section provide coherent sets of guidance based on different combinations of the key parameters.

Table 1 – Pre-assessed configuration guidance framework

Configuration	<i>See configuration Table 2</i>									
General conditions	Precautions should be taken to confirm that feeder and other supporting structures do not significantly radiate.									
Case 1:	No part of the antenna should be below minimum height AGL.									
Compliant configurations	No person should be able to access closer than the minimum horizontal clearance from the nearest part of the antenna. ^{Note 1}									
	Transmit power ^{Note 2}	Minimum height AGL for radiating structure ^{Note 3}				Minimum horizontal clearance from wire ^{Note 4}				
		160m	80m	60m	40m	160m	80m	60m	40m	
	<= 10 W ^{Note 5}	<i>See configuration Table 2</i>				0.5m	0.5m	0.5m	0.5m	
	<= 50 W					1.2m	1.1m	1.1m	1.1m	
	<= 100 W					1.2m	1.1m	1.1m	1.1m	
	<= 400 W					2.2m	2.0m	N/A	2.0m	
	Notes: 1. To address antenna wires adjacent to accessed elevated areas. 2. Use the peak envelope power at the antenna without reduction factors for mode or duty cycle since below 10MHz such reduction is not valid for the main limiting case. 3. Measured vertically from lowest part of element to ground or walkway. 4. Measured horizontally from wire. 5. Translates approximately to being out of reach of anyone even with extended arms.									
	Case 2:	If any part of antenna element is below the minimum height, then consider the exclusion zone to be all points directly under the antenna wires extending either side and from the antenna ends at ground level by the minimum horizontal clearance distance (see above).								
	With mitigation	Do not transmit if anyone is in the exclusion zone.								

Table 2 presents the minimum height data for several configurations of ground and V angle. Simply establish which configuration most accurately describes your station and insert the corresponding minimum height data from Table 2 into the guidance framework in Table 1 and that will define your pre-assessed configuration. The figures in red indicate the most restrictive case for that configuration.

By demonstrating and recording that your station and operating practices are consistent with the Table 1 framework, you will have met the Ofcom EMF licence condition for your resonant half-wave 160m to 40m dipoles.

You will see that the minimum height of your dipole that can be demonstrated to be compliant is critically dependent on the ground conditions and the vertical V angle.

Table 2 – Minimum height for pre-assessed configuration cases

Configuration Description			Transmit power	Minimum height AGL for radiating structure			
#	Ground	V angle		160m	80m	60m	40m
1	Any excluding Sea	Any		160m	80m	60m	40m
			<= 10 W	2.3m	2.3m	2.3m	2.3m
			<= 50 W	3.2m	3.0m	2.9m	2.8m
			<= 100 W	3.7m	3.6m	3.4m	3.3m
			<= 400 W	6.4m	5.3m	N/A	4.3m
2	Any excluding Sea, Rich Soil	Any		160m	80m	60m	40m
			<= 10 W	2.2m	2.2m	2.2m	2.2m
			<= 50 W	2.7m	2.6m	2.6m	2.6m
			<= 100 W	3.1m	3.0m	3.0m	2.9m
			<= 400 W	4.8m	4.4m	N/A	4.0m
3	Any excluding Sea, Rich Soil	$\theta \geq 100^\circ$ or $\theta \leq 85^\circ$		160m	80m	60m	40m
			<= 10 W	2.2m	2.1m	2.1m	2.1m
			<= 50 W	2.6m	2.5m	2.5m	2.5m
			<= 100 W	3.0m	2.8m	2.8m	2.7m
			<= 400 W	4.3m	4.0m	N/A	3.6m
4	Any excluding Sea	$\theta \leq 80^\circ$		160m	80m	60m	40m
			<= 10 W	2.0m	2.0m	2.0m	2.0m
			<= 50 W	2.0m	2.0m	2.0m	2.1m
			<= 100 W	2.0m	2.1m	2.2m	2.3m
			<= 400 W	2.1m	3.0m	N/A	3.3m
5	Any	$\theta \leq 80^\circ$		160m	80m	60m	40m
			<= 10 W	2.0m	2.0m	2.0m	2.1m
			<= 50 W	2.1m	2.3m	2.4m	2.5m
			<= 100 W	2.4m	2.8m	2.7m	2.9m
			<= 400 W	5.0m	4.4m	N/A	4.0m
6	Any	Any	<= 400 W	160m to 40m			
				9.0m			

Observations:

- From configuration #1, unless you are on sea marsh or maritime mobile, if you have a 160m to 40m dipole that is all above 6.4m AGL and have the Table 1 horizontal clearance – assessment done!
- From configuration #4, if the open ends of your 160m to 40m dipole are well above ground i.e., the $\theta \leq 80^\circ$, then minimum height (at the centre) is not difficult to achieve.

Using Annex C data directly

For most people it is expected that the Table 2 configurations will enable them to demonstrate compliance. A few people may wish to dig deeper to get a more precise alignment between their specific configuration and the pre-assessed configurations in Annex C. These data provide a great resource for those who need to optimise their assessment. However, it may be daunting for those who would like to have the simplest route to demonstrating compliance.

The Annex C plots can be used as follows.

- Choose your band and select Figure C.3 to C.6 accordingly.
- Select the chart for the ground that best represents your ground conditions.
- Select the plot with closest representation of V half angle θ from Figure C.1. For V angles between those modelled, select the modelled one nearest to a horizontal dipole ($\theta = 90^\circ$).
- Read the required compliance data from the plot:
 1. If you wish to establish the minimum compliant height for your intended operating power, then go across from that power level on the Y axis as far as the θ for your antenna and read the corresponding minimum height from the X axis.
 2. If you wish to establish the maximum compliant power for your installed antenna, then go up from the minimum height on the X axis as far as the θ for your antenna and read the corresponding maximum compliant power from the Y axis.
 3. If your case is “off the plot”, then compliance is achieved for legal limit at the minimum plot height.

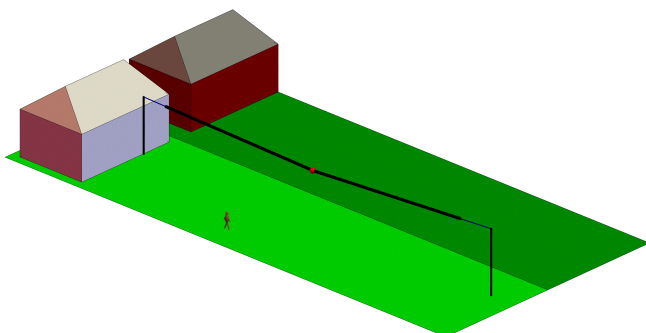
Note: For a configuration where each leg has a different V angle, the most restrictive case should be applied.

The minimum height information derived from Annex C should then be inserted into Table 1 with the appropriate power.

3. Case studies

Let's have a look at a few examples to help illustrate the application of the pre-assessed configurations. You should note that these are expressed colloquially to show how even with limited data the pre-assessed configurations can be interpreted to provide a route to demonstrating compliance with the EMF licence condition.

Example 1 - 80m dipole strung between the house and a pole



The house end of the dipole is at 6m AGL attached via an insulated extension 2.5m long.

The garden end of the dipole is at 7m AGL with a similar insulated extension.

The dipole runs at 90° from the house wall and forms a catenary down to 5.5m AGL in the middle where a balun feeds good quality coax.

The ground type is not known but the station is not at the seaside and the ground is not flooded with sea water.

Figure 2 – Example 1 scenario - 80m dipole strung between the house and a pole

Assessment:

First, you can declare the ground constraint as “Any excluding Sea”.

The ends of the dipole are definitely above the middle so $\theta < 90^\circ$ but let's see if you need to consider the V angle.

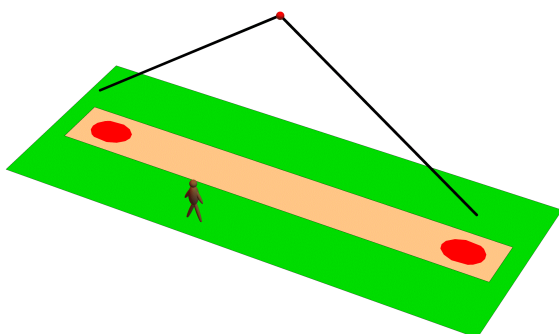
If you look at Table 2 configuration #1, this is defined as “Any excluding Sea” and for “any V angle” so the station is consistent with this description. For 80m, from Table 2 configuration #1 the minimum height for any part of the antenna should be 5.3m or more for full licence power – so since the actual antenna is 5.5m minimum height, the station is consistent with the pre-assessed configuration #1.

Checking the other constraints in Table 1 Case 1 compliant without mitigation:

- Antenna is fed such as to minimise radiation from the feeder so should meet the first general constraint.
- The insulated extensions to the wire ends are longer than the minimum horizontal clearance distance of 2m for full licence power, therefore the horizontal separation constraint is met unless people are climbing ladders.

Therefore, this 80m dipole can be demonstrated to be compliant for use at full licence power using pre-assessed configuration Case 1 compliant without mitigation, based on pre-assessed configuration #1.

Example 2 – 40m /P operation



40m dipole suspended from an 8m fibreglass pole, with dipole ends at 2m AGL attached to insulated rope attached to guy stake.

Fed with coax and balun.

Operation intended at 100W.

Unknown ground conditions.

Figure 3 – Example 2 scenario - 40m dipole /P operation

Assessment:

Looking down the pre-assessed configurations in Table 2, all of them require a minimum height AGL greater than 2m. This means that this operation needs to be addressed via Table 1 Case 2 mitigation.

This then establishes an exclusion zone to be all points directly under the antenna wires extending either side and from the antenna ends at ground level by the horizontal clearance distance – that Table 1 defines as 1.1m for 100W for 40m.

Therefore, provided care is taken not to transmit if anyone is within 1.1m of the line under the antenna wire at ground level (extending 1.1m beyond end of the wire) – compliance can be demonstrated for 100W operation based on Table 1 Case 2 mitigation.

Figure 3 shows the NEC 5 computed potential exceedance zones (red) under the wire ends and the guidance exclusion zones (amber) that are easier to manage.

4. Items for further study

While a lot of data has been presented in this edition of PAC-1, at least the following cases need further investigation for this class of antenna:

- Use of wire doublet on non-resonant or harmonic bands
- Effect of having vertical end wires dropping down vertically
- Trap dipoles
- Radiation from feeder
- Arbitrary length single wires
- Off-centre fed dipoles
- Short (loaded) dipoles
- T2FD / T3FD “broadband” dipoles
- Building entry loss



References and Notes

- [1] UK Amateur Radio Licence:
https://www.ofcom.org.uk/_data/assets/pdf_file/0027/62991/amateur-terms.pdf
- [2] RSGB EMF pages: <https://rsgb.org/emf>
- [3] EMF Technical Note 1 What you need to know about EMF <https://rsgb.org/emf>
- [4] EMF Technical Note 2 EMF Compliance – an introduction [Under development]
- [5] Technical report on the framework for applying advanced computation methods for EMF compliance assessments [under development]
- [6] Technical report interpreting ICNIRP 2020 [under development]
- [7] ICNIRP: <https://www.icnirp.org/> (for ICNIRP guidelines and supporting documentation)
- [8] FCC OET65b: <https://www.fcc.gov/general/oet-bulletins-line>

Artwork

All artwork is acknowledged to be the copyright of its respective owners. It is copied here under 'fair use' conditions for educational purposes.

All Figures – Peter Zollman Consultancy (PZC), G4DSE

Annex A – Defining the exposure limits 160m to 40m

In this annex we will expand on the content of the technical report interpreting ICNIRP 2020 [6] to define the exposure limits for the 160m to 40m bands. ICNIRP includes two classes of exposure limit based on occupational or general public exposure. This PAC-1 refers to the more restrictive general public case as required by Ofcom. Radio amateurs will need to ensure that in nearby locations that are outside their control (such as a neighbour's property or adjacent public land) there are no people present who would be exposed above the ICNIRP general public limits.

ICNIRP has two types of exposure limit. The **basic restrictions** are the defining quantities, and these are exposure levels evaluated **within the human body**. Techniques for direct compliance with basic restrictions are outside the scope of amateur assessments, so for practical purposes we must always use the alternative method that ICNIRP provides, which are called **reference levels**.

Reference levels are parameters **in the external environment** that can be measured or computed. Compliance with ICNIRP reference levels is taken as evidence that the underlying basic restrictions are not being exceeded; but a number of different reference levels may need to be evaluated in order to confirm this. For the amateur 160m to 40m bands, ICNIRP defines no less than **seven** reference levels for the general public that could be applicable (Table A.1) – so the simulation results will need to be checked against each one of them.

Table A.1 – ICNIRP 2020 reference levels for 160m to 40m

ICNIRP 2020	Symbol ^a	Approximate value				Unit	Time average ^b	Spatial average ^c
		1.85	3.65	5.3	7.1			
Table 5	E_{wba}	195	121	93.4	76.1	V/m	30 min	Whole body
Table 5	H_{wba}	1.19	0.603	0.415	0.310	A/m	30 min	Whole body
Table 6	E_{loc}	436	271	209	170	V/m	6 min	-
Table 6	H_{loc}	2.65	1.34	0.924	0.690	A/m	6 min	-
Table 8	E_{pk}	83	83	83	83	V/m	-	-
Table 8	H_{pk}	21	21	21	21	A/m	-	-
Table 9	I_{limb}	45	45	45	45	mA	6 min	-

^a E is electric field strength, H is magnetic field strength, and I_{limb} is current in the limb (ankle) when standing on ground. The subscripts are spatial qualifiers. All values are rms since, when squared, they relate to the transmitted peak envelope power (PEP).

^b Where a time average is specified, this means the average of the square root of the sum of the squares of field values taken at a number of sample points in time over the specified averaging time.

^c Where a spatial average is specified, this means the average of the square root of the sum of the square of field values from a number of sample points over the area of the body.

In all cases, ICNIRP reference levels are for an “unperturbed EM field”, meaning the field strength that exists *before* a human body enters the field and distorts it. This definition makes field strengths much easier to compute, but more difficult to measure because the operator cannot be present within the test area.

While Table A.1 lists seven possible reference levels, in this particular case these can be simplified to three assessments: electric field strength, magnetic field strength, and limb (ankle) current – see Table A.1 shown in **red**.

1. For electric field strength, the critical limit is the value of E_{pk} , the maximum field strength at any point in time at any sample point over the within the 3D space that the human body will occupy (note again that the field strength is determined before any person actually arrives).

Unfortunately, for frequencies below 10 MHz, ICNIRP really do mean the maximum RMS field strength without any time averaging. This means that when calculating E_{pk} for 400W PEP SSB or CW below 10 MHz, no duty cycle or mode factors may be applied to the 400W power level. (The same would apply to the peak magnetic field, if H_{pk} happened to be the critical limit below 10 MHz. That isn't the case for a dipole, but H_{pk} might be the constraining limit for other types of antenna, so will be checked when those are evaluated.)

2. For magnetic field strength, the value of H_{wba} is the time averaged field strength averaged over the whole of the body.
3. Limb current refers to the current that flows from the body to ground. It is only relevant when an exposed person is in contact with ground (directly or capacitively coupled through footwear). ICNIRP's intent here is to protect against localised heating in the ankle where the small cross section of conductive tissue can locally create a high current density. Ankle current is usually measured using a toroid transformer clamped around the ankle such that the leg is the primary and a secondary pick-up winding connects to a meter calibrated to indicate the RF current flowing in the primary. How to take the limb current reference level into account is currently a subject of study since we need to establish a firm relationship between external fields and the consequential limb current for assessment purposes, and no method has yet been validated. For the 160m to 40m bands, initial modelling suggests this may not be a significant consideration (although at higher frequencies above 10 MHz, I_{limb} may become a significant constraint). For this version of PAC-1, limb current is not considered.

Annex B – From field strength to exposure

For the modelling of field strength, the process described in [5] has been applied to establish appropriate modelling constraints for NEC 5. In this annex, we can now finally start to look at some modelled fields and see how they can be analysed and presented as exposure compliance plots. For brevity, only the 80m dipole case is presented.

In Figure B.1, the plots show the electric and magnetic field strengths for an 80m inverted V with centre at 10.5m and ends at 3.8m above average ground when radiating 400 W. A small human figure is included to help appreciate the scale. The black line shows the dipole element itself, and the coloured contours represent the electric and magnetic field strengths corresponding to the most restrictive of the ICNIRP 2020 reference levels for general public exposure at this frequency (Table A.1).

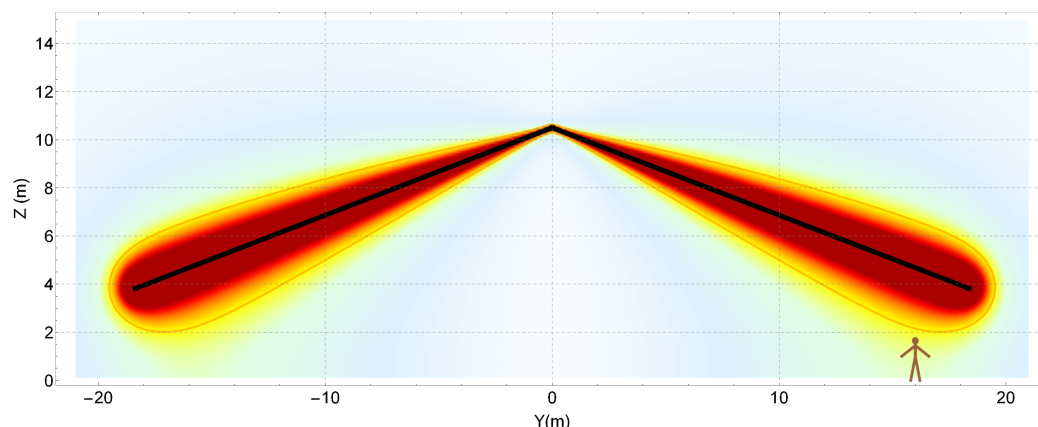
The most obvious feature is that the most likely areas of non-compliance are nowhere near the antenna feed point. They are due to the electric fields at the two open ends of the dipole. The magnetic fields are largest at the centre feed point where the RF current is greatest, but for dipole-type antennas they are of little significance for EMF compliance. This illustrates why ICNIRP compliance in the near field requires an open-minded assessment of both electric and magnetic field strengths around the whole antenna and its surrounding environment, including ground effects. The lesson to be learned is “Assume nothing in advance!”

Each diagram also includes a contour at the critical ICNIRP reference level for this frequency, 83 V/m for E_{pk} and 0.6 A/m for H_{wba} (Table A.1).

Figure B.1 also shows some well-known features of RF fields around a dipole. The electric field is maximum around the open ends of the wire element, and extends a little way into the space beyond, while at the centre feed point the electric field is close to zero. The magnetic field is completely the opposite: it is maximum at the feed point where RF current is greatest, but tapers to zero at the open ends of the elements. It is also apparent that if the V angle between the wires is changed, these near-field contours will follow the wires.

However, it is also very clear that these plots bear little resemblance to a far-field dipole pattern; we are much too close to the wires for that pattern to be relevant or accurate. Far-field thinking can easily lead us astray – so that’s another lesson to be learned, and another reason to keep the assessment open-minded.

a) Electric field strength with 83 V/m contour



b) Magnetic field strength with 0.6 A/m contour

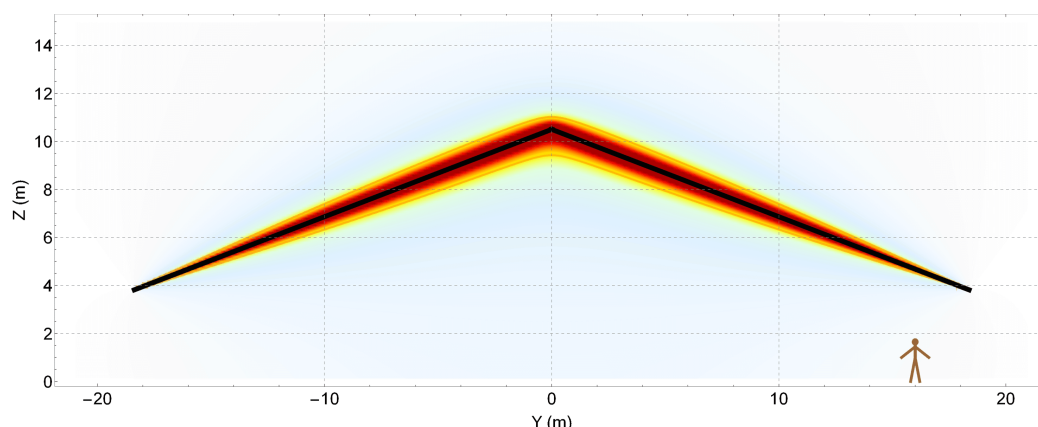


Figure B.1 – Field strengths near to inverted V half-wave dipole, centre at 10.5m ends at 3.8m fed with 400W @ 3.65 MHz

While the Figure B.1 field strength presentation is of interest, it doesn't give a definitive assessment of compliance. It also doesn't show what the situation would be for other transmit powers. We need to analyse the field strength data further to resolve these critical points.

The first step is easy to imagine, converting the data into contours in space around the antenna, representing the "limits of closest approach" for any given RF power level (averaged over time as appropriate).

The next step is to notice that field strengths close to ground can vary quite rapidly across the height of the human body, so whenever average whole-body exposure is a factor, or the peak field at any point of the body, the entire map of field strength needs to be considered over a body height that is standardised at 1.8m as per [6].

Applying both of these steps, we can then draw new contours (including the spatial averaging or maximum field over the body where appropriate) to determine at any point in space the transmit power level that would just give a compliant field strength for each specific reference level. We then take the lowest compliant transmit power level for that point in space since that is the most restrictive case consistent with ICNIRP exposure guidelines. This can then be plotted as shown in Figure B.2:

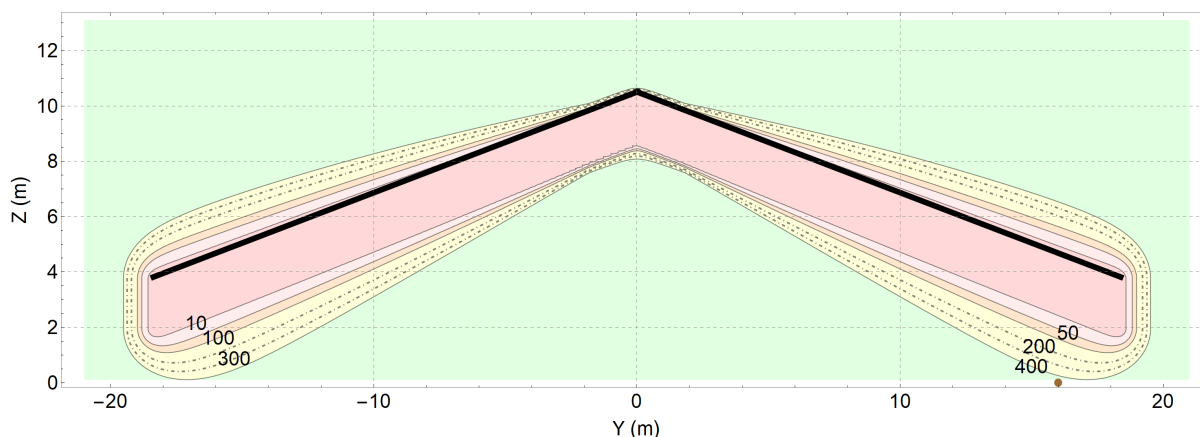


Figure B.2: Exposure plot showing spatial contours for ICNIRP 2020 compliant transmit powers for same case as Figure B.1

In Figure B.2 you should note that the person is now represented as a single point (in this example, the dot at $Z=0$, $X = 16\text{m}$). That is a by-product of the ICNIRP requirement for fields to be assessed over the height of the body. If a peak value is required, then it is the maximum value of any sampled point over the height of the body and if a spatially-averaged value is required then it is determined from the set of sampled points over the height of the body. That means that any specific point in space may need to be assessed with several different sets of adjacent points depending on the body position.

The only reasonable way to deal with all these subtleties is to standardize on just one way to define the “height above ground” for the exposed person that will work for all cases. We do this by defining the location of the whole body by reference to the height of the feet alone. So even though the 400W power contour in Figure B.1 a) swoops close to 1.8m above ground at $X=16\text{m}$, that plotted location at $Z=0$ is compliant (just) for a 1.8m tall person and a transmit power of 400W. The apparent lowering of the exceedance zones in the exposure plot as compared with the more familiar field strength representation is simply due to the height of the body. To confirm that this makes sense, you can see that the head of the person is just about on the electric field strength compliance contour in Figure B.1 a) and in Figure B.2 the 400 W contour is just about on the level of the person’s foot. Both represent the same physical antenna with the same person standing at the same place; both suggest compliance at 400 W is just about achieved for a person standing at that point on the ground.

A simpler interpretation of Figure B.2 might be that on 80m, if both ends of the inverted V are above about 4 m, that is just sufficient to establish compliance at 400W PEP, and more than sufficient to establish compliance at lower power levels. However, more work is required to establish how such simple ‘rules of thumb’ would work for a range of different antenna configurations and also at other frequencies (see following annexes).

Annex C – From exposure to guidance – Minimum height above ground

One result is just not enough

In Annex A and Annex B a process is presented to take a specific antenna configuration, modelling the fields around the antenna, and then establishing limit compliant power contours. Unfortunately, that data is only sufficient for the assessment of that specific case. What is needed for the development of more general guidelines, is the modelling of a range of cases in which critical parameters are changed and the effect on compliance adequately considered.

The next stage of our story is to stand back and think about how the exposure assessment methodology can be applied to the range of dipole implementations that will be “out there” and then to establish findings that translate to simple guidance for amateurs.

We should consider that the example discussed so far is just one case with a specific V angle. We have not determined how the situation might change with different implementations e.g., from horizontal dipoles with 3 supports, a non-inverted V catenary with supports at the ends and the whole range of effective V angles that therefore may arise. Also, we have not yet considered the effect of different ground conditions – potentially a critical factor.

From modelling an example case such as in Annex B, we have determined that the highest field strengths occur under the dipole and along its length. We have noted that the electric field strength at the ends is a critical factor but may, or may not, be limiting if those ends are high and the centre (with its high magnetic field strength) is near the ground.

One approach might be to model hundreds or thousands of cases with different heights and V angle, each presenting a plot in the form of Figure B.2. We could then look at each such case and try to interpret the results. What a job!

Fortunately, we can apply our learning to automate this significantly. Let's concentrate on one critical question – *“For a given minimum height of any part of the dipole leg, what is the maximum power that can be transmitted that will just result in compliance with ALL the relevant ICNIRP reference levels for our reference person standing on the ground?”*

Minimum height constraint considering V angle

We have established that we do need to model several cases, but we actually need only model the fields directly under the antenna (and just beyond the end) and only sufficient to evaluate the exposure relating to a person standing on the ground at any such point on that line. Further, rather than a complex diagram for each case, we are only looking for a single number – the most restrictive (for any of the relevant ICNIRP reference limits), just-compliant transmit power determined along that line.

First, we define a range of V angles that are representative of the range of installed antennas (Figure C.1).

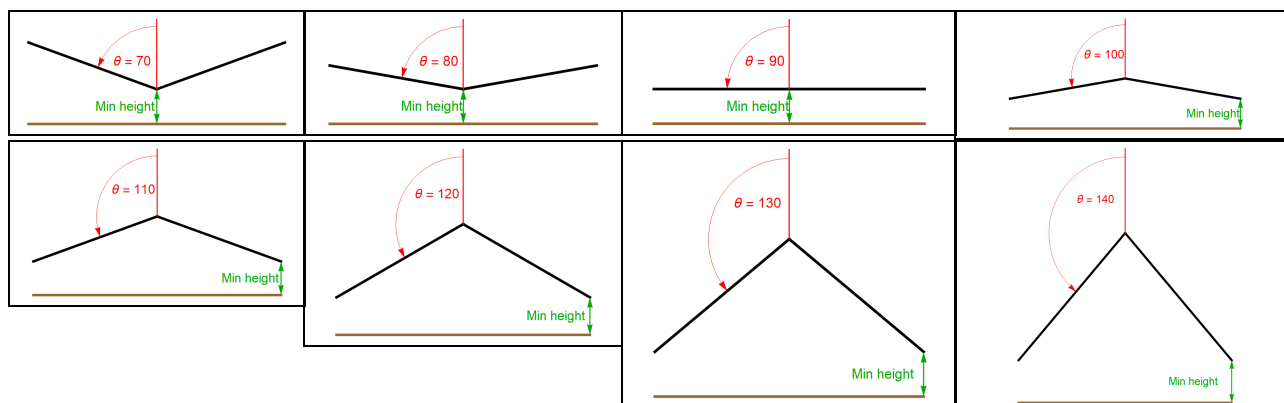


Figure C.1- Half-wave dipole V half-angle (θ deg) configurations

These cases can then be run in a batch of simulations over a range of heights and the results plotted. Figure C.2 presents an example plot showing the minimum height (see Figure C.1) for 80m band dipoles and just-compliant power for person at ground level for the range of V angles in Figure C.1. Note that Figure C.2 is for the ground condition Clay soil ($\epsilon_r=13$, $\sigma=0.005$ – also termed “average” in FCC OET65b) [8].

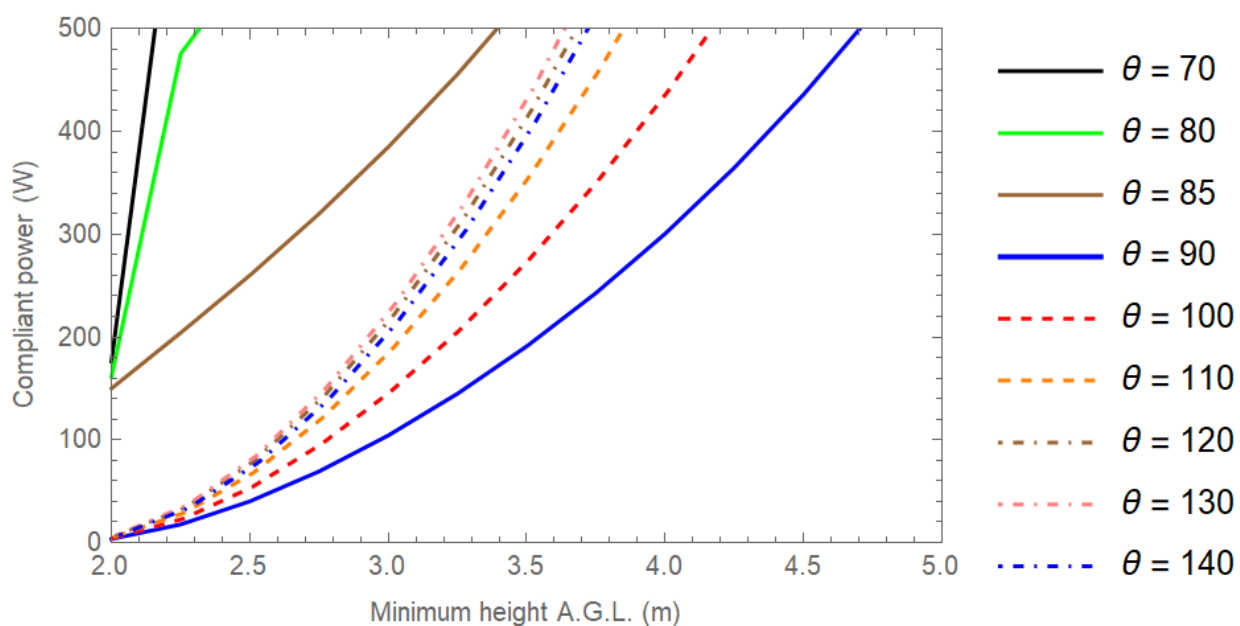


Figure C.2: Compliant power v minimum height for different V angle θ deg for 80m half-wave dipole antenna – “Clay ground”

Establish minimum antenna height considering different ground conditions

We stated earlier that the ground near and under the dipole is another factor that can affect the near field and as a consequence the minimum height at which exposure can be demonstrated to be consistent with ICNIRP guidelines. Up until now, all modelling has used “Clay” which is the same as the “average ground” defined by the FCC [8]. While this may initially seem to be a rational basis for guidance, it cannot be justified unless it can be shown that even for other ground conditions, the guidance remains valid.

To investigate this, the modelling from Figure B.2 (“Clay”) has been repeated for three other ground types: “Sea”, “Rich soil”, “and “Sandy” together giving good representation of the range of grounds that can be found (Table C.1).

Table C.1 – Ground parameters used in model.

Name	ϵ_r	σ	Comment
Sea	81	5	For maritime use
Rich soil	20	0.0303	Good ground
Clay	13	0.005	Average ground as used by the FCC in OET65b [8]
Sandy	10	0.002	Poor ground

The full set of plots for each ground, each V angle, and each band is presented in Figure C.3, Figure C.4, Figure C.5, and Figure C.6.

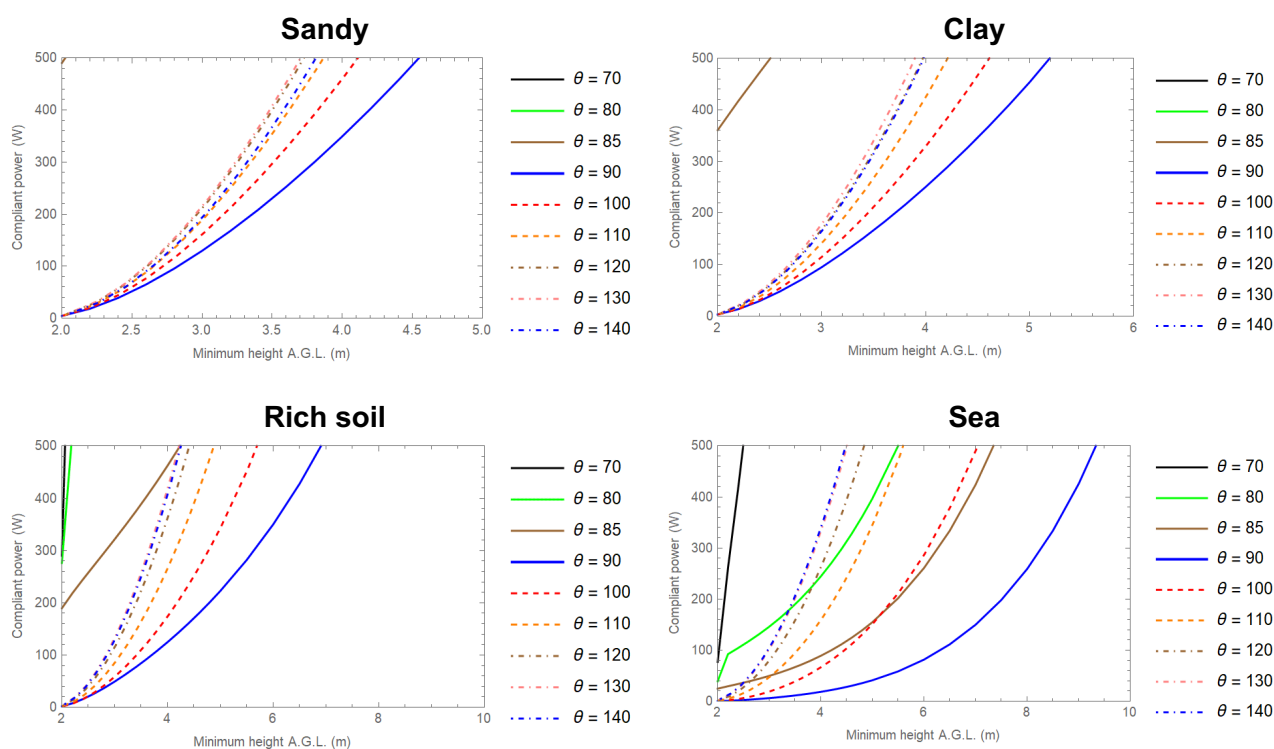


Figure C.3: Compliant power v minimum height for half-wave dipole antennas different V angle θ deg for different ground conditions - 160m

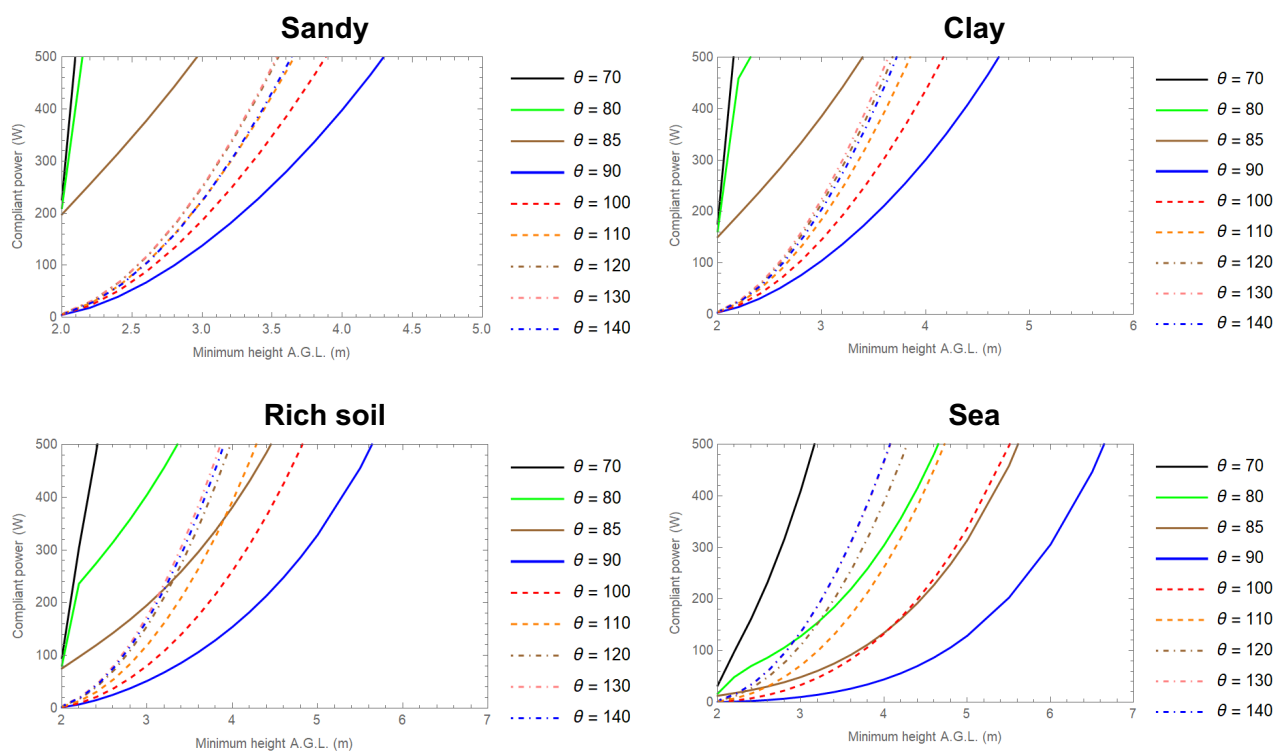


Figure C.4: Compliant power v minimum height for half-wave dipole antennas different θ deg for different ground conditions - 80m

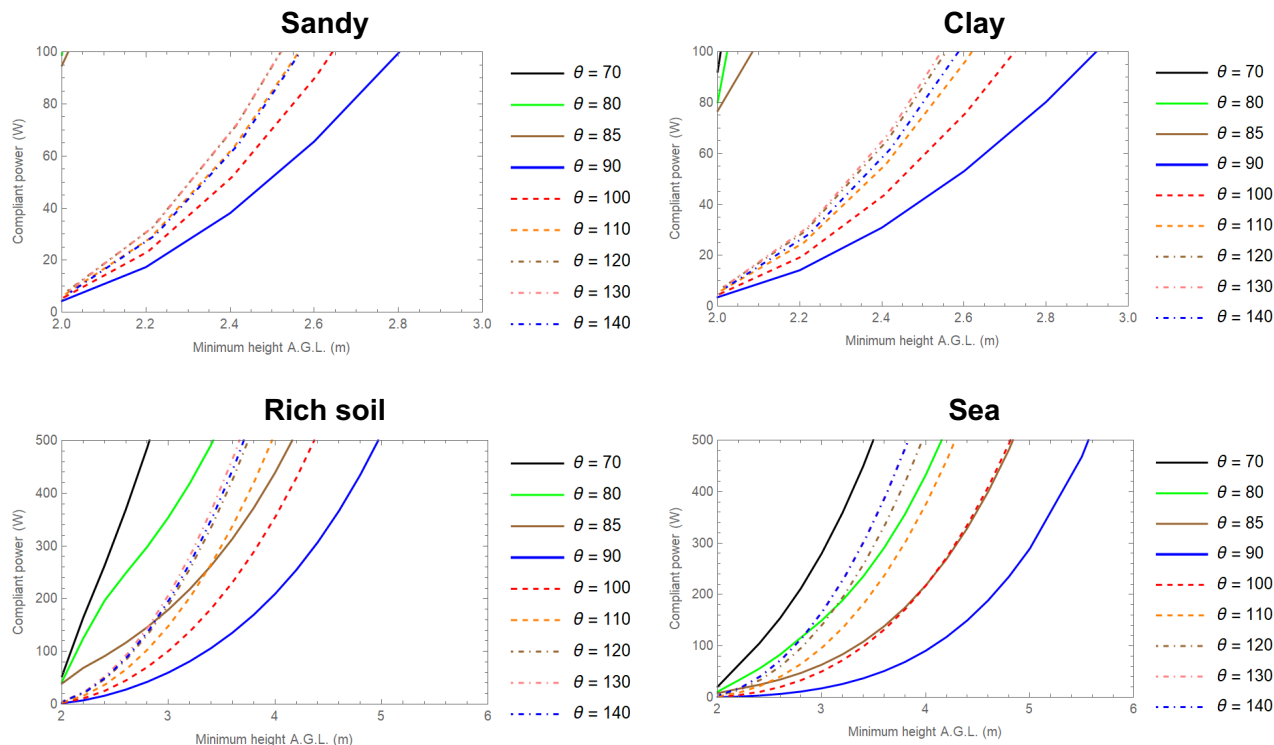


Figure C.5: Compliant power v minimum height for half-wave dipole antennas different θ deg for different ground conditions - 60m

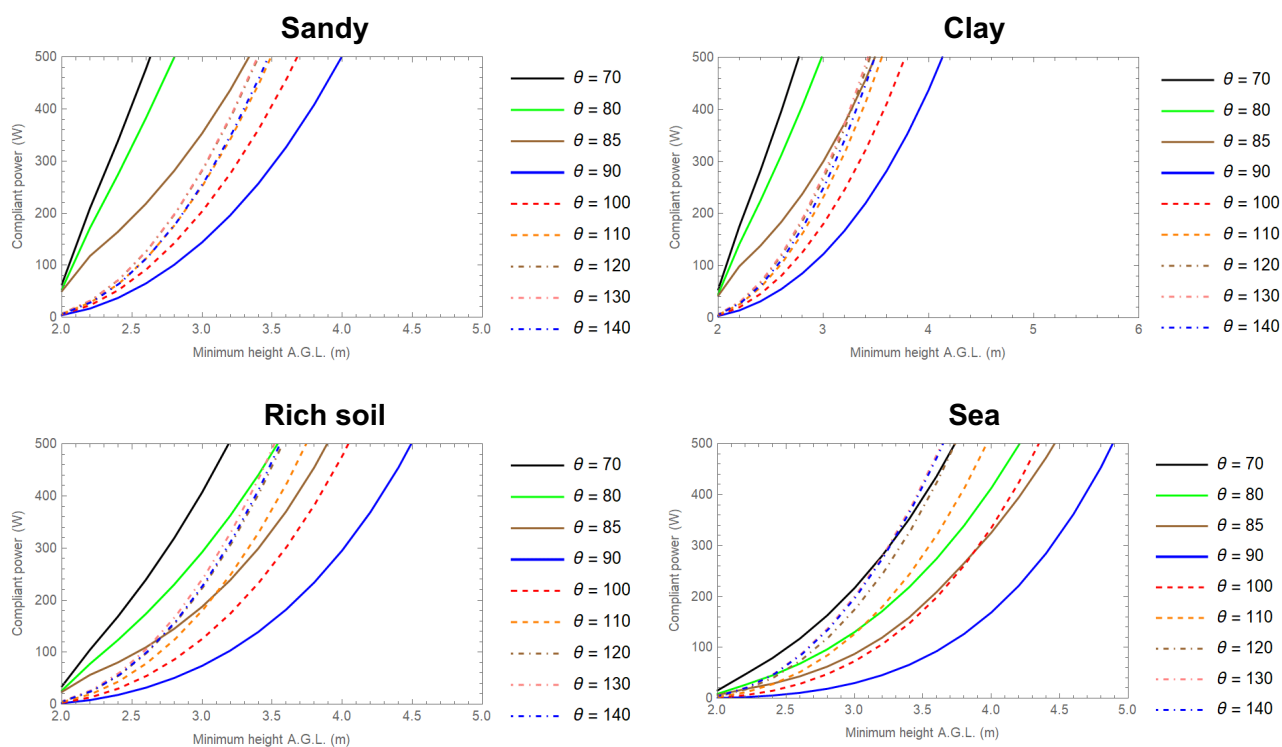


Figure C.6: Compliant power v minimum height for half-wave dipole antennas different θ angle θ deg for different ground conditions - 40m

Annex D – From exposure to guidance – Minimum horizontal separation from wires

In addition to a constraint on the minimum height, a minimum separation should be established to address situations where either the minimum height cannot be achieved or when the antenna may be attached close to residential buildings.

For the horizontal dipoles at the minimum height (critical condition in Figures C.3 to C.6), Figures D.1 to D.4 are a set of exposure plots showing (for one leg of the dipole) the maximum power exposure contours in the horizontal plane and a set of simple exclusion zones for each band set at the minimum horizontal separation distance that encompasses the maximum exposure contour for that transmit power.

160m Horizontal separation	
10W	0.5
100W	1.2
400W	2.2

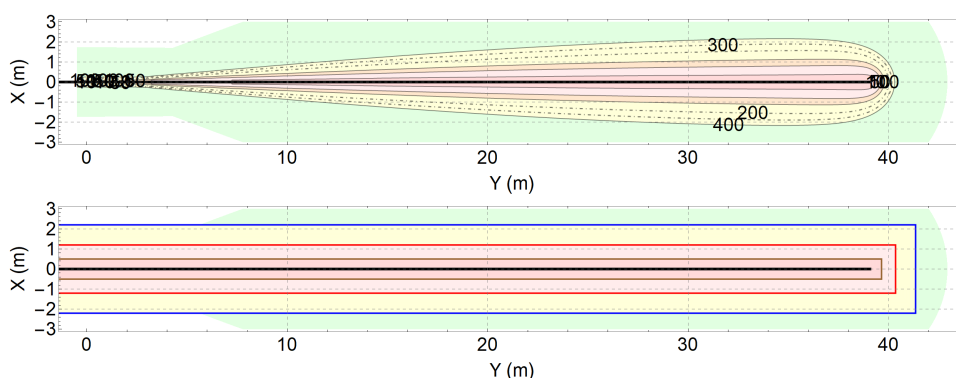


Figure D.1 – Determining the horizontal separation distance – 160m

80m Horizontal separation	
10W	0.5
100W	1.1
400W	2.0

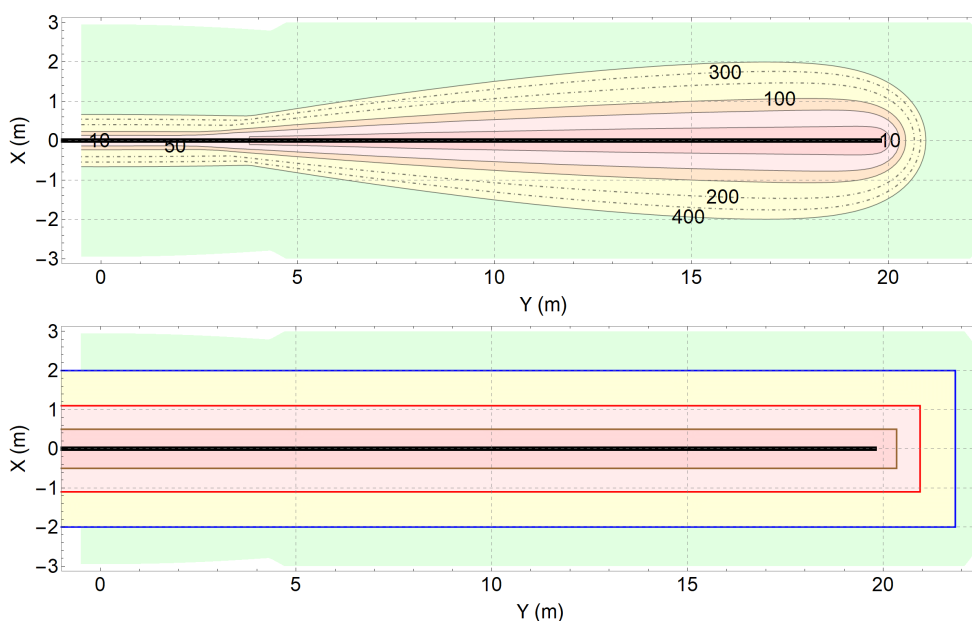


Figure D.2 – Determining the horizontal separation distance – 80m

60m Horizontal separation	
10W	0.5
100W	1.1
400W	2.0

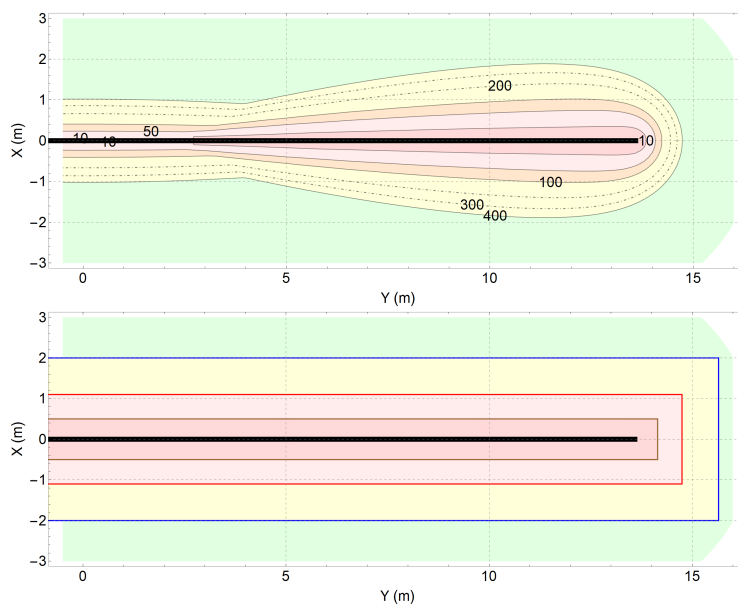


Figure D.3 – Determining the horizontal separation distance – 60m

40m Horizontal separation	
10W	0.5
100W	1.1
400W	2.0

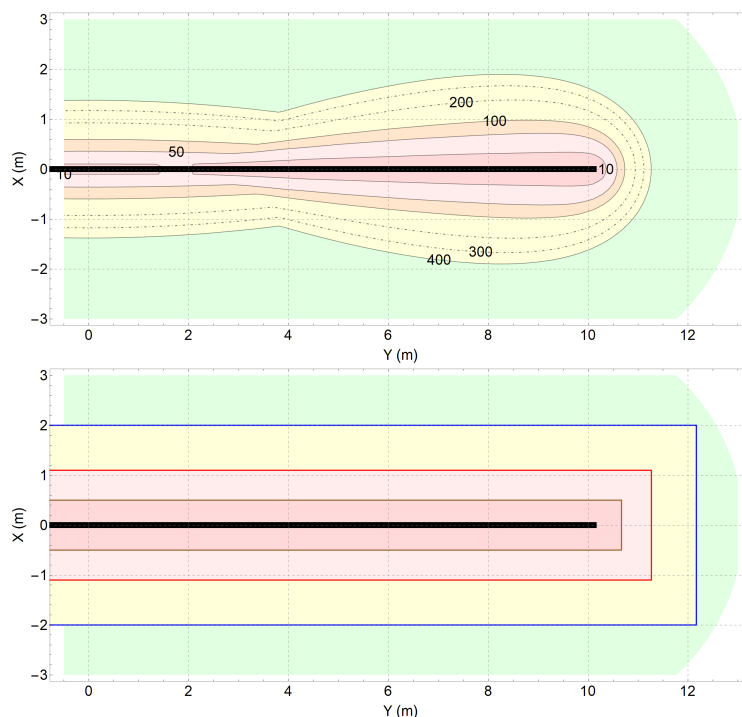


Figure D.4 – Determining the horizontal separation distance – 40m

It should be noted that the precise shape of the plotted contours would be challenging to reproduce on the ground or to assess as a separation at a height e.g., from a balcony. For that reason and also to err slightly on the conservative side to account for uncertainties, the simplified exclusion zone contour is recommended for general guidance.