Operating from a Motor Home: Antenna for 40 – 10 Meter

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Parking the motor home (camper van) in a lonely spot with a wide view in the middle of nature, ideal for shortwave radio communications because of the low interference level and plenty of space for antennas? Unfortunately, this is a nice vision but unrealistic under present conditions. More likely: Parking the motor home on a motor home parking space or a campsite, often there are very limited spaces with neighbours on the left and right. The only antenna choice left is a vertical radiator which, however, should be good for DX connections.

Figure 1: Vertical antenna placed on the motor home's bicycle rack

Motor home with vertical antenna

The vertical radiator should be easy to assemble and dismantle and store in the motor home. The use of a GRP telescopic mast that can be pushed together is therefore obvious. In my case a version with 9 segments and an extended height of 8.7m. The antenna wire is led up inside the mast where a “capacitance hat“made of wire (side length 20 cm x 20 cm) extends the radiator electrical length by top loading. A bicycle rack on the back of the motor home serves as a stable attachment - the mast is placed on a wooden plate attached to the rails of the rack and is held vertically by the two arms of the bicycle supports. This arrangement can be seen in Figure 2. The 9.2 m long antenna wire (1.5 mm^2 insulated copper wire) is led out through an opening in the wooden plate under the mast and led in a loop to the match box next to the mast. Together with the top load, this loop ensures that the electrical length of the radiator is approximately 10 m. The Match Box houses a cable choke for connecting a coax cable to the interior of the motor home and an impedance matching circuit for the vertical radiator.

Figure 2: Set up of the vertical radiator mast on the bicycle rack. The match box is at the bottom left next to the mast.

However, the current distributions on the radiator and thus the feed point impedances are quite different for the different bands. Figure 3a shows the current distributions calculated with EZNEC on a simple 10 m wire excited against ground (Real/MININEC): At 7 MHz the radiator is in resonance with λ/4 (quarter wave) with a feed point impedance of around 35 Ω. At 14 MHz, however, it is high-impedance with 1 to 2 kΩ due to resonance as a λ/2 radiator. At 10 MHz, the radiator is slightly over 1/3 λ long and non-resonant, with an impedance in the 200 Ω range with a large inductive reactive component. Similar at 18 MHz, where the length is about 5/8 λ and the impedance is also around 200 Ω, but with a high capacitive reactive component. All of these current distributions produce low elevation angle radiation patterns ranging from 16° in the 17-meter band to 26° in the 40-meter band - good for DX links. However, operation at higher frequencies is less attractive, as more and more sky radiation is generated, most clearly at 28 MHz: Here the vertical radiator has a high impedance due to resonance as a full-wave radiator with a current distribution with two half-waves - however, these are in anti-phase, so that a null is generated in the pattern towards the horizon and the radiation beam is squinted upward by 36°. The vertical radiation patterns in comparison can be seen in Figure 3b. Without a buried ground radial system, there are significant power losses in the ground due to the vertical polarization of the antenna - the antenna gain is therefore only around 0 dBi between 7 and 18 MHz. Because of the upward tilted radiation pattern, only small losses occur in the ground at 28 MHz, so the gain reaches 3.7 dBi.

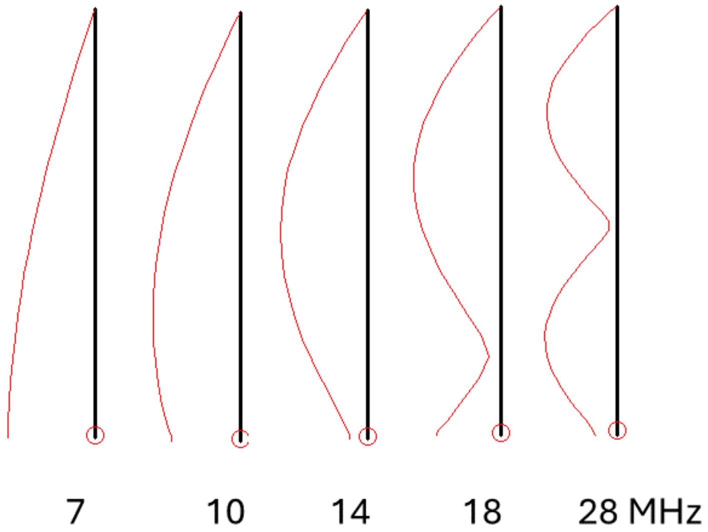


Figure 3a: Current distributions on 10 m vertical radiators above ground calculated with EZNEC.

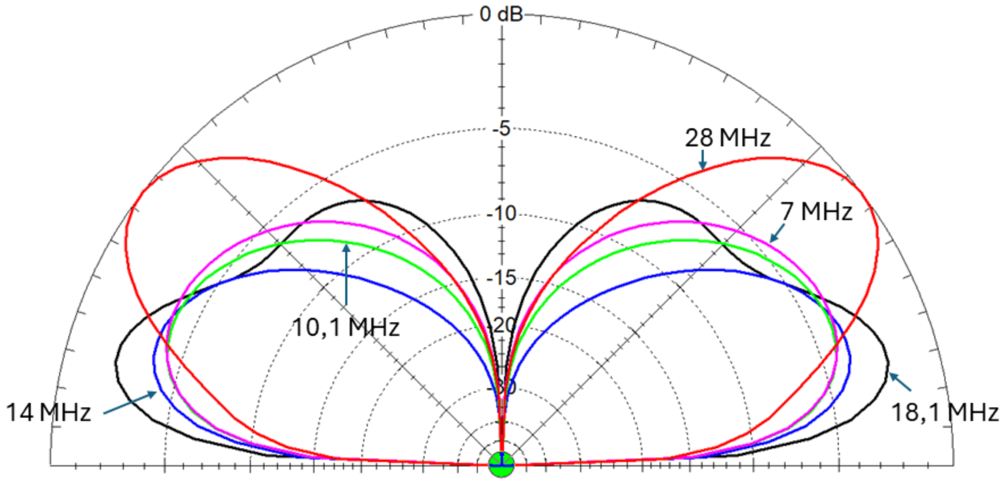


Figure 3b: Elevation radiation patterns of the 10 m vertical radiator above ground calculated with EZNEC. The 0-dB level corresponds to a gain of 3.7 dBi.

However, one important element is still missing for operating the vertical radiator - the counterweight! Of course, an extensive ground radial network is not an option, as in the case with a stationary antenna system. And a single ground rod that is driven into the ground is not a good solution, at least for the 40-meter band, where the lowest possible ground resistance is necessary. The better solution is a single elevated “radial” in the form of a horizontally laid wire. The wire, together with the ground, forms a transmission line with a few 100 Ω characteristic impedance. However, this line is subject to losses due to radiation and limited ground conductivity, so its input impedance always contains a resistance component - in order to keep the contribution due to ground losses low, the radial height should be at least 0.5 m. The input impedance of this line depends on its “electrical” length (length in wavelengths): At λ/4, the open circuit is ultimately transformed into an impedance close to a short circuit - the usual dimensioning of the radials in a ground plane antenna, for example. The interconnection of the vertical wire and radial wire results in the terminal impedance of the antenna system - it is the sum of the impedances of the vertical wire and radial wire. The resistance component of the radial impedance increases the terminal impedance, but a suitably sized radial wire can also compensate for the reactive component of the impedance of a non-resonant vertical radiator by the reactance of its input impedance.

For the 40-meter band, however, the vertical wire is in resonance, so no compensation is necessary. A short circuit, i.e. a λ/4 radial, is required as an ideal counterweight, so that a kind of λ/2 angle dipole is created, see Figure 4a. The asymmetrically warped radiation diagram with strong vertical radiation (in z-direction) shows that the radial wire radiates significantly, with horizontal polarization and with the main radiation direction vertically upwards. This could be interesting for contacts within the minimum skip zone or for NVIS propagation, but: You usually don't have ten to eleven meters of space behind the motor home. The solution is to “fold” the radial wire to save space, see Figure 4b. Because currents flow in opposite directions on the wire in sections, the radiation on the individual sections of the radial is largely cancelled out. This ensures that the radiation resistance of the radial almost disappears; the feed point impedance drops by around 14 Ω - the remaining effective resistance of the radial impedance is mainly due to ground losses. The reduced radiation resistance matches the significant reduction in vertical radiation, which means that the resulting radiation pattern appears almost symmetrical.

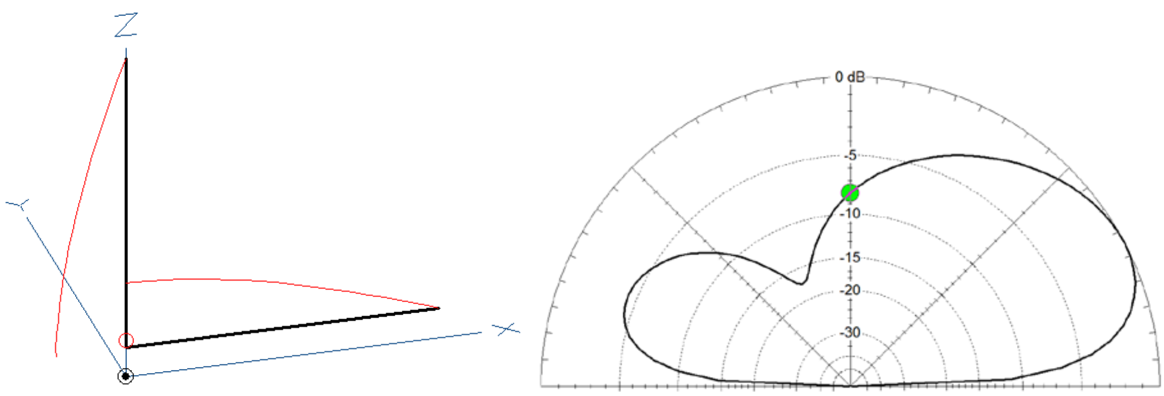


Figure 4a: Vertical radiator with stretched out radial wire in 1 m above real ground. Antenna with current distribution (in red) and radiation pattern in the x-z plane. Calculation with EZNEC.

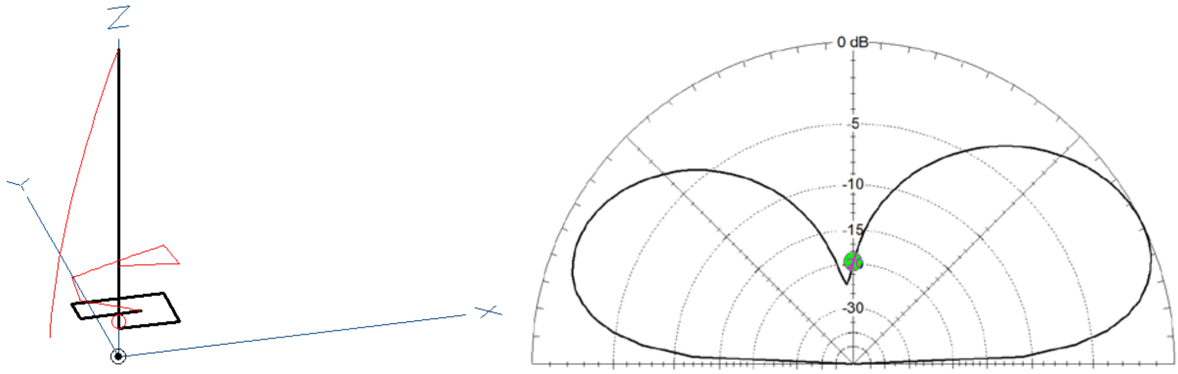


Figure 4b: Vertical radiator with folded radial wire in 1 m above real ground. Antenna with current distribution (in red) and radiation pattern in the x-z plane. Calculation with EZNEC.

The simulation with a more realistic wire model in EZNEC for the vertical radiator with top load and the wire loop at the bottom as well as real ground type (Real/MININEC) confirms the choice of the folded radial for the 40-meter band. However, it also shows that for bands above 7 MHz, different lengths of the radial wire would be necessary in order to achieve compensation for the reactive component of the vertical radiator impedance.

Realization for all bands

First, calibrated impedance measurements were carried out at the base of the antenna using a NanoVNA. In order not to influence the antenna near fields, the VNA was connected to the end of a coaxial cable at a distance of 5 m. The inner and outer conductors of the cable were connected to the vertical wire and the radial wire with the insertion of choke balun on the wooden plate - with different radial lengths and each also "folded": With radial lengths from 5 m to 11 m five supports of 1 m hight were used (the yellow rods in Figure 1!) to hold the radial wire according to the folding pattern of Figure 4b, for smaller lengths folding with only three supports. However, with the length of 6 m, the measurement shows a good compromise: At 14 MHz, the impedance of the radial is sufficiently low to effectively excite the high-impedance λ/2 resonance, as is the full-wave resonance at 28 MHz, and at 10.1 MHz and 18.1 MHz there remains an inductive reactance of up to around 150 Ω in addition to a resistance of around 200 Ω. And in order to cover the 40-meter band without changing the radial wire to a length of 11 m, the 6 m long radial wire can be electrically extended using a coil with around 9 µH, albeit with a slight loss of bandwidth.

So, it made sense to build a suitable matching circuit. This match box, Figure 5, in addition to a standing wave barrier (on an FT 140-43 core), it contains an auto-transformer with 13 turns, also on an FT 140-43 core. The different impedances of about 30 Ω at 7 MHz, about 200 Ω at 10.1 MHz and 18.1 MHz and about 1000 Ω at 14 MHz and 28 MHz are matched by using different taps on the coil: While the 50 Ω coaxial cable is connected to the third turn, the wire of the vertical radiator in the 40-meter band is connected to the second turn for upward transformation and for downward transformation in the 30- and 17-meter band to the fifth and in the 20- and 10-meter band connected to the last turn. The inductive reactive component of the radiator impedance at 10.1 MHz and 18.1 MHz is additionally compensated for by a 120 pF capacitor connected in series. Accordingly, three different banana sockets are used to connect the vertical wire to one side of the box. The radial wire also plugs into a banana jack on the other side. In the picture you can see a few thin-film resistors that can be contacted to the corresponding outputs to test the transformation.

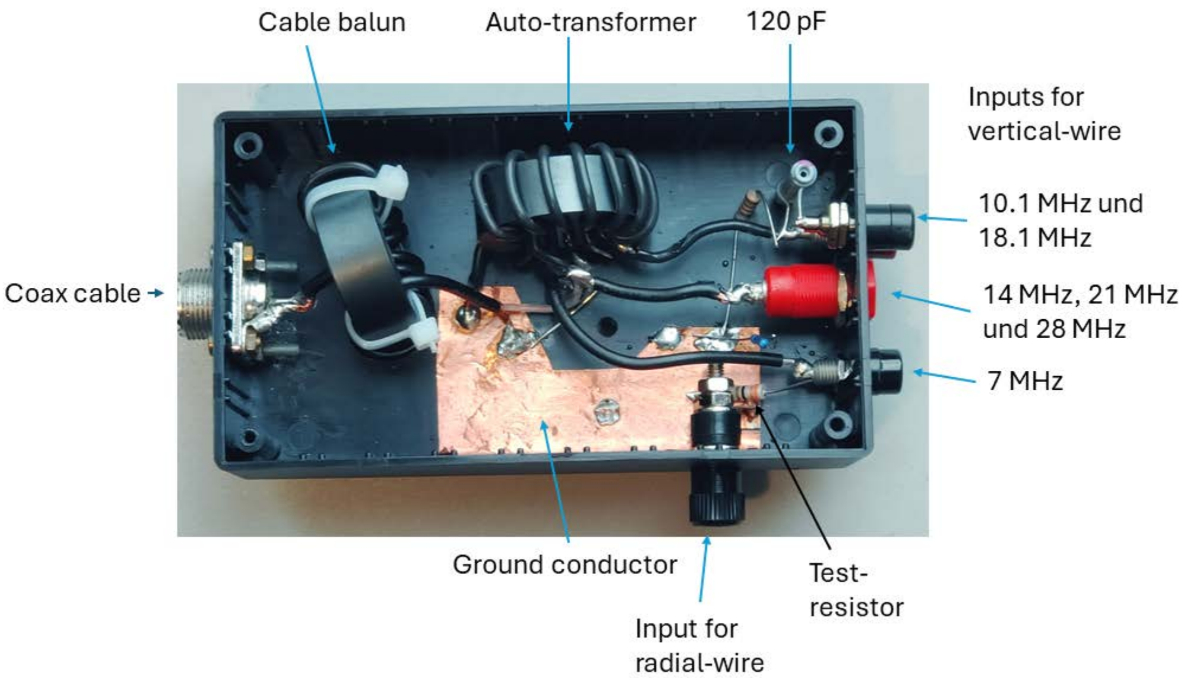


Figure 5: Match box of the antenna in a plastic box.

Applying a 1 kΩ test resistor to the output for the upper bands results in approximately 41 Ω plus 21 Ω inductive reactance at 14 MHz. The transformation does not correspond exactly to the number of turns ratio (with a number-of-turns ratio of 3:13 you would expect 55 Ω) and the transformer also contributes a leakage inductance of around 4.5 µH on the output side. For the vertical radiator at 14 MHz, the leakage inductance acts like a coil at the base terminal, which shifts the resonance of the λ/2 radiator by around 100 kHz. In the lower transformer taps on the fifth and second windings, the leakage inductance is not clearly noticeable, but here too the transformation ratio is somewhat lower than expected based on the number-of-turns ratio.

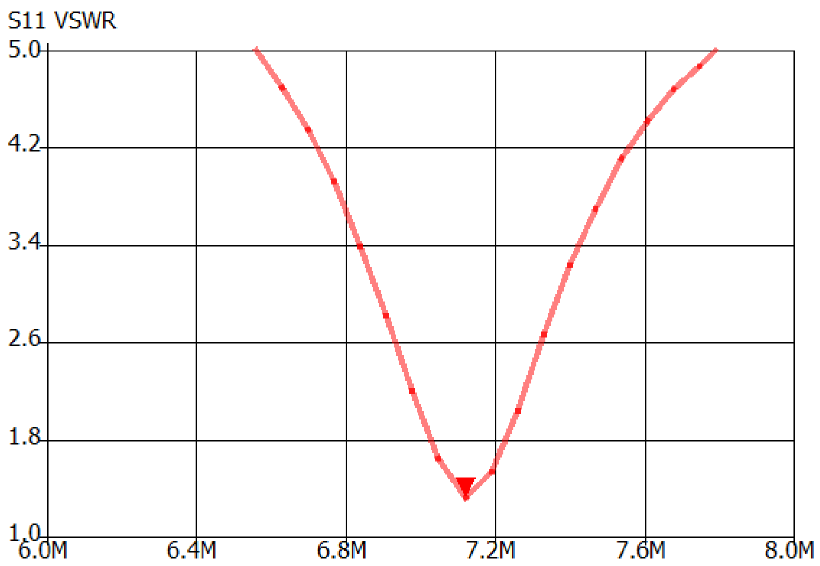
The reward for the effort: Useful impedance match for all bands

With the NanoVNA, again at a distance of 5 m, the impedance was measured by appropriate calibration at the “50 Ω” terminals of the match box’s auto transformer, while the vertical wire was plugged into the appropriate socket depending on the operating frequency. The 6 m long radial wire (strand wire 2.5 mm^2) was laid folded with five supports (distances from Match Box 1.55 m - 0.9 m -1.75 m - 0.4 m - 1, 4 m) , as can be seen from the yellow supports in the example in Figure 1. The extension coil for the 40-meter coil was inserted near the match box and was bridged for the higher frequencies.

The measurement results are shown in Figure 6 as VSWR plots. All shortwave bands between 7 MHz and 28 MHz are covered with usable match, with the exception of the 12-meter band, for which a significantly shorter radial wire would be required. The impedance match in the 15-meter band is a special feature: In this band, the simulation with the realistic wire model of the antenna shows that because of the selected length, the radial wire exhibits a λ/2 resonance, where a current flows several times higher than flows on the vertical wire. The roles of radiator and counterweight appear reversed, the resulting radiation pattern is determined by the radial wire and not the vertical wire; the radiation pattern is therefore mainly “to the sky” and practically useless for DX operation.

For the 40-meter band, due to the selected inductance of the coil, the best match is around 7.15 MHz. For this band and for 30- and 17-meter bands, changing the routing of the radial wire can cause a slight shift in the frequencies of the best match: If the fold is less tight, the frequency decreases. In the extreme case, with stretched out wire, the frequencies drop by 30 kHz at 7 MHz and 150 kHz at 18.1 MHz. The best-match frequencies in the 20- and 10-meter bands, however, are only slightly dependent on the laying of the radial wire.

Depending on the local conditions, other folding patterns could also be necessary, e.g. laying the radial wire to the side of the motor home - such variants also showed only slight shifts in the impedance match characteristics.



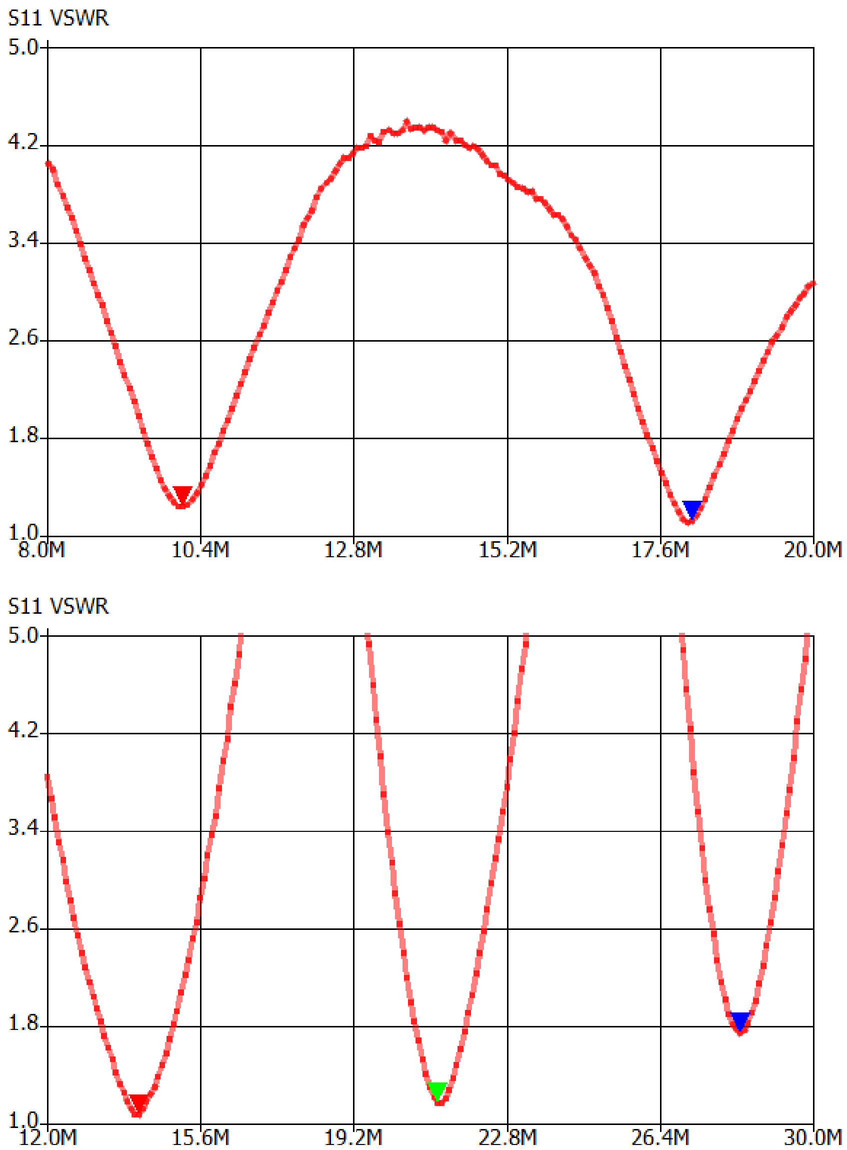


Figure 6: Measured VSWR at the Match Box for the 40- to 10-meter bands. Markers at 7.12 MHz, 10.13 MHz, 18.11 MHz, 14.16 MHz, 21.18 and 28.29 MHz.

Safe distance

The EZNEC simulation model was used to calculate the field strengths around the antenna to determine the approximate safe distance limits. The safe distance on all bands is determined by the high electric field strength around the radial wire, which is of course highest at its open end. Of all bands, in the 40-meter band, the highest field strengths are found. The resulting safe distance is shown in dashed line in Figure 7: An area of roughly 3 m - radius around the open end of the radial wire should not be entered when operating with 50 W (CW or SSB) on the 40 meter band in order to meet safe exposure limits for general public based on the German Regulation (26.BImschV); for the higher bands, with the exception of the 15-meter band, the safe distance is reduced to a radius of approx. 2.5 m.

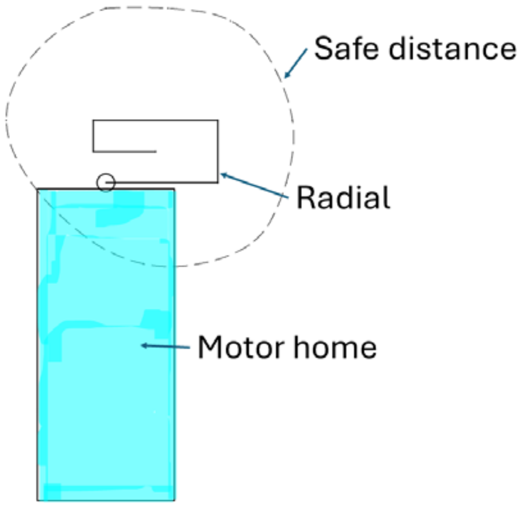


Figure 7: Sketch of the motor home with antenna and limit of the safe distance at 50 W transmission power (CW or SSSB). Limits@7MHz: 33 V_{eff}/m and 0.1 A_{eff}/m squared averaged over 6 min.