Can Ground-Wave Tests help determine electrically small, vehicular, HF-Mobile Antenna Radiation Efficiency?

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Abstract

HF (short-wave) communications are recently increasingly used by military, NGOs, and radio amateurs e.g. in emergency/disaster support scenarios. Small vehicular antennas are inefficient and must function under various discussed propagation conditions. Efficiency testing options, using known reference antennas, are shown, considering reliability, low budget, and simplicity. A combination of Ground-Wave (GRW) Testing (46-1650m) and MOM Simulation was chosen. The dielectric soil (e.g. farmland) under the car and beyond plays a key role, not easy to measure. We assumed and simulated soil to best fit the tests on the important 7MHz/40m band. A 50 Ohm forced match, broadband, 1m long car rod-antenna was developed.160/80/40/20/10m GRW propagation/attenuation was measured. This can be used, e.g. for EMC in large PV-Installations.

1 Introduction

Antenna applications and users are, aside from Military, Special Forces and Special Government-Agency Services licensed Amateur Radio operators (Author: HB9CVQ, DK2VQ, AK4IG) performing interference-sensitive, experimental radio services (ITU) throughout the world. This happens over various distances and various assigned frequency bands, adjacent to commercial HF-spectrum. Short-Wave (HF) is also used by UNHCR, or other humanitarian, (medical, technical, administration support) NGOs, with partly very mission-critical crisis/emergency communication needs. They operate typically in remote (natural) disaster/conflict areas. These organizations start using nowadays increasingly again mobile, vehicular Short-Wave communications. Voluntary local amateur radio services are many times effectively supporting these helpers in civil defense missions. Reliable, cost-effective Short- and partly Longer-Distance radio communications are essential.

Satellite Phone Networks may be too congested or expensive. Additionally, coverage may not always be available. Hardware can be destruction/jamming vulnerable by e.g. adverse electromagnetic attacks. Breach of data protection, eavesdropping is a further potential threat.

Mobile phones 3G/4G/5G are often no option, because the usually existing, supporting infrastructure (base stations, electricity, internet) is temporarily down or destroyed. VHF/UHF may not bridge the needed distance from a critical mission front-location to a temporarily established headquarters. HF Short-Wave (1.6 to 3-30 MHz) communications, on the move, can here provide a rapidly deployable, reliable, and cost-effective land mobile radio solution (or fallback position).

The tricky question is however how to trustworthy measure antenna radiation efficiency. Detailed HF Know-How is needed to master this using a very limited budget and sufficiently calibrated low-cost instruments.

A typical short, resonant, vertical, HF automotive TX (transmit) antenna system (typ.<100W input) is relatively lossy, if not over perfectly conducting ground (PEC). This is dependent on soil under/in front of the car, frequency, ground penetration skin depth, and overall system design/geometry. Such radiators are electrically small/short vs. operating wavelength (160m- ca.1.8MHz to 10m - ca. 28 MHz). Therefore, the system is narrowband (Hi Q), inefficient and lossy. Inefficiency on receive (RX) calls for good EMI-denoising the car to have reasonable Signal/Noise (S/N) ratio. TX efficiency is generally defined here as a ratio of max. radiated far field power (density) to accepted conducted antenna input power (matched).

Often efficiency is only a few precent (160m <1% (ca. -20dBi), 80m <5%, 40m >10% (ca.-10dBi) and on 10m sometimes >50% (ca. -3dBi) [1] [2]. Such a system is shown in general terms in Fig. 1. (PEC: perfectly conduction ground). Furthermore, EU road traffic regulations dictate, for on the move use, a vertical height (street to car antenna tip) of max. 4m.

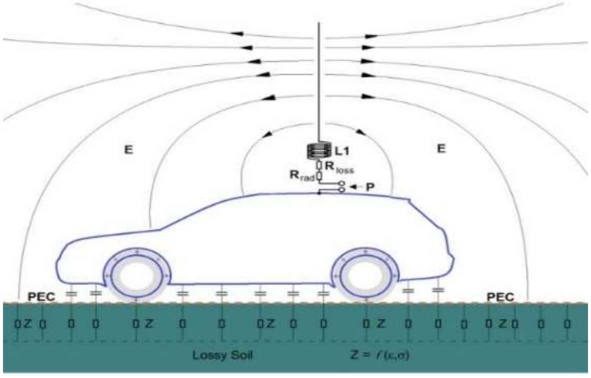


Fig.1: Metal car, resonant antenna, transmitting, and capacitively interacting with lossy soil/PEC.

1.1 Signal Propagation Modes

Two-way simplex HF-communication happens typically via strongly varying ionospheric propagation, affecting almost all propagation modes.
These are Skywaves [3] [4] for bridging long distances. This requires vertical elevation antenna radiation pattern, with low take-off angle, minimizing lossy multi-hop reflections (ground-ionosphere). NVIS (near vertical incident skywave) [5] needs vertical antenna radiation pattern with steep elevation angle, reaching (max ca. 500km) shorter distances.
More stable, almost independent of ionosphere, if measured e.g. on 40m Band around noon, for short distances is Ground-Wave (surface wave) propagation [6] [7]. Impacting factors: Air-Soil interface, signal soil skin effect and its wave-penetration, surface-weather (soil conductivity, dielectric properties). Vertical polarization is here about one order of magnitude less attenuated over surface distance than horizontal. This effect was also used in LW/MW Radio Broadcasting.
Surface waves reach [8] typ. on 160m Band up to 200km and typ. on 10m Band up to 8km. Assumptions: A good readable RX signal at the measurement receiver with -73dBm (S9, 50µV/50Ohm IARU) over flat ground/soil. Furthermore: Low RX S/N ratio, TX 100W and ground mounted, co-polarized vertical antenna, typ. ¼ WL, soil assumption 0.08mS/m/15 rel. epsilon.

1.2 Solar Space Weather

The ionosphere, a gaseous medium, surrounding the globe (ca. 80 to 800 km, several layers [9]) is basically ionized by various solar emission effects (space weather). This represents a time varying “Mirror Volume” for HF-signals. The earth magnetic field is e.g., interacting with the solar emissions, before setting temporary radio propagations in MF and HF bands on the ground. There is the well-known 11-year solar cycle, with low and high sunspot numbers, affecting ionization. Additionally, we see geographical propagation differences, perturbances, and seasonal effects. Generally, in the daytime, the max. usable HF-frequency goes up. At nighttime normally only the lower bands can be used effectively. There is mostly more man-made (local) and natural (lightning, statics) EMI background noise on the lower bands. This impacts Signal/Noise (S/N) ratio. Space weather is caused by solar radiation and particles interacting e.g., with the earth magnetic field lines. They define acute radio propagations for MF and HF bands on the ground/earth. Additionally, we see geographical propagation differences, perturbances, and seasonal effects. At daytime the max. usable HF-frequency goes up and at nighttime normally down. Only the lower bands can now be used effectively.
What will be the set of options for possible measurement procedures and test scenarios for determining electrically short, vehicular antenna radiation efficiency, in a trustworthy and cost-effective way?

2 Options for testing Radiation Efficiency of vehicular (HF-mobile)-Antennas

The following list presents the generally available options: [10]

1. Calculated, theoretical, low Antenna Radiation Resistance vs. all measured System Losses, at antenna feed point in resonance. Soil losses are dominant on low bands. (careful: no consideration here of any antenna radiation Far-Field (FF) pattern characteristics)

2. Antenna accepted input power vs. Far-Field (FF) radiated power (considers antenna pattern)

3. Trustworthy measurements <u>and</u> trustworthy simulation-models (seeking converging trends, using tailored reference antennas [10] that are representative, efficiency is finally simulated)

4. Sky-wave (careful: uncontrolled ionospheric variations (amplitude/phase/polarization) over time issues)

5. Drones/Aircrafts RX measurements in FF tricky, (low altitude ground reflections, expensive, difficult to get above 120m height (that's < 1WL on 160m), due to drone regulations in EU)

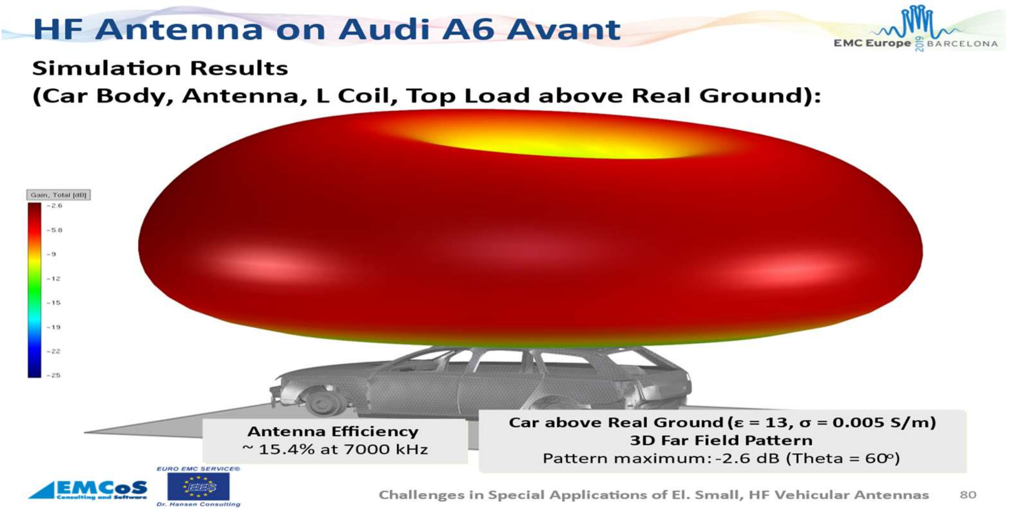
6. EMC Absorber/Reverb-Chambers (costly, geometrically too small (NF/FF) and absorbers too ineffective at HF)

7. EMC Open Area Test Site (metallic ground, no soil -epsilon/sigma- vs. frequency, too small sized metal ground plane for needed FF distance)

8. Antenna comparison to known RX Reference Antenna in FF (TX source here natural, hopefully omni-directional sky background noise distribution, a frequency selective EM-Noise-Power test, only doable in very hard to find, flat, quiet, rural environments [10].

9. **Ground-Wave** (careful: no direct consideration of antenna pattern, but a solution in combination with input power/impedance tests, field strength **measured and simulated** for reference antennas, including hereby antenna pattern in FF. If measured antenna impedance well matches simulated one, we can rightfully trust the predicted FF pattern)

Chosen procedure: HF Far-Field (FF) for a station wagon (<5m), over avg. soil (assumed 0.005 mS/m, eps13), with Hi-Q (ca.1000) inductor, resonated 2.2m long vertical car roof antenna Al-rod (ca. d=20mm). Vertical antenna elevation angle, over avg ground, **MOM simulated example** result see (Fig.2) and from literature is also generally ca. 30/40 deg. vertical elevation angle [11]



HF Antenna on Audi A6 Avant

EMC Europe 2019 BARCELONA

Simulation Results
(Car Body, Antenna, L Coil, Top Load above Real Ground):

Antenna Efficiency
~ 15.4% at 7000 kHz

Car above Real Ground (ε = 13, σ = 0.005 S/m)
3D Far Field Pattern
Pattern maximum: -2.6 dB (Theta = 60°)

EMCoS Consulting and Software
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Challenges in Special Applications of El. Small, HF Vehicular Antennas 80

Fig. 2: Simulated, resonant 7 MHz (40m), Reference Antenna, efficiency ca. 15% over soil (5 mS/m, 13), 30° elevation angle.

Just as a side remark, tested Far-Field starts in about one wavelength horizontal distance from the car, parked over avg. farmland soil. We could however only measure amplitude, not phase.

2.1 Choice of Reference Antennas in our previous Antenna Efficiency Testing

As documented in [4], comparing antennas to a predictable reference requires co-polarization of the pair. Fig 3 shows left a 40m short, resonant, vertical reference, followed by a co-polar ¼ WL vertical, excited against the car. The following are non-co-polarized, tunable 3 (2 on 40m) el. Yagi (DB18E SteppIR) with barely visible, tunable, sloping inverted-Vee System (2x36m, 90° opening, mixed polarization, 24m up) from the mast top.

Fig. 3: Two co-polarized 40m verticals, and two non-co-polarized reference test antennas

3 Special Broadband 50 Ohm TX Antenna, Set-up for Ground-Wave (Propagation)Tests

We tested west of Munich (Puchheim, Germany) in autumn 2019, over free, dry, flat farmland, with ground water table just a few meters below the surface. Extreme care was taken not to test at busy frequencies/channels or times with negatively impacting Skywave/NVIS propagation.
Aircraft scatter (flutter) was rarely observed, and if so, tests repeated. Day to day test range variation results (procedure: RX 200Hz BW, band start frequency, avg. detector mode, 30 s observation, TX CW carrier, TX identification), given constant local surface weather, were within typ. +/-1.5dB. Very few small houses were in front of our “wooden house/roof floor” test stand. We measured with selective Scharzbeck (H-Field Antenna, FMZL 1514) CISPR EMI RX System in ca.10m height. The transmitting car was out in the flat field. The vehicle was an Audi A6 Avant (2003) transmitting with a specially test-designed short vertical rod antenna (way too insensitive for communications, ca. -47dBi over PEC). The TX was 80W CW HF out, 50Ohm, ant. base up ca. 1.5m, well bonded to the center metallic roof. The test antenna (Fig. 4) was a 1m long, roughly 2mm diameter, vertical steel rod. Base was terminated into 50Ohm dummy load. There was a T-BNC-connector to attach the rod, therefore forcing broadband, rod antenna TX performance and good TX matching with VSWR better than 1.5 (14dB RL) from 160m to 10m. This rod gave enough distant RX test signal even at 160m and 1.65km and simplified quick frequency band changes. Longer rods with more stray capacitance (> ca. 18pF rod to car) worsen the VSWR.

Fig. 4: Special 50Ohm, forced match, 1m TX Rod Antenna, well bonded to mechanical carrier platform and bonded to metal car roof

The TX (1.5m up) measurements were done in 8 test positions A to H (46m A-right to 1.65km, H-left), see Fig. 5, car distance to the RX test stand (H-field test stand, up right) in 10m height. The coax (50 Ohm RG58U), inside to the car roof, was above decoupled against common mode shield currents by a ca. -20dB ferrite cable sleeve CM - choke. The TX was inside the car and the cable shield was bonded at the penetration front-side door to the metal car body (zoning concept). The TX was battery powered and boosted to 13.8VDC.

Fig. 5: 8 TX Positions A to H (1.65km H - 46m A) car distances to the RX (up right) 10m high

Tested bands ranged from 160m to 10m; each time with half wavelength / doubled frequency. We used an old, manually operated, selective, recalibrated Schwarzbeck EMI Test Receiver System with small magnetic loop, rotatable frame antenna, and preselector. Measured H-field (dBµA/m) is automatically converted here to dBµV/m, as per CISPR convention 377Ohm => 51.5 dBΩ conversion. Using a true E-field reading sensor proved again very unreliable [6]; high measurement uncertainties, based on uncontrolled capacitive near-field coupling effects around the test stand. Additionally, the H-field sensor location/environment should, prior to testing, be carefully checked for any potential secondary radiator coupling effects, if any! Using the horizontal direction-finding capabilities of our RX system we always ensured only receiving signals from the known, line of sight, car position bearing.

4 Test results, MOM EM-Simulations and Discussion

Fig. 6 shows the results of the E-field strength test (80W, Audi A6 with 1m broadband rod) at various test distances and several HF-bands (1.8, 3.5, 7, 14, 28MHz (10m)). As ITU [6] predicts and [7] tested, the distance roll-off is roughly between 1/r^2 (40dB/dec, green) and 1/r (20dB/dec, red). Our data is close to [7], Fig. 19, 7MHz, validation measurements 1 and 2 in the Netherlands. His antenna beacon reference to 1W EIRP is, however, probably a little generous estimate.

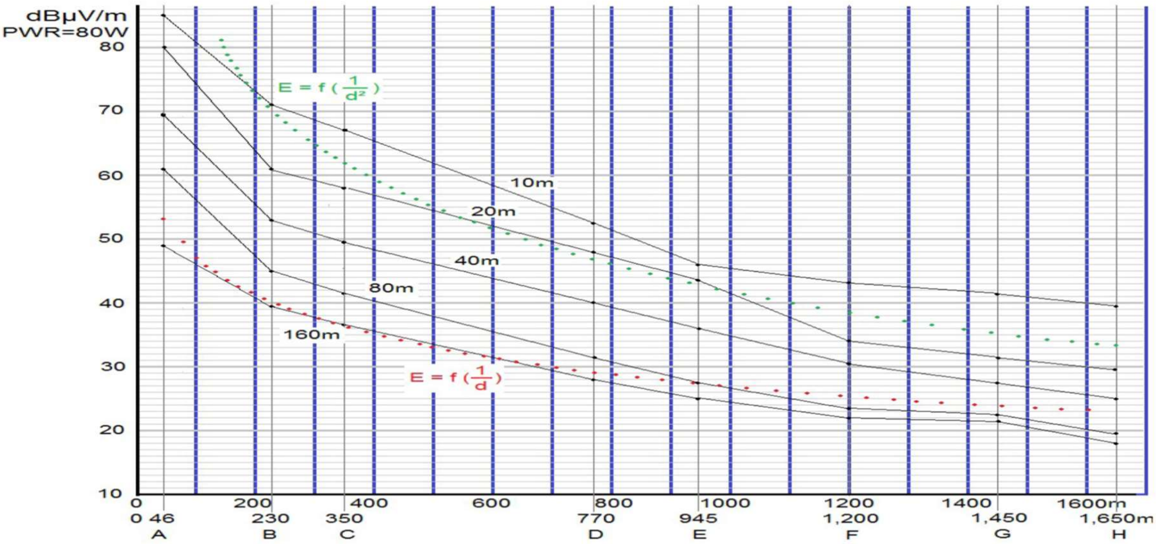

Fig.6: Tested field strength 10-160m vs. distance, farmland, TX 80W (945m/7MHz: 36dBµV/m RX)

Our soil parameters (assumed 0.005/13) were not measured but later reverse simulated/fitted.

For this we used USA, CA. LNLL developed NEC2, part of new free of charge, Roy Lewallen MOM-Code EZNEC 7.0 (incl. ITU GRW) [12]. Additionally, we had NEC 5 (LLC 110$), export restricted, and AutoEZ, AC6LA, CA (79$). After rechecking our test data for 40m **(7MHz), the most important daytime EU HAM band,** and using best fit by AutoEZ-Optimizer (Excel based), <u>our original assumption of soil (0.005/13) turned into (0.01/14) best fit.</u>

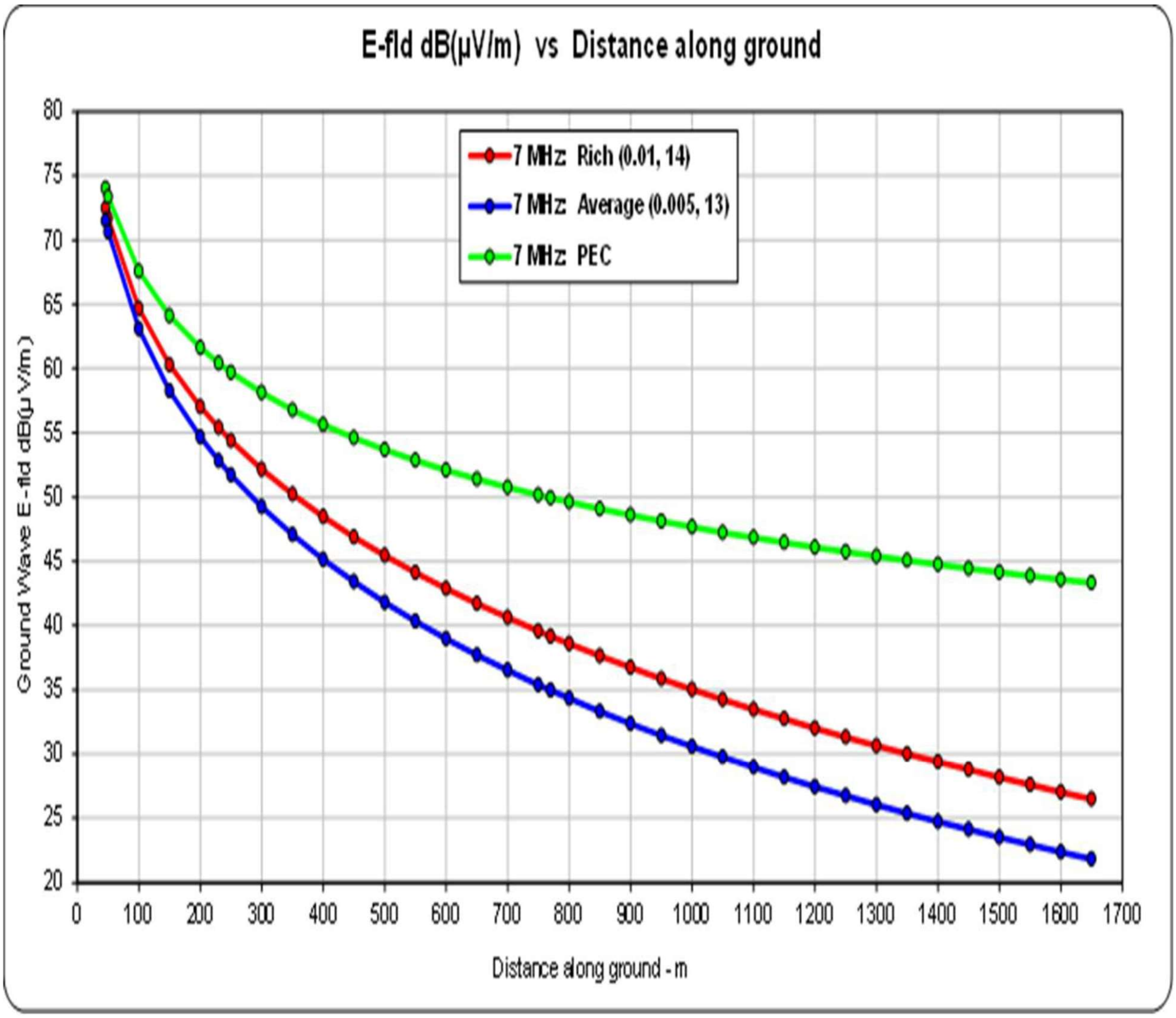

Fig. 7: EZNEC 7.0/NEC5/AutoEZ, simulated (DAN AC6LA) field strength (dBµV/m) **7MHz**, (soil 0.01/14 **red,** 0.005/13 **down, blue,** PEC **up, green**) vs. distance (46m to 1.65km), over flat ground. **Car TX 80W**, 50Ohm forced base matching, **1m long rod antenna** on center of Audi A6 roof.

PEC assumes a perfect electrically conducting ground. The best fit of unknown soil is the red, mid curve (0.01/14) in Position E is 945m (36dBµV/m vs. 32: 0.005/13) away from the RX Field sensor.

It is also interesting to compare data from our previous, excellent cooperation with EMCoS Ltd. [11]. Here we have comparative simulation data (however, not including GRW ITU program), but PEC (Fig.8), perfect conductivity, and real soil (Fig.9). This Code is a big, complex, automotive industry MOM-Code. **For 7MHz** (**PEC**, **945m**, (Pos.5, green, mid) 80W, 1m-rod 50Ohm), **EMCoS** shows ca. **48dBµV/m**. **EZNEC** also shows **48dBuV/m,** as expected an **excellent agreement**.

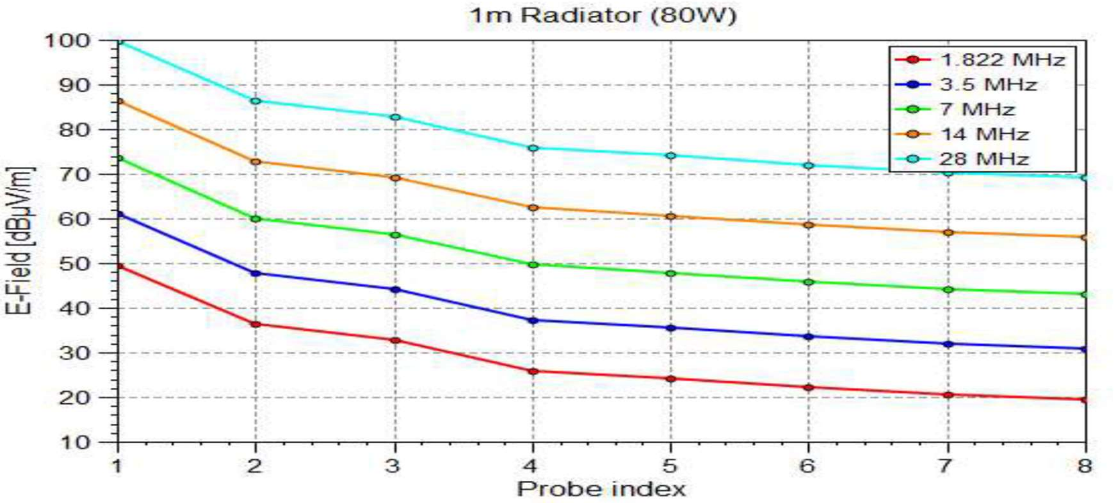

Fig. 8: **EMCoS** simulated **PEC** field strength on HAM bands vs. distance. Car TX at **80W** into a 50Ohm forced base matched of **1m long rod antenna** on central Audi A6 roof. Probe index 5, middle plot, 7MHz/40m (48dBµV/m) is 945m away from the Field sensor.

EMCoS real soil in Fig. 9, for 7MHz (same 945m -Pos.5, green, mid-, TX 80W, 1m-rod 50Ohm). shows ca. 37dBµV/m. EZNEC (blue, lowest, 0.005/13) shows ca. 32 dBµV/m. *Codes and tests are very sensitive to soil parameter changes.* Measurement shows 36dBµV/m.

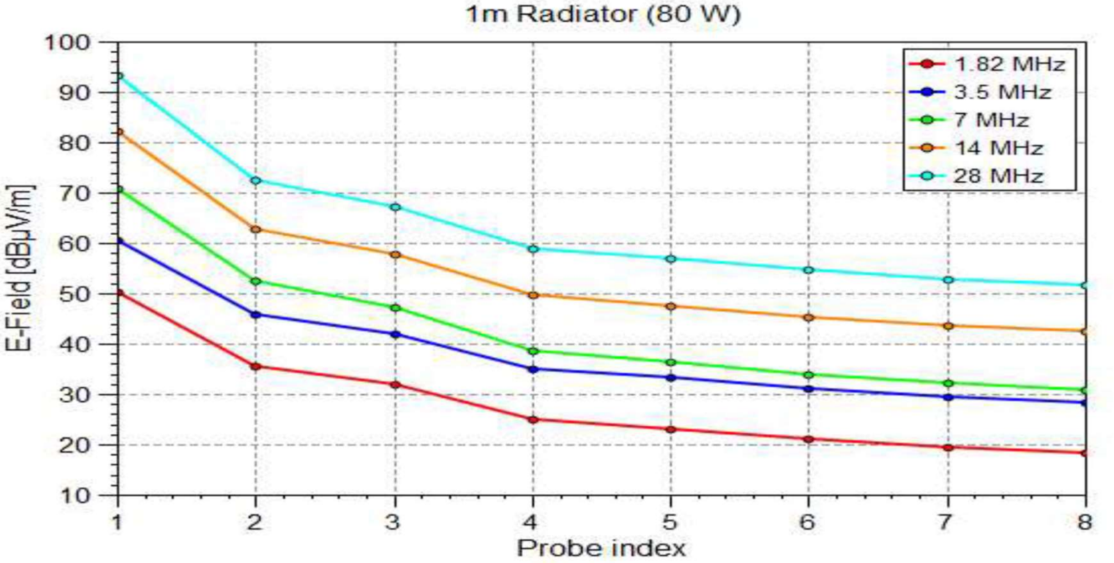

Fig. 9: Same EMCoS Simulation as in Fig. 6, now **EMCoS** (**Soil 0.005/15**), but **without ITU Gound-Wave** program included. Pos. 5 (945m), 7 MHz 37dBµV/m

In other areas and bands, the agreement, without using ITU GRW, was not so good.
It needs to be mentioned that dielectric ground characteristics do change locally. Therefore, spot measurements do not help much. In essence an average value must be used over longer distances. Precise computation is hard based on mostly exsisting layered ground structures.

5 Conclusions and relevance for specific System EMC below 30MHz

Herein documented Ground-Wave (GRW) data and low budget test procedures are appropriate for relative/absolute small HF-mobile, vehicular antenna efficiency (gain) estimations.
This avoids difficult to control, ionospheric tests with instabilities due to time varying, potentially fast, and even locally changing propagation (fading). Variations occur regarding time, phase,

amplitude, and wave polarization. Performing long observation times test, with data averaging, will not necessarily give more accurate test results, because the overall system is time variant.
For doing GRW low gain, lossy, antenna assessment each time a reference calibration test, with a known antenna (e.g. simulated), shall be made. The used antennas shall have the same polarization. Any temporary soil characteristic variation, e.g., by changed surface weather, can be consequently eliminated. The overall procedure is overly sensitive to changes in dielectric soil parameters, both for measurements and simulations. The longer the test distance (minimum one wavelength -> FF) the stronger the soil propagation impact (E-Field vector leans, tilts forward into GRW propagation direction). With additional, trustworthy simulations of the antenna free space radiation pattern and efficiency can be estimated, even in absolute terms, e.g. dBi.
Another promising, future, alternative test is using automated H-field sensor RX-Drone measurements in far field over any soil. By prudent choices the ionospheric impact can be minimized.
Our presented experimental Ground-Wave (GRW) measurements involved surface-wave attenuation (ITU program integrated into EZNEC 7.0) simulations. This might also be useful for realistically assessing the spread of local EMI system/installation emissions over soil distances. The same applies to e.g., electrical vehicles on the road (new EV Std. CISPR 36, H-Field tests below 30MHz), home EV-battery quick-chargers, photovoltaic installations, and wind turbines, all producing considerable radiated emissions below 30MHz, not only above.

All photos taken by author, contact: www.euro-emc-service.com, only Fig. 5 taken from Google, with added test distance - line (A-H) and RX-sensor position.

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