Wirkungsgrad-Messungen an elektrisch kurzen KW-Mobil-Antennen

- Radiation Efficiency Testing of *electrically small HF-vehicular Antennas (ESA)* -

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www.qrz.com/db/HB9CVQ (**under "breaking news" much more technical details/tests**)

- **Sponsor Experiments:** www.euro-emc-service.com
- **Sponsor EM-Simulations:** www.emcos.com , specialist **Ilona Danelyan**, EMCoS LLC, Tbilisi, Georgia

Selected Background Info: (Deutsches Kurzabstract befindet sich am Ende.)

Typical applications are, aside from Military / Special-Forces users, e.g., NGOs with mission critical emergency communication needs in remote disaster areas. These Organizations use mobile, vehicular shortwave communications for humanitarian, medical and technical support purposes. Voluntary amateur radio services are many times effectively supporting these helpers. Reliable Short and Long Distance could be essential.

Satellite Phone Networks may be congested, non-secured, vulnerable, and expensive. 3G or 4G mobile phones are often no option because the supporting infrastructure (base stations) is down or destroyed. HF shortwave (1.5/3-30 MHz) communications, on the move, can provide a quickly deployable, reliable, and cost-effective land mobile radio solution.

For driving vehicles civilian road safety regulations however often limit the permissible mechanical height of mounted vertical whip antennas to max. 4m (ground to tip). This is short in terms of used wavelength (e.g.,**160m/1.8MHz** to **20m/14MHz**).

Therefore, a major technical challenge occurs: **Low antenna efficiency** with may be only 1% or less at e.g., 2MHz. Car-battery powered HF-Transceivers (RX/TX) with about 100W output will under these conditions only effectively radiate 1W. Even this is optimistic! Efficiency is further reduced by unfavorable vertical radiation pattern (momentarily needed optimal skip/elevation distance via ionosphere) of short, typically resonated monopole antenna (a distributed series resonance circuit) [Fig. 1]. In this presentation we are mainly dealing with **resonated whip/rod antennas.**

Long distance communications call for low elevation take off antenna angle**. Short distance** needs steep take-off angles (NVIS) into the conducting **ionosphere**. Low antenna efficiency makes equally the received signals low. This requires the vehicle to have low conducted/radiated EM emissions (automotive EMC). Additionally, the external, EM environmental background noise must be low, if a reasonable signal to noise (SNR) is to be achieved. Some, partly underestimated, EMI Noise data is published in ITU-R-P.372-13 (now to be updated) and lately correctly evaluated in [0].

Antenna fundamentals are treated in well-known textbooks [1], [2] and [3], but not all aspects are yet very well researched. The **limited size of the ground plane**, the metallic car chassis, is one major challenge. The additional antenna system interaction with the soil/ground under the vehicle is another one. Therefore, it is not surprising that electrically short vehicular HF antennas are still today a current Ph.D. and R&D topic [4] and [5], at least for a specialized, small community.

From earlier R&D work 1949/48 [6], [7] on electrically small antennas we know there are fundamental performance limitations in efficiency/bandwidth. Short whip antennas are capacitive/Hi-Z. A coil is needed to compensate/resonate the antenna. A small antenna, with low internal losses, has a very limited bandwidth. Inductance with quality factor Q (unloaded e.g., 100 to 1000) of this series resonance circuit affects performance. Ant. Radiation resistance is typically very low. Because of the series resonance nature, the ground losses contribute strongly, essentially on the low bands. This loaded circuit Q of the total system is relevant.

The ratio of radiation resistance to the sum of all losses, including the radiation resistance, defines the best basically possible efficiency. The effective radiation pattern/take-off angle however, in far field, will further determine efficiency. Low Antenna (input/feed point) impedance matching networks may additionally add losses to the overall system.

Depending on the planned radio communication application of such a vehicular HF-antenna system there is a need for short or long-distance communications.

Short wave propagation, via the ionosphere, acting like conductive mirror. At higher altitudes there are a several geographical, local, and time-dependent ionized gas layer effects with signal mirror propagation forward relaxions back down to earth. These propagation modes are used for wanted long- or short-range communications. Propagation is solar cycle, season and day/nighttime affected. The sun/solar activities initiate ionization.

The maximum usable frequency (MUF) is high at daytime and drops at dusk. Consequently, there are at night often only the lower bands e.g., 1.8/3.5/7 MHz left for effective communications. Unfortunately, right here we have **low antenna efficiency** (ca. **160m 1%, 80m 5%, 40m 15%**) based one short radiator length vs. wavelength and system losses. The ionized, conducting E, F1 and F2 ionospheric layers (less than 100 to 700km high), acting as "spherical mirror" around the earth, reflect incoming transmitted HF signal to far destinations (e.g., 100km to > 1000km) or even closer areas (NVIS: near vertical incidence sky-wave, mostly from vertical mag. loops) [8], [9]. The vertical elevation take-off angle of the antenna (radiation pattern [10] e.g., DX ca. 40 deg, NVIS ca. 80 deg.) and any capacitive impact by e.g., soil/ground under the car or possibly tires [11] can be important. We have shown tires do not affect antenna efficiency in the low bands by losses. However, their added capacitance to ground detunes the resonance of an overall antenna system Fig. 1. Care must be taken to maximize the upper pace capacitance of the vertical rod. The lower areas are rather not radiating and ineffective stray capacitance -near field- effects.

It goes without saying a suitable **far-field test site**, for such HF vehicular antenna systems, **is very big**. Mostly frequency bands above 3MHz are used to communicate. To get into the 80m (3.5MHz) wavelength far-field region, for a full-blown dipole, where the antenna pattern is completely developed, it takes a distance of at least 3 to 4 wavelengths**. No EMC anechoic test chamber** or Antenna Test Chamber **is therefore big enough**. Aircrafts and drones were not available to us. Therefore, we used **ground-wave tests, sky-wave, ionospheric tests** (WSPR) and complex automotive **computer code simulations**.

For the efficiency critical low bands of the shortwave spectrum (around 1.8/3.5/7 MHz) we first mostly measured **Ant.-Efficiency over 2.8 km flat farmland** with **Ground-Wave**. This includes comparing prototypes and commercially available antenna systems. In this test no antenna elevation radiation diagram can be measured. Detailed measurements of the dielectric soil properties could also not be done. The soil may not have always have constant properties (typically epsilon 13, sigma 0.005 S/m, our rich farmland). We used overall mostly 2.8 km/1.2km free farmland test distance.

Repeatability was ca. +/-1 dB to 2 dB, under same seasonal weather conditions from day to day. Each time a reference test was performed first, and other antennas compared to this. The absolute antenna efficiency was deduced form simulations (REF.-Ant). All result compared reasonably well.

Ground-Wave was followed by **Sky-Wave testing** with efficiency estimates from extended HF ionospheric propagation experiments and statistics in the EU. In all these tests the key factors are our **self-designed Reference Antennas (160**/80/40m**)** for the, to be tested, frequency range. Care must be taken here to also monitor EU - lightning/thunderstorm effects (www.blitzortung.de). Best time was often around noon on 40m. No near aircraft backscatter (QSB) was noted.

Our prototypes of low loss, vertical, resonant **reference antenna-systems 1.8 /3.5/ 7 MHz** allowed detailed, **absolute efficiency simulations**. [Fig. 2] shows a reference antenna for 1.8 MHz (Q, unloaded coil ca.1000) on a saltwater beach in Denmark/ Romo Island. This environment has close to ideal "metallic ground" properties.

For further details of experiments/simulations, refer to [Fig. 3] to [Fig. 13] and under selected viewgraphs.

In the **ionospheric tests** we used a widely, globally distributed, digital SDR receiver/ antenna beacon network. This network reports, via internet, received/decoded identification/call-signs of a HF transmitting mobile or sometimes also a HF fixed reference station. The relative result, in the spectrum band of interest, is a signal noise ratio (SNR) in dB values between the two antennas. A histogram in numbers of reported beacons vs. SNR is given. Since there are many simultaneously receiving beacons in the EU, this leads to a mean / standard deviation comparison of two antennas, e.g., **averaged over hours**. This procedure somehow minimizes variations by unavoidable fading and propagation changes. The worldwide **WSPR (Weak Signal Propagation Reporter)** beacon system network was first developed (2008), for Amateur Radio use, by **Prof. Dr. Joe H. Taylor**. He has the US-FCC Amateur Radio Call sign K1JT and received, in his professional career, the Nobel Prize in Physics-Astronomy, 1993.

Our research shows clearly such complex experiments must be supplemented by experimentally **validated simulations** (e.g., for reference antennas) to be sure the trend and the in-situ antenna efficiency on the HF low bands are about right. The changing ionosphere status and the corresponding radio propagation, with strong fading effects (up to over 20dB), need to be analyzed very carefully.

Estimating the accuracy of our simulation was done e.g., **comparing to Near Field (H) measurement data around the Audi A6** on a wide spaced, object-free parking lot. Fig. 14 shows the very good agreement for H fields. The exact dielectric soil characteristic could not be measured. Furthermore, considering our simple H field sensor system, with about +/-1.5 dB measurement uncertainty, this is excellent agreement between test and simulation data.

E-field testing is far more sensitive [12], [13] to externally impacting factors. These may be reflections from the ground (soil) /car surface and the presents of a human body (dielectric) testing personnel holding the sensor.

Keep in mind: Experiment and EM-Simulation need to reasonably agree to be confident! This is many times a challenge on both sides. However, Fig. [15 to 18] show such good agreement.

Presentation Contents:

1. **Motivation, Background,** R&D **Project Goals**

2. **Principles of Testing Antenna Radiation Efficiency**

3. **State of the Art in HAM** and Commercial **ESA** (Electrically Small Antenna)

4. Some Basic **EM-Theory of ESA** (Verticals, Loops)

5. **Complex Simulation Model** (Car, Tires, ESA, Soil, etc.)

   5.a) 160/80/40m ESA Reference Antennas for Simulation and Testing

   5.b) Absolute "Gain" comparison with predictable Reference Antennas (by EM-Simulations)

6. **Experimental** Radiation Efficiency, **Comparing Antennas**
7. Antenna efficiency **impacting factors** (e.g., soil on low bands, elevation angle)
8. **Conclusions**, incl. lessons learned for restricted space antenna locations, HOA, and QTH/p

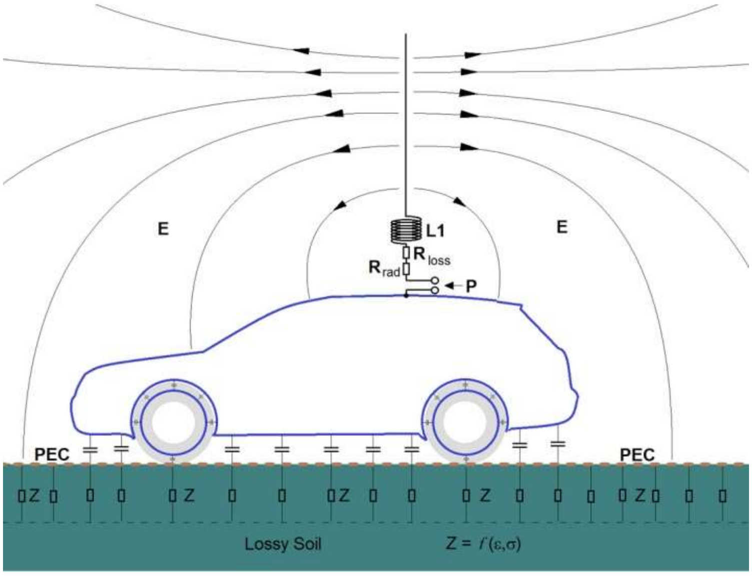
9. **Project outlook** (future R&D topics), **Literature**

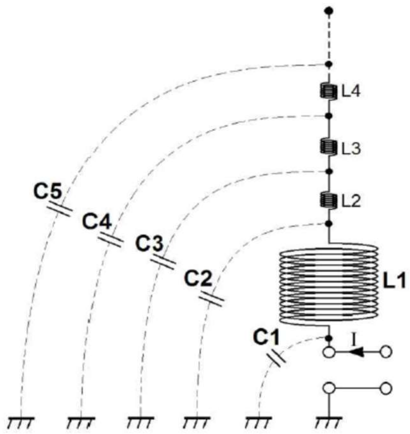
Selected Viewgraphs and Fig. Descriptions

With a validated, trusted model (background realistic equivalent circuit see Fig.1, whip antennas are presently mostly in use in this field for civilian applications) one can quickly and cost effectively run simulated parameter studies. At P the input TX power to the antenna is applied vs. the metallic car chassis. L1 is the resonating inductance, compensating the stray capacitance of the vertical radiator rod. A capacitive top loading may be added to reduce losses (less inductance, higher radiation resistance). Conjugate impedance matching at the feed point is important to get the maximum accepted power into the antenna.

Fig.1 Equivalent Circuit Model for an el. short, transmitting, vertical Monopole Antenna (no top loading, E-Field simplified, PEC: perfectly conducting ground, stray capacitances visualized)

Stray capacitance at the start of antenna is less effective for radiation and should therefore be minimized e.g., by moving the coil higher. That also increases radiation resistance/efficiency. The inductance (L_n) compensates the rod capacitance (C_n). We get resonance. This monopole antenna is excited against the metallic car body. The TX is inside the car. Ideally a low loss 50 Ohm impedance matching circuit is installed on the roof. By properly bonding the feeding coaxial cable, when leaving the passenger compartment, a good "inside" shielding effectiveness is maintained e.g., for the low bands.





The losses occur predominately in the real ground/soil. PEC means Zero loss over a perfectly conducting, large metal plate. In practice saltwater comes close. There is additionally coil loss resistance (CU-losses + skin effect + inter-winding proximity effect). Electrically small antennas (low band) exhibit a very small radiation resistance of may be less than 1 ohm. For better efficiency we like to make this value as high as possible. Various procedures will be discussed.

One ground/soil position example is given in Fig.2. Audi A6 Avant test car with 160m Monopole on a saltwater beach.

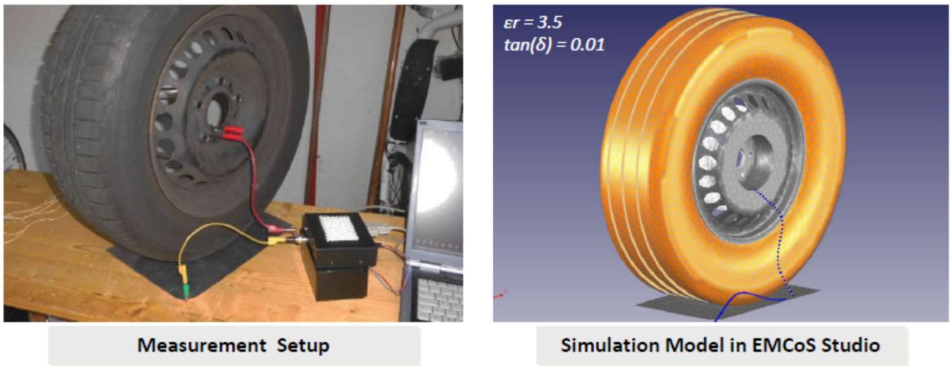
The coupling to the ground is primarily important on the low bands. This affects capacitance between car body/chassis and ground. In case of a real ground/soil a frequency dependent dielectric epsilon and conductivity sigma comes into play.

Fig.2 **Audi A6 test car with 1.8 MHz / 160m** R&D Antenna (3.5m long radiator, large Hi-Q coil, 1m diameter top load) Monopole on a saltwater beach. This is only a stationary, experimental reference antenna.

Fig. 3 shows the individually measured and simulated capacitance of a BMW tire (like Audi).

Part I: Validation of Wheel Model

BMW 316i Individual Tire/ Rim Capacitance Tests (Model 1)



Model BMW 316i Wheel (Metal Sheet 35 cm x 25 cm)	Capacitance
Measurements	53 pF
Simulations (without test leads)	57.7 pF
Simulations (with test leads)	58.5 pF

Measurements were provided by EES Dr. Hansen Consulting

Measurements were taken with a Vector Network Analyzer and a 1 kHz low frequency capacitance bridge (not shown). Losses up to 7/10 MHz are minor.

Fig. 4 demonstrates the car body + tire capacitance (basically lossless up to 10MHz). This capacitance is an important element in the near field coupling HF-current return path of the antenna through soil / ground. These values are to our knowledge not publishes elsewhere, doing a systematic investigation. Audi A6 Avant over metal plane (PEC) with/out tires: tires about 400pF, car body about 600pF

Fig.4 Measurement and simulation results car body with/out tires

Part II: Audi A6 Avant Capacitance Tests

Comparison of Simulation and Measurement Results

Audi A6 Avant (Ground Plane 3.5 m x 7 m)	Capacitance
Measurements (car body/ rim/ break disk/ tire)	900 pF – 1000 pF
Simulations (car body/ rim/ break disk)	613 pF
Simulations (car body/ rim/ break disk/ tire)	1023 pF

- *Intel Xeon CPU L5640 @ 2.27 GHz (12 cores)*
- *Calculation time ~20 min*

Measurements were provided by EES Dr. Hansen Consulting

Note:

Characteristics, geometric parameters and internal structure of the tires play important role in the capacitance simulation. Slight changes will have an impact.

Fig.5 shows the charge density concentation in the static model at the low part of the tires.

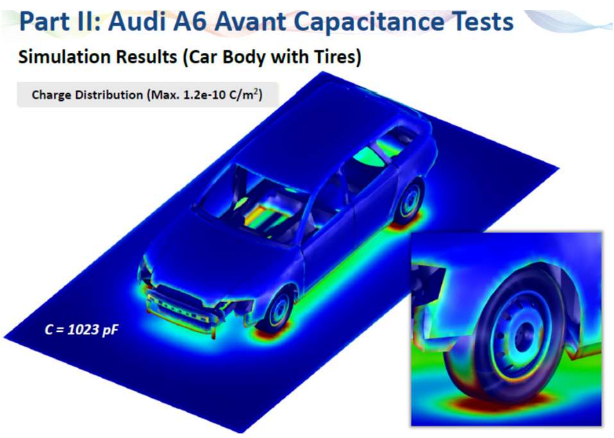


Fig.6 displays **Input Impedance test** and simulation result for **real ground (15/003)** of the **Reference R&D 80m XL antenna** (1.88m radiator/ Top Load 1m diam.) Results of Test and Simulation are very close.

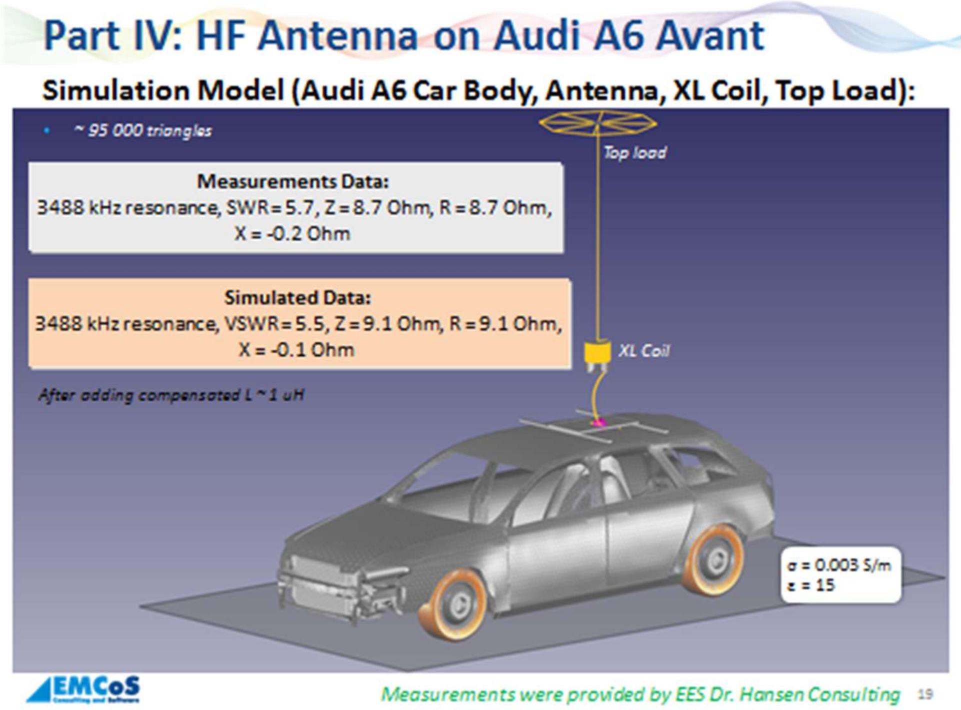


Fig.7 Audi A6 over real ground (poor 0.001S/m, Epsilon 5), FYI: avg. 0.05/13, very good 0.03/20, sea water5/80. Aside from **XL 80m**, all other Reference Antennas 160/40m were simulated.

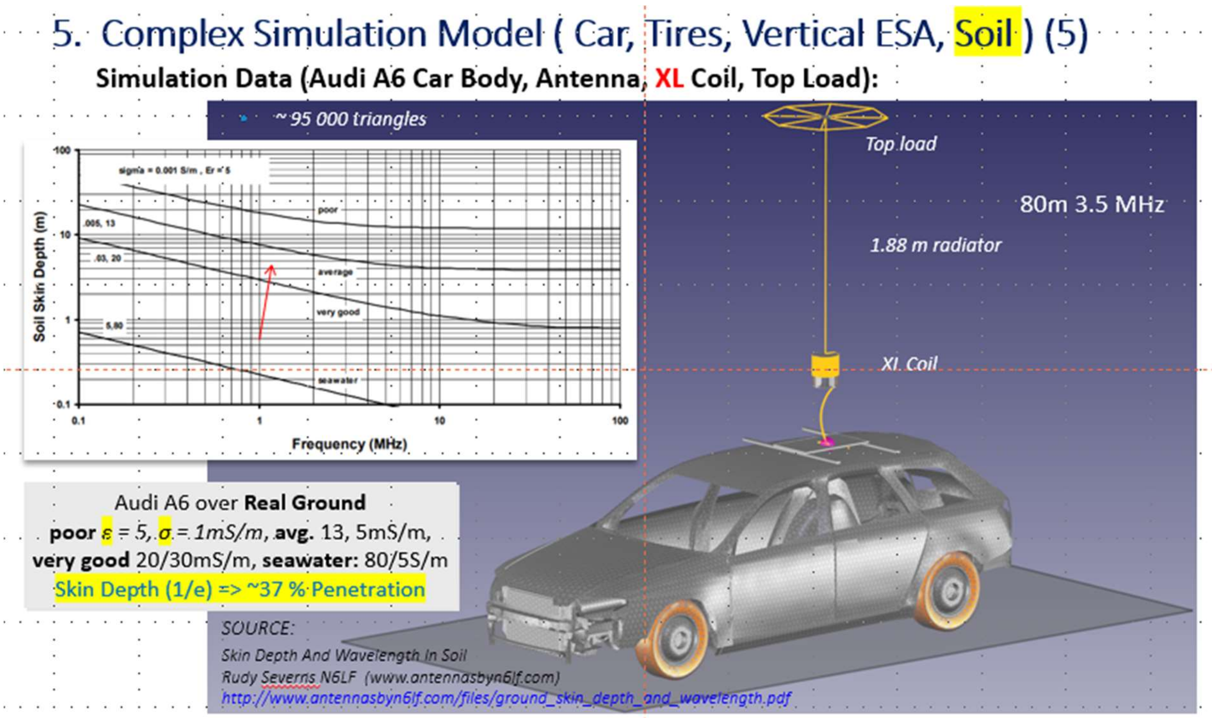


Fig.8 shows simulated Reference Antenna XL Data, **80m** Ant.-efficiency in [dB] for various grounds and Elevation-Angles. **Max. performance difference is approximately 14dB, a major variation/loss contribution.**

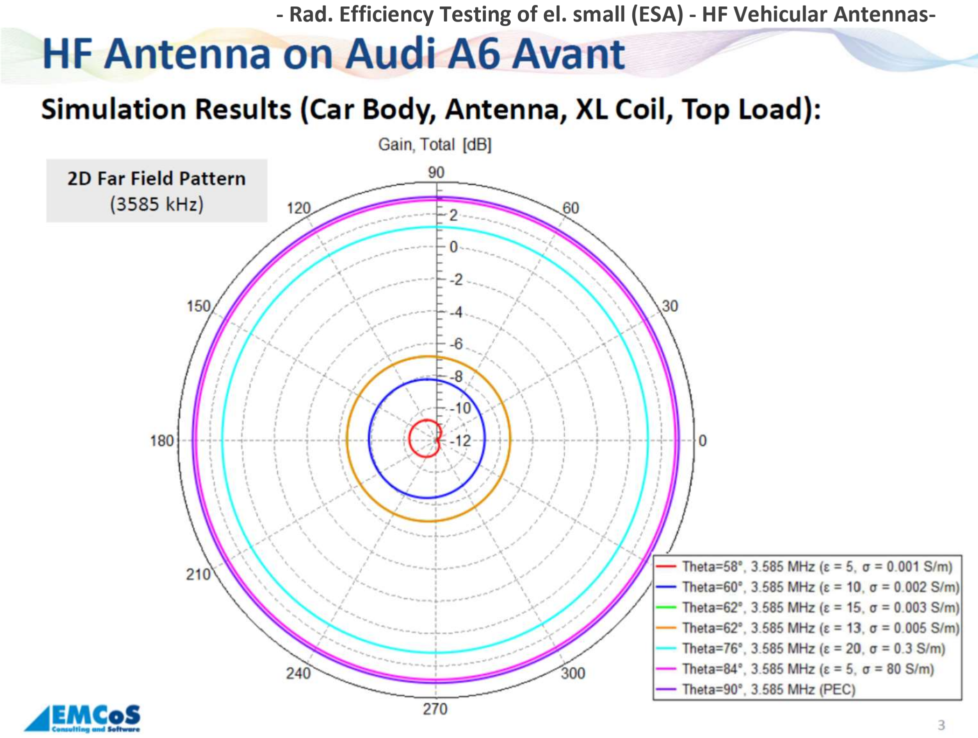
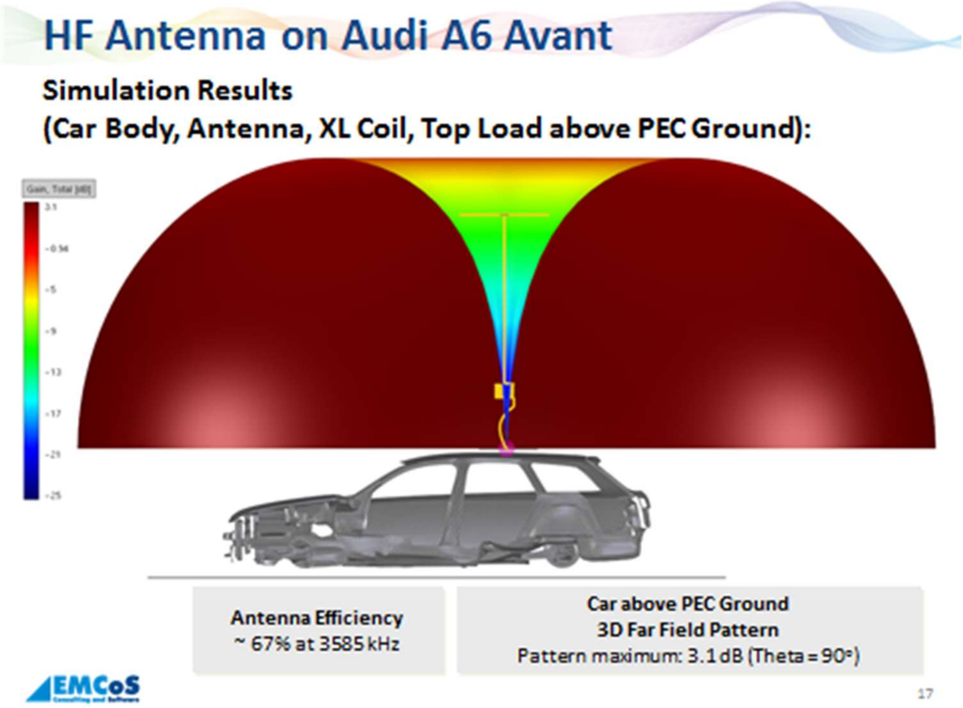


Fig.9 displays simulated **80m XL** Ant.-Efficiency in [dB] **<u>for PEC Ground</u>** and max., flat 0deg. Elevation. Tires do not really contribute to efficiency but change system resonance.



Best case <u>over metal ground plane</u> for short, resonated **80m** XL Reference Ant. (eff. =**67%**!)

With flat take-off angle, ideal for DX. Small low loss antennas can be effective.

Fig.10 presents **6.5% (80m) Efficiency** for (90-62=>38 deg. Elevation), **<u>rich Farmland Ground</u>**.
Sky-Wave tests indicate approx., in 900 km distance, *<u>6%</u>* (-12.2 dB mean, std. dev.3.8dB),
Ground-Wave tests show *<u>2 to3 %</u>*.

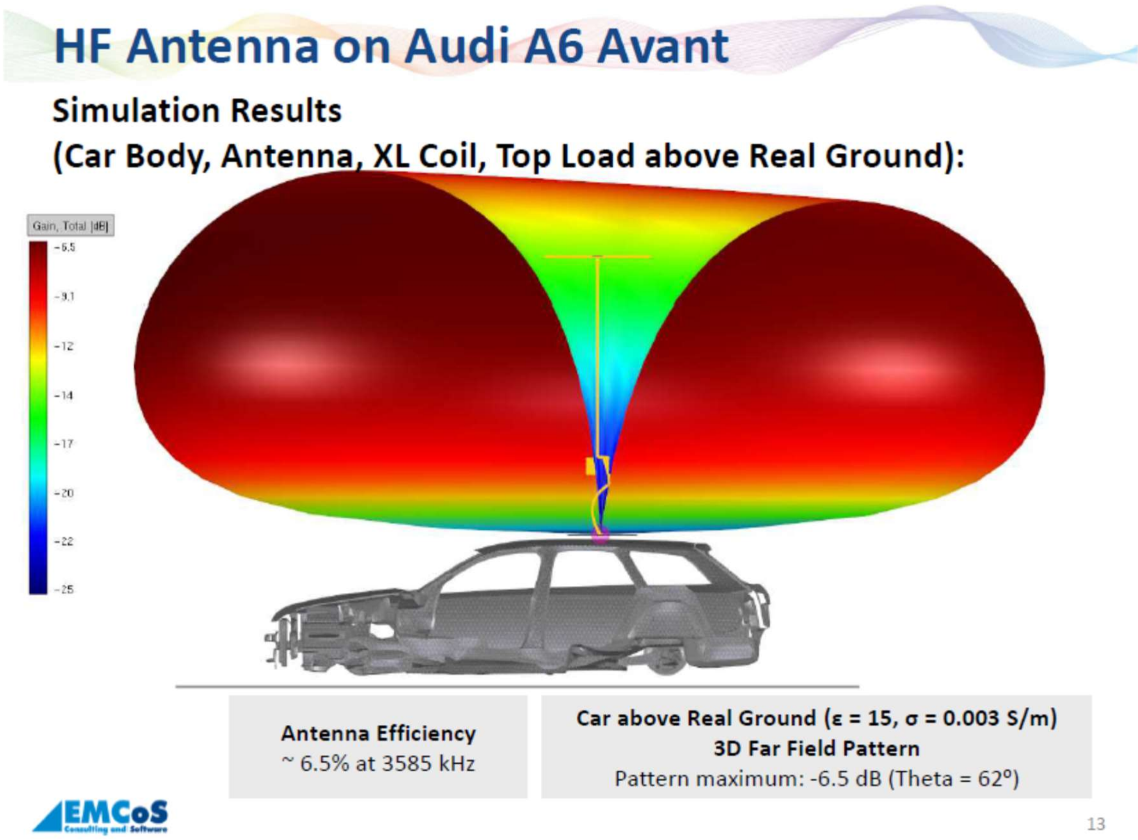


Fig.11 shows 2.4 % (80m, simulated) efficiency for (90-58=>32 deg. elevation), over more lossy Road Soil (**5/0.001**)

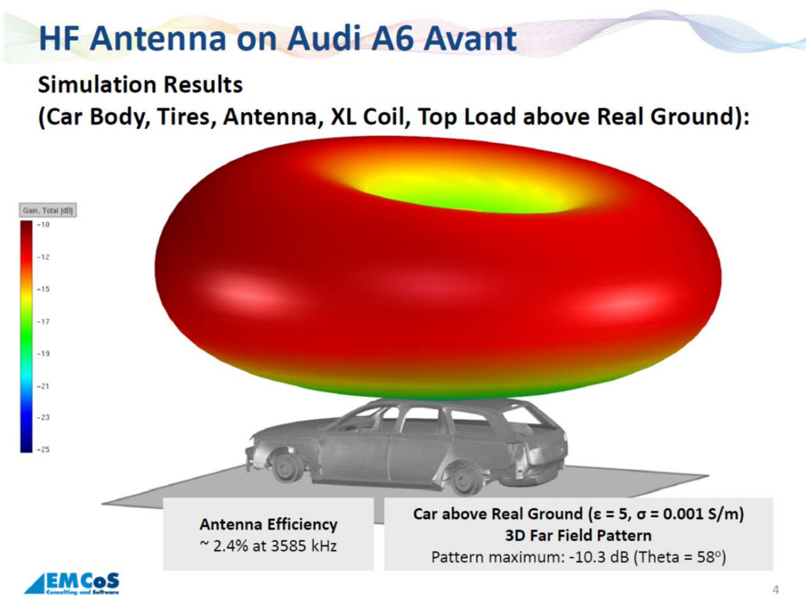


Fig.12 Antenna with **"lower antenna height/profile"**, resonated around **3.5 MHz**; we are now looking for different antenna principles (Near Field is E dominant).

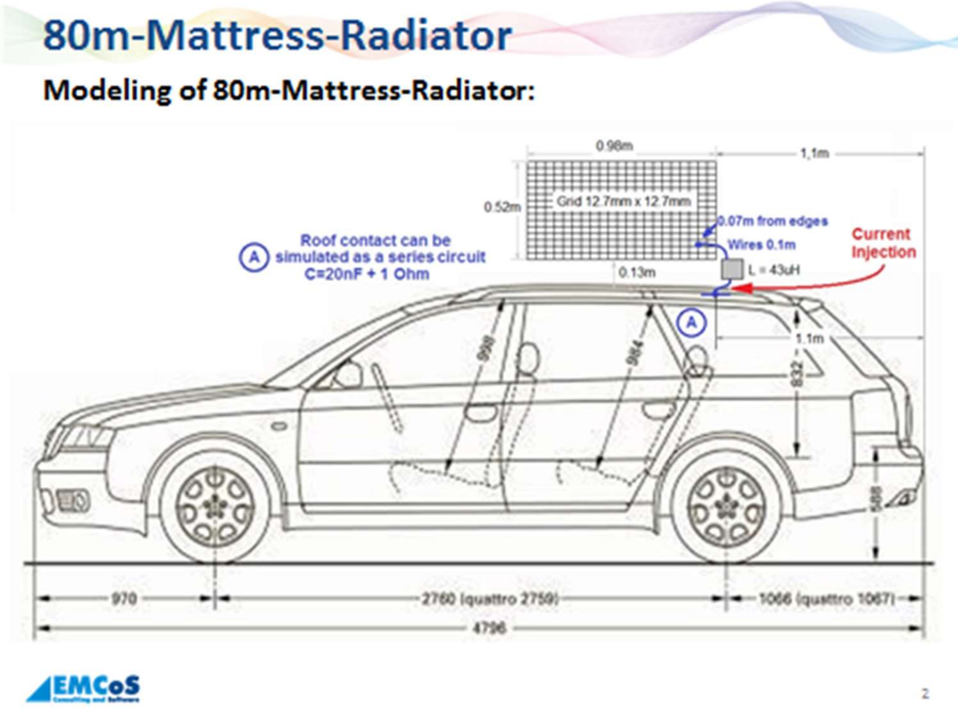
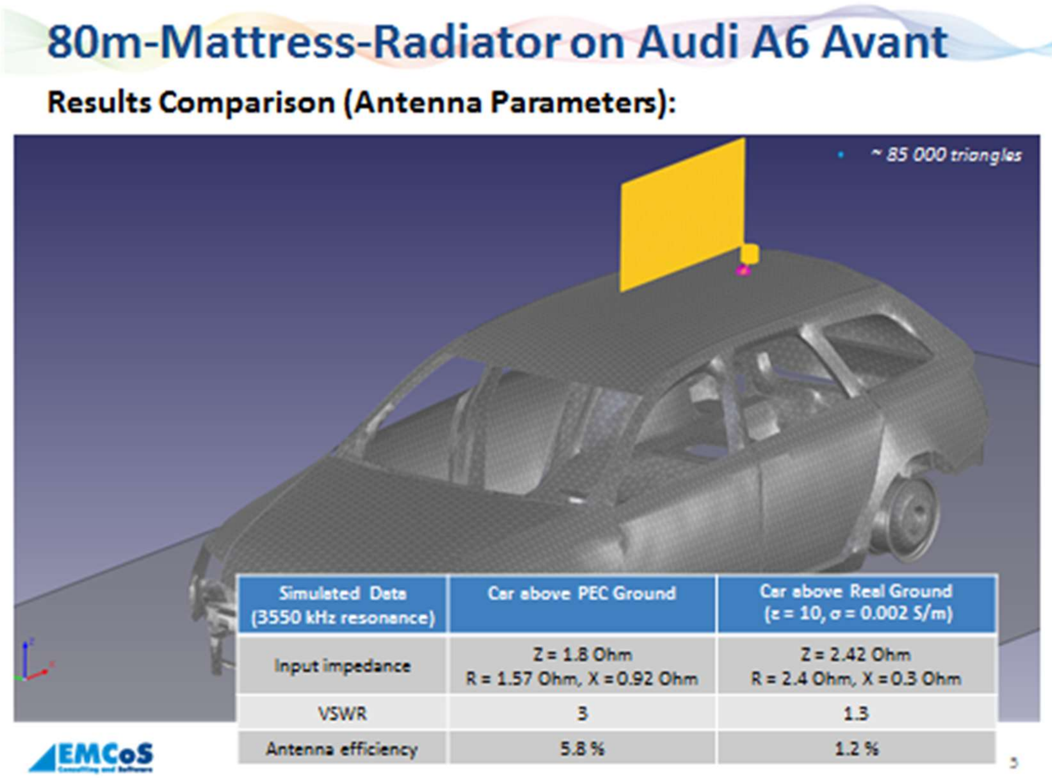


Fig.13 **Simulation** of Ant. Efficiency with lower eff. antenna height (<u>over PEC, real ground</u>) –



Simulated Data (3550 kHz resonance)	Car above PEC Ground	Car above Real Ground (ε = 10, σ = 0.002 S/m)
Input impedance	Z = 1.8 Ohm R = 1.57 Ohm, X = 0.92 Ohm	Z = 2.42 Ohm R = 2.4 Ohm, X = 0.3 Ohm
VSWR	3	1.3
Antenna efficiency	5.8 %	1.2 %

80m Efficiency ca. 1.0% (-20dB Gain) simulated, Ground-Wave tested vs. Ref. Ant. (80m XL set to 0 dB=6.5% Efficiency => ca. -12dB). Mesh Ant. experiment shows =>-12dB below XL, therefore -24dB Gain (**4 IARU S-Units down from full GP/Dipole**)

This antenna is practical but misses more radiation effective antenna height to load space capacitance for Far-Field.

Fig. 14 **Near-Field (mag. H-Field) around the Audi** A6, on an asphalted parking lot, at **3585 kHz** / Refereence Ant (XL 80m) shows **very good agreement between measurement and simulation**. The measurement uncertainty of the sensor instrument is about +/-1.5 dB. This indicates valid simulation results. <u>This proves generally the suitability of the model and the computer code used</u>.

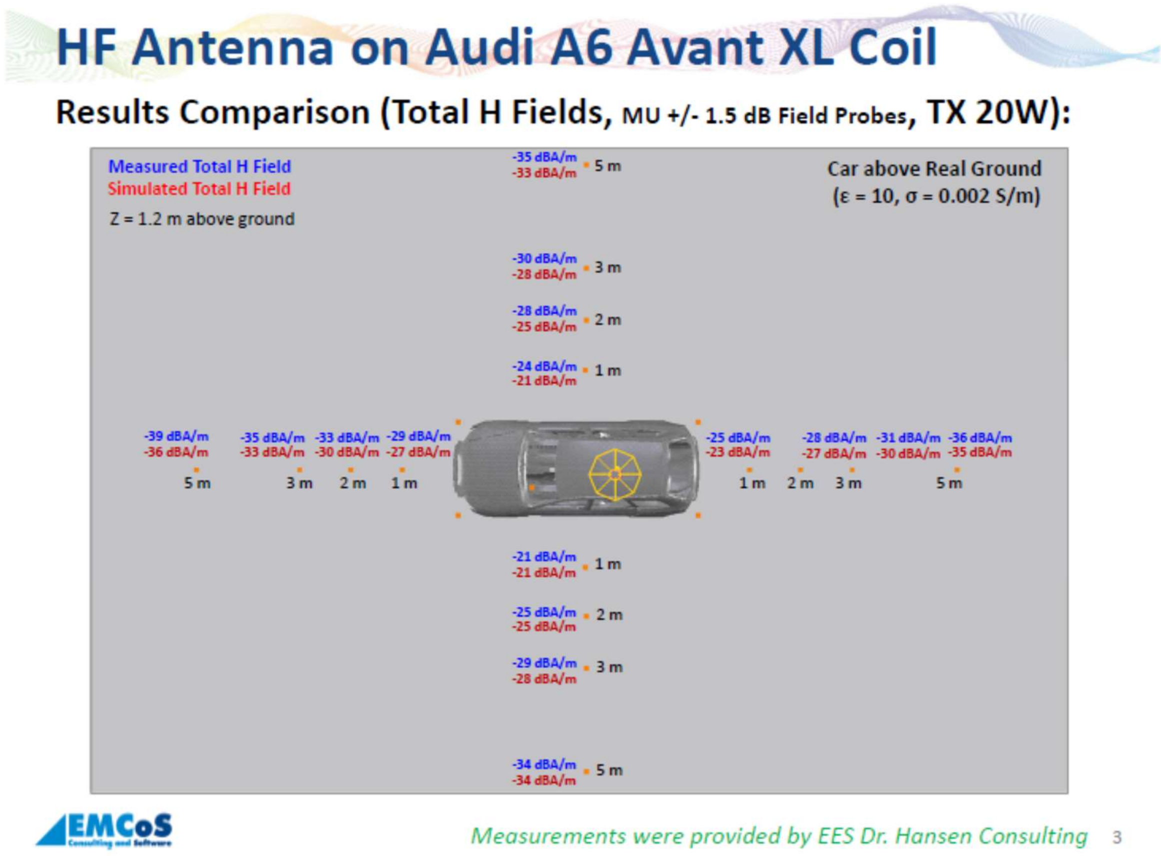


Fig.15 **Measured and simulated Reference Antennas**

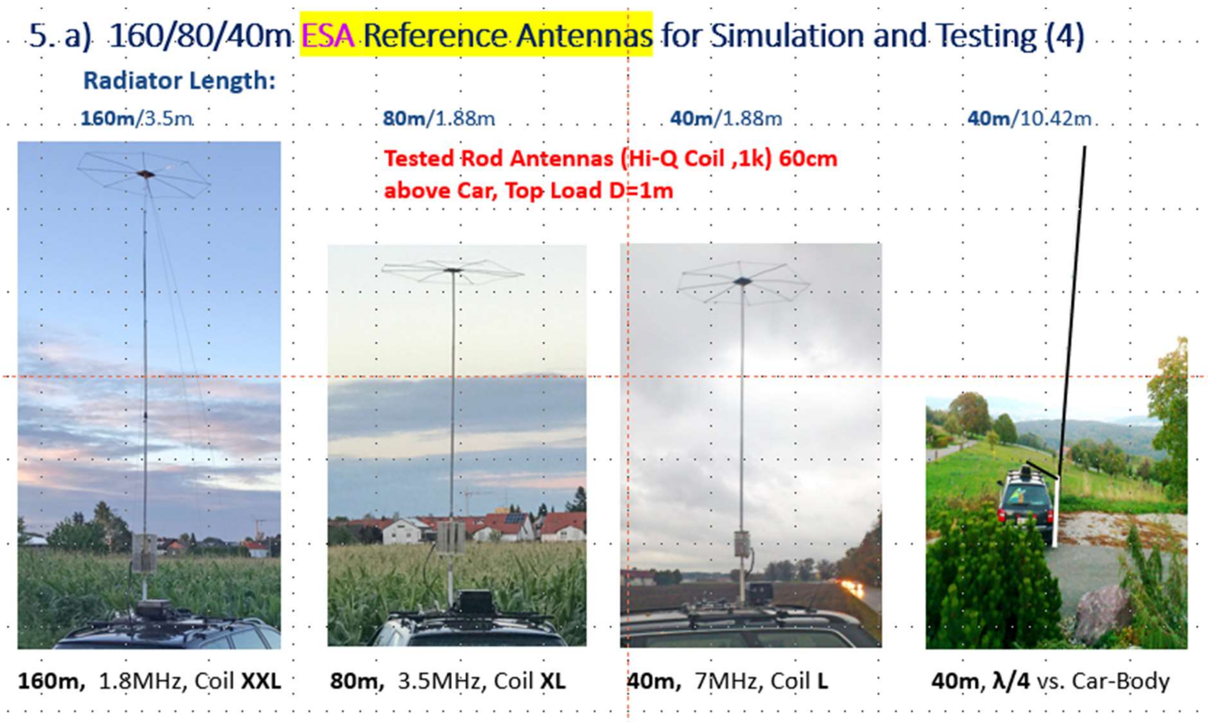


Fig. 16 **80m with/without Tires <u>only 0.2dB difference</u>**

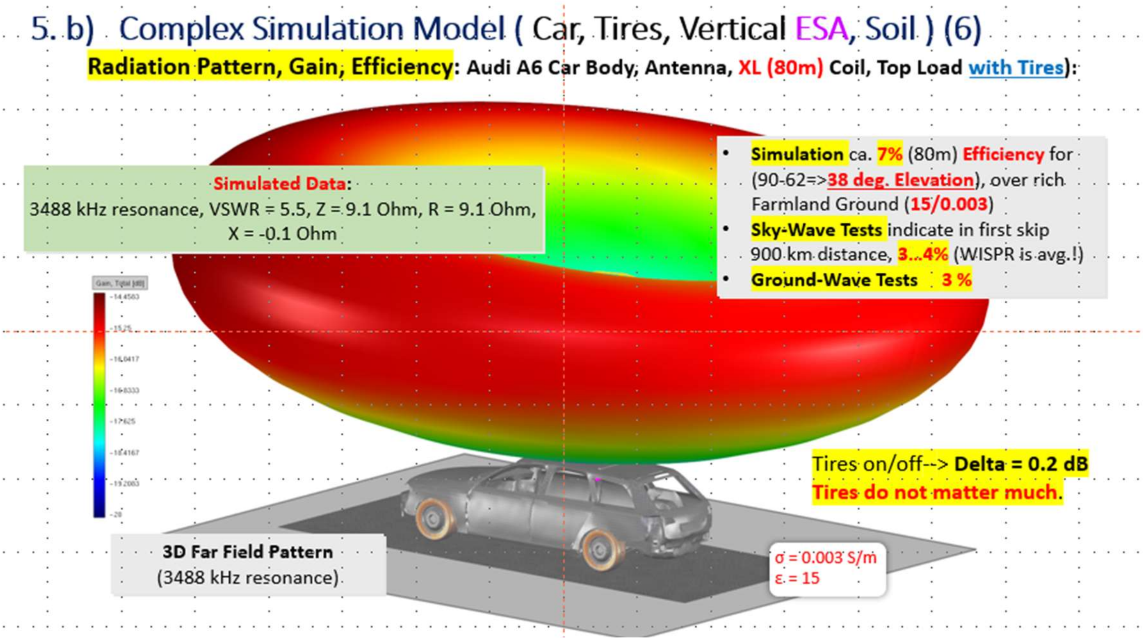


Fig. 17 Measured test result 80m in comparison to Ref. XL Antenna + simulated efficiency XL

6. Experimental Radiation Efficiency Antenna Comparison (6)

80m Groundwave Test over 2.74 km flat farmland

Groundwave small HF-mobile Antenna-Comparison-Tests (HB9CVQ and group 2017 to 2019)

	Ant. Name/Type	Test Result in **[dB]** -with manual low loss tuner used- **6dB=1 S-Unit** (IARU)	Photo # HB9CVQ QRZ.com	Comment Status: 07-April-2021
80m	**XL** EM-Simulated Reference-homemade	**0 dB (Reference)** ~ **6.5%** efficiency simul. (15/0.03)	7	1.88m rod+1m cap head, Hi-Q coil 60cm up
	6.5m Whip	0	9	With elevated loading coil
	Conical cage radiator	-1	6	With elevated loading coil
	Tarheel 200 HP (USA)	-2	-	Large Screwdriver
	Hustler 400W (USA)	-3	10	Resonant whip center loaded
	Stealth Telecom 9360	-8	8	Vertical 2.5m

Groundwave small HF-mobile Antenna-Comparison-Tests (HB9CVQ and group 2017 to 2019)

	Ant. Name/Type	Test Result in **[dB]** -with manual low loss tuner used- **6dB=1 S-Unit** (IARU)	Photo # HB9CVQ QRZ.com	Comment Status: 07-April-2021
80m	DJ0HV experimental	-9	11	2.3m screwdriver
	Ranger-80 (EA-land)	-10	-	Light weight, 1.6m, base loaded PL monoband
	Vertical wire mesh	-12	5	On top of car roof
	HF-MB01 Helical (YB-land, max 130W)	-13	-	3.75 to 30MHz, PL multi-band, 1.95m
	1m rod forced 50Ohm input	-56	13	broadband test antenna

R&D XL 80m, 0dB is 6.5% absolute efficiency, corresponding to ca. -12 dB Gain

Fig.18 Efficiency impacting factor

7. Antenna Efficiency impacting factors

What makes a more effective ESA System (160/80/40m), aside from **good HF-Propagation**

some interesting spot checks

Measured Far-Field-Antenna Gain (1,2 km, average soil, via GRW, **on 160/80/40m**):

- **Top Loading** (1m diam.) on DL and 1.88m Radiator, no coil => **+9dB**
- **Top Loading** (1m diam.) **and resonance Hi-Q Coil** and 1.88m Radiator => **+36dB**
- **Doubling radiator length** from 0.5m to 1m and 2m => **+10dB** each time
- 1m radiator length and **Stray Cap. increased** (d = 2mm (20pF) to d = 7.5cm (40pF) => **+ 8dB**
- 1m radiator length (d=2mm) **with/or without distributed 42 Ohm resistance +/-0dB**
- **ATAS 120 (40m, l =1.6m) with 1m added radiator length => +2dB**
- **160m mag. Half loop vs. XXL R&D Reference (3.5m, Top load) = - 12 dB** (very lossy, but NVIS)
- **160m L (open Loop) vs. XXL R&D Reference (3.5m, Top Load) = - 6 dB**

- **Generally: (remember to operate QRP-conform in QSOs…listen…listen…listen !)**
  good Soil, radiator length/height vs. quarter wavelength, free Location/good take-off angle, large coils radiate, minimize Dead Cap, optimize Space Cap. , min. Tuner losses, Car RFI de-noising, min. secondary radiator coupling, favorable antenna pattern for DX/NVIS

DL = Dummy Load 50 Ohm. Always minimize any antenna stray capacitance to metal car chassis.
Feed the radiation effective (typ. 30% down from top @ ca.2m long rod) upper capacitance.

Fig. 19 Concluding Remarks

Remember: **www.qrz.com/db/HB9CVQ** **(under "breaking news" much more technical details/tests)**

8. Conclusions

Feasible Antenna Radiation Efficiency : **Mono-Pole-ESA** typ. **40 deg** Take off Angle, **160m ca. 1% – 80m ca. 5% – 40m ca. 15% (soil dependent)**

One central problem is the limited size (car) ground plane ....presently large Tarheel 200A HP (80 to 10m) is a good compromise...

- We analyzed **physics** of el. small, **vehicular HF- Antennas** (ESA whips and some ESA loops)
- There is **no " black magic"**, not even in the low bands (160m-1.8MHz/80m-3.5 MHz/40m-7MHz)
- These HAM-Bands are also **representative for** neighboring **Commercial-Bands**
- Test Methods => **Ground-Wave**, **Sky-Wave** Experiments and **Simulations** to get to **Ant. Efficiency %**
- **Study** of different **% impacting Parameters** (Dead Cap., Tires, Soil, Elevation Angle, System Losses …)
- We built, tested and simulated **suitable Reference Antennas** for Ant. Performance Comparisons
- There is **reasonably good Correlation between** our **various Ant. Efficiency Analysis Methods**
- Establishment of "**Performance Ranking List**" between Commercial/Proto-Type Antennas
- In many **restricted space QTHs** it is better to use magnetic Loop Antennas (H-Field penetrates walls better)
- Our **Final Goal**: Create a well performing proto-type **HF-Ant. for (long *and* short)-haul Communications**

Literature:

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German Abstract: **Wirkungsgrad-Messungen an elektrisch kurzen KW-Mobil-Antennen** (siehe auch www.qrz.com/db/HB9CVQ)

Solche Antennen werden bei HAM-Radio, Emergency Comm. / Krisenfunk, NGOs, speziellen staatlichen Funkdiensten und beim Militär eingesetzt. Unsere F&E-Erkenntnisse können auch auf portablen Funk und Situationen mit Antennenbeschränkungen angewendet werden. Es wurde z.T. die AFU/Profi-Literatur/Papers/Fachbücher von ca. ab 1920 analysiert. Vieles bleibt hier immer noch unklar. Klassifizierte Doku ist uns nicht zugänglich, jedoch die meisten Patente. Eigene Teilzeit-Forschung ,7-Jährige, war somit nötig. Es werden die physikalischen Wirkmechanismen vornehmlich von elektrisch kurzen Stabantennen (160/80/40m) auf einem KFZ analysiert. Das Antennen-System (kapazitives Nahfeld, Stabantenne) muss gesamthaft, in seiner Wechselwirkung mit dem Erdboden, und dem Antennen-Gegengewicht des Autos, hier PKW unter 5m Länge, betrachtet werden. Der verlustbehaftete Erdboden unter dem KFZ bestimmt wesentlich die Abstrahlungs-Effizienz und den Abstrahlwinkel (typ. 40 Grad über Durchschnittsboden). Salzwasserstrand erhöht den Wirkungsgrad wesentlich, teilweise auf fast 50%. Durch die gesetzliche Vorgabe, bei KFZ-Fahrbetrieb, mit der Antennenhöhe (Boden/Spitze) von max. 4m (sehr klein vgl. mit Wellenlänge) haben die «Low Band Ant.», selbst wenn Wirkungsgrad optimiert, typ. nur max. **160m 1%** ->100W out -> 1W abgestrahlt -> QRPP-, **80m 5%** und **40m 15%.** Die Wirkungsgrad-Bestimmung am angepassten Antennenfusspunkt (Strahlungswiderstand <1Ohm z.B. zu gesamten Verlustwiderstand z.B. 12 Ohm => Wirkungsgrad 8%) ist unzureichend und muss mit optimalem Erhebungswinkel und Fernfeld-Abstrahlungsleistung-Daten korrigiert werden. Der Übergang Nah/Fern-Feld tritt ggf. erst in mehreren Wellenlängen Abstand auf. Hier erst -ideal im Freiraum- bildet sich über Phasenbedingungen das wahre Strahlungsdiagramm des Systems aus. Kleine (mag.) Schleifenantennen haben einen noch kleineren Strahlungswiderstand (z.B. 50 milli-Ohm, 90cm Loop, 40m). Hierbei ist ggf. aber Steilstrahlung mit z.B. 80 Grad Erhebungswinkel möglich. Abstrahlungs-Wirkungsgrad-Messungen/Abschätzungen können, nach unserer Forschung über Bodenwelle/ Raumwelle-Ionosphäre (viele schwer kontrollierbare Einflüsse) gemacht werden. Am besten wären speziellen Drohnen/Flugzeugen mit x-y-z H-Feld-Sensoren, im Fern-Feld. Reale Kommunikation findet später über weiterer Distanz (z.B. DX) oder mit Steilstrahlung (NVIS z.B. aus tiefen Bergtälern) statt. Die Ionosphäre der Standort und die Tageszeit legen die MUF (max. mögliche Strecken-Übertragungsfrequenz) fest. Zur Nacht sink diese oft bis auf 160/80m ab. Es werden kurz die Ant- Theorie/ Messungen sowie durchgeführte Computer-Simulationsberechnungen (Profi-MOM) für 160/80/40m Referenzantennen vorgestellt. Dann folgen Bodenwellen Vergleichsmessungen mit absoluter Referenz und kommerziellen Antennen. Hierbei stehen hauptsächlich kurze, resonante Vertikal-Ant. Im Focus. Die wesentlichen Einflussfaktoren auf den Wirkungsgrad wurden experimentell ermittelt. Es folgt eine Zusammenfassung mit Projektausblich und weiteren, zu untersuchenden Forschungsthemen.

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