Measuring **Radiation-Efficiency** of electrically **small**, automotive-on the move, short-wave **(HF) antennas**, including lessons learned for **restricted space antenna (160/80/40m)** optimization.

Dr.-Ing. Diethard (Andy) Hansen (Ph.D.) HB9CVQ, DK2VQ, AK4IG

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

- **This R&D was performed mainly between 2015 to 2022 with a strong link to HAM RADIO applications.**
- **Sponsor Experiments:** www.euro-emc-service.com (author's company)
- **Sponsor EM-Simulations:** www.emcos.com , specialist **Ilona Danelyan**, EMCoS LLC, Tbilisi, Georgia
  (Joint 5h Workshop at annual EMC Europe Symposium, Sept. 2019, Barcelona, Spain)
- Testing was supported:
  - in **DE** by: Christoph Schumacher DL7SAQ , Enzo Cardarelli DJ0HV, Dennis Willigmann DB6BD
  - in **CH** by: Remo Reichlin HB9TPR and Reto Voser HB9TPX
- We used mostly **calibrated**, traceable **Low Budget Test Equipment**

Bio

- Dr.- Ing. (Ph.D) Diethard E. A. (**Andy**) Hansen
- **Professional** (international EMC Consulting Expert)
- **40/32 years** of professional **EMC** experience (Consultant/registered EU-Auditor/INARTE-US) in **Electromagnetic** (EM) **Disturbance and Interference Control in Electronics**, incl. commercial/ government/military installations/equipment www.euro-emc-service.com . 160+ international technical papers/ 50+ patents are assigned to him. Auditor assessments: worldwide 400+ Test-Labs, incl. EU-D EMC, RTTE/RED and Automotive; since over 30 years active in international Electromagnetic (EMC/Radio/Automotive) standards/regulations. Senior iNARTE US certified EMC/PS Eng., since **2020 Life Senior Member IEEE EMC Society (USA)**
- **55 years HAM RADIO** (**HB9CVQ** (1983), DK2VQ (**1968**), AK4IG (2011), www.qrz.com/db/hb9cvq
- Since 2000 basically only QRV on HF: **160 to 10/6m in CW and SSB**. 2x36m @24m Doublet, SteppIR DB18E with 2 el. on 40m and 3el. 30m to 10m @19m, max 1 kW output. “Rag-Chewing”, Contesting, Technical Experiments, …one **R&D focus** in the **last 7 years** was **HF-mobile Antennas** for on the move

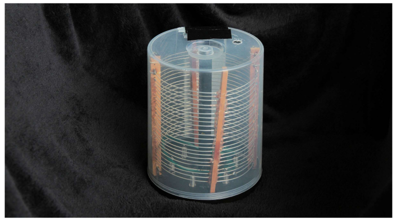
Bizarre HF – mobile Installations

Source: unknown, Internet, IT, US, DE ?

An amazing QRP/mobile real world Case Story (1)

No Antenna:
Street Light Mast

Audio: (DL7)SAQ kn ...**QSO handover**, response DL7SAQ de EA8/DF8KN...
About CW 559 signal RX copy at DL7SAQ near Munich



- CW DX QRP/m QSO on **20m** on **Easter 2014** (SFI ca. 100)
- **Canary Island** TX **EA8/DF8KN** **(ESA)** to **Germany** RX **DL7SAQ** (near Munich)
- Distance EA8 to DL ---> over 3000km
- TX Car 10W out to **<<<** **Ant. Size** (inefficient ESA, tuned L) => ERP? ca. **30mW EA8/DF8KN**
- RX DL7SAQ vertical halfwave dipole in EMI very quiet location
- What can we learn from this? **What is the underlying physics?**

Works as **Coupling Cap. (xx nF)=> ESA to Chassis**
- it is a rental car
- we can not drill in a car body roof connections!

Contents (1)

Contents (2)

1. Motivation, Background and Final R&D Project R&D Goal (1)

- **Feasibility** of an optimally efficient HF-mobile (on the go/not stationary) antenna (ESA Reference?)

- Most Road Safety Regulations **restrict,** max. permitted height for any automotive antenna:

  Ground to Ant. Tip: max**.** **4m**

- **Ultimate project goal**: (not yet fully achieved)

  Can we **combine** low (**DX**) and high angle **(NVIS**) radiation/elevation in one antenna?

- Potential **Benefits** for **HAM Radio** and Commercial **Community** ? Who needs these ESAs?

- **Future Application Relevance** under **E-Mobility** and **Satellite Sky-Internet** worldwide coverage?

1. Motivation, Background and Final R&D Project R&D Goal (2)

- Potential **Benefits** for **HAM Radio** and Commercial **Community** ? Who needs these ESAs?

  There are direct implications of our R&D, aside from Military/ Special-Forces/ Government, in mobile HAM RADIO and NGOs. **Humanitarian-medical-technical crisis-relief organizations**, with mission critical emergency communication needs, possibly in remote disaster areas, may also profit from our practical R&D.

- **Future Application Relevance** under **E-Mobility** and **Satellite Sky-Internet** worldwide coverage?
- **EMC Norms** for EU **E**lectrical **V**ehicles Type Approval do not yet include CISPR 36 (radiated emissions 150kHz to 30MHz) off-board RX,@ 10m CISPR 36-**2020** , on-board, @1m RX CISPR 25 **2021**, EU (UNECE Reg. 10) Vehicle Type approval Regulations automotive EMC **2019**
- **US Car Manufacturers step away from AM-Radio integration?** US FEMA Civil Defense: Important Emergency Communications tool !) OE5SLN/m Stefan Remote QRV HF
- **US Senator on continued AM-Radios in Evs** **Industry response April 2023 on AM radio in EVs**

2. State of the Art in HAM and Commercial ESA (1)

HAM ESA dating back to ca. **1950** (USA/EU) ...focus is here mostly on longer distance communications

- Whips, resonant Rods, **1957** Screwdriver / helically wound verticals
- **1968** US, 80m tuned car-loop / **1969** QRO 1.5kW, cap. Head (**1993** calculation of Top Load / Efficiency, Gain)
- Ca. **1970/80** BENELUX and Germany kW-QRO Tests with PL-TV-Sweep-Tubes, mainly on low bands
- 1977 to **1999**, adding WARC, Z_{in} matching optimization/automation, Base vs. Top loading
- ESA "shootout contests" (NF/Far-Field problems !?) 2002- **2017**, http://www.k0bg.com/
- Various Patents, may be now ca. 10 (**USA**, EU, **Asia, VK**) commercial manufactures
- **Almost no overall systematic/scientific analysis and controlled testing** except**:**

"Short antennas for Mobile Operation", **Dr. John. S. Belrose VE3BLW,** QST Sept. *Patter***1953**, pp- 30-35 (a very informative overview)

"Short Coil-Loaded HF Mobile Antennas, an Update and *Calculated Radiation"*, **Dr. John. S. Belrose**, Ottawa, Canada, The ARRL Antenna Compendium Vol.4, **1996**, ISBN 0-87259-491-2, pp. 83-91

"Actual *Measured Performance* of Short Loaded Antennas Part 1+2", **Barry A. Boothe**, USA, ARRL QEX, Magazine Jan./Feb (1). **2014**, pp. 34 – 42, March/April (2) **2014**, pp. 18 – 31

http://www.**ad5x**.com/images/Presentations/AD5XMobileOpsHintsandKinks.pdf (undated, probably **after 2005**)

2. State of the Art in HAM and Commercial ESA (2)

- **Commercial and military ESA** (electrically small antennas)

Commercial/Government HF-users mostly in remote, widespread countries,
e.g., Indian Police Forces, Coastal Border Control Radar, oceanographic surface wave monitoring,
technical, humanitarian, medical NGOs, disaster emergency operator-Many applications are for **NVIS.**
(3 to 10 MHz, daytime, up to 300-600 km, bridging Dead/Skip Zone)

Ph.D-Diss. Ben a. Witvliet, **2015** **University of Twente, NL,** Near Vertical Incidence Skywave - Interaction of Antenna and Propagation Mechanism [PhD Thesis]

Military HF Communications, vehicular platform installations **starting pre-WW II (DL)** and continue till today
Used in Special Forces, US-Marines, Army, Navy, Intelligence Organizations and for Stealth applications.
Most military applications are focused on **NVIS** (**Near vertical incidence skywave**), a shorter-range HF propagation.
This was used e.g., in **D-Day Operation WW II** during allied F-Invasion ; several **ESA** **Patents mainly US, UK, F, Australia, China**
There are major, **unclassified R&D / ESA optimization efforts** (radiation efficiency, bandwidth, minimum size) **ongoing**:

Wide-Band High-Frequency Antennas for Military Vehicles Designing and testing low-profile half-loop, inverted- L, and umbrella NVIS antennas
Maxim Ignatenko, ,Dejan S. Filipovic et. al, IEEE Antennas Propagation Magazine Dec. **2016** --**Univ. of Boulder CO USA**

Mid-Latitude Mobile Wideband,Jeffery Allen, **USA Ca. Think Tank Study** **2017**

Platform-Based, Electrically-Small HF Antenna..., Ruben Delgado Castillo et al, IEEE TAP Feb-**2021** **University of Wisconsin-Madison Wi, USA**

2. State of the Art in HAM and Commercial ESA (3)

Typical commercial <u>HF-Whip</u> Antennas for "on the move" Applications

<u>Stealth Telecom 9360 (U.E.)</u>

Frequency Range: **1.6 to 30MHz** Transmit, 250KHz-30MHz Receive

Power Rating: **125W PEP** CW/data, 200W PEP SSB Voice

VSWR: Typical Less than 1.3:1, 50 Ohm

Tuning Speed: 200 Channels Memory tuning Less than 0.35s

Power Consumption: 90mA static/1.3A tuning, 10-16VDC – supplied from transceiver

Interface: UHF socket/MIL-DTL5015, 7-pin/TTL and serial via USB/CPS

Operating Temperature Range: **-40°C to +60°C**

Environmental: Dust and Vibration to MIL-STD-810G, water ingress to IP 68

EMC: MIL-STD-461F

Size and Weight: **<u>2,49m</u>**, 5.2 kg

ANTENNA SPECIFICATIONS **<u>Tarheel 200A HP (USA)</u>**
Lower Mast Length -- 4 ft.
Frequency Coverage with 6ft. whip -- **3.2 to 26 MHz**
Power Rating -- **1.5 Kw P.E.P.**
Typical SWR -- 1.5 to 1 or less
Total Height with 6ft. whip at 26 MHz -- 10'4"
Total Height with 6ft. whip at 3.2 MHz -- 12'4" **<u>3.76m</u>**
Weight -- 8.5 lbs.

2. State of the Art in HAM and Commercial ESA (4)

Typical commercial HF-Whip Antennas for "on the move" Applications

Source: https://www.hiqantennas.com/

Hi-Q Antennas™ AEC LLC (USA, Anchorage AK) ***up to 160/80 to 6m***

- with **tuning center loading coil** / capacitive head
- **Radiation Efficiency** (80m/3.5MHz , < xx % ?) *Specifications seem to apply only to optimal Ground* (e.g., **Salt Water**/PEC)
- *How realistic is then claimed performance over **road/sand ground** ? !*
- This small Company also supplies such Antennas to e.g., the **US-Navy** (saltwater) and **US-Army** (dessert)

This Antenna uses always Center Loading and some ***Capacitive*** (loading) ***Head*** above the **motorized**, variable Hi-Q **Tuning-Coil**

2. State of the Art in HAM and Commercial ESA (5)

The “only” commercial HF-Magnetic Loop Antenna for “on the move” NVIS Applications

Mag. Half Loop (Source: **2018 Barrett Communications, Australia**)
for NVIS, shorter distance communications
High take-off-angle (Elevation Pattern) , typ. for < 500km

Specs:
Auto-Tuning, Frequency controlled by Transceiver 50 Ohm TRX

3.9 to 12.5 MHz , **125Watt PEP** , Tuning Power 2 to 15W max.
Bandwidth (-3dB) : 40 kHz (!) @3.9 MHz, 280 kHz @12.5 MHz

Indicates relatively **low Efficiency** by low-Q Tuner Coils**?**
From our experience: **5 to 10kHz** can be done with small single loops**.**

2. State of the Art in HAM and Commercial ESA (6)

Typical Military (**NVIS !**) HF-Products

2-30

MHz

Always critical:
Tuner Losses due to very low loop radiation resistance (mΩ) !

Source: L3HARRIS™.com (USA), **NVIS: RF-3134-AT003/5**
(-24dBi@2MHz, -15dBi@3.5MHz, -8dBi@8MHz, 150WCW)

Wide-Band High-Frequency Antennas for Military Vehicles Designing and testing **low-profile half-loop**, inverted-L, and umbrella NVIS antennas**, Maxim Ignatenko, Dejan S. Filipovic** et. al, **Source:** IEEE Antennas Propagation Magazine Dec. **2016** --**Univ. of Boulder CO, USA**

3. Some Basic EM-Theory of ESA (Verticals, Loops) (1)

Challenges of el. short (**Rod**, **automotive**) Antennas :

- HAM main Interest in mobile is on **EU** QSOs **40m**@Day/**80m**@Night (20m and up for **DX** need **low take off angle**!)
- 2.5m **Rod** , ~ 0.038 λ, 80m/3.5MHz (85.7m) => ... 11% of λ/4-vertical (21.43m) rod/coil antenna
- (forming basically a **Series Resonant Circuit** f= 1/ (2π * $\sqrt{L * C}$)
- El. small Ant.: low efficiency (few %, 3.5 MHz), narrow BW (Q>>), low radiation R -> feed point matching losses, tires…?, lossy car underground/soil impact

- **Radiation Efficiency [%]** $\eta = [Rrad / (R_{rad} + R_{Loss})]$ x 100%
- Minimize major Losses $R_{Loss} = R_{coil} + R_{\text{ground/soil}}$

  Maximize Radiation Resistance ($Rrad$)

  Experiments [%] indicate increase (**up to +10dB ?** with **short rod length doubling**

  -> more than square law from Theory!

  (May be due to limited car metallic chassis "ground size")

many observed effects are not exactly acc. to classic textbook predictions

Efficiency increases with **square** law over **Frequency** (on 20 to 10m no major efficiency problems)

Capacitive Top Loading -> Less L needed -> less coil losses, **Radiation Efficiency** (e.g., 80m) increases somehow

3. Some Basic EM-Theory of ESA (Verticals, Loops) (2)

Short, resonant Vertical/Rod

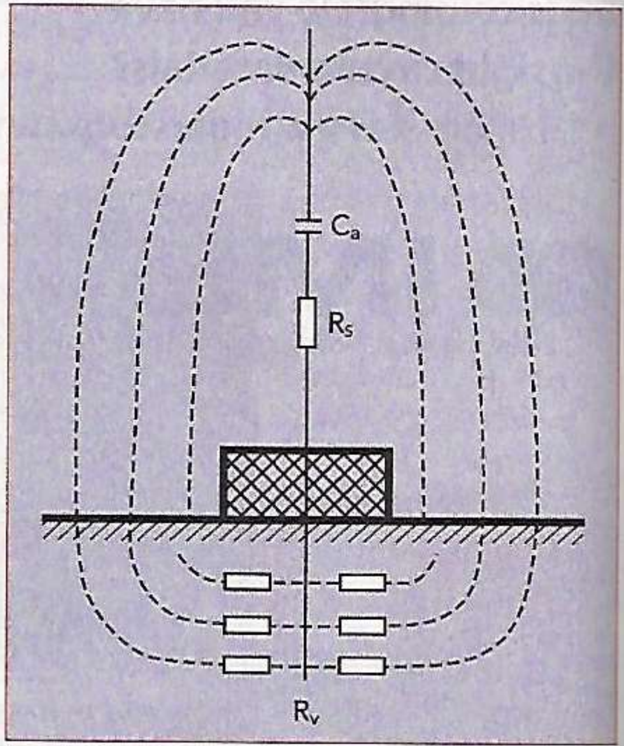
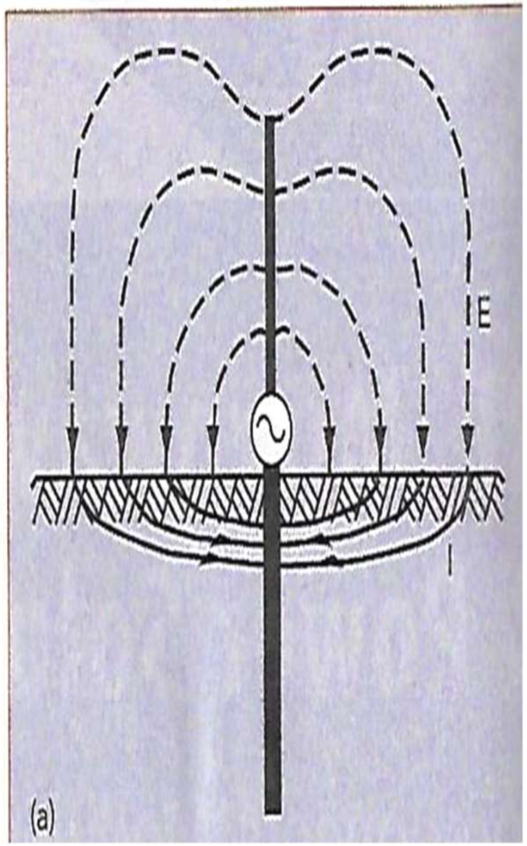


Fig. 4 Vertical antenna showing the current loop through the ground.



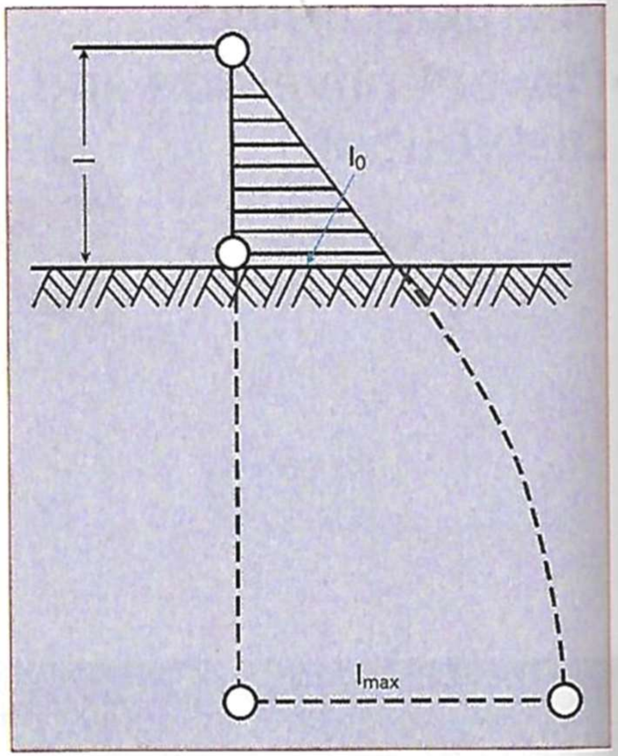


Fig. 6 Current distribution in a short antenna, including the ground current.[3]

Source: Tuning Electrically Short Antennas for Field Operation, K. Siwiak, U.L. Rhode, Microwave Journal, Vol. 62, No.5 May **2019**

3. Some Basic EM-Theory of ESA (Verticals, Loops) (3)

"Ohms Law" equivalence in **"Free Space** (Vacuum)"

R=U/I **Z= E/H** (3D (x,y,z) special vector quantities !)

R= Voltage / Current **Z = electrical Field / magnetic Field**

R = Resistance **Z = Impedance**

Z (free space => index 0) according to Maxwell = sq root (μ_0/ε_0) = 377Ohm

Power:

$$P = U \cdot I = \frac{U^2}{R}$$

$$S = E \cdot H = \frac{E^2}{Z_0}$$

Poynting-Vektor – Wikipedia

magnetic field constant

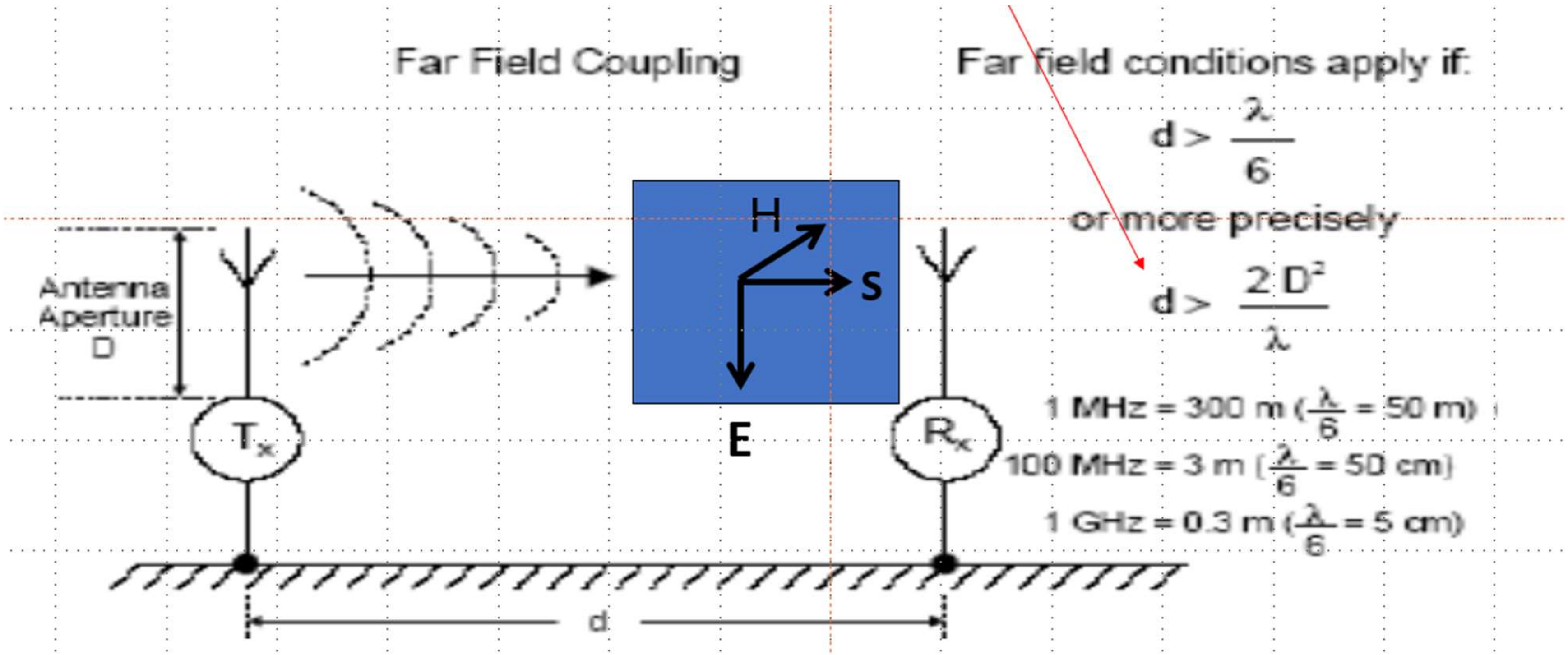
(vacuum, permeability) $\mu_0 = 4\,\pi * 10^{-7}$ V s/A m Henry/m

electric field constant
(vacuum, permittivity) $e_0 = 8{,}8541*10^{-12}$ A s/V m Farad /m

$$\left(Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = \mu_0 c_0 \approx 376{,}73\,\Omega\right)$$

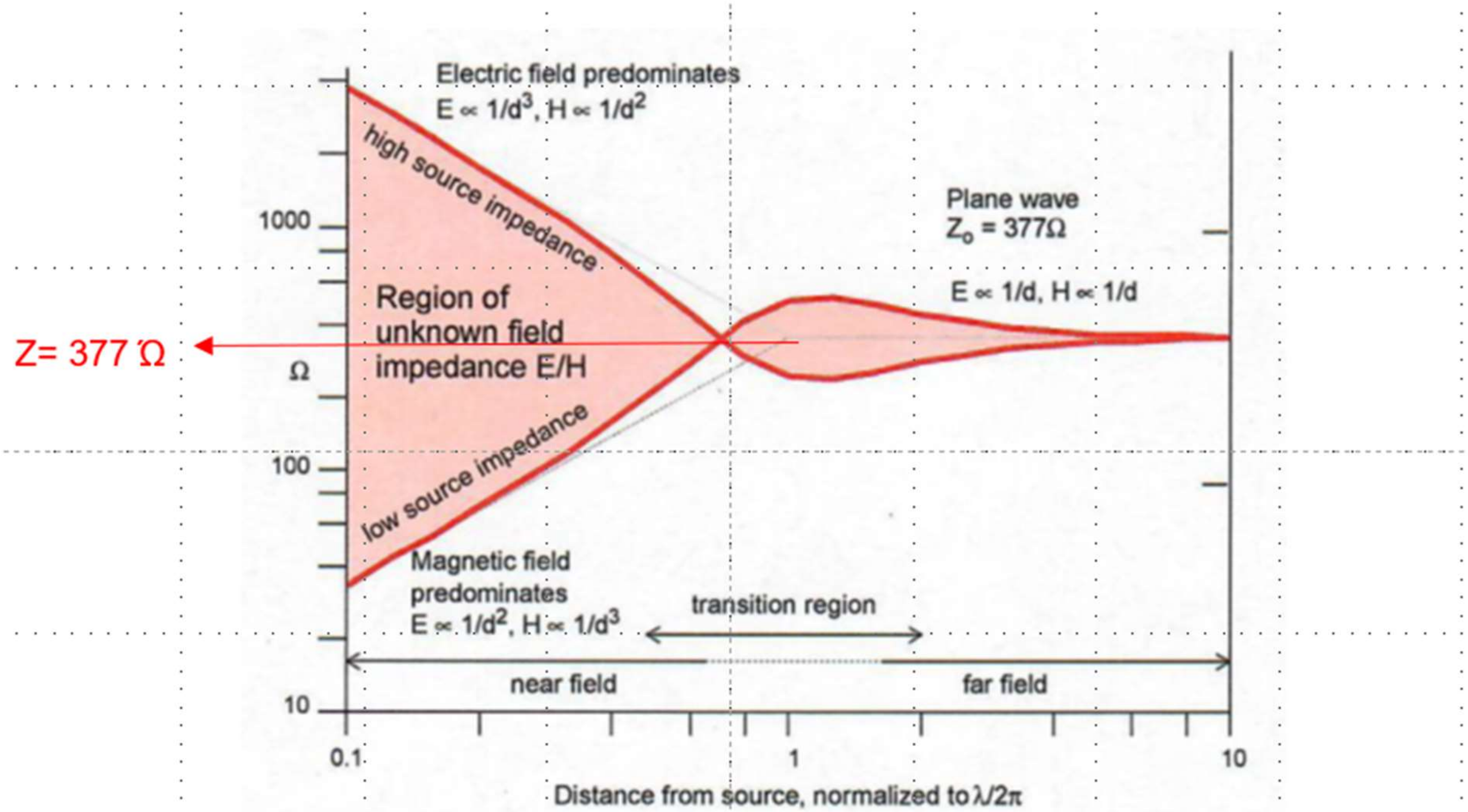
3. Some Basic EM-Theory of ESA (Verticals, Loops) (4)

Near and Far Field of a Whip Antenna (Monopole)



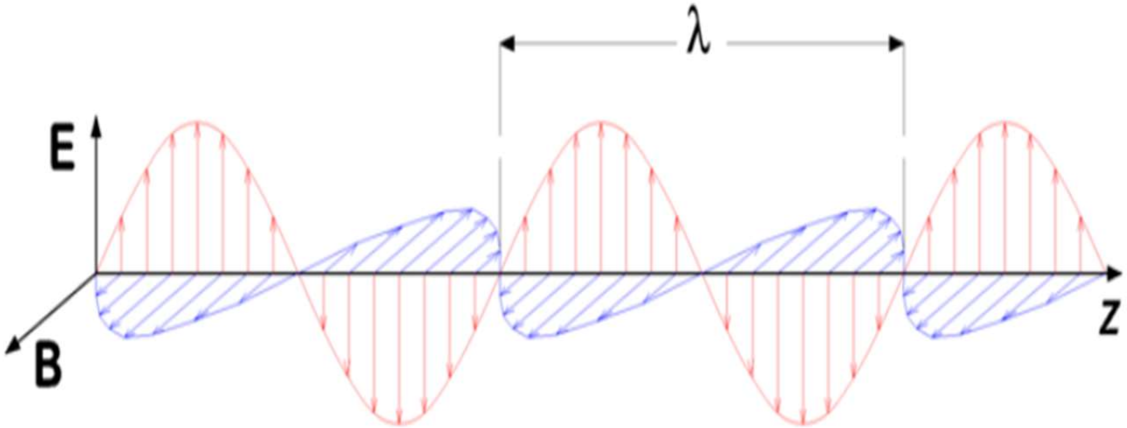
3. Some Basic EM-Theory of ESA (Verticals, Loops) (5)

Near and Far Field (Source: Schaffner Guide 2001)



3. Some Basic EM-Theory of ESA (Verticals, Loops) (6)

TEM Wave , Linear Wave Polarization, no Phase Shift, Right Hand Rule



$$\mathbf{D} = \varepsilon \mathbf{E} = \varepsilon_r \varepsilon_o \mathbf{E}$$

$$\mathbf{B} = \mu \mathbf{H} = \mu_r \mu_o \mathbf{H}$$

[Polarization (waves) - Wikipedia]

3. Some Basic EM-Theory of ESA (Verticals, Loops) (7)

Radiation Resistance (here called R_s), **Efficiency**

Source: Antennas for all Applications , 3. Ed., John D. Kraus et al., Mc.Graw-Hill 2002, ISBN 0-07-112240-0, page 709

$$R_S = 40\pi^2\left(\frac{l}{\lambda}\right)^2 = 395\left(\frac{l}{\lambda}\right)^2\ \Omega \qquad (9)$$

The radiation resistance of the short antenna is obviously very low.

l is the geometrical length (height) of the Monopole

Example 1: 4m / 80m (85.7m, 3.5MHz) -> ~**-12dB**

=> **Rs** = **0.86 Ohm** **Radiation Resistance** for this short Ant.

Example 2: 2.5m / 80m (85.7m, 3.5MHz) -> ~**-16dB**

=> **Rs** = **0.34 Ohm** **Radiation Resistance** for this short Ant.

Length / effective Ant.-Height is a very important Factor !

Very simple, optimistic Estimate **without radiation pattern !**:

Radiation Efficiency: **$\eta = R_s/(R_s + R_{Loss})$**

R_{Loss} is basically the Sum of Ground and Ant. Coil Losses

Example (Data see Experiments/Simulations later) **:**

80m /3.5 MHz/ R_s = 0.34Ohm (2.4m Rod)

typ. Soil/Ground 10 Ohms, Resonance-Coil =2 Ohm

R_{loss} = 12 Ohm

η **=** (0.34/12.34) x 100% **= 2.7 % ->**

-15.6dB = 10 log (0.34/12.34)

Source: Tuning Electrically Short Antennas for Field Operation, K. Siwiak, U.L. Rhode, Microwave Journal, Vol. 62, No.5, May **2019**

3. Some Basic EM-Theory of ESA (Verticals, Loops) (8)

Effective Antenna Height / Ant. Current Distribution

To calculate the effective height of an electrically short antenna, consider that the open circuit voltage, V_0, of the antenna is proportional to the antenna field strength, E, where the antenna is located:

$$V_0 = h_{eff} E \tag{10}$$

The effective height is related to the effective area, A, and characteristic impedance Z_0[3-4] as follows:

$$A = \frac{h_{eff}^2}{4} \frac{Z_0}{R_S}, h_{eff} = 2\sqrt{A \frac{R_S}{Z_0}} \tag{12}$$

For short Monopole:
h_{eff} = geom. length/2

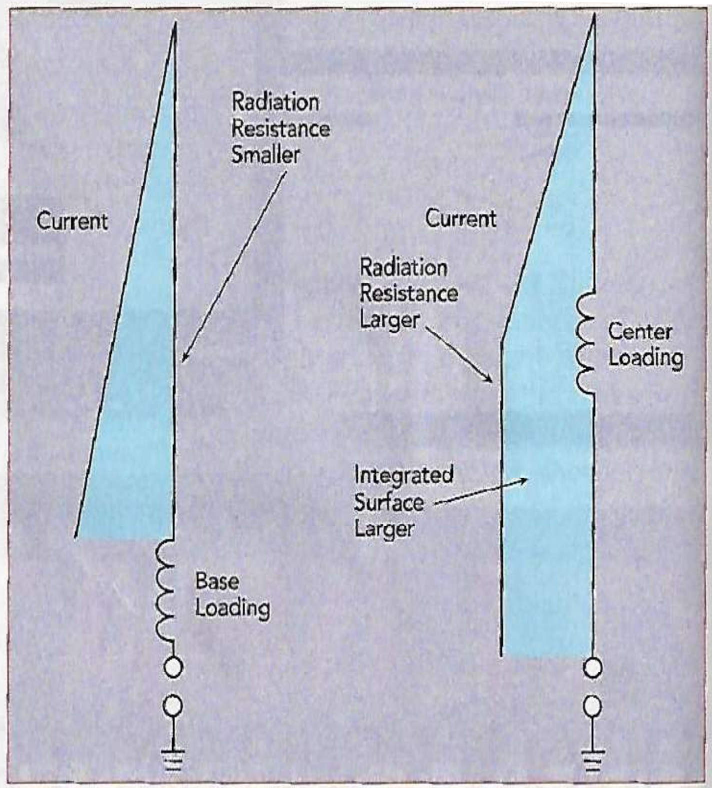


Fig. 9 Center loading a whip antenna creates a larger integrated surface for the current than base loading, which improves radiation.[6] The two figures are not to scale.

Source: Tuning Electrically Short Antennas for Field Operation, K. Siwiak, U.L. Rhode, Microwave Journal, Vol. 62, No.5 May **2019**

3. Some Basic EM-Theory of ESA (Verticals, Loops) (9)

Antenna Bandwidth (BW), Quality Factor Q, minimum Antenna Size* **

- **1947/48-Wheeler and (Chu for Hertzian-Dipole enclosed in a sphere) first to observe physical Limitations***
- Time Domain Analysis of a Radiation Process (Energy L, C , Near Field, Far-Field)
- Question: In which Space is the Energy stored (lumped approach is insufficient for us)
- The Q-Factor is a thermodynamic-based Definition
- **Q**= $2\pi \times \frac{(max.)\ Stored\ Energy}{Energy\ Dissipated\ per\ Cycle}$, **Bandwidth** = $\frac{Resonance\ Center\ Frequency}{Delta\ Frequency}$ => at VSWR of 2.6 is about -3dB BW
- Q = $\frac{2\pi \times f \times \mathbf{L}}{\mathbf{R}}$ with Coil Inductance **L** ….but there are Stray Effects to be considered ! One is Inter-Winding Cap.
- **R** includes ohmic *DC-Losses, frequency dependent Skin-Effect and Proximity-Effect*
- Inter-Winding Capacitance (Pitch) and Wire Diameter are important Parameters (Coil Self-Resonances are critical)
- For **optimal, unloaded Q**: Coil Height 1 to Coil Diameter < 2 (Coil Self-Resonances are critical) Tricky Metrology !
- A sharp Resonance is causes by high Q (in our case: Series Resonance Circuit by Ant. Rod Stray-Capacitance C and Compensation L)

Source: Madjid Manteghi, Fundamental Limits, Bandwidth, and information rate of El. small Ant., IEEE Antennas & Propagation Magazine Vol. 61/ No.3, June **2019**
***ESA Optimization:** Design and Optimization of ESA for HF applications, Ph.D. Thesis, EE, Dec. **2014**, USA University of HAWAI'I at Manoa
** Mats Gustafsson, Trade-off Between Antenna Efficiency and Q-Factor, IEEE Transactions on Antennas and Propagation (Volume: 67, Issue: 4, April **2019**)

3. Some Basic EM-Theory of ESA (Verticals, Loops) (10)

Near Field (NF) / Far-Field (FF) => Radiation Pattern Formation

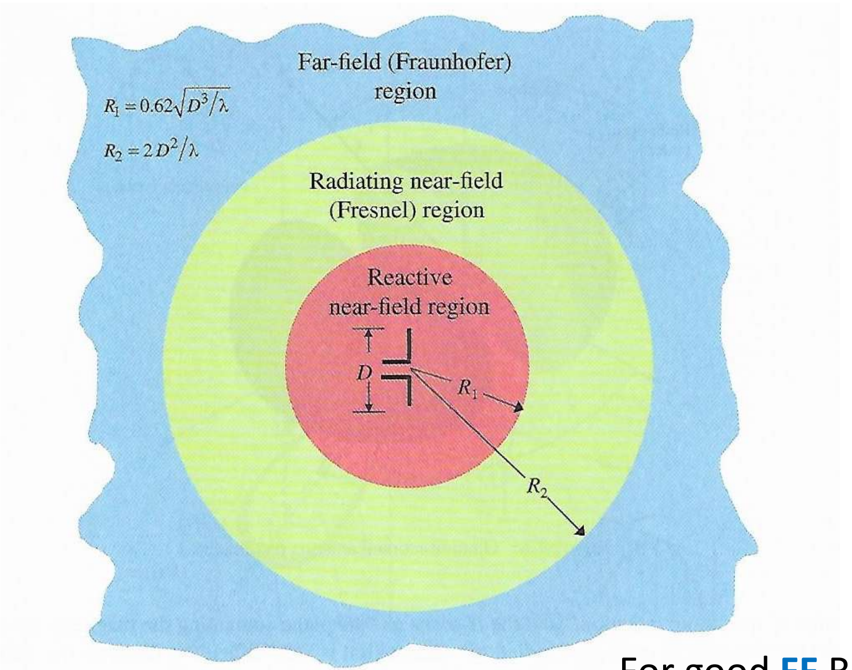
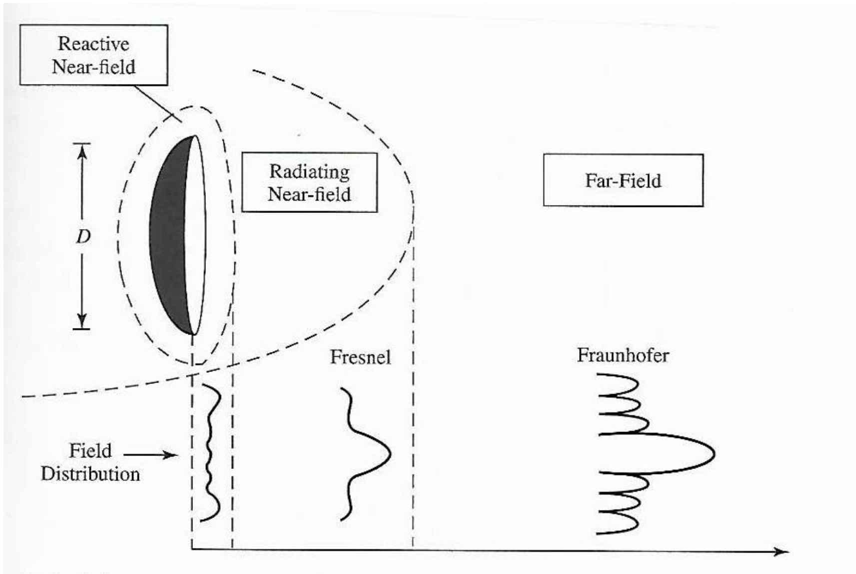


Figure 2.7 Field regions of an antenna.



For good **FF** Results use **3 to 4 …** 10 **Wavelength Test-Distance**

(truly valid for large λ/2 full size, Gain **Antennas ! For smaller ants. -> less distance needed)**

Our Ground-Wave Test was at 2.8 km: λ= 160m (1.8MHz)

Be careful… Do only H-Field Measurements, ITU: => H more reliable than E (Fields)

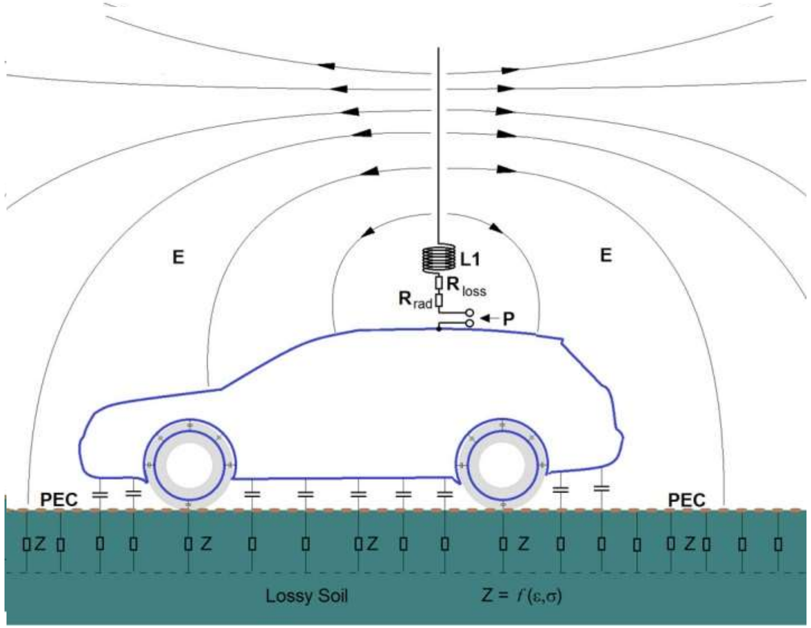
Source: C. Balanis , Antenna Theory, Analysis and Design , 4. Ed. **2016**, John Wiley & Sons Inc., ISBN 987-1-118-642060

3. Some Basic EM-Theory of ESA (Verticals, Loops) (11)

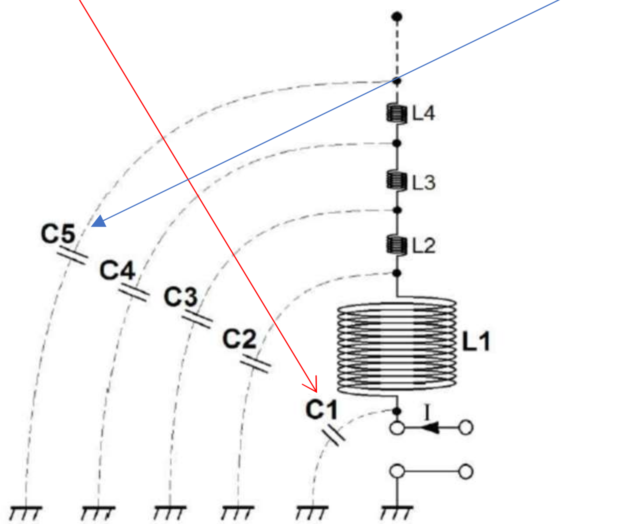
Equivalent Circuit Model for an el. short, transmitting vertical Monopole Antenna

- No top loading, E-Field simplified, **PEC**: perfectly conducting ground, Stray Capacitances visualized
- **Minimize** Stray Capacitance (C1), **maximize** (C5):

PEC
or
Soil



C1 less effective **(Dead Cap.)** , more radiation efficient **(C5)**



- Losses are basically in the **real ground/soil** (PEC = Zero Loss over a perfectly conducting, large Metal Plate is close to Salt Water),
- Coil Resistance (CU-losses + Skin/Proxi-Effect), very **small Radiation Resistance** (often less than 1 Ohm)

3. Some Basic EM-Theory of ESA (Verticals, Loops) (12)

Basic TX-Antenna Problem Analysis and Equivalent Circuit (short rod, with no resonating compensation coil)

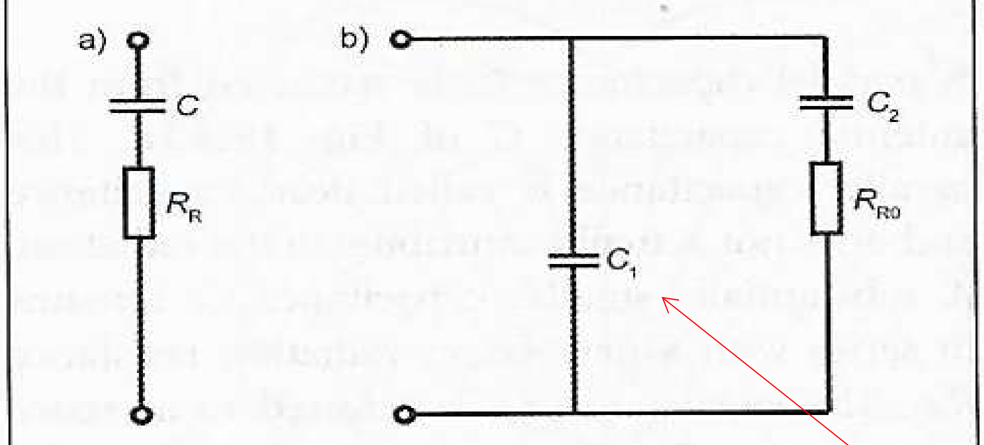


Fig. 19.3.1 Equivalent circuit diagram for short rod radiators
a) initial circuit b) revised circuit

C2 = Space/Room Capacitance (Radiation)

C1 = Radiation ineffective Stray Capacitance (e.g., to metallic car roof)

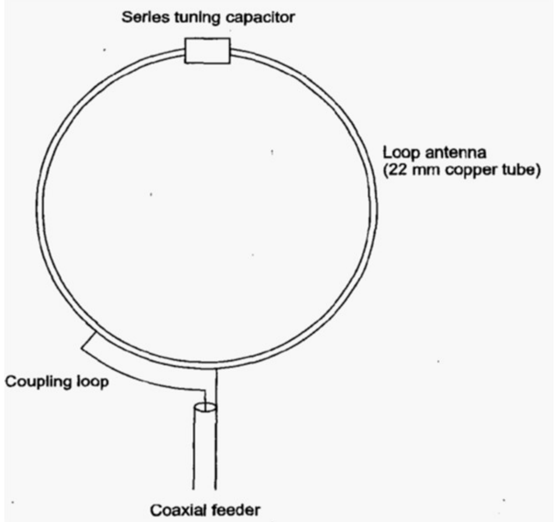
Application to *minimize* **Antenna** to **Car Stray Capacitance ->** Conical Radiator Design

Source: 2019 ,p.666, Rothammel's Antenna Book
ISBN: 978-3-00-062427-8

Literature: Landstorfer et al., NTZ (in German) , No.11, **1973**, pp. 490 to 495 (introducing Dead Capacitance C1)

3. Some Basic EM-Theory of ESA (Verticals, Loops) (13)

Small Loop (D=1m), Antenna Bandwidth (BW), Quality Factor Q, Rad. Resistance R_r /Efficiency



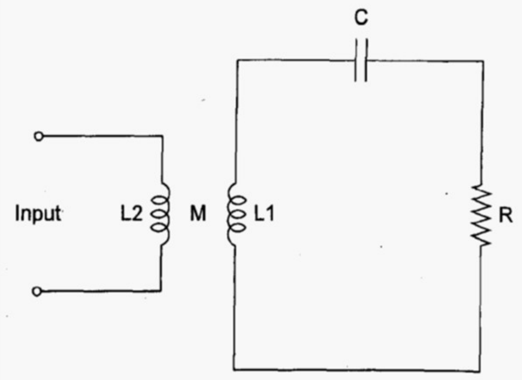


Figure 1. The equivalent circuit of the loop. L_1 **: main loop;** L_2 **: coupling loop;** M **: mutual inductance;** C **: resonating capacitance;** R **: total resistance.**

$$R_r = \frac{\mu_0 c}{6\pi} k_0{}^4 A^2 \approx 20 k_0{}^4 A^2 \text{ Ohms,}$$

A is the loop area and $ko = 2\pi/\lambda$ (5)

Center Frequency (MHz)	Bandwidth (kHz)	Q Factor	Reactance (Ω)	Total Resistance (Ω)
3.6	11.05	326	55.5	0.170
5.1	18.35	278	78.7	0.282
7.04	16.90	417	108	0.260
10.1	14.70	688	155	0.225

Frequency (MHz)	Radiation Efficiency (%) (Measured)	Radiation Resistance (mΩ)	
		Measured	Equation (5)
3.6	0.25	0.42	0.36
5.1	0.84	2.4	1.6
7.0	2.3	6.0	5.7
10.1	18	40	25

$$L_1 = \frac{\mu_0 D}{2}\left(\log_e \frac{8D}{d} - 2\right), \tag{6}$$

where D is the loop diameter and d is the conductor diameter.

Ant. 1.5m height above lossy UK- Soil (10/0.005)

Source: Performance of a Small Loop Antenna in the 3-10 MHz Band, Alan Boswel et al., IEEE Antennas and Propagation Magazine, Vol. 47, No. 2, April **2005**

4. Principles of Testing Antenna Radiation Efficiency

- By *trustworthy* **measurements** and *trustworthy* **simulation**-models … look for converging trends
- Antenna **radiation resistance vs. all system losses** (careful: no consideration of antenna pattern)
- Antenna accepted **input power vs. Far-Field (FF) radiated power** (ok, considers antenna pattern)
- **Ground-wave** (careful: no direct consideration of antenna pattern)
- **Sky-wave** (careful: uncontrolled ionospheric variations-amplitude/phase/ polarization issues)
- **Drones / Aircrafts RX measurements in FF** (careful: tricky ground reflections, expensive, permits?)
- **Absorber Chambers are geometrically too small and absorbers too ineffective for HF.**
- **Open Area Test Site is ok** (careful: soil effects, large metal ground plane scenario is unrealistic)

1. Best procedure: **Comparing with known TX Reference Antenna in** FF (RX-H-Fields!)
2. Also possible: **Comparing with known RX Reference Antenna in FF** (TX natural, omni-directional sky background **frequency selective** **EM-Noise-Power Test** in quiet/rural location-developed by DL2NK Fred, ULM) https://www.qrz.com/db/DL2NK

4. Principles of Testing Antenna Radiation Efficiency
go / no-go metrology and designs

- ESA (verticals) are not suitable for direct application of any sort of current probes on the radiator
- If done strong cap. detuning will result , based on principally small rod stray capacitance
- Trustworthy **measurements** should always **check** first for **uncontrolled coupling** into “sensor” by doing a Null Test- only the probe near the powered antenna
- Any indication (**current probe**) should be very small

- **Better** metrology avoids conducted approaches by rather radiated tests. (E (V), H (A) **field probes**)
- Consider near E-field distortions by body of person testing
- **unloaded Hi-Q (>800) inductors** tests: at operating frequency and minimal loading (use loose coupling loops for TX and RX) VNAs not very useful because of very high impedance of L
- Building High-Q Ferrite Core Coil will fail , Q too low any not broadband enough

5. Need for Professional Simulations, Creating 160/80/40m ESA Reference-Antennas

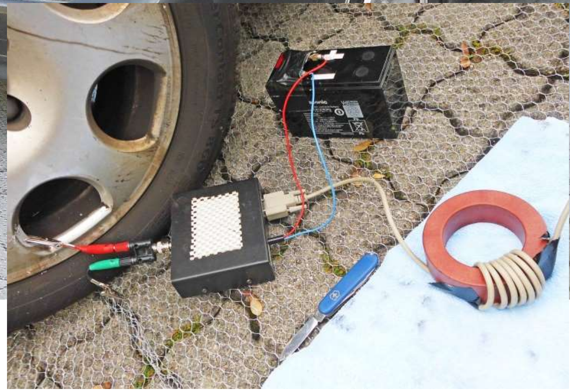
- trustworthy simulations
- Model must match experiments within accepted error bounds
- Model: must include ESA interaction Car, Tires, ESA, Soil, etc.

5. Complex Simulation Model (Car, Tires, ESA, Soil) *based on Tests* (1)

Audi A6 Avant <u>Car Body</u> / Rim / Break / Tire over <u>Ground Plane</u>

VNA Capacitance Tests:

Chassis via **Tire** to **Ground Mesh**

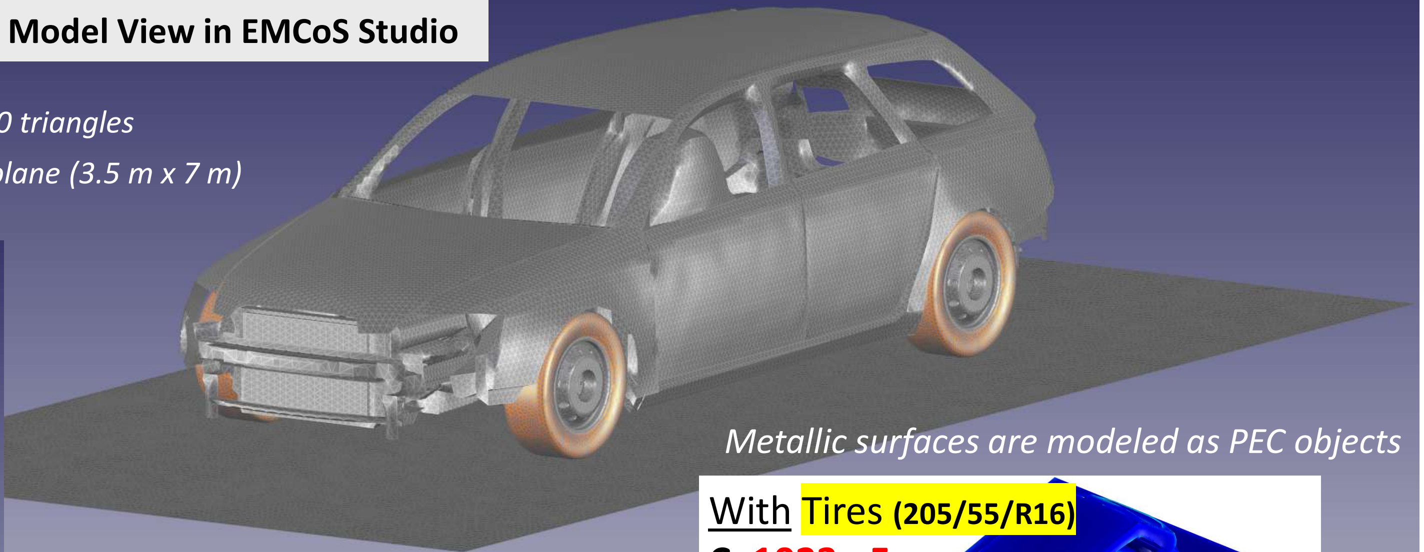


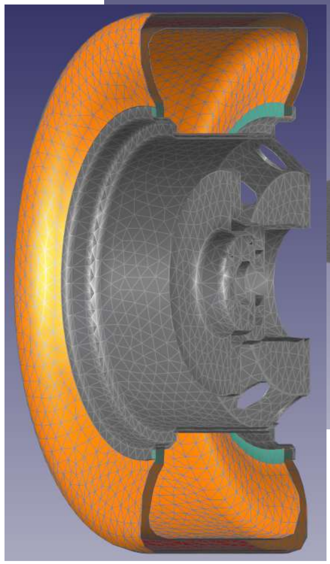
Measurement Setup
Wire-Mesh/Ground-Plane 3.5 m x 7 m

Automotive Electromagnetic Compatibility:
Prediction and Analysis of Parasitic Components in Conductor Layouts, Sabine Alexandersson, Lund Univ. Sweden, Ph.D. Thesis **2008**

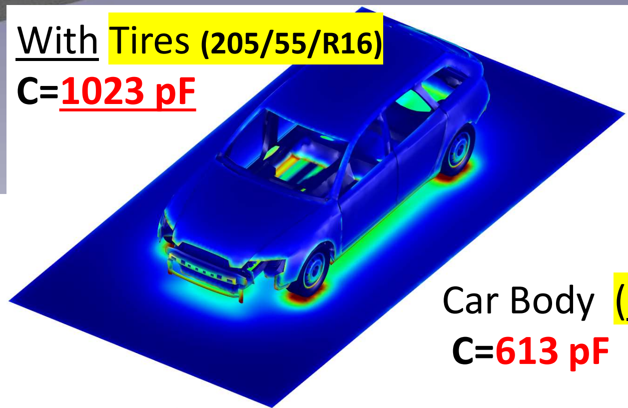
5. Complex Simulation Model (Car, Tires, ESA, Soil) (2)

Electro-Static-Simulation Model (Audi A6 Avant Car Body / Rim / Break Disk / Tire):





The tire is modeled as a homogeneous piece of rubber (eps = 3.5, loss factor = 0.01) with metallic belt inside it.

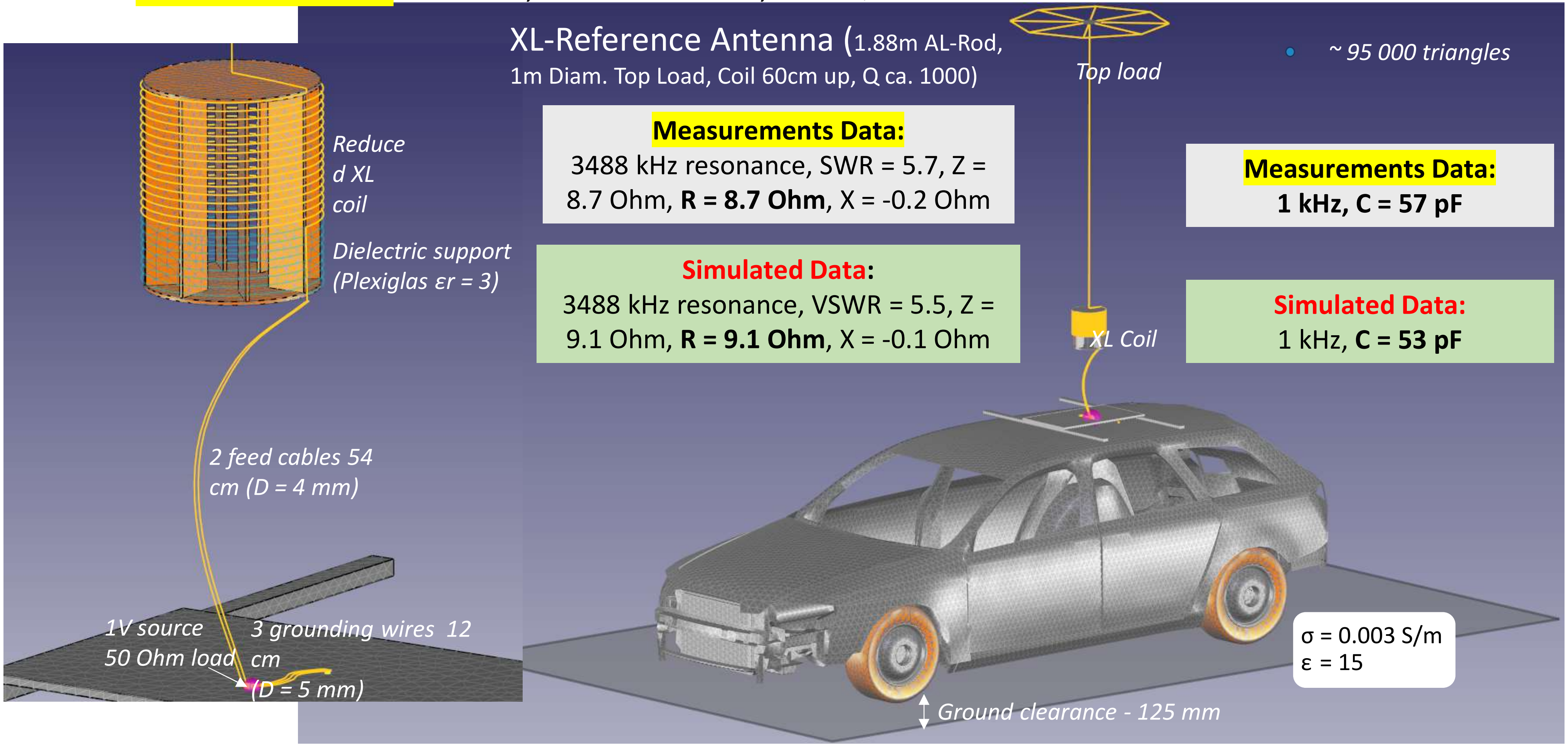


Note:

*Characteristics, geometric parameters and internal structure of the tires play important role in the capacitance simulation. Slight changes will have an impact. Tires are basically **lossless up to 10 MHz**. Therefore, we can **use 1nF as avg. value for a passenger car.***

5. Complex Simulation Model (Car, Tires, Vertical ESA, Soil) *based on Tests* (3)

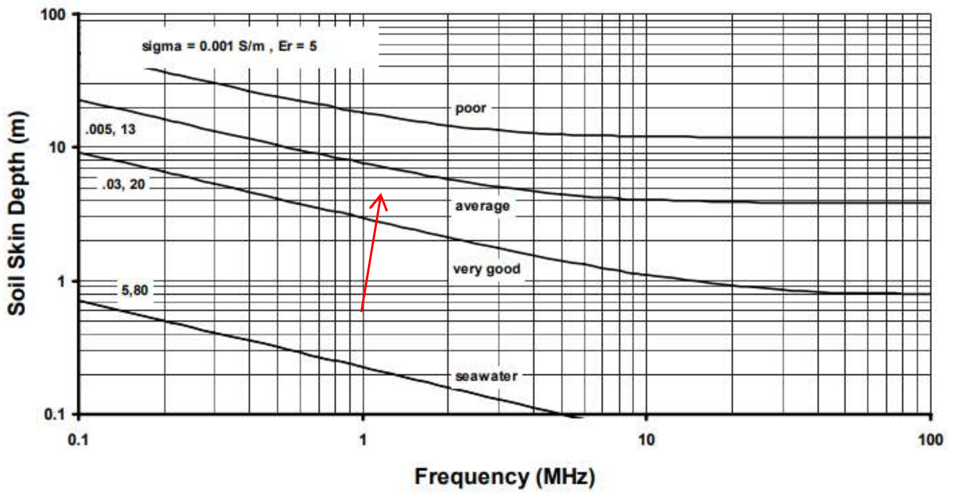
Simulation Check: Audi A6, **3.5MHz** XL Ant, L~40uH,

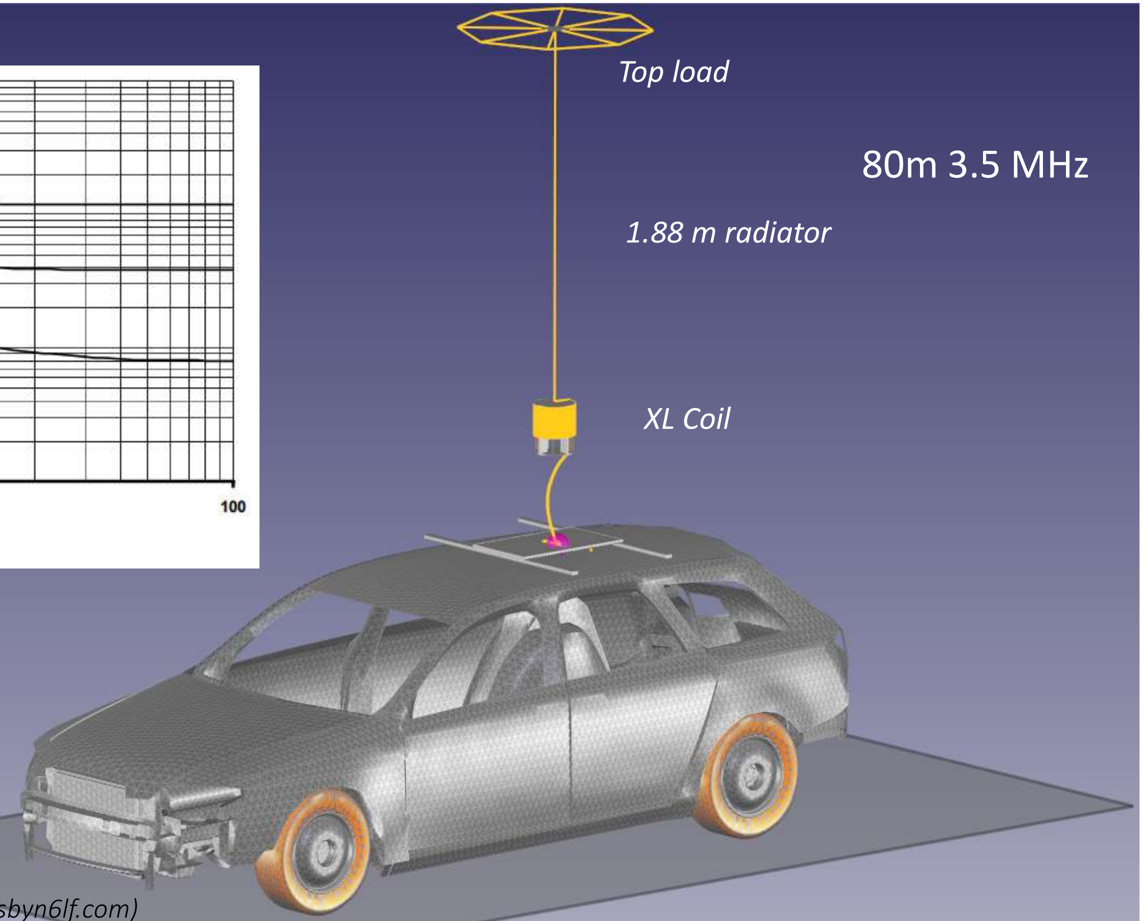


5. Complex Simulation Model (Car, Tires, Vertical ESA, Soil) (2)

Simulation Data (Audi A6 Car Body, Antenna, XL Coil, Top Load):

- *~ 95 000 triangles*





Audi A6 over **Real Ground**
poor *ε = 5, σ = 1mS/m*, **avg.** 13, 5mS/m,
very good 20/30mS/m, **seawater:** 80/5S/m
Skin Depth (1/e) => ~37 % Penetration

SOURCE:
Skin Depth And Wavelength In Soil
Rudy Severns N6LF (www.antennasbyn6lf.com)
http://www.antennasbyn6lf.com/files/ground_skin_depth_and_wavelength.pdf

6. Creating 160/80/40m ESA Reference-Antennas, comparing Simulation and Testing

- Design of a low loss prototype antenna which can be tested by physics-based measurements and first order estimations from theory

- Design of this low loss prototype antenna which can now be computed/simulated

- Experience showed simple in HAM Radio available codes failed
  We needed to team up with professionals in the automotive simulation industry → **complex method of moment codes**, **big memory work-stations**, disadvantage 240K to 90K variables (triangles), **mono frequency** system simulation may take sometimes **over 20h**.

- We later cooperated also with a company using Finite Element (TD).
  Some of the system sweeps (1 to 60MHz) simulations (without tires, and still enormous discretization efforts) took over 36h. Car **Chassis resonances start roughly above 30MHz.**

6. 160/80/40m ESA Reference Antennas for Simulation and Testing (1)

Radiator Length:

160m/3.5m | **80m**/1.88m | **40m**/1.88m | **40m**/10.42m

Tested Rod Antennas (Hi-Q Coil ,1k) 60cm above Car, Top Load D=1m

160m, 1.8MHz, Coil **XXL**

80m, 3.5MHz, Coil **XL**

40m, 7MHz, Coil **L**

40m, **λ/4** vs. Car-Body

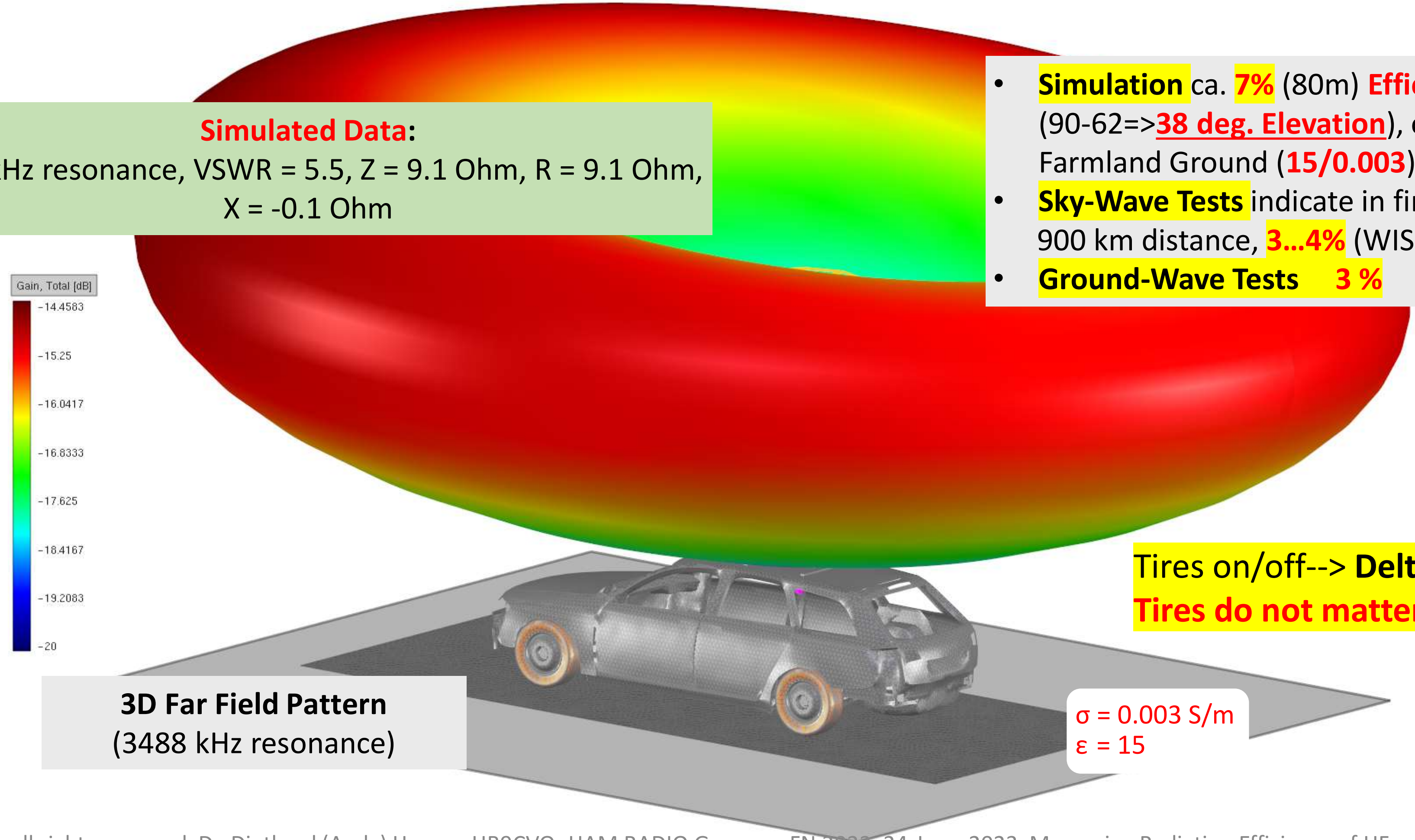
7. Absolute “Gain” comparison by means of predictable Reference-Antennas (using EM-Simulations)

7. Complex Simulation Model (Car, Tires, Vertical ESA, Soil) (1)

Radiation Pattern, Gain, Efficiency: Audi A6 Car Body, Antenna, XL (80m) Coil, Top Load with Tires):

Simulated Data:
3488 kHz resonance, VSWR = 5.5, Z = 9.1 Ohm, R = 9.1 Ohm, X = -0.1 Ohm

- **Simulation** ca. **7%** (80m) **Efficiency** for (90-62=>**38 deg. Elevation**), over rich Farmland Ground (**15/0.003**)
- **Sky-Wave Tests** indicate in first skip 900 km distance, **3…4%** (WISPR is avg.!)
- **Ground-Wave Tests 3 %**



Tires on/off--> **Delta = 0.2 dB**
Tires do not matter much.

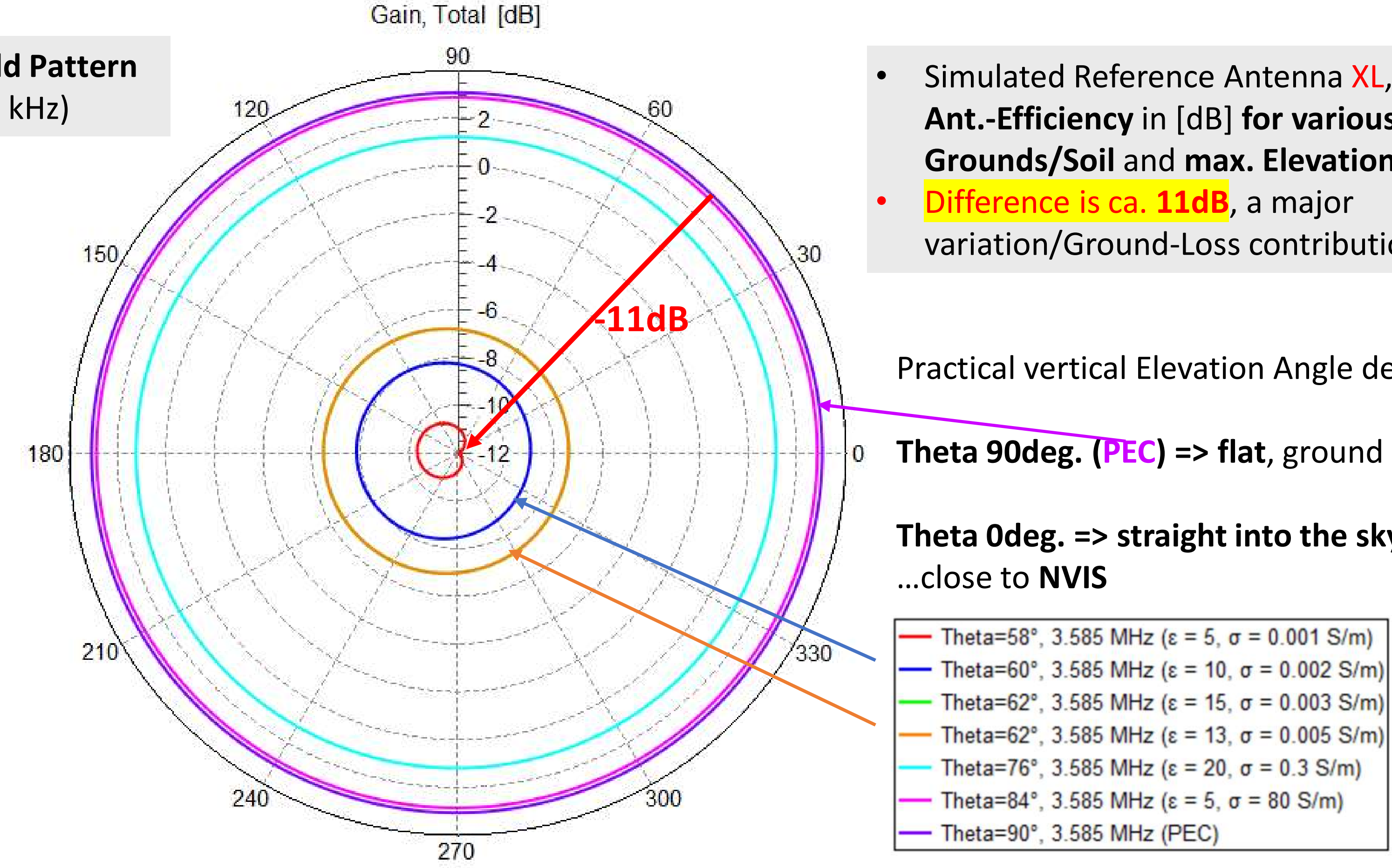
3D Far Field Pattern
(3488 kHz resonance)

σ = 0.003 S/m
ε = 15

7. Complex Simulation Model (Car, Tires, Vertical ESA, Soil) (2)

Soil Impact on almost omni-directional **Ant. Gain [dB]** (80m XL-Coil, Top Load)**:**

2D Far Field Pattern
(3585 kHz)



- Simulated Reference Antenna XL, **80m Ant.-Efficiency** in [dB] **for various Grounds/Soil** and **max. Elevation Angles**
- Difference is ca. **11dB**, a major variation/Ground-Loss contribution

Practical vertical Elevation Angle definition:

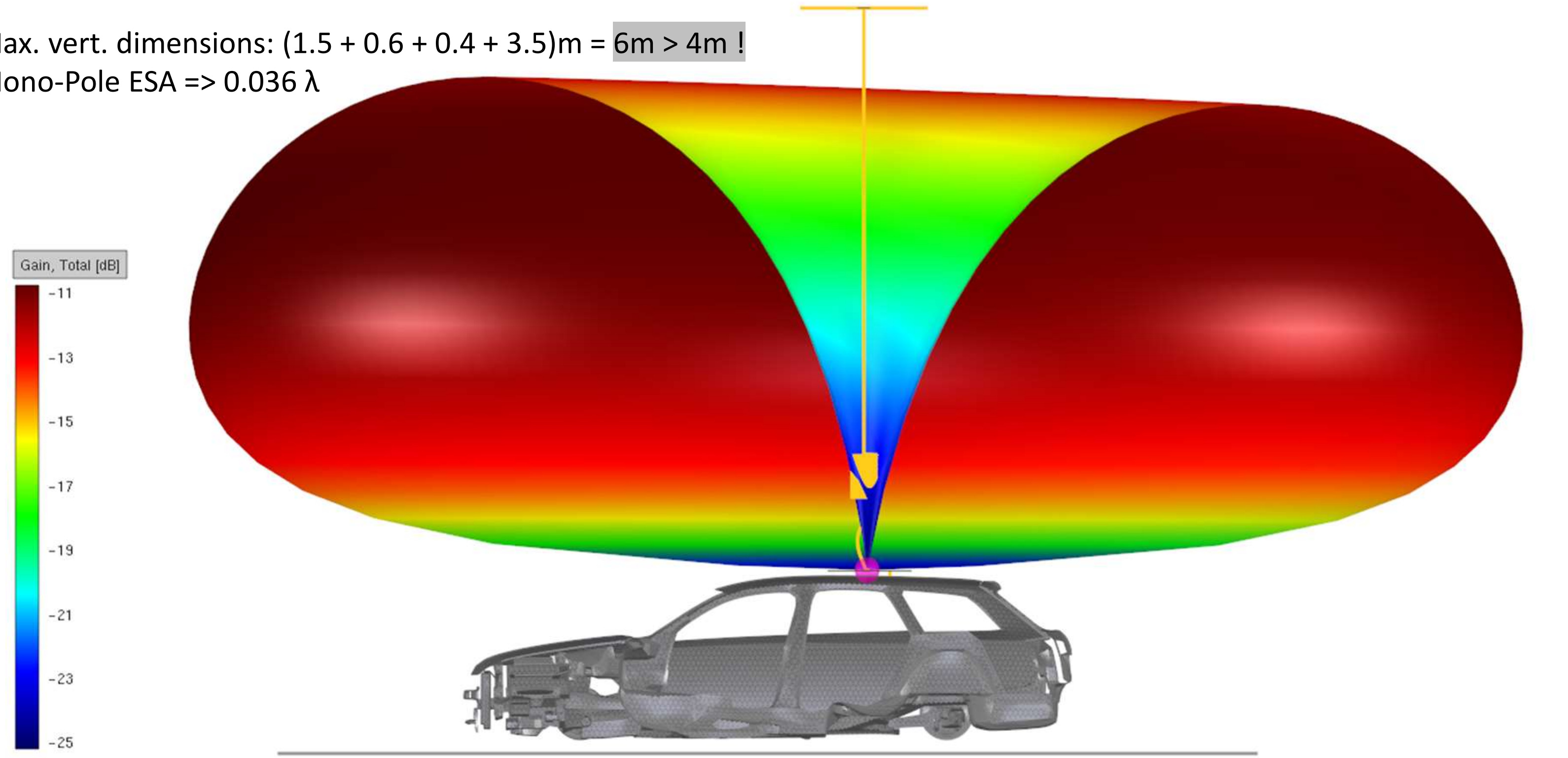
Theta 90deg. (PEC) => flat, ground level

Theta 0deg. => straight into the sky, ...close to **NVIS**

7. Complex Simulation Model (Car, Tires, Vertical ESA, Soil) (3)

160m Reference Monopole , XXL-Coil, 1m Top Load, **above Real Ground** 15/3mS/m**)**

Max. vert. dimensions: (1.5 + 0.6 + 0.4 + 3.5)m = 6m > 4m !
Mono-Pole ESA => 0.036 λ



Antenna Efficiency
~ 2.6% at 1800 kHz

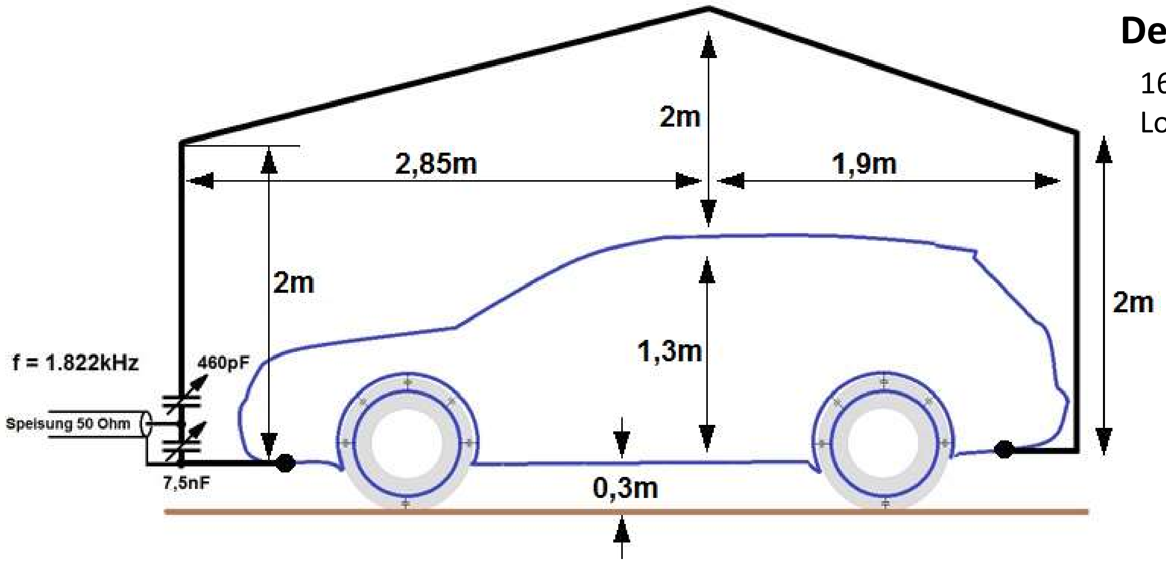
Car above Real Ground (ε = 15, σ = 0.003 S/m)
3D Far Field Pattern
Pattern maximum: -11 dB (Theta = 62°...38° Elev.)

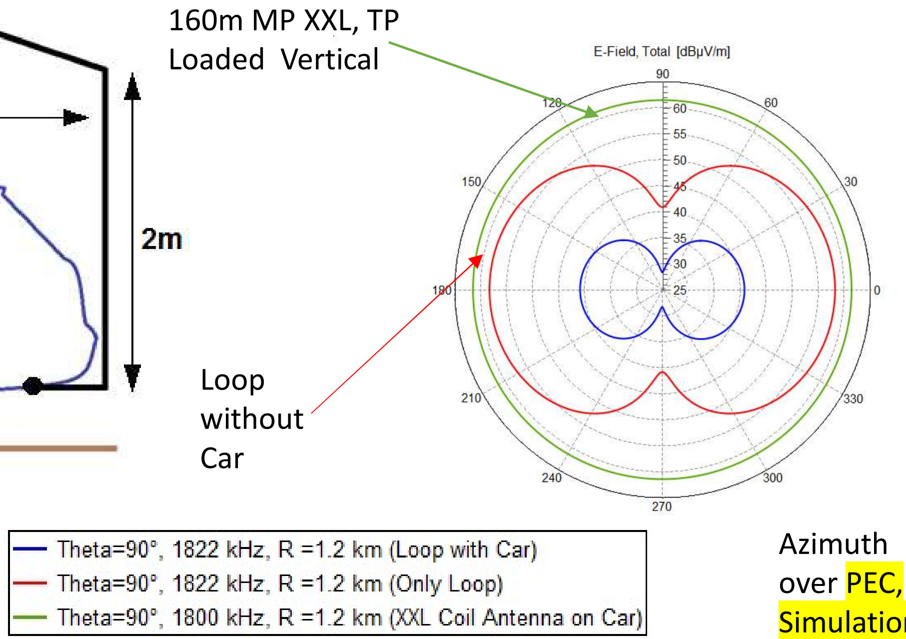
7. Complex Simulation Model (Car, Tires, Loop ESA, Soil) (4)

160m Reference Loop (Efficiency/Horiz.-Pattern)
above Real Ground/PEC:

Comparison Theory/Simulation
Monopole XXL 160m →160m **Loop**
Delta ~-20dB **over PEC** ! ? *Work **is still** ongoing*

Comparison Ground-Wave Test
Monopole XXL 160m→160m **Loop**
Delta = -11.5dB (**13/5mS/m,** not tested)





Azimuth
over PEC,
Simulation

8. Experimental Radiation -Efficiency Antenna-Comparison

commercial/homemade -ant. ranking

Groundwave Test over 2.74 km flat farmland (160/80/40m)

- 160m Ref. Ant. Top loaded, resonant Vertical, Mesh Ant, Stealth Telecom, Half Loop
- 80m Ref. Ant. Top loaded, resonant Vertical, Mesh Ant, Stealth Telecom, and various comm. Ant.
- 40m Ref. Antennas (λ/4 vs. Car, Top loaded, resonant Vertical) , Mesh Ant, Stealth Telecom, and various comm. Ant.., 90cm mag. Loop on 40m

8. Experimental Radiation Efficiency Antenna Comparison (1)

Ground-Wave Tests over 2.74 km flat Farmland near Munich, Germany

Not fully ideal Test Site: Several Compromises had to be accepted !

- ***TX*: 20W / 50 Ohms , CW for typ. 10 Sec.,** Testing only during Daytime, only free (CW) channels chosen
- EMC Zoning (Filtering/Shielding), Protection Concept (outside/inside car) was fully implemented/checked
- Using Non-HF-interfering GSM Communication with RX-Base

8. Experimental Radiation Efficiency Antenna Comparison (2)

Ground-Wave Test: Receive Test-Stand (RX) in "non-conductive" environment

Non automated Schwarzbeck EMI-Test System
Frequency selective Field Strength Measurement System (9 kHz to 30 MHz)

Calibrated in **dBµV/m** by **convention**:

$Z_0 = \frac{E}{H}$, E => H: -51.5 dB <= log (377) Ω

Measuring E-Fields proved very problematic / unstable!
➔ **measure H-Field** and convert to E (**dBµV/m** ¦**50Ohms**)

ITU and some EMC/ Radio Standards strongly recommend using mag. Loops!

FELDSTÄRKE MESSZUSATZ FMZL 1514
Active Pre-Selector with Direction-Finding H-Frame

VLF RX only **serving as Power Supply** for

9 kHz to 30 MHz CISPR 16-1 Measurement Receiver (RX)

- we used 200 Hz BW and Peak Mode, Dwell Time ca. 10sec
- Complete Test System and Test Range about +/- 1 dB repeatability Day/Day, for the same Soil Conditions

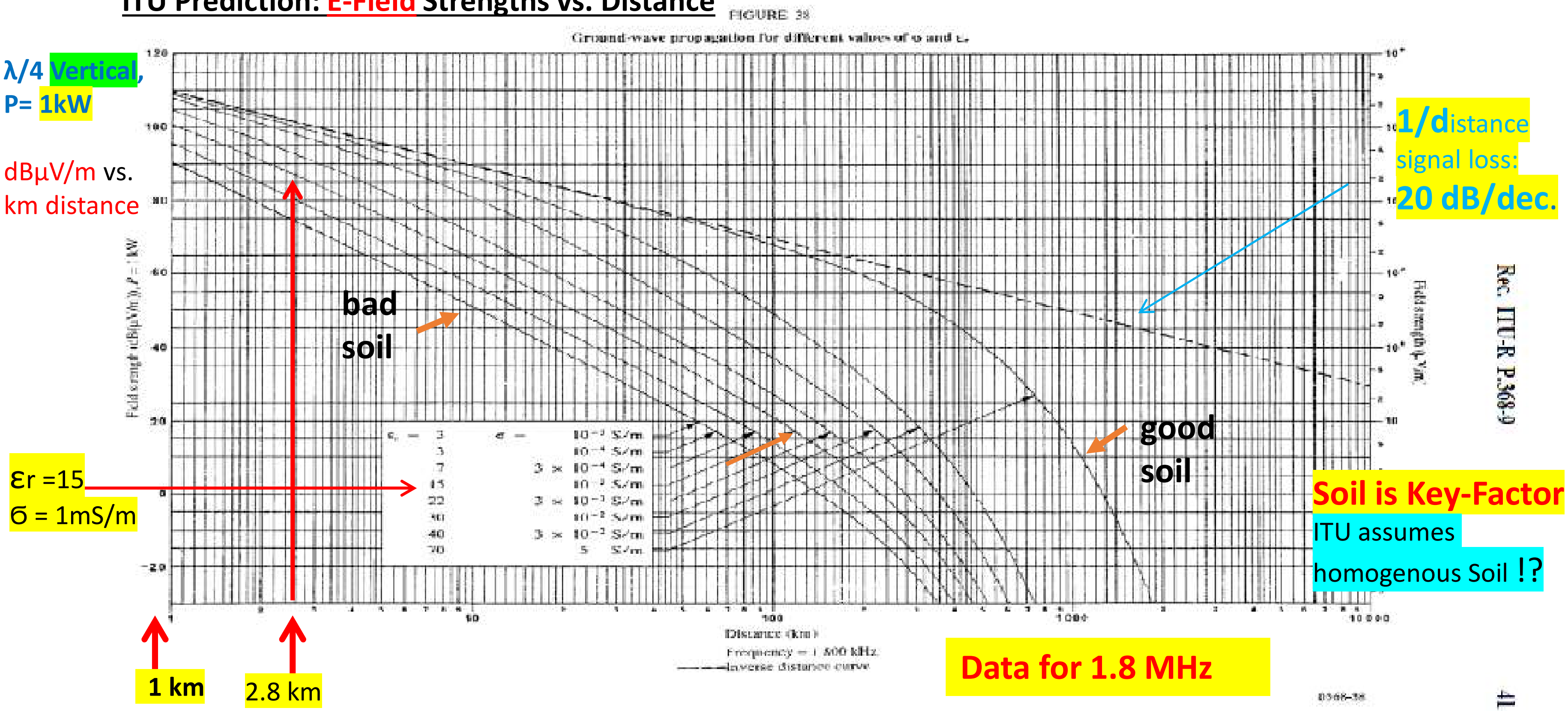
8. Experimental Radiation Efficiency Antenna Comparison (3)

Ground-Wave attenuation acc. to ITU

Even Vertical Groundwave **suffers more than 1/d attenuation** (wave penetration soil / wave front tilt by air/ground interface*)

Source: Recommendation ITU-R P.368-9 (02/2007) Ground-wave propagation curves for frequencies between 10 kHz and 30 MHz

ITU Prediction: E-Field Strengths vs. Distance



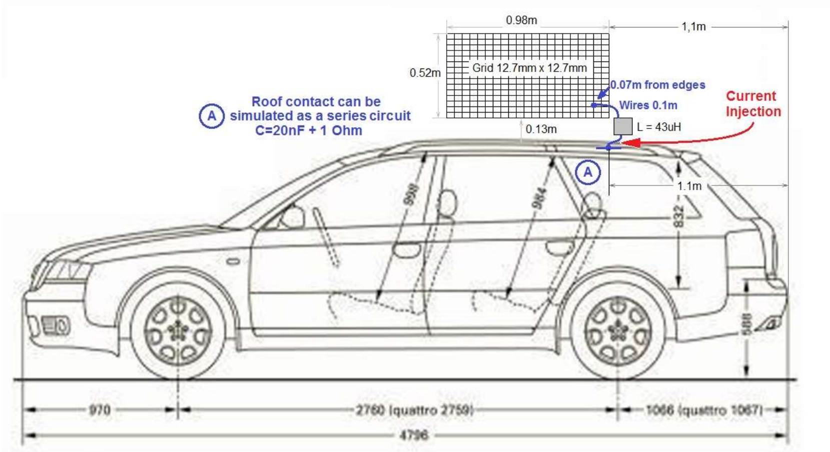
*Factors Affecting Surface Wave Propagation, Janice Hendry, 4th SEAS DTC Technical Conference – Edinburgh UK, 2009

8. Experimental Radiation Efficiency Antenna Comparison (4)

160m Antenna Pics from our Groundwave Test over 2.74 km flat farmland

XXL Reference (1m Top Load)

Stealth Telecom 9360 (short)



Vertical wire mesh (Mattress Ant.)

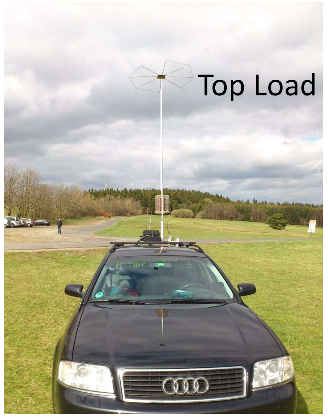
8. Experimental Radiation Efficiency Antenna Comparison (5)

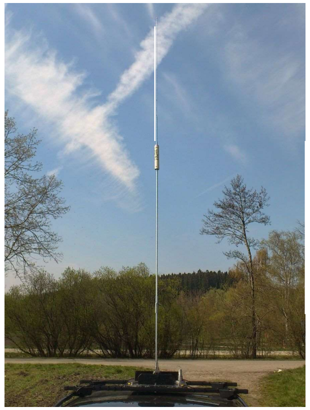
160m Groundwave Test over 2.74 km flat farmland

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
160m	XXL EM-Simulated Reference-homemade	**0 dB** (Reference) **~ 2.6%** efficiency-simul. (15/0.03)	3	3.5m rod+1m cap head, Hi-Q coil, 60cm up
	Vertical wire mesh	**-9**	5	On top of car roof
	Stealth Telecom 9360	**-10**	8	Vertical 1.6-30MHz, 2.5m

8. Experimental Radiation Efficiency Antenna Comparison (6)

80m Antenna Pics from our Groundwave Test over 2.74 km flat farmland





From left to right: **XL** (D=**1m Top Load**), **Conical, Hustler, DJ0HV Screwdriver** (80-10m),
1m long-50 Ohm Dummy Load-Rod (forced input matching)

8. Experimental Radiation Efficiency Antenna Comparison (7)

80m Groundwave Test over 2.74 km flat farmland

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

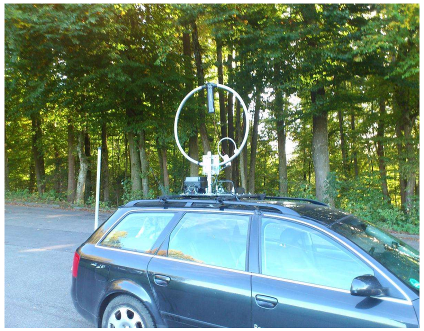
	Ant. Name/Type	Test Result in **[dB]** -with manual low loss tuner used- **6dB=1 S-Unit** (IARU)	Photo # HB9CVQ QRZ.com	Comment Status: 07-April-2021
80m	**XL** EM-Simulated Reference-homemade	**0 dB** (Reference) ~ **6.5%** efficiency simul. (15/0.03)	7	1.88m rod+1m cap head, Hi-Q coil 60cm up
	6.5m 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

8. Experimental Radiation Efficiency Antenna Comparison (8)

40m Antenna Pics from our Groundwave Test over 2.74 km flat farmland



From left to right:

λ/4 vs. Car-Body, **L** (1.88m/10uH, 1m Top Load), **ATAS 120A, 90cm Loop-40m**

8. Experimental Radiation Efficiency Antenna Comparison (9)

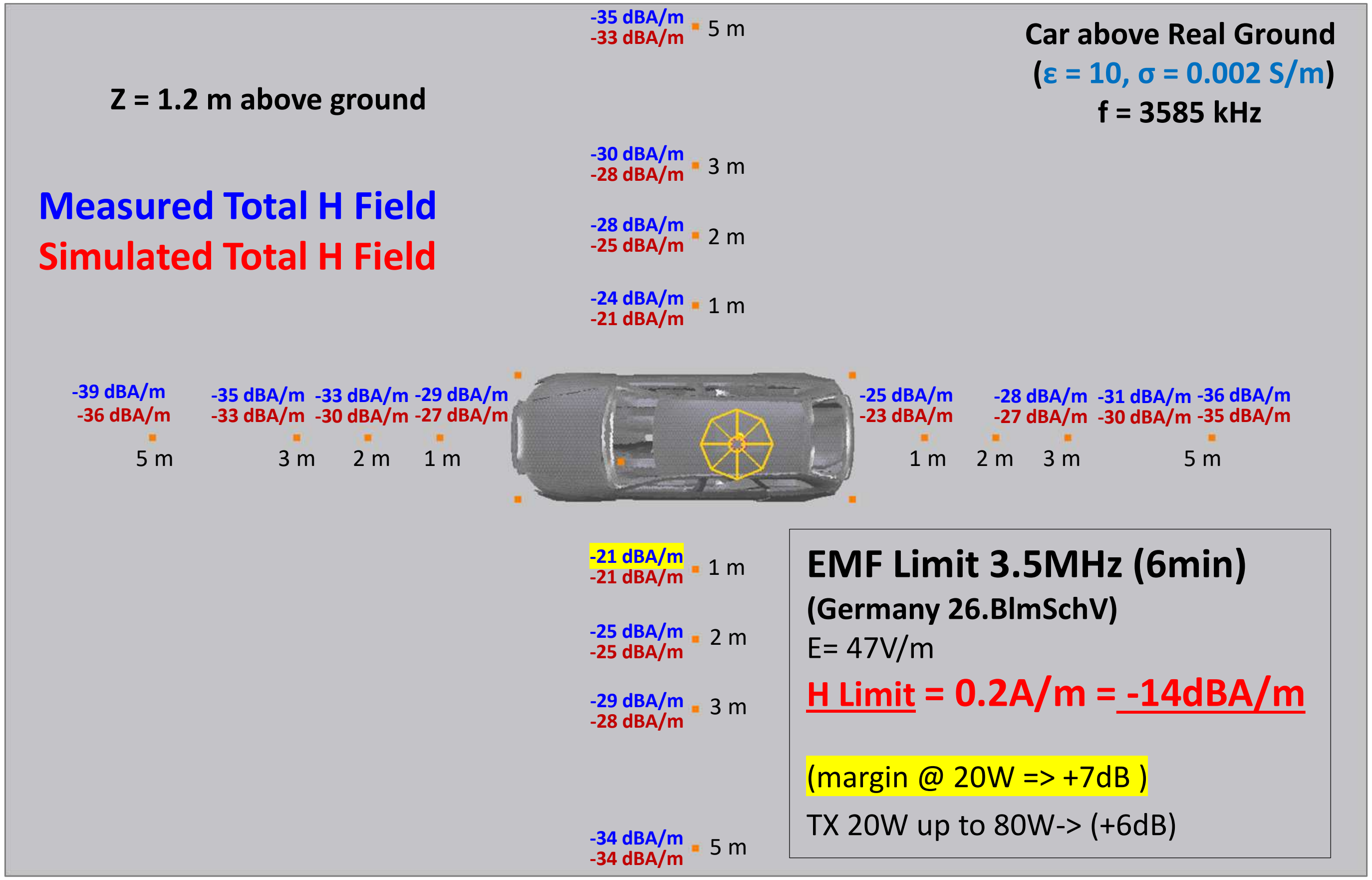
40m Groundwave Test over 2.74 km flat farmland

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
40m	**¼ wavelength GP**	**0 dB** (Reference) **~ 40%** simul. Efficiency (13/0.003)	4	10m Vertical vs. metallic Car Body
	L EM-simulated 2. Reference	**-2** Simul. 16.5% (15/0.03)	1	1.88m rod+1m cap head, Hi-Q coil 60cm up
	DJ0HV with split coils	**-7**	-	2.3m center load
	40-1 Hi-Q base loaded	**-8**	-	1m rod
	Stealth Telecom 9360	**-8**		Vertical 2.5m
	ATAS 120A extended	**-8**	-	Original+1m rod
	Vertical wire mesh	**-9**	-	On top of car roof
	ATAS 120A	**-10**	12	1.6m screwdriver
	DK2RZ 90cm	**-10**	-	like "Microvert"
	0.9m mag. Loop	**-13**	2	30cm above roof

General Discussion on why:
Groundwave, Skywave, Noise Power NPR all showed reasonably similar results (160/80/40m)

8. Some EMF considerations (human safety V/m, A/m vs. distance) (10)

EMF Simulation vs. Test Comparison: total H-Fields, 80m-XL ESA Vertical, TX 20W



Near-Field (mag. H-Field)
around the Audi A6, on an **asphalted parking lot**,
@ 3585 kHz / 80m

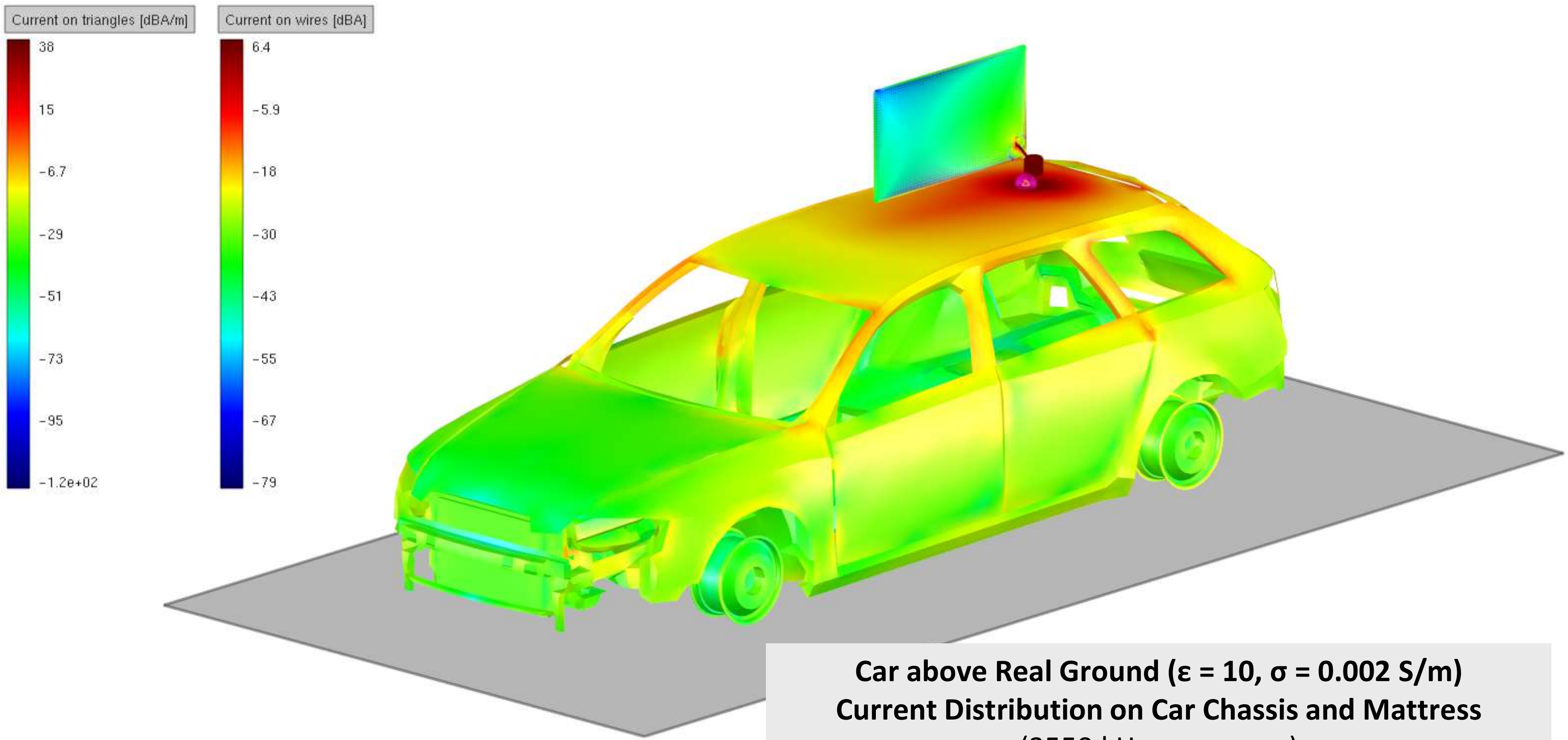
Reference Ant. (**XL 80m**)
Measurement Uncertainty
H-Sensor MU ~ +/-1.5dB.

- Excellent **Agreement** of **Simulation and Test**
- Proves **Suitability** of **EM Computer Code** used!

80m-Mattress-Radiator on Audi A6 Avant

EMC Europe 2019 BARCELONA

Simulation Results (Current Distribution):

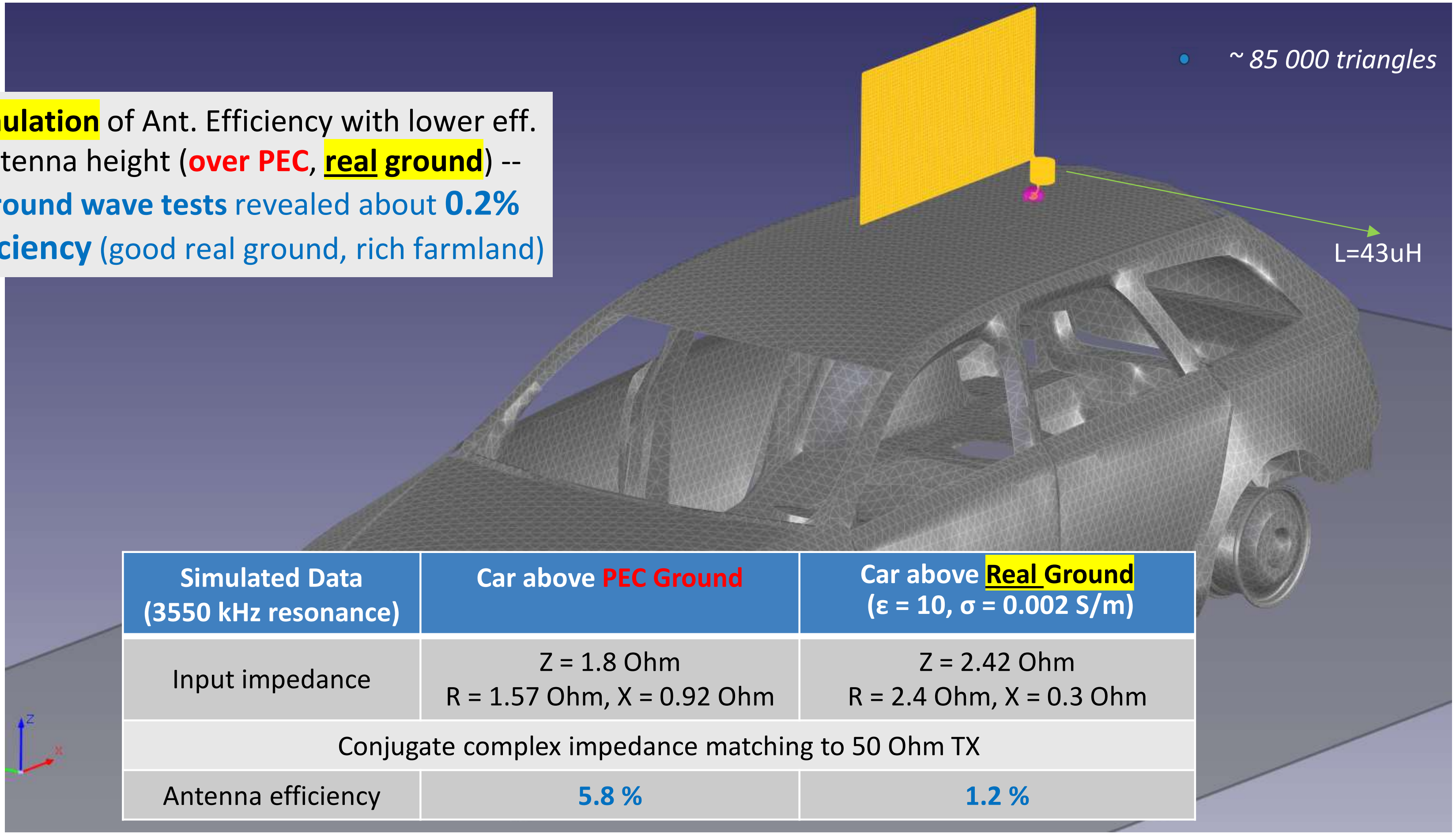


Car above Real Ground (ε = 10, σ = 0.002 S/m)
Current Distribution on Car Chassis and Mattress
(3550 kHz resonance)

8. Some EMF considerations (human safety V/m, A/m vs. distance) (10)

Compact 80m "Mattress" Antenna (TX 5W, Mesh 1m x 0.5m, 0.13m above roof, High E-Field Generator)

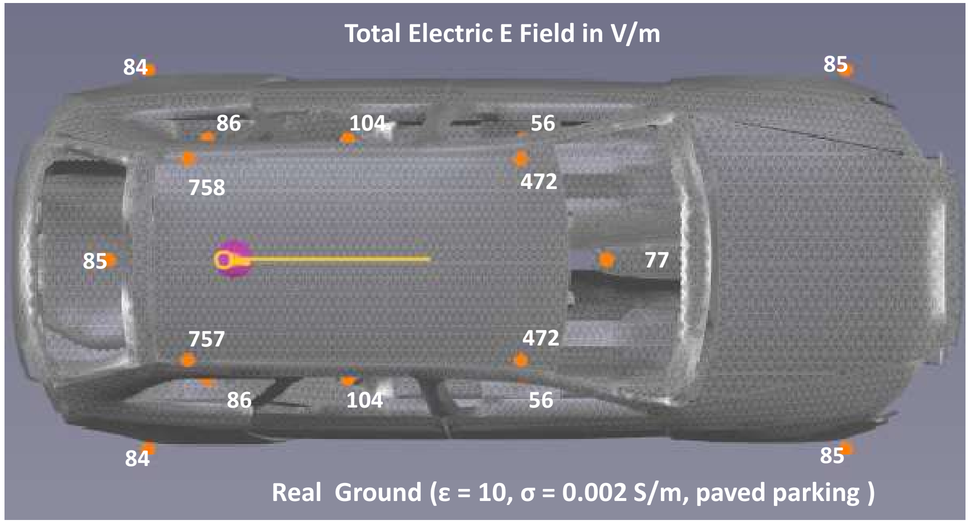
Simulation of Ant. Efficiency with lower eff. antenna height (**over PEC**, **real ground**) -- **Ground wave tests** revealed about **0.2% efficiency** (good real ground, rich farmland)

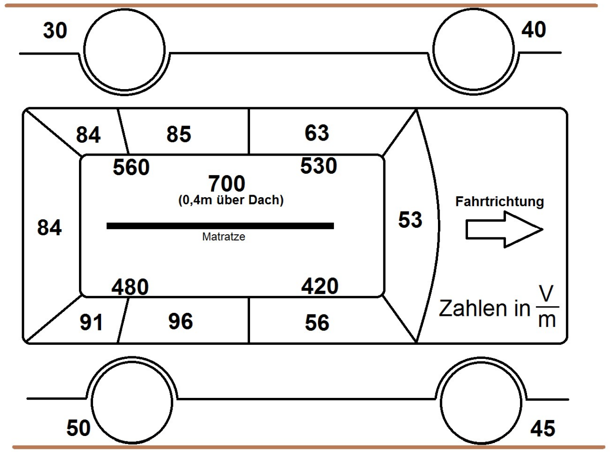


Simulated Data (3550 kHz resonance)	Car above PEC Ground	Car above Real Ground (ε = 10, σ = 0.002 S/m)
Input impedance	Z = 1.8 Ohm R = 1.57 Ohm, X = 0.92 Ohm	Z = 2.42 Ohm R = 2.4 Ohm, X = 0.3 Ohm
Conjugate complex impedance matching to 50 Ohm TX		
Antenna efficiency	5.8 %	1.2 %

8. Some EMF considerations (human safety V/m, A/m vs. distance) (11)

Simulation vs. Test: Total Electric Fields (here more critical than H-Fields) **in Near Field:**





Measurements Data **E ~** $\sqrt{P_{Tx}}$

(3550 kHz, E field inside car ~ 4V/m)

500W @2m behind car (11x 10= 110V/m **!!**

Simulated Data: **TX=5W, 80m 3.55 MHz**

Near Field Probes (3550 kHz resonance)	Total E Field [V/m] PEC Ground	Total E Field (77V [V/m] Real Ground (ε = 10, σ = 0.002 S/m)
Wheel group	~ 100 in all points	84, 85, 85, 84
Window group	104, 105, 127, 67, 94, 68, 128, 105	85, 86, 104, 56, 77, 56, 104, 86
Roof group	937, 582, 582, 936	758, 472, 472, 757
Near field probe inside car	4.3	3.3

Measured results behind Ant., to **rear side of car :** 1m -> 65V/m, 2m -> 11V/m, 4m -> 5V/m, 6m -> 1,3V/m **26.BImSchV Limit: E=47 V/m**

9. 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**):

- **Propagation, Location, surrounding Terrain (Cliff, saltwater Beach)**
- **Top Loading** (1m diam.) on forced Dummy Load matching 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

10. Lessons learned for restricted space antenna locations, HOA and portable-QTH.

1. **Balcony situation or indoor, with close by concrete or brick walls:**
   - If mostly enclosed do not use Hi-Z Antennas like Verticals , better use **mag. Loops** (d=2.5m for 80m, EMF strong H-Near Fields already at 100W, keep distance!)
   - If fiberglass mast can temporarily (at night) stick out of balcony use ca. 10m if you can
     The monopole and any radial system form a lossy dipole
   - For EMI reasons do not connect the Protective Earth (green yellow) –ground loops, EMI, TVI,
     BCI….use common mode chokes correctly (only work in low Z areas)
   - if you must use coils to resonate the ant. radiator try to max. Q (no small diameter inductors, stay away from metallic surfaces)
   - Try to max. radiator length or loop diameter at low bands , HOA flag poles + radials work ok , check EMF
   - **Minimize losses, think of any potential coupling -wires/loops- and assess EMF!**

10. Lessons learned for restricted space antenna locations, HOA and portable-QTH.

2. ESA Antennas, Compromise Ant., Stealth etc. should preferably be symmetrical, even if el. small

- Use appropriate test instruments, 2 port vector analyzers **(ant. coupling)** or one port antenna analyzer **(impedance tests)** , always display complex Z(resistive, inductive , capacitive- Smith Chart .
- **A system is generally <u>resonant if Phase = 0</u> , => C and L are compensated on that frequency of interest (remember to think: resonance first. matching second)**

- Now design the matching circuit , by individual low loss networks or suitable tuners

- BALUNS do transform (1:2, 1:4, 1:6, 1:9) like this only into resistive loads

- For **publicly accessible** stealth antennas **surely consider EMF-Regulations** (human health issues/ el. safety)

- Portable QTH/ stationary mobile : max. radiator length, height, try symmetry –like G5RV-ZS6BKW, good a quarter wave vertical excited against car chassis works.

11. 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**

11. Project Outlook (future R&D topics), open Literature

- We covered short, **vehicular HF –Whip/**some **mag. Loop** Antennas-**more simulations needed in mag. Loops**
- **Whips** show typically around **30/40 Degree Elevation Angle**
  (Take Off, over rich Farmland)=> ok for Medium Distance Communications)
- **Low Bands Ant.** for "on the move" (1.8 MHz/160m and 3.5 MHz/80m) show very **low efficiency over typ. Soils**
- 160m ca. 1% -- 80m ca. 5% -- 40m ca. 15% (soil dependent) Therefore good Automotive EMC needed !!
- **Ionospheric Propagation** on Low Bands is presently very variable, sometimes DX , sometimes NVIS**.**
- **Mag. Loops ESA or Half Loops** => **NVIS** by steeper Elevation (**80 to 90 deg.**)
- These Ant. may be less efficient than Whips, but the **NVIS Effect may** still lead to a **positive Signal Budget**
- **Outlook:** Finally, we try to **combine DX and NVIS** (respecting 4m Height Limit)

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Thank you for your kind attention => Any Questions or Comments ?
We always try to learn more!

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