Technical challenges and limitations in vehicular, on the move, **HF-mobile-antennas (160/80/40m)**

-Radiation Efficiency of ***electrically small antennas*** (ESA) by Experiment/Simulation-

Diethard (Andy) Hansen **HB9CVQ DK2VQ AK4IG**
www.qrz.com/db/HB9CVQ

- The HAM Radio license defined the legally (TX) used shortwave spectrum bands for this R&D project
- **Sponsor Experiments:** www.euro-emc-service.com
- **Sponsor EM-Simulations:** www.emcos.com , specialist **Ilona Danelyan**, EMCoS LLC, Tbilisi, Georgia
  Joint 5h Workshop at 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
- Calibrated **Low Budget Test Equipment** was mostly used

Bizarre HF – mobile Installations

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

Contents

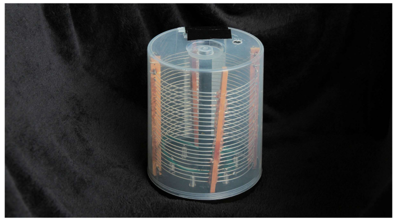
1. Motivation, Background and Final R&D Project R&D Goal

- **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 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?

2. 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!

2. An amazing QRP/mobile real world Case Story (2)

QSO Effect Analysis

=> HF-Sky-Wave (3000km)

Different Shortwave (HF)

***Propagation Modes** do exist*

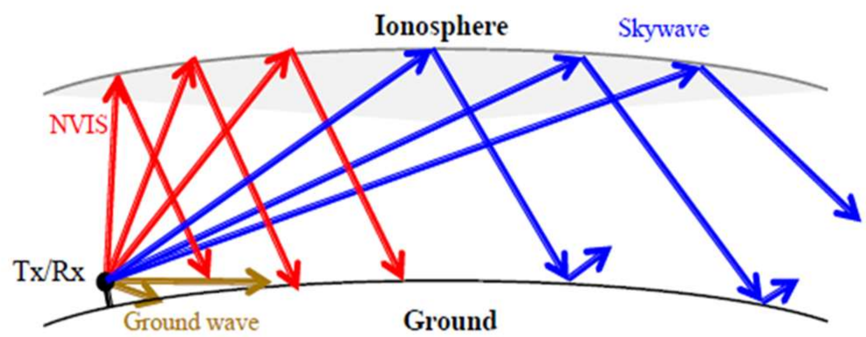
Source: Prof. Dr. Dejan Filipovic

Antenna Research Group

Department of Electrical, Computer and Energy Engineering

425 UCB, Boulder, CO 80309, USA

HF frequencies : point to point communication from 0 to 1000s of km



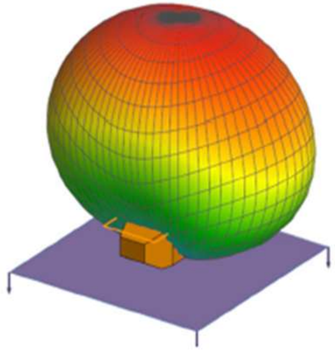
Three modes of communication:

1. Ground wave
2. Sky wave (long range propagation)
3. Near Vertical Incidence Skywave (NVIS)

Near Vertical Incidence Skywave (NVIS) communication:

- 2-10 MHz
- High incidence angles
- Any polarization
- Beyond line-of-sight

NVIS antenna pattern



3

2. An amazing QRP/mobile real world Case Story (3)

Changes in HF-Radio-Wave Propagation Conditions over Time*:

- **Long Time Effects**: Solar Cycle with 11 Year Periods (Summer 2021 still rel. low SFI)
- UV-Light and X-Ray create the ionized, conductive Ionosphere Layers…Faraday Wave Polarization Effect
- **Short Time Effects**: MUF , Day , Night, Season, Signal Fading (easily 10 to over 30 dB)
  (magnetic storms / sudden, local ionospheric perturbations)
- **MUF** (max. usable Frequency) Trend: **High during Daytime, Low during Nighttime**
- **NVIS** is mainly a **Daytime Effect**, overcoming geographical "**dead (Skip) Communication Zones**"
- **Critical**: Often (e.g., winter nights) only low bands (160/80/40/?20m?) left for communications
  (if low Sunspot number)
- Exactly here 160m (1.8 MHz), 80m (3.5 MHz) are *ESA inefficient*

- **Challenge**: Making useful **measurements/simulations**, considering time-varying parameters!
  Must do => Parameter Studies e.g., antenna size, impact of soil under the car on efficiency ?

* Non-HAM Radio applications often use Comm.-Link (Channel) optimizing, automated Frequency Selection (**ALE**)

3. 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**)

3. 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**

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

Typical commercial HF-Whip Antennas for “on the move” Applications

Stealth Telecom 9360 (U.E.)

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: **2,49m**, 5.2 kg

ANTENNA SPECIFICATIONS **Tarheel 200A HP (USA)**
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“ **3.76m**
Weight -- 8.5 lbs.

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

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

Hi-Q Antennas™ AEC LLC (USA, Anchorage AK) *up to 160/80 to 6m*
All HAM products sold out (7/2021) ?

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

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

3. 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**.**

3. 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) !

2-15MHz, **24kHz** BW
Focus NVIS (2-6MHz)

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**

4. 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…+ rel. small user community, but still remarkable, **current R&D** (Ph.D. Dissertations, Papers) **efforts**
- **Radiation Efficiency [%]** $\eta = [Rrad \,/\, (R_{rad} + R_{Loss})]$ x 100%
- Minimize major Losses $R_{Loss} = R_{coil} + R_{\text{ground/soil}}$

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")

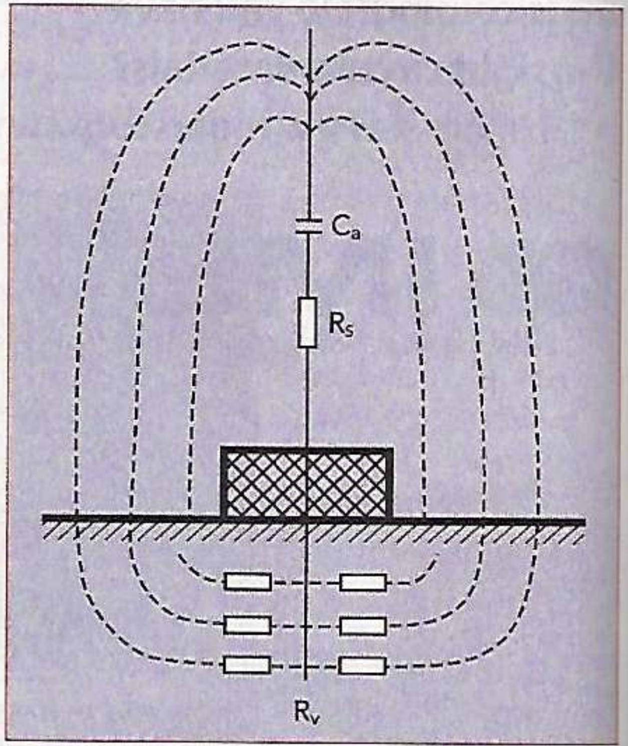
Efficiency increases with **square** law over **Frequency** (on 20 to 10m no major efficiency problems)

Capacitive Top Loading -> Less L needed -> less coil losses, **Radiation Efficiency** (80m) increase only ~ 3dB

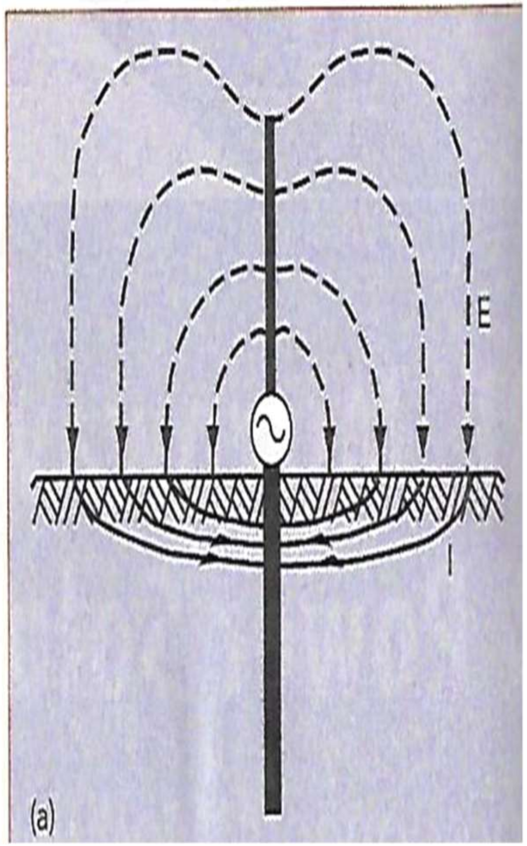
(not as expected with 6dB, factor 4 in power)

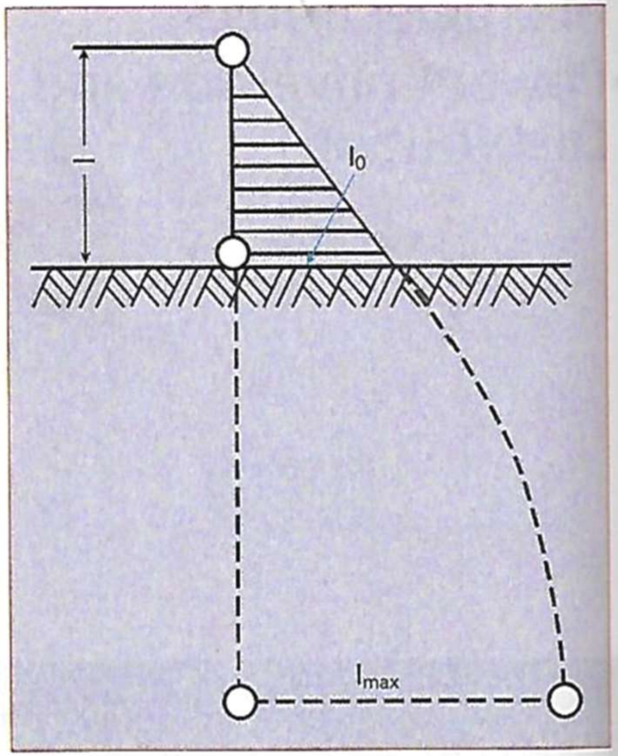
4. Some Basic EM-Theory of ESA (Verticals, Loops) (2)

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**

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

"**Ohms Law**" equivalent for "**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

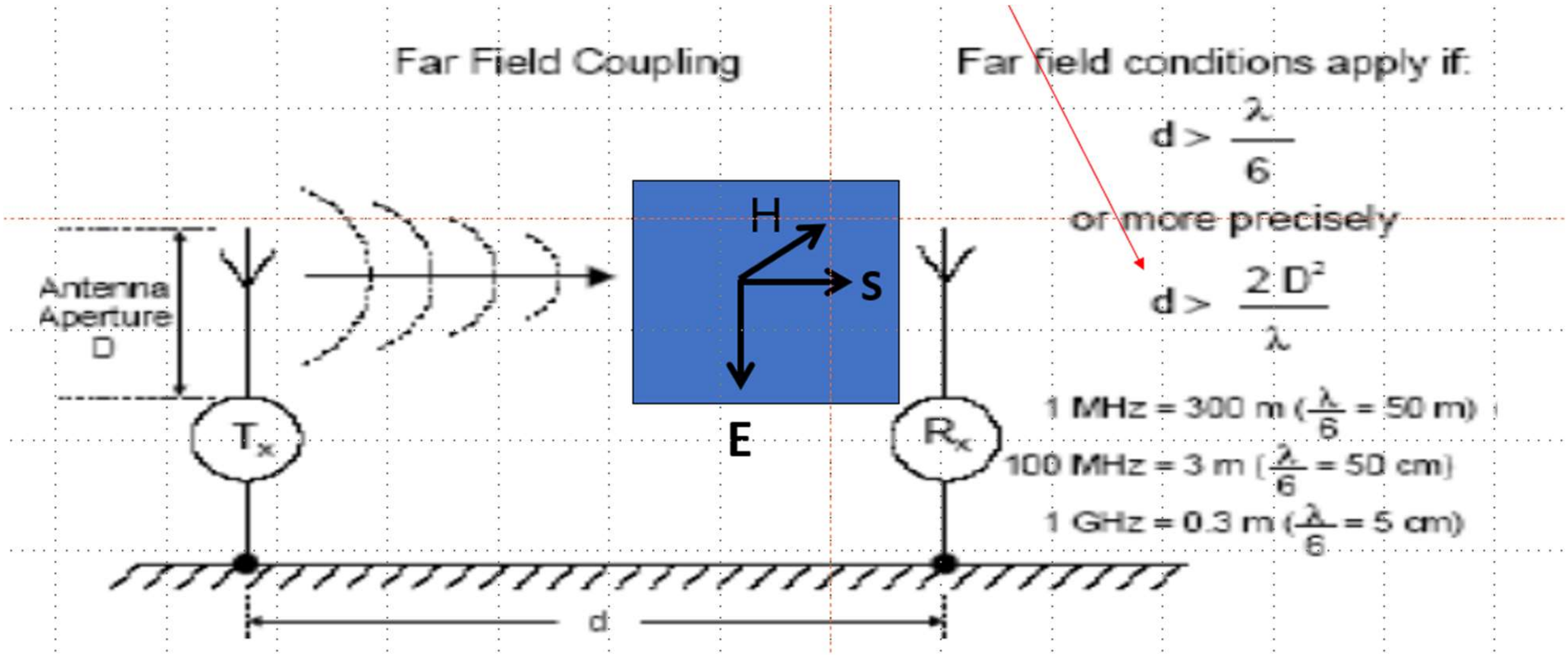
(vacuum, permeability) $\mu_0 = 4\,\pi * 10^{-7}$ V s/A m Henry/m

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

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

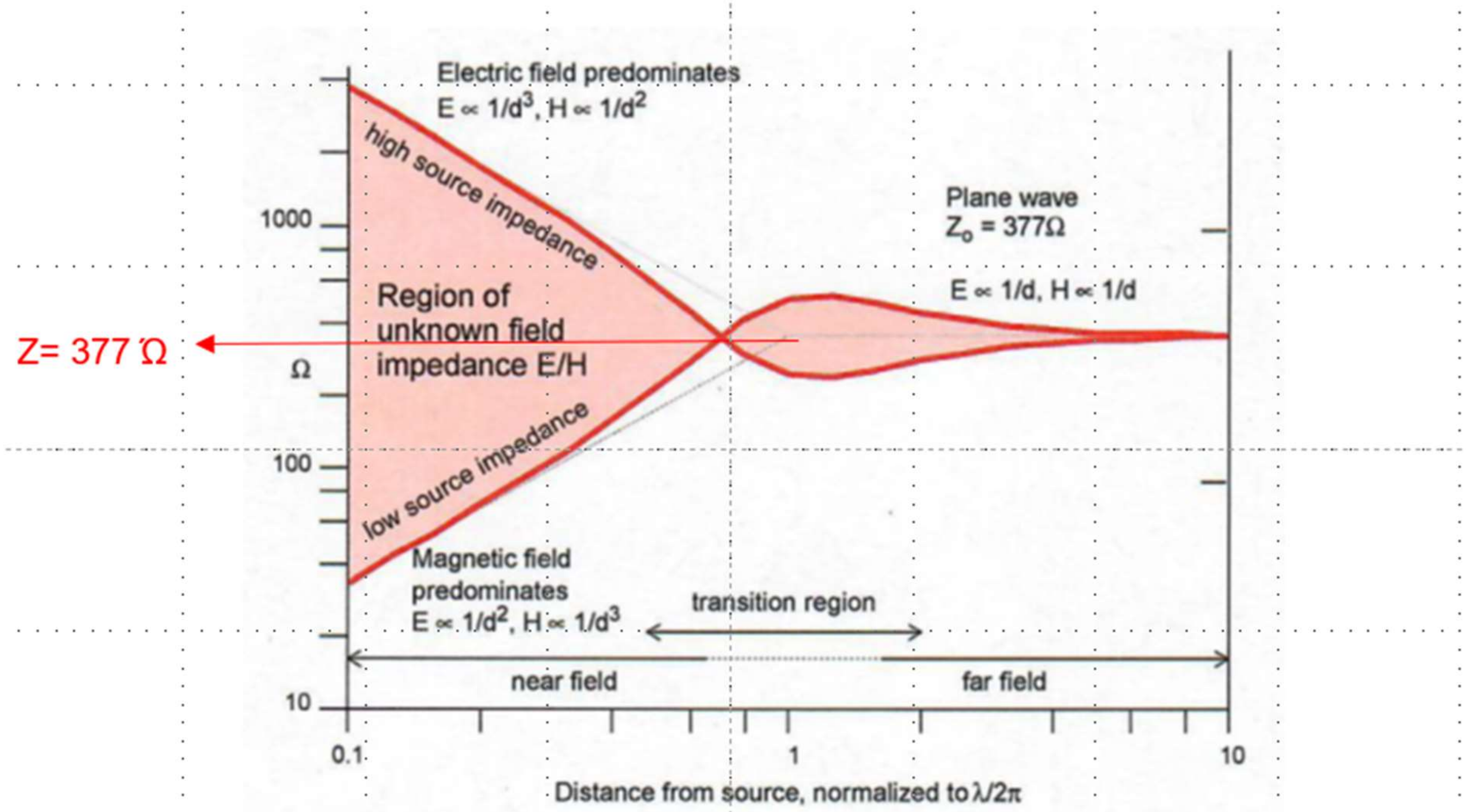
4. Some Basic EM-Theory of ESA (Verticals, Loops) (2b)

Near and Far Field of a Whip Antenna (Monopole)



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

Near and Far Field (Source: Schaffner Guide 2001)



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

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**

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

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

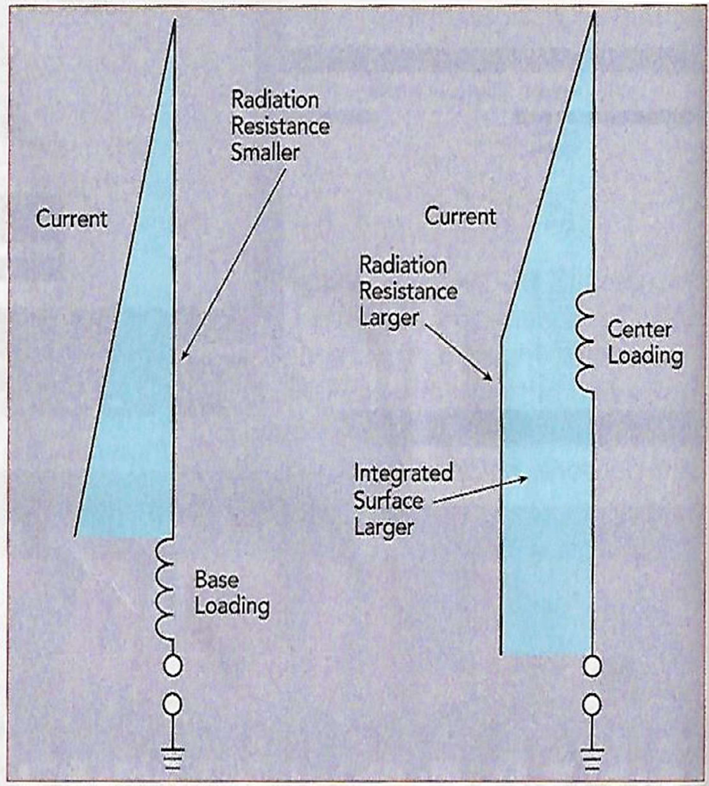


Fig. 9 Center loading a whip antenna creates a larger integrated surface for the current than base loading, which improves radiation.[6] The two figures are not to scale.

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

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

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)
- 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**)

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

Near Field (NF) / Far-Field (FF)

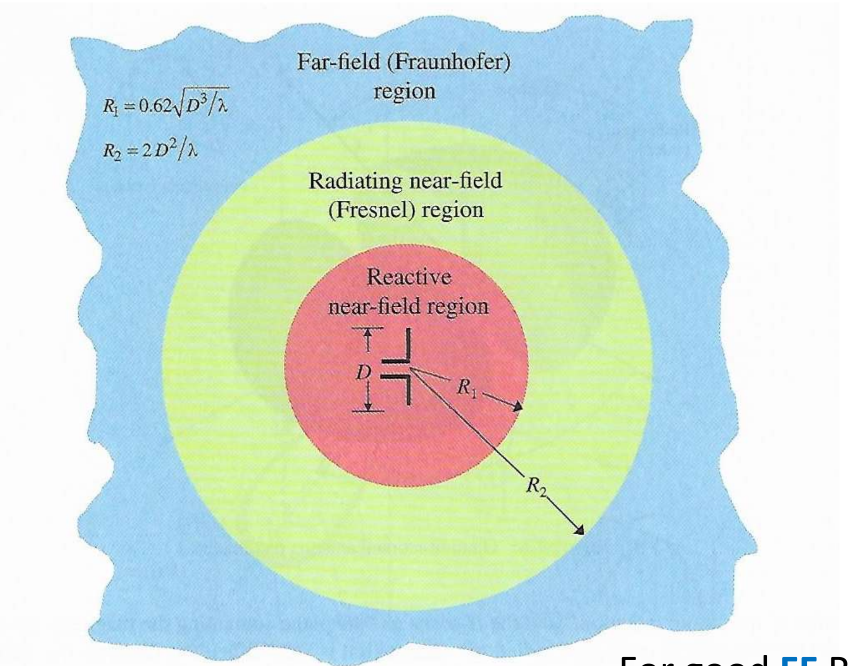
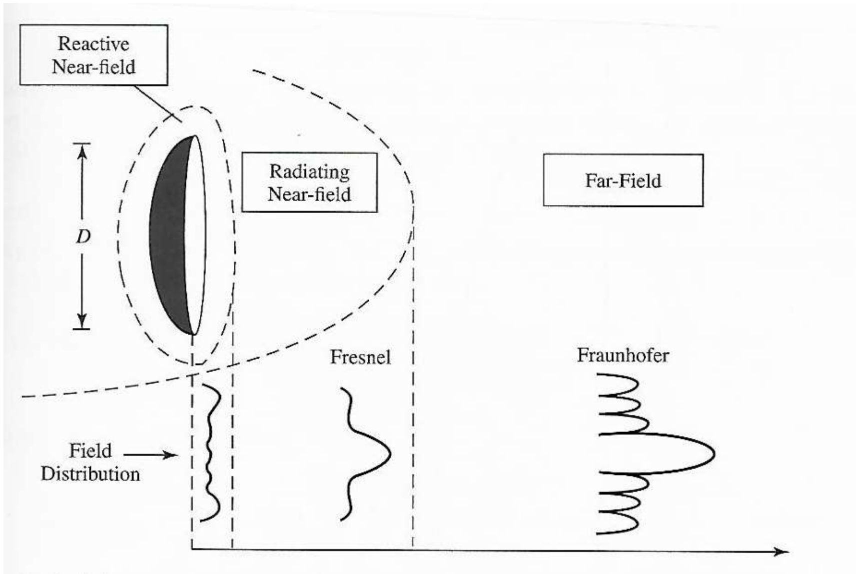


Figure 2.7 Field regions of an antenna.



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)

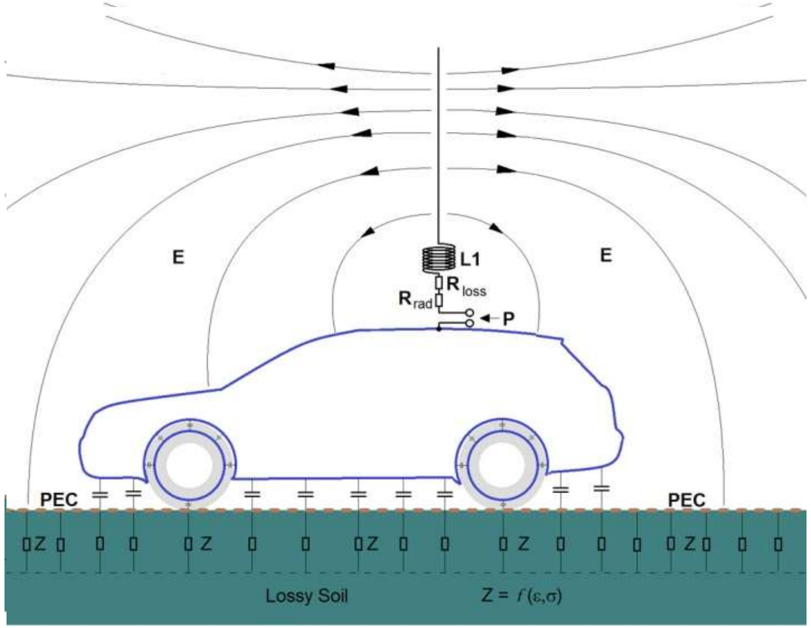
Source: C. Balanis , Antenna Theory, Analysis and Design , 4. Ed. **2016**, John Wiley & Sons Inc., ISBN 987-1-118-642060

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

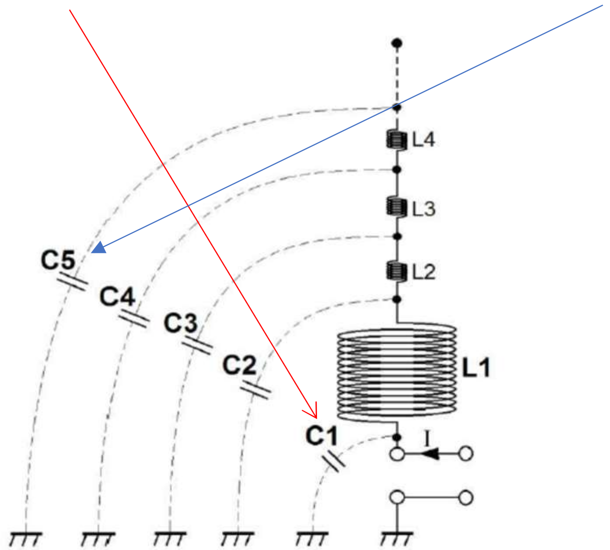
Equivalent Circuit Model for an el. short, <u>transmitting</u> vertical Monopole Antenna

- 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)

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

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

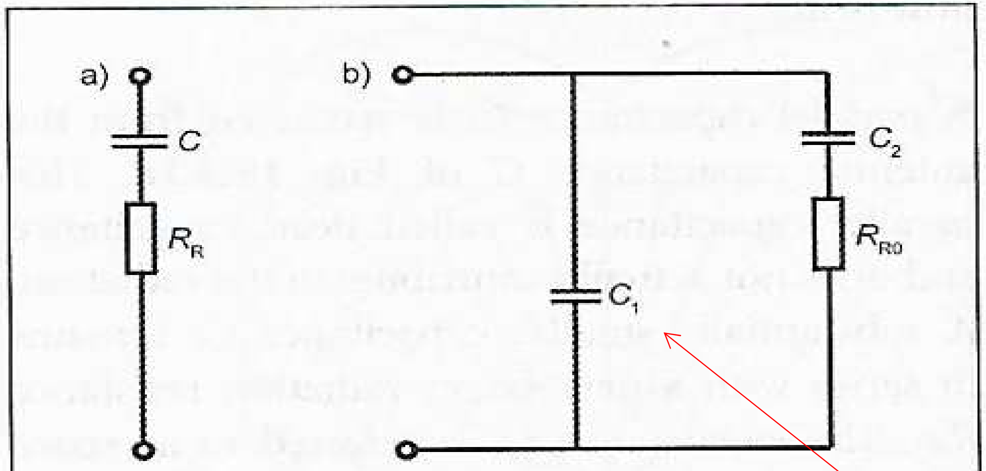


Fig. 19.3.1 Equivalent circuit diagram for short rod radiators
a) initial circuit b) revised circuit

C2 = Space/Room Capacitance (Radiation)

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

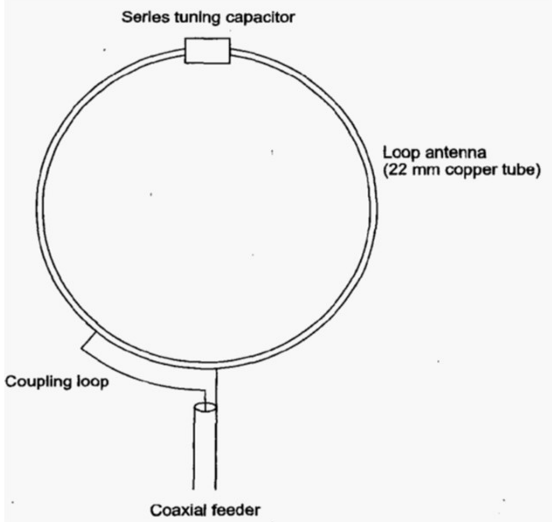
Application to *minimize* **Antenna** to **Car Stray Capacitance ->** Conical Radiator Design

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)

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

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



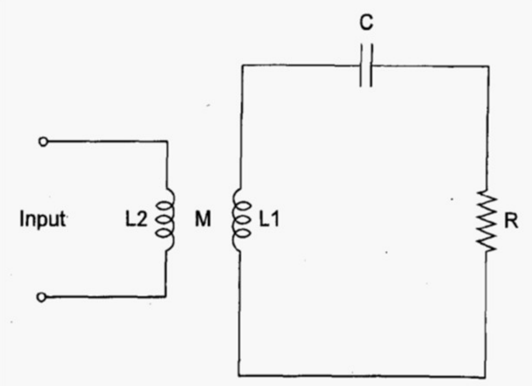


Figure 1. The equivalent circuit of the loop. L_1 **: main loop;** L_2 **: coupling loop;** M **: mutual inductance;** C **: resonating capacitance;** R **: total resistance.**

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

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

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

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

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**

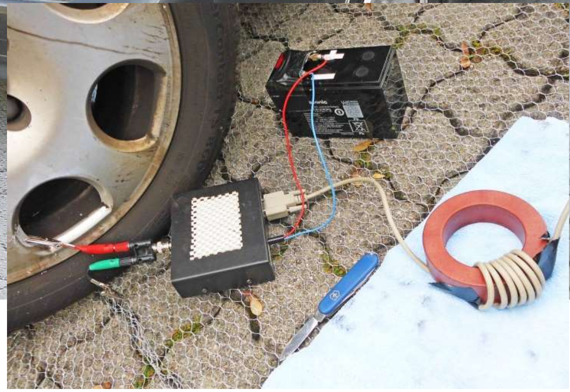
5. Complex Simulation Model (Car, Tires, ESA, Soil) *based on Tests* (1)

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

VNA Capacitance Tests:

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

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



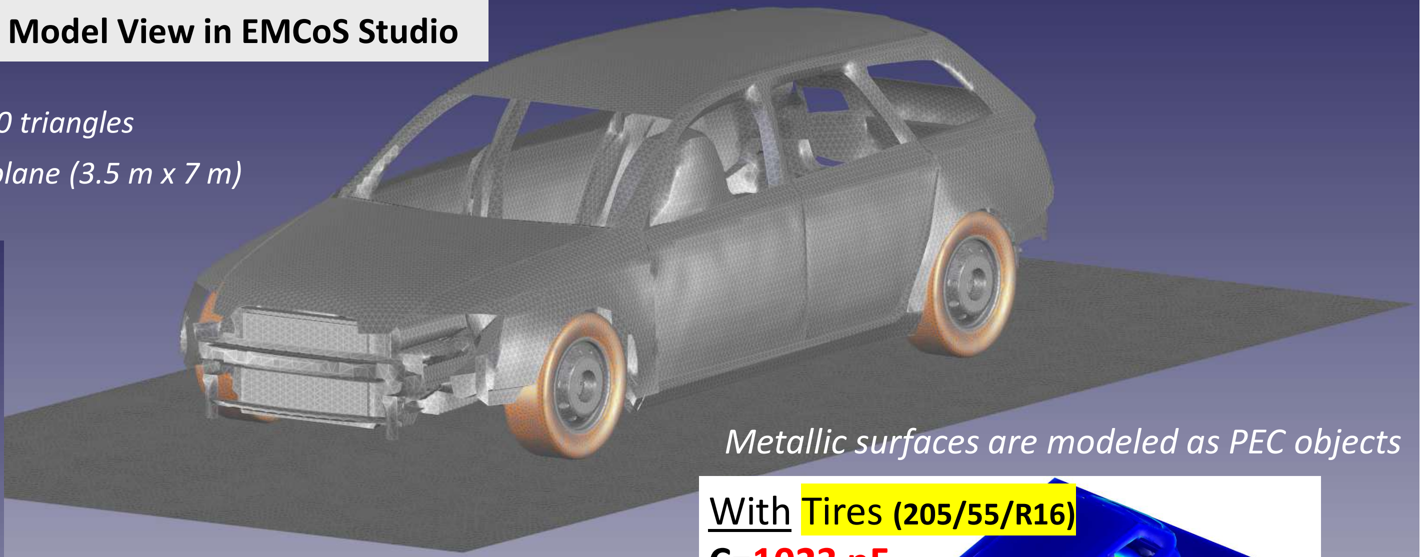
Automotive Electromagnetic Compatibility:
Prediction and Analysis of Parasitic Components in Conductor Layouts, Sabine Alexandersson, Lund Univ. Sweden, Ph.D. Thesis **2008**

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

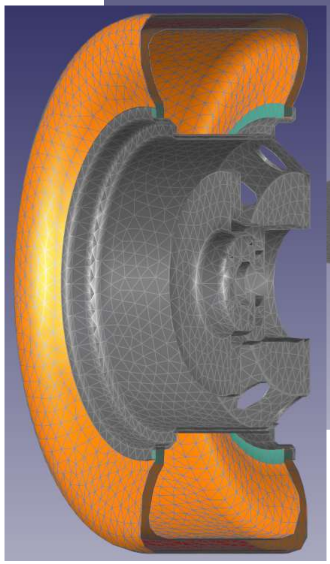
Electro-Static-Simulation Model (Audi A6 Avant Car Body / Rim / Break Disk / Tire):

Simulation Model View in EMCoS Studio

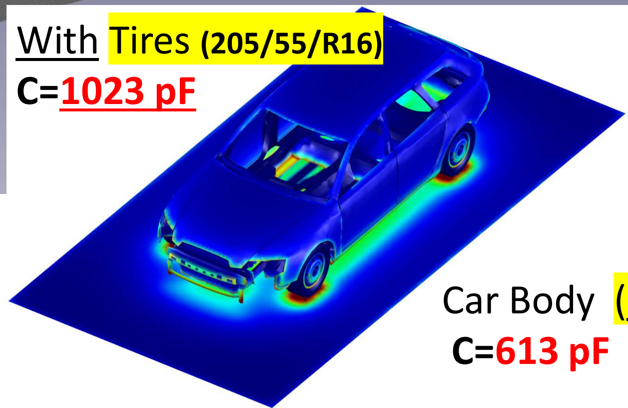
- *~ 240 000 triangles*
- *Ground plane (3.5 m x 7 m)*



Metallic surfaces are modeled as PEC objects



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



With Tires **(205/55/R16)**
C=1023 pF

Car Body (no Tires)
C=613 pF

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,

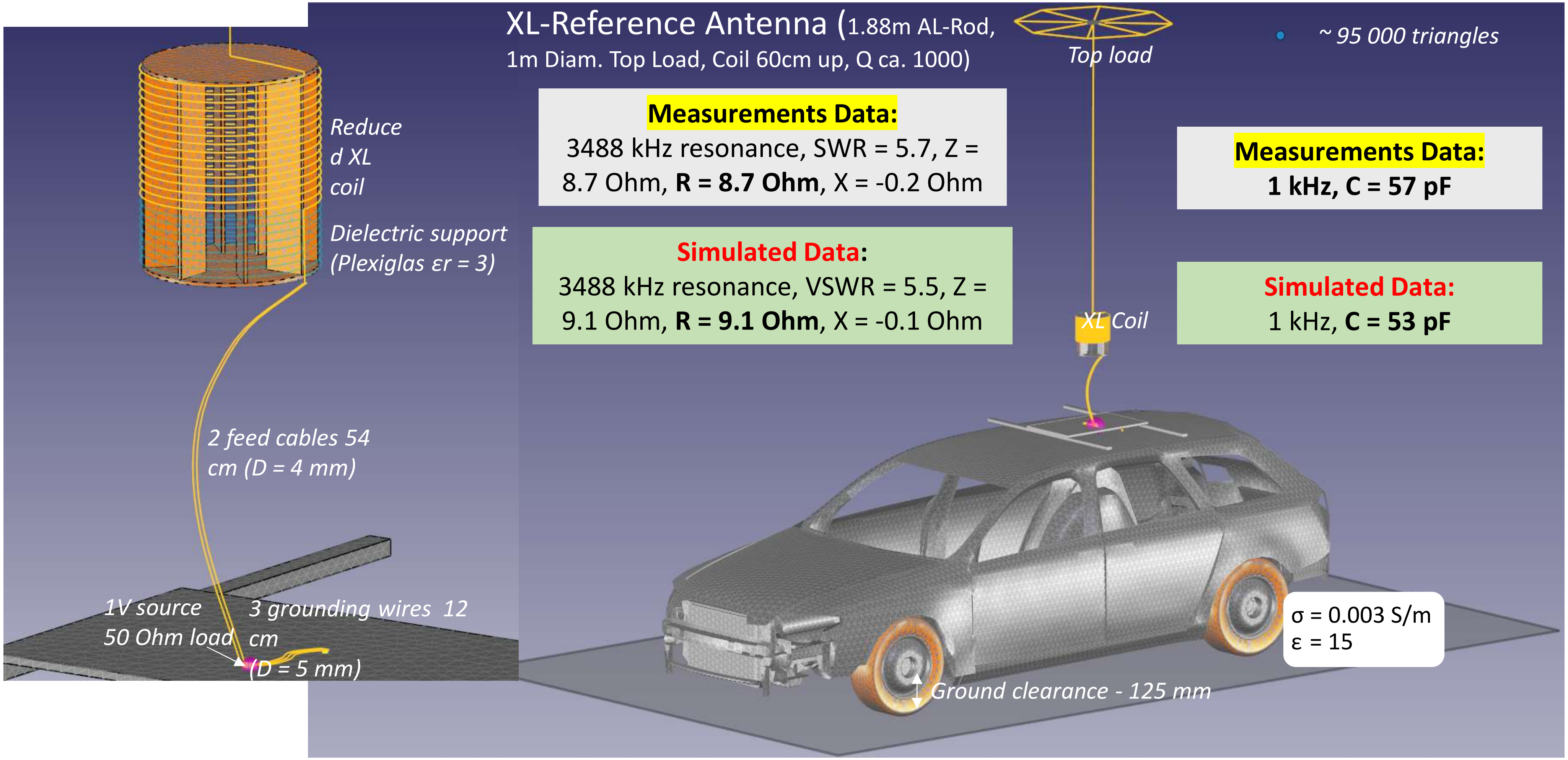
XL-Reference Antenna (1.88m AL-Rod, 1m Diam. Top Load, Coil 60cm up, Q ca. 1000)

Measurements Data:
3488 kHz resonance, SWR = 5.7, Z = 8.7 Ohm, **R = 8.7 Ohm**, X = -0.2 Ohm

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

Measurements Data:
1 kHz, C = 57 pF

Simulated Data:
1 kHz, **C = 53 pF**



5. a) 160/80/40m ESA Reference Antennas for Simulation and Testing (4)

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**

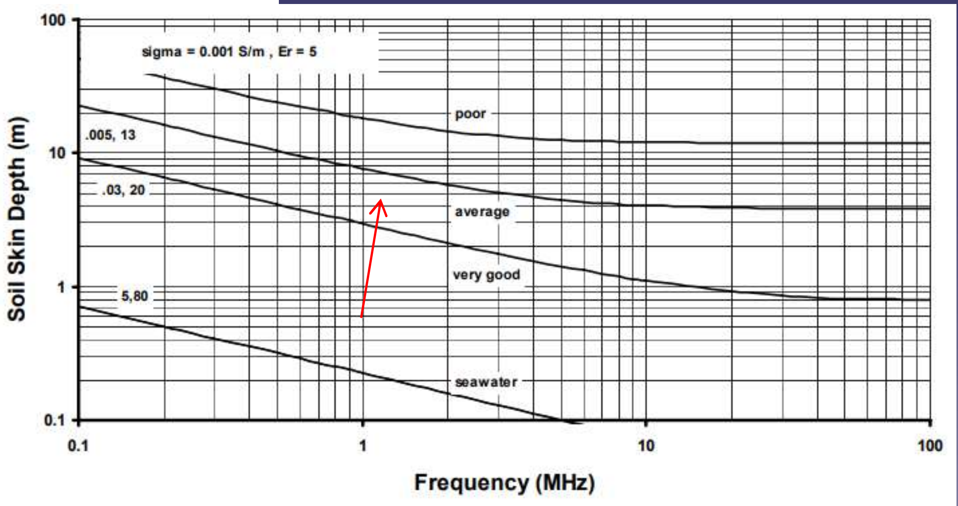
40m, 7MHz, Coil **L**

40m, **λ/4** vs. Car-Body

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

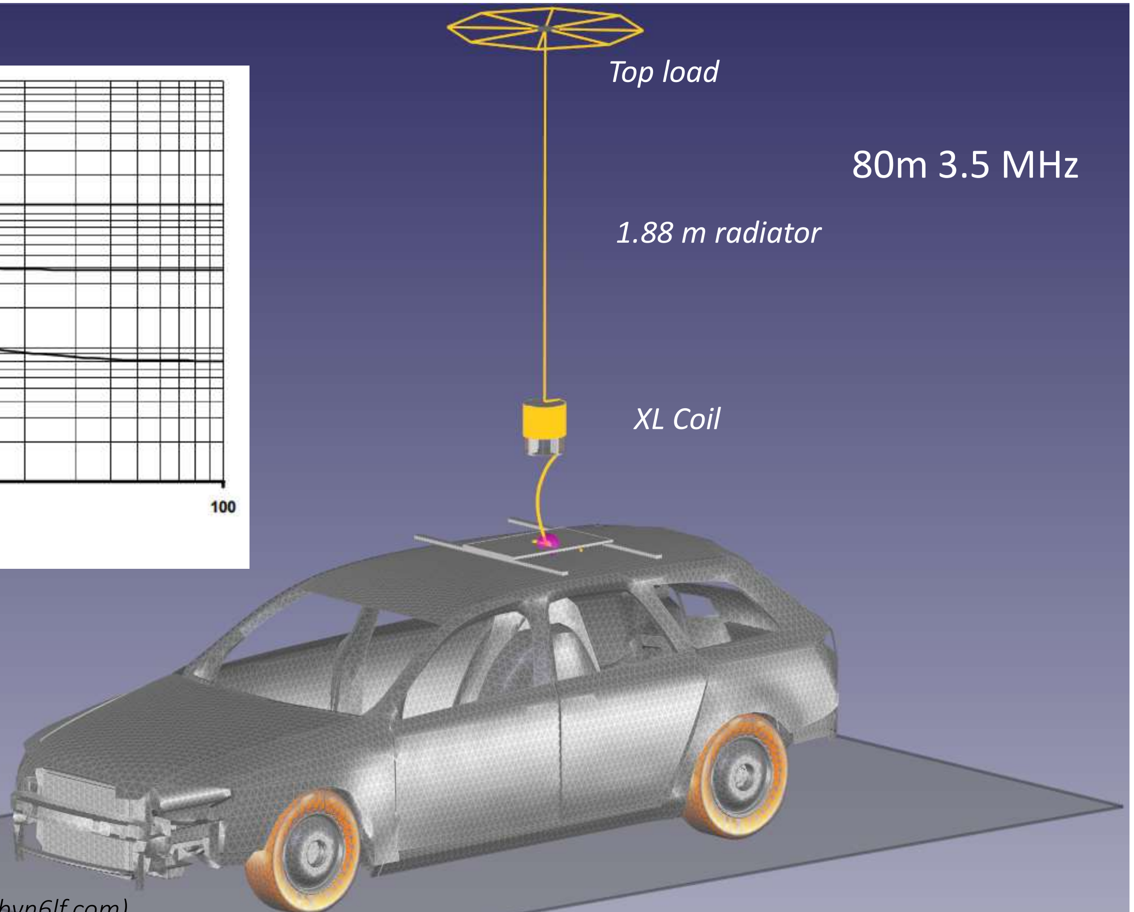
Simulation Data (Audi A6 Car Body, Antenna, XL Coil, Top Load):

- *~ 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

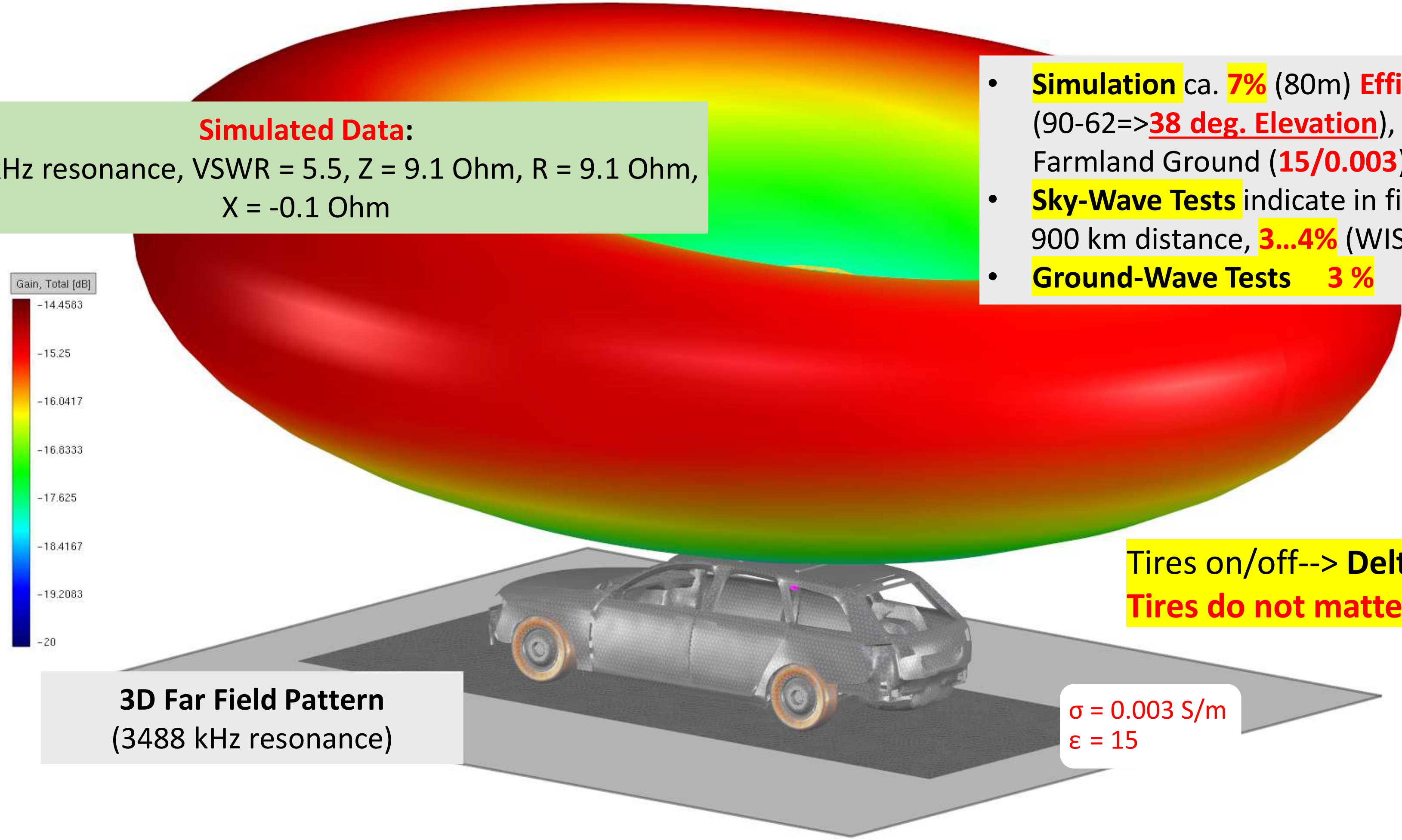


5. b) Complex Simulation Model (Car, Tires, Vertical ESA, Soil) (6)

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.

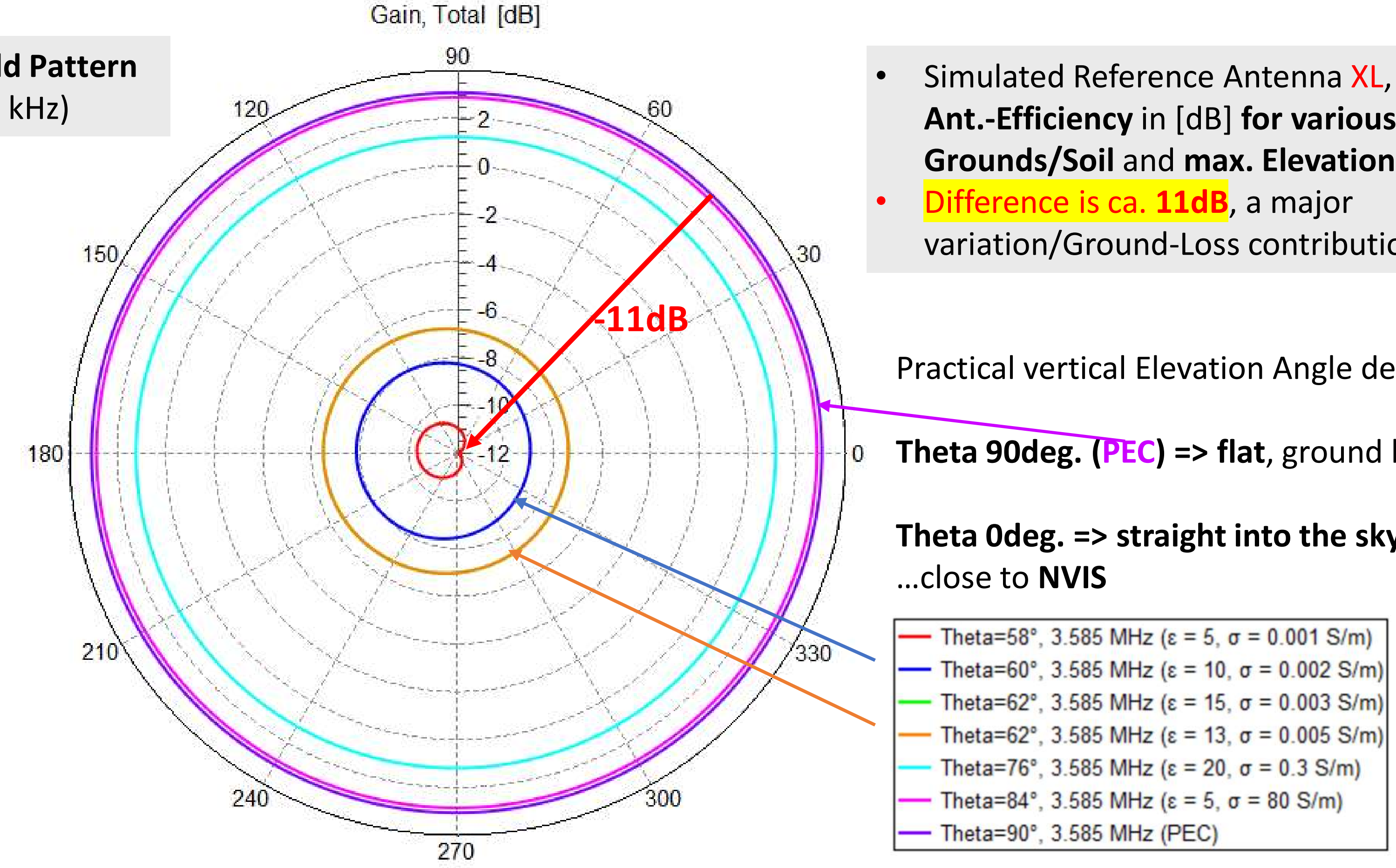
3D Far Field Pattern
(3488 kHz resonance)

σ = 0.003 S/m
ε = 15

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

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:

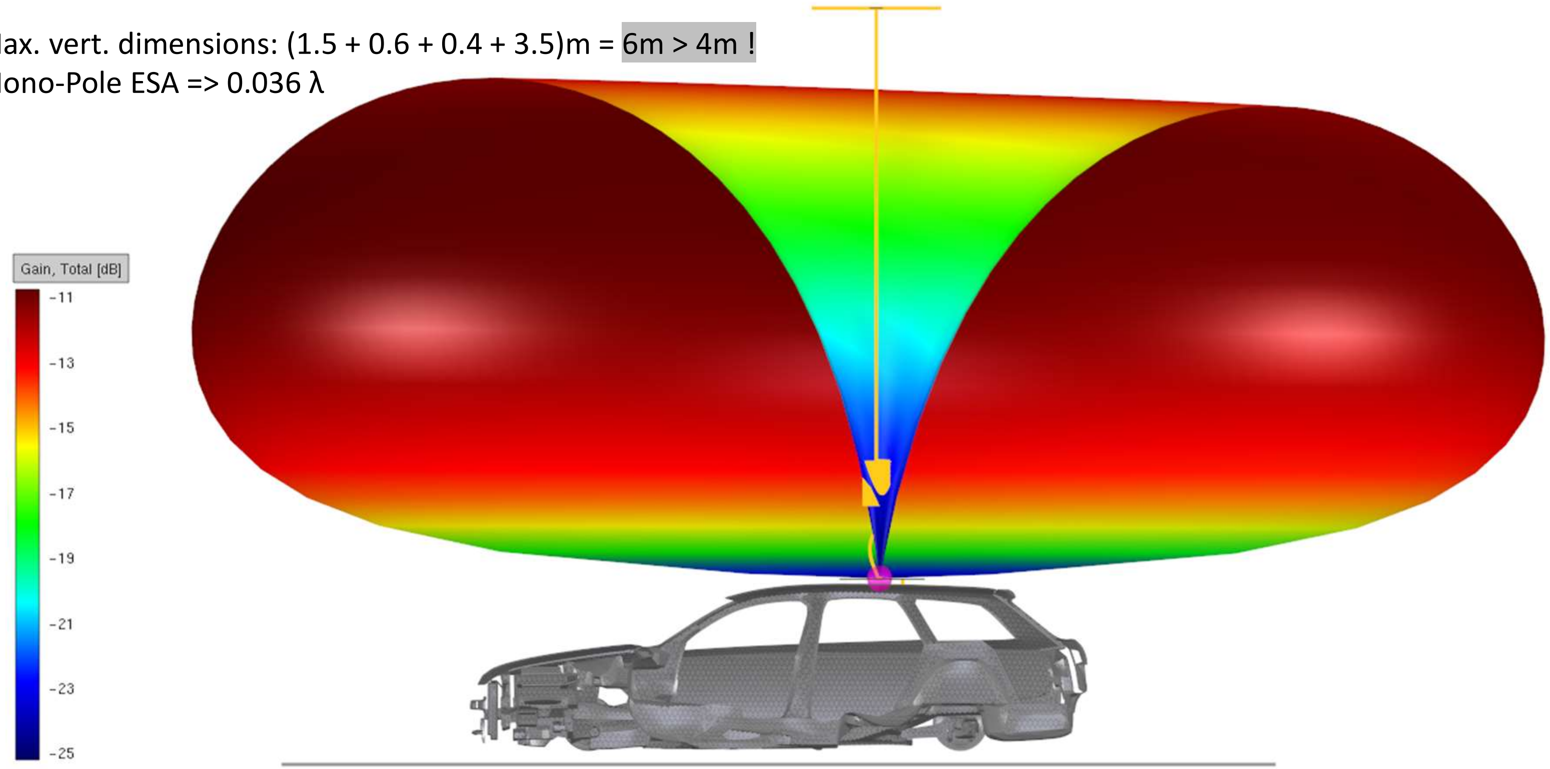
Theta 90deg. (PEC) => flat, ground level

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

5. b) Complex Simulation Model (Car, Tires, Vertical ESA, Soil) (8)

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

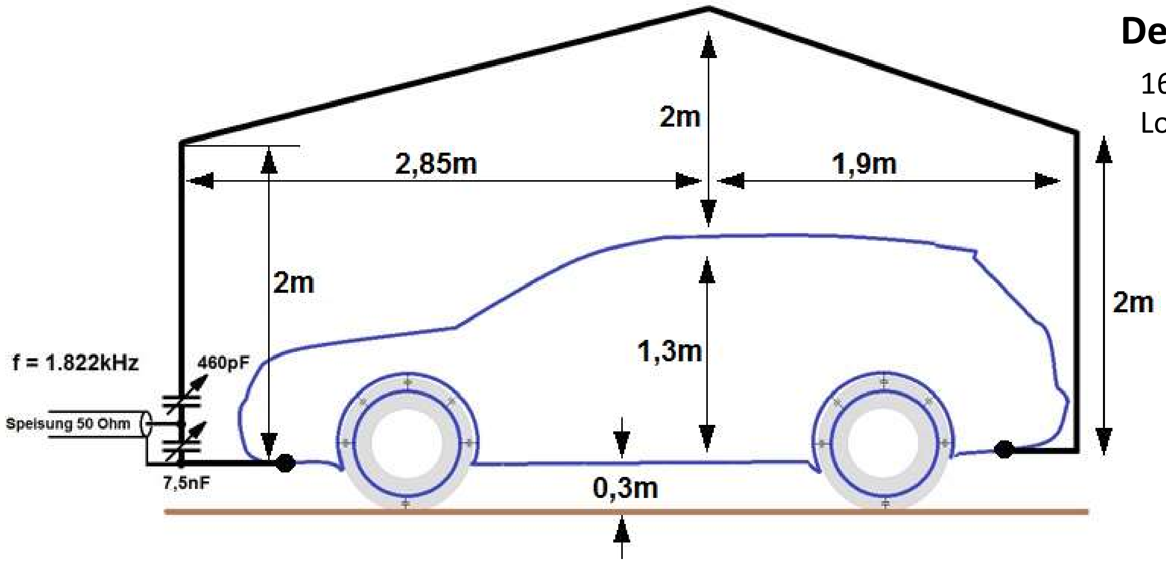


Antenna Efficiency
~ 2.6% at 1800 kHz

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

5. b) Complex Simulation Model (Car, Tires, Loop ESA, Soil) (9)

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

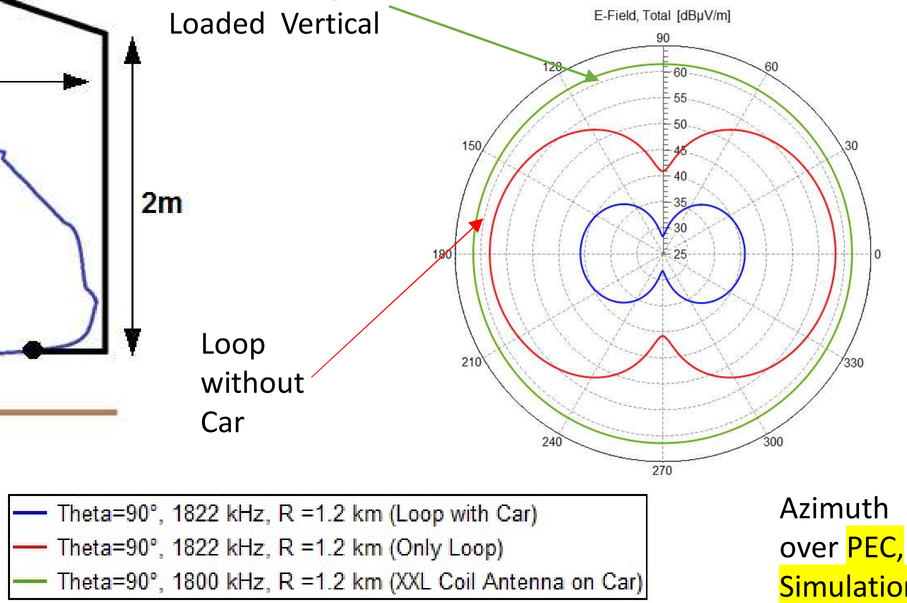


Comparison Theory/Simulation
Monopole XXL 160m →160m **Loop**
Delta ~-20dB over PEC ! ? *Work **is still** ongoing*

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

160m MP XXL, TP
Loaded Vertical

Loop
without
Car



Azimuth
over PEC,
Simulation

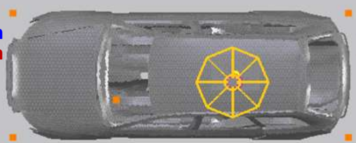
5. c) Some EMF considerations (human safety V/m, A/m vs. distance) (1)

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

Z = 1.2 m above ground

Car above Real Ground
(ε = 10, σ = 0.002 S/m)
f = 3585 kHz

Measured Total H Field
Simulated Total H Field



EMF Limit 3.5MHz (6min)
(Germany 26.BlmSchV)
E= 47V/m
H Limit = 0.2A/m = -14dBA/m

(margin @ 20W => +7dB)
TX 20W up to 80W-> (+6dB)

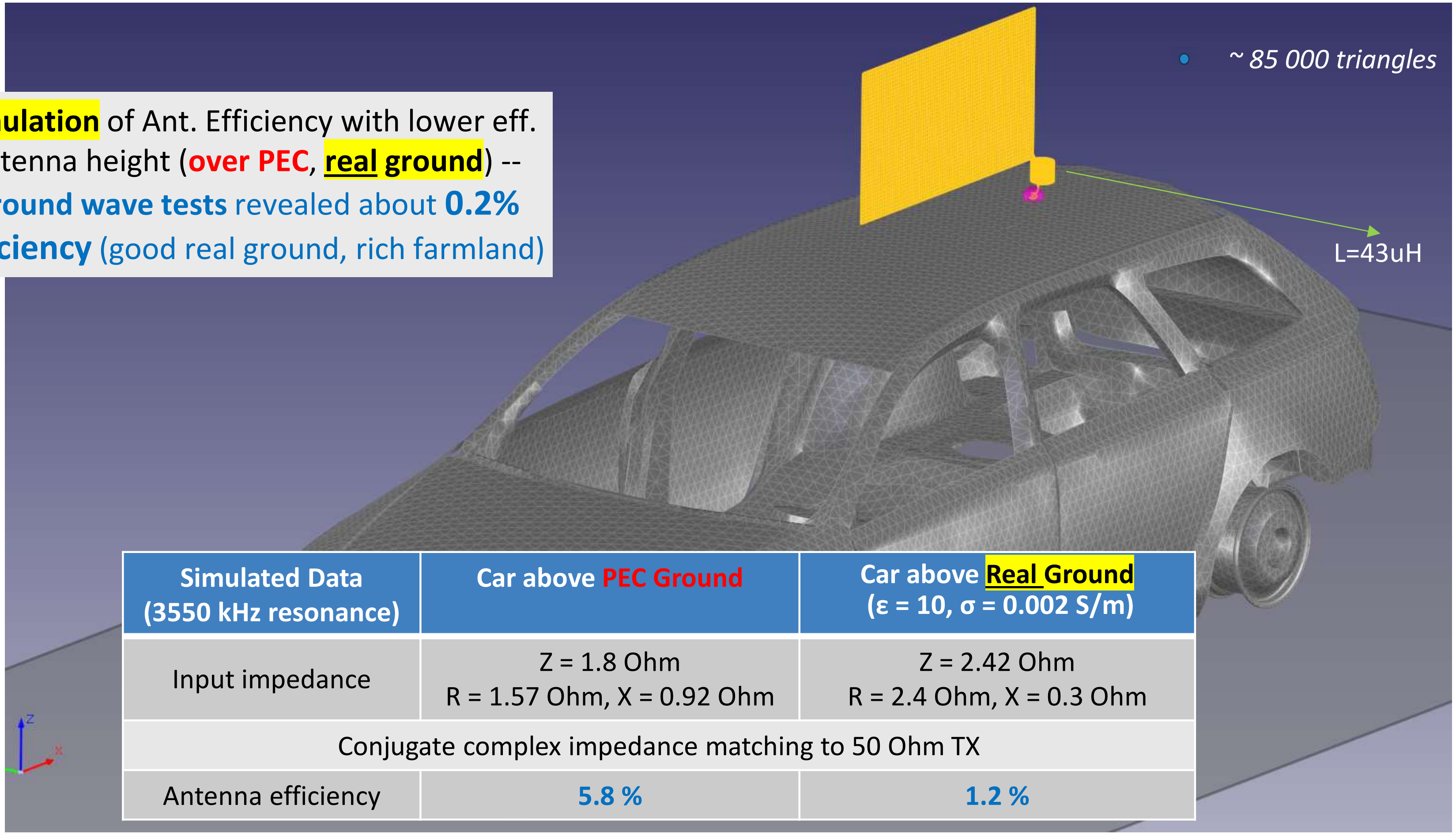
Near-Field (mag. H-Field)
around the Audi A6, on an **asphalted parking lot**,
@ 3585 kHz / 80m

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

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

5. c) Some EMF considerations (human safety V/m, A/m vs. distance) (2)

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

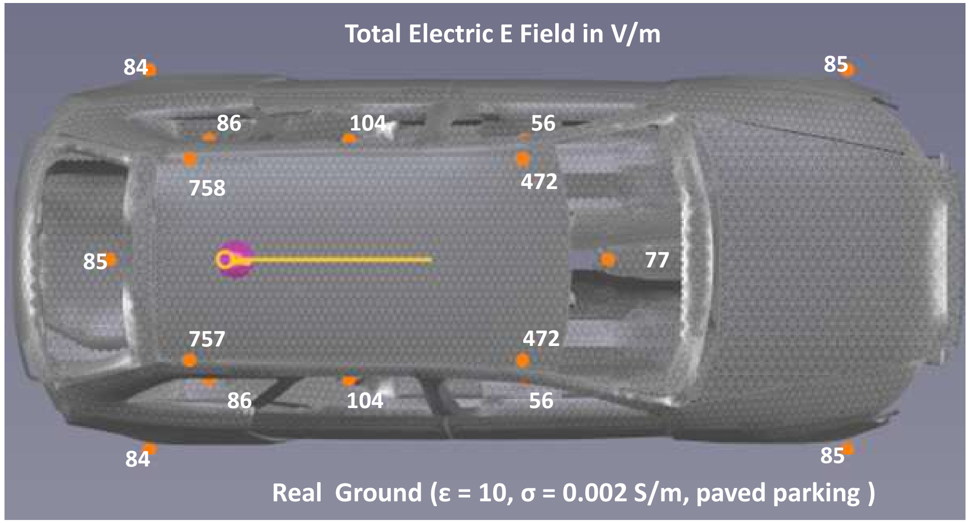


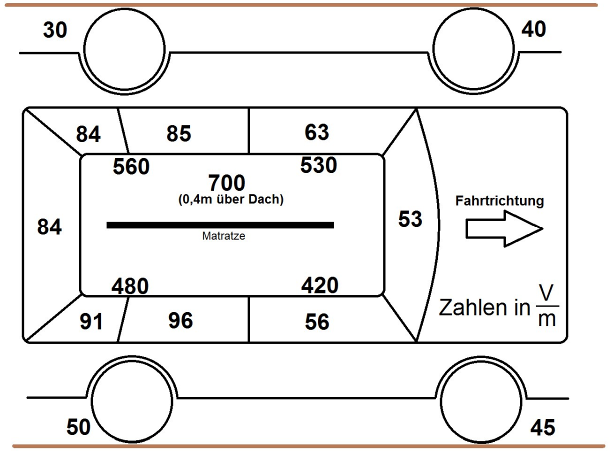
Simulation of Ant. Efficiency with lower eff. antenna height (**over PEC**, **real ground**) -- **Ground wave tests** revealed about **0.2% efficiency** (good real ground, rich farmland)

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 %**

5. c) Some EMF considerations (human safety V/m, A/m vs. distance) (3)

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**

6. 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

6. 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 <u>same</u> Soil Conditions

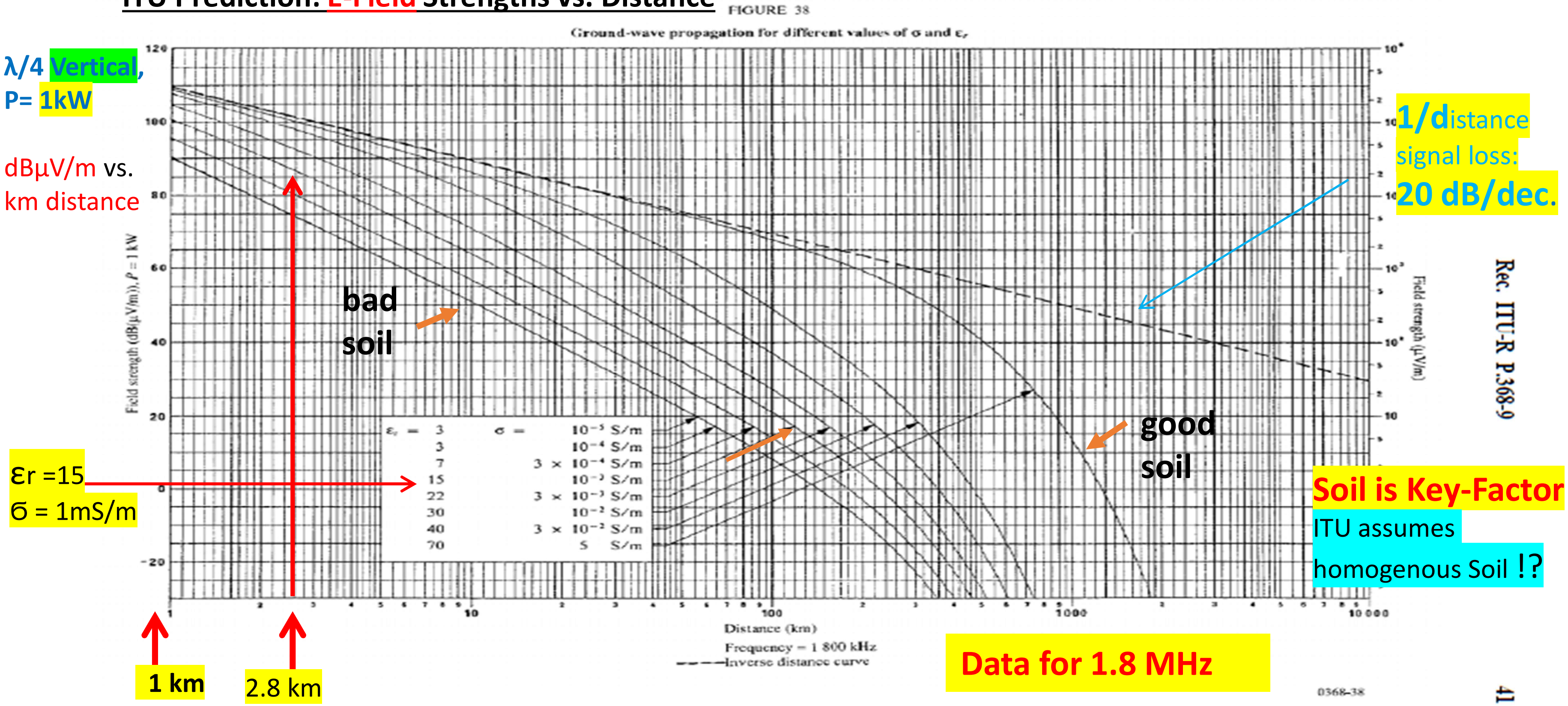
6. Experimental Radiation Efficiency Antenna Comparison (3)

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

6. Experimental Radiation Efficiency Antenna Comparison (4)

160m Groundwave Test over 2.74 km flat farmland

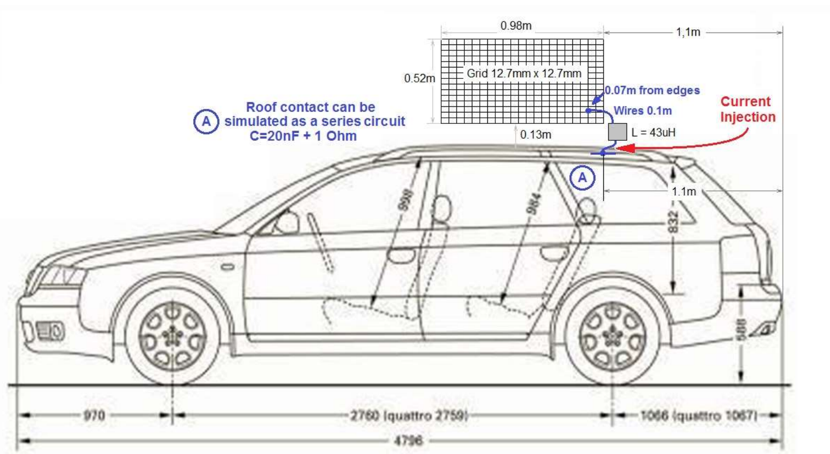
Groundwave small HF-mobile Antenna-Comparison-Tests (HB9CVQ and group 2017 to 2019)				
	Ant. Name/Type	Test Result in **[dB]** -with manual low loss tuner used- **6dB=1 S-Unit** (IARU)	Photo # HB9CVQ QRZ.com	Comment Status: 07-April-2021
160m	XXL EM-Simulated Reference-homemade	**0 dB** (Reference) **~ 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

6. Experimental Radiation Efficiency Antenna Comparison (5)

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.)

6. Experimental Radiation Efficiency Antenna Comparison (6)

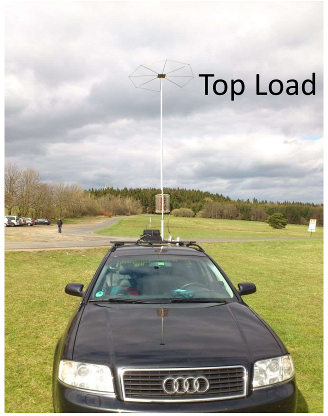
80m Groundwave Test over 2.74 km flat farmland

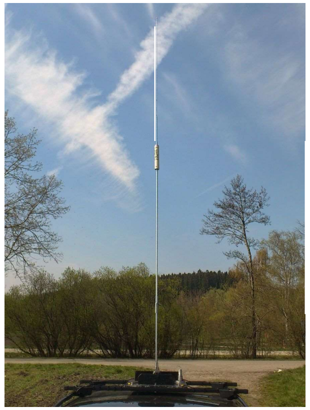
Groundwave small HF-mobile Antenna-Comparison-Tests (HB9CVQ and group 2017 to 2019)				
	Ant. Name/Type	Test Result in **[dB]** -with manual low loss tuner used- **6dB=1 S-Unit** (IARU)	Photo # HB9CVQ QRZ.com	Comment Status: 07-April-2021
80m	**XL** EM-Simulated Reference-homemade	**0 dB** (Reference) **~ 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

6. Experimental Radiation Efficiency Antenna Comparison (7)

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-50 Ohm-Rod** (forced input matching)

6. Experimental Radiation Efficiency Antenna Comparison (8)

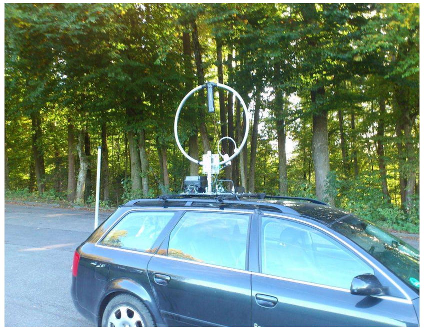
40m Groundwave Test over 2.74 km flat farmland

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)

6. Experimental Radiation Efficiency Antenna Comparison (9)

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**

7. Antenna efficiency impacting factors (1)

What makes a more effective ESA System (160/80/40m), aside from **good HF-Propagation, S/N Ratio** and **good QTH** ?

- **Effective Antenna Height** of the system (“ length ” e.g., compared to λ/4 Monopole)
- **Soil** => Over **PEC** (or Saltwater) even a Vertical ESA can reach **41%** (XXL **160m**) to **94%** (L **40m**) Radiation Efficiency
- **Take-off angle**/Polarization (**NVIS/DX**), clear **Near-Field** (NF) Environment (**secondary radiator coupling**)
- Maximize **Space (Room) Capacitance**….current radiates, voltage too
- Minimize local (NF) **Stray-Capacitance** (Dead Cap.) => use conical radiator
- Use Hi-Q coils to compensate (**resonate**) …using a tuner to resonate a rod can be very lossy!
- Even smaller **Hi-Q Coils will radiate** ! (EA8 QRP Case)
- **Longer (lower-Q) Coils** (Screwdriver-e.g., Tarheel) will most definitely **radiate**! …even without whip
- Added Top Capacitance lowers needed **(lossy) Inductance** BTW: **good automotive EMC !! ... << EMI**

8. Conclusions (1)

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/some 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** (Tires, Soil, Elevation Angle, System Losses …)
- We build, tested, simulated suitable **Reference Antennas** for Ant. Performance Comparisons
- There is **reasonably good Correlation between** the **various Analysis Methods**
- Establishment of "**Performance Ranking List**" between Commercial/Proto-Type Antennas
- Some tests and a few, still open simulations, incl. el. **small mag. Loop Antennas** need to be done
- 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**

9. Project Outlook (future R&D topics), Literature (1)

- We covered short, **vehicular HF –Whip/**some **mag. Loop** Antennas
- **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**
- **Ionospheric Propagation** on Low Bands is presently **mostly mediocre.**
- **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** can still lead to a **positive + Signal Balance**
  (We need to do WISP tests)
- **Mag. Loops** are known to have **better Signal/Noise Ratio** (S/N) => may therefore **reduce local** some **EMI**
- First **Experiments** done with an el. small **magnetic half loop over the car** and max. dimensions (**4m Height Limit**)
- **Outlook:** Finally, we try to **combine DX and NVIS** (respecting 4m Height Limit)

Further Literature (1)

[1] Measurement Methodology and Results of Measurements of Man-Made Noise Floor on HF in The Netherlands, T.W.H. Fockens, A.P.M. Zwamborn, F. Leferink, IEEE Transactions on EMC, Vol 61, No. 2, April **2019**

[1a] Antennas for all Applications, 3. Ed., John D. Kraus et. al, McGraw-Hill ISDN 0-07-112240-0, **2002**

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Thank you for your kind attention => Any Questions or Comments ?

We always try to learn more!

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