# Extremely Low Frequency Magnetic Fields inside Electric Vehicles

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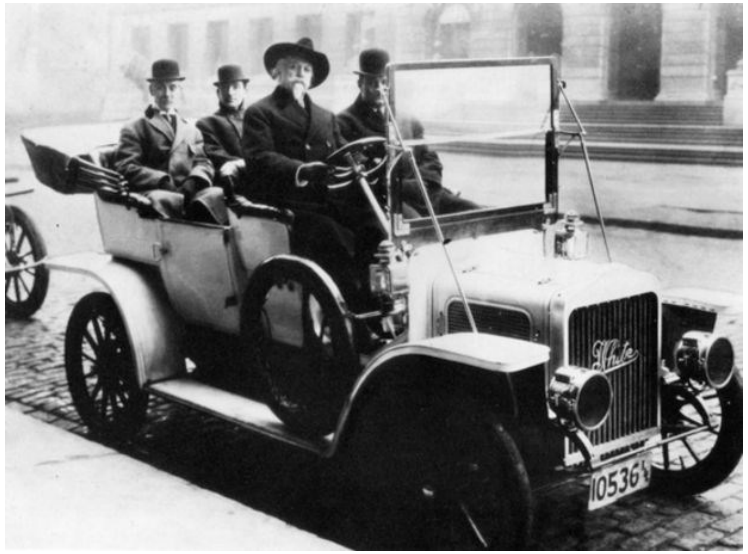
# Summary

- Introduction
  - Electric vehicles
  - Exposure guidelines
  - ELF effects on human body
  - Contribution
- Material and Methodology
- Results
- Conclusions and Future work

# Early 1900s…

- **Steam-powered engines**
  - Speed
  - Less expensive
  - Long time to fire up
  - Frequent stops for water




Model O Steamer (1904)

# Early 1900s…

- **Gasoline-powered internal combustion engines**
  - Dirtier
  - More difficult to start
  - Moderately more expensive
  - They could travel longer distances at a reasonable speed without stopping

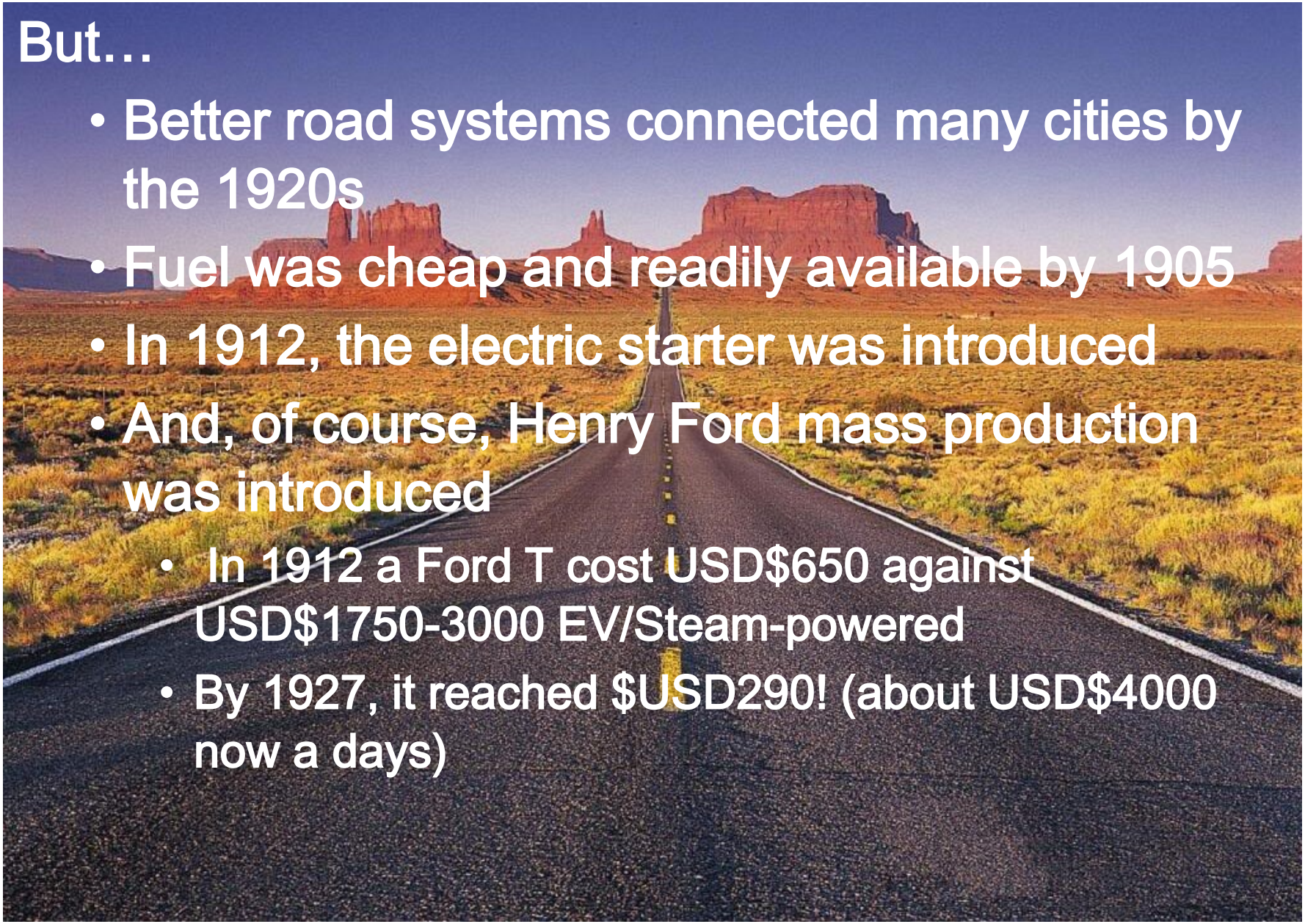
Winton Phaeton (1899)

# Early 1900s…

- **Electric vehicles**
  - Clean
  - Quiet
  - Slow
  - Expensive

City and Suburban
Electric Victoria (1902)

Babcock Electric
Coupé (1912)

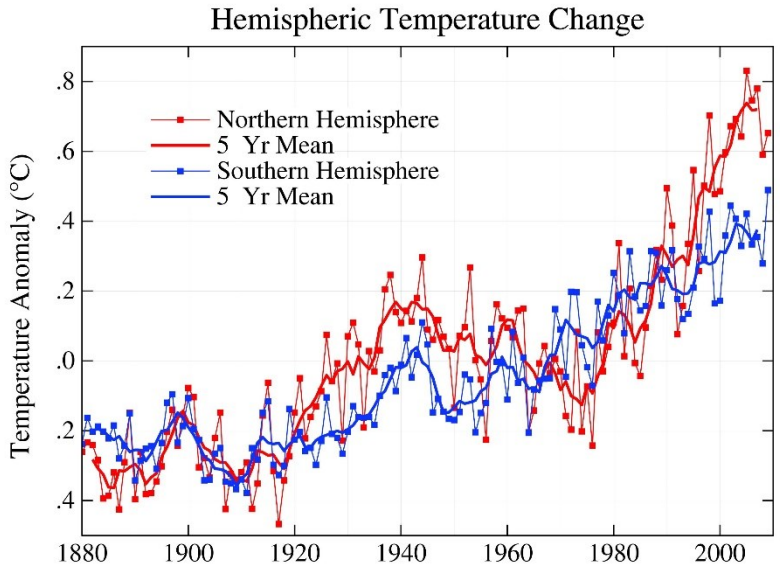


# But…

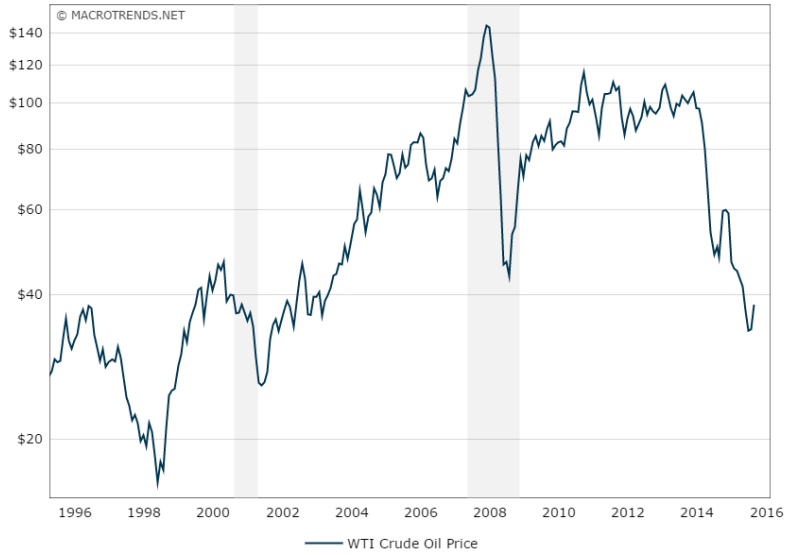
- Better road systems connected many cities by the 1920s
- Fuel was cheap and readily available by 1905
- In 1912, the electric starter was introduced
- And, of course, Henry Ford mass production was introduced
  - In 1912 a Ford T cost USD$650 against USD$1750-3000 EV/Steam-powered
  - By 1927, it reached $USD290! (about USD$4000 now a days)

# Early 2000s…

- The global warming concept
- Rising oil costs

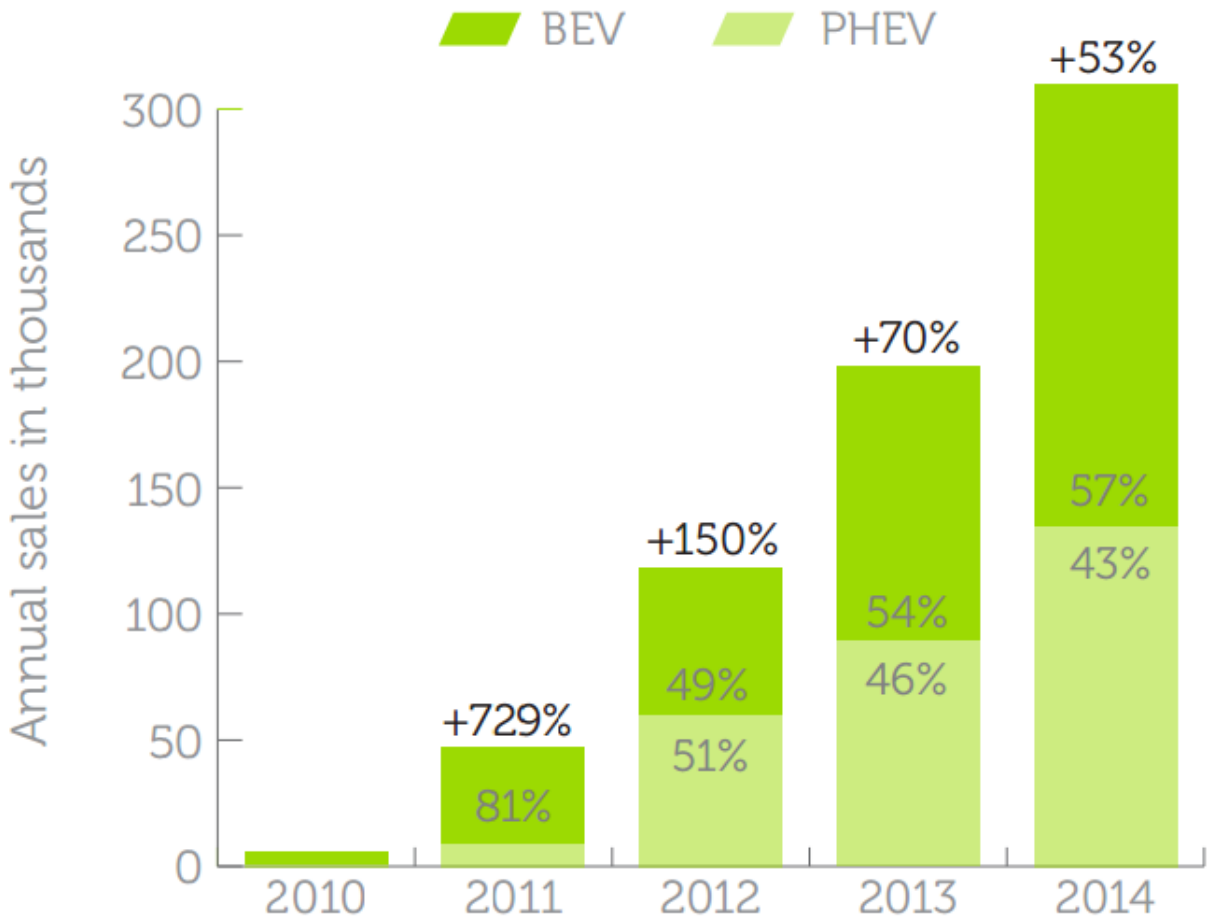



http://www.giss.nasa.gov/research/news/20100121/




http://www.macrotrends.net/1369/crude-oil-price-history-chart

# EV Market evolution




http://www.iea.org/evi/Global-EV-Outlook-2015-Update_1page.pdf

BEV - Battery Electric Vehicle
PHEV - Plug-in Hybrid Electric Vehicle

# EV Market evolution

- Charging infrastructure deployment has continued growing
- Battery costs have come down
- Energy density has climbed
- Vehicle electrification has gone multi-modal
  - 46 000 electric buses and 235 million electric two-wheelers deployed

# EU/ICNIRP 1998 Exposure Guidelines

- ICNIRP - International Commission on Non-Ionizing Radiation Protection
- Guidelines For Limiting Exposure To Time-varying Electric, Magnetic, And Electromagnetic Fields (up To 300 GHz) – 1998
- Later, these guidelines where updated and divided in three frequency ranges: Static fields (0 Hz), LF (1 Hz – 100 kHz), and HF (100 kHz – 300 GHz)

# EU/ICNIRP 1998 Exposure Guidelines

- 1999/519/EC – Council Recommendation on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)
- This Council Recommendation is based on the ICNIRP 1998 Exposure Guidelines
- It recommends that Member States introduce these limits for public exposure with certain provisos:
  - taking account of the costs and benefits
  - where the time of exposure is significant

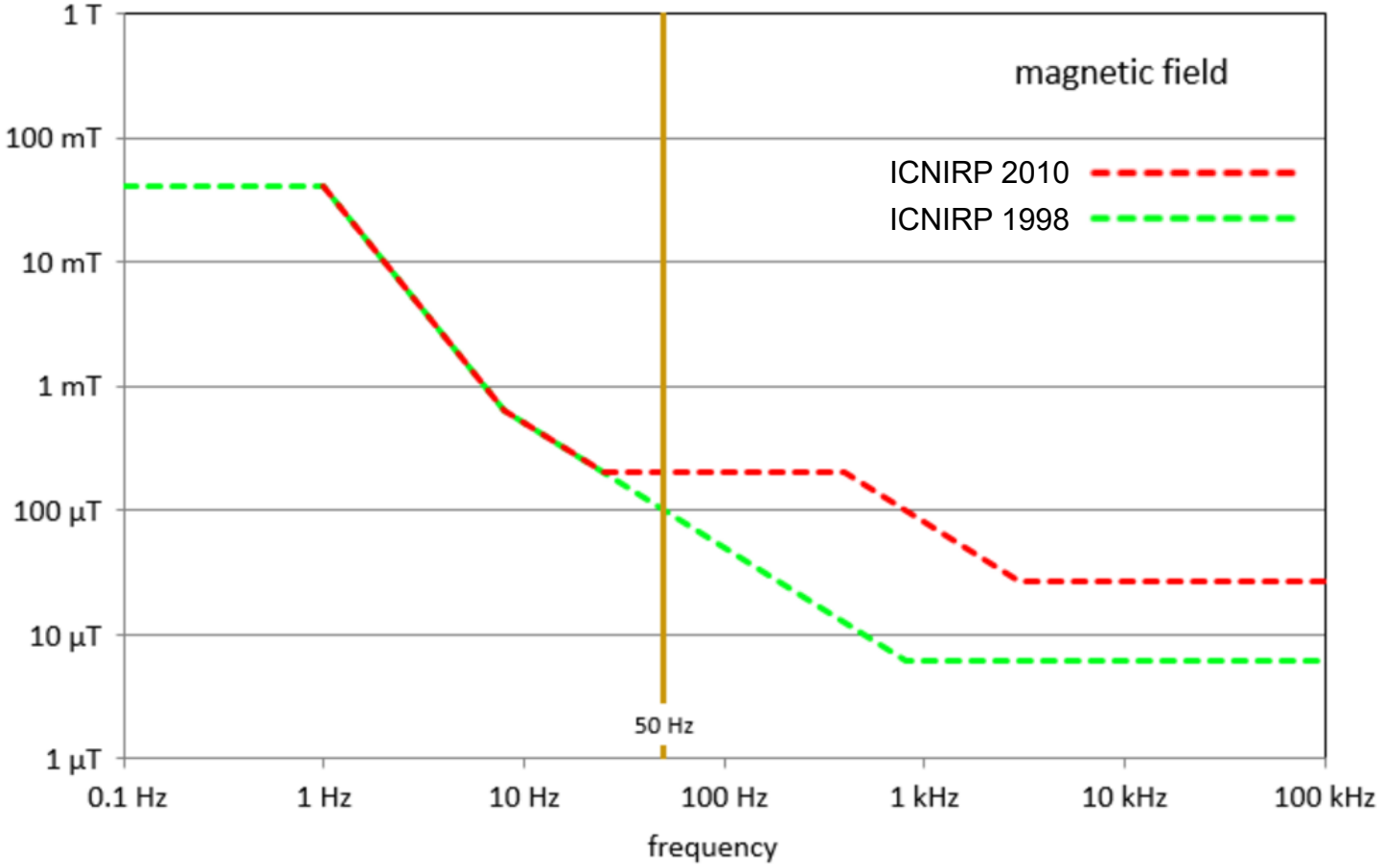
# EU/ICNIRP 1998 Exposure Guidelines

| Frequency range | E-field strength ($V\ m^{-1}$) | H-field strength ($A\ m^{-1}$) | B-field ($\mu T$) |
|---|---|---|---|
| up to 1 Hz | — | $3.2 \times 10^4$ | $4 \times 10^4$ |
| 1–8 Hz | 10,000 | $3.2 \times 10^4 / f^2$ | $4 \times 10^4 / f^2$ |
| 8–25 Hz | 10,000 | $4{,}000/f$ | $5{,}000/f$ |
| | | | |
| 3–150 kHz | 87 | 5 | 6.25 |
| 0.15–1 MHz | 87 | $0.73/f$ | $0.92/f$ |
| 1–10 MHz | $87/f^{1/2}$ | $0.73/f$ | $0.92/f$ |
| 10–400 MHz | 28 | 0.073 | 0.092 |
| 400–2,000 MHz | $1.375 f^{1/2}$ | $0.0037 f^{1/2}$ | $0.0046 f^{1/2}$ |
| 2–300 GHz | 61 | 0.16 | 0.20 |

*f* as indicated in the “Frequency range” column

# EU/ICNIRP 1998 Exposure Guidelines

## General Public Exposure



# EMF effects on human body

- ELF Main interaction:
  - Induction of electric fields and associated currents in tissues
  - Surface electric charge effects
- Electrostatic discharges
  - most sensitive 10% of volunteers at 50–60 Hz ranged between 2 and 5 kV/m
  - 5% found 15–20 kV/m annoying
- Induction of magnetic phosphenes
  - minimum threshold flux density around 5 mT at 20 Hz, rising at higher and lower frequencies

# State of the art and contribution

- Public concern about the MF exposure level from new transportation technologies
- Published studies about magnetic field (MF) levels in electric cars is scarce
- Major sources of MF in cars include the tires and electric currents
  - one study on non-hybrid cars
  - two studies of hybrid cars
  - few studies have systematically compared exposures in both hybrid and non-hybrid cars

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# Measurement Equipment

- Aaronia Spectran NF-5020
  - 1 Hz – 1 MHz
  - Noise floor: Reading bandwidth limitation
- Laptop with Aaronia Spectrum Analizer Software MCS

# Methodology

- MF levels were measured in 3 different vehicles
  - 1 Battery Electric Vehicle (BEV)
  - 1 Plug-in Hybrid Electric Vehicle (PHEV)
  - 1 Diesel vehicle
  - Three different manufacturers
- Measurements along three frequency ranges
  - 30 – 60 Hz
  - 60 – 120 Hz
  - 120 – 3000 Hz

# Methodology

- Measurements at each of the four seats
- Measurements at three different heights
  - Floor level
  - Seat level
  - Head level
- Measurements at:
  - Constant Power: 20kW / 40kW (EV)
  - Constant Speed: 60km/h (Diesel)
- Avoided High Voltage Power Lines

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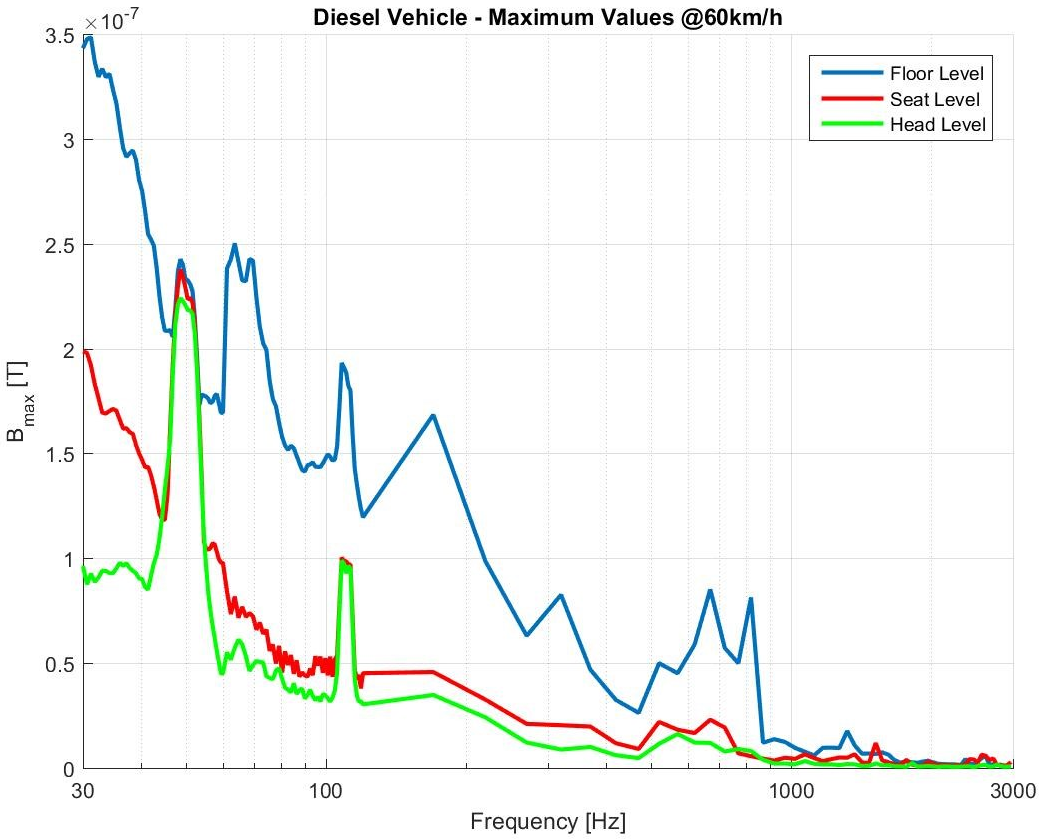
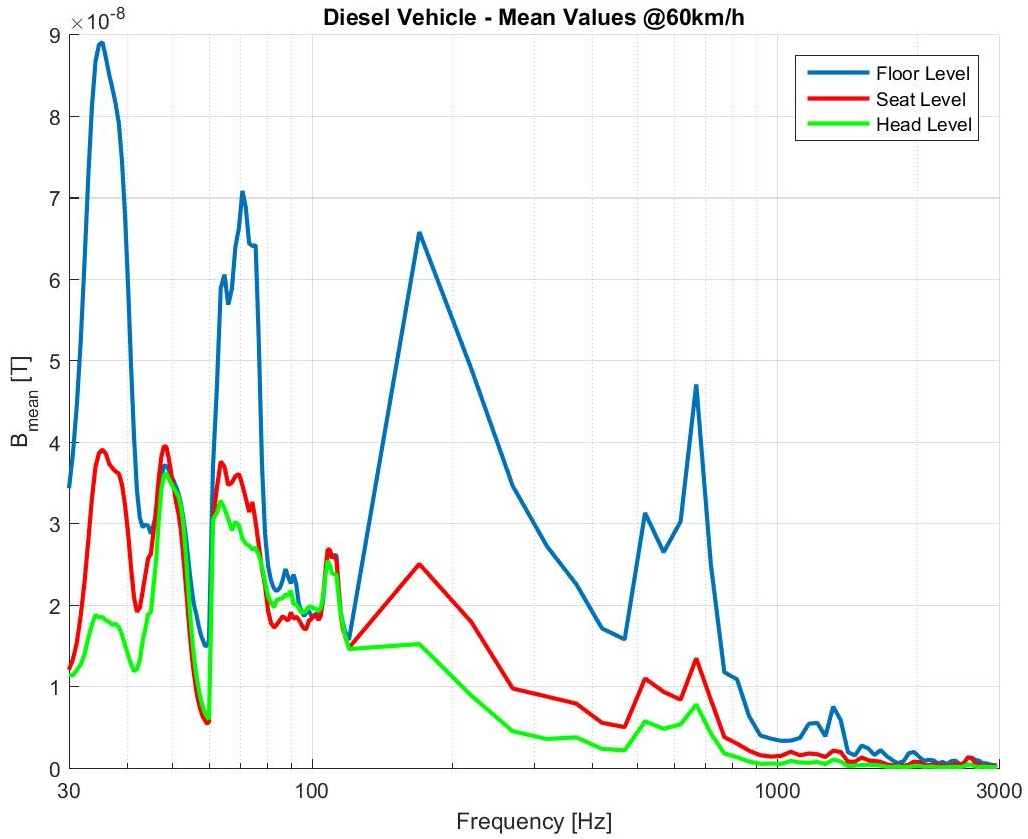
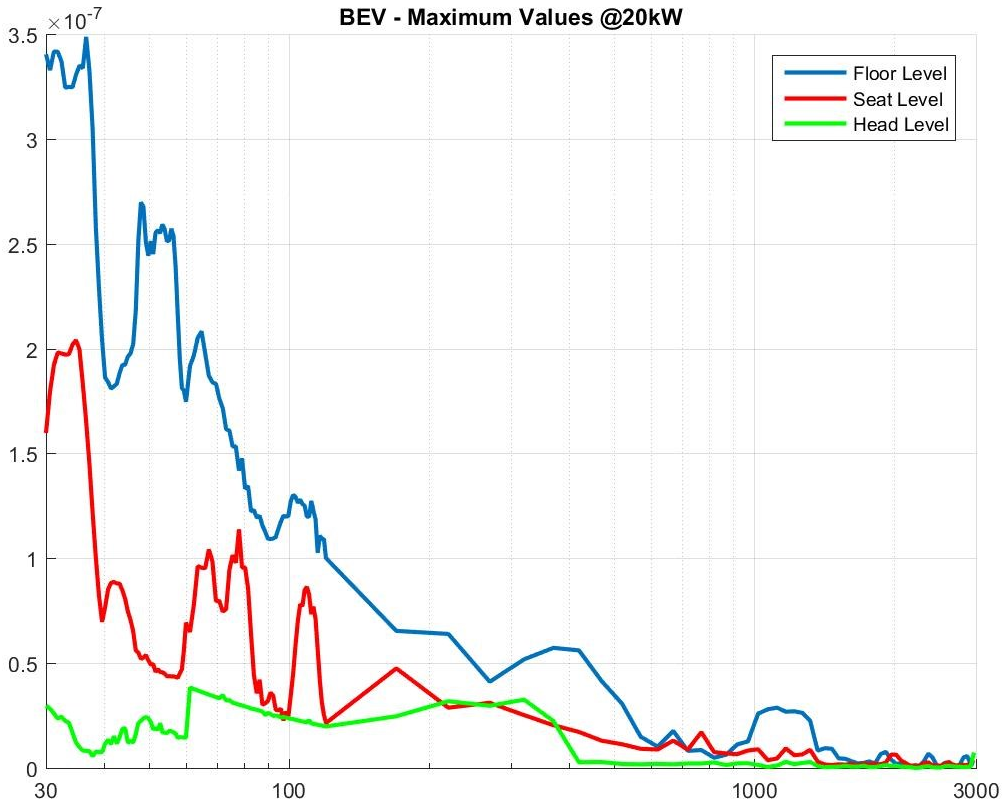
# Results – Diesel Vehicle ($B_{max}$)



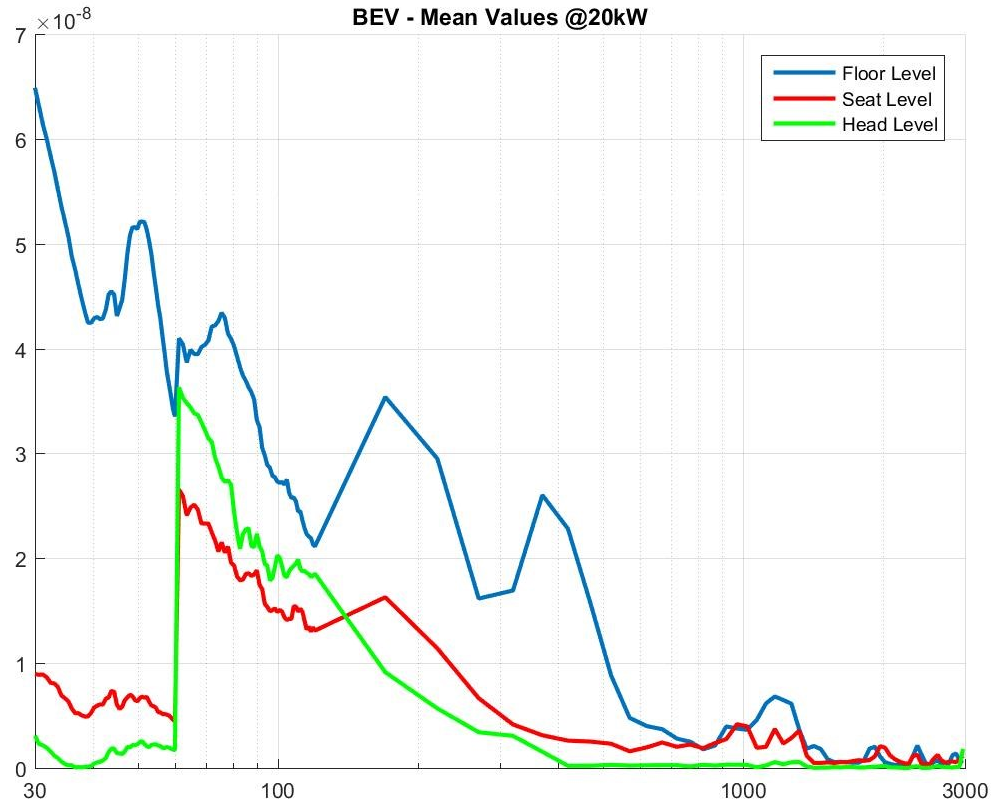
# Results – Diesel Vehicle ($B_{mean}$)



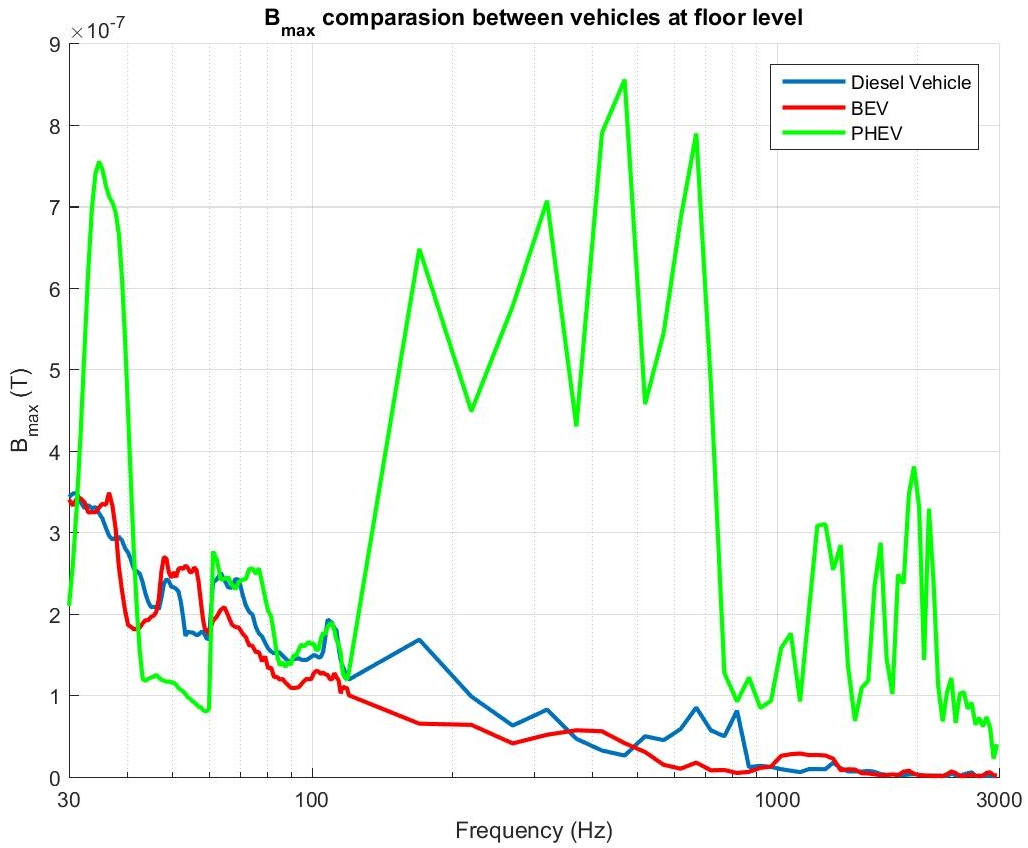
# Results – BEV ($B_{max}$)



# Results – BEV ($B_{mean}$)



# Results – Comparasion between vehicles



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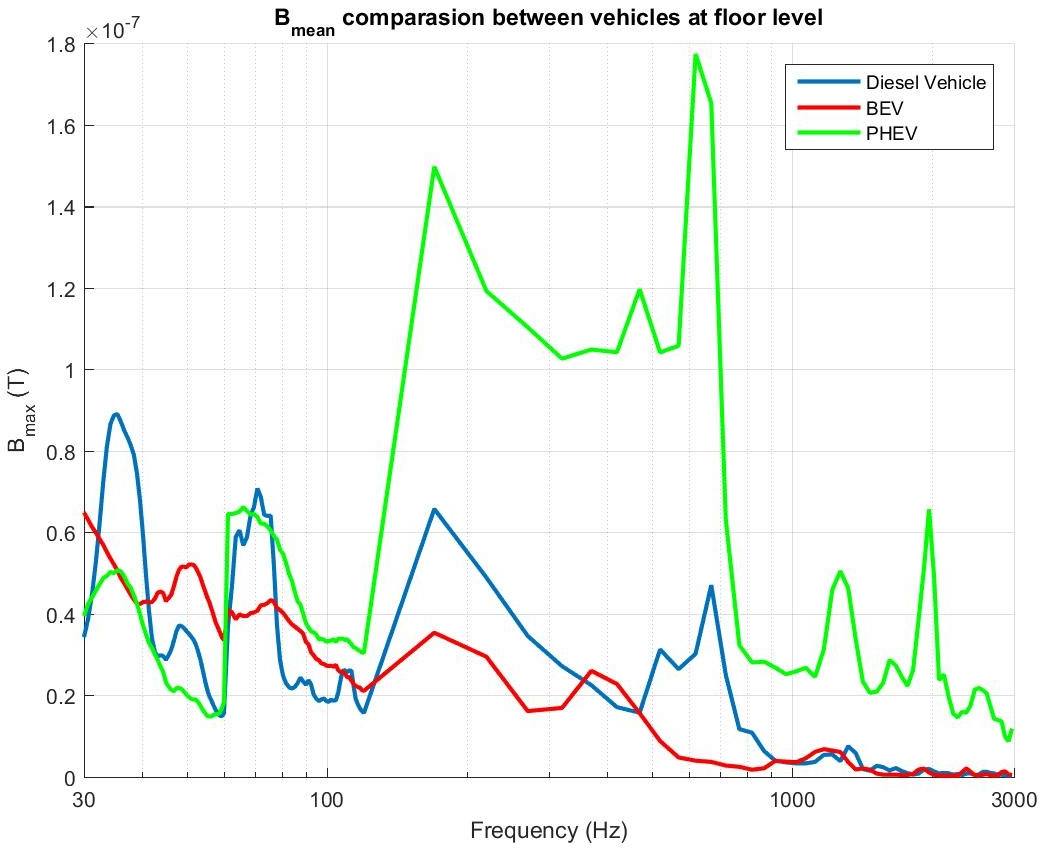

# Results

## Frequency Range 30 – 60 Hz

| | Diesel | BEV | PHEV |
|---|---|---|---|
| $B_{max}$ (nT) | 348 @31.2 Hz | 349 @34.8 Hz | 755 @34.8 Hz |
| $B_{mean}$(nT) | 89 @35.4Hz | 65 @30 Hz | 51 @35.4 Hz |

| | Rural Home | Urban Home |
|---|---|---|
| $B_{max}$ (nT) | 53 @48 Hz | 389 @48 Hz |
| $B_{mean}$(nT) | 30 @48Hz | 347 @48 Hz |

# Results

## Frequency Range 30 – 60 Hz
### Microwave oven ON

| | Rural Home | | Urban Home | |
|---|---|---|---|---|
| | 50 cm | 100 cm | 50 cm | 100 cm |
| $B_{max}$ (nT) | 617 @48 Hz | 148 @48 Hz | 628 @48 Hz | 147 @48 Hz |
| $B_{mean}$(nT) | 592 @48 Hz | 142 @49,8 Hz | 583 @48 Hz | 130 @48 Hz |

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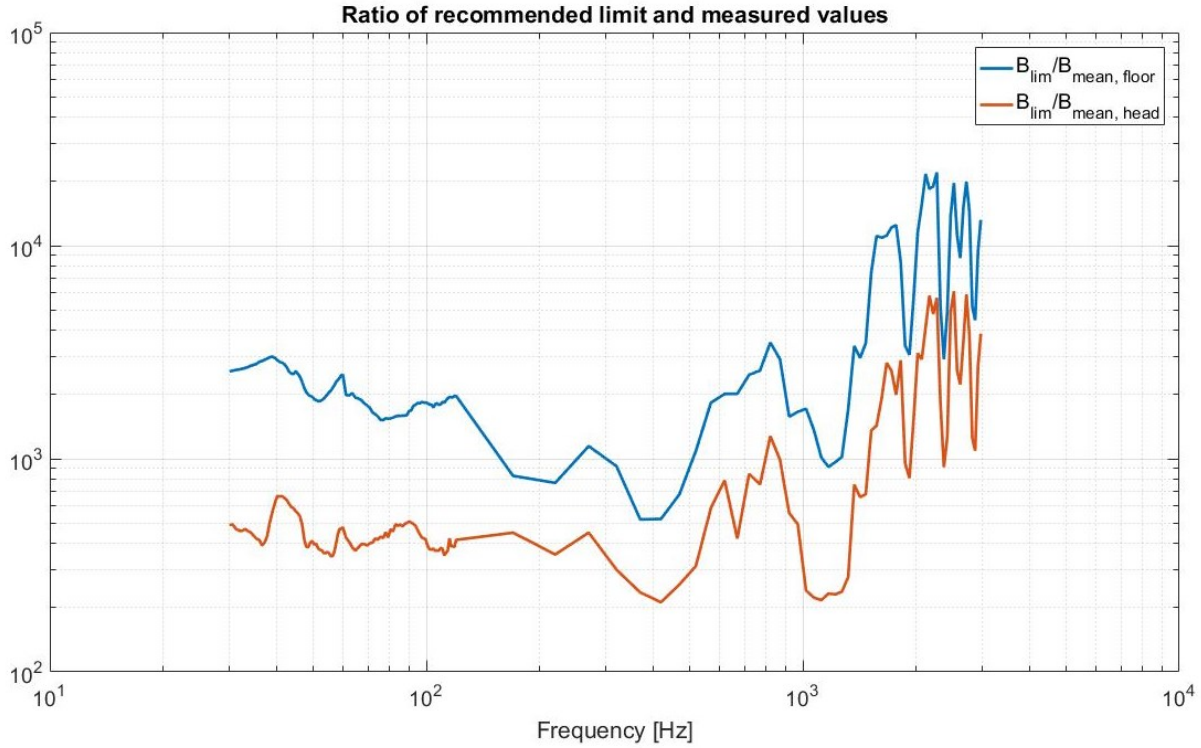
# Conclusions

- Measurement of MF in three different vehicles: Diesel, BEV and PHEV
- Preliminary work. Intended to enlarge the number of vehicles to be assessed.
- The MF are higher at the floor level, decreasing with height: proximity to cables
- In general, MF are higher at lower frequencies

# Conclusions

- Values obtained are significantly lower than those recommended by ICNIRP/EU



# Conclusions

- Finally, values are similar to those measured in domestic environment (well… unless you have a power line over your house)

# Future work

- Enlarge the measurement (Statistical significance)
- Assessment of MF in different electric vehicles
  - Trams
  - Trains
  - E-bikes
  - Segways

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