

The Effect of the Human Body on Wireless Microphone Transmission

Eugenia Cabot and Myles Capstick



ETH

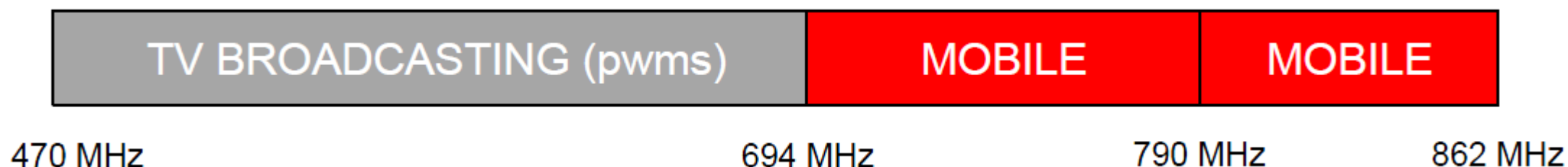
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Outline

- Background
- Objectives
- Methods
- Simulation Scenarios
 - Simulation Scenario 1: Hand Held Microphone
 - Simulation Scenario 2: Body Pack Microphone
- Conclusions and Future Work

Background

- Frequencies assigned for use by wireless microphones are in the VHF and UHF bands.
- With the recent clearance of the UHF 800 MHz band to broadband mobile, and the potential clearance of the 700 MHz band, wireless microphones are losing the available spectrum.
- The remaining spectrum will no longer be able to satisfactorily accommodate the increasing demand for frequencies.
 - Migrate wireless microphone services to higher frequency bands as well (such as the 1492 – 1518 MHz band, which is currently being implemented by CEPT working group FM or even higher frequency bands).



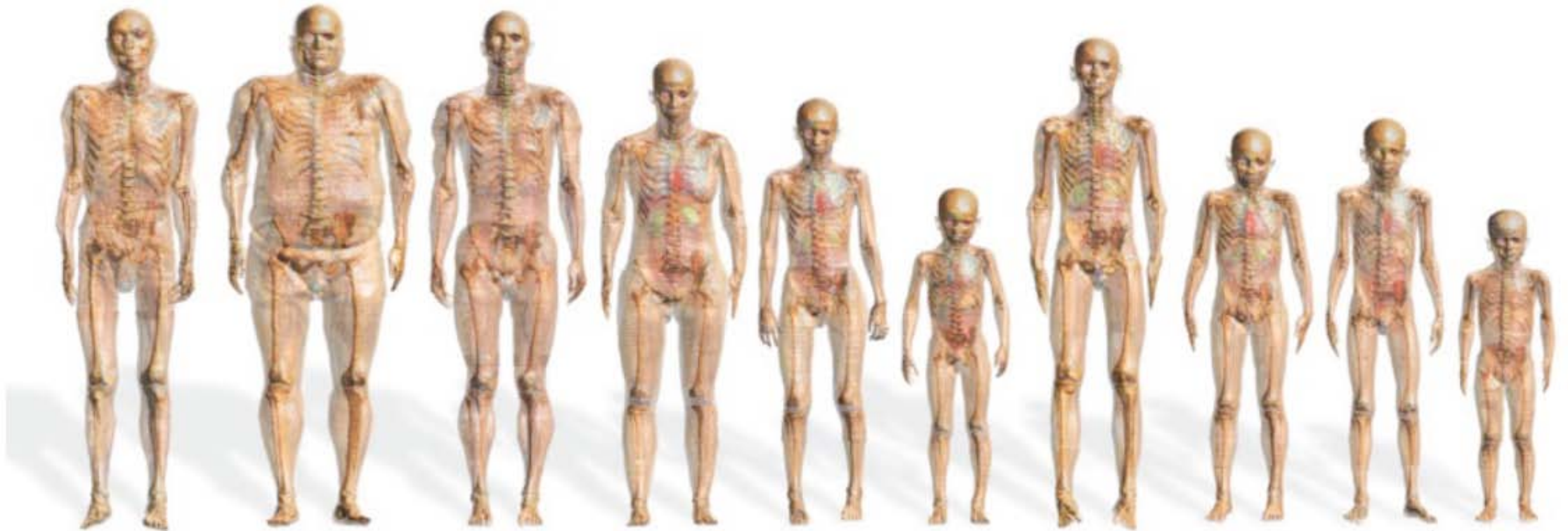
Objectives

- Quantification of the degradation in the wireless microphone transmission performances at higher frequencies as compared to the performances in the UHF band.
- Assessment of the changes of the radiation pattern of wireless microphones (in the presence of a human body) as the transmission frequency increases.
 - This project focuses on the radiation of wireless microphones in the presence of the body. The transmission equation will be completed by OFCOM.

Outline

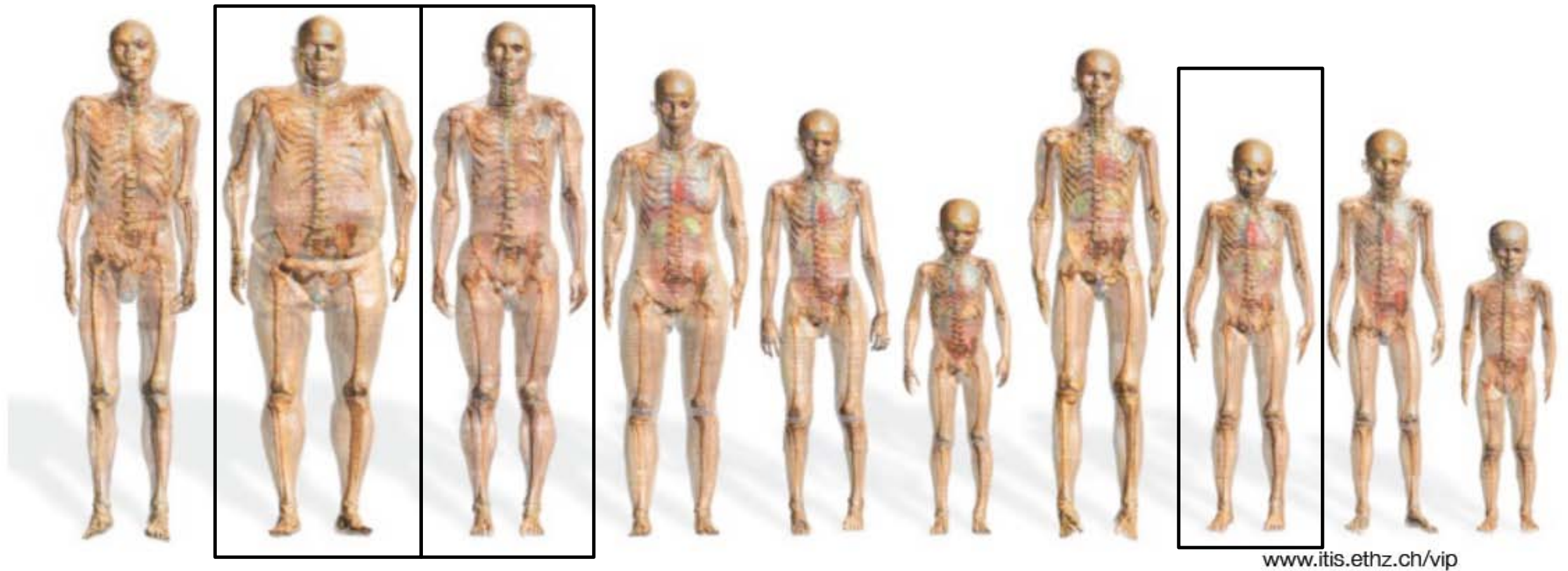
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The Virtual Population (ViP)



www.itis.ethz.ch/vip

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www.itis.ethz.ch/vip

Selected Human Anatomical Phantoms



Fats
120 kg
1.78 m

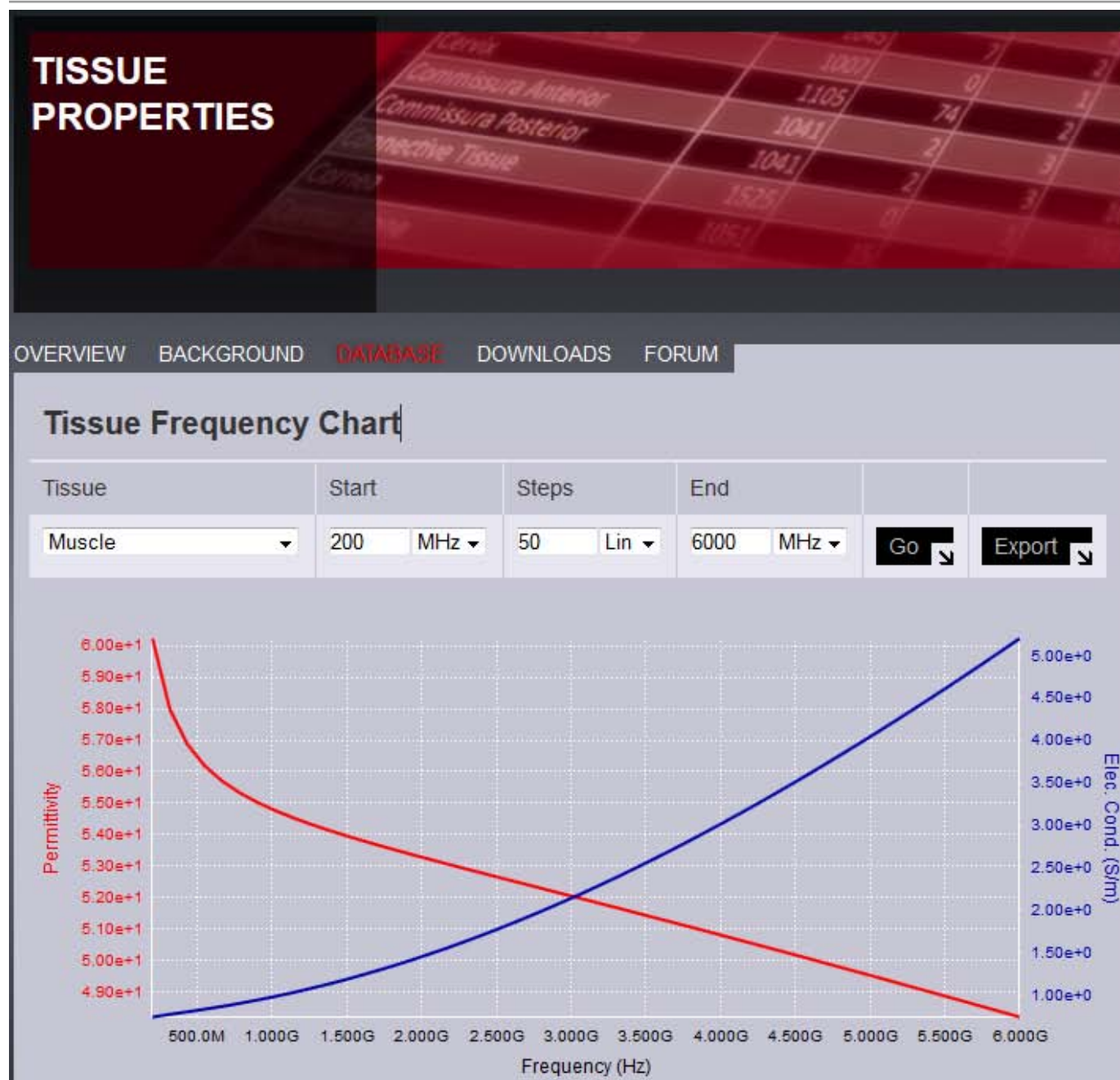
Duke
70 kg
1.74 m

Eartha
30 kg
1.35 m

- High-fidelity anatomical computable phantoms
- Segmented from MRI images of volunteers
- SEMCAD-X (full wave EM simulation software)
- Online tissue parameter database (literature-based) [1]

[1] Hasgall PA, Neufeld E, Gosselin MC, Klingensböck A, Kuster N, "IT'IS Database for thermal and electromagnetic parameters of biological tissues," Version 2.6, Jan 13, 2015. DOI: 10.1099/21001-02.6. www.itis.ethz.ch/database

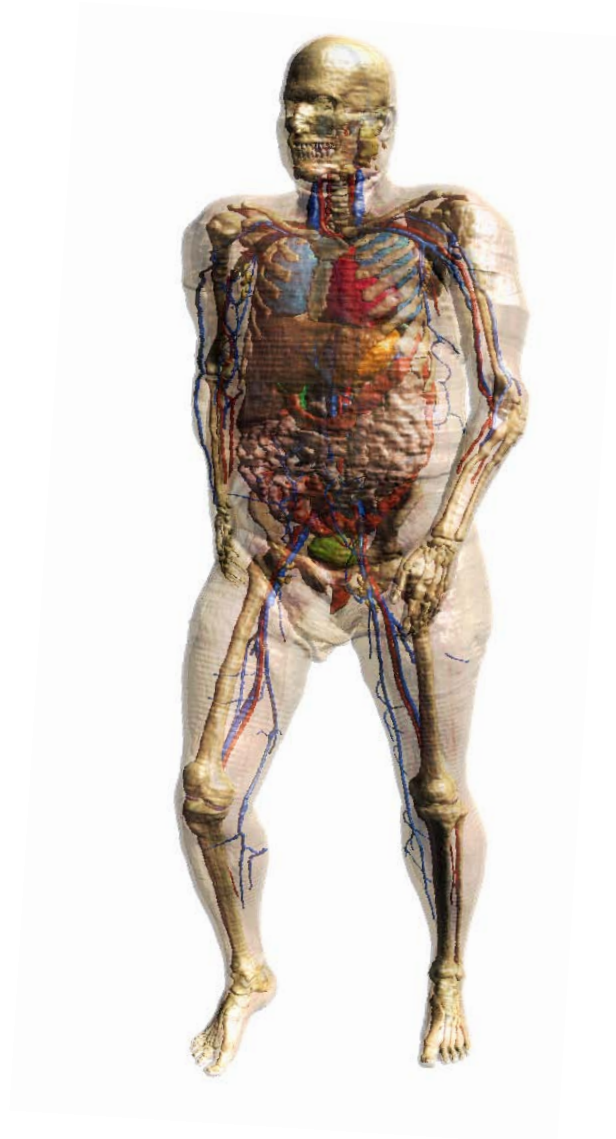
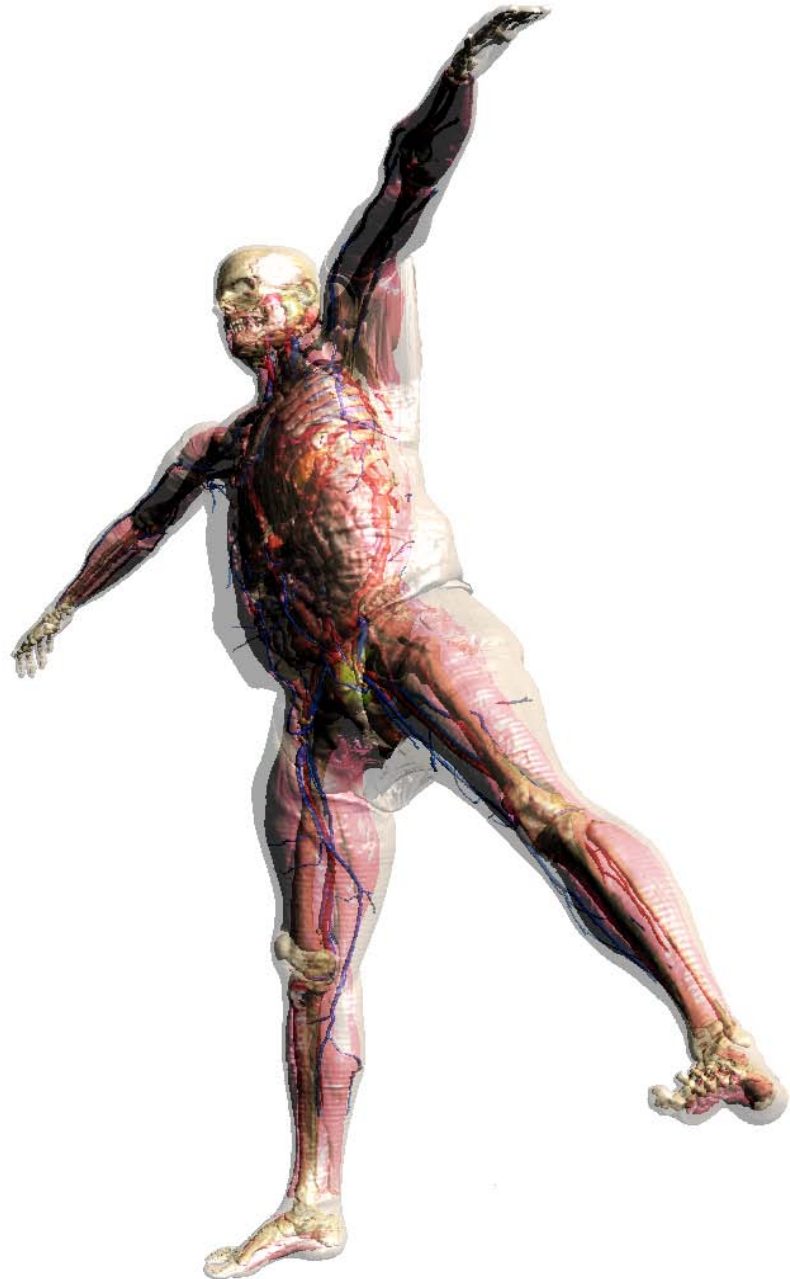
Frequency Dependent Tissue Parameters



- Frequency space:
 - 235 – 825 MHz
 - 945 – 1890 MHz
 - 2380 – 3780 MHz
 - 4760 – 6000 MHz

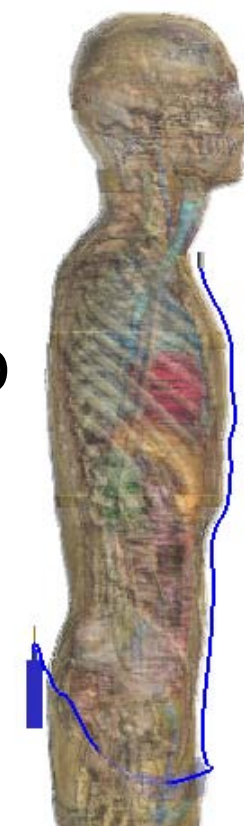
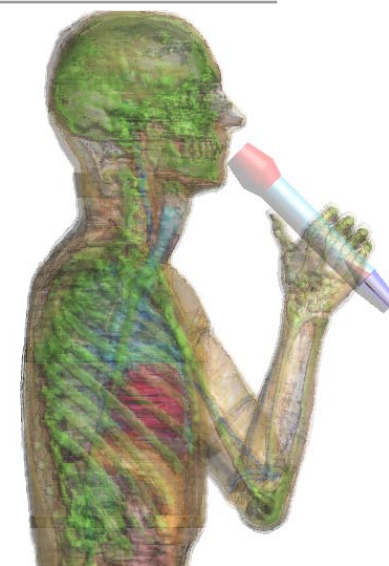
<http://www.itis.ethz.ch/virtual-population/tissue-properties/database/tissue-frequency-chart/>

Poser Tool



Simulation Scenarios

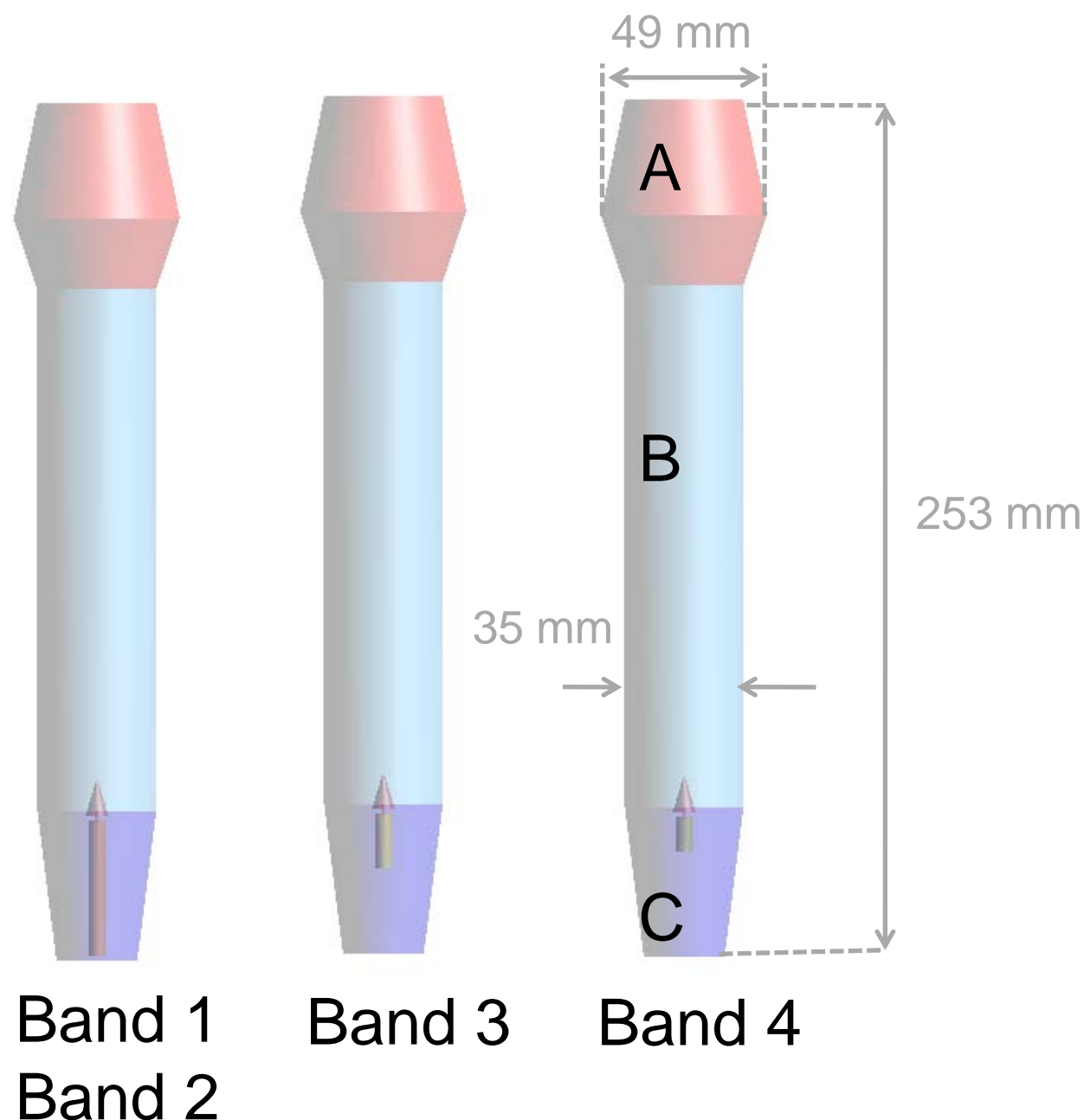
- Scenario 1: Hand-Held Wireless Microphone
 - Human model posed into a representative posture so as to hold the microphone in one hand close to its mouth and with an inclination angle of 45°
- Scenario 2: Body-Pack Wireless Microphone
 - A lapel-worn microphone is connected via cable to the body pack transmitter:
 - Attached to the belt on the human model's back side
 - Attached to the belt on the human model's front side



Outline

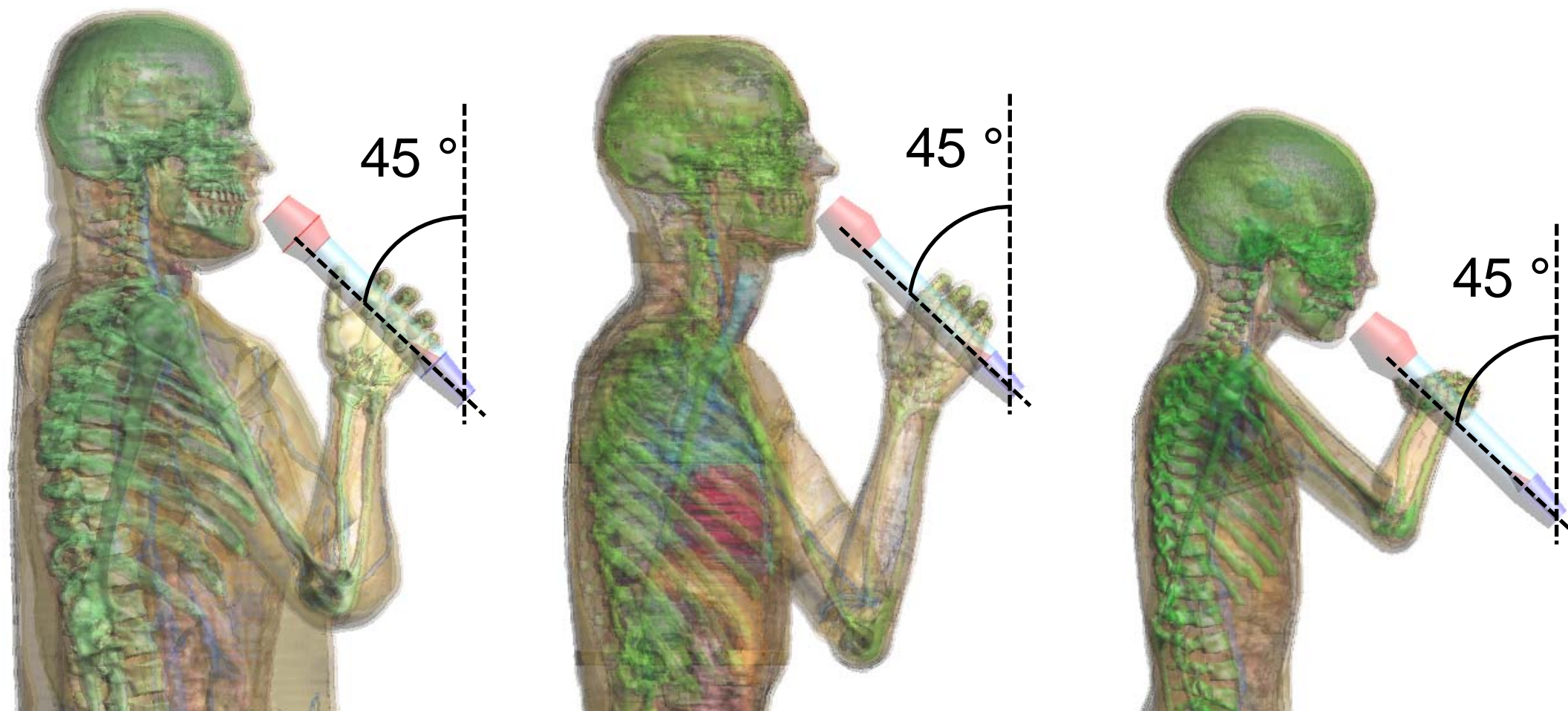
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Wireless Microphone Model



- Monopole lengths ($< \lambda/4$)
 - 235 – 825 MHz: 40 mm
 - 945 – 1890 MHz: 40 mm
 - 2380 – 3780 MHz: 16 mm
 - 4760 – 6000 MHz: 10 mm
 - Materials
 - Monopole: Perfect Electrical Conductor (PEC)
 - A,B: PEC
 - C: dielectric $\epsilon_r = 3$, $\sigma = 0$
- ▶ **Lossless Antennas**

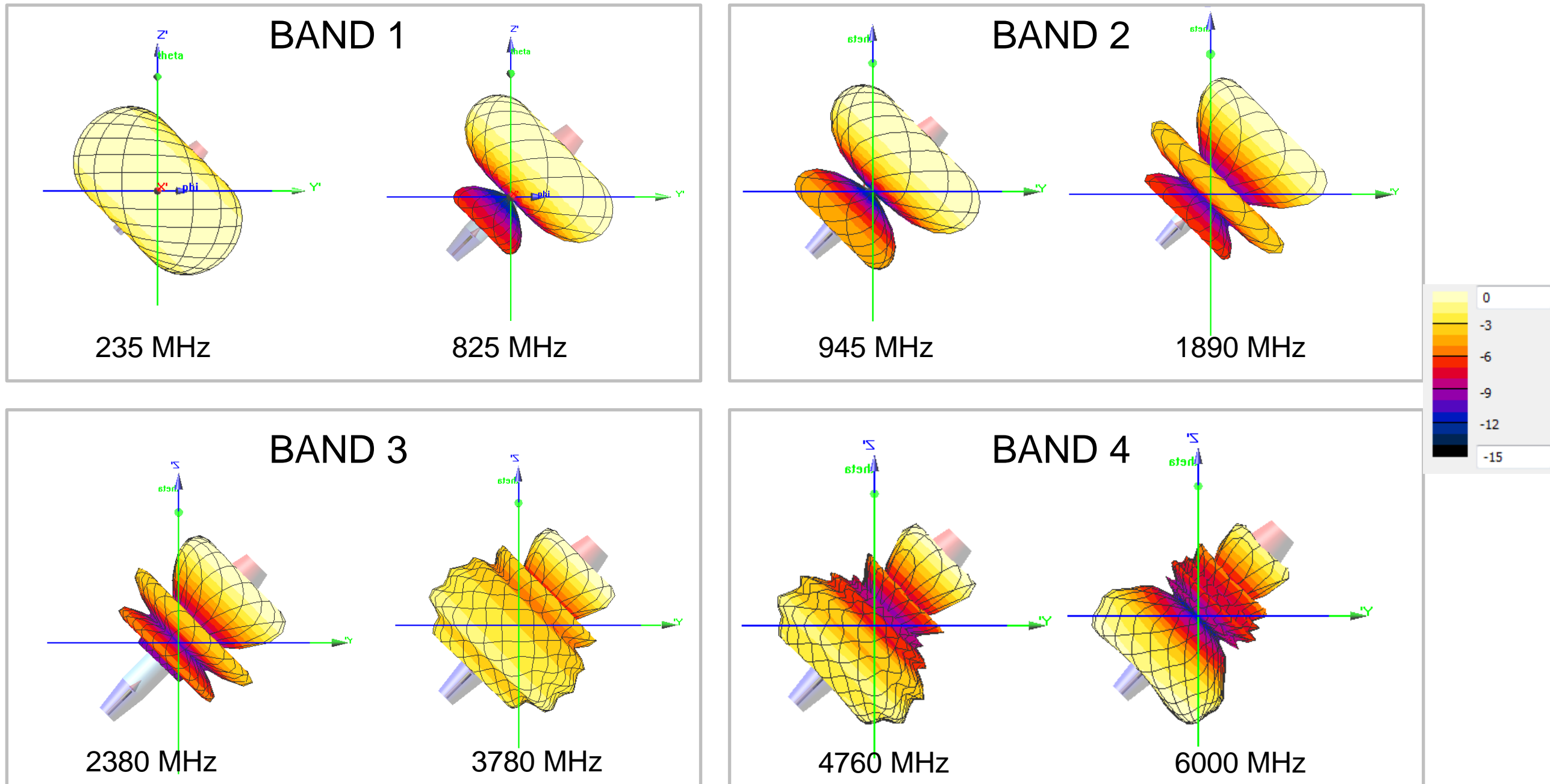
Microphone + Human Anatomical Phantoms



- Broadband simulations covering the whole band
- Tissue properties assigned for each frequency as in [1]

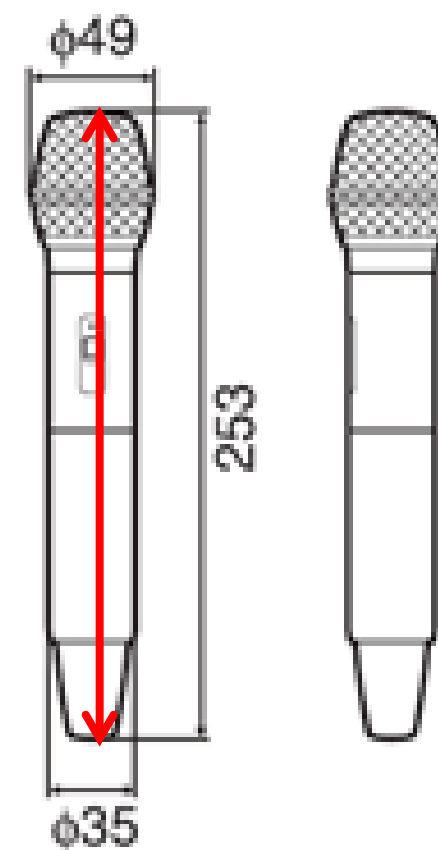
[1] Hasgall PA, Neufeld E, Gosselin MC, Klingeböck A, Kuster N, "IT'IS Database for thermal and electromagnetic parameters of biological tissues," Version 2.6, Jan 13, 2015. DOI: 10.1099/21001-02.6. www.itis.ethz.ch/database

Rad. Patterns in Free Space, 45° Tilting Angle



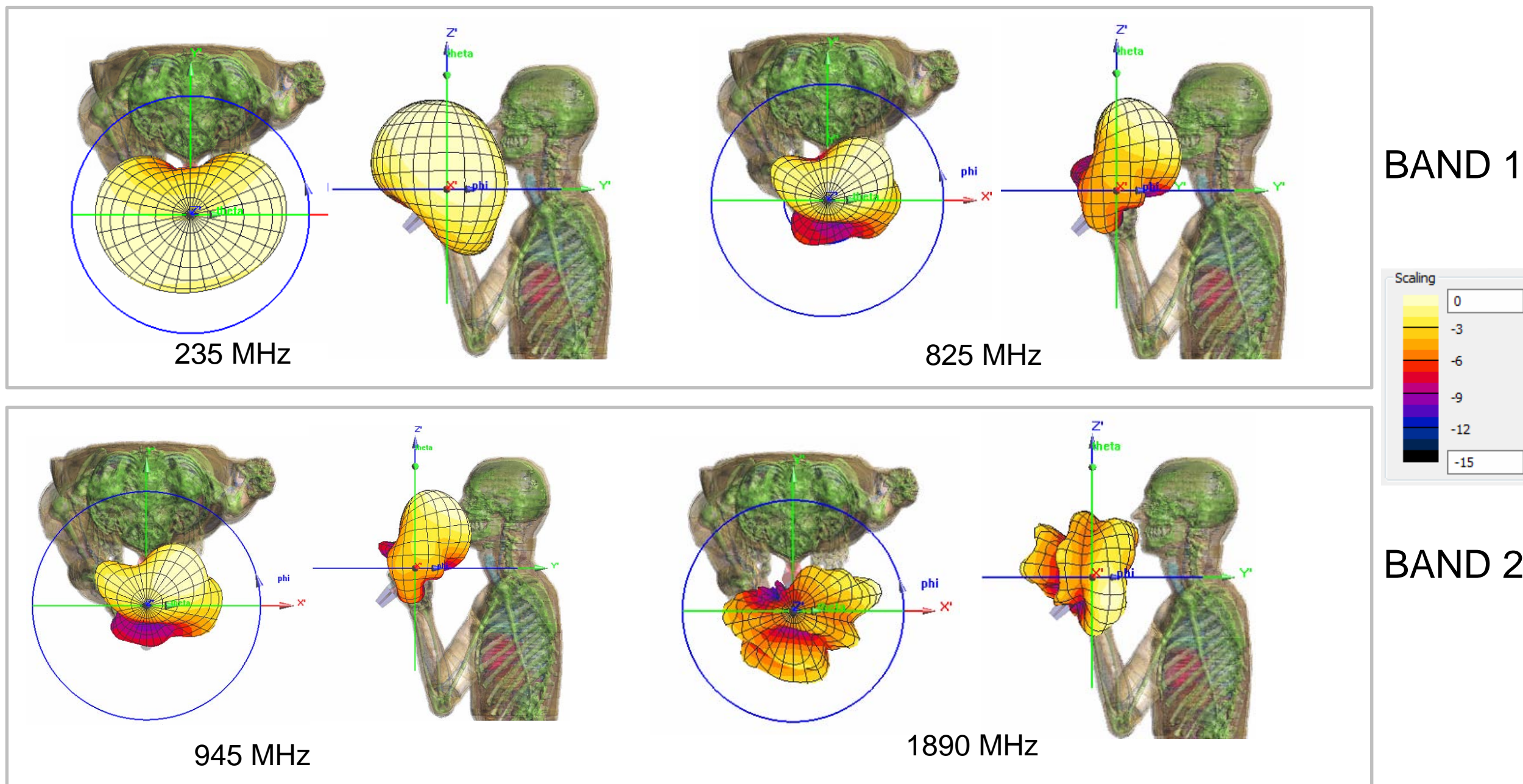
Pattern complexity

- Effective length for a 40 mm monopole including microphone ~ 266 mm
- Half wave at ~ 565 MHz
- Above this frequency it will be expected that additional side lobes are introduced
 - Even though the monopole is at, or below, resonance
- The radiation patterns when held by the hand will be dampened with respect to the microphone in free space

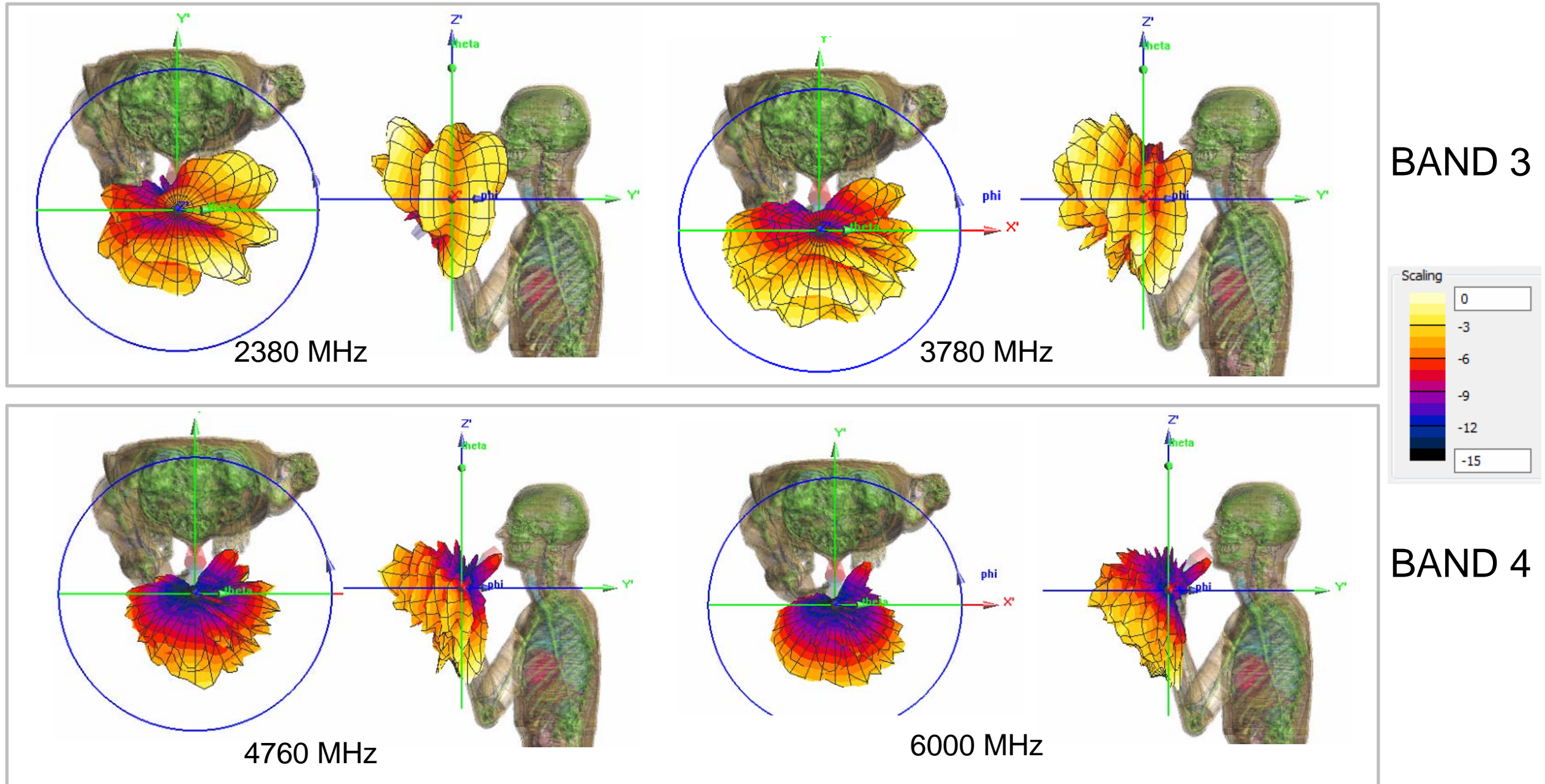


Unit: mm

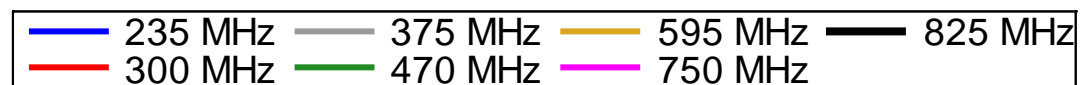
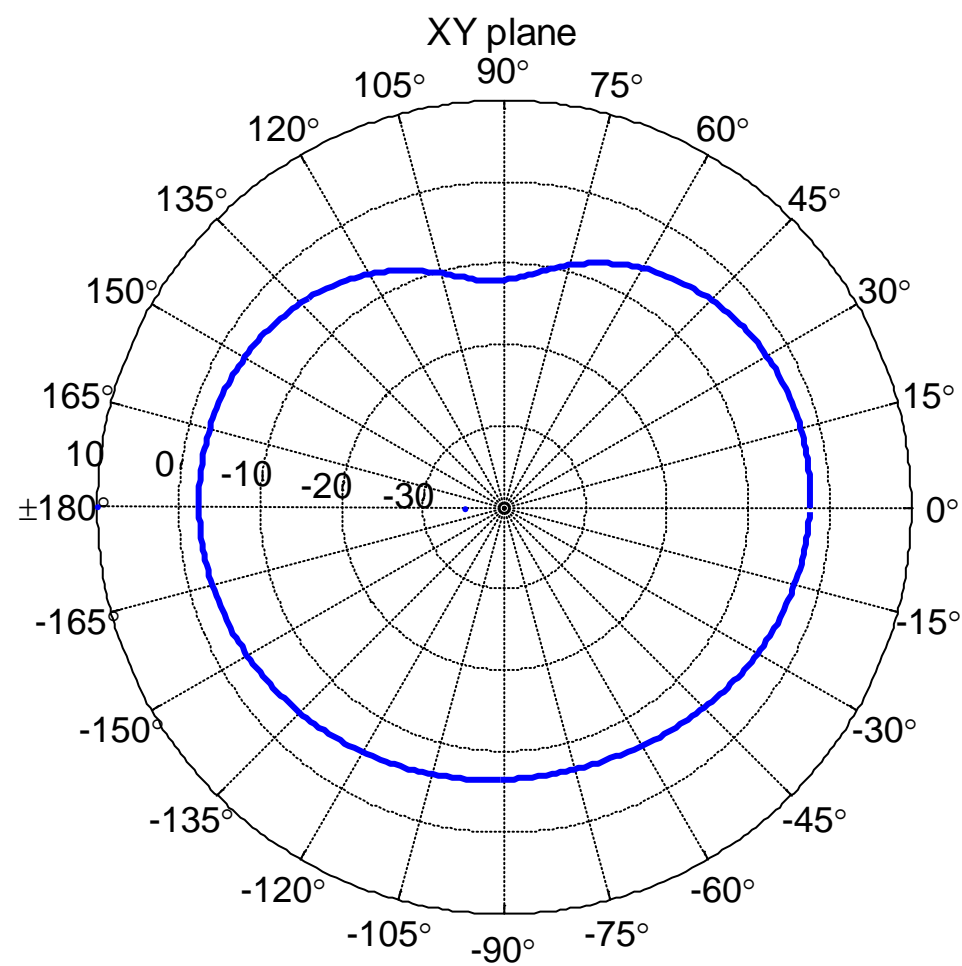
Duke Band 1, Band 2: 235, 825, 945, 1890 MHz



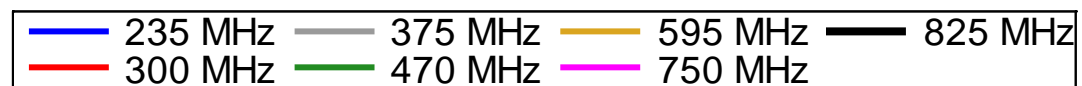
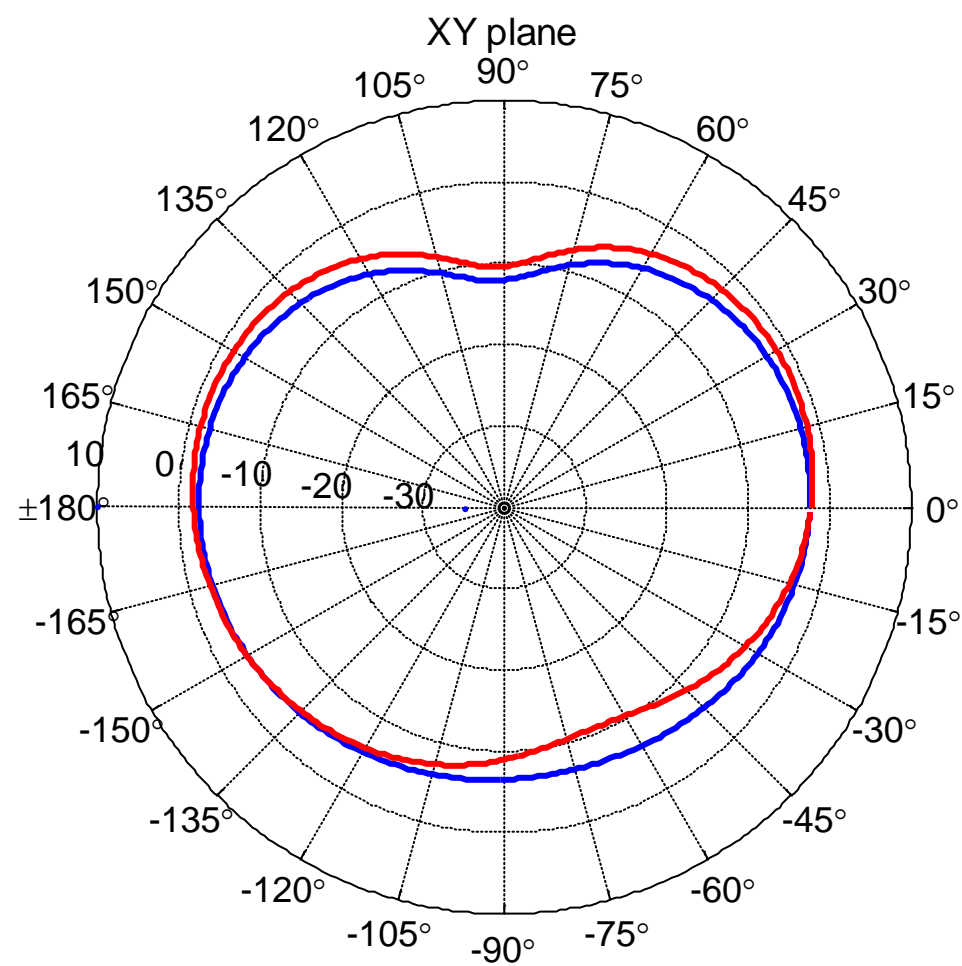
Duke Band 3, Band 4: 2380, 3780, 4760, 6000 MHz



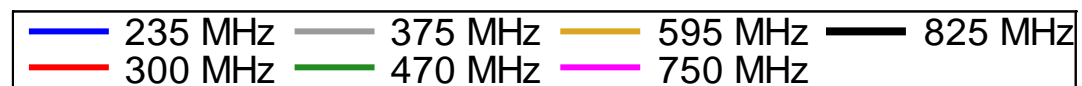
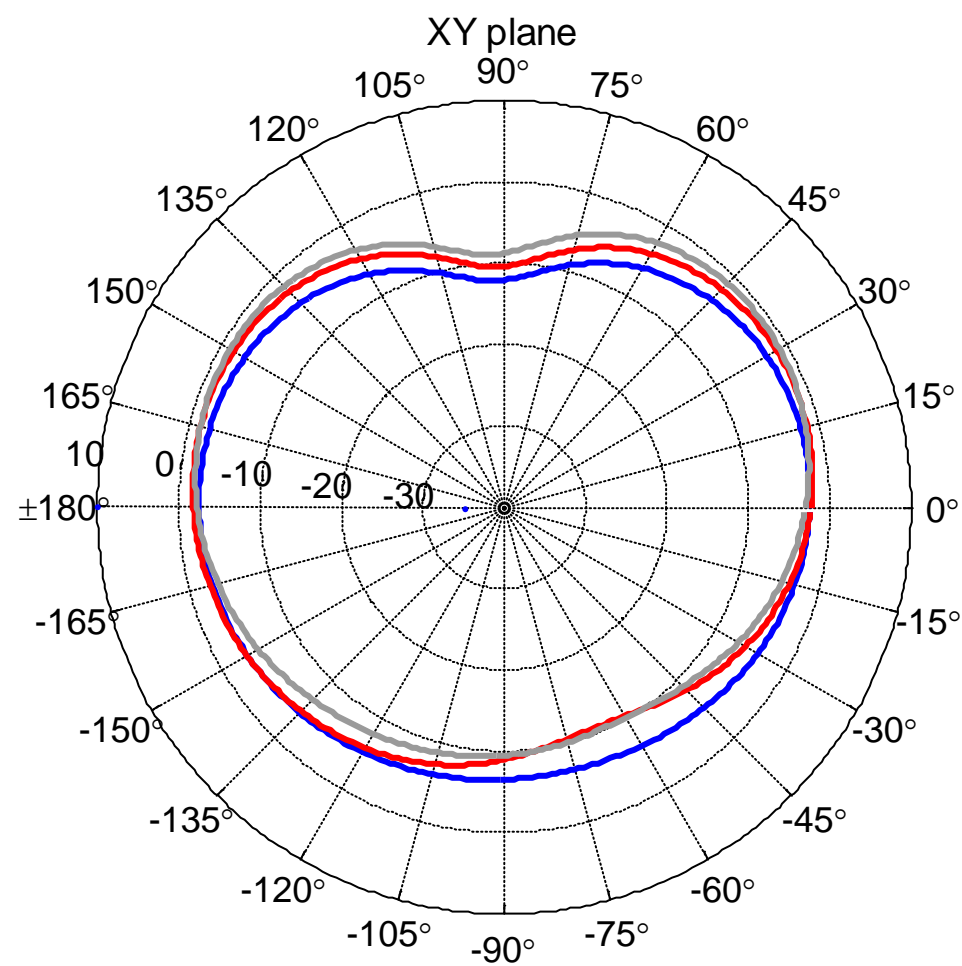
Duke: All Frequencies Band 1



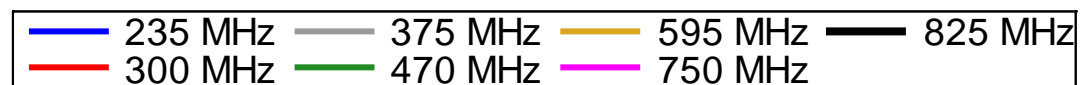
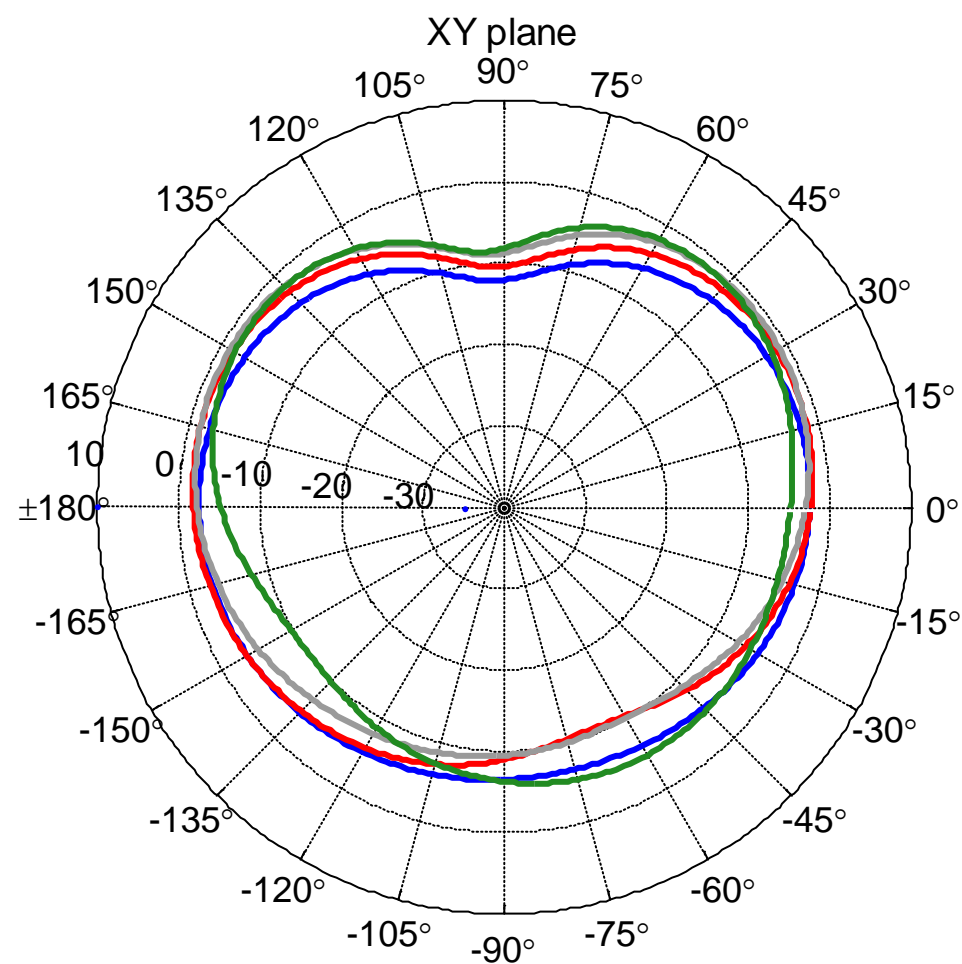
Duke: All Frequencies Band 1



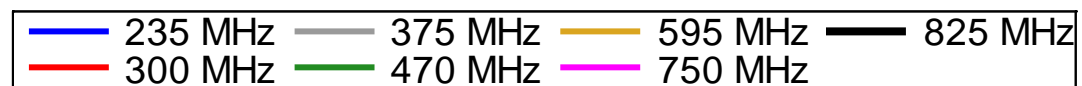
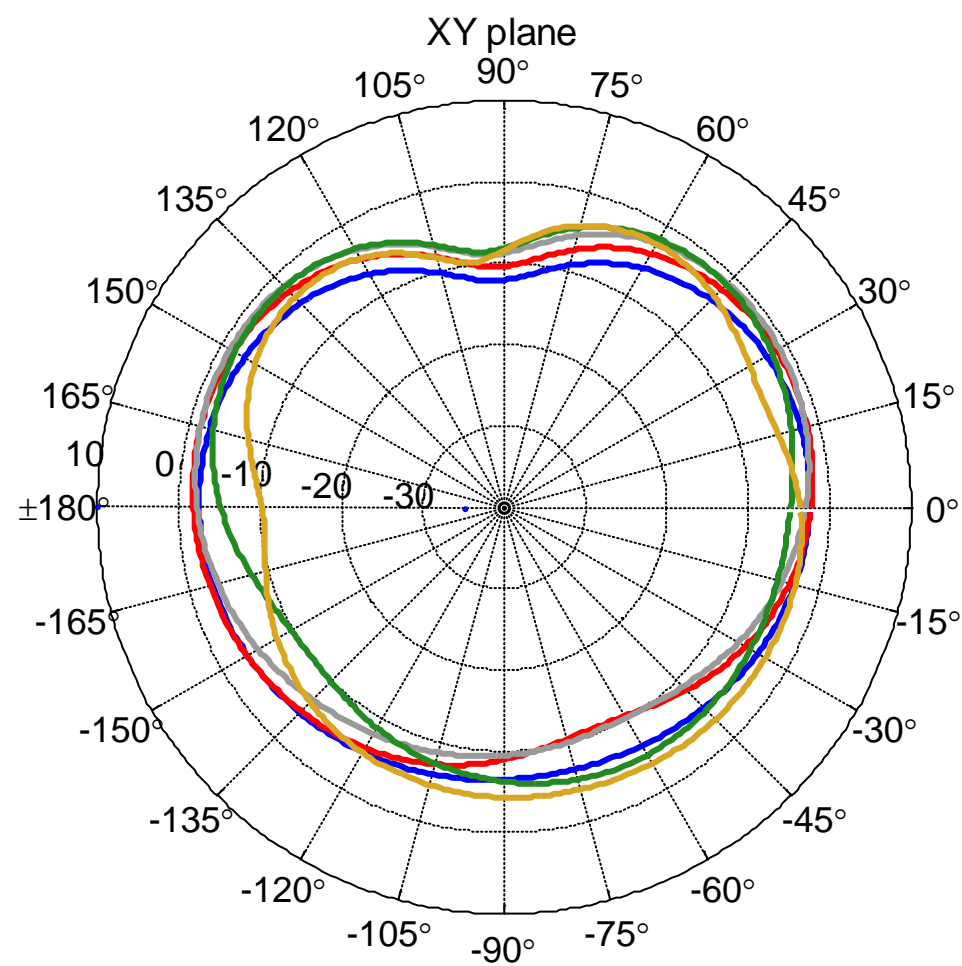
Duke: All Frequencies Band 1



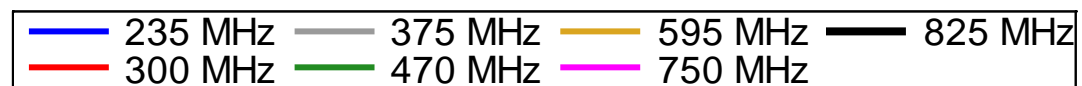
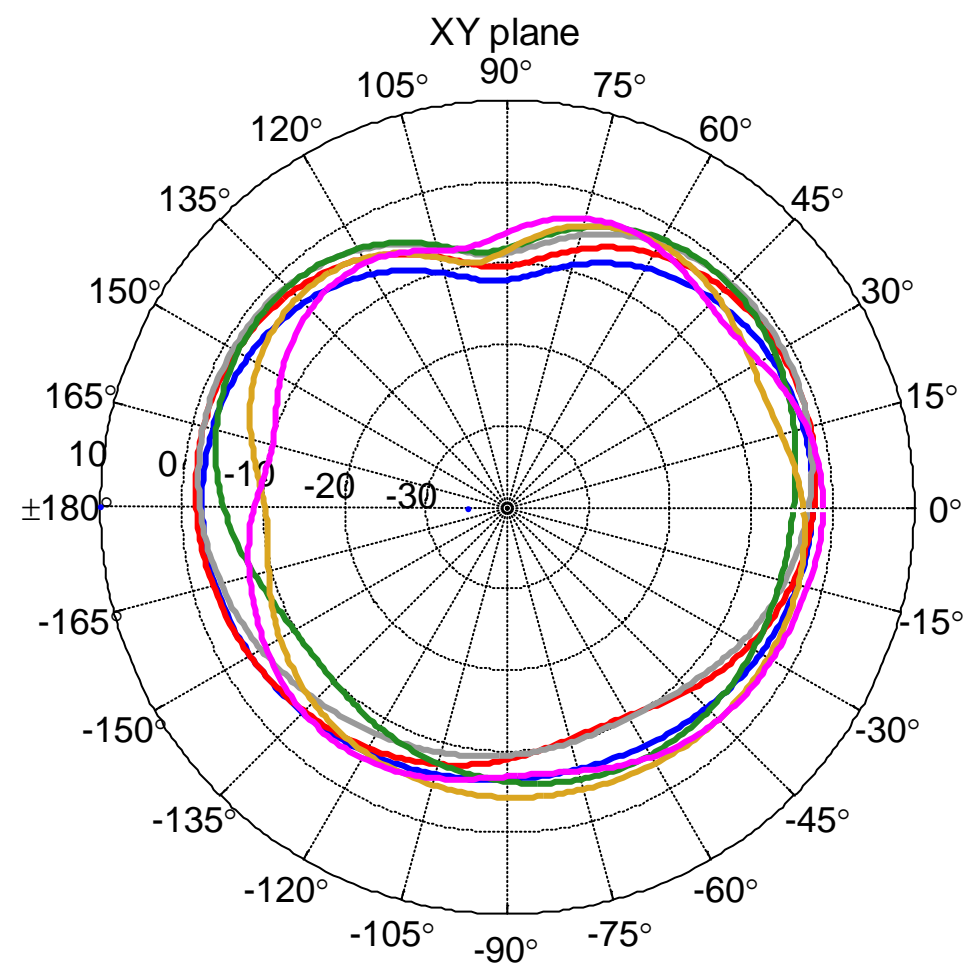
Duke: All Frequencies Band 1



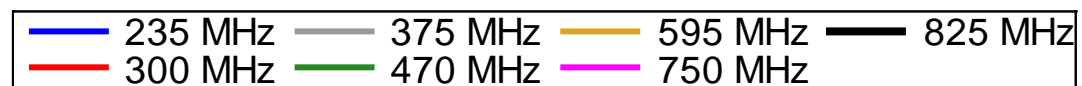
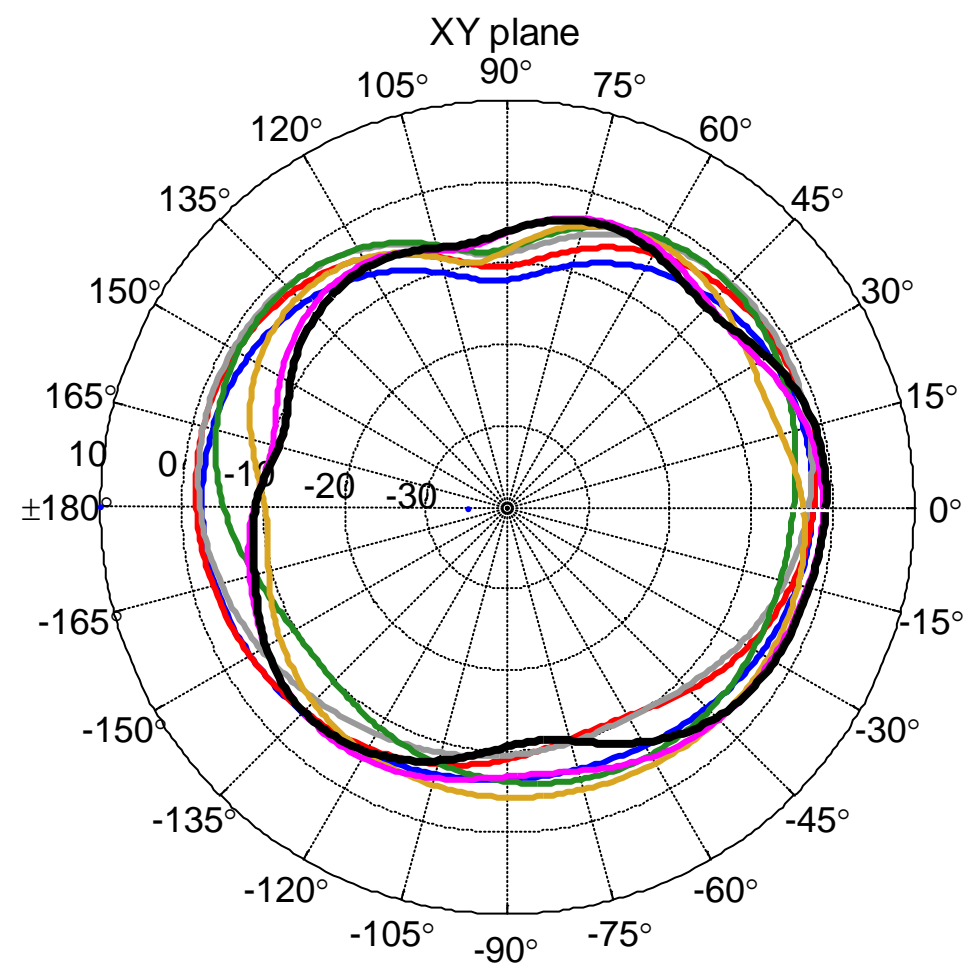
Duke: All Frequencies Band 1



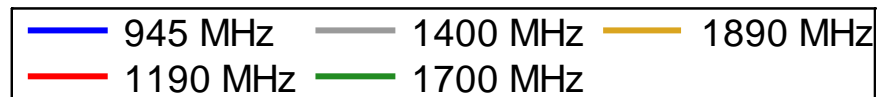
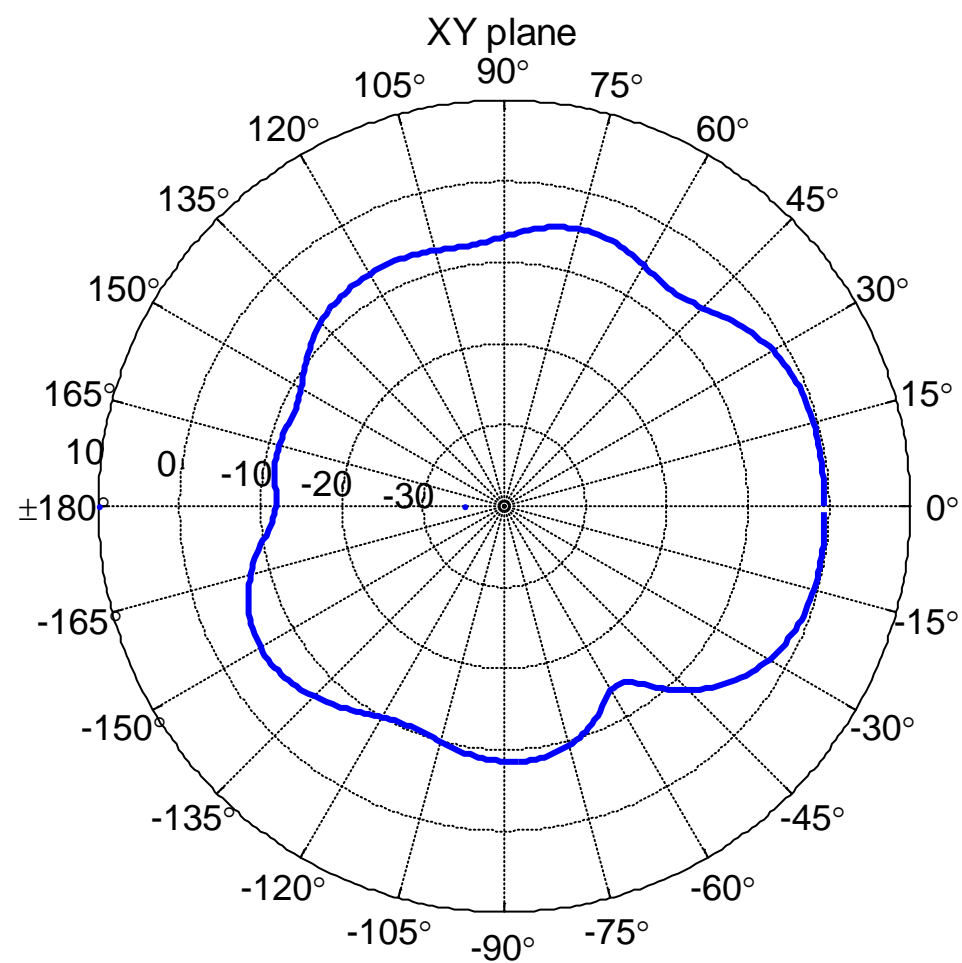
Duke: All Frequencies Band 1



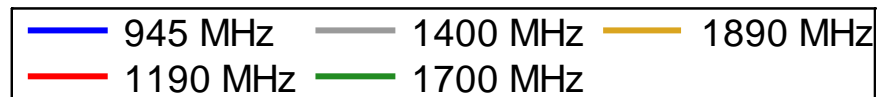
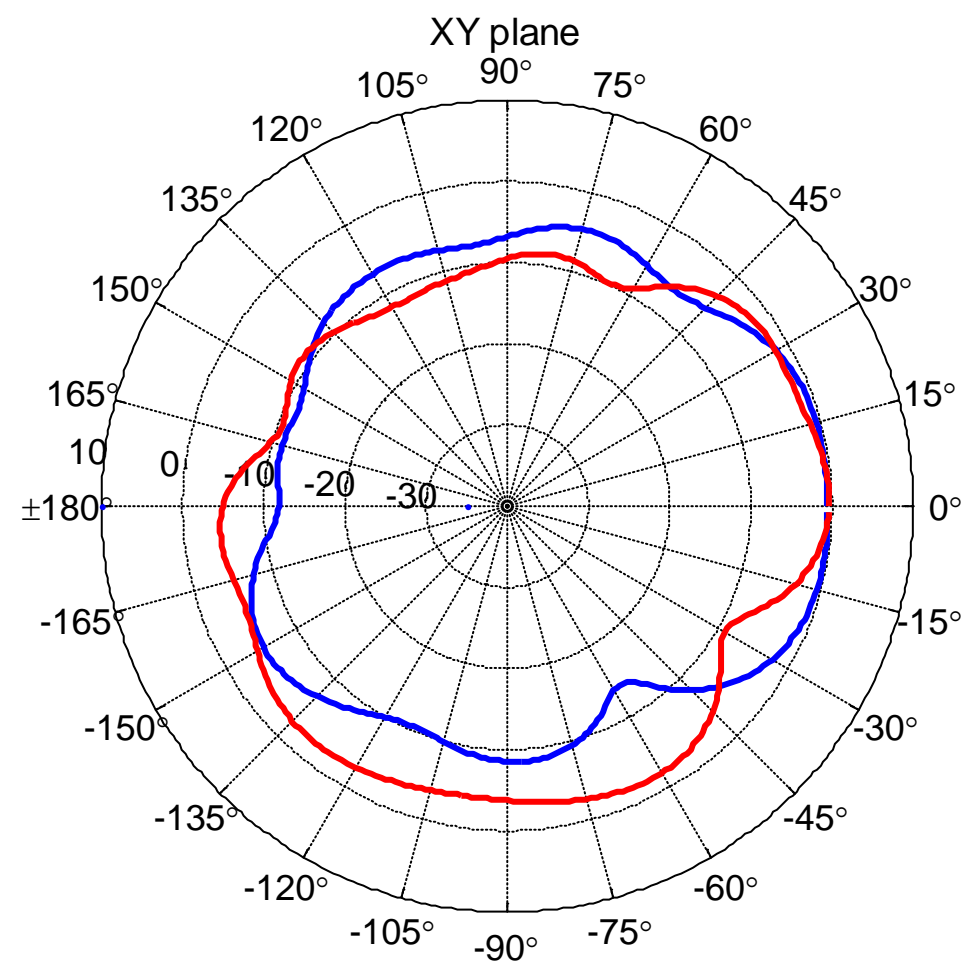
Duke: All Frequencies Band 1



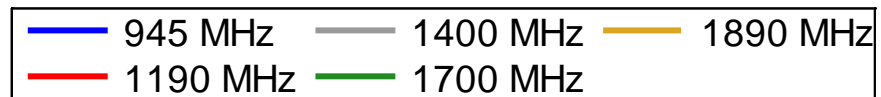
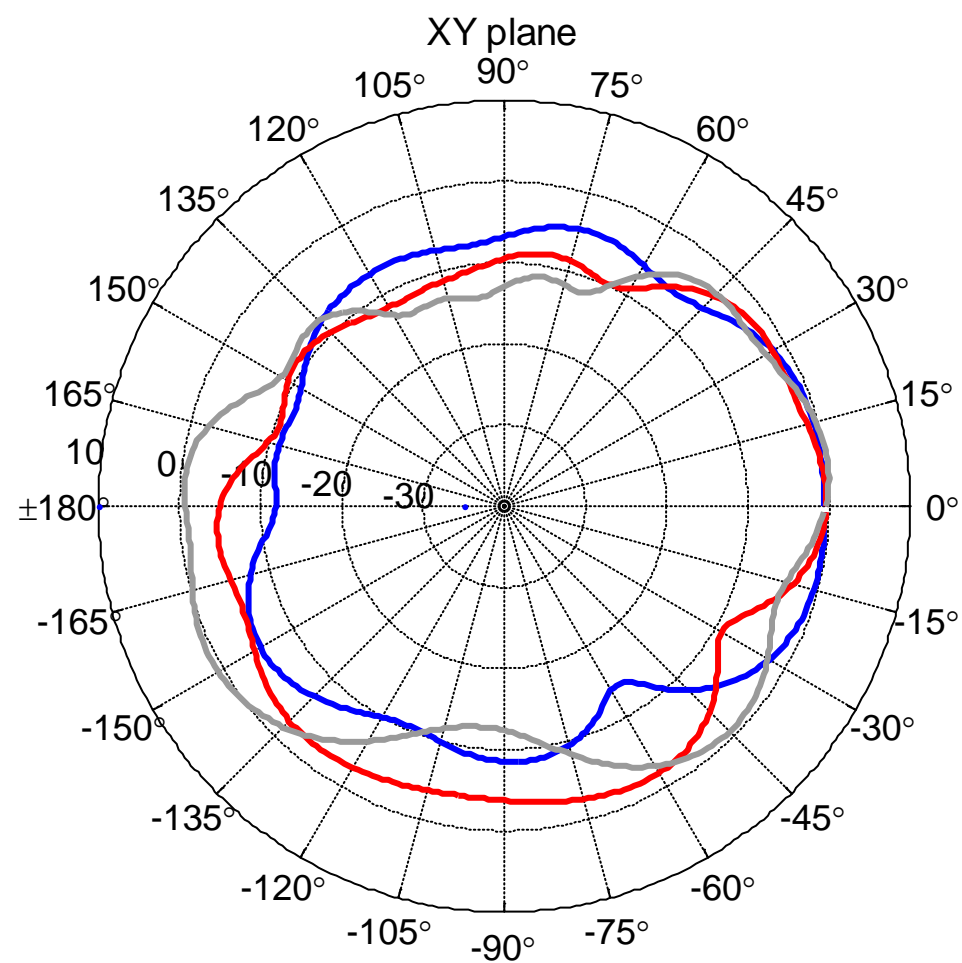
Duke: All Frequencies Band 2



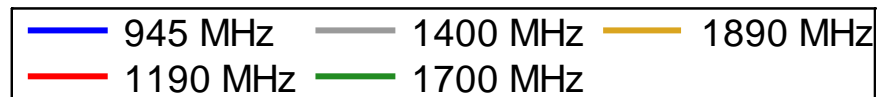
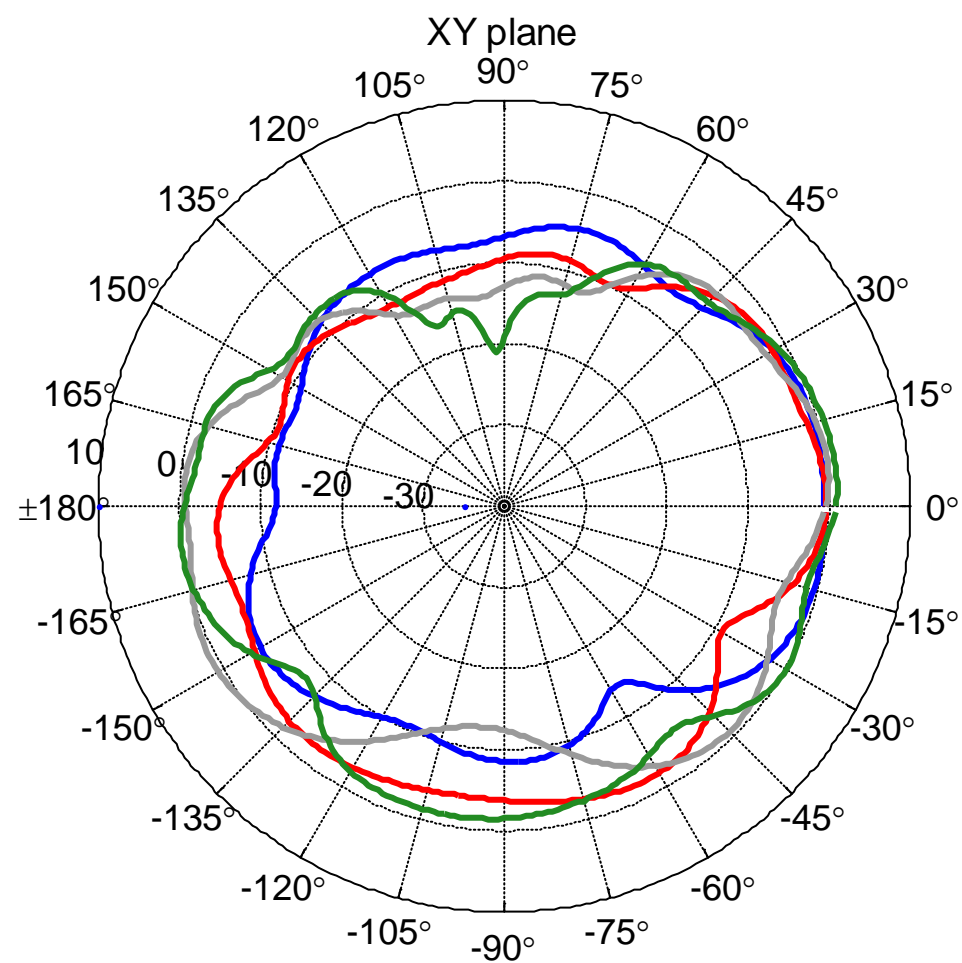
Duke: All Frequencies Band 2



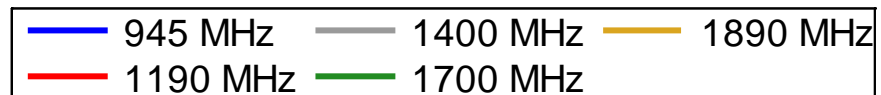
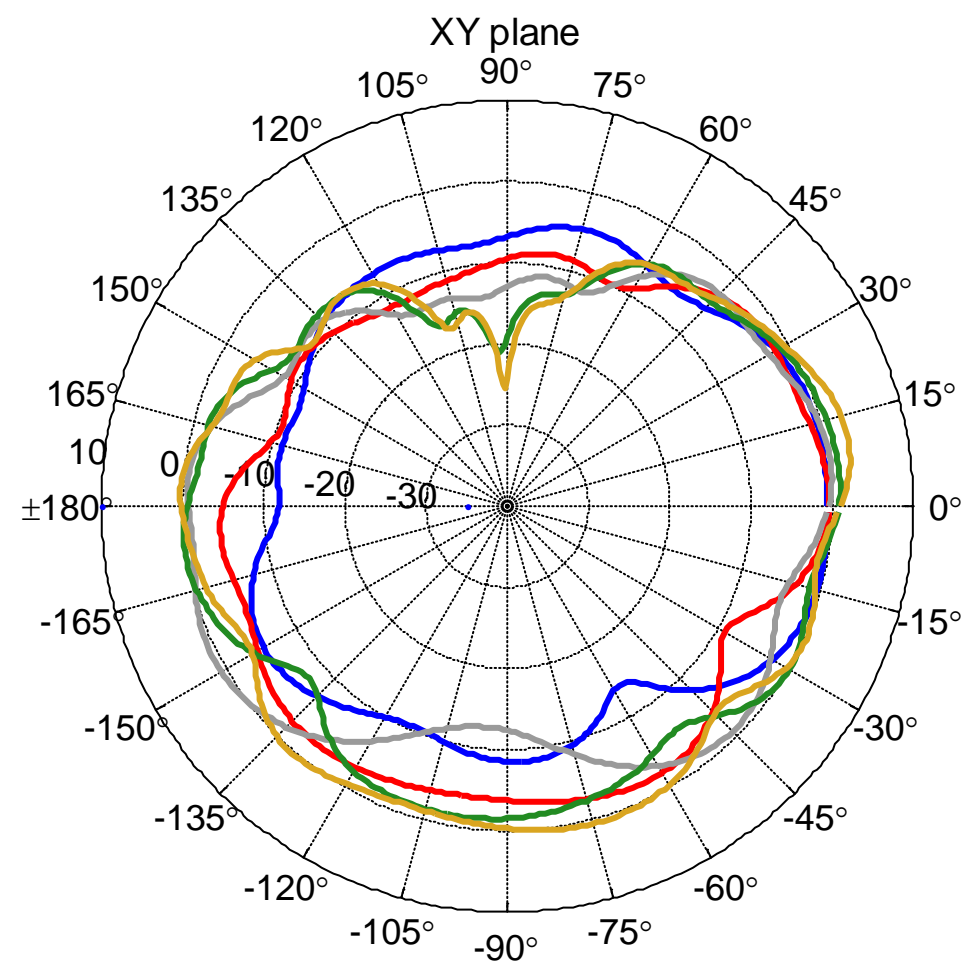
Duke: All Frequencies Band 2



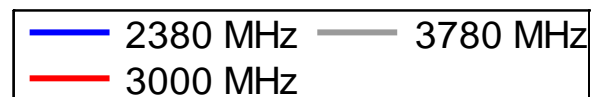
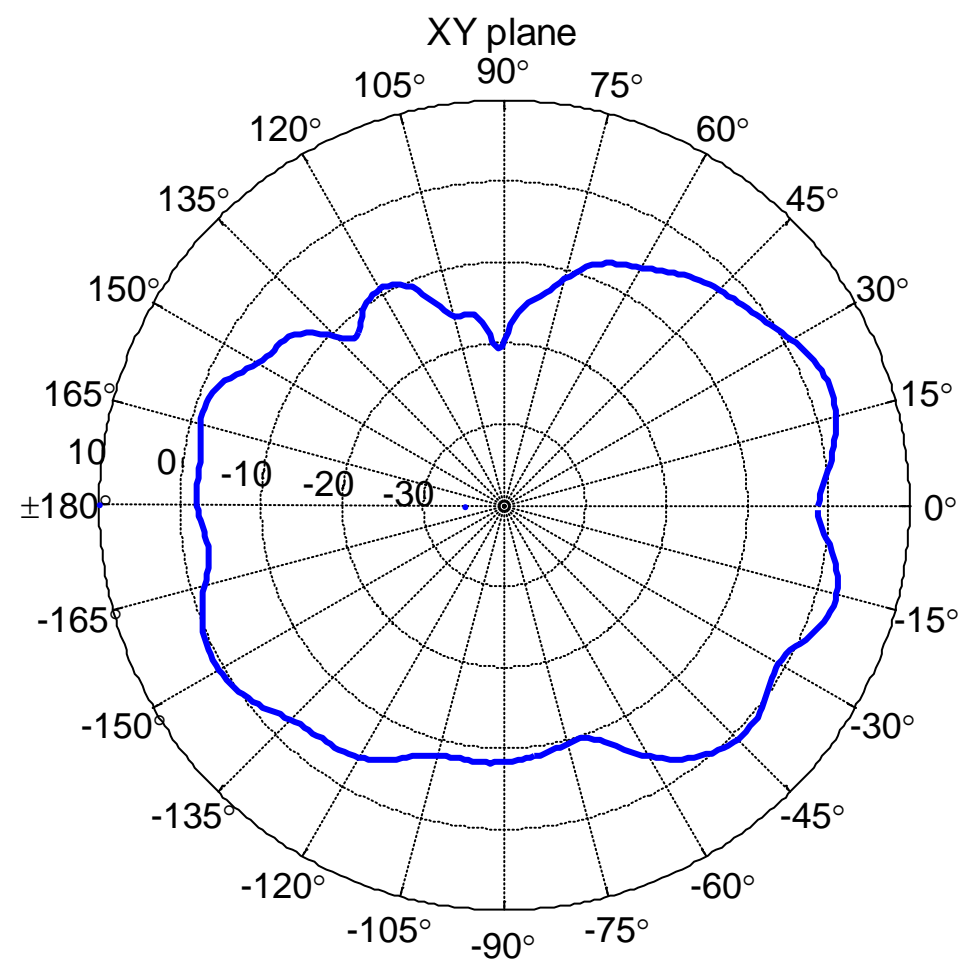
Duke: All Frequencies Band 2



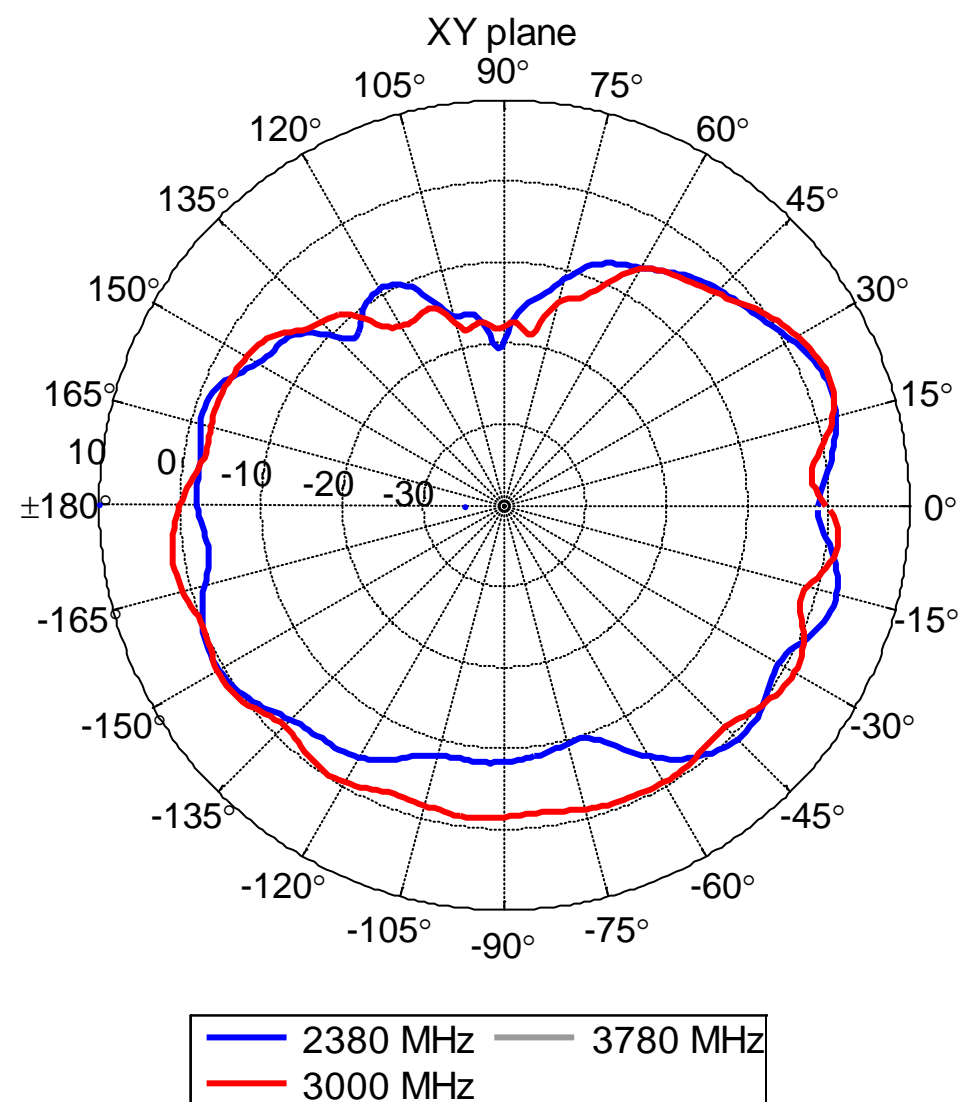
Duke: All Frequencies Band 2



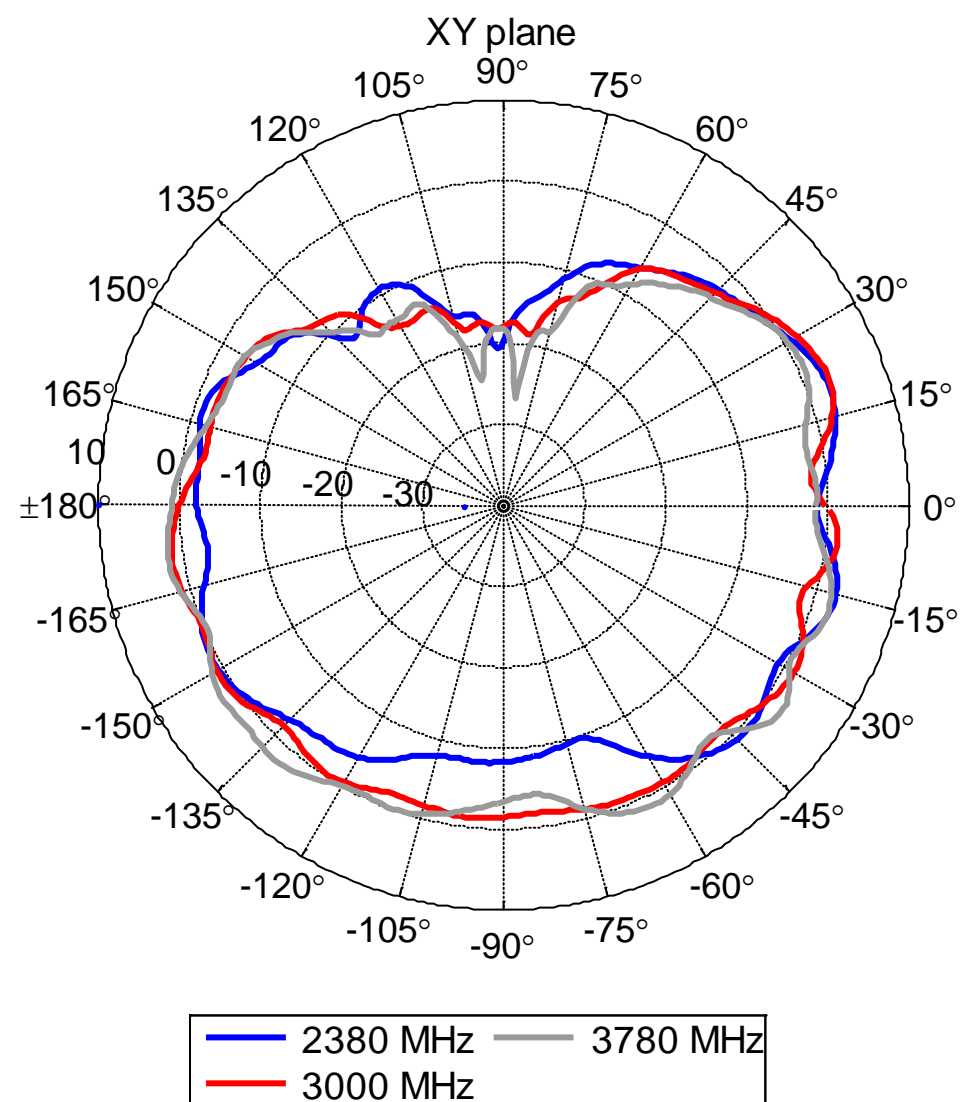
Duke: All Frequencies Band 3



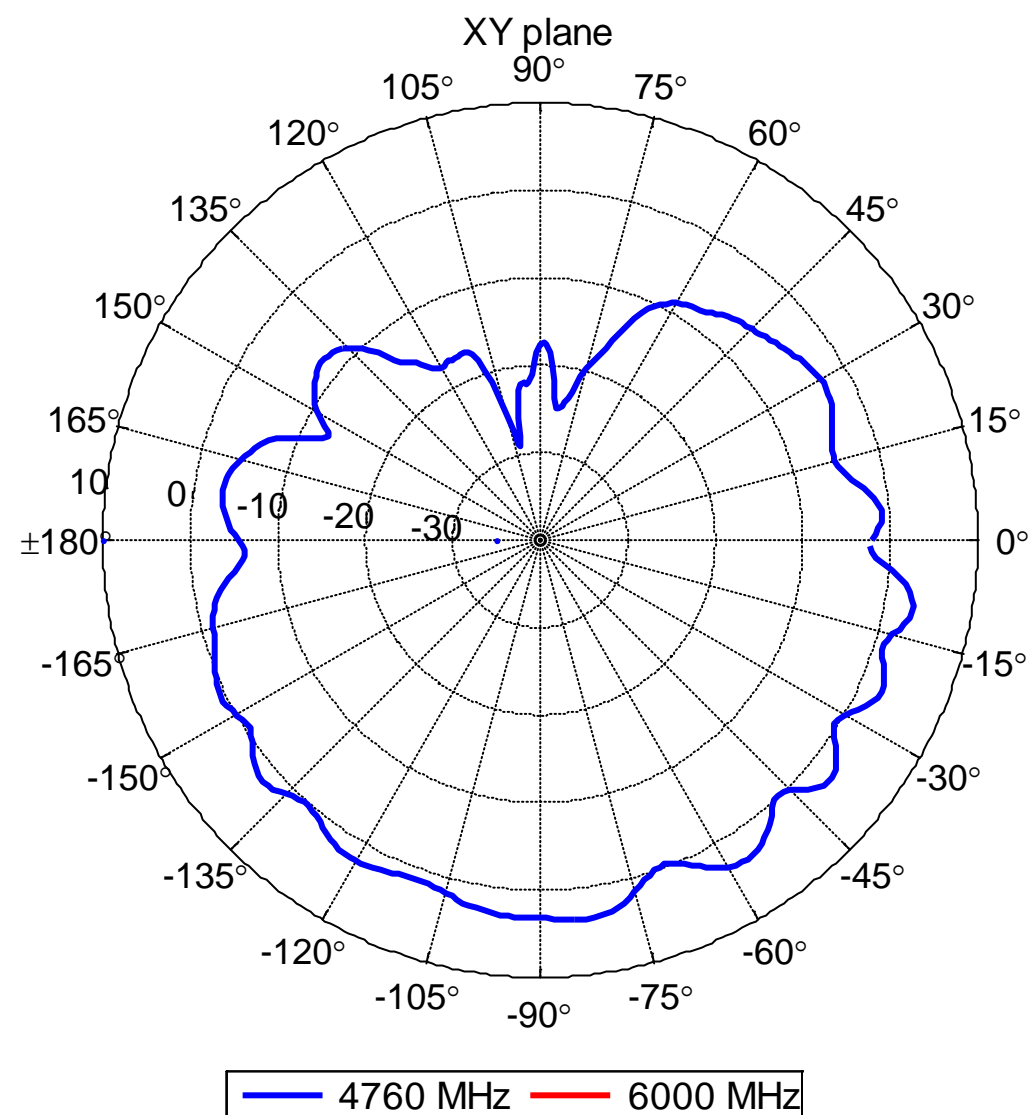
Duke: All Frequencies Band 3



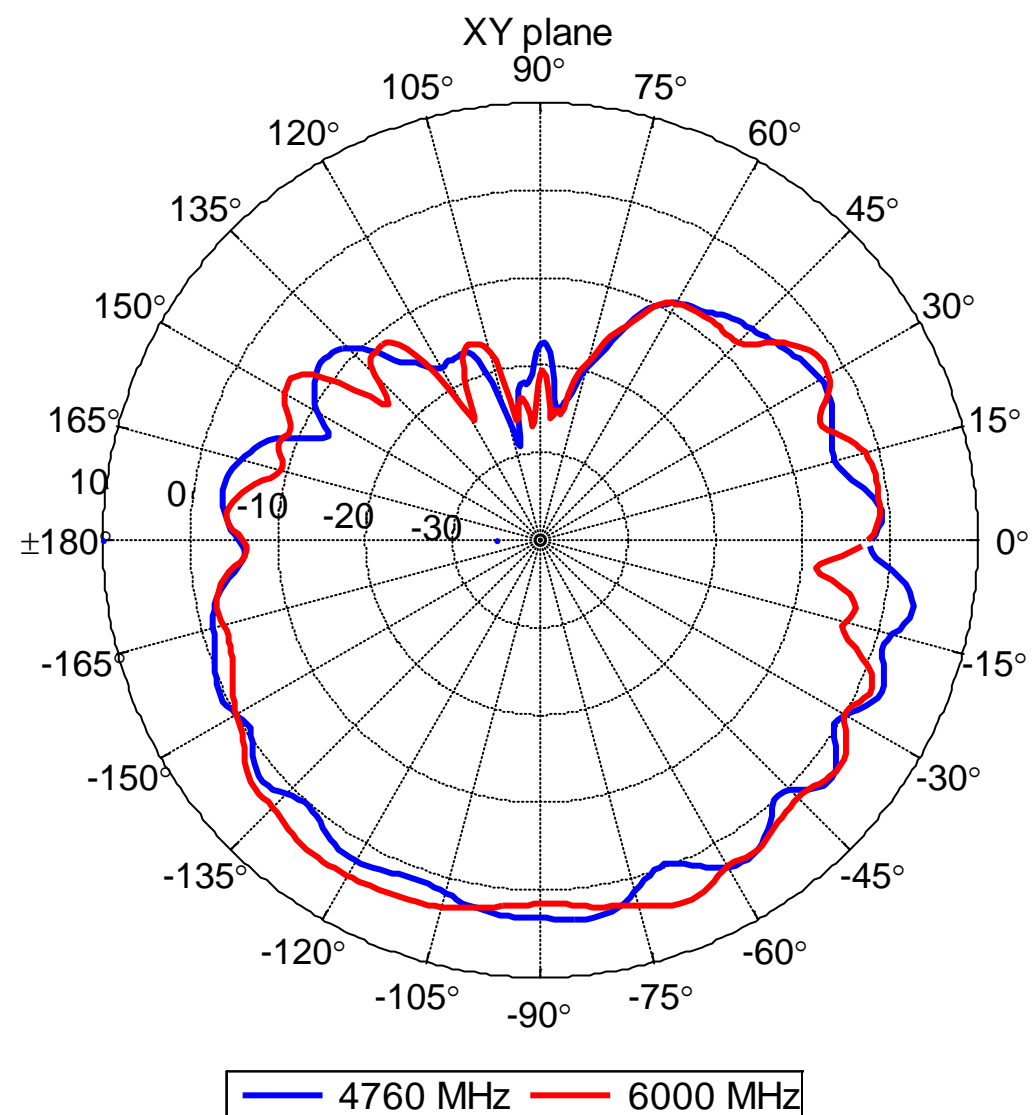
Duke: All Frequencies Band 3



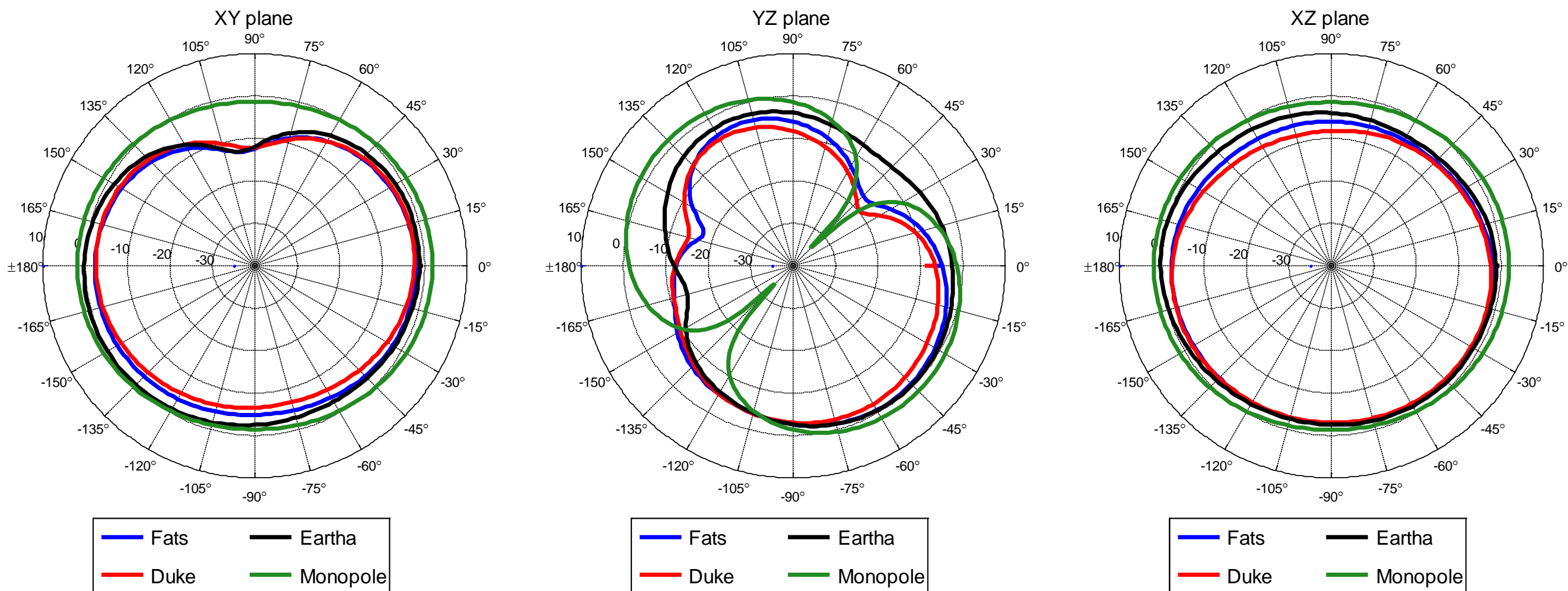
Duke: All Frequencies Band 4



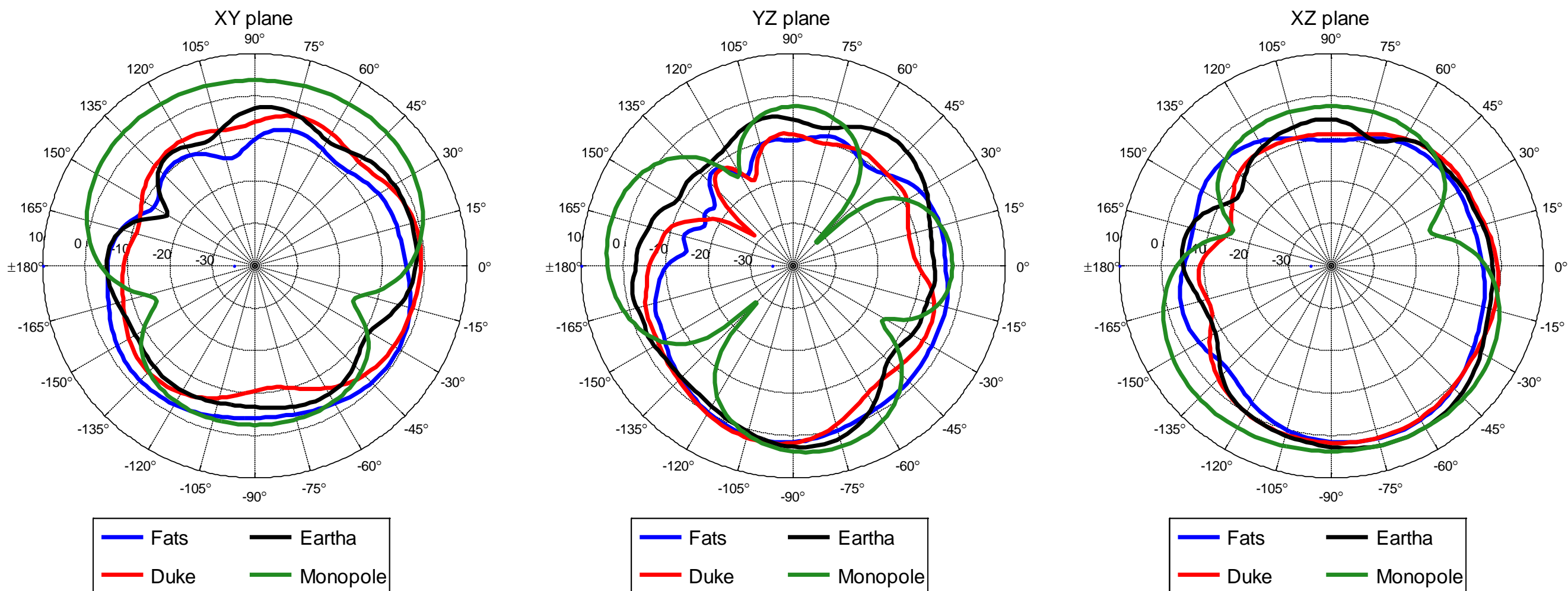
Duke: All Frequencies Band 4



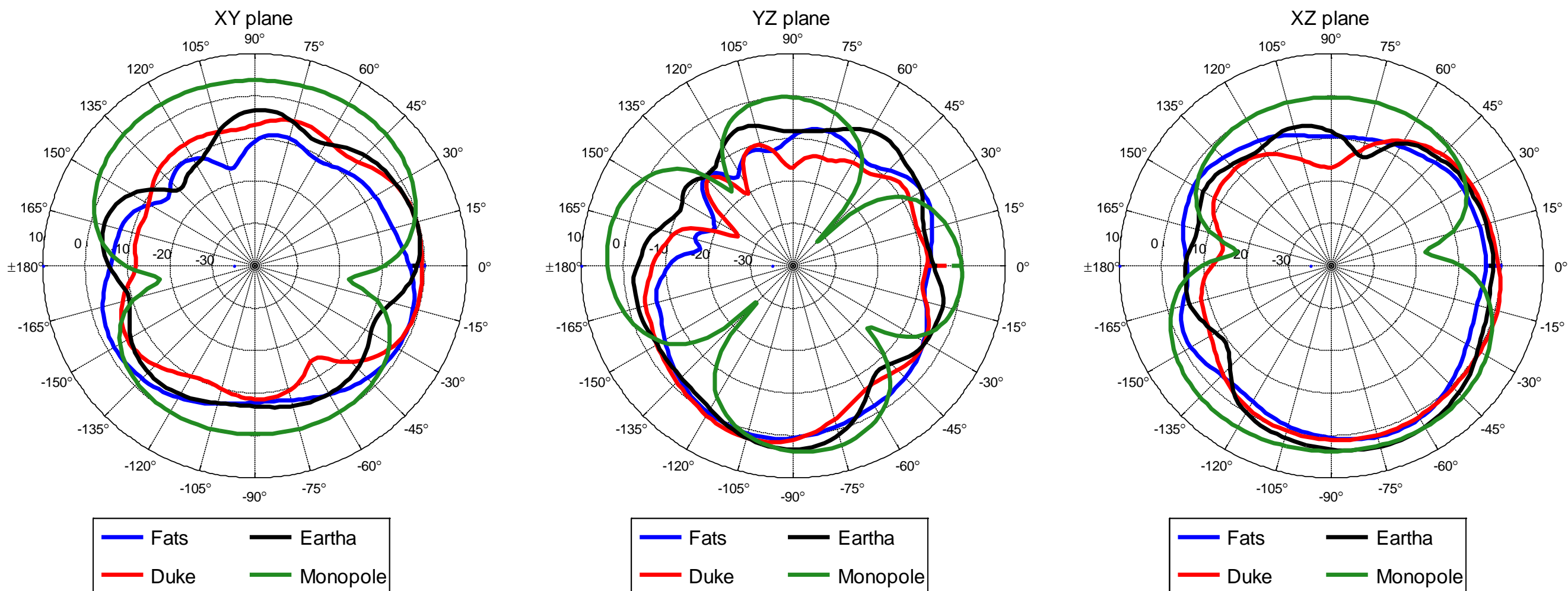
All Models Band 1: 235 MHz



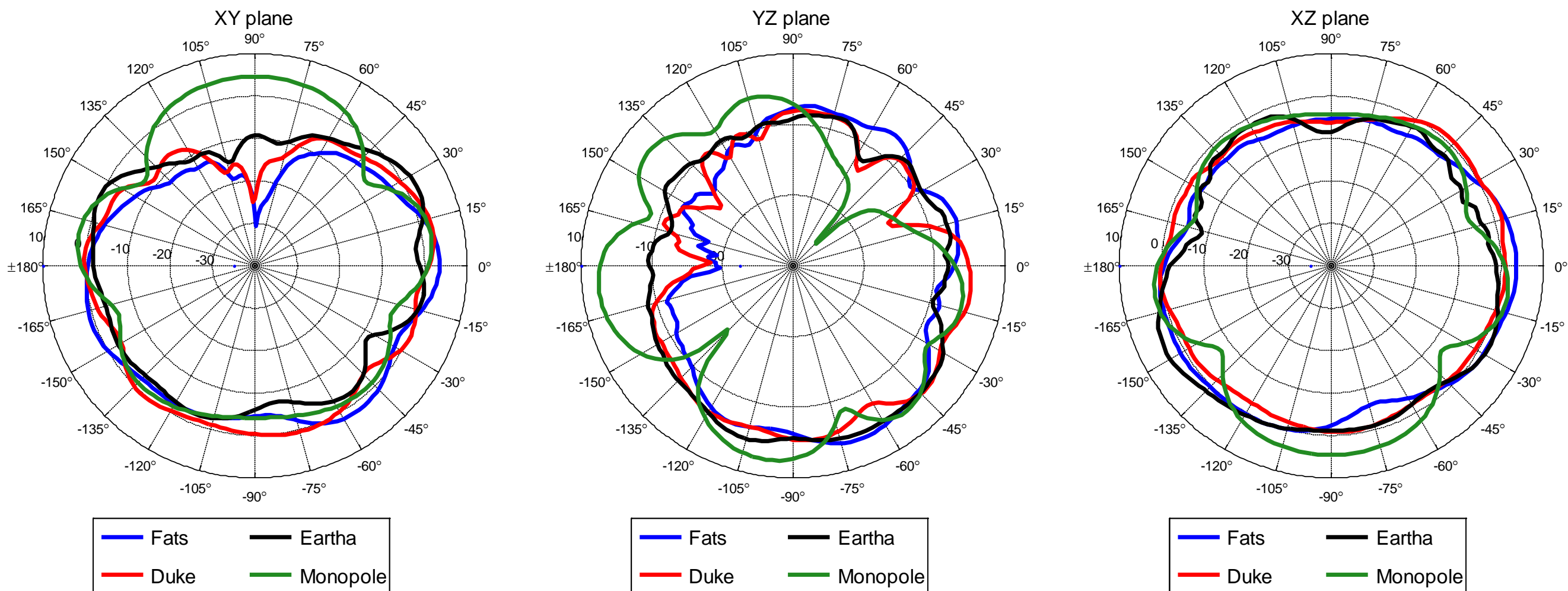
All Models Band 1: 825 MHz



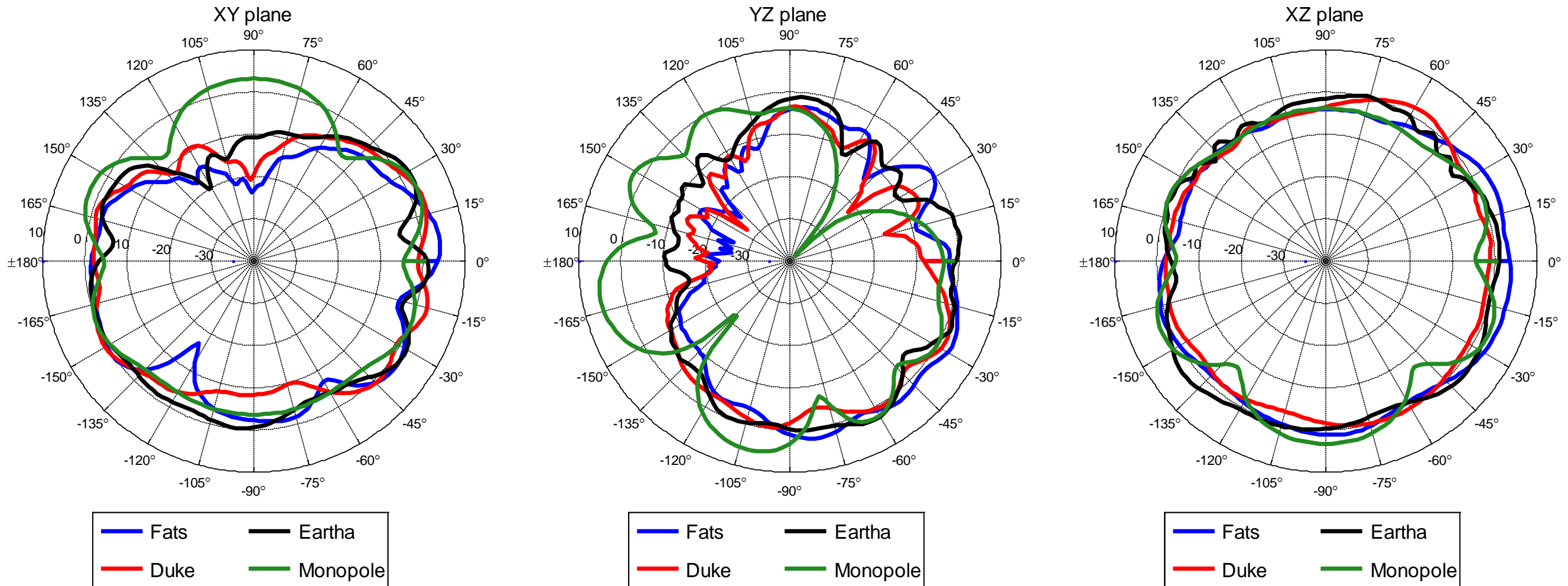
All Models Band 2: 945 MHz



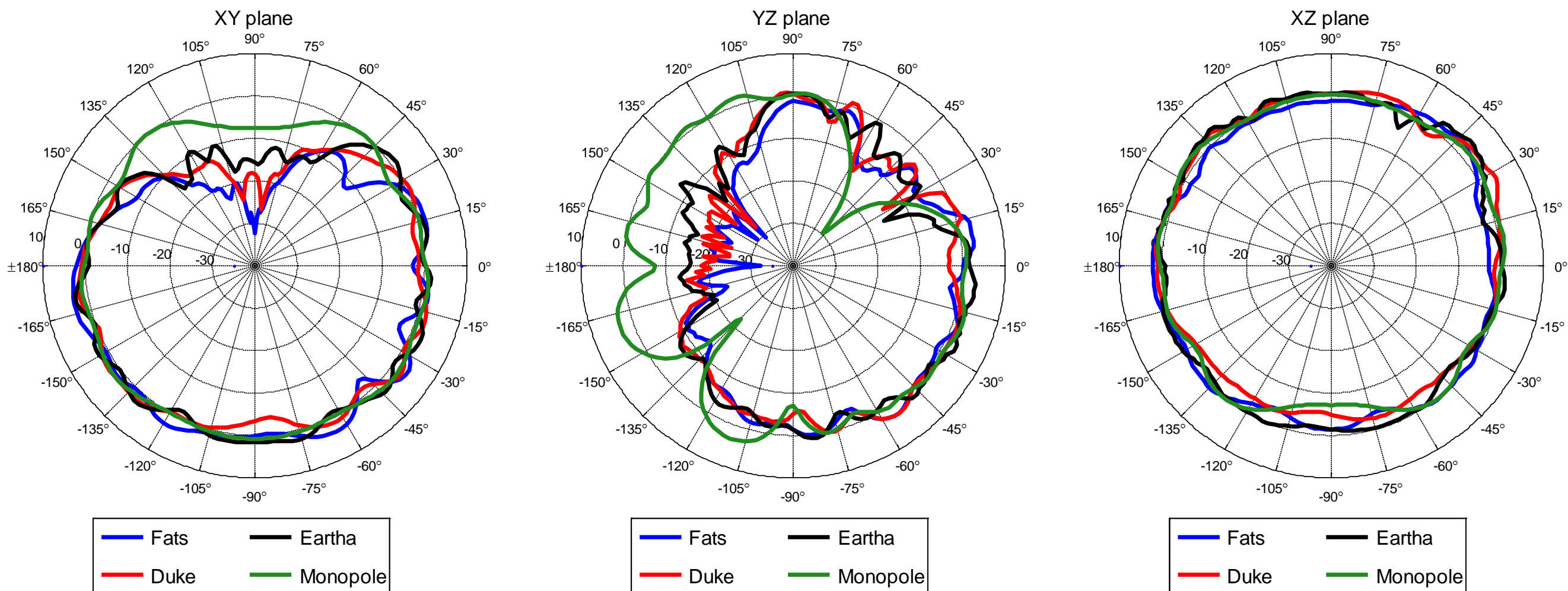
All Models Band 2: 1890 MHz



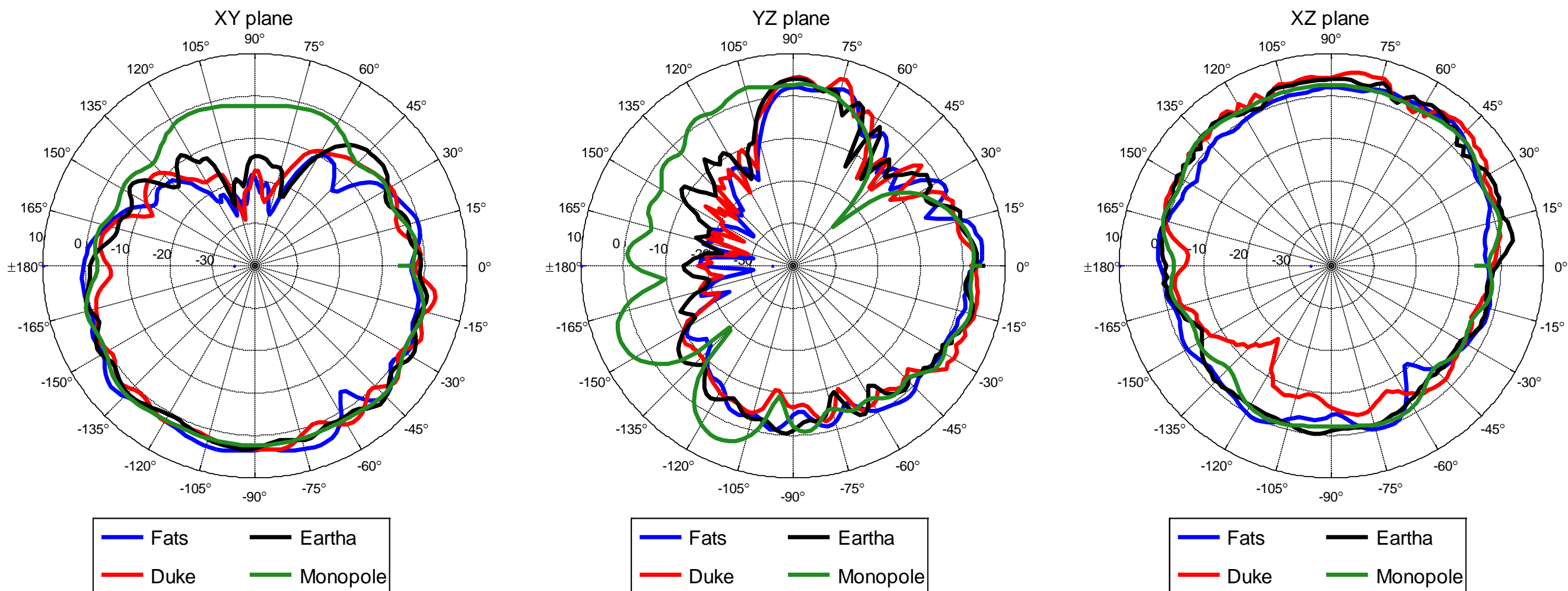
All Models Band 3: 2380 MHz



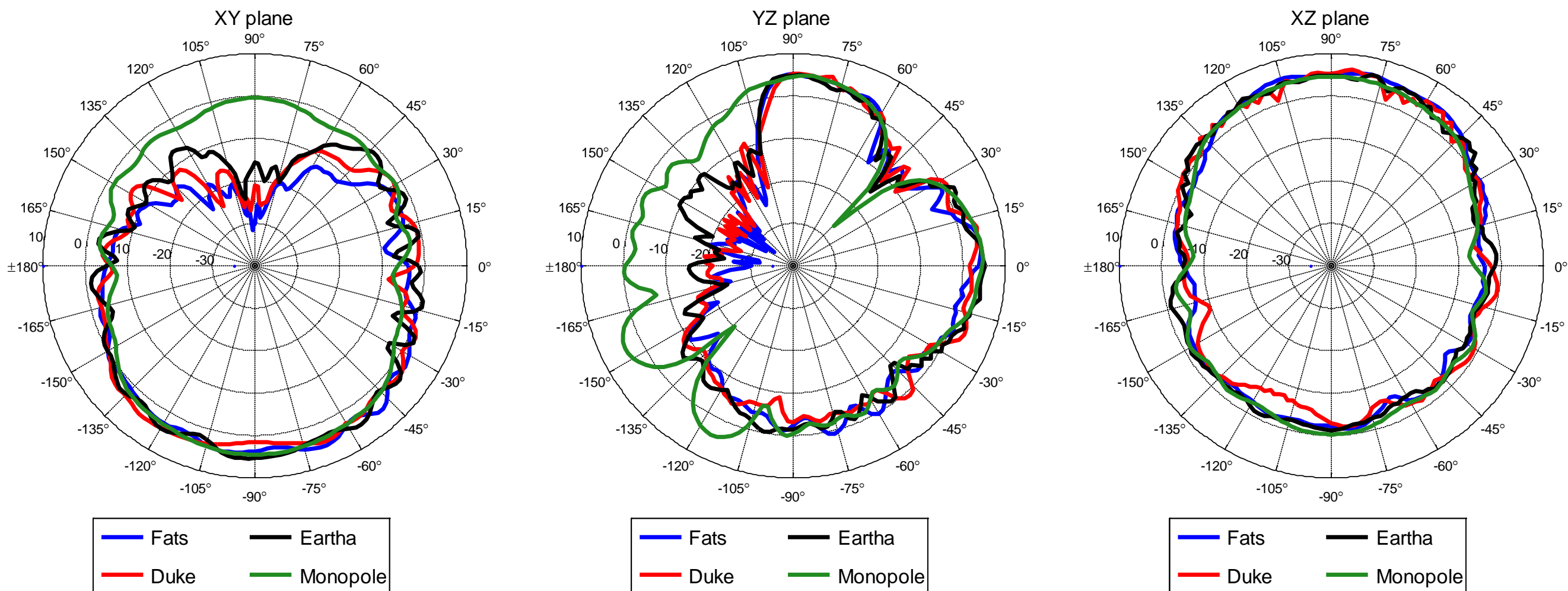
All Models Band 3: 3780 MHz



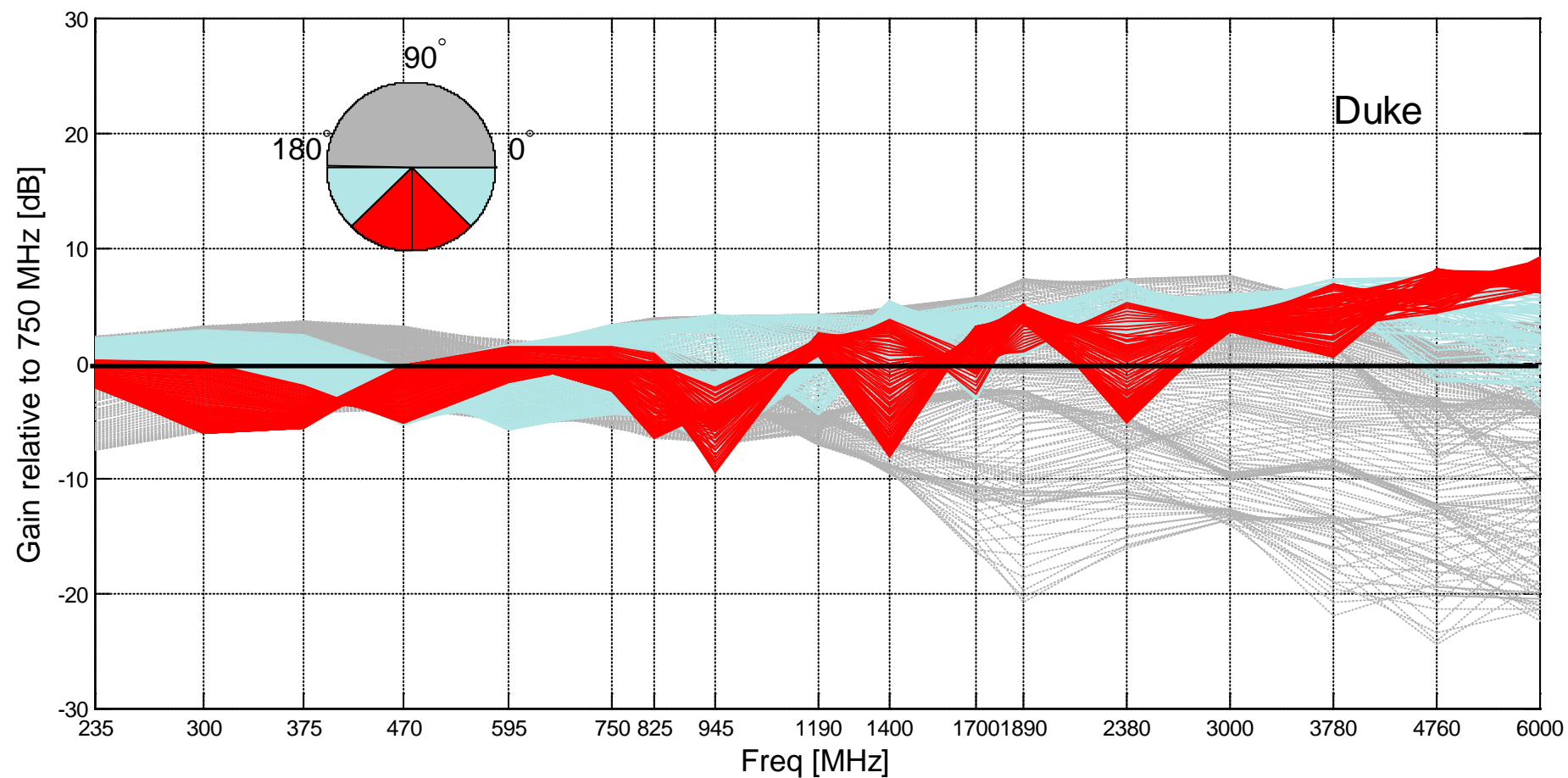
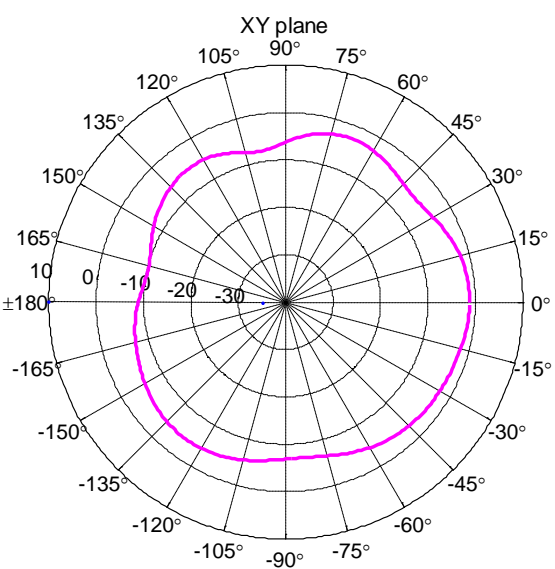
All Models Band 4: 4760 MHz



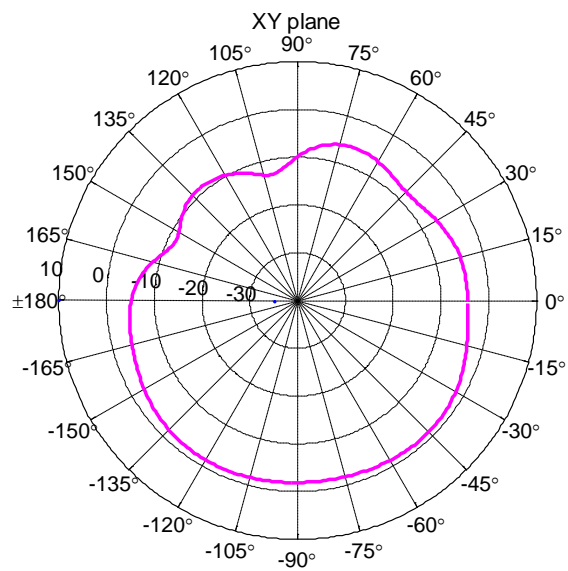
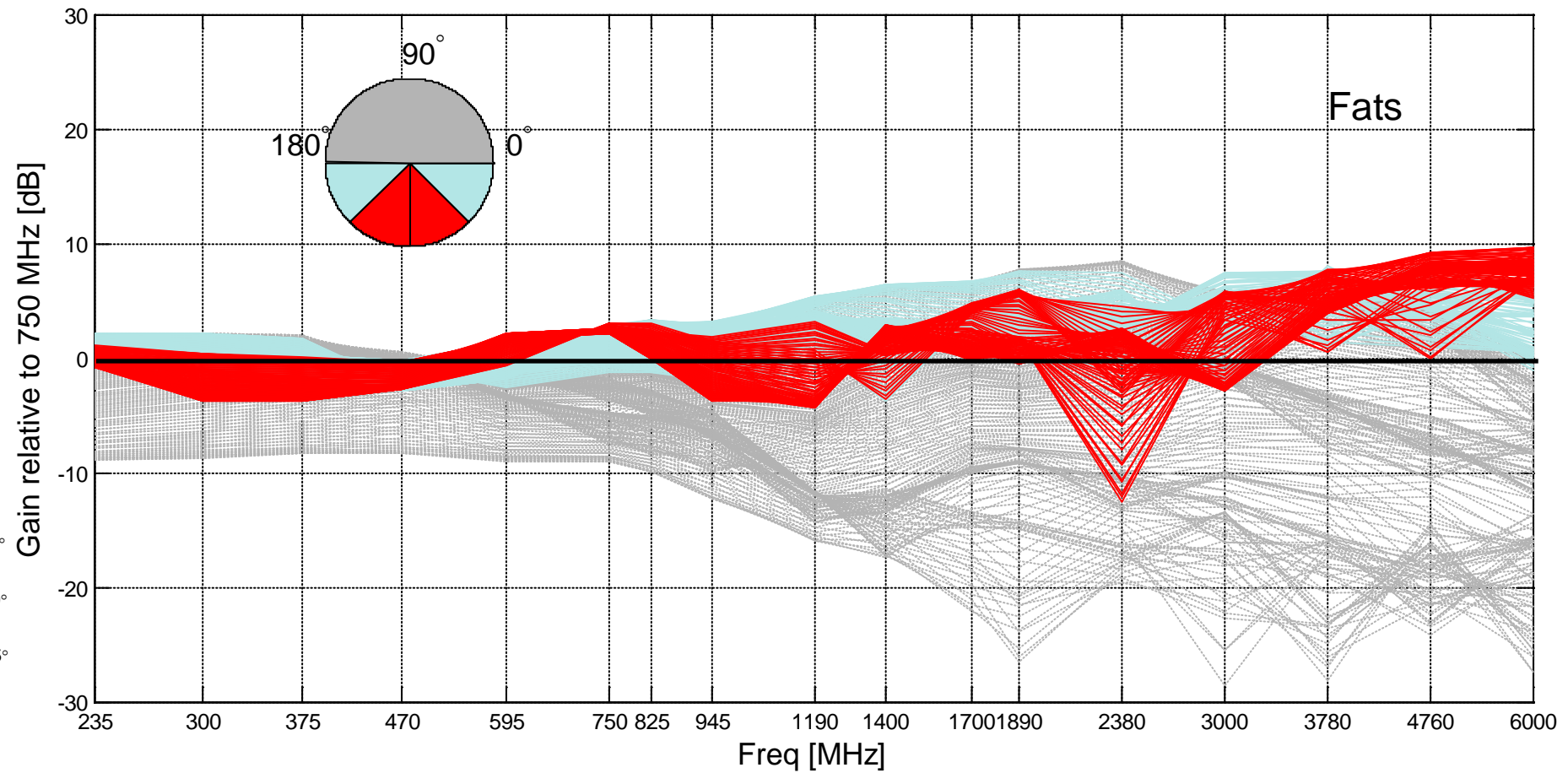
All Models Band 4: 6000 MHz



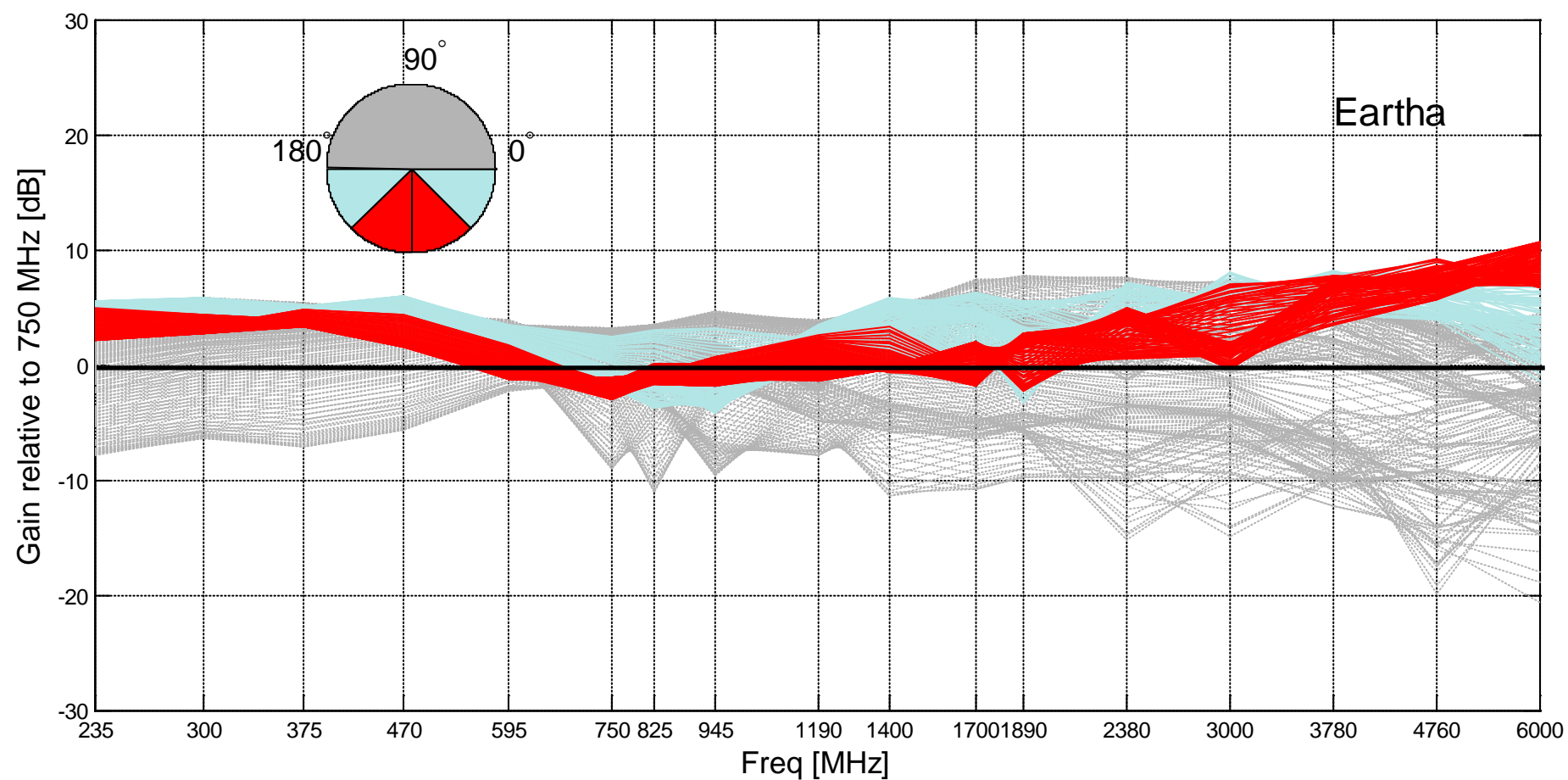
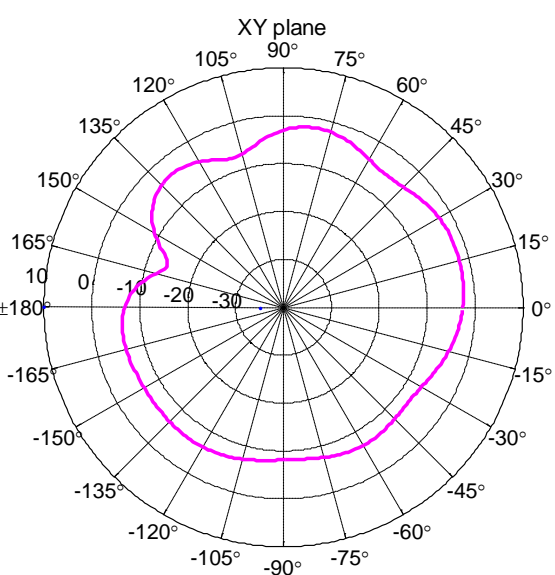
Duke: Gain Relative to Average at 750 MHz



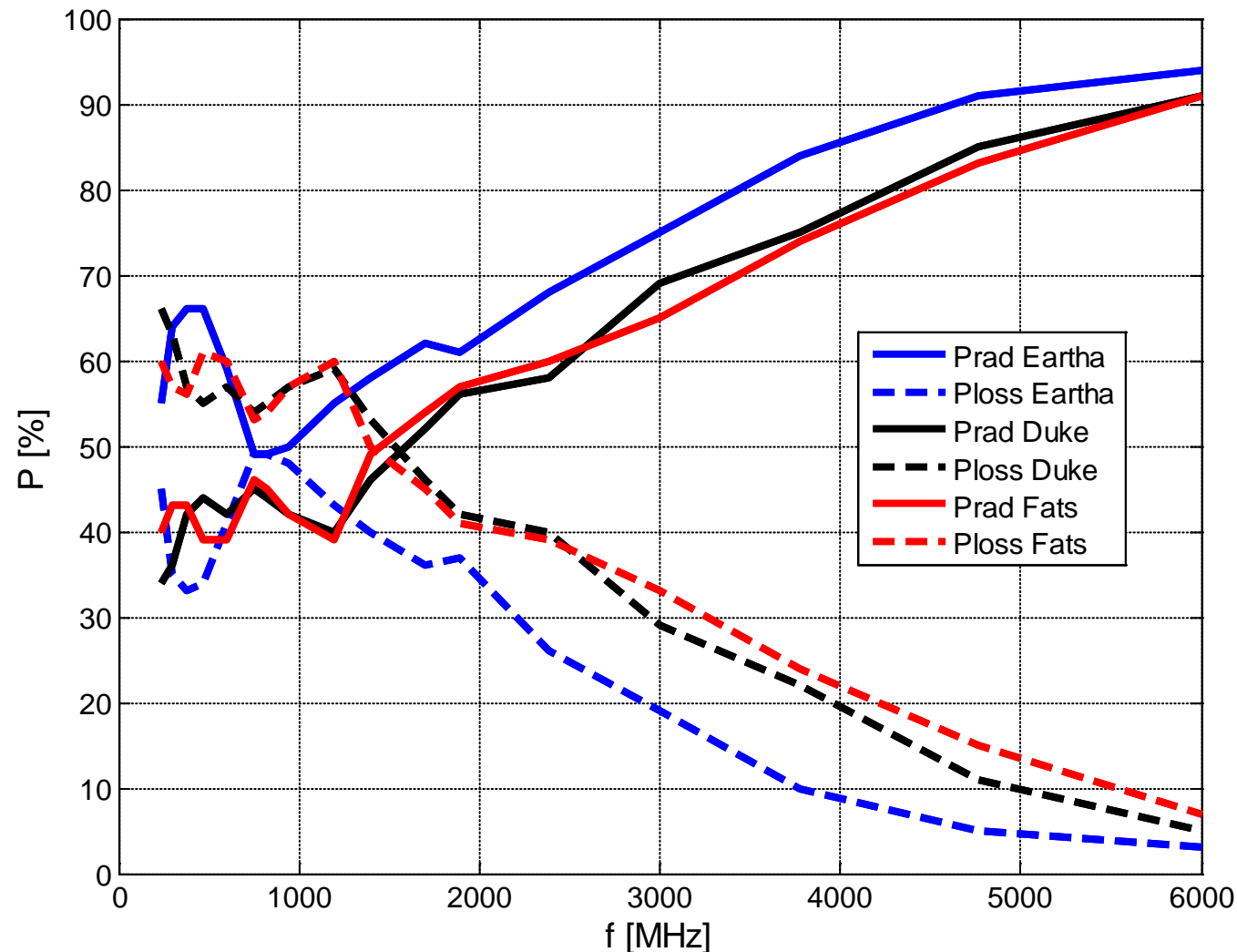
Fats: Gain Relative to Average at 750 MHz



Eartha: Gain Relative to Average at 750 MHz

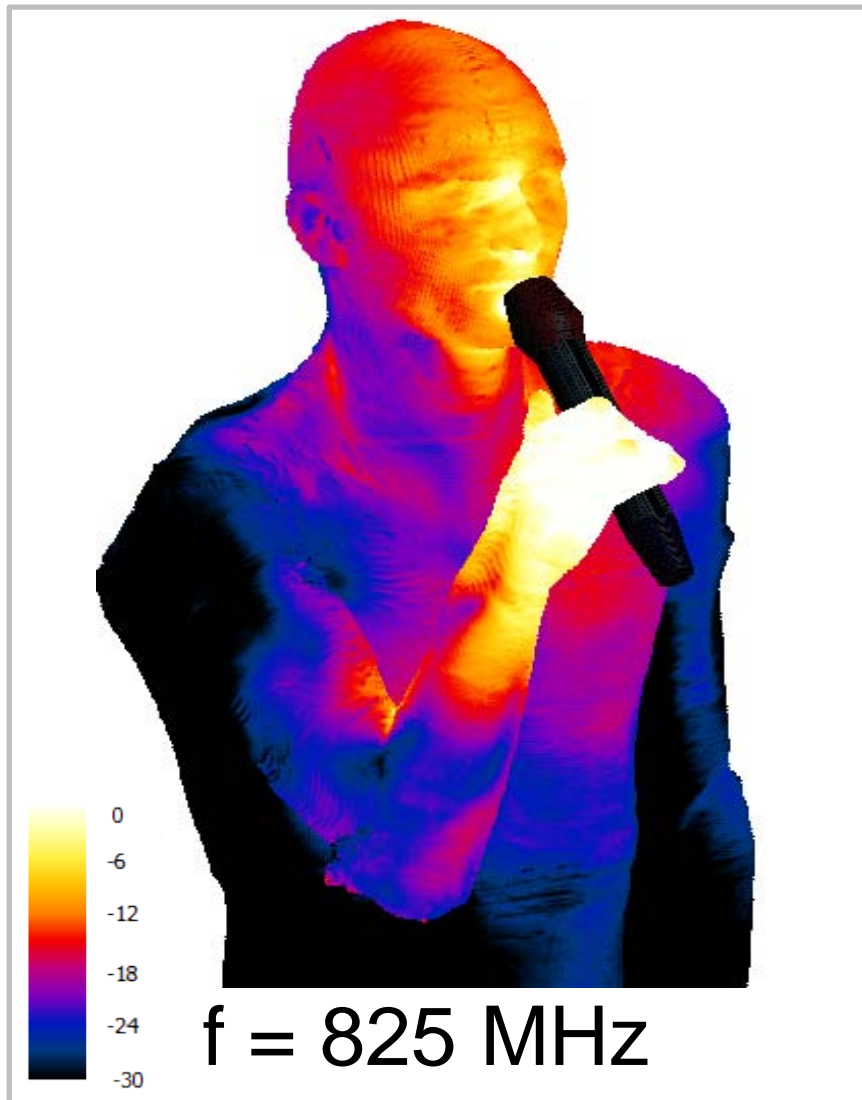


Radiated Power vs. Power Loss

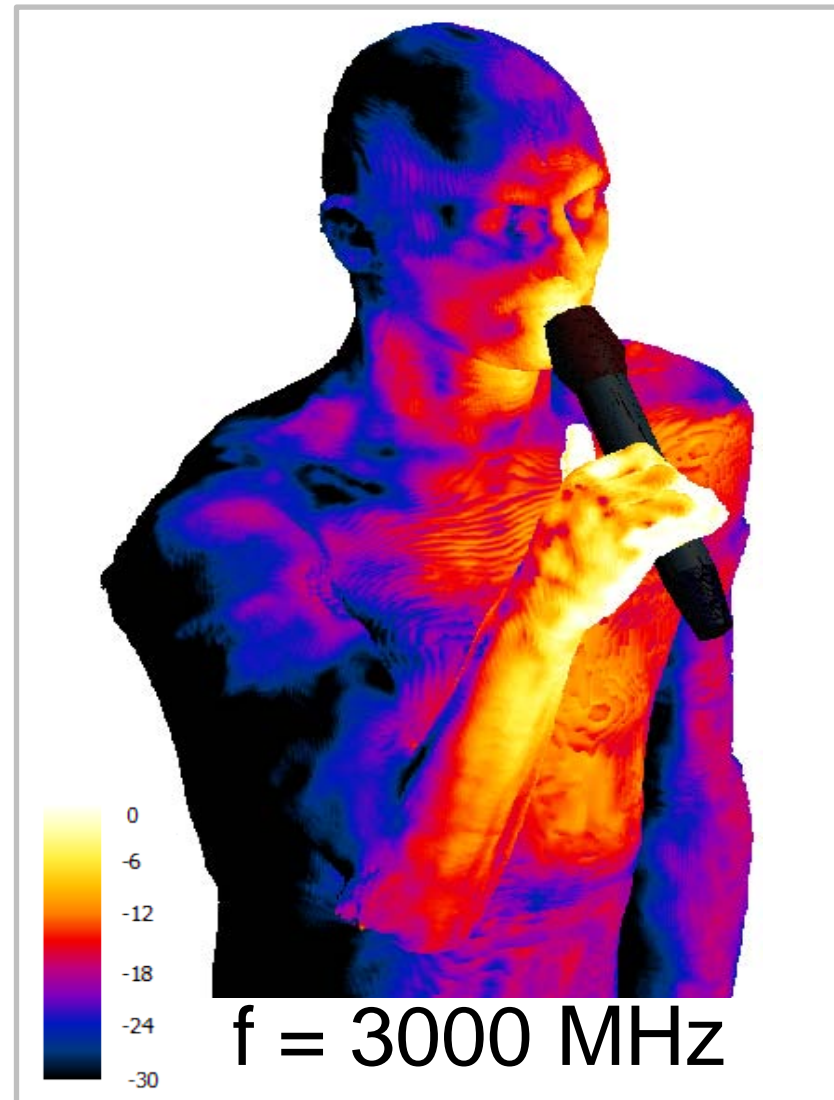


- PLoss: Power absorbed in the lossy tissues of the body
- Prad: Power radiated by the antenna
- $f < 1500$ MHz
 - Duke, Fats: Ploss $>$ Prad
 - Eartha: Prad $>$ Ploss
- $f > 1500$ MHz
 - Eartha, Duke, Fats: Prad $>$ Ploss

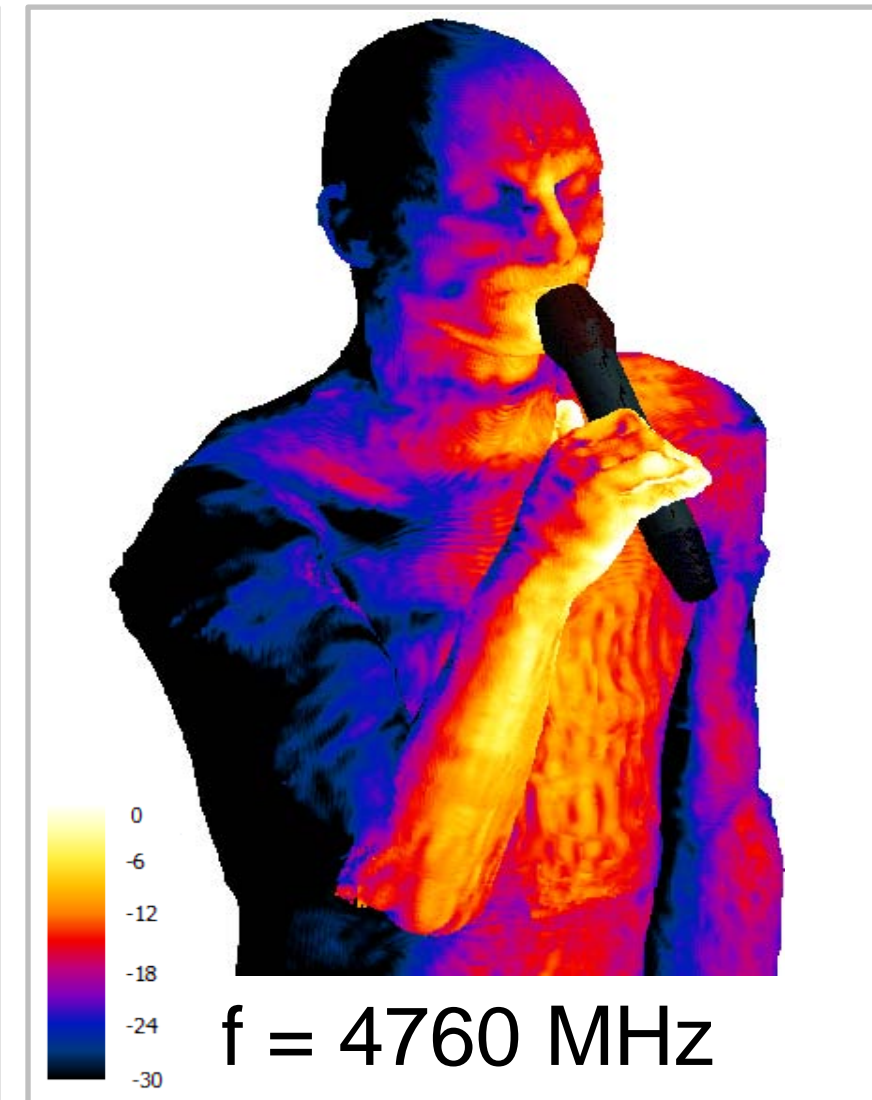
Duke: Surface SAR Distribution (W/kg)



0 dB is 1 W/kg for 1 W Pin

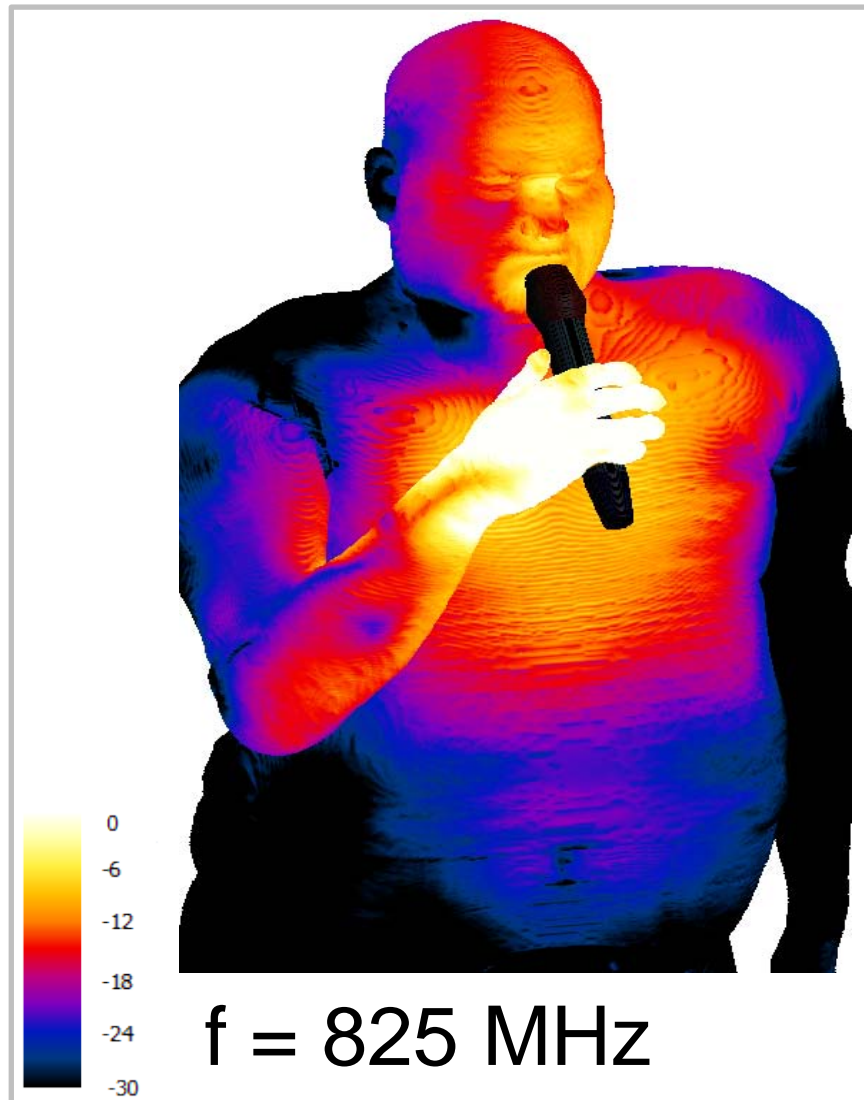


0 dB is 1 W/kg for 1 W Pin

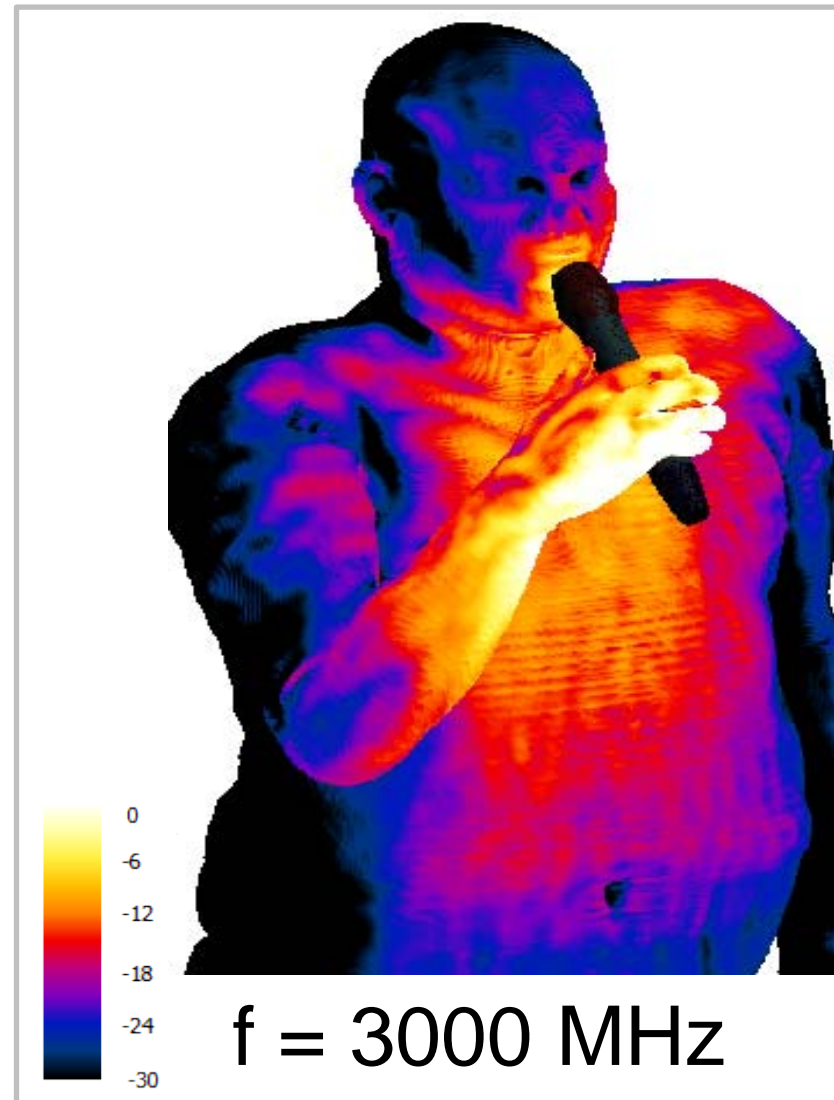


0 dB is 1 W/kg for 1 W Pin

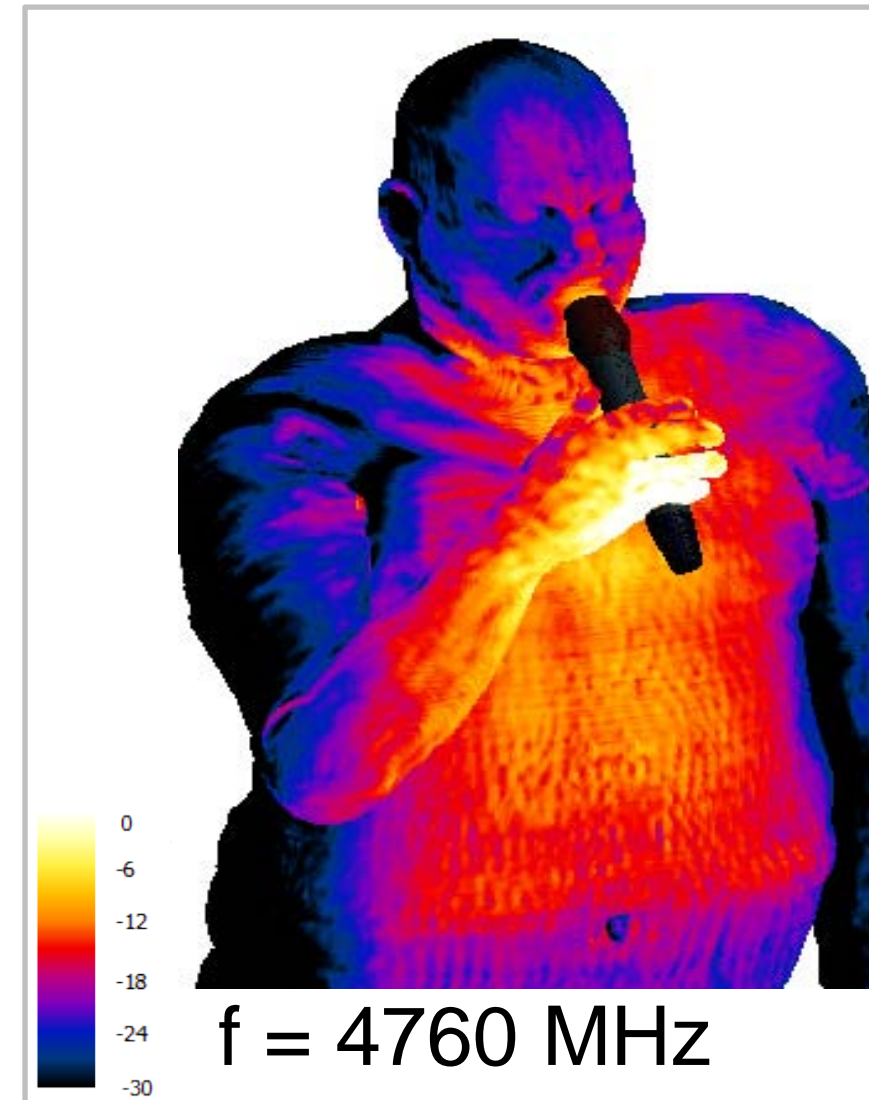
Fats: Surface SAR Distribution (W/kg)



0 dB is 1 W/kg for 1 W Pin

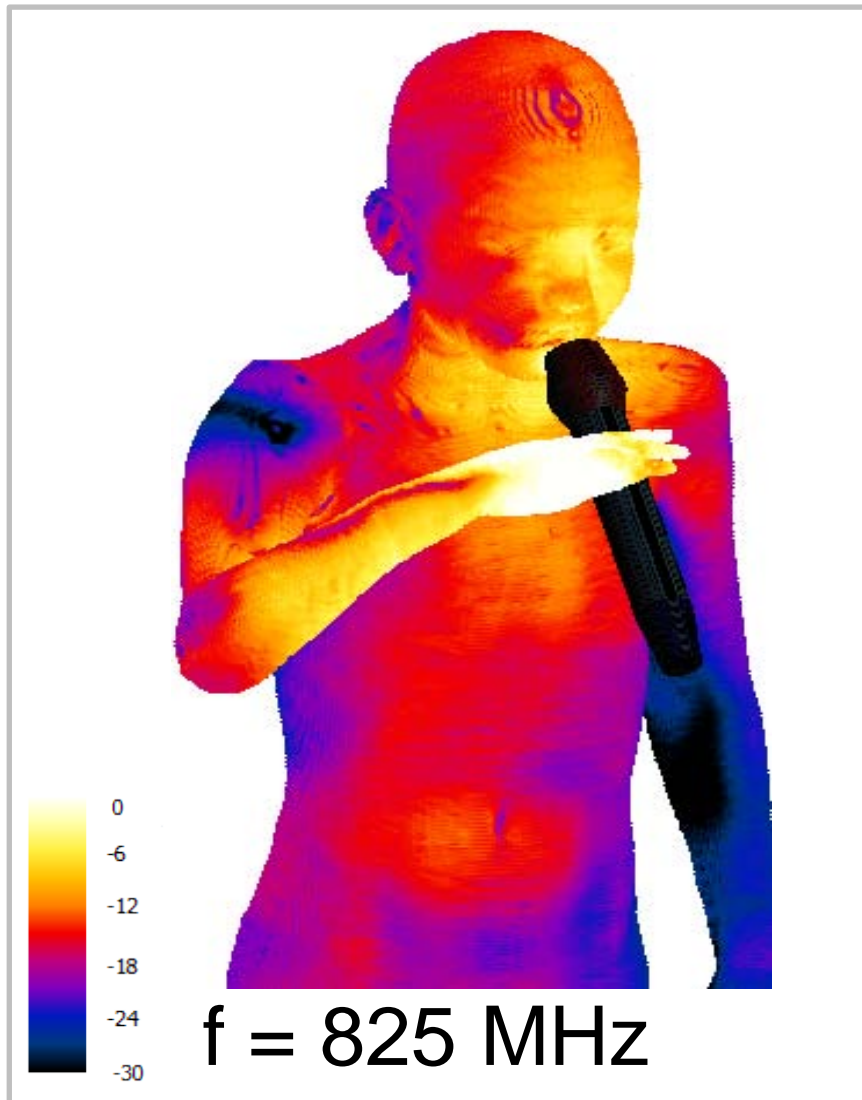


0 dB is 1 W/kg for 1 W Pin

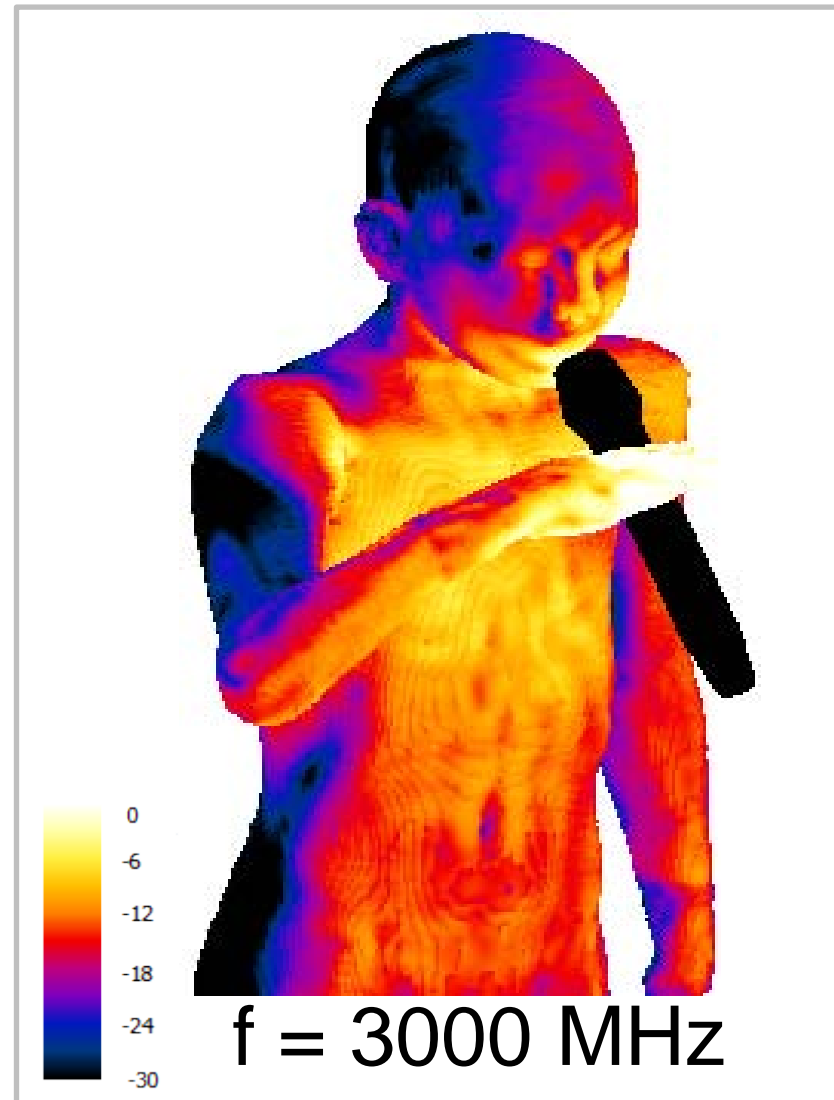


0 dB is 1 W/kg for 1 W Pin

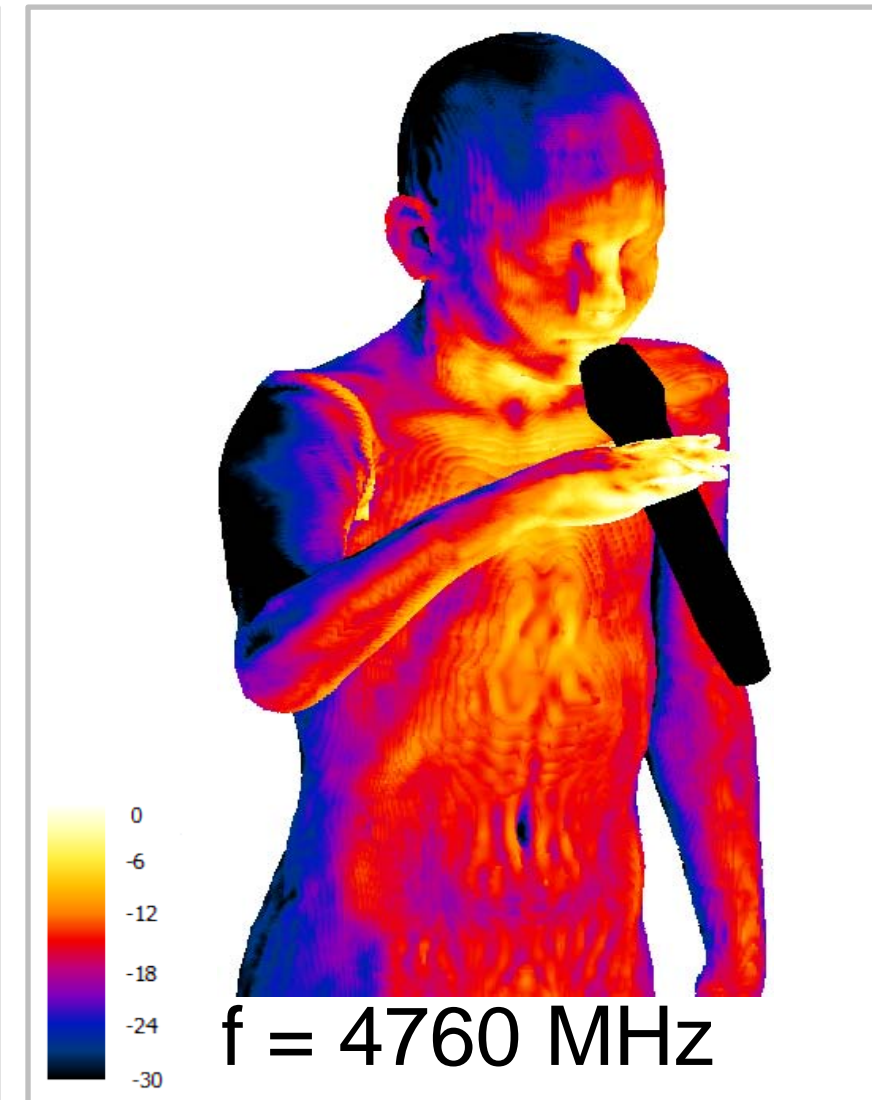
Eartha: Surface SAR Distribution (W/kg)



0 dB is 1 W/kg for 1 W Pin



0 dB is 1 W/kg for 1 W Pin

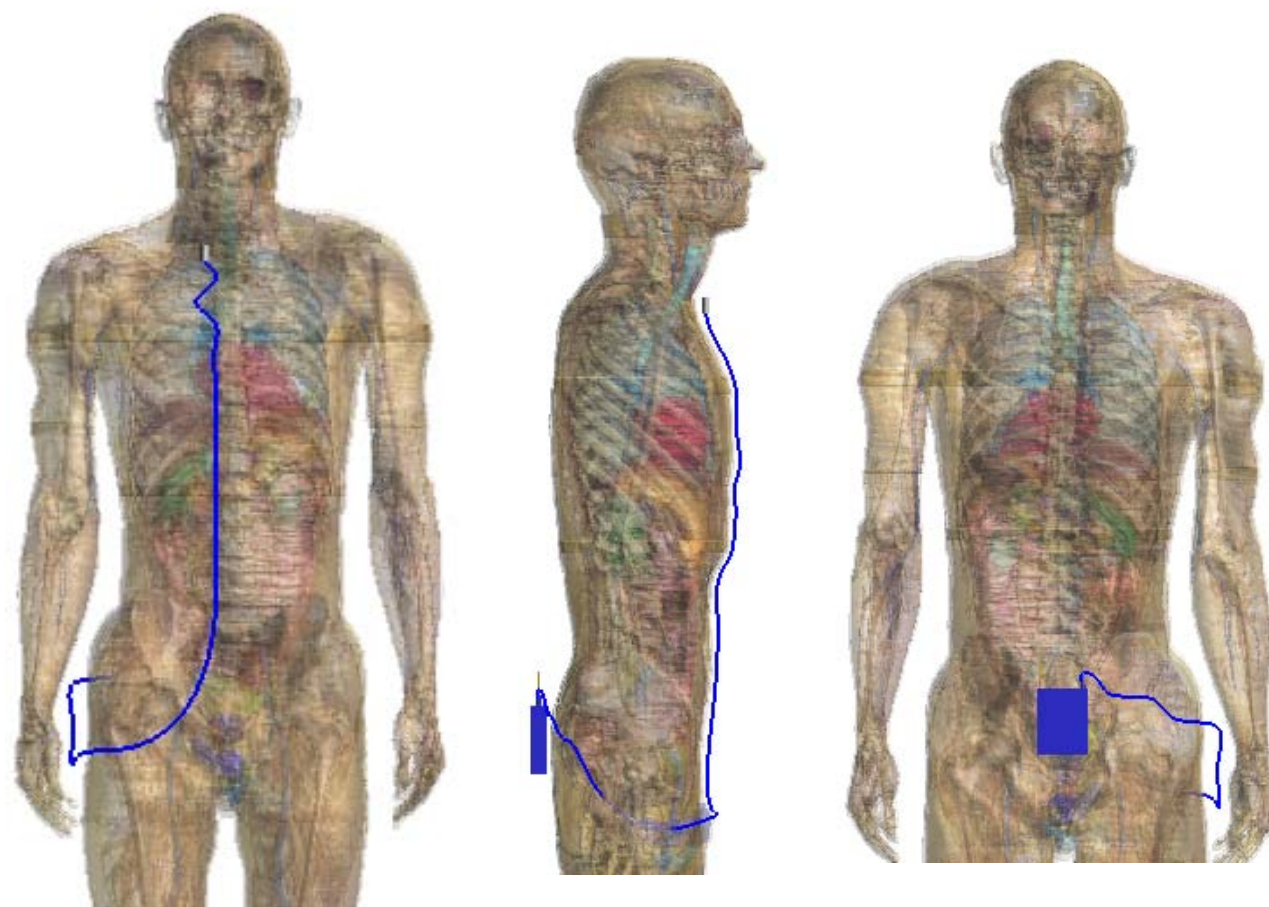


0 dB is 1 W/kg for 1 W Pin

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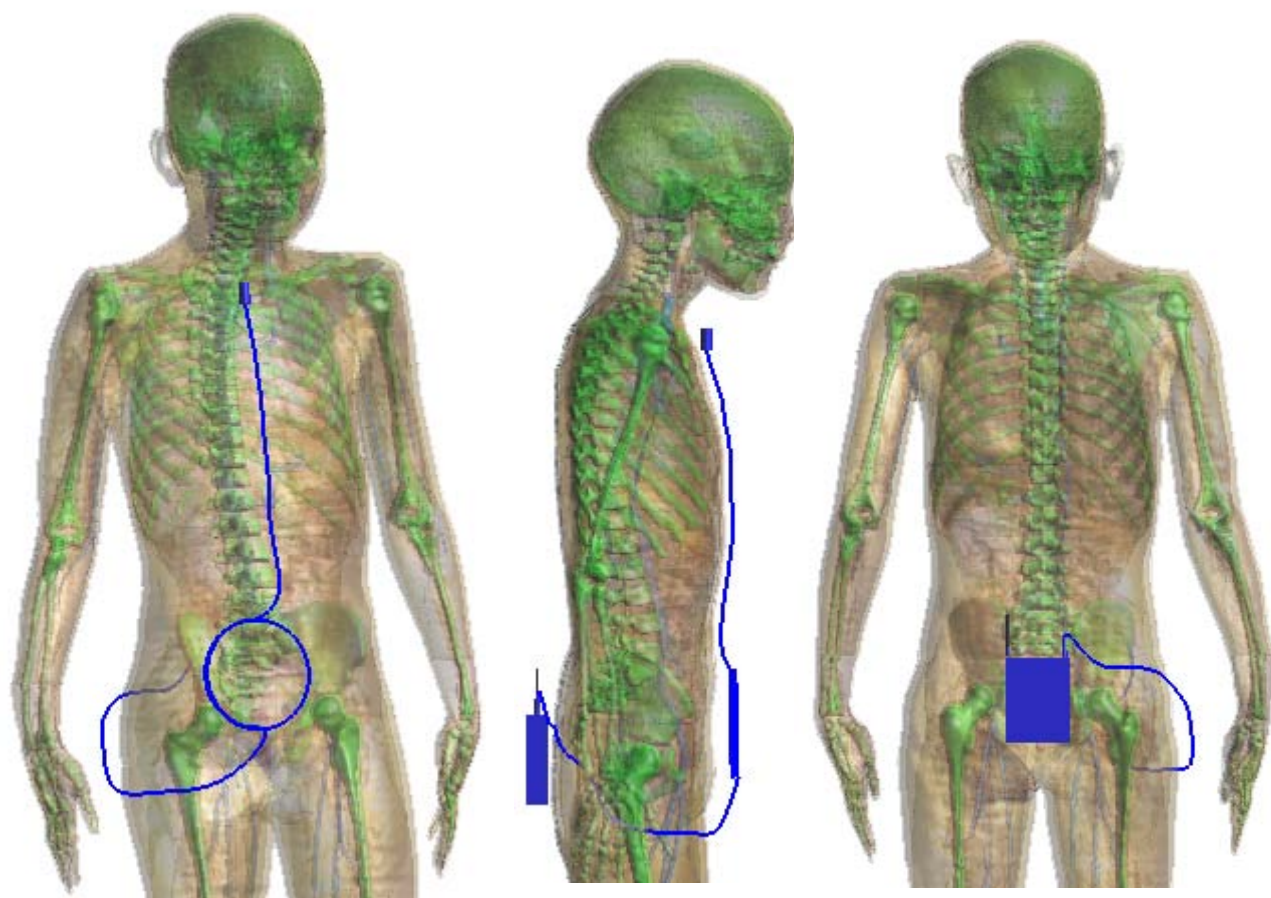
Duke and Body Pack Microphone



- Wire length ~ 1.2 m
- Wire – body distance ~ 5 mm
- Pack – body distance ~ 5 mm
- Antenna – body distance
- From 15 to 30 mm due to model curvature
- Tissue properties assigned for each frequency [1]

[1] Hasgall PA, Neufeld E, Gosselin MC, Klingenberg A, Kuster N, "IT'IS Database for thermal and electromagnetic parameters of biological tissues," Version 2.6, Jan 13, 2015. DOI: 10.1099/21001-02.6. www.itis.ethz.ch/database

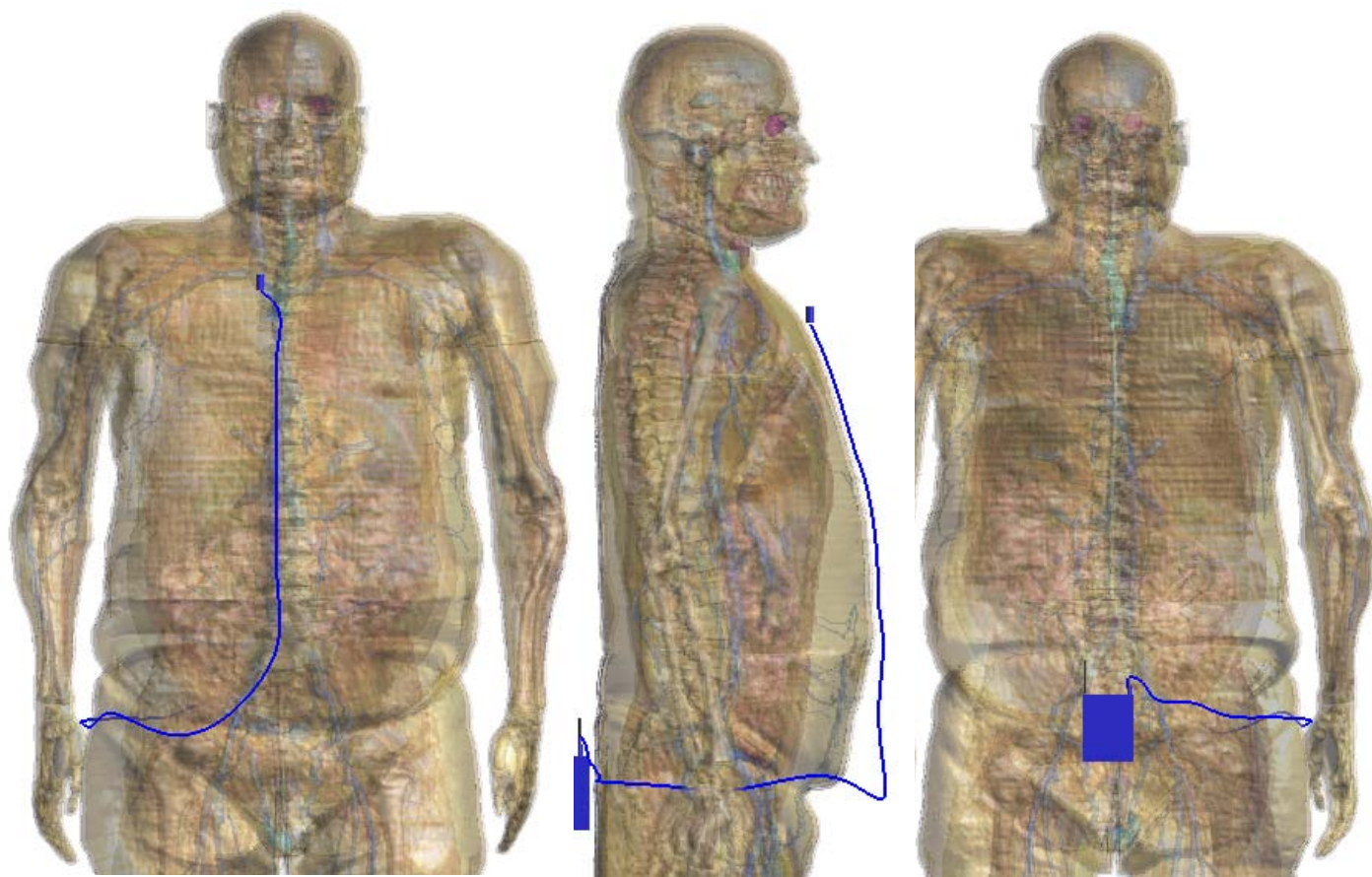
Eartha and Body Pack Microphone



- Wire length ~ 1.2 m, looping needed ($r \sim 50$ mm)
- Wire – body distance ~ 5 mm
- Pack – body distance ~ 5 mm
- Antenna – body distance
- From 13 to 20 mm due to model curvature
- Tissue properties assigned for each frequency [1]

[1] Hasgall PA, Neufeld E, Gosselin MC, Klingenberg A, Kuster N, "IT'IS Database for thermal and electromagnetic parameters of biological tissues," Version 2.6, Jan 13, 2015. DOI: 10.1099/21001-02.6. www.itis.ethz.ch/database

Fats and Body Pack Microphone

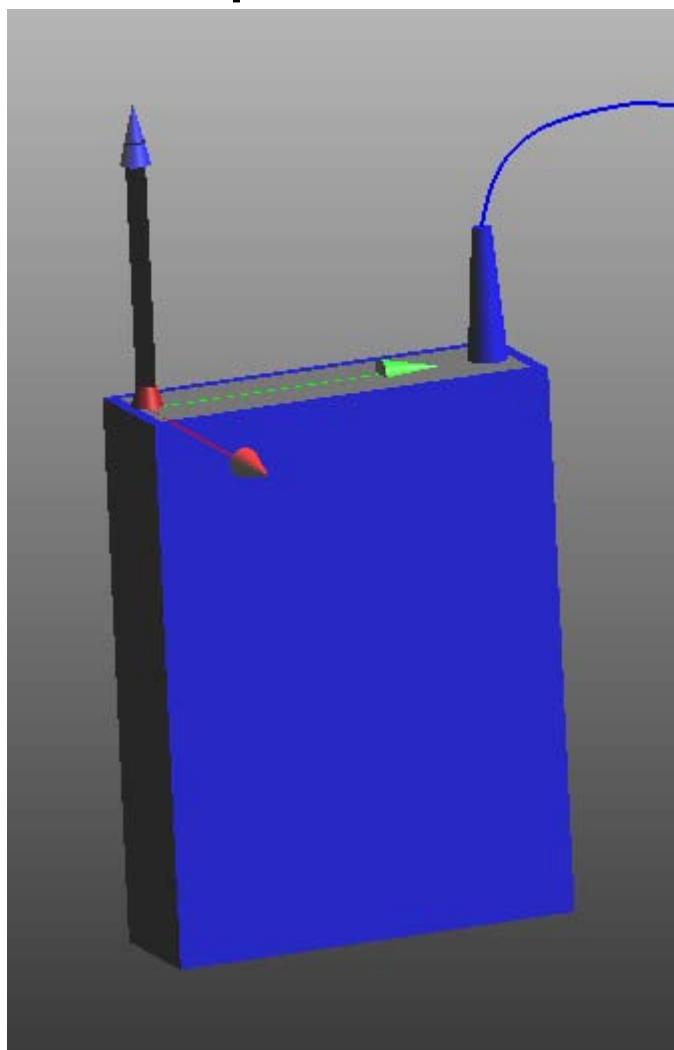


- Wire length ~ 1.2 m
- Wire – body distance ~ 5 mm
- Pack – body distance ~ 5 mm
- Antenna – body distance
- Approx 13 mm along whole antenna
- Tissue properties assigned for each frequency [1]

[1] Hasgall PA, Neufeld E, Gosselin MC, Klingenböck A, Kuster N, "IT'IS Database for thermal and electromagnetic parameters of biological tissues," Version 2.6, Jan 13, 2015. DOI: 10.1099/21001-02.6. www.itis.ethz.ch/database

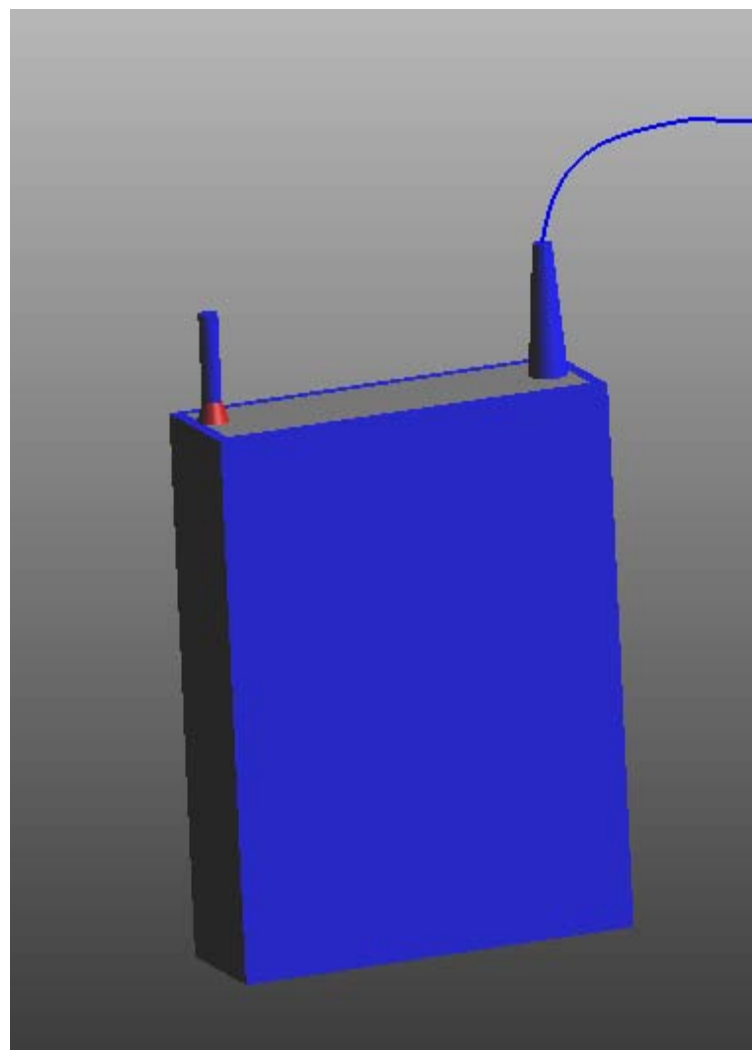
Body Pack Microphone Models

Monopole 40mm



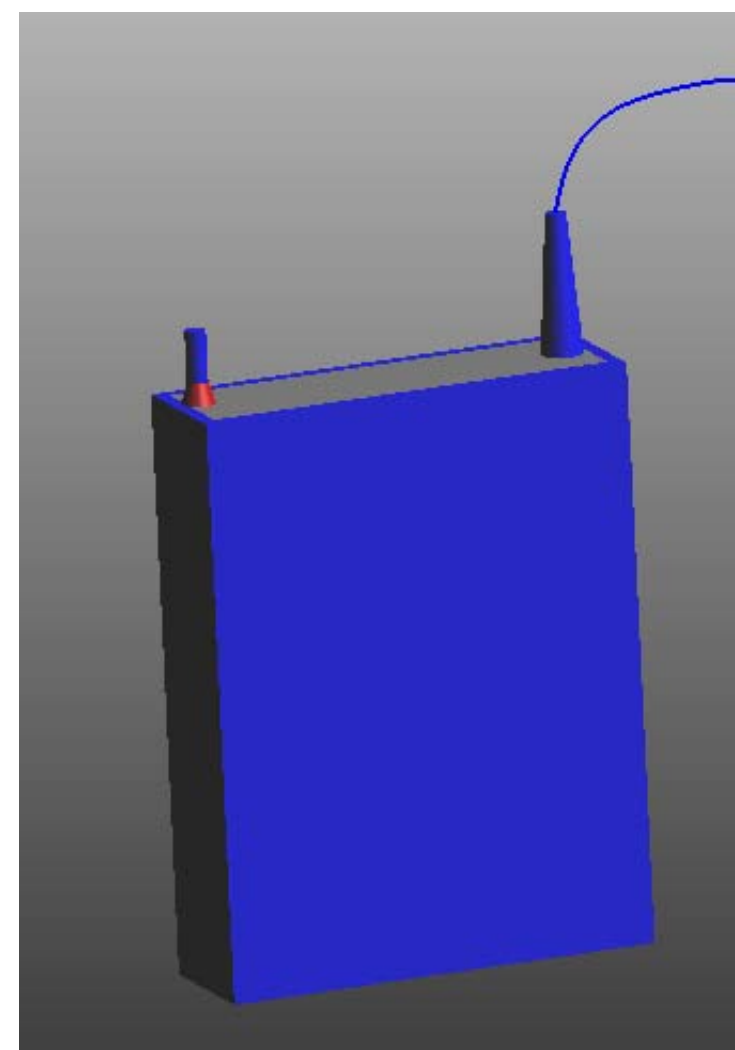
235 – 1890 MHz

16mm



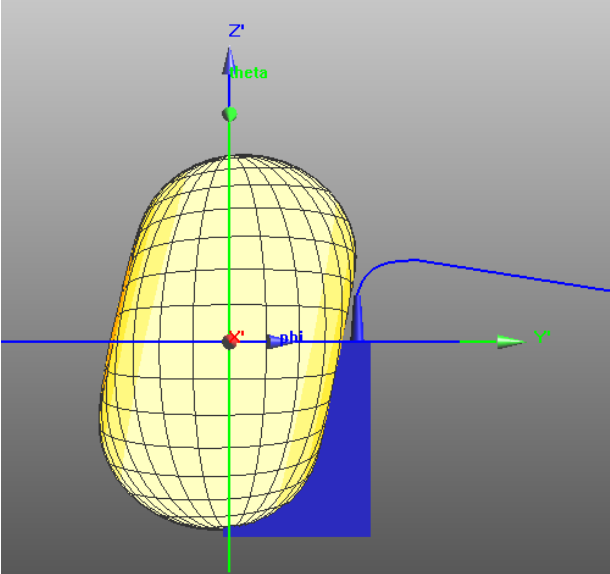
2380 – 3780 MHz

10mm

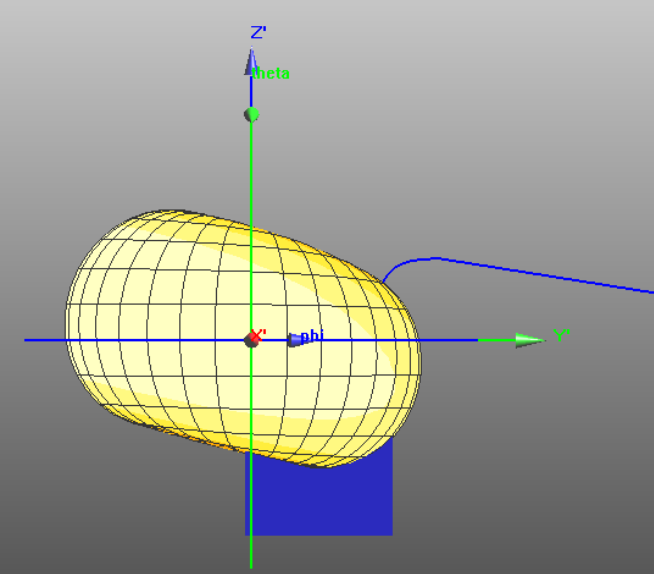


4760 – 6000 MHz

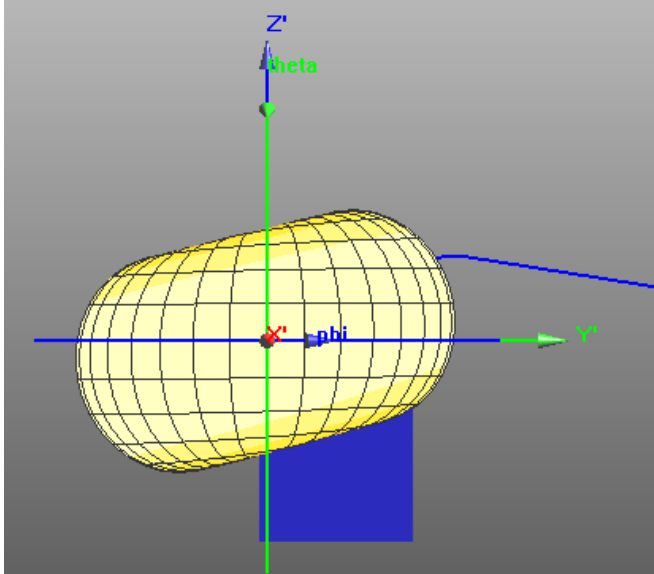
Radiation Patterns



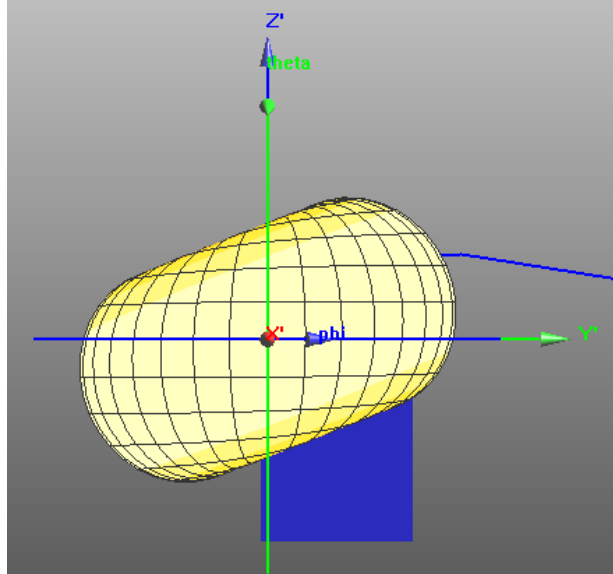
235 MHz



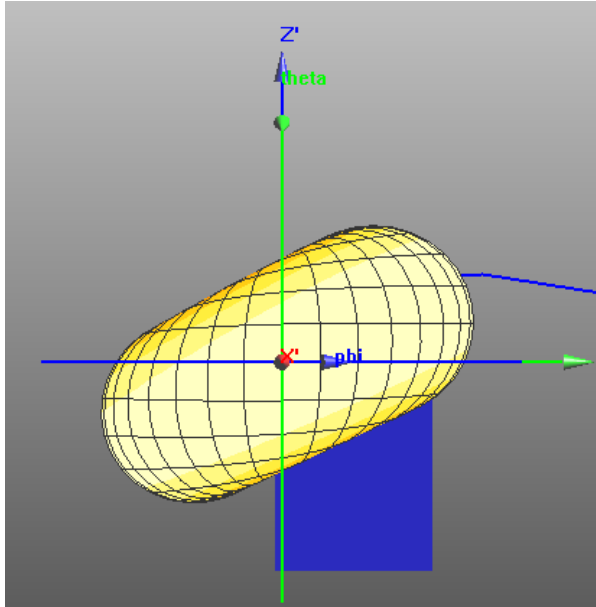
300 MHz



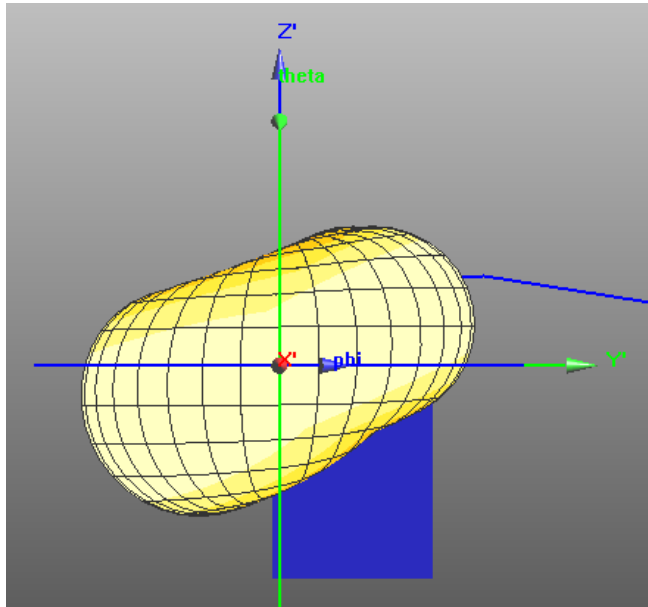
375 MHz



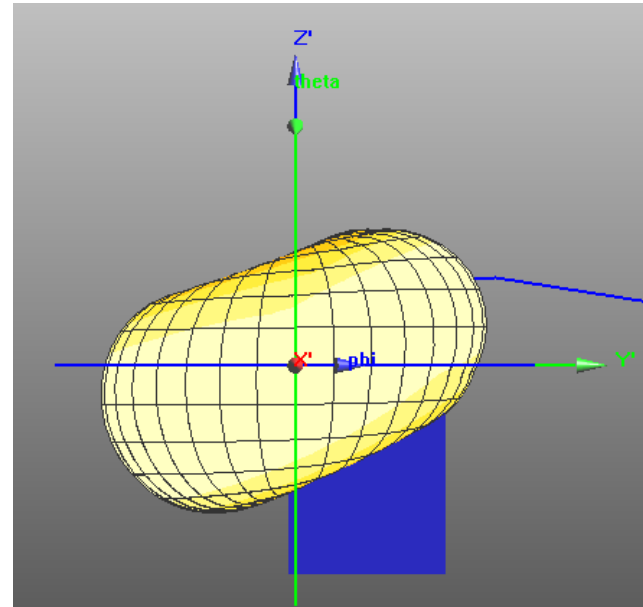
470 MHz



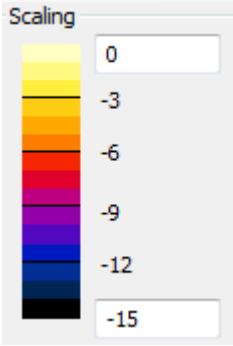
595 MHz



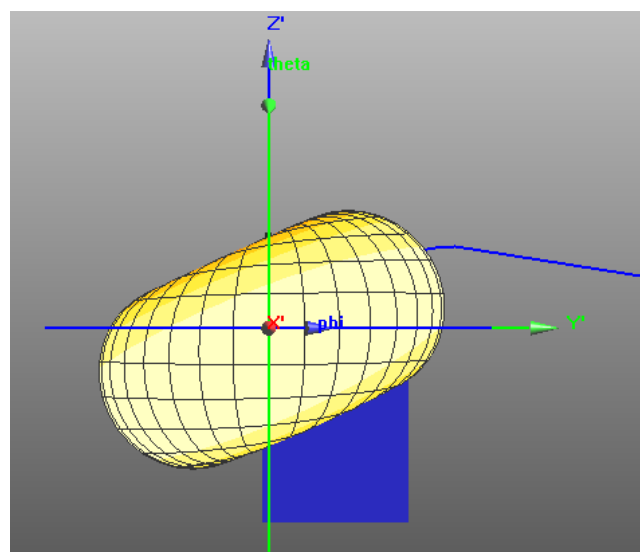
750 MHz



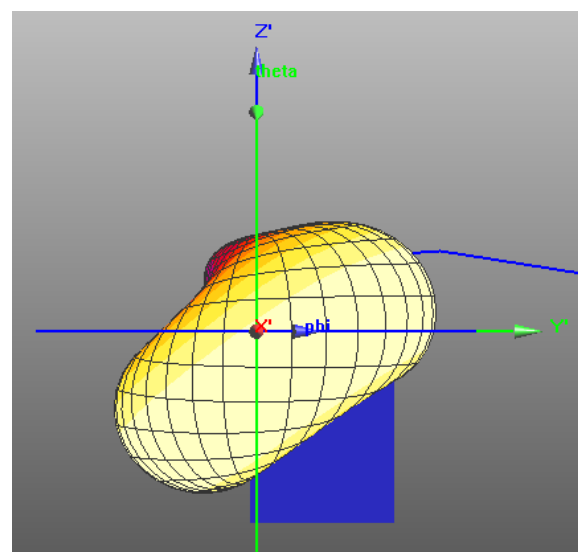
835 MHz



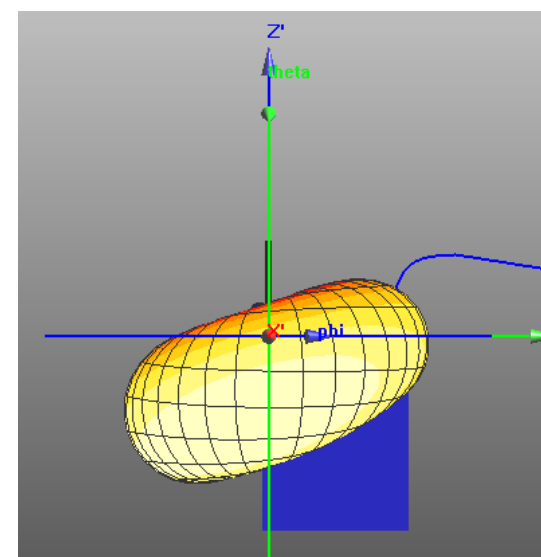
Radiation Patterns



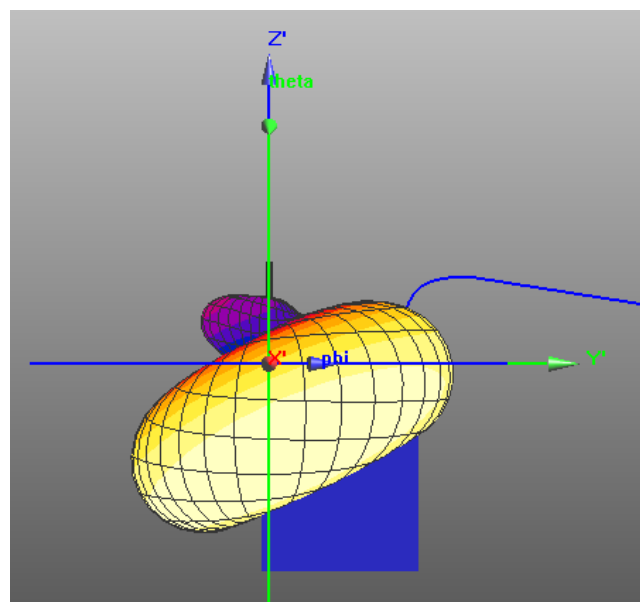
945 MHz



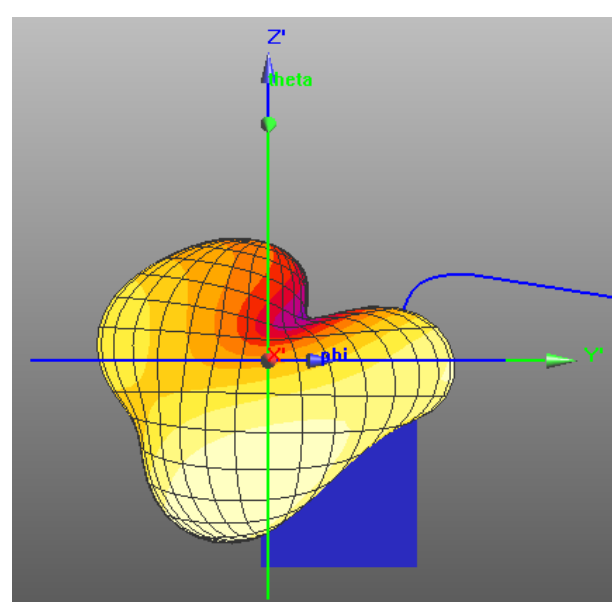
1190 MHz



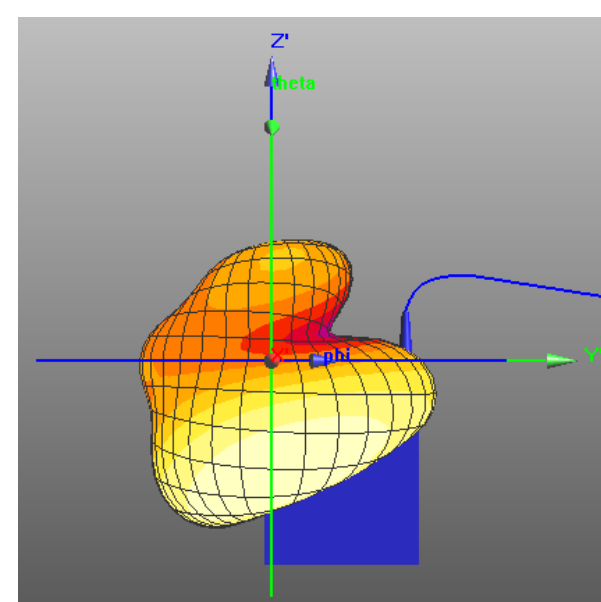
1400 MHz



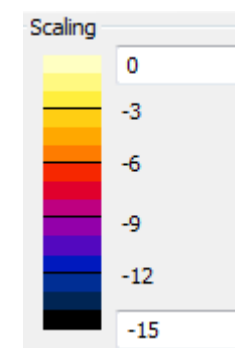
1500 MHz



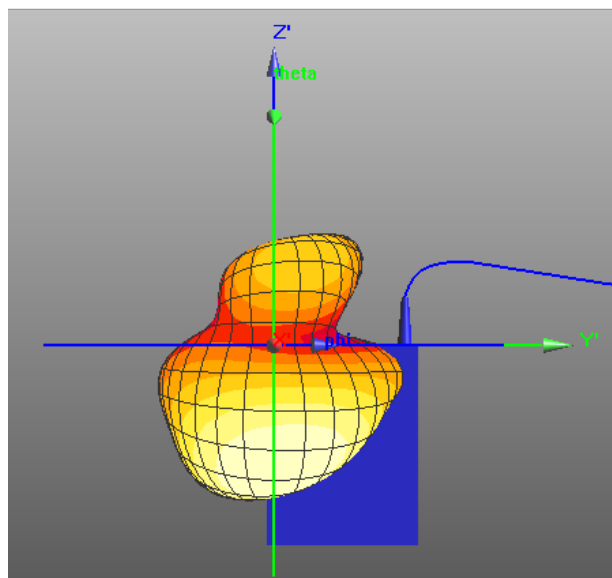
1700 MHz



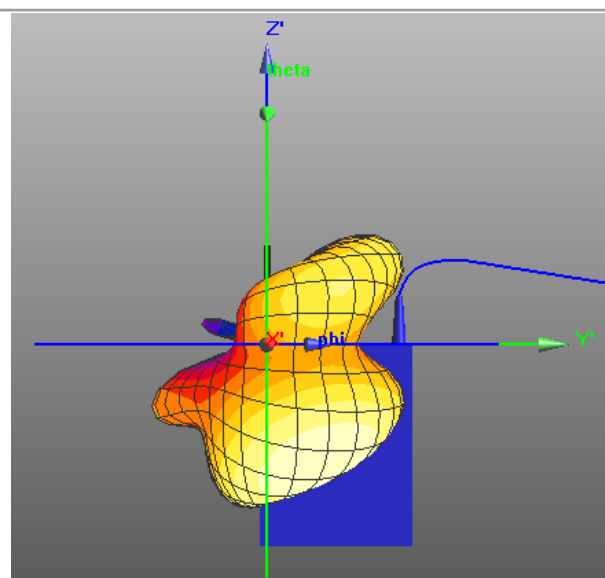
1890 MHz



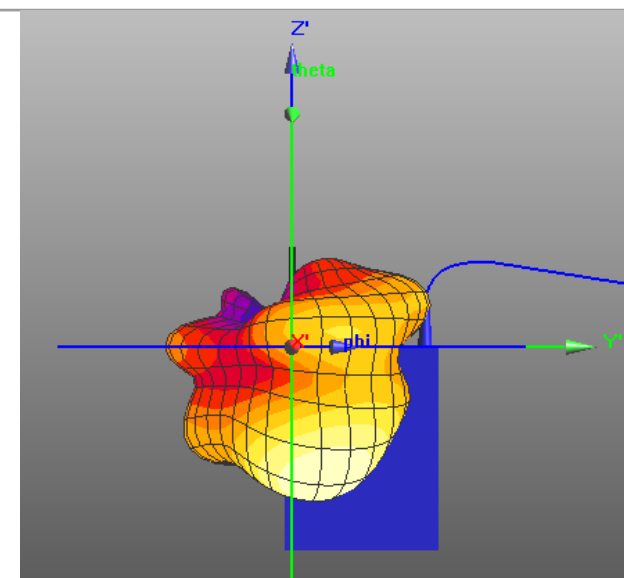
Radiation Patterns



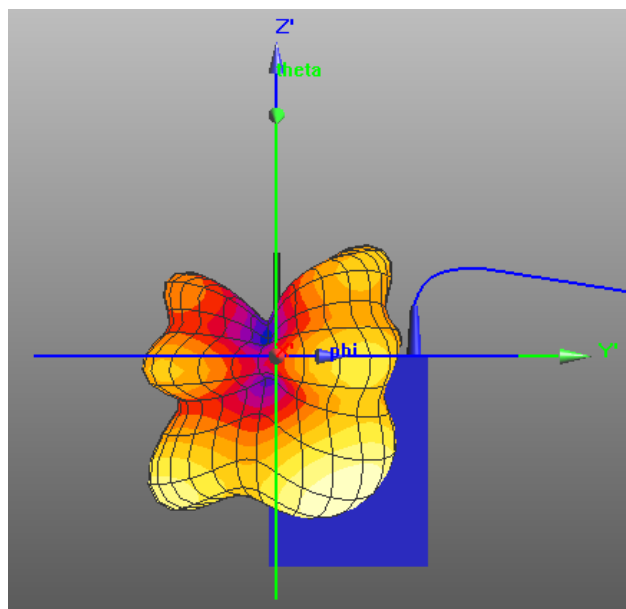
2380 MHz



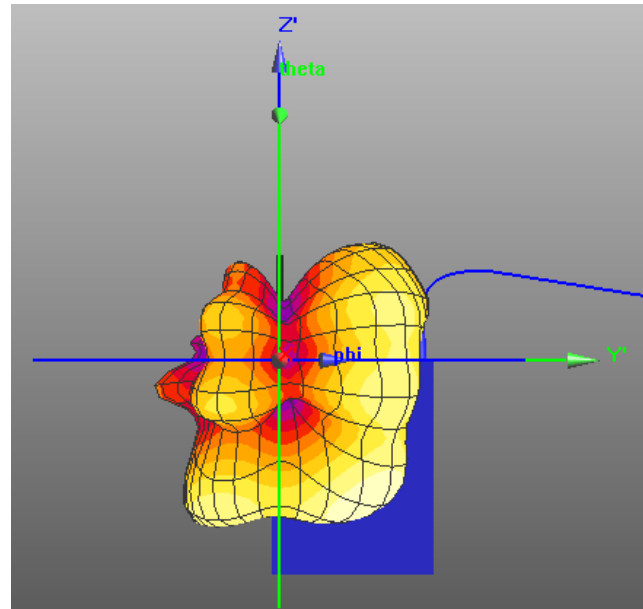
3000 MHz



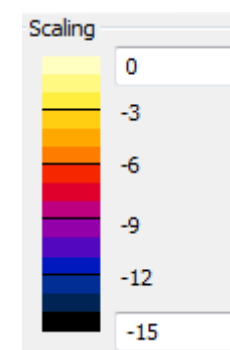
3780 MHz



4760 MHz

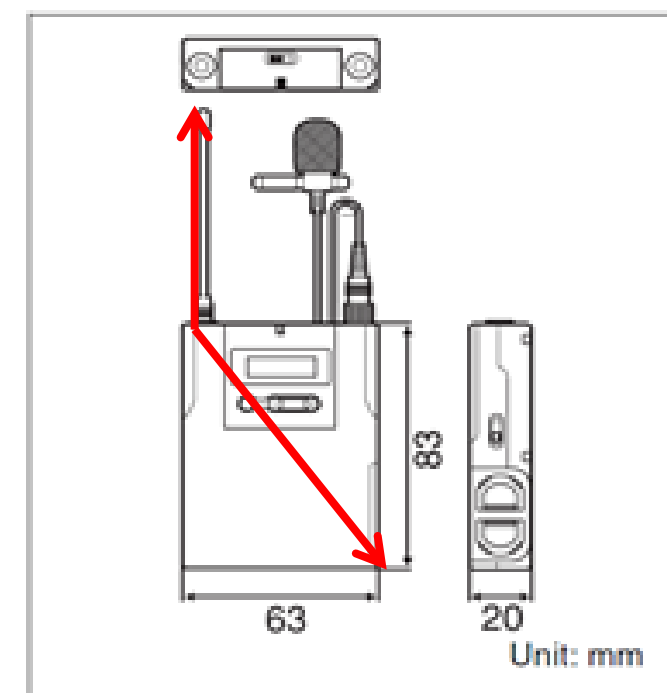


6000 MHz



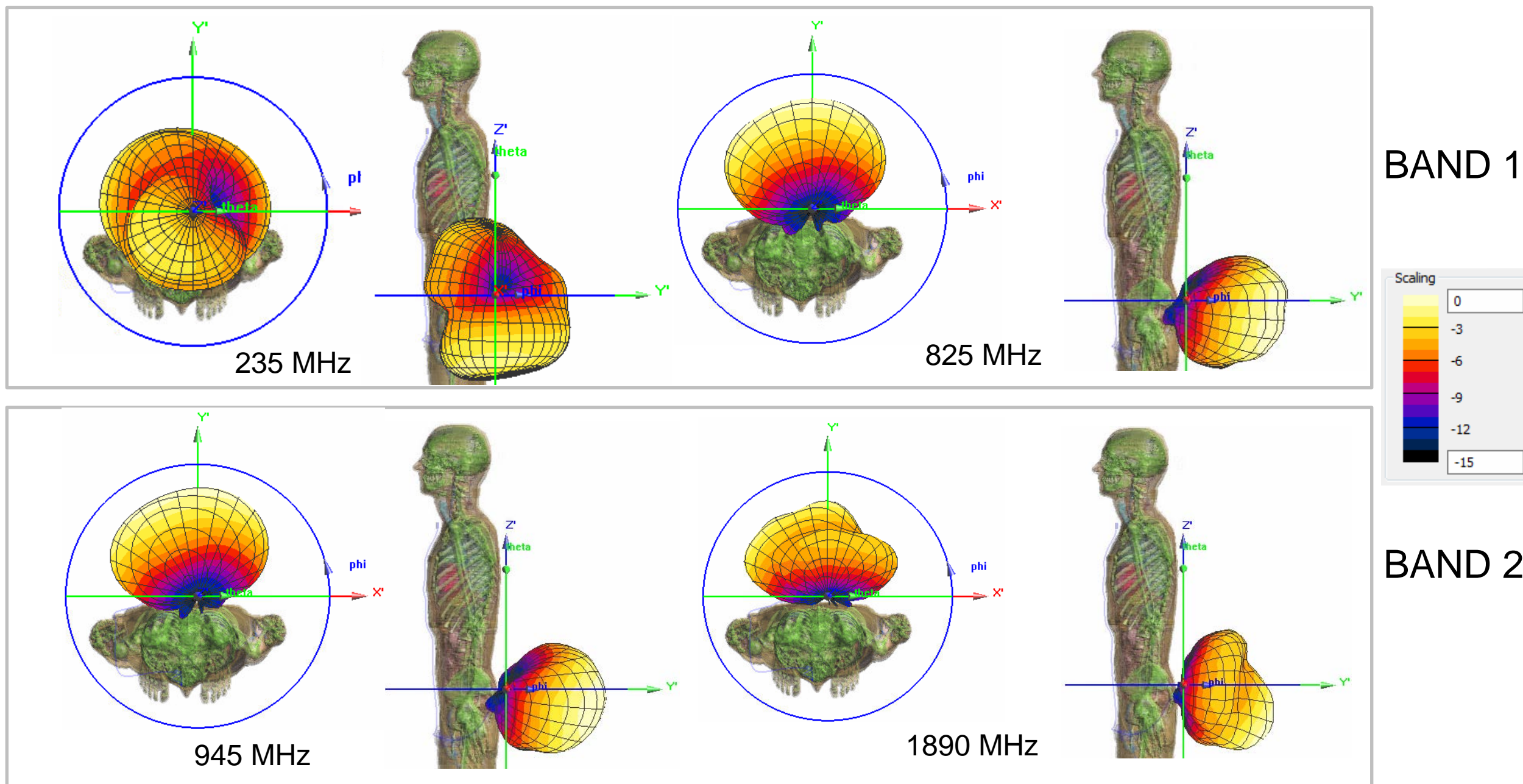
Pattern complexity

- Effective length for a 40 mm monopole including bodypack ~ 152 mm
- Half wave at ~ 985 MHz
- Above this frequency it will be expected that additional side lobes are introduced
 - Even though the monopole is at, or below, resonance

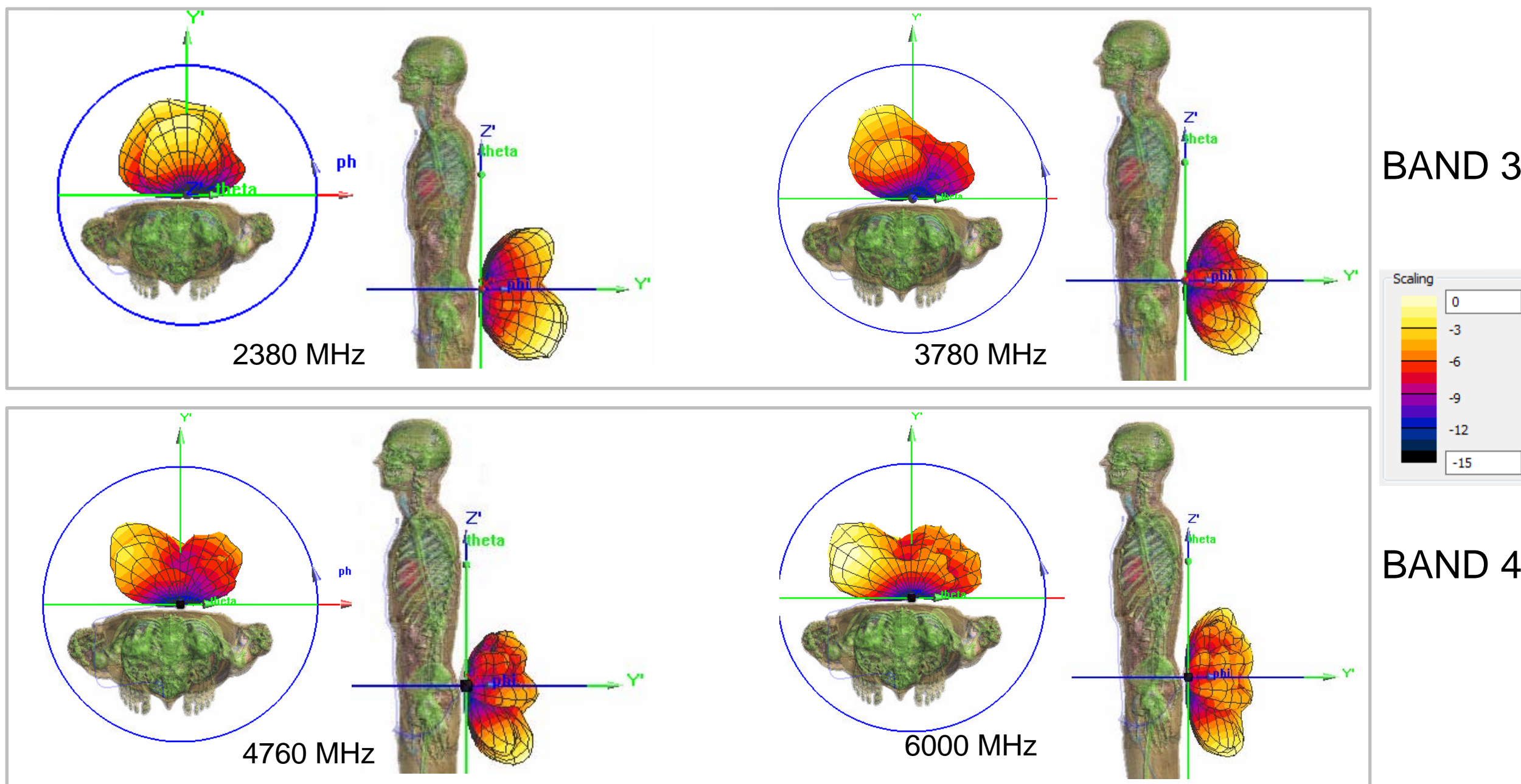


63 × 82.5 × 18.7 mm (2 1/2 × 3 1/4 × 3/4 inches) (w/h/d) (excluding the antenna)

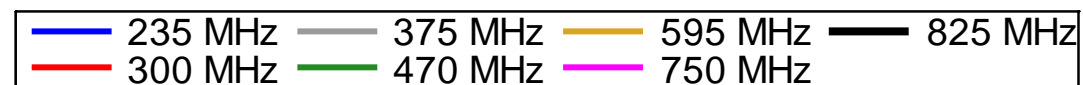
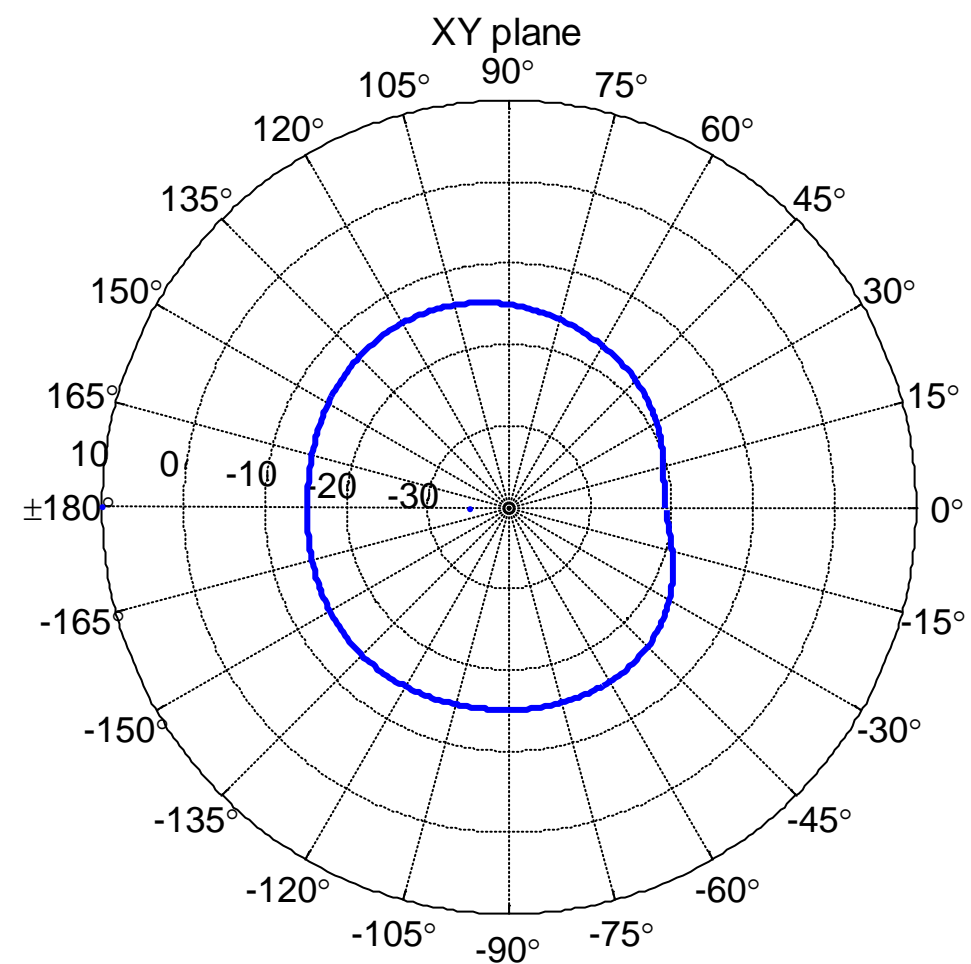
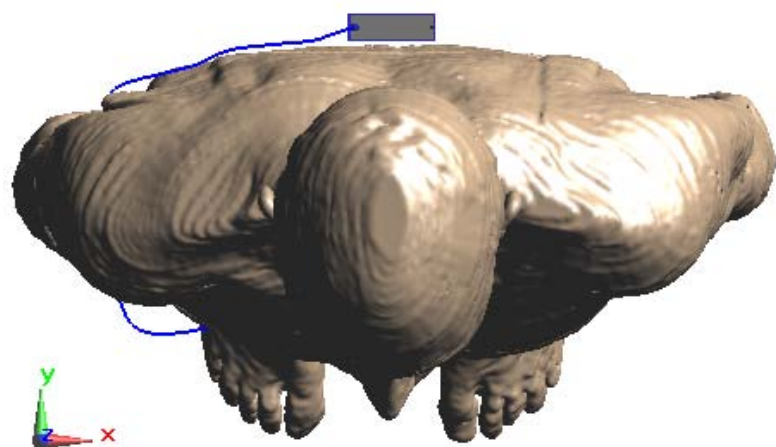
Duke Band 1, Band 2: 235, 825, 945, 1890 MHz



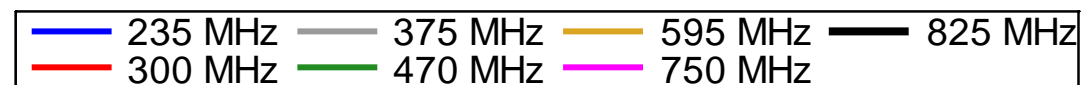
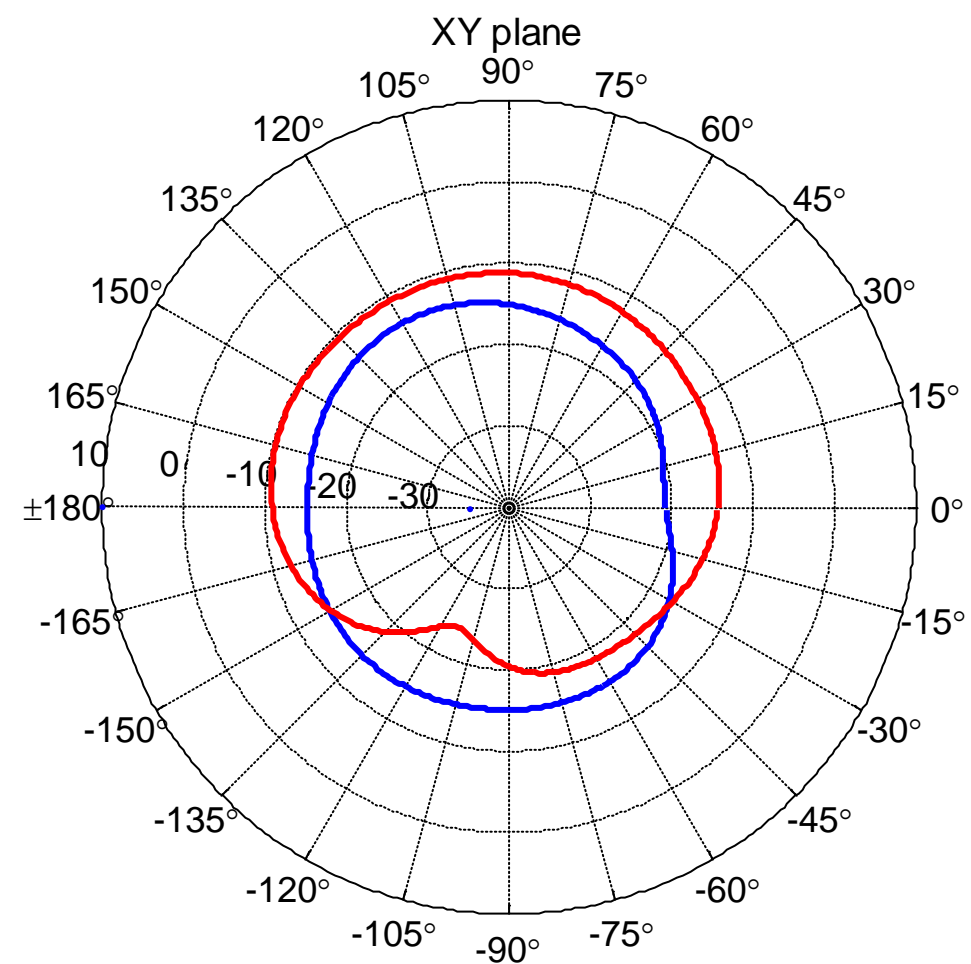
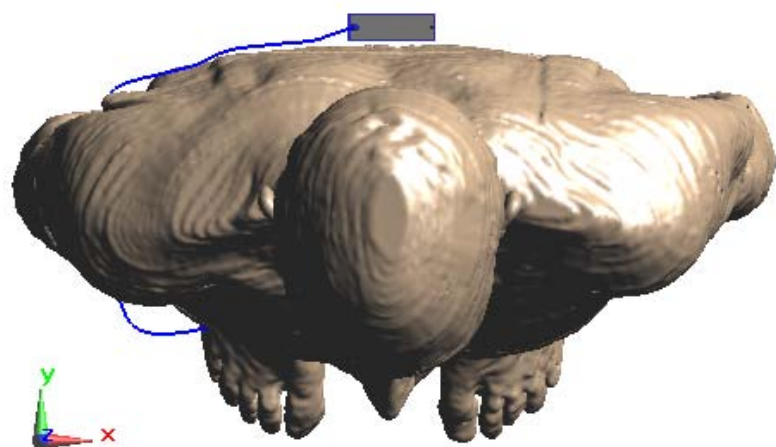
Duke Band 3, Band 4: 2380, 3780, 4760, 6000 MHz



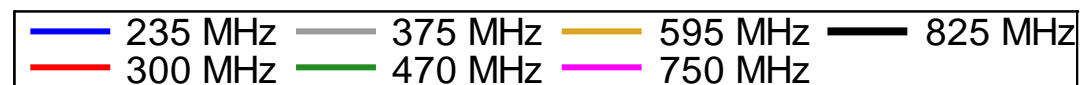
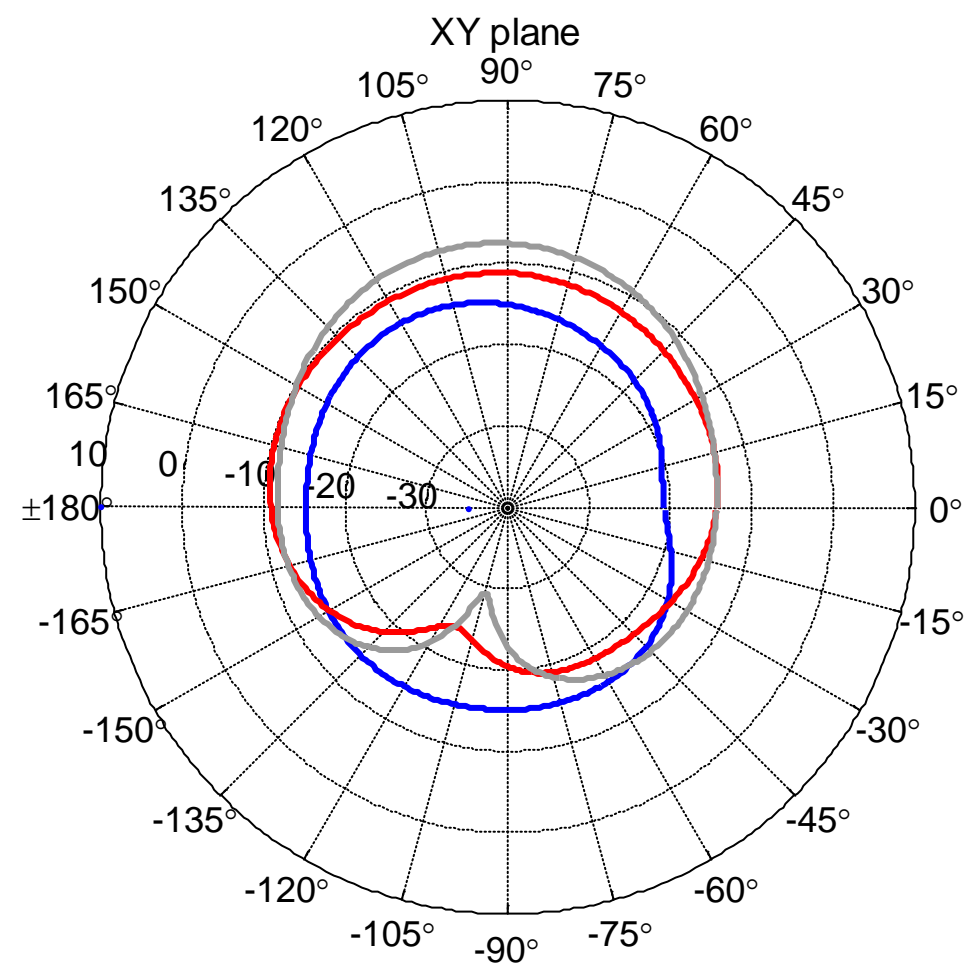
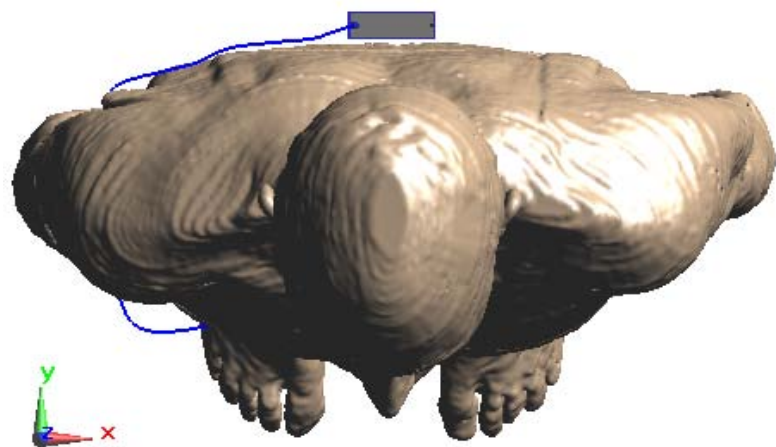
Duke: All Frequencies Band 1



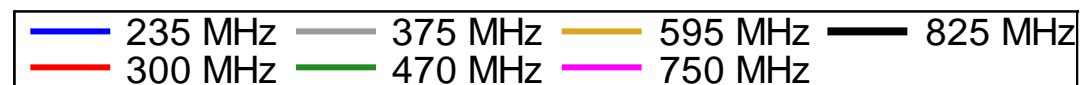
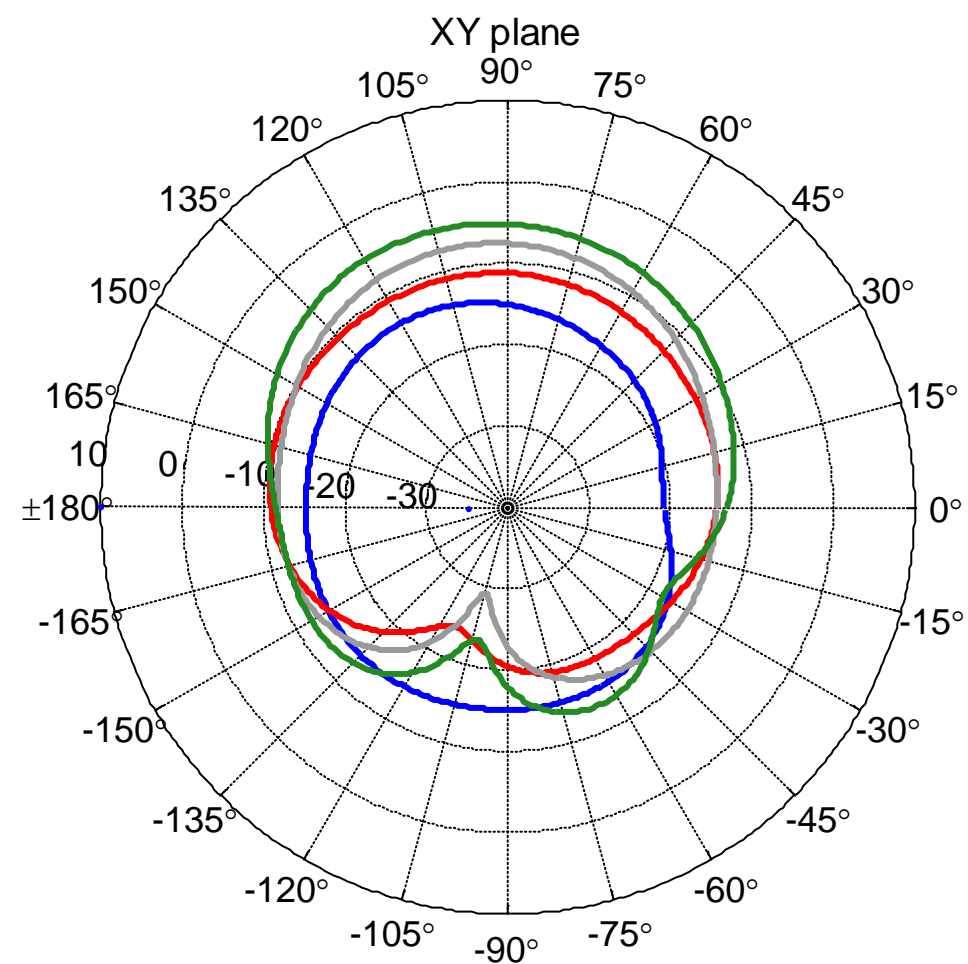
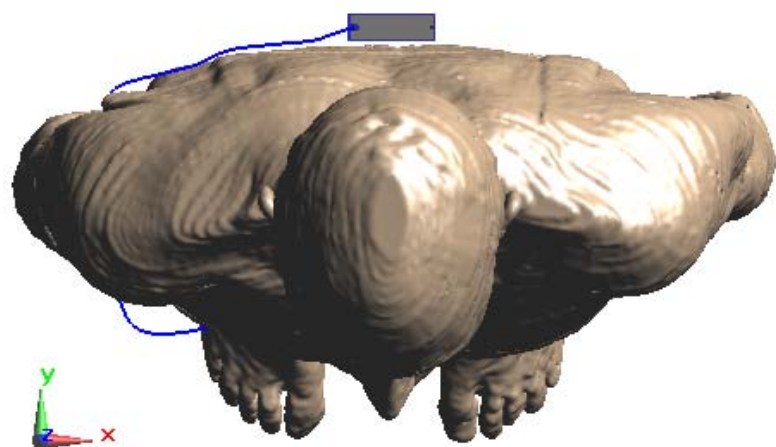
Duke: All Frequencies Band 1



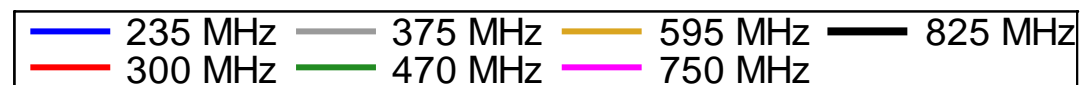
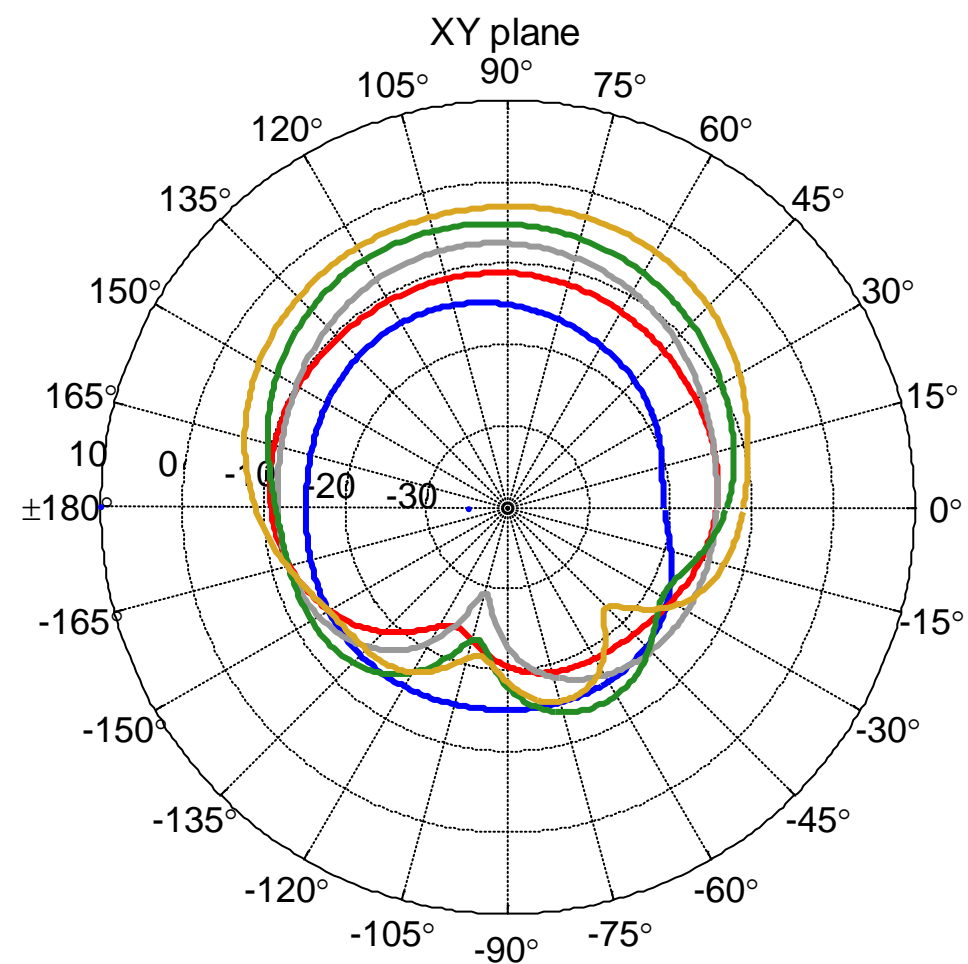
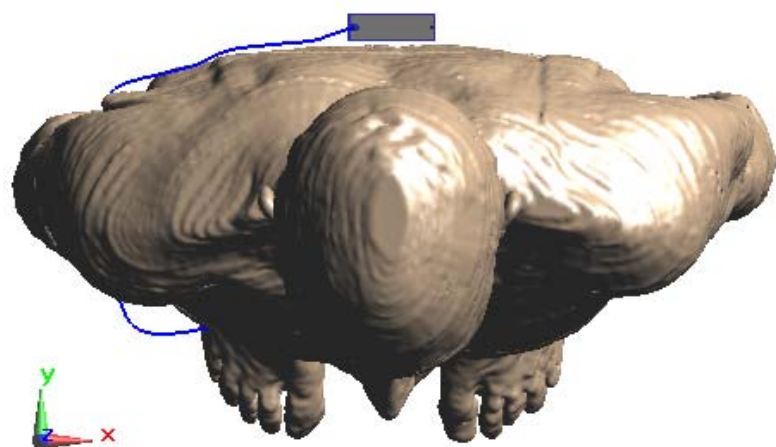
Duke: All Frequencies Band 1



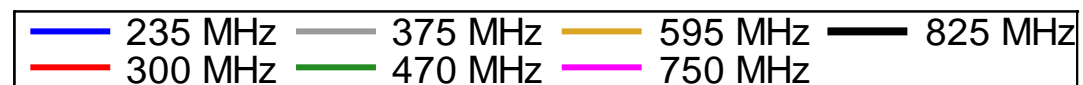
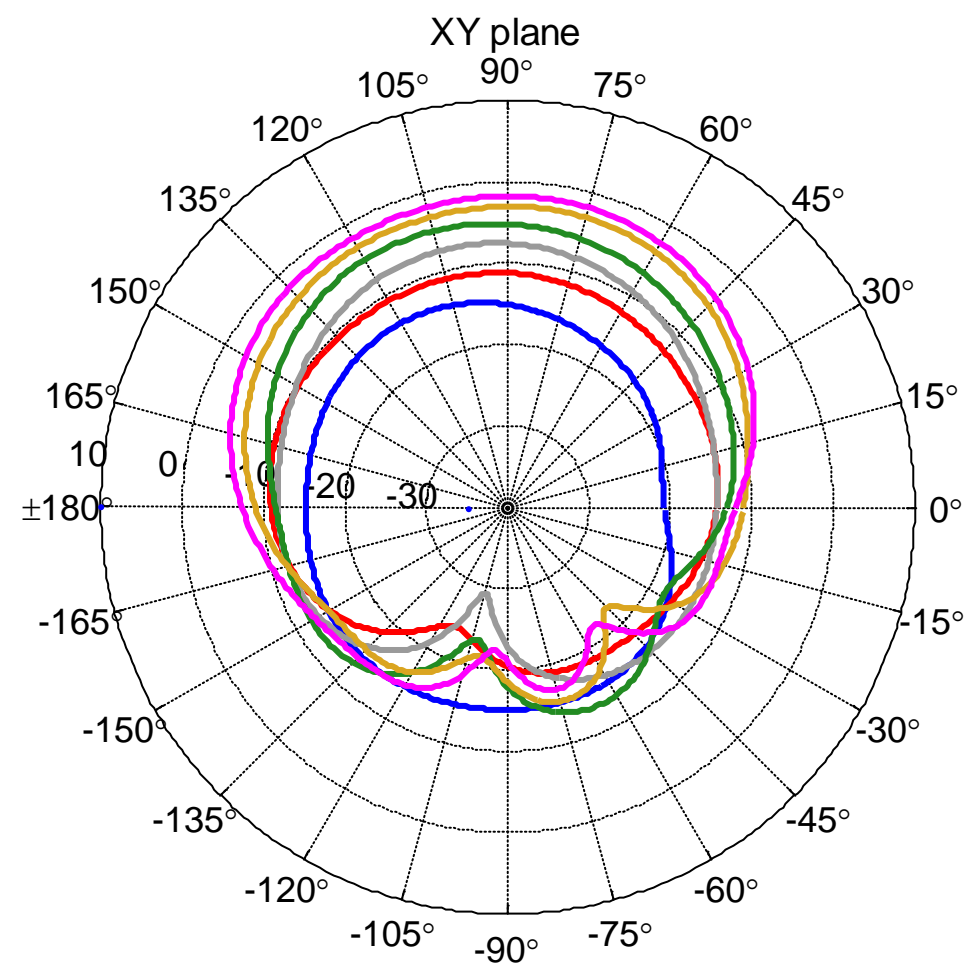
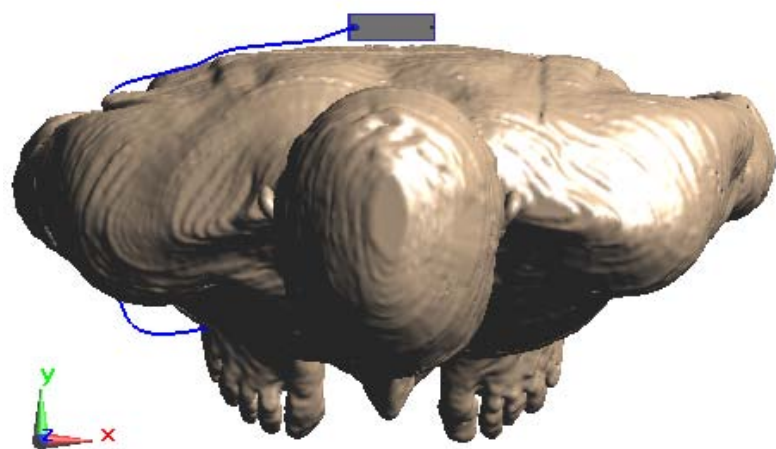
Duke: All Frequencies Band 1



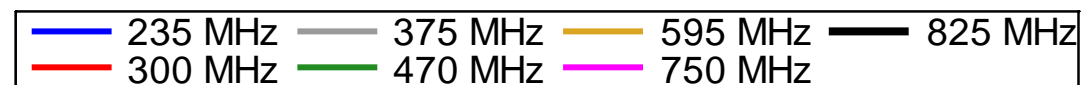
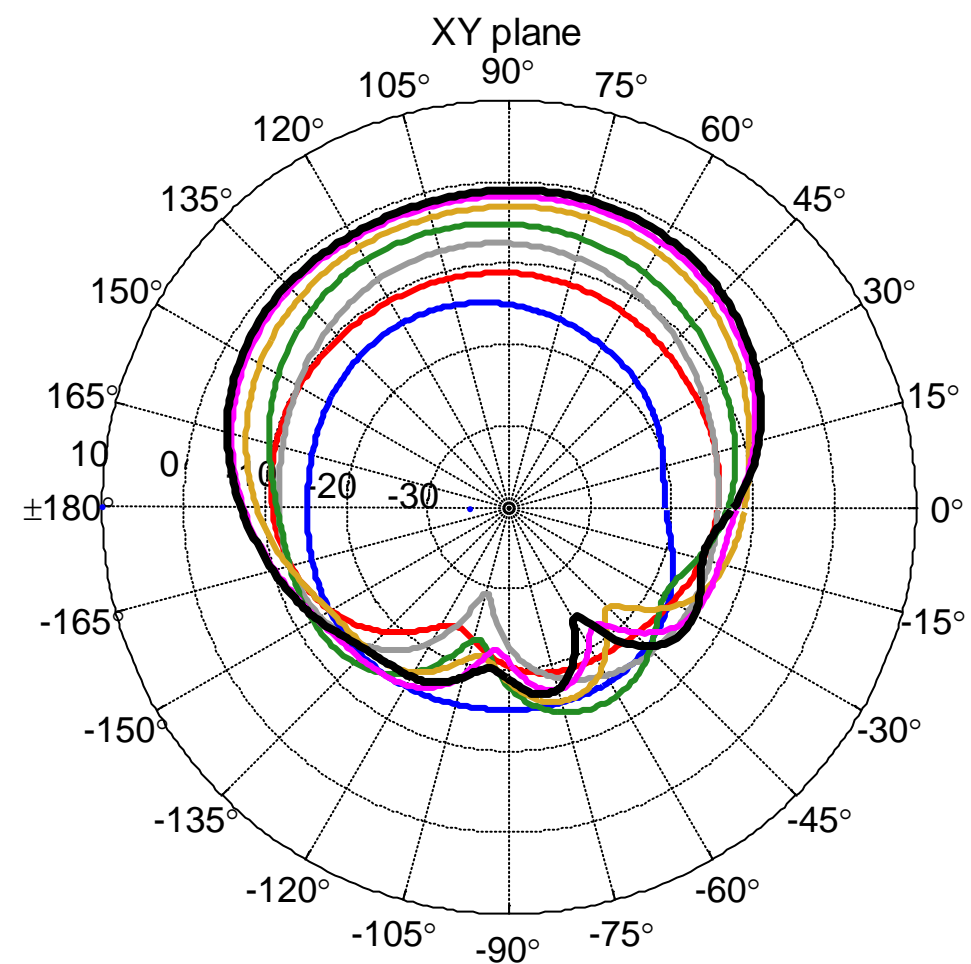
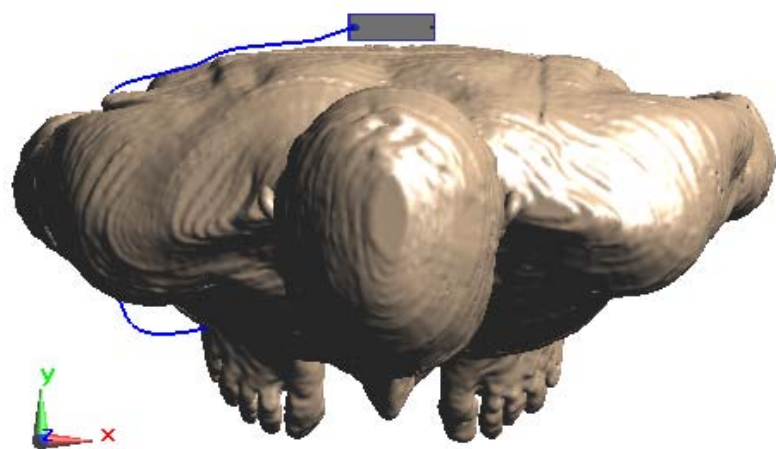
Duke: All Frequencies Band 1



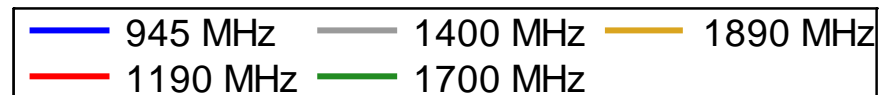
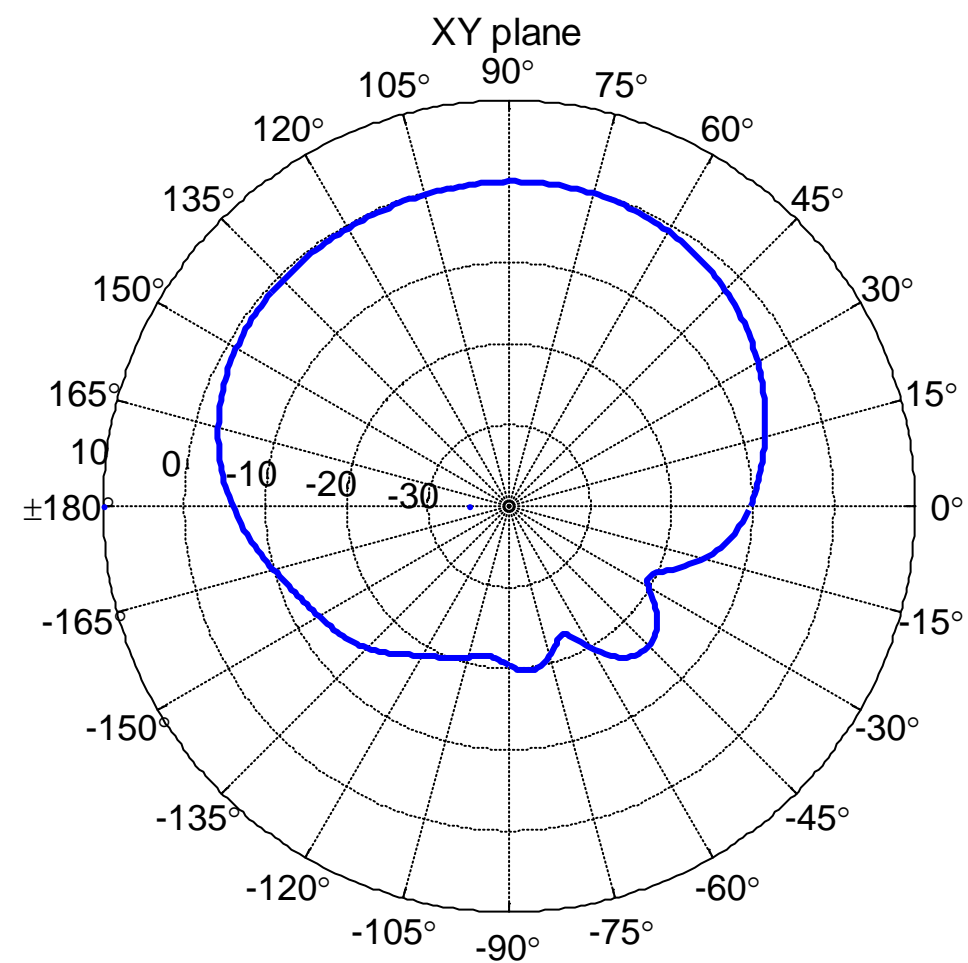
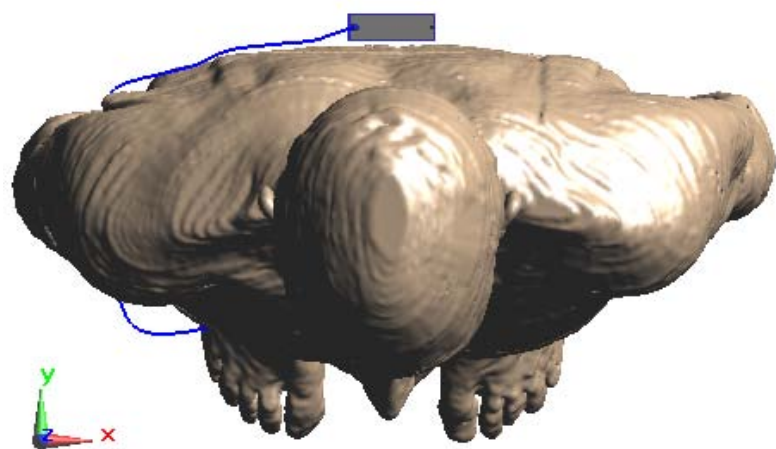
Duke: All Frequencies Band 1



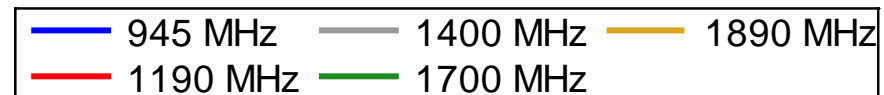
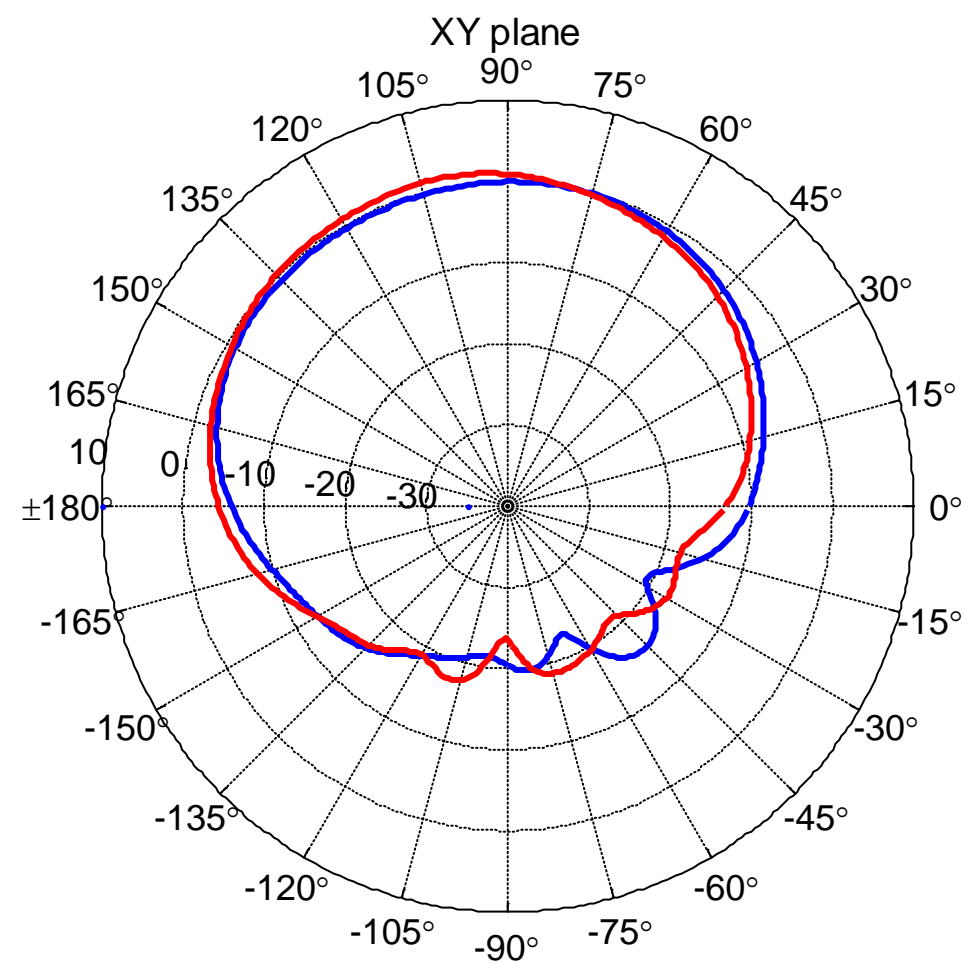
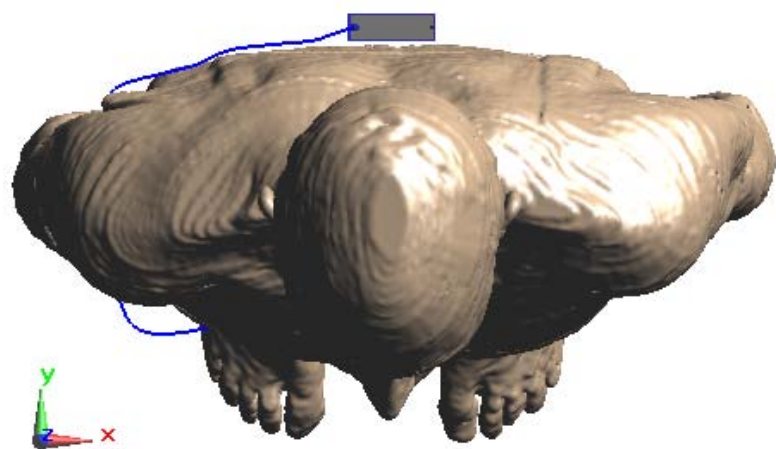
Duke: All Frequencies Band 1



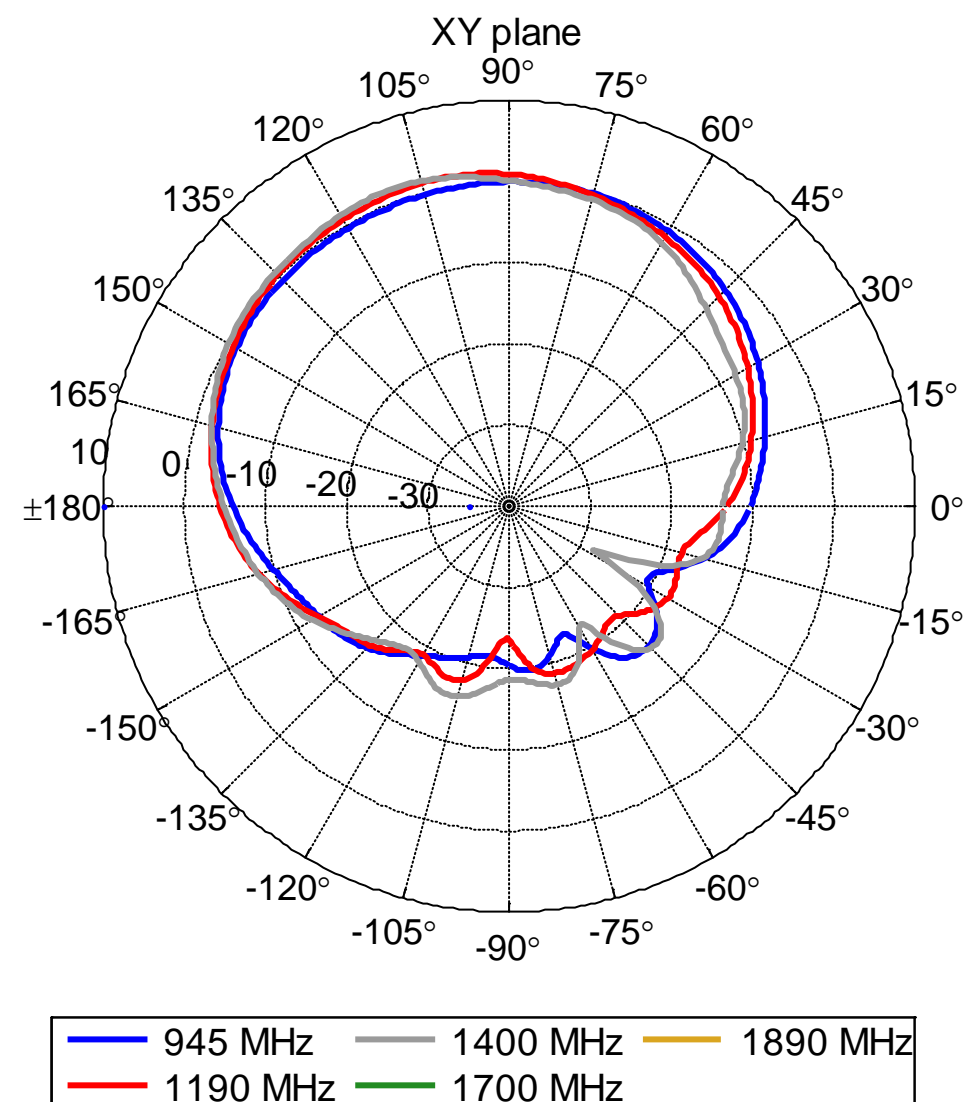
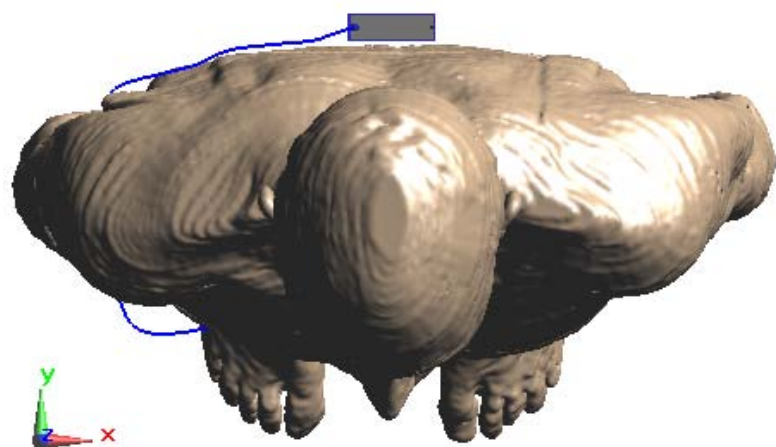
Duke: All Frequencies Band 2



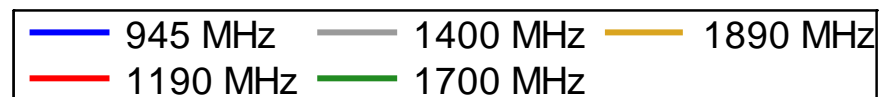
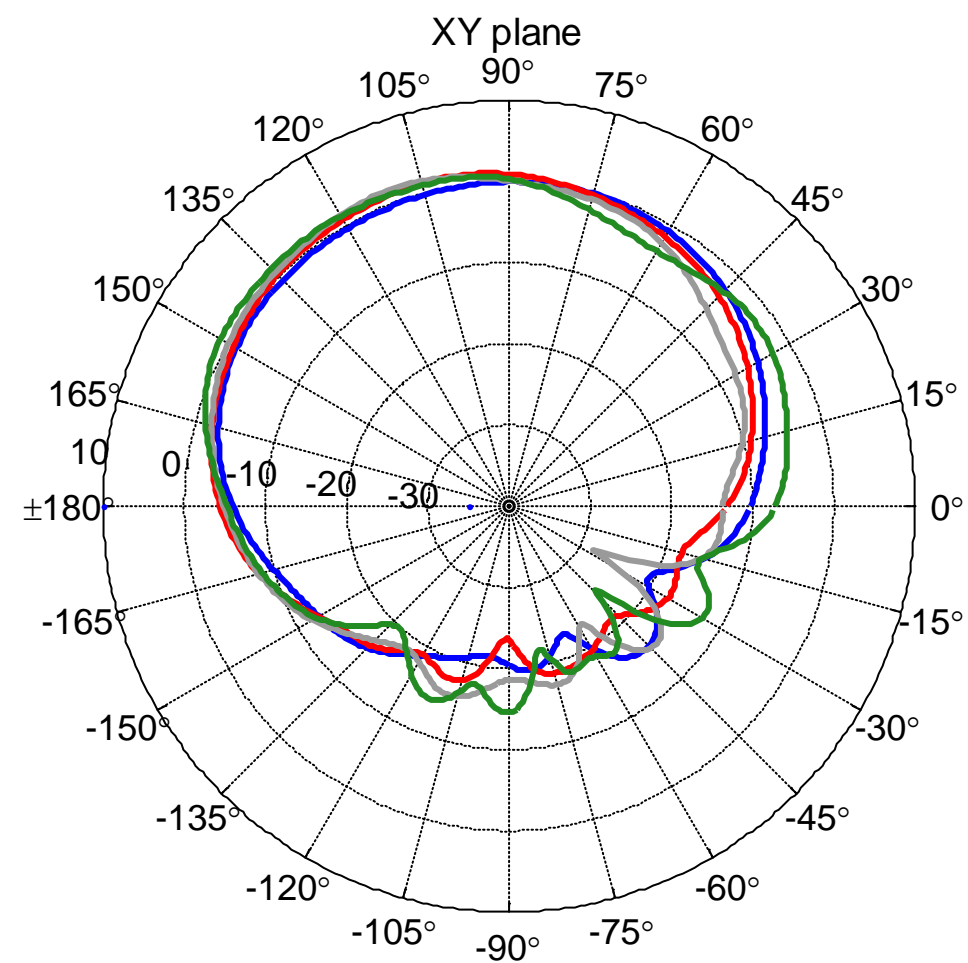
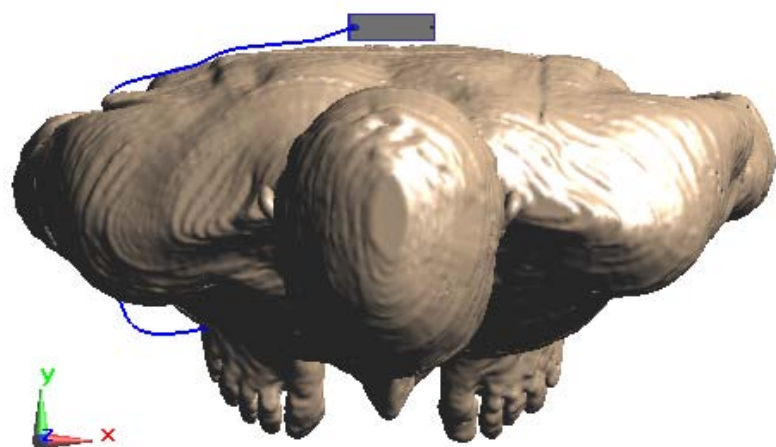
Duke: All Frequencies Band 2



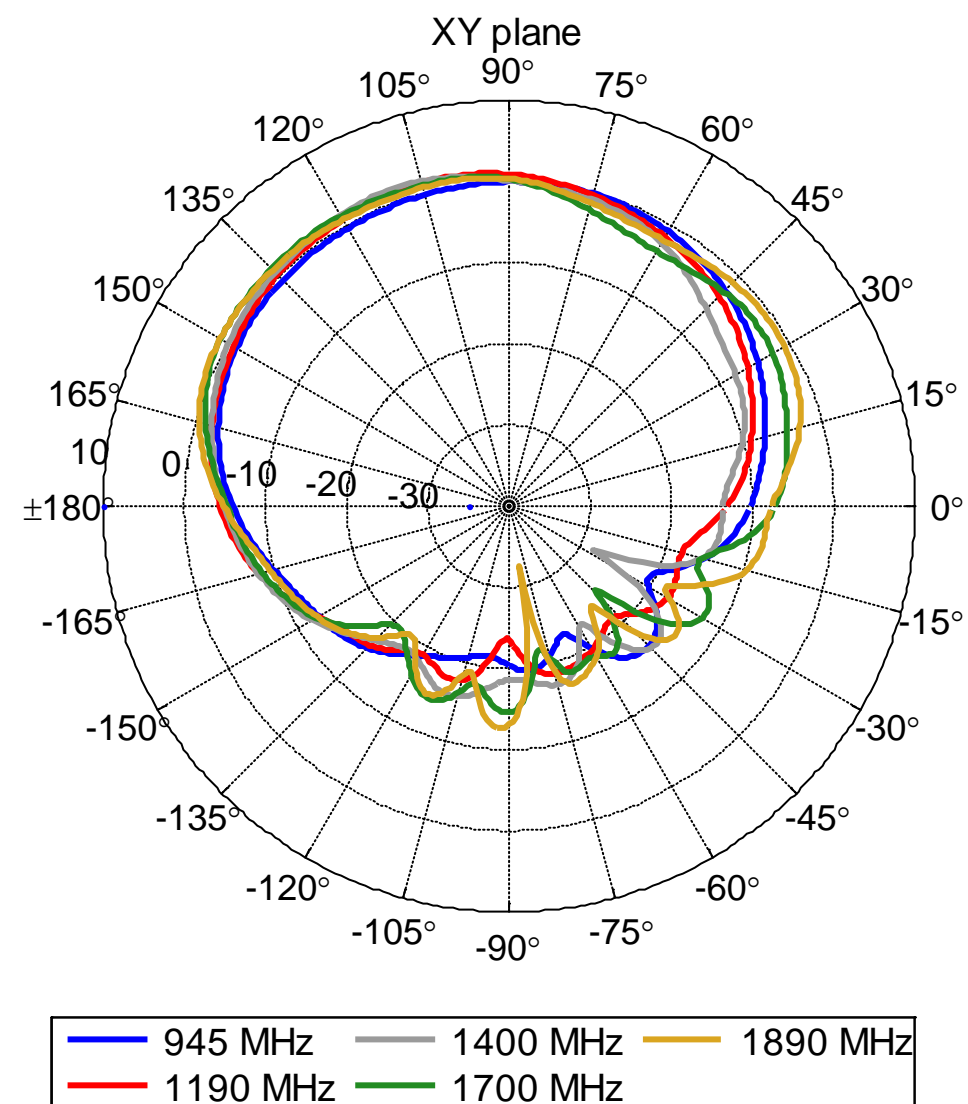
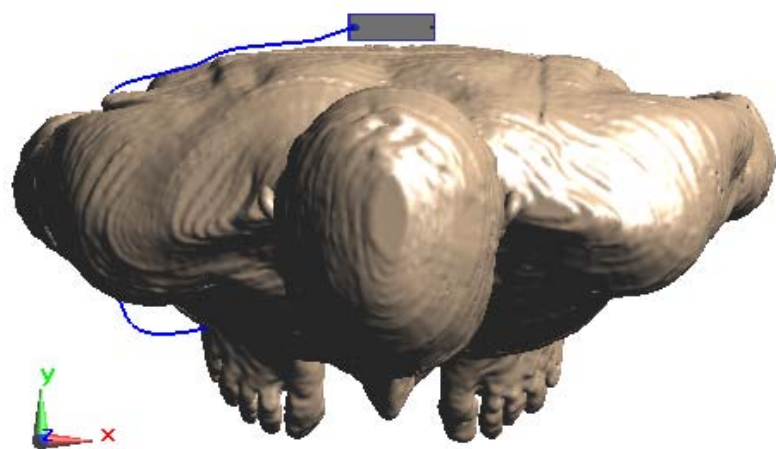
Duke: All Frequencies Band 2



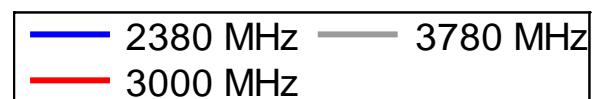
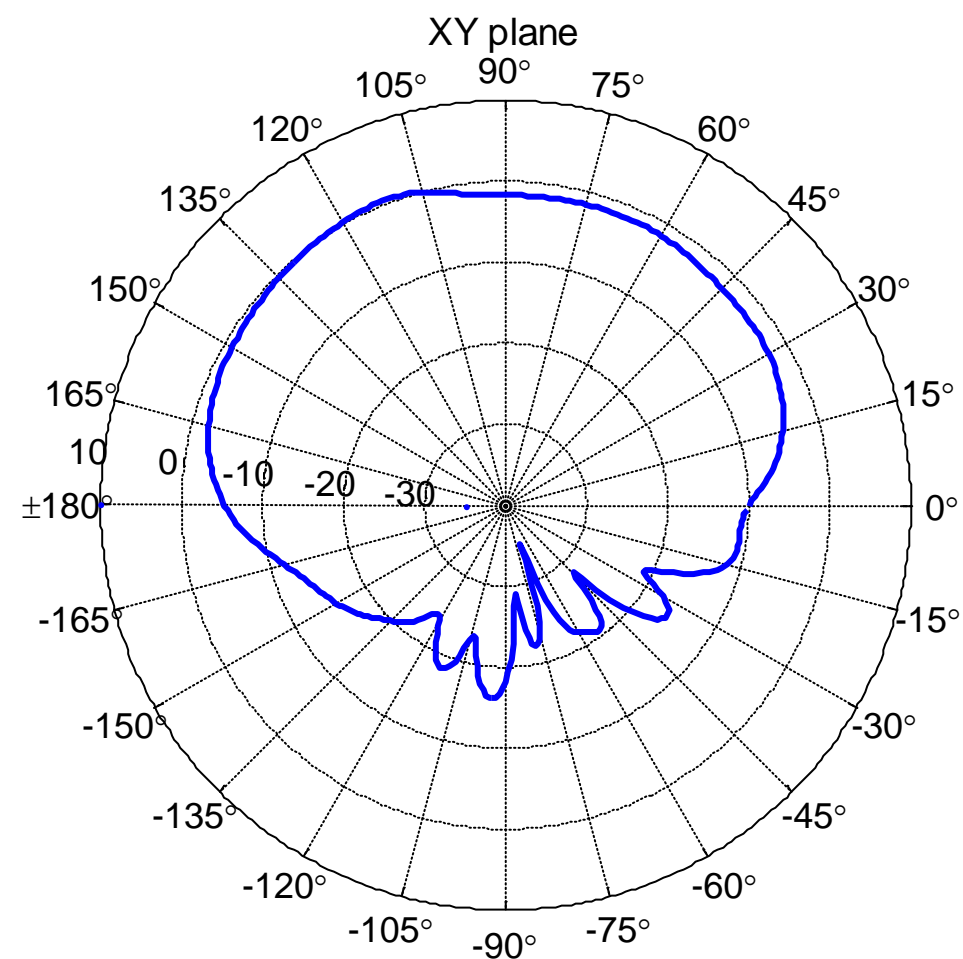
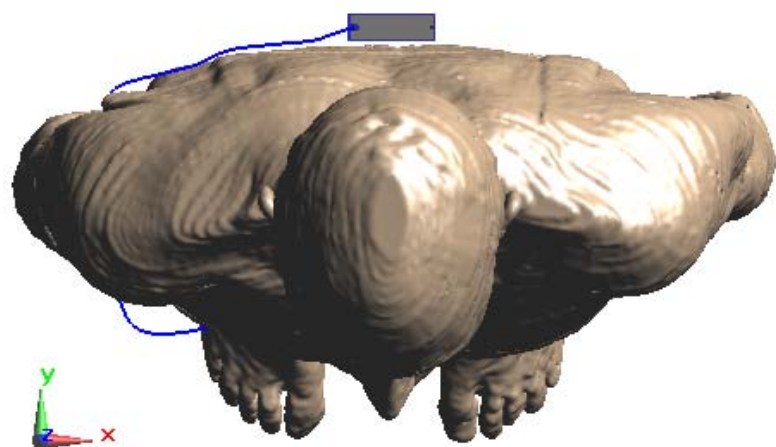
Duke: All Frequencies Band 2



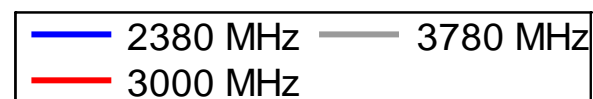
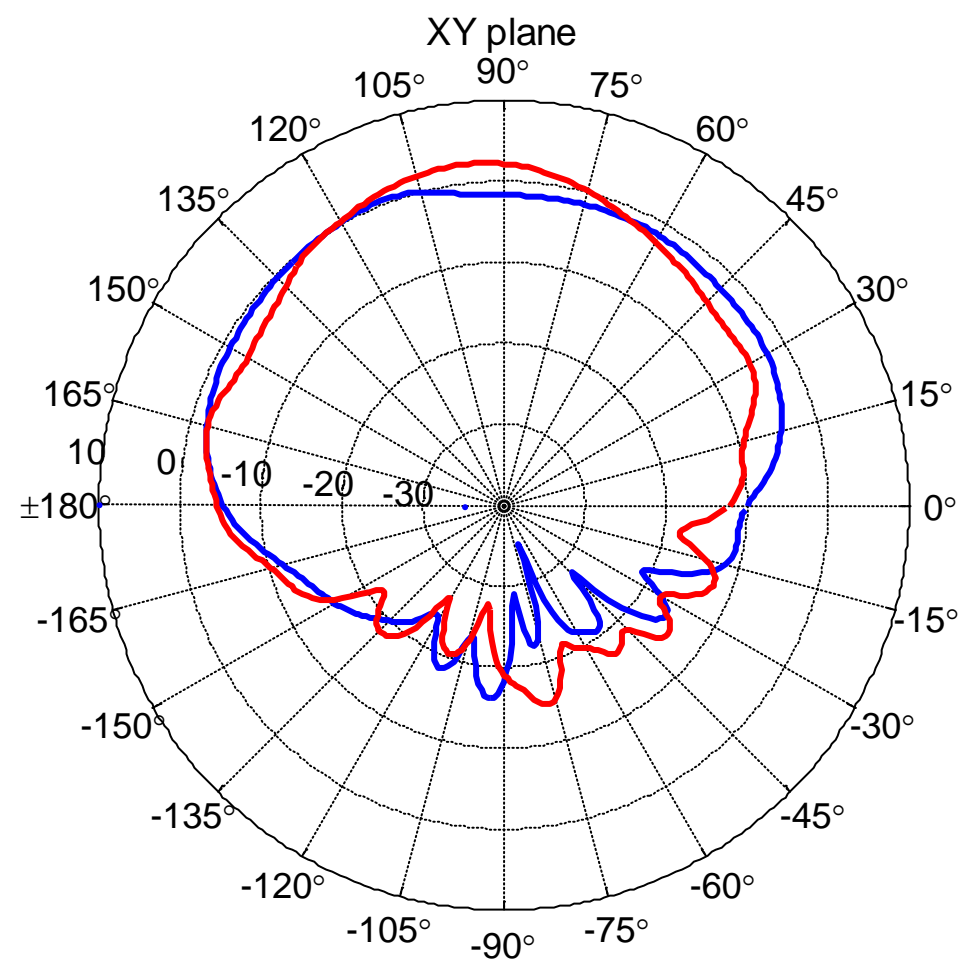
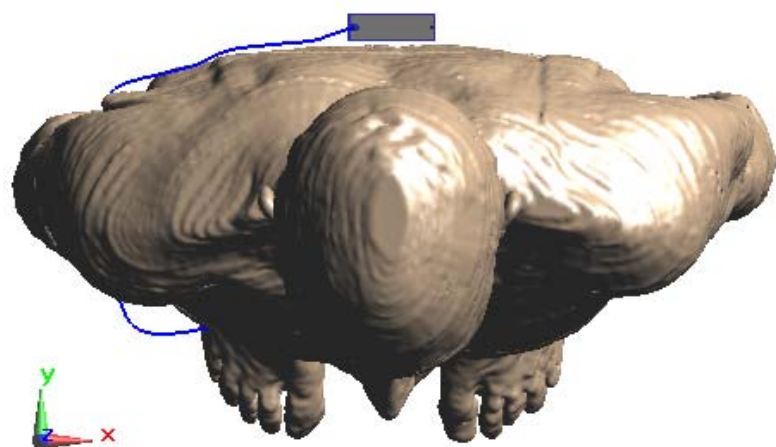
Duke: All Frequencies Band 2



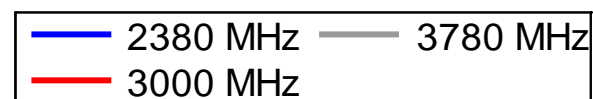
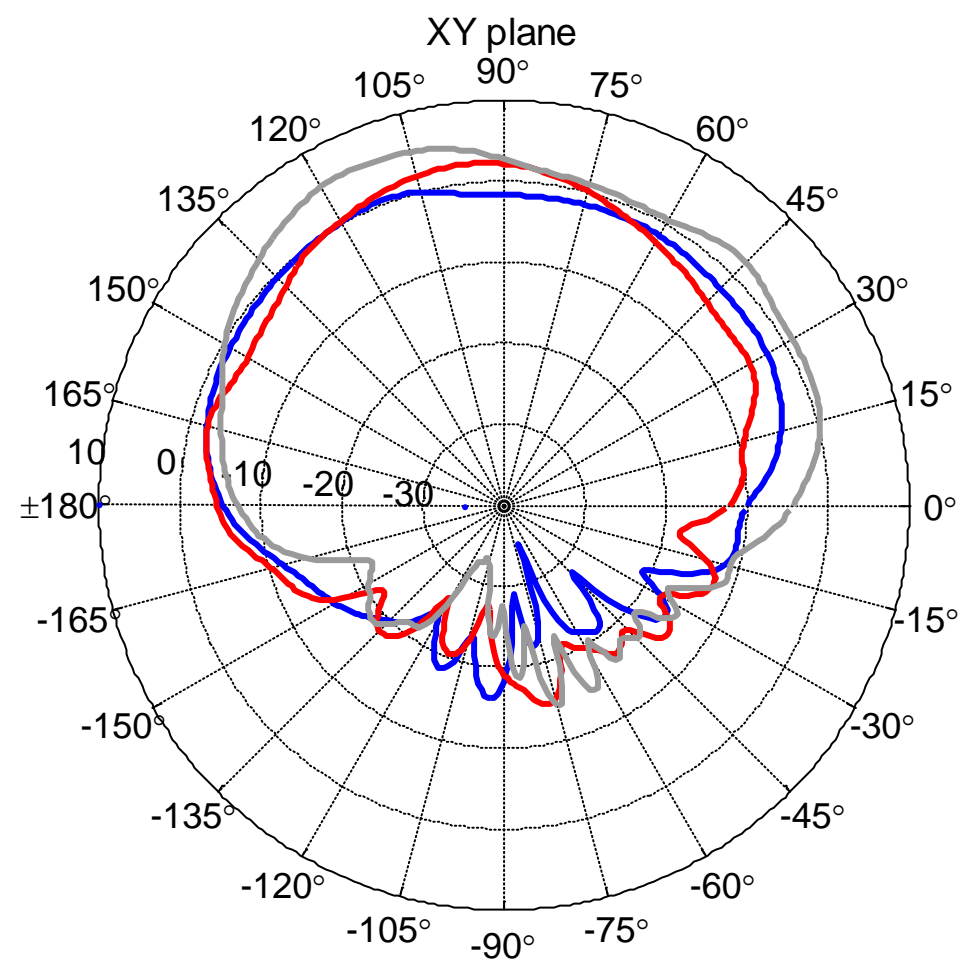
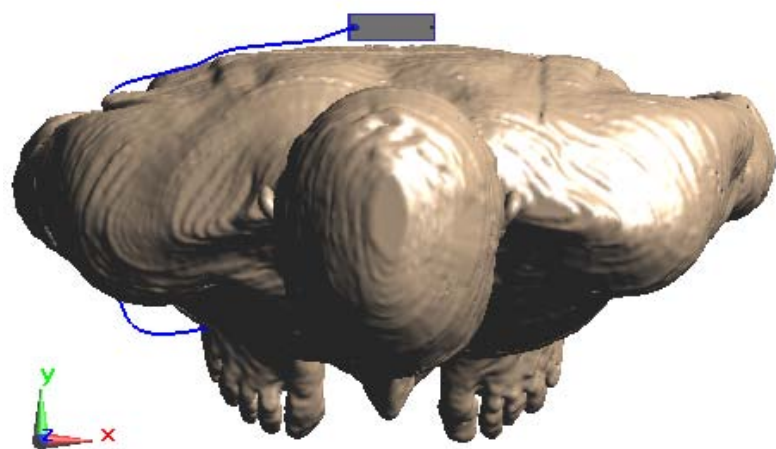
Duke: All Frequencies Band 3



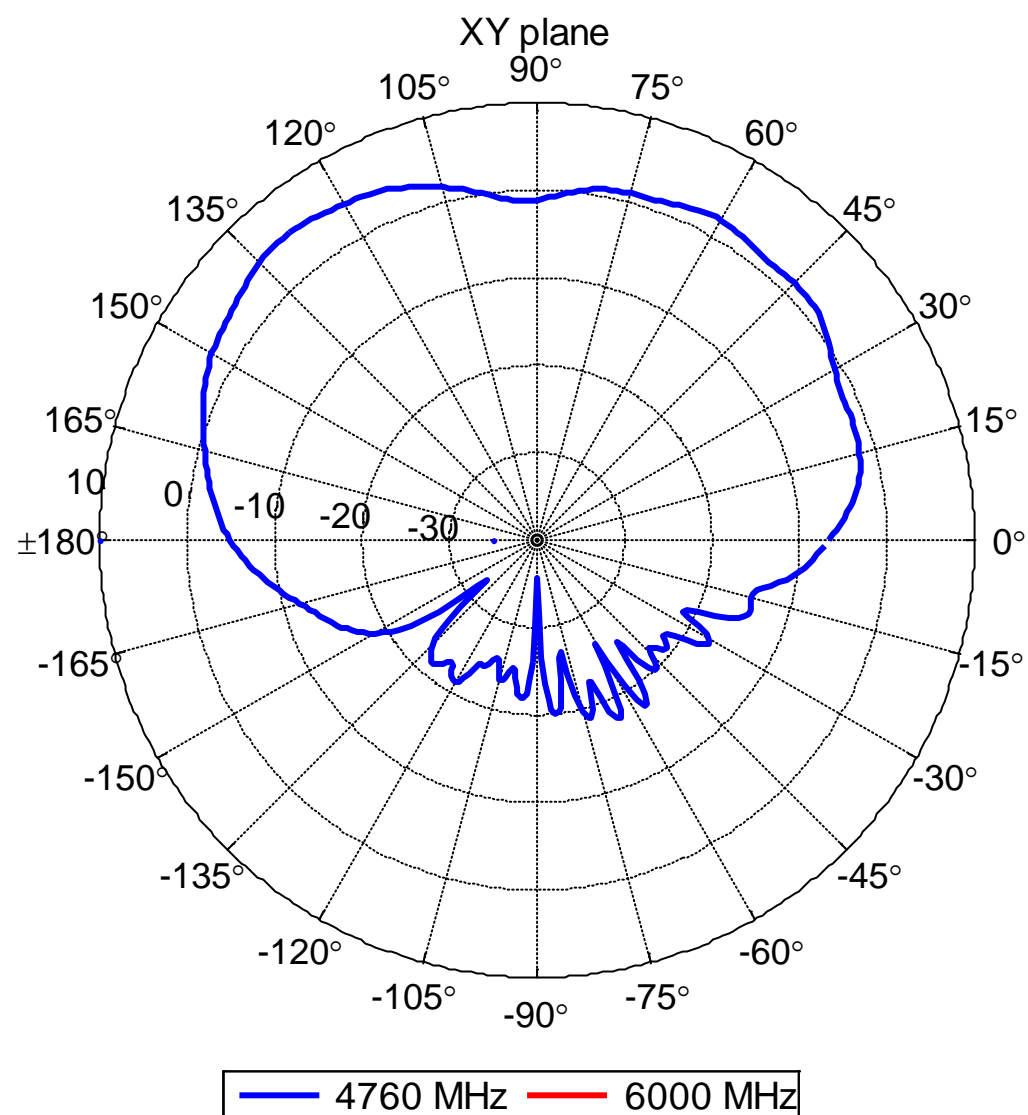
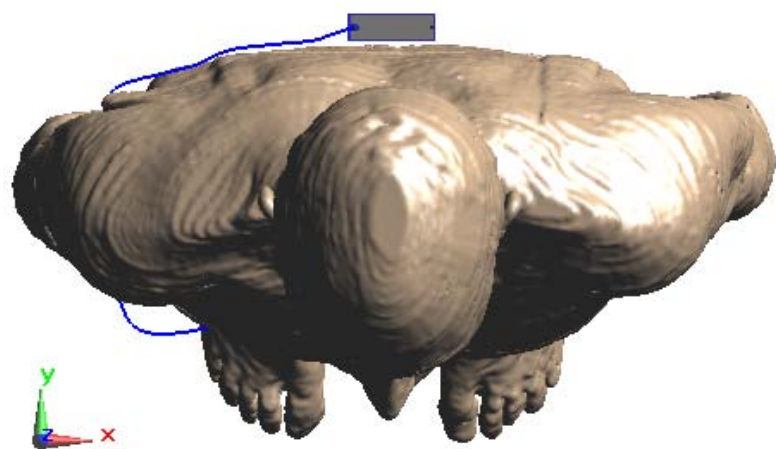
Duke: All Frequencies Band 3



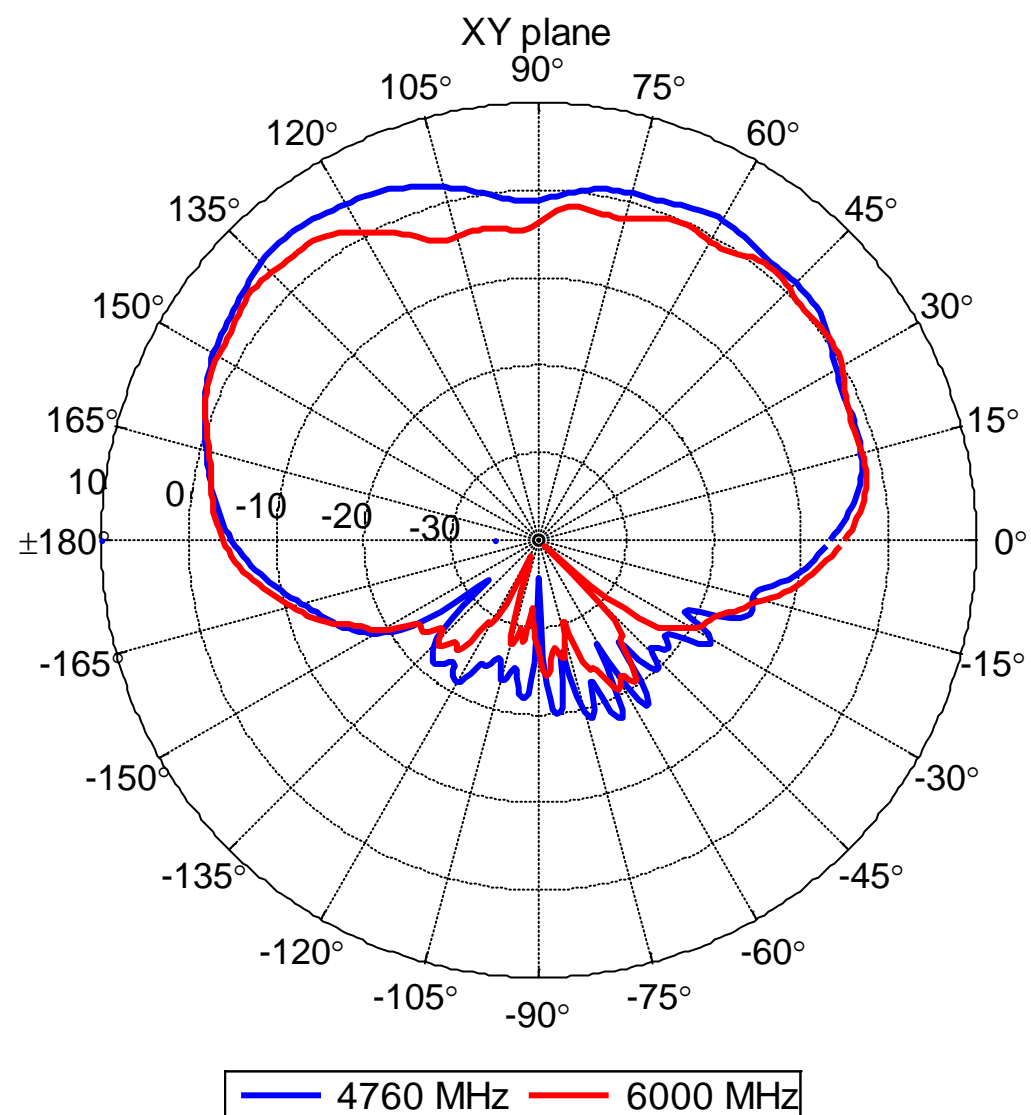
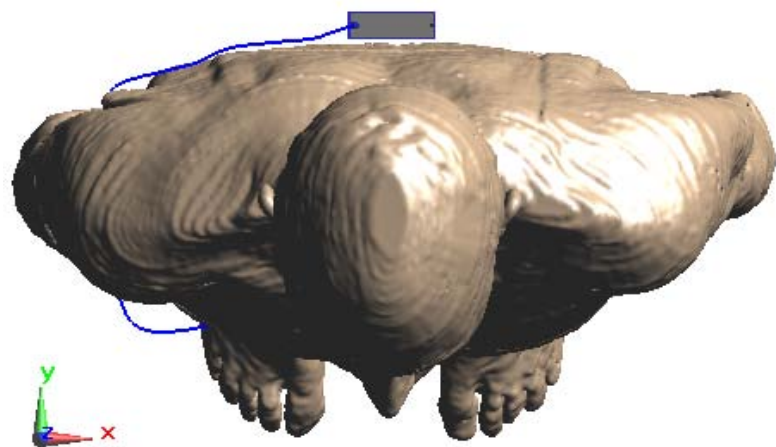
Duke: All Frequencies Band 3



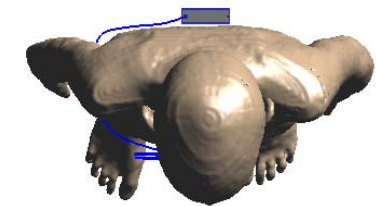
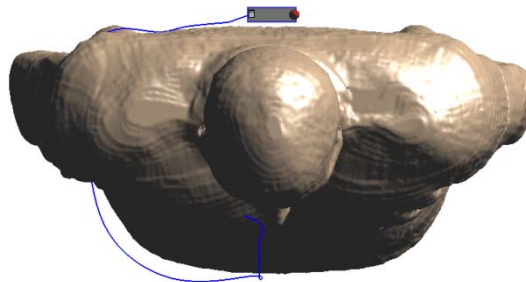
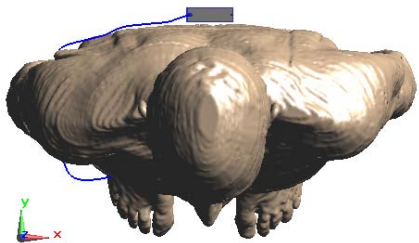
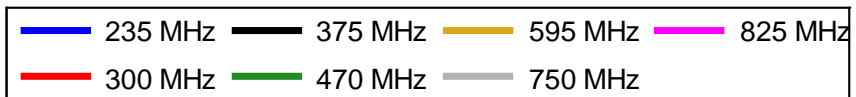
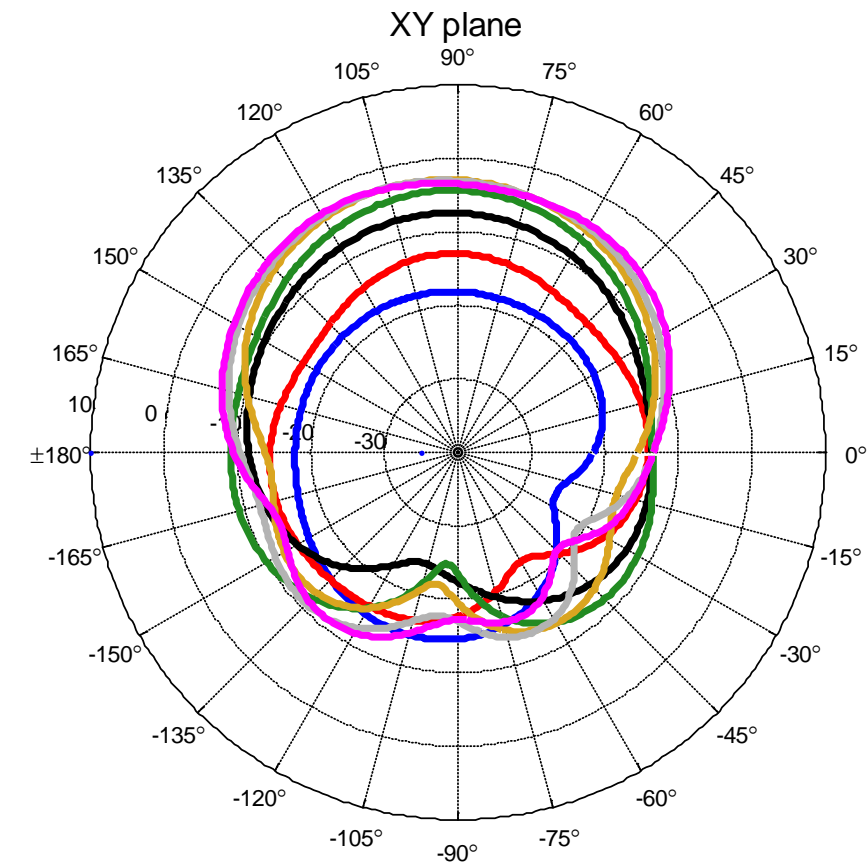
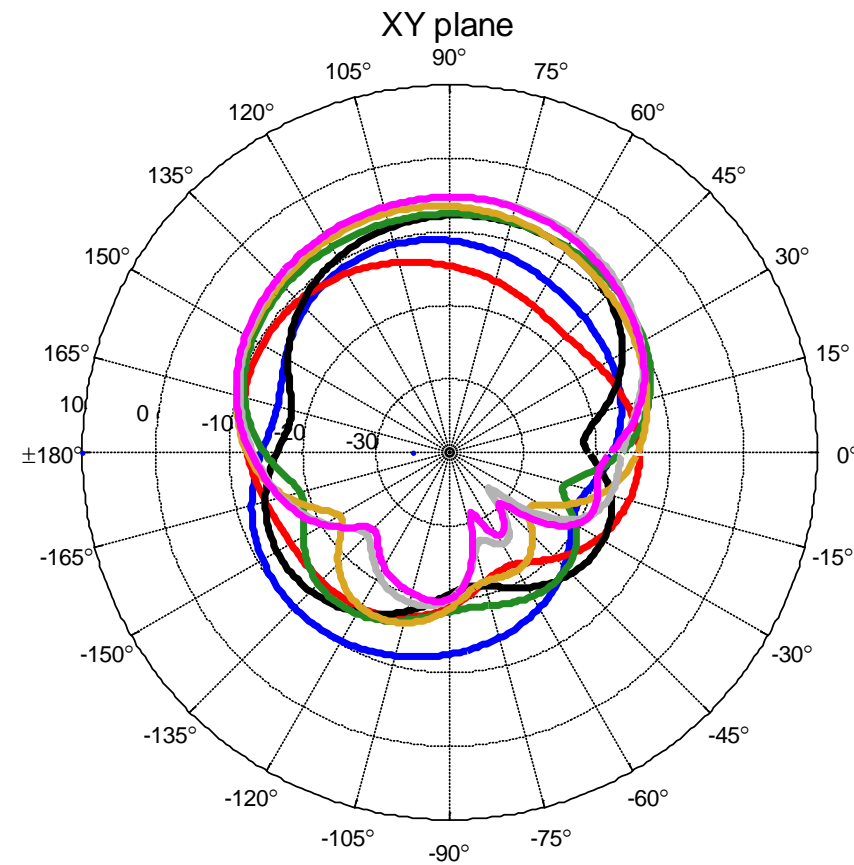
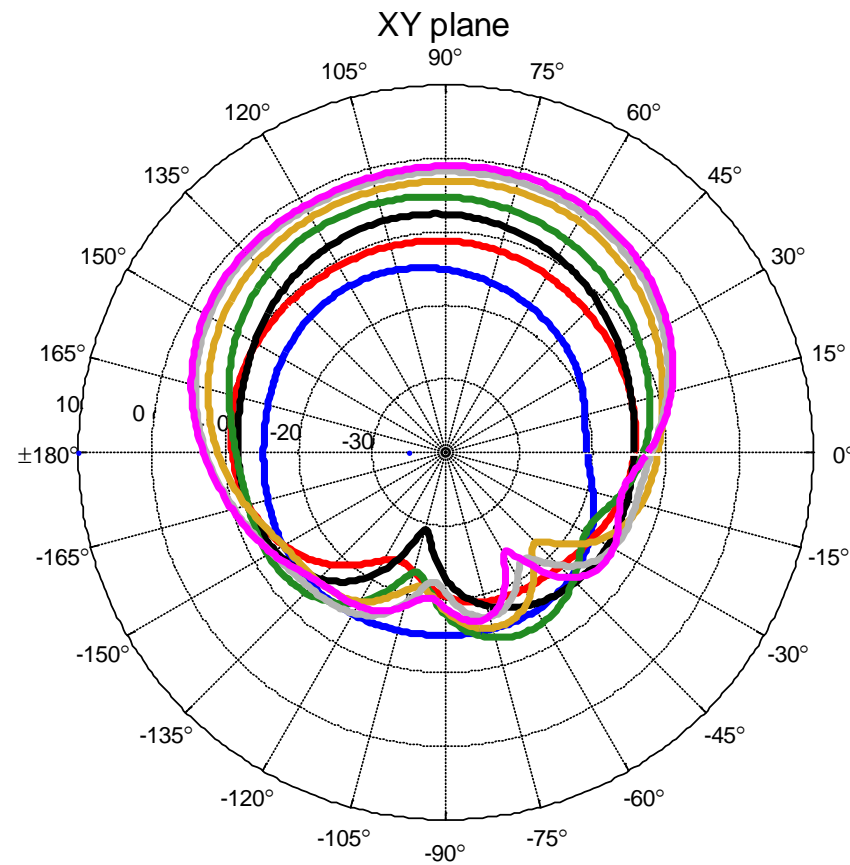
Duke: All Frequencies Band 4



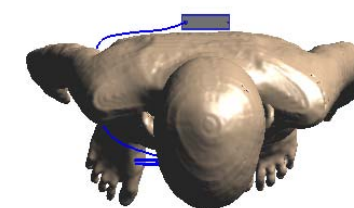
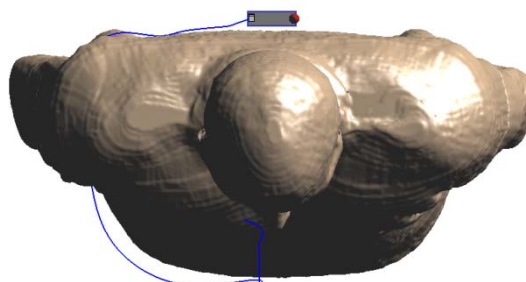
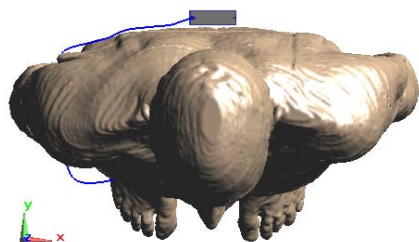
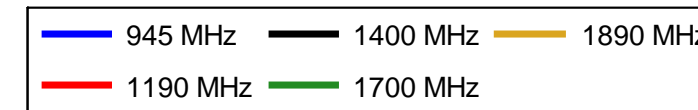
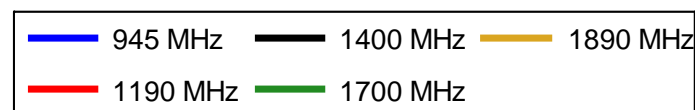
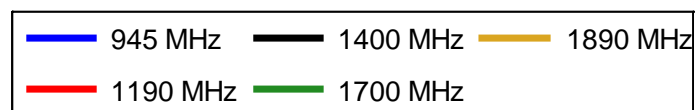
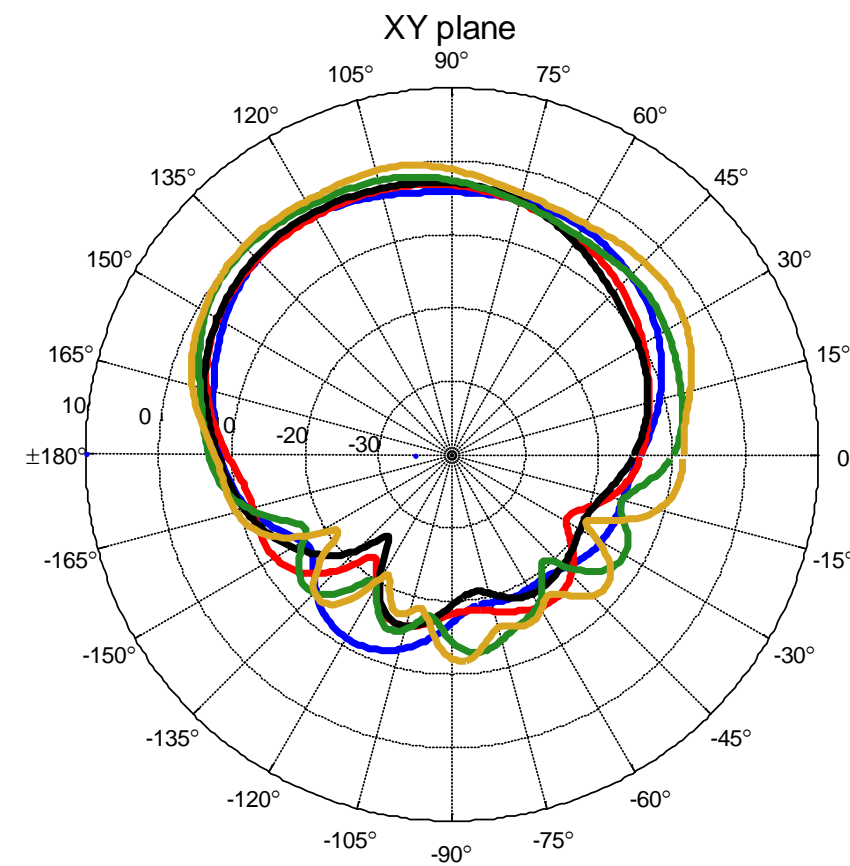
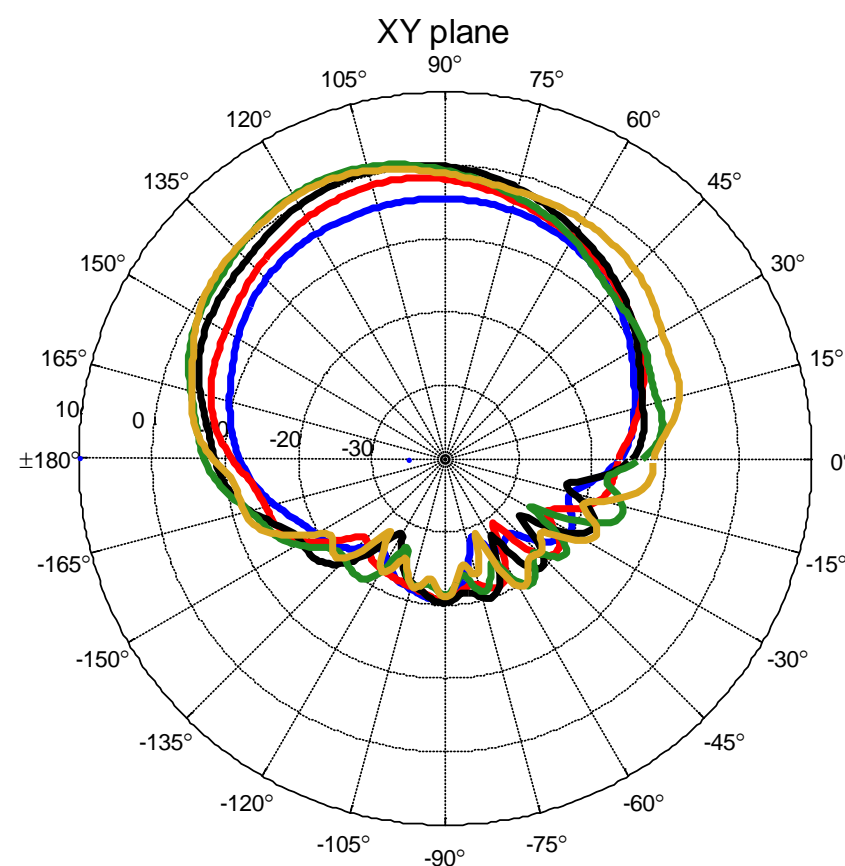
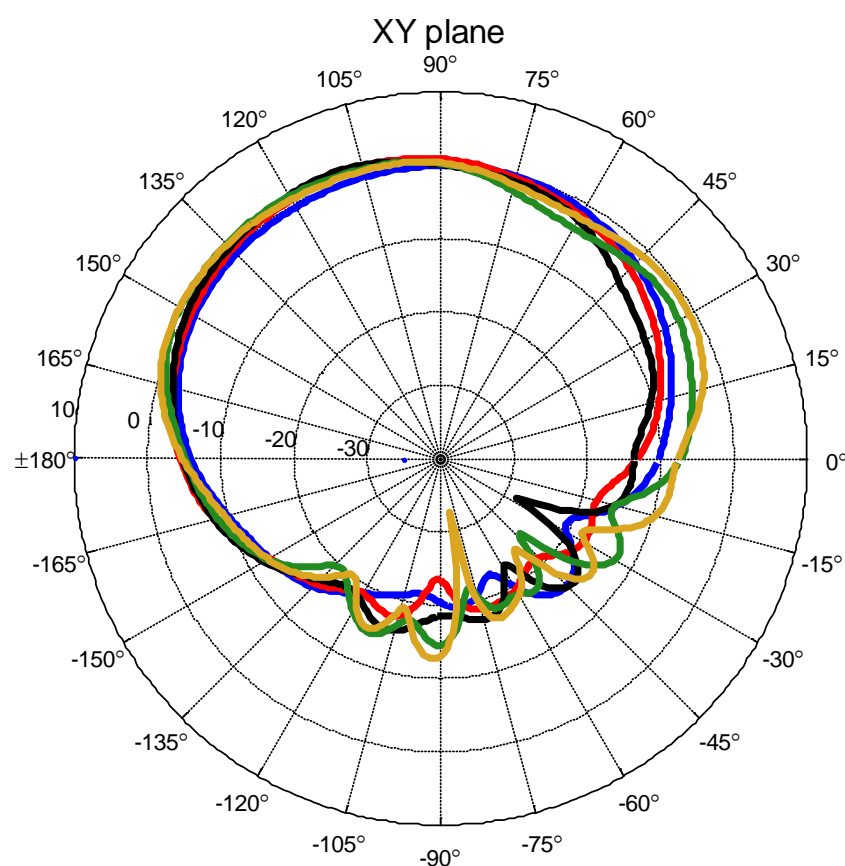
Duke: All Frequencies Band 4



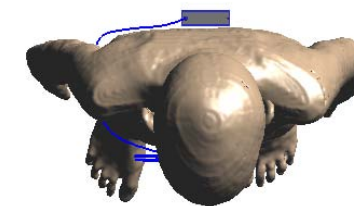
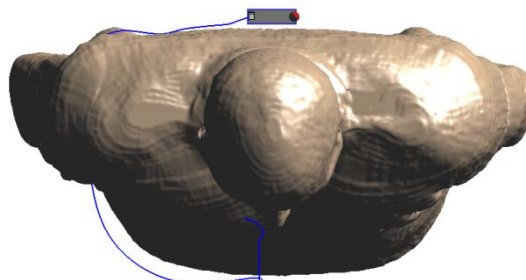
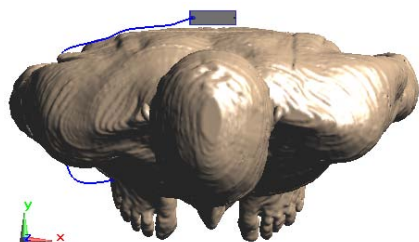
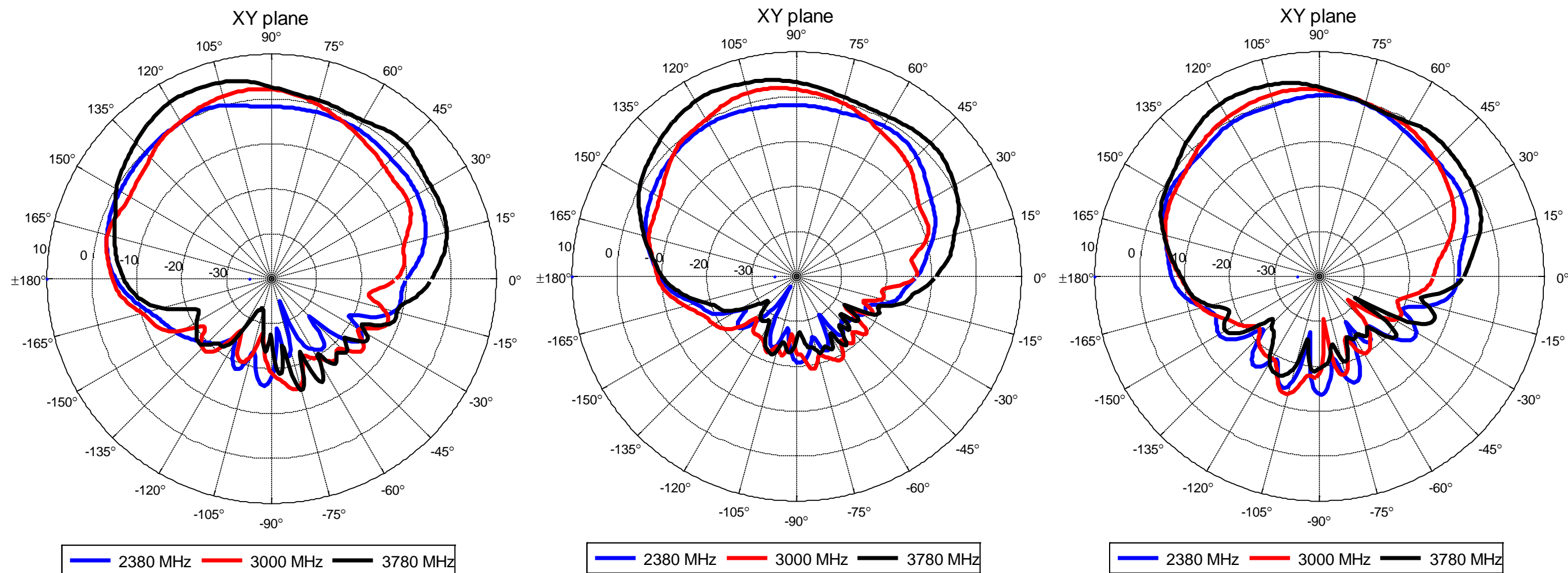
RP Band 1: 235 MHz – 825 MHz



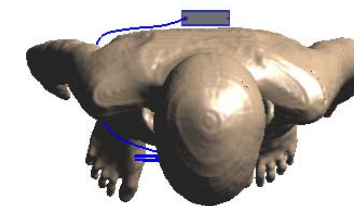
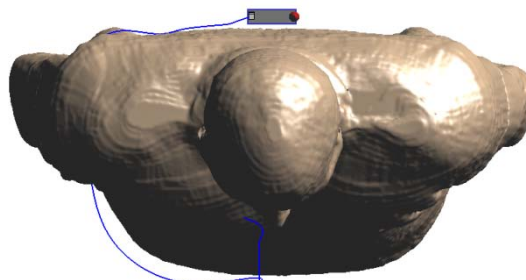
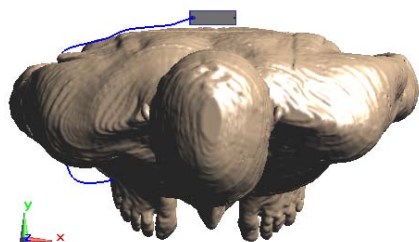
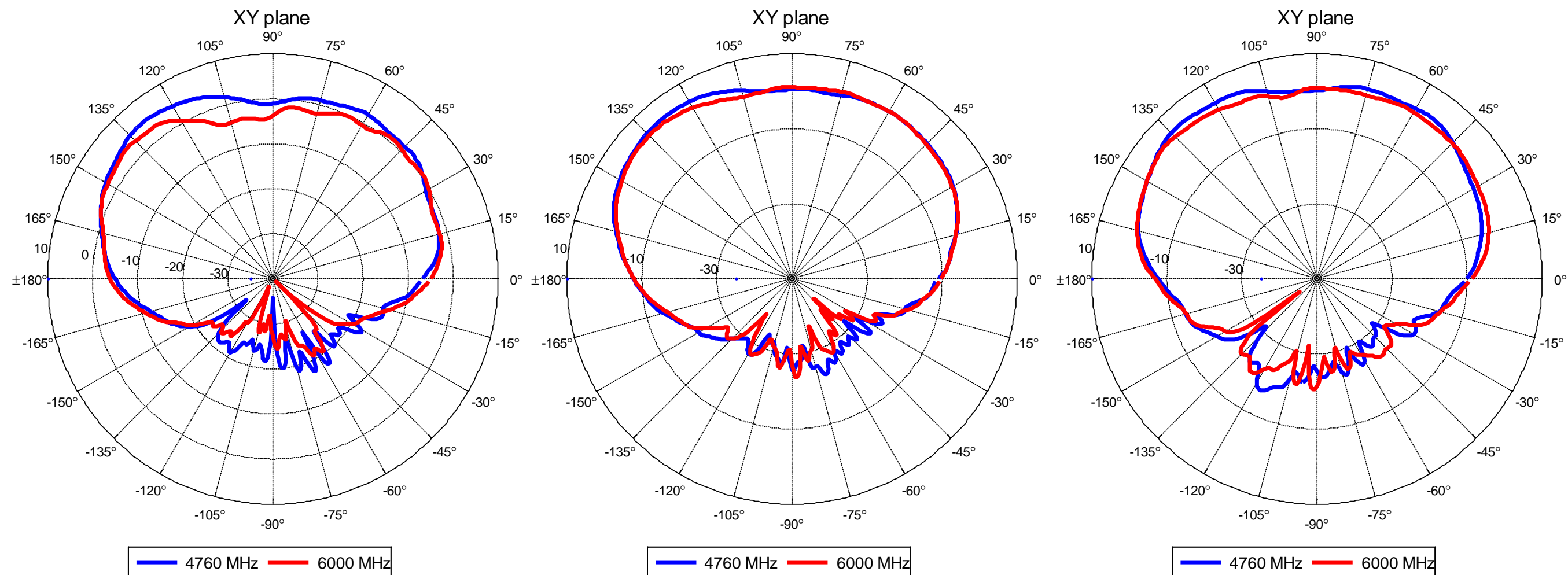
RP Band 2: 945 MHz – 1890 MHz



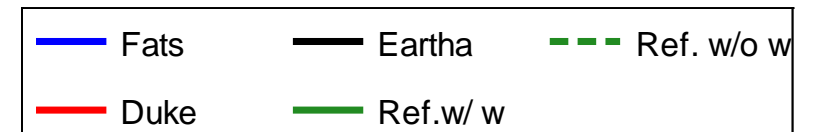
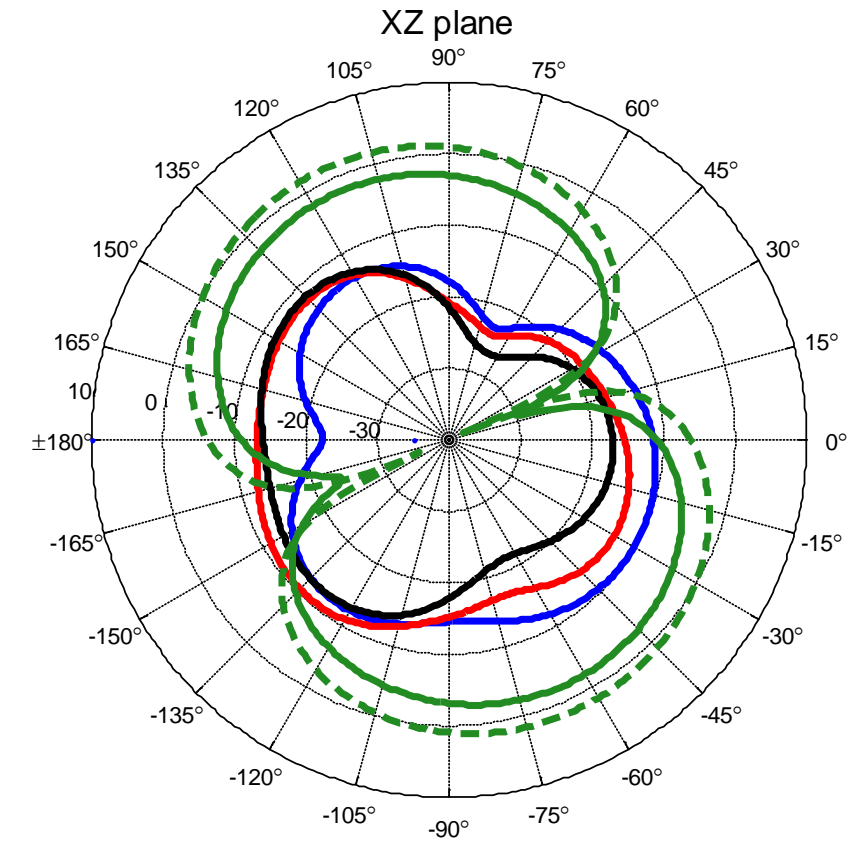
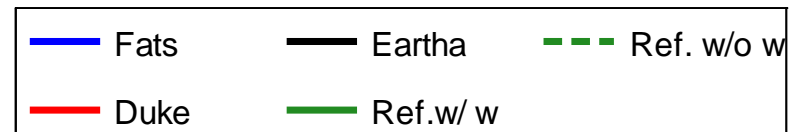
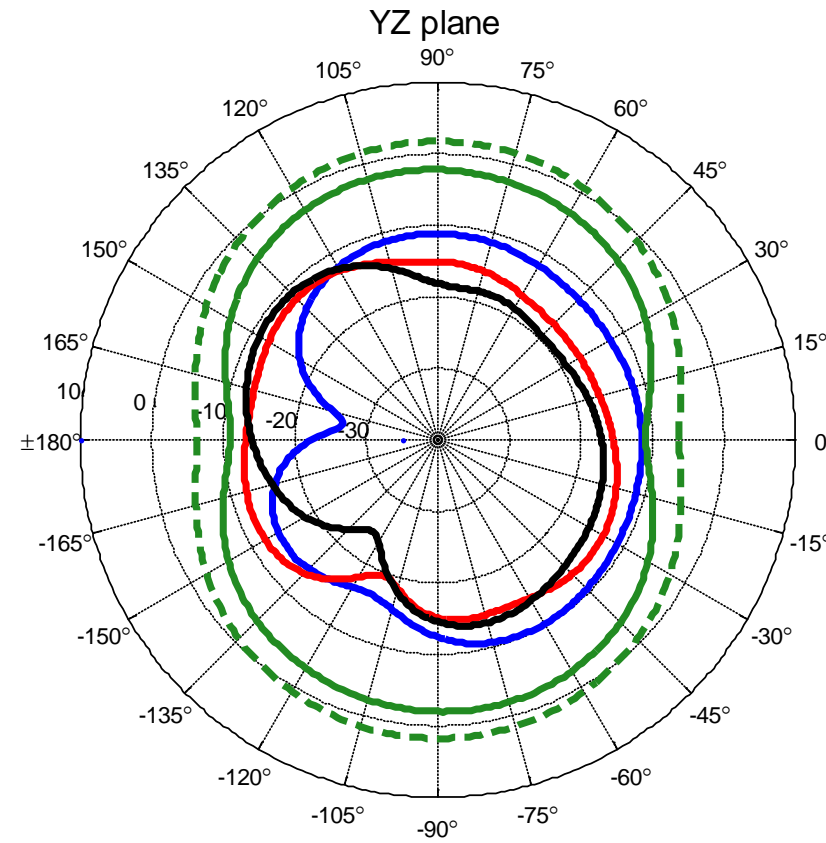
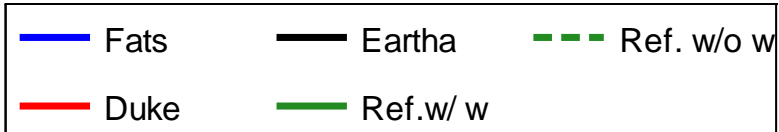
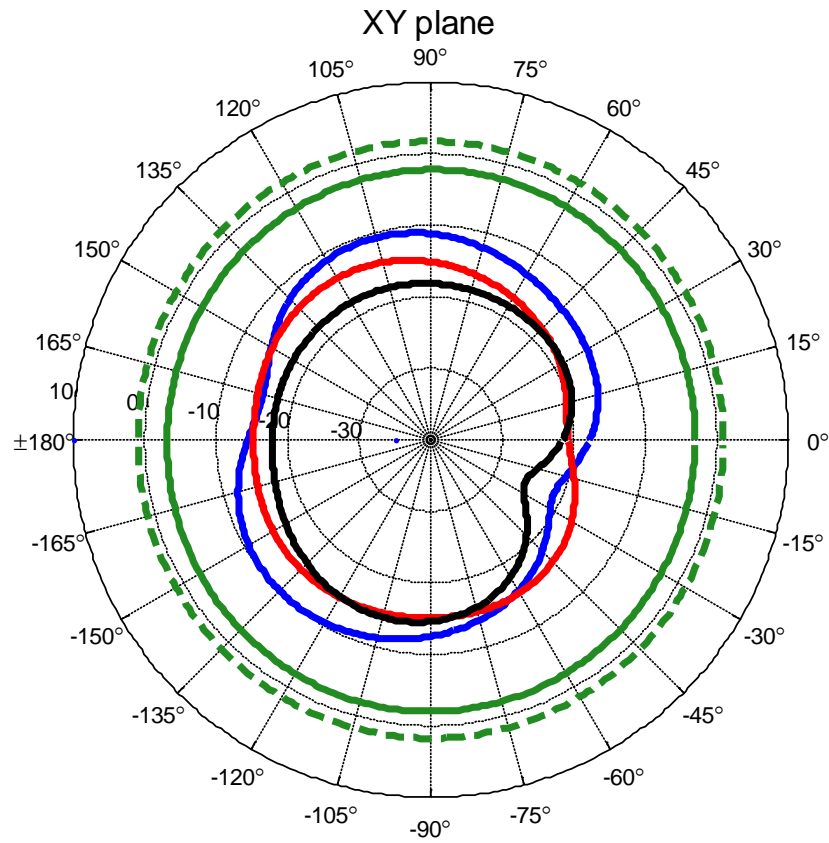
RP Band 3: 2380 MHz – 3780 MHz



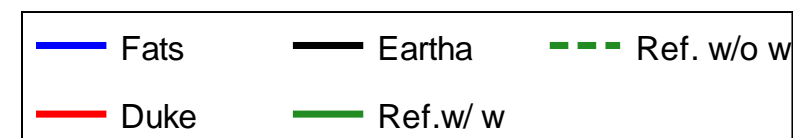
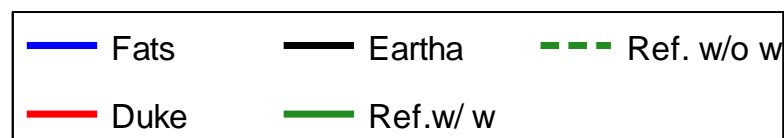
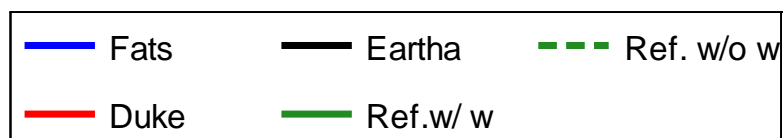
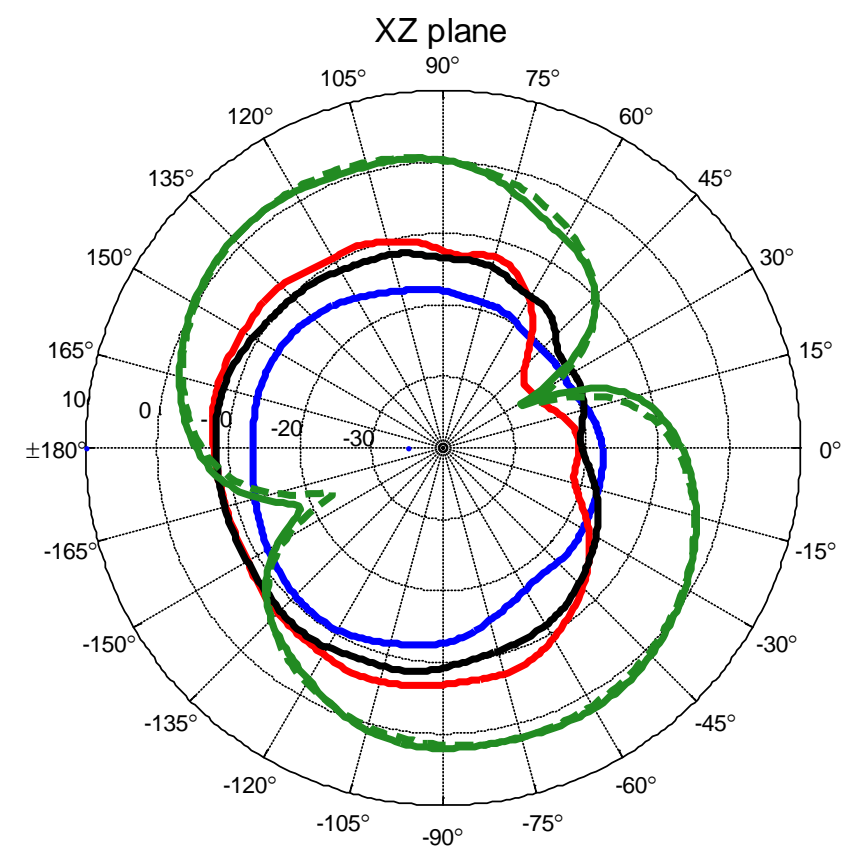
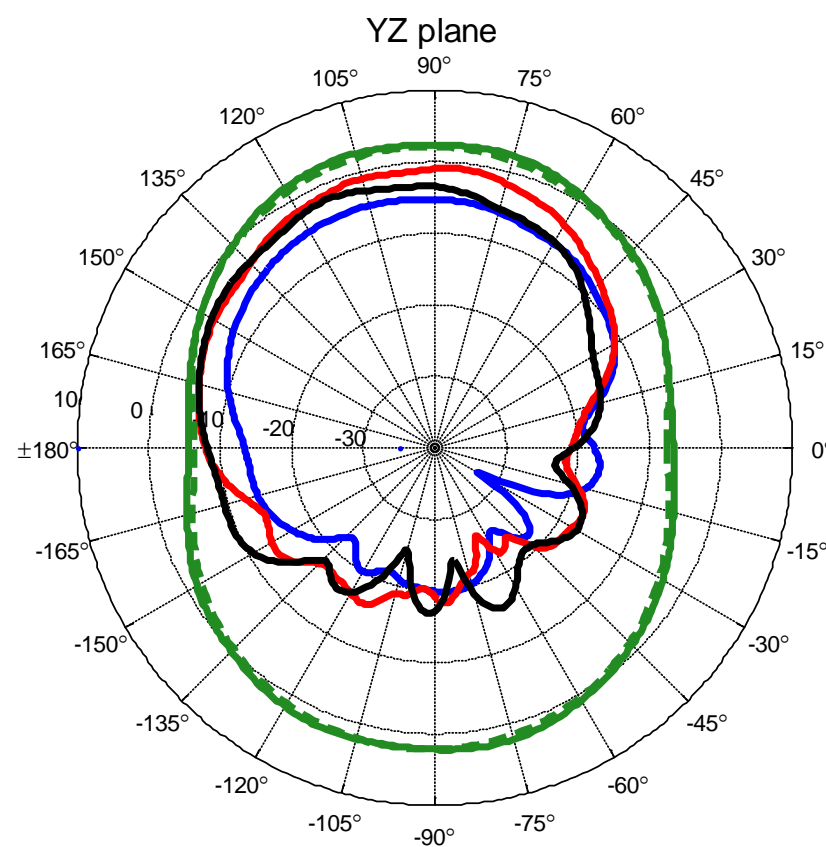
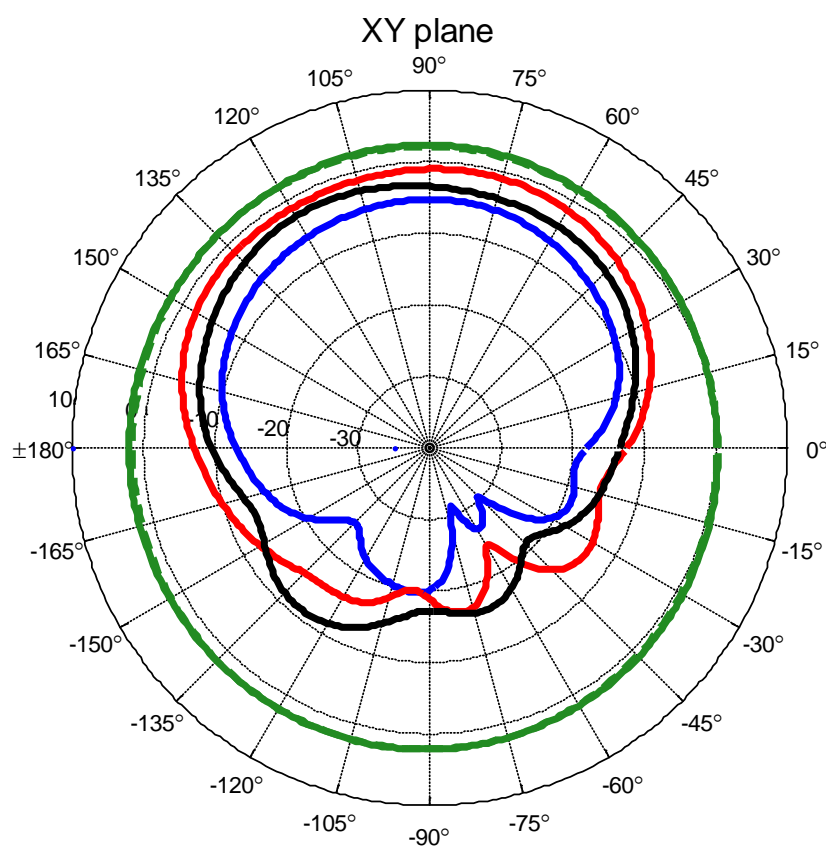
RP Band 4: 4760 MHz – 6000 MHz



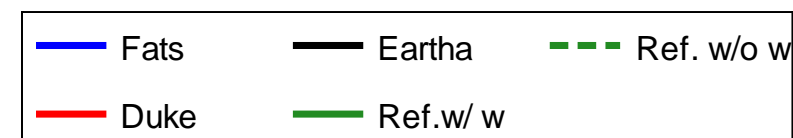
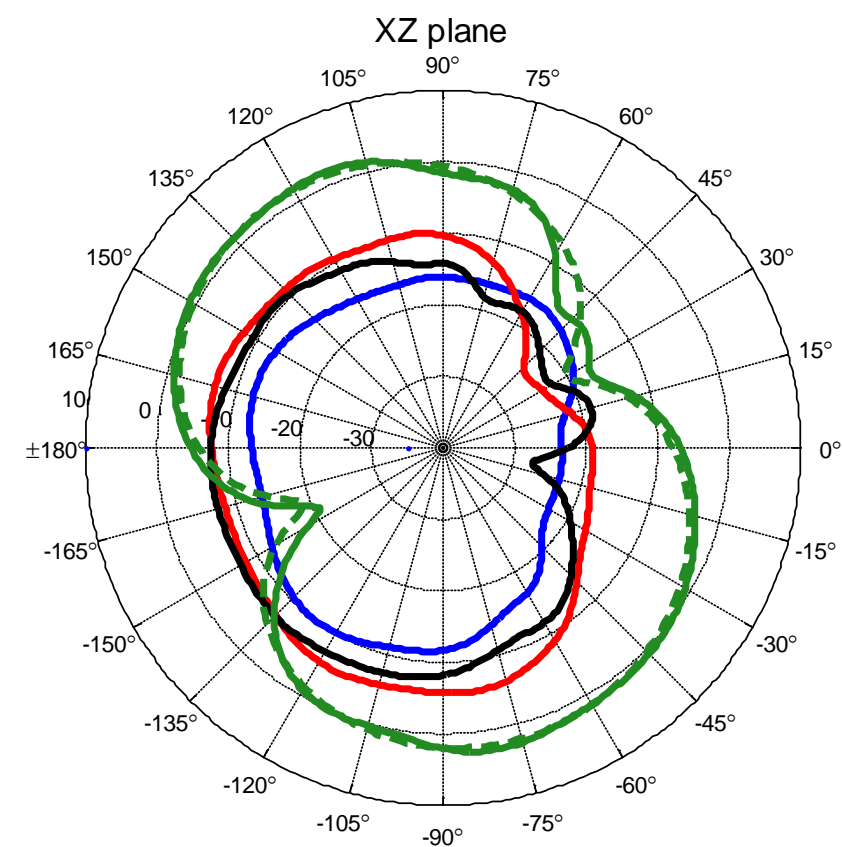
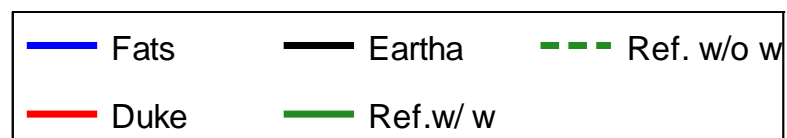
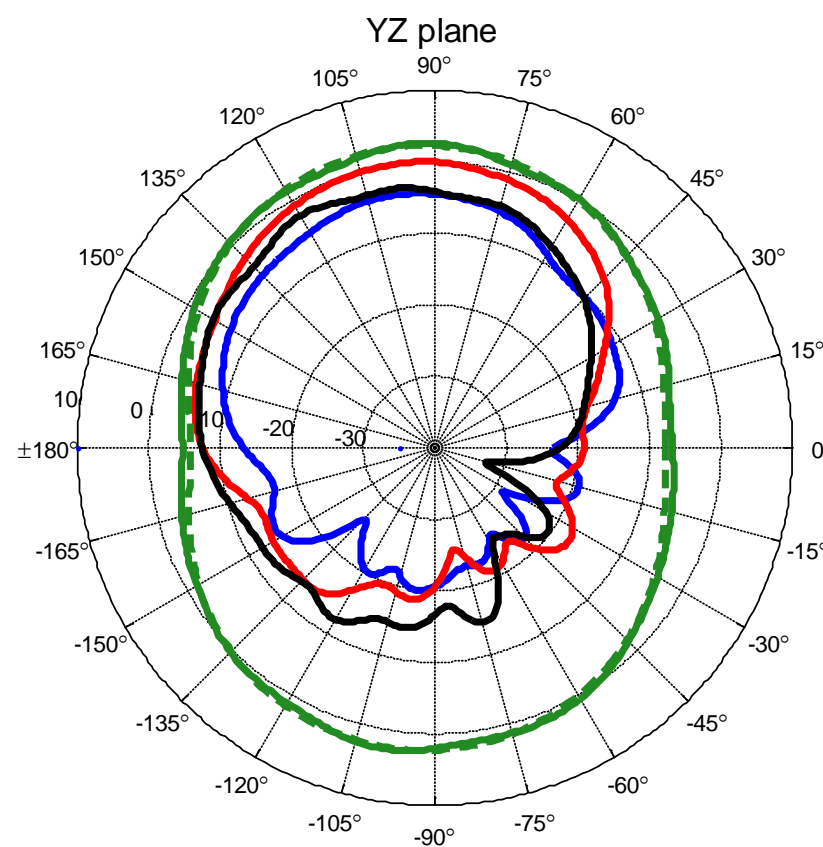
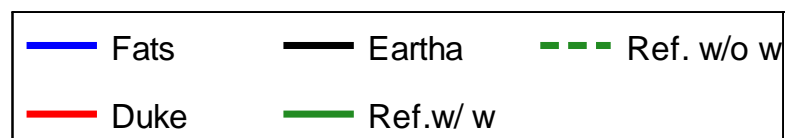
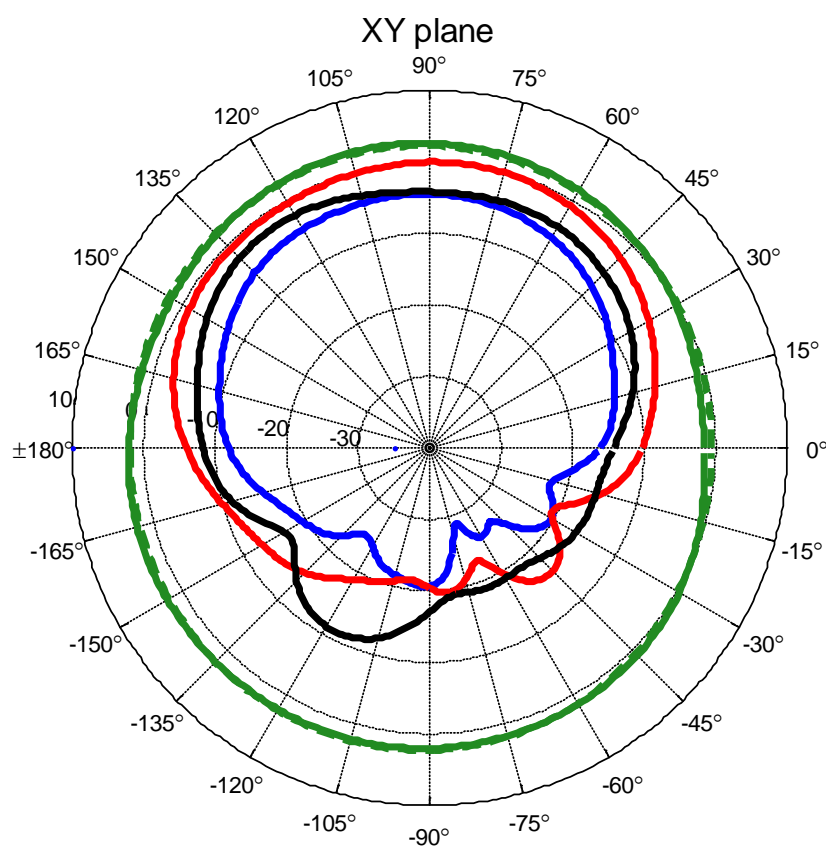
All Models Band 1: 235 MHz



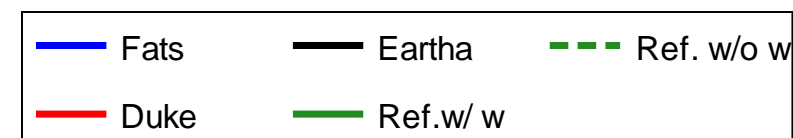
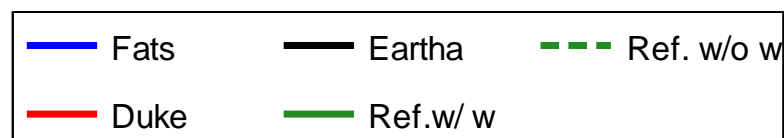
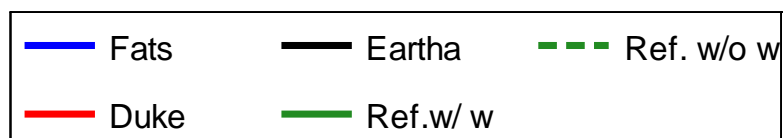
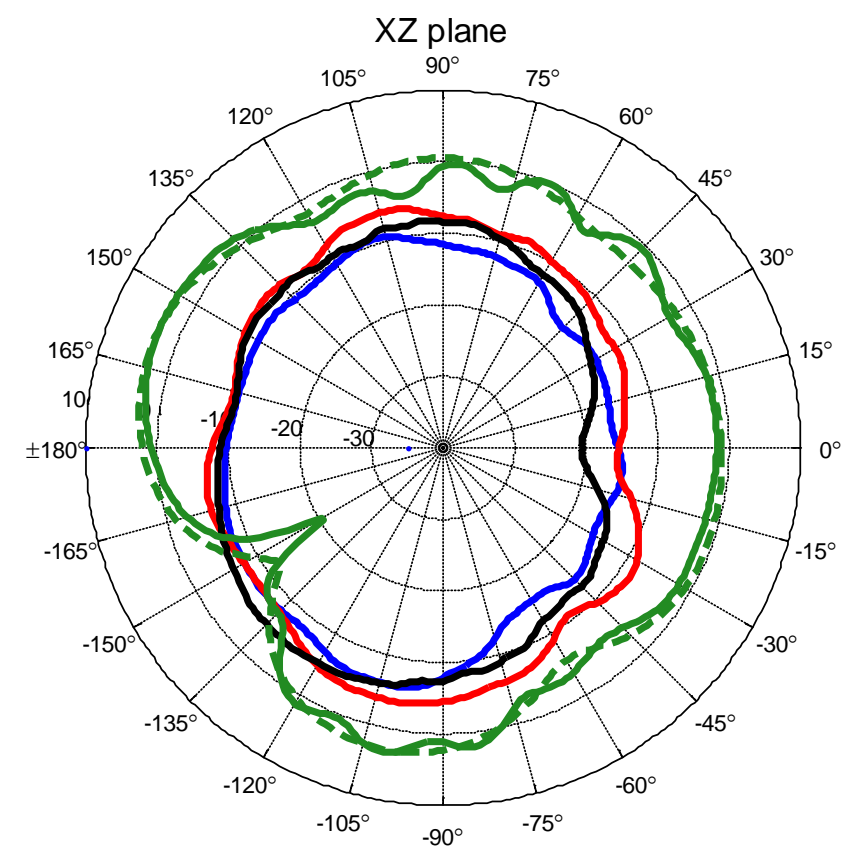
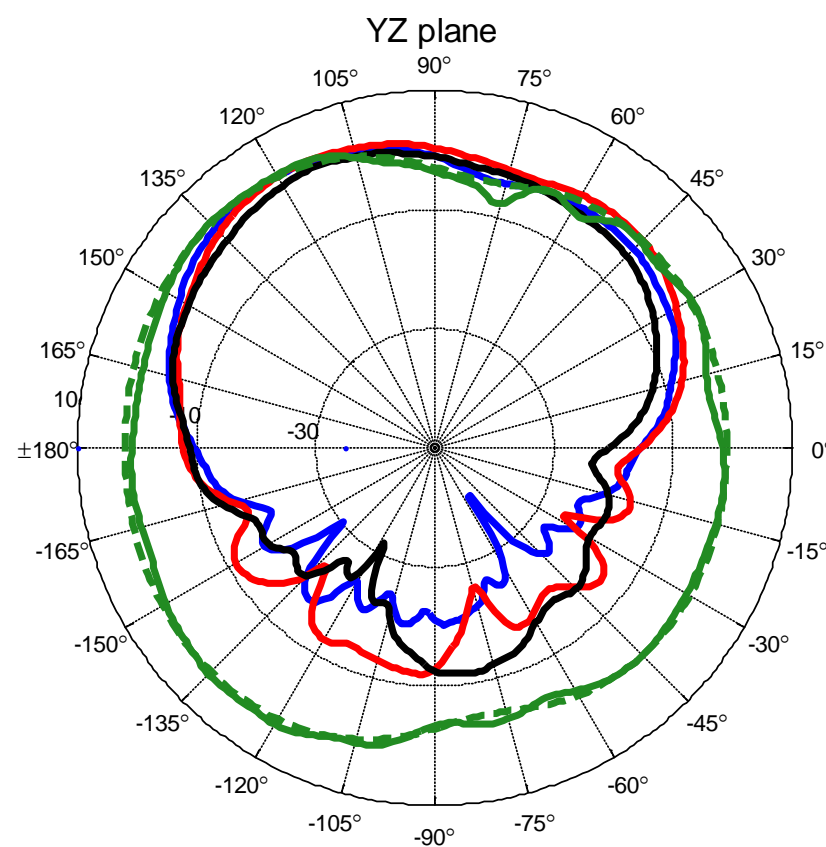
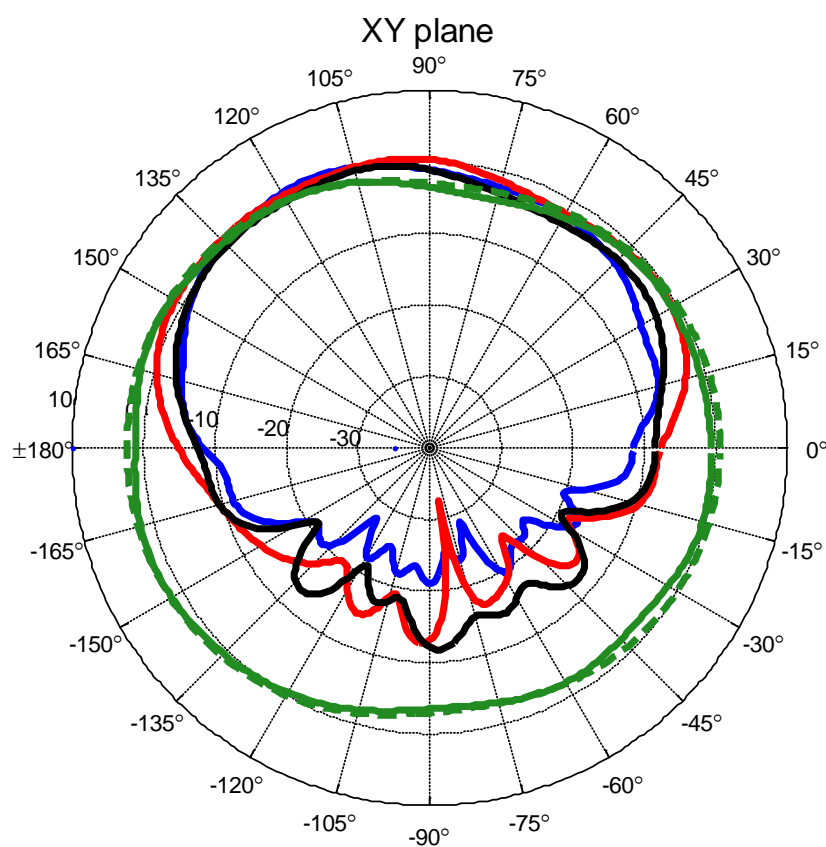
All Models Band 1: 825 MHz



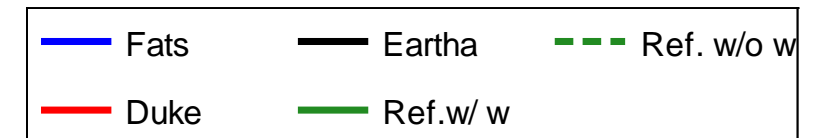
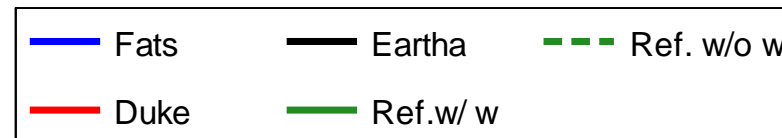
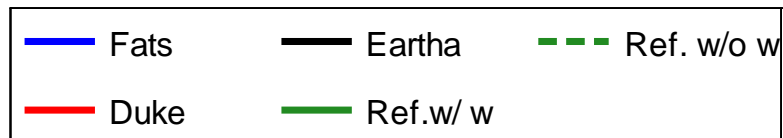
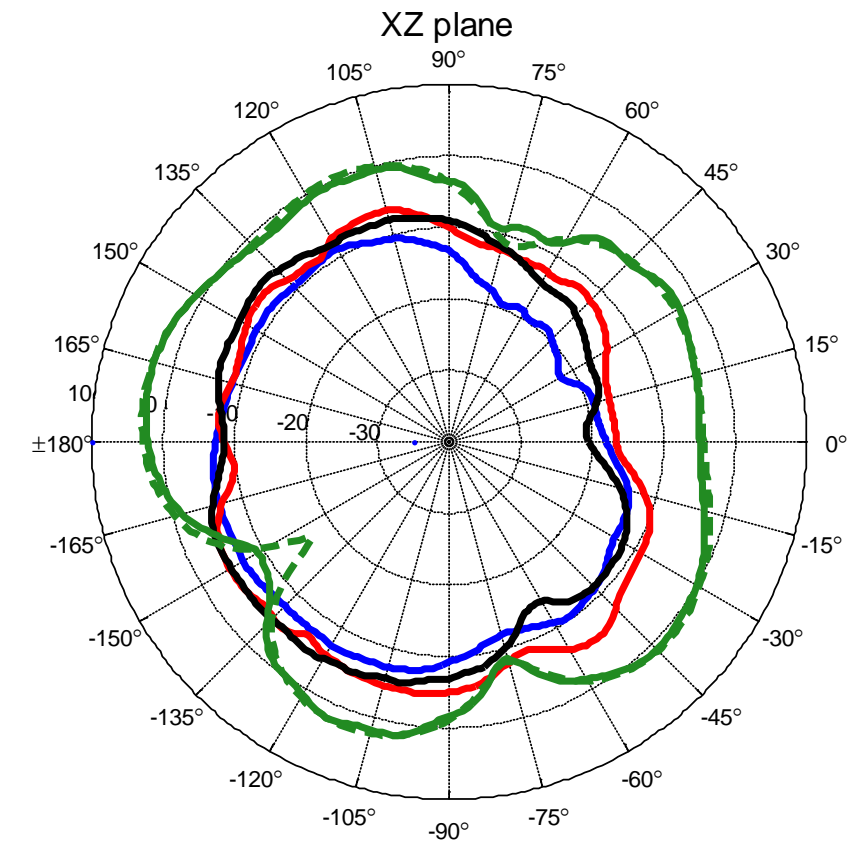
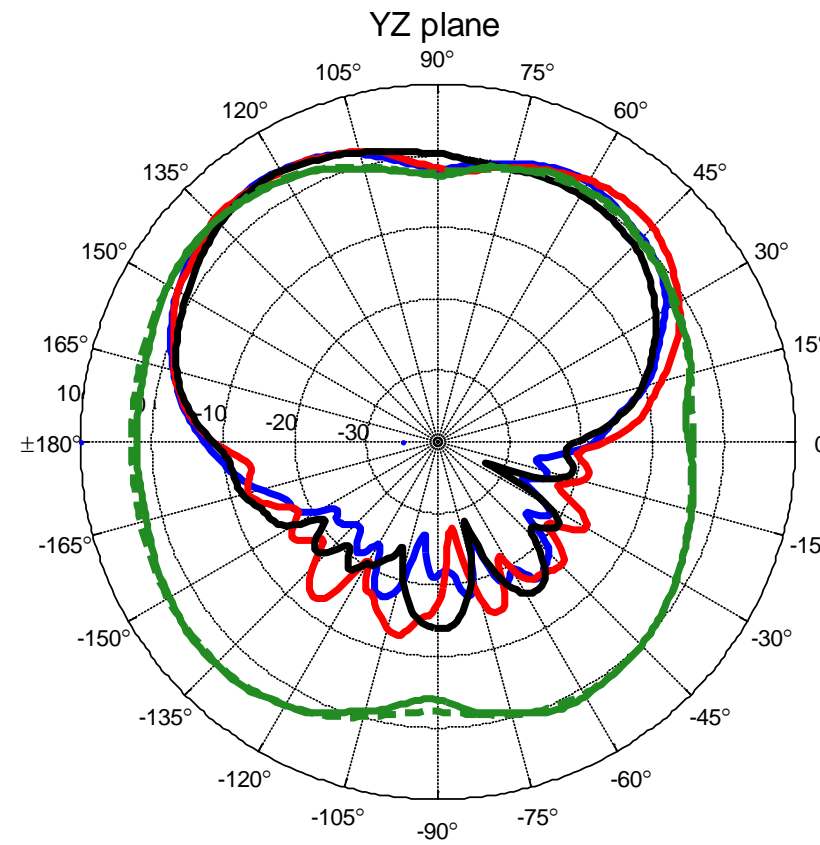
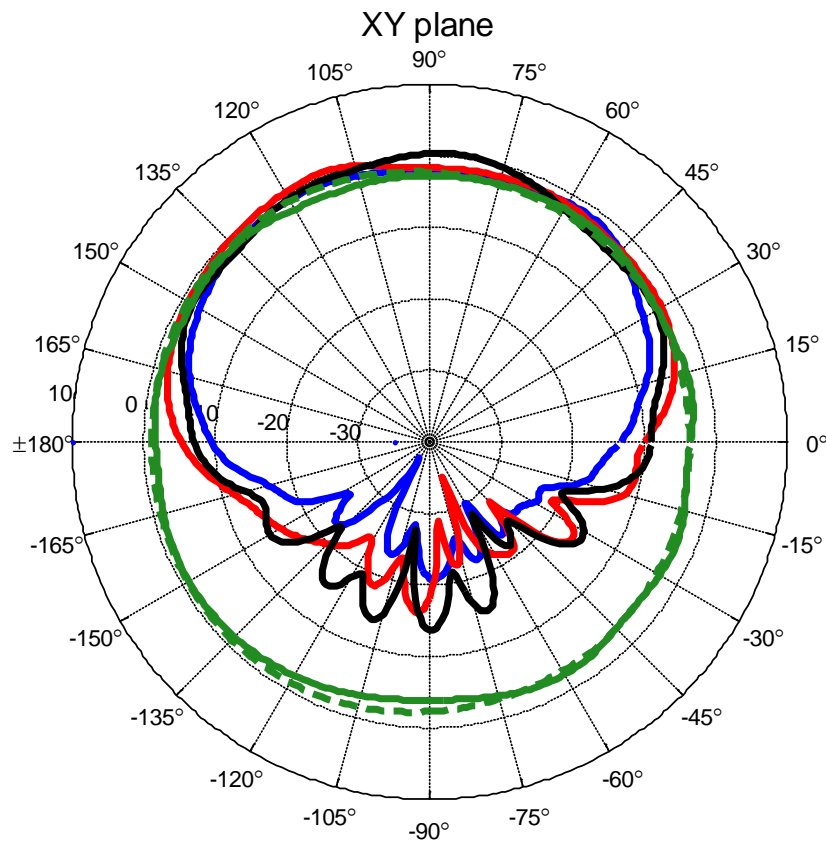
All Models Band 2: 945 MHz



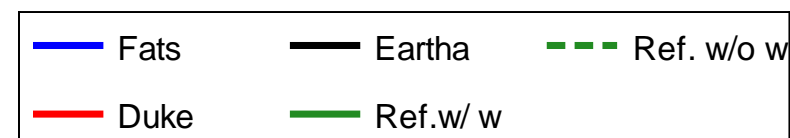
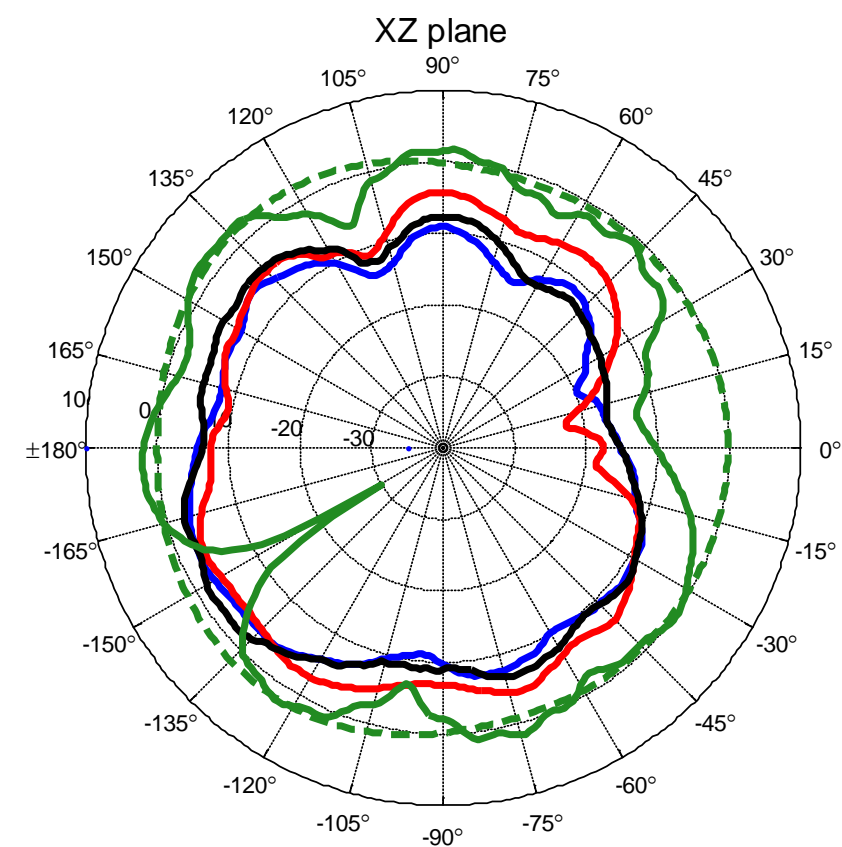
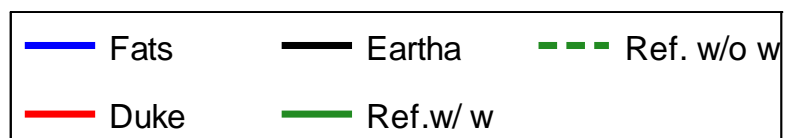
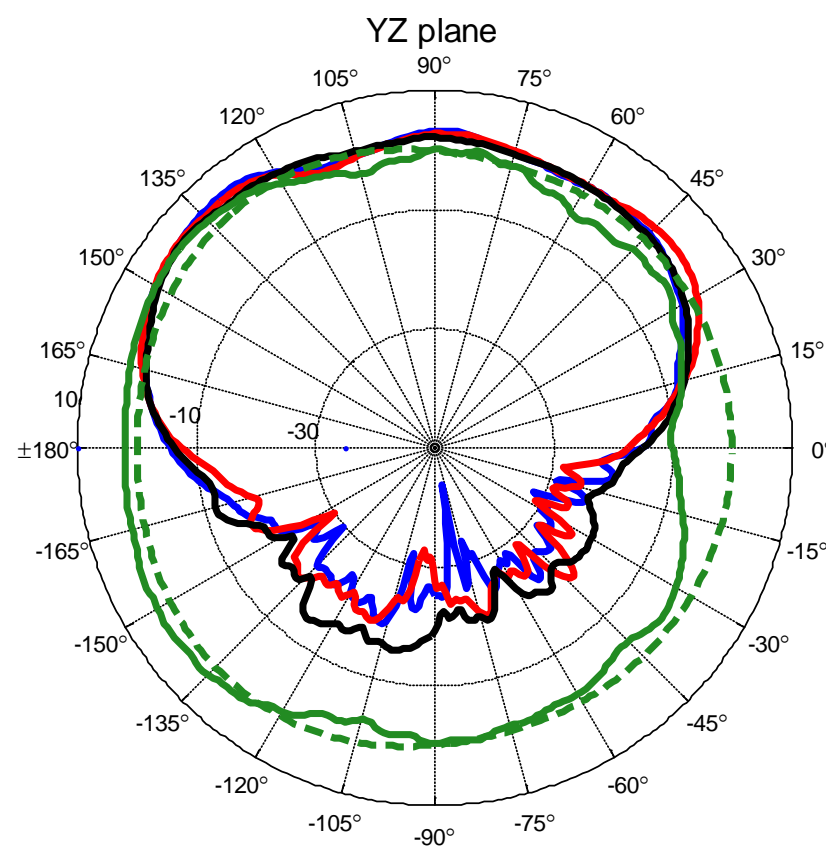
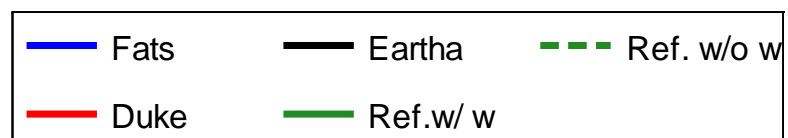
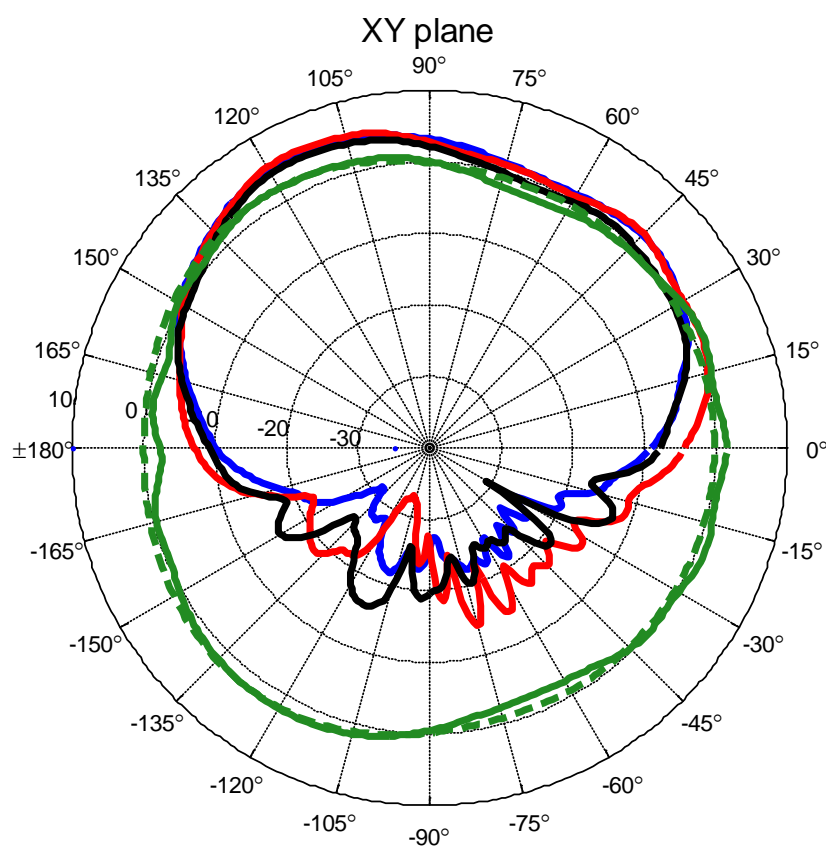
All Models Band 2: 1890 MHz



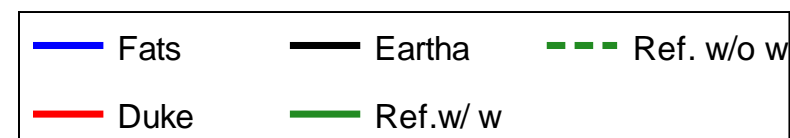
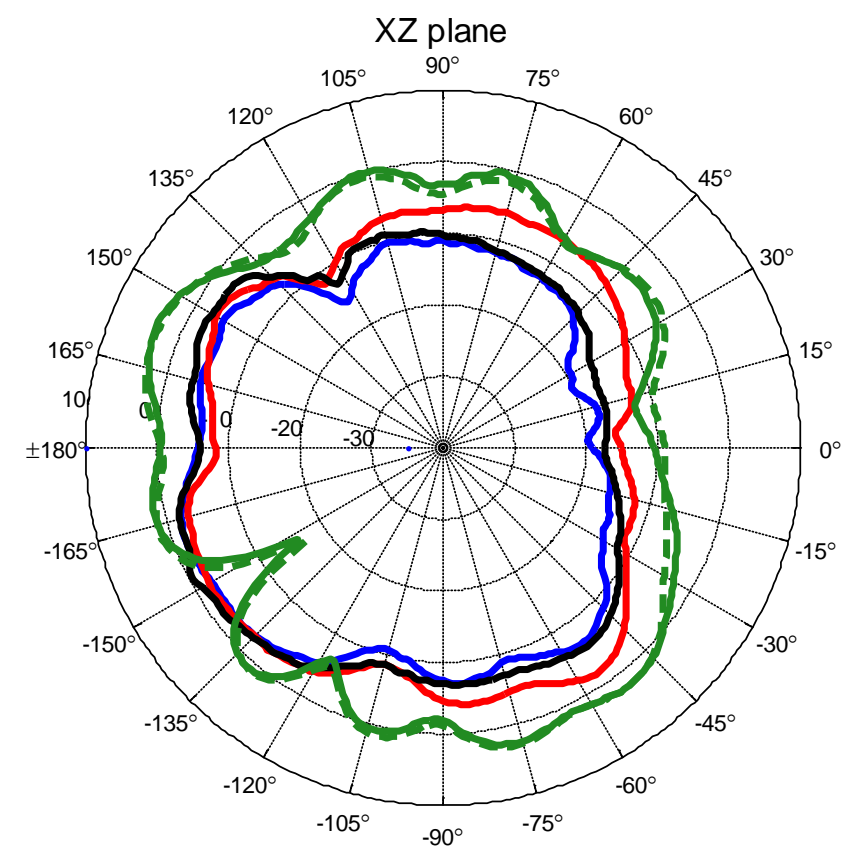
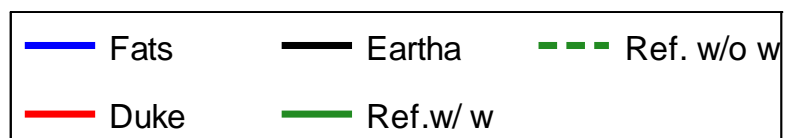
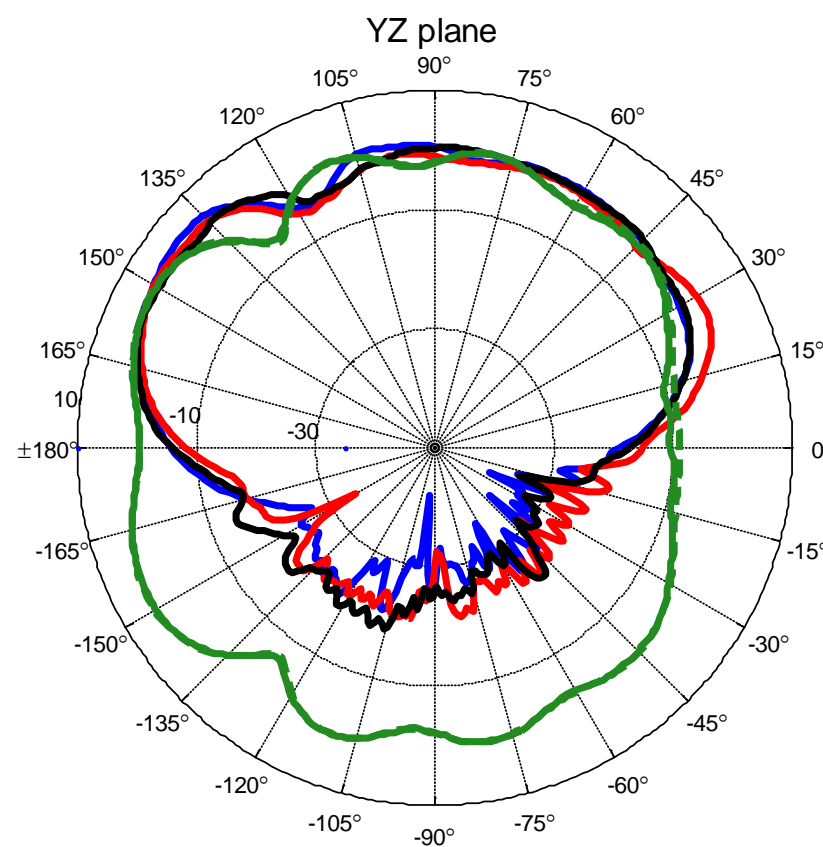
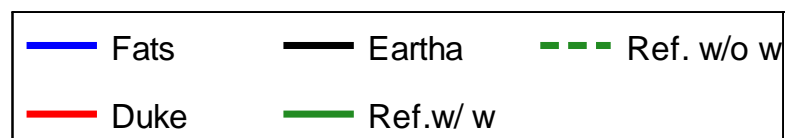
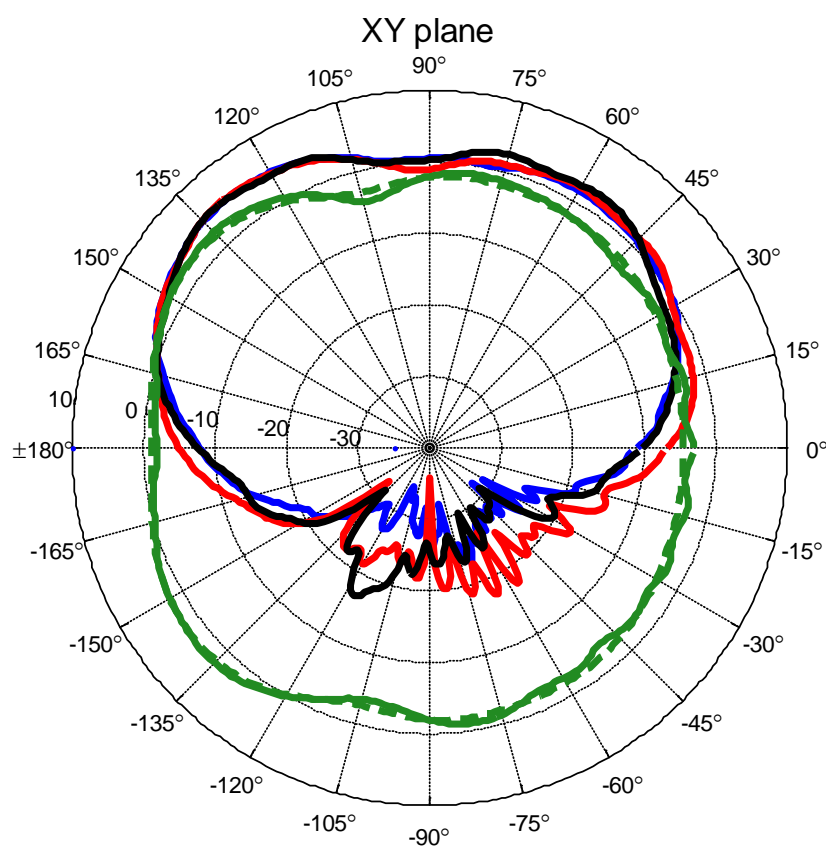
All Models Band 3: 2380 MHz



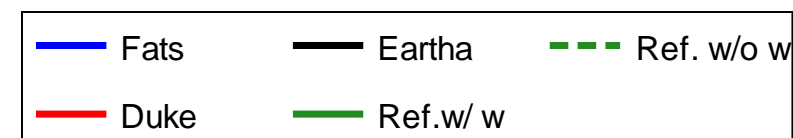
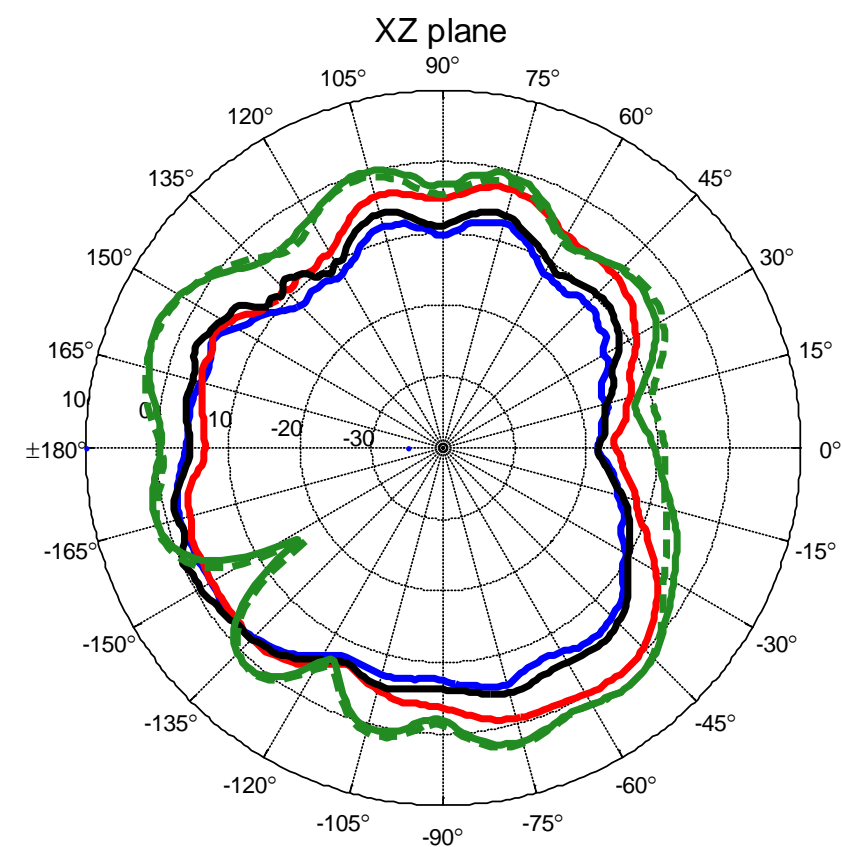
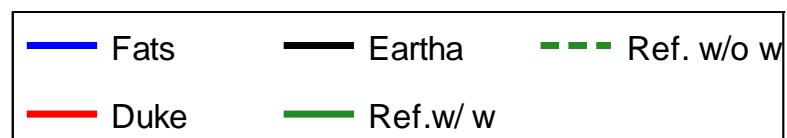
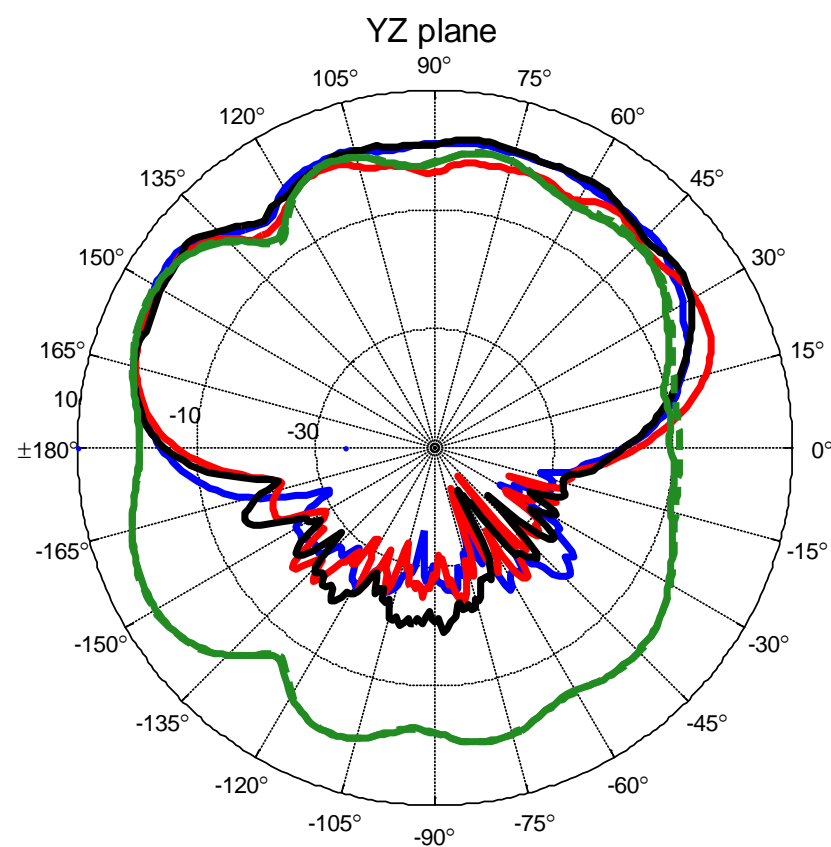
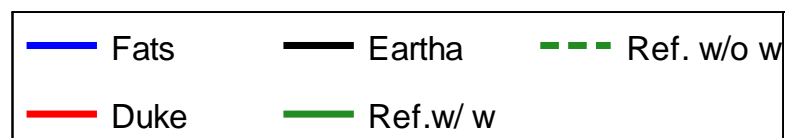
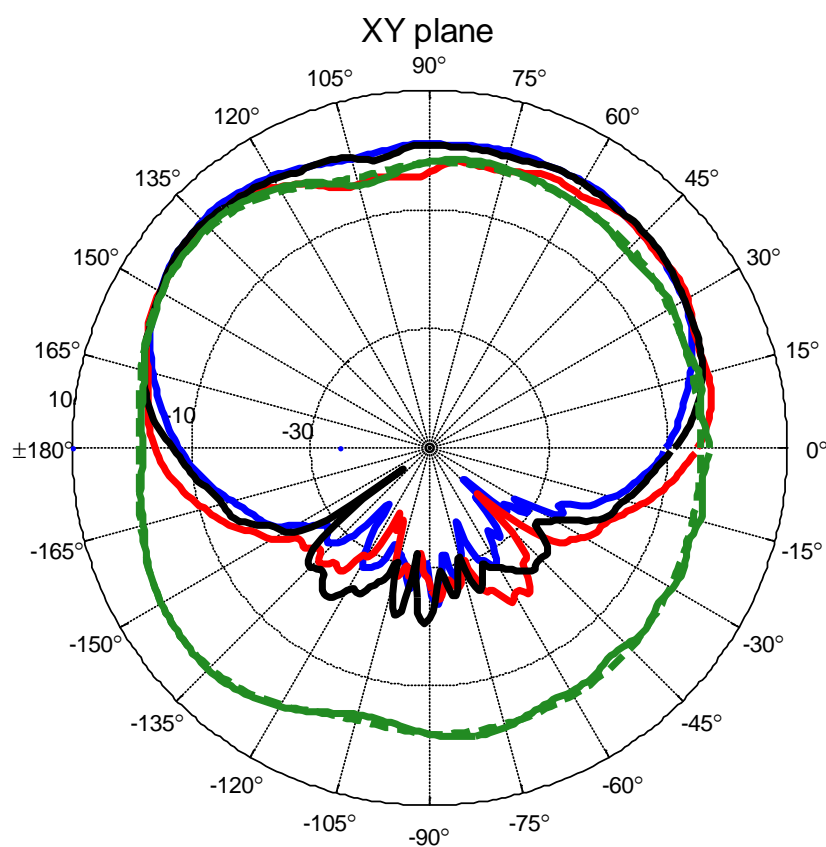
All Models Band 3: 3780 MHz



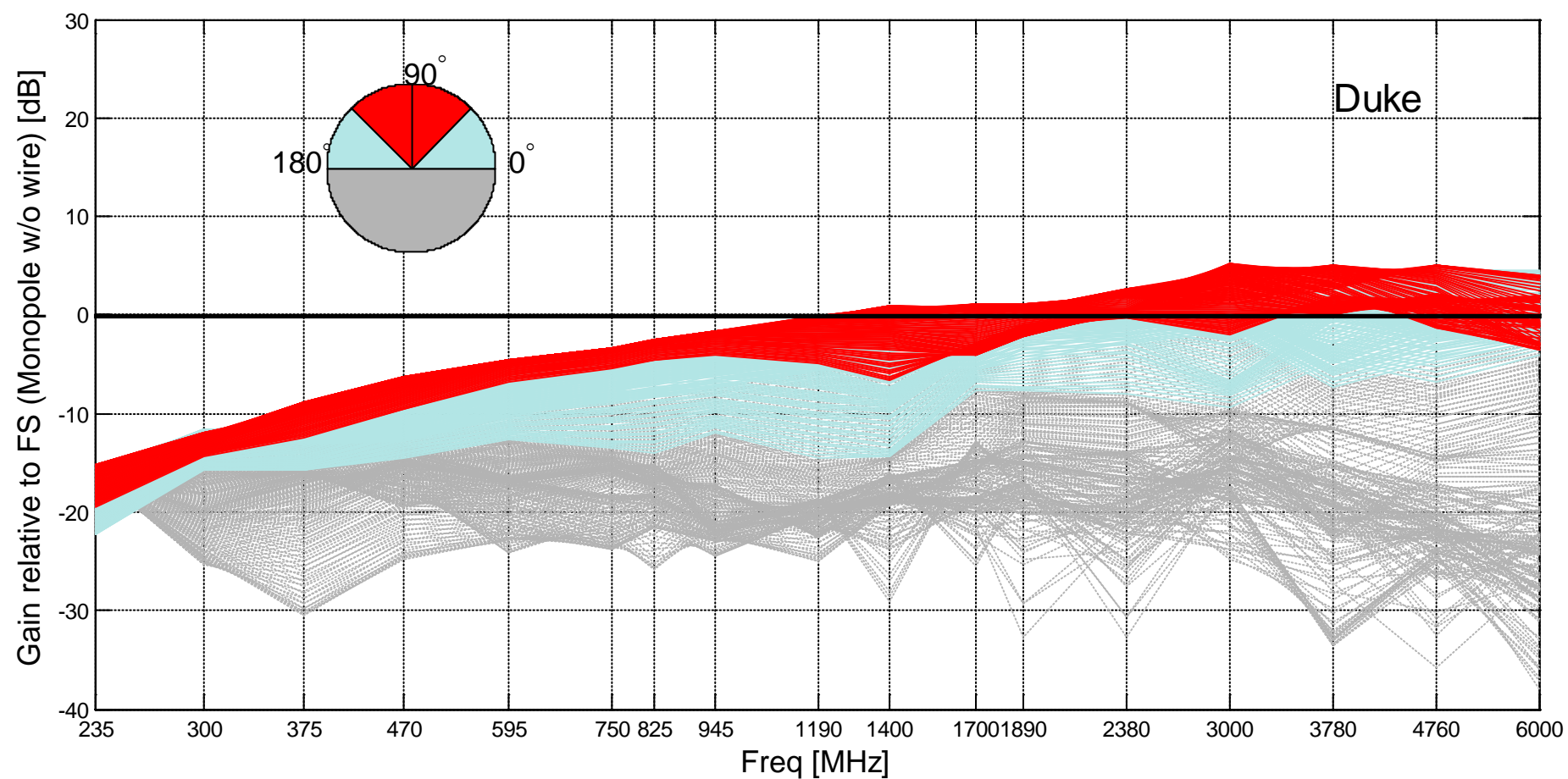
All Models Band 4: 4760 MHz



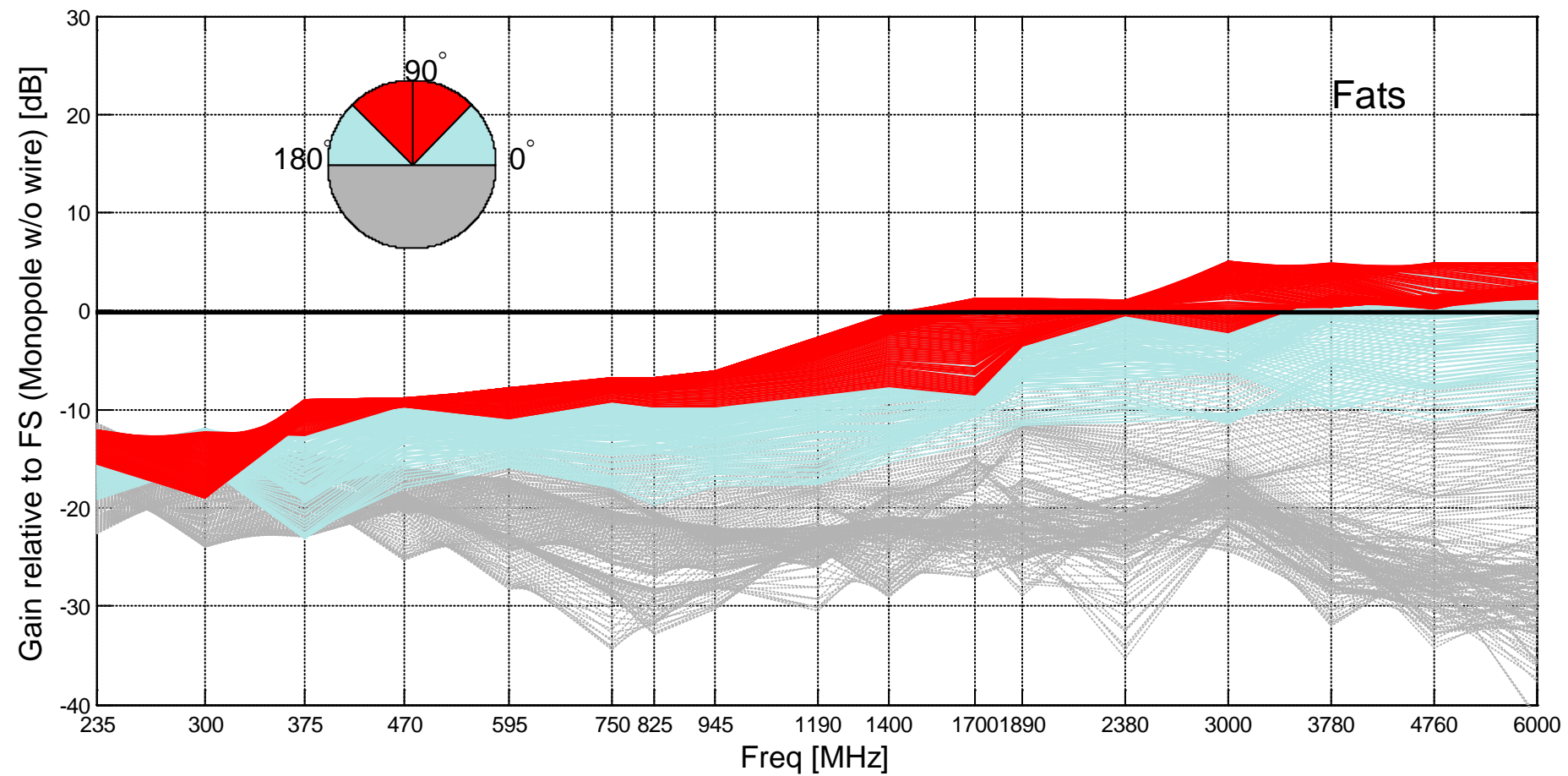
All Models Band 4: 6000 MHz



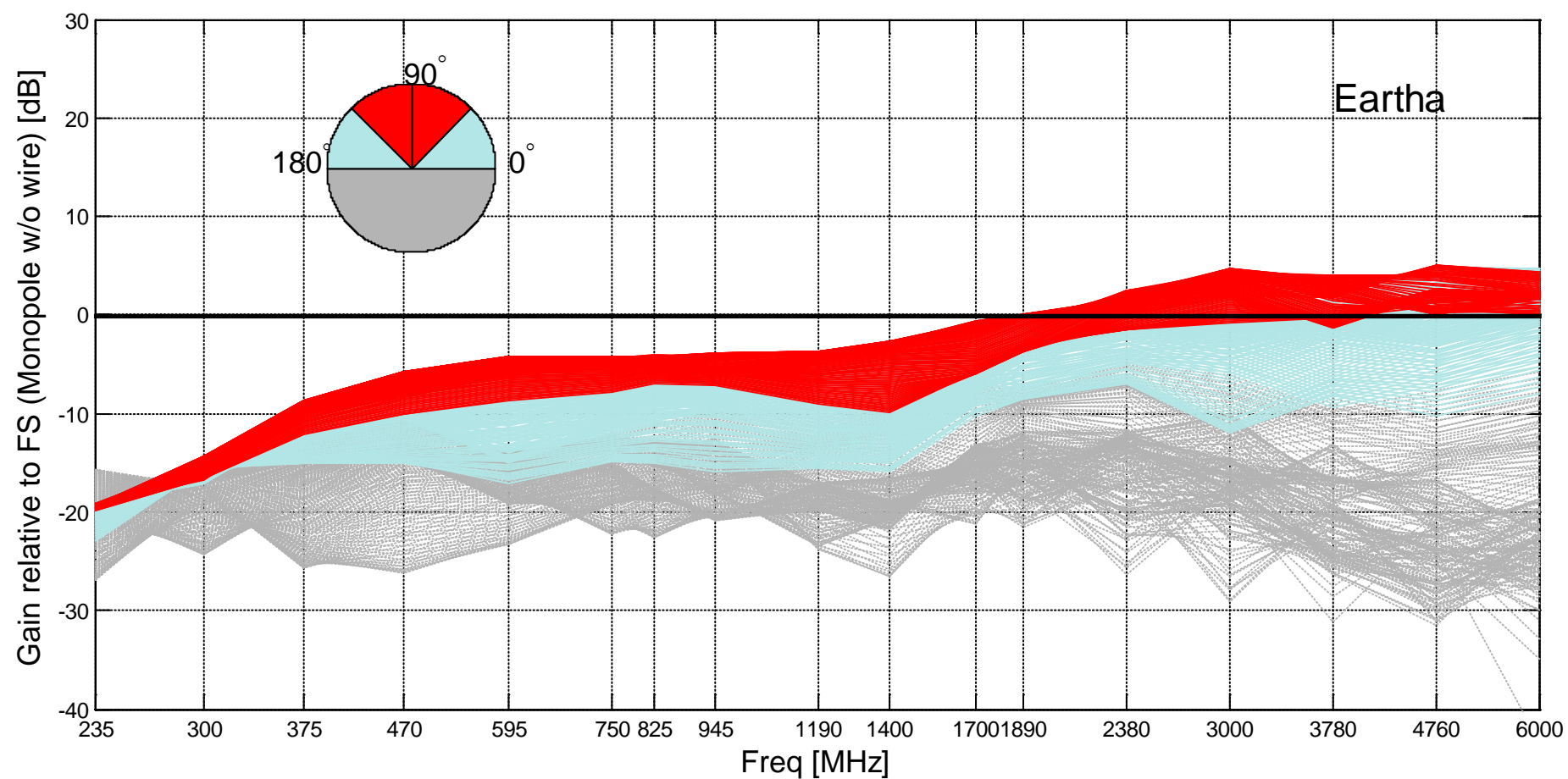
Duke: Gain Relative to Average FS



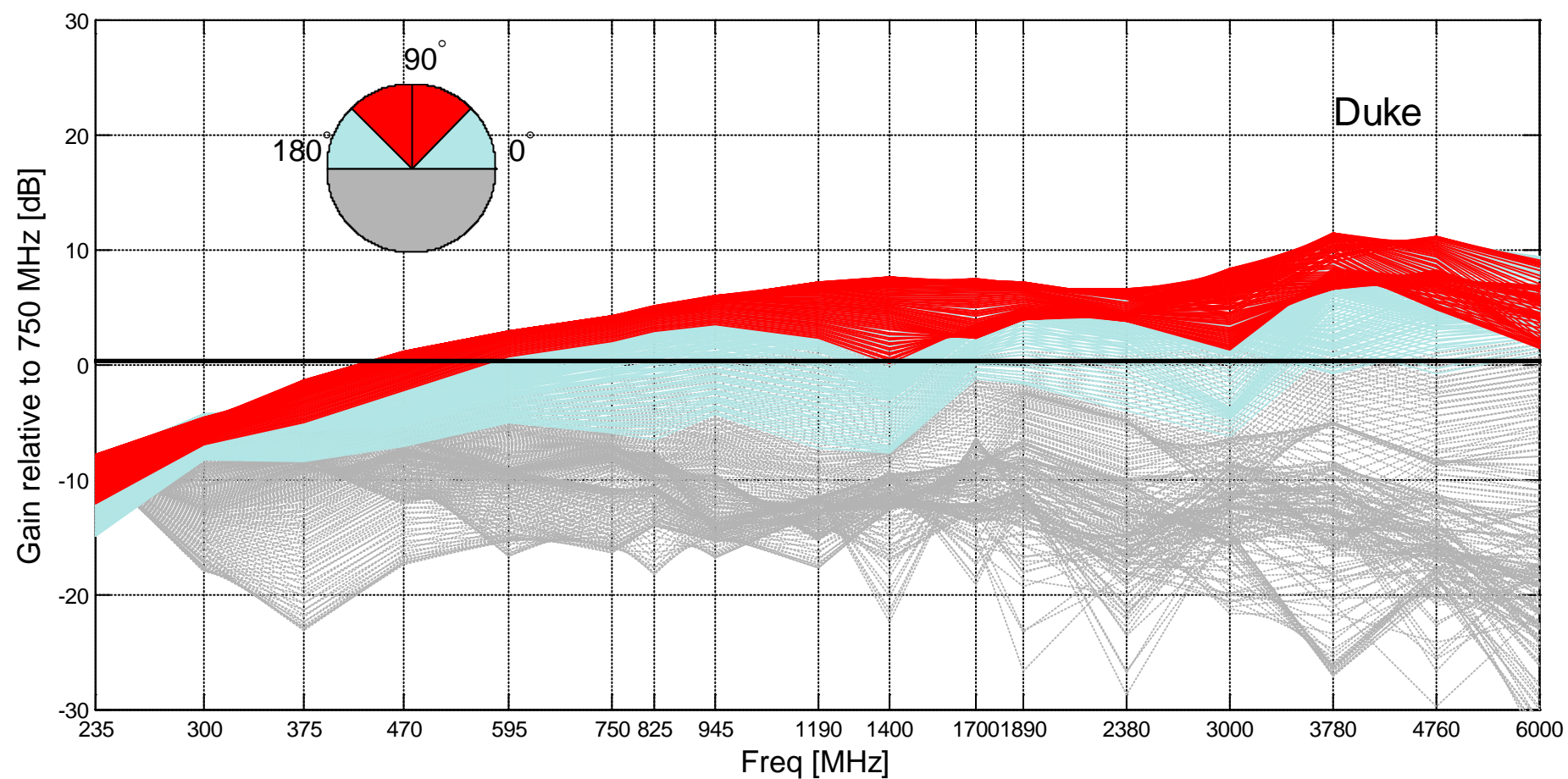
Fats: Gain Relative to Average FS



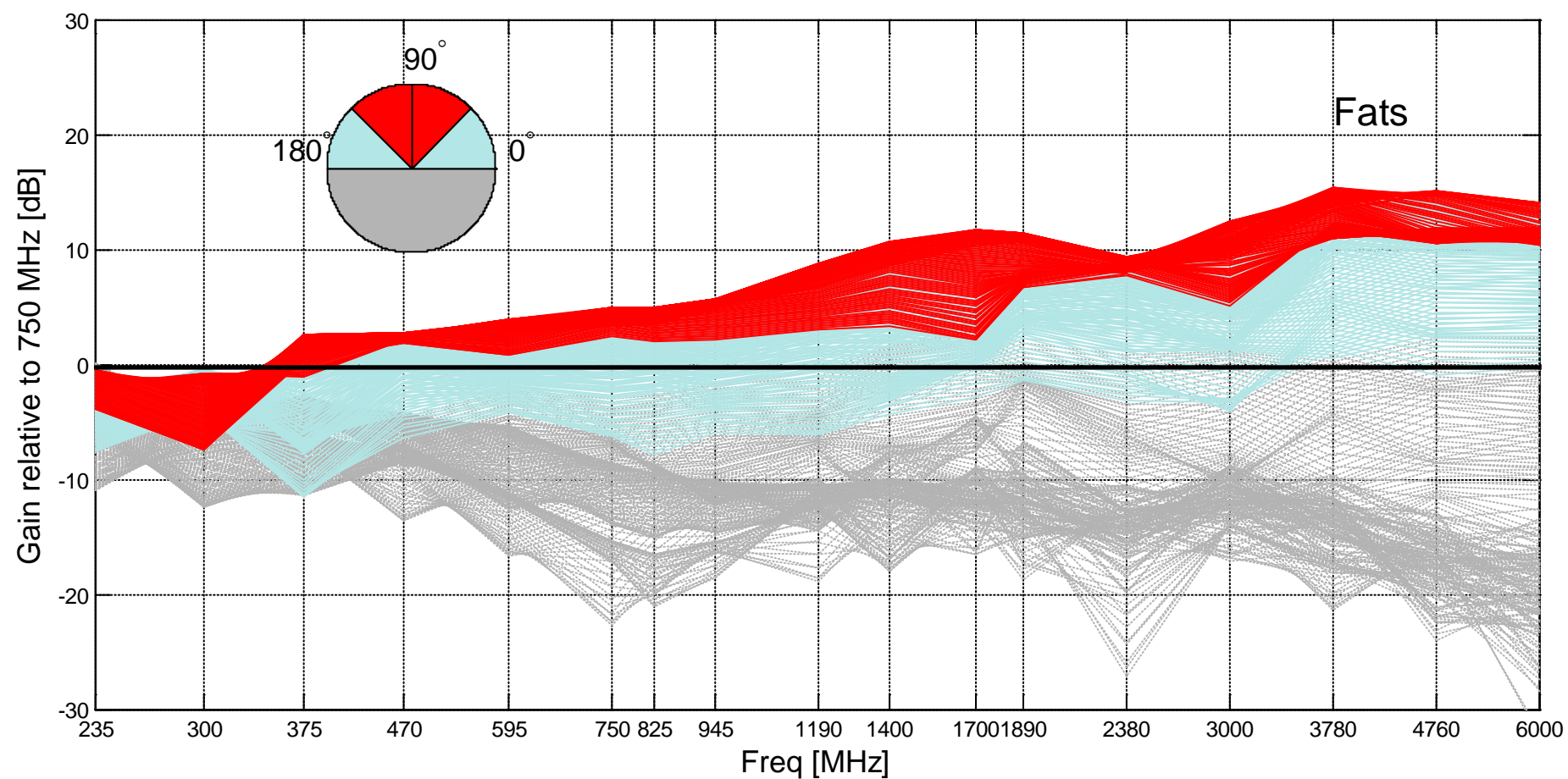
Eartha: Gain Relative to Average FS



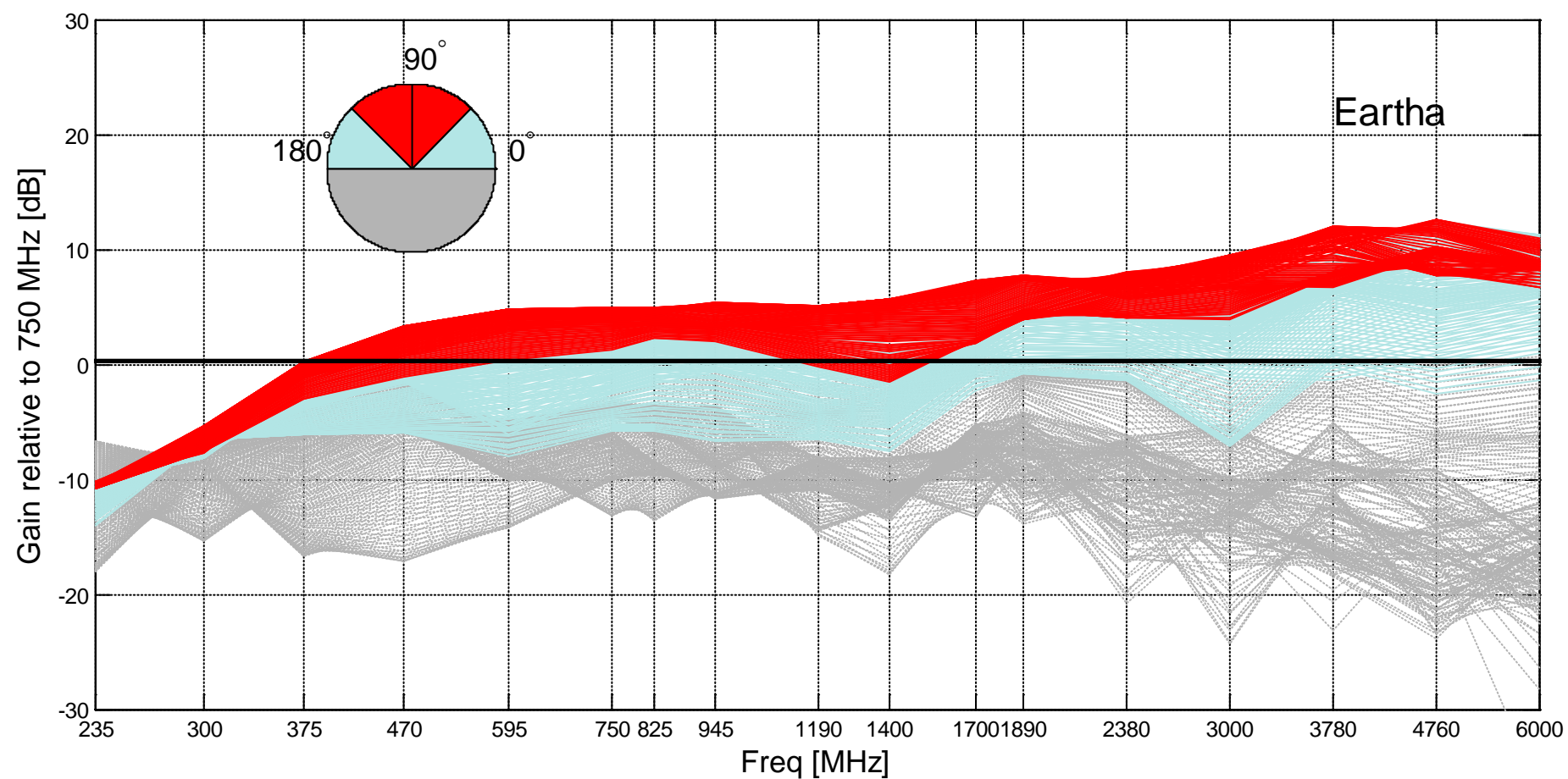
Duke: Gain Relative to Average at 750 MHz



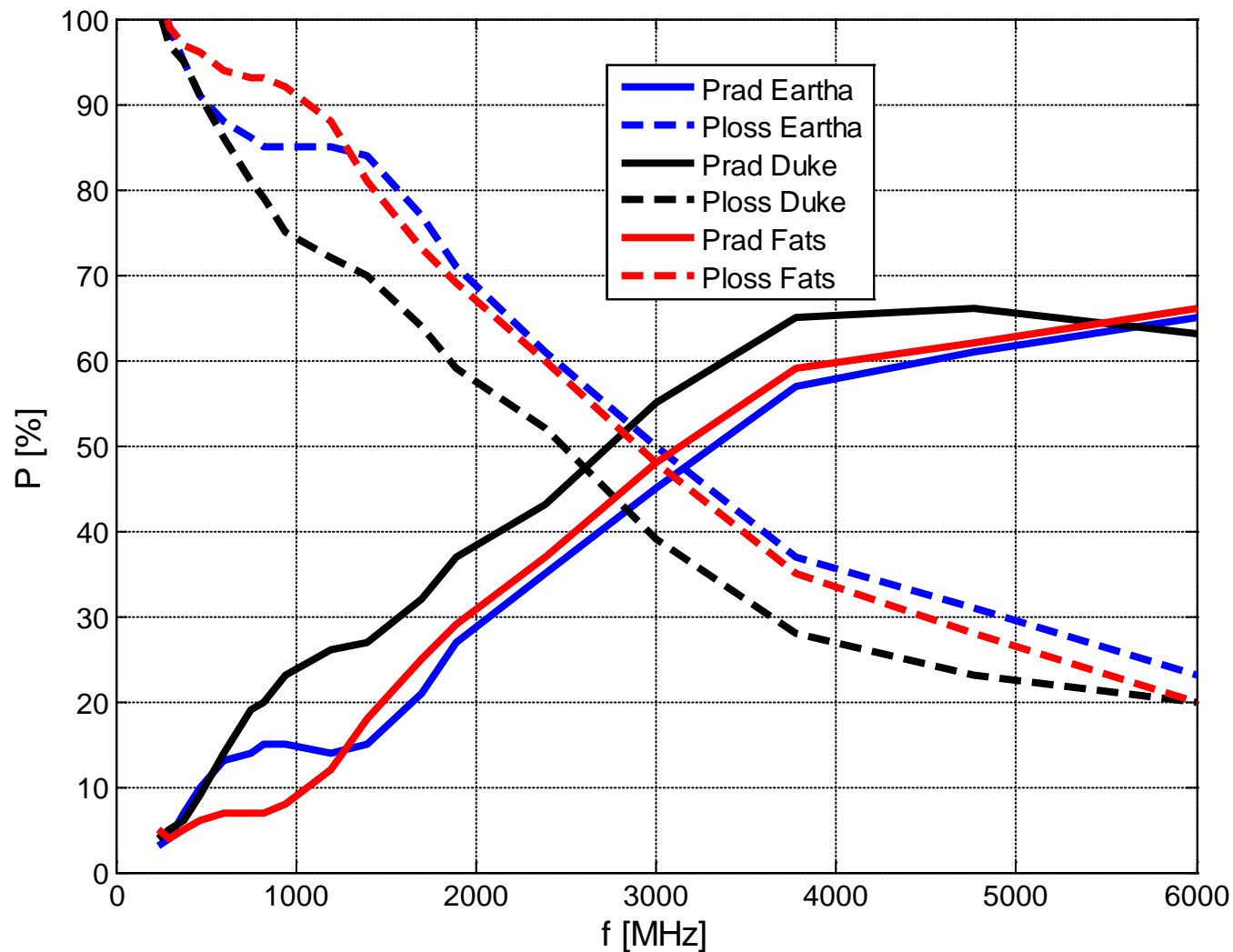
Fats: Gain Relative to Average at 750 MHz



Eartha: Gain Relative to Average at 750 MHz

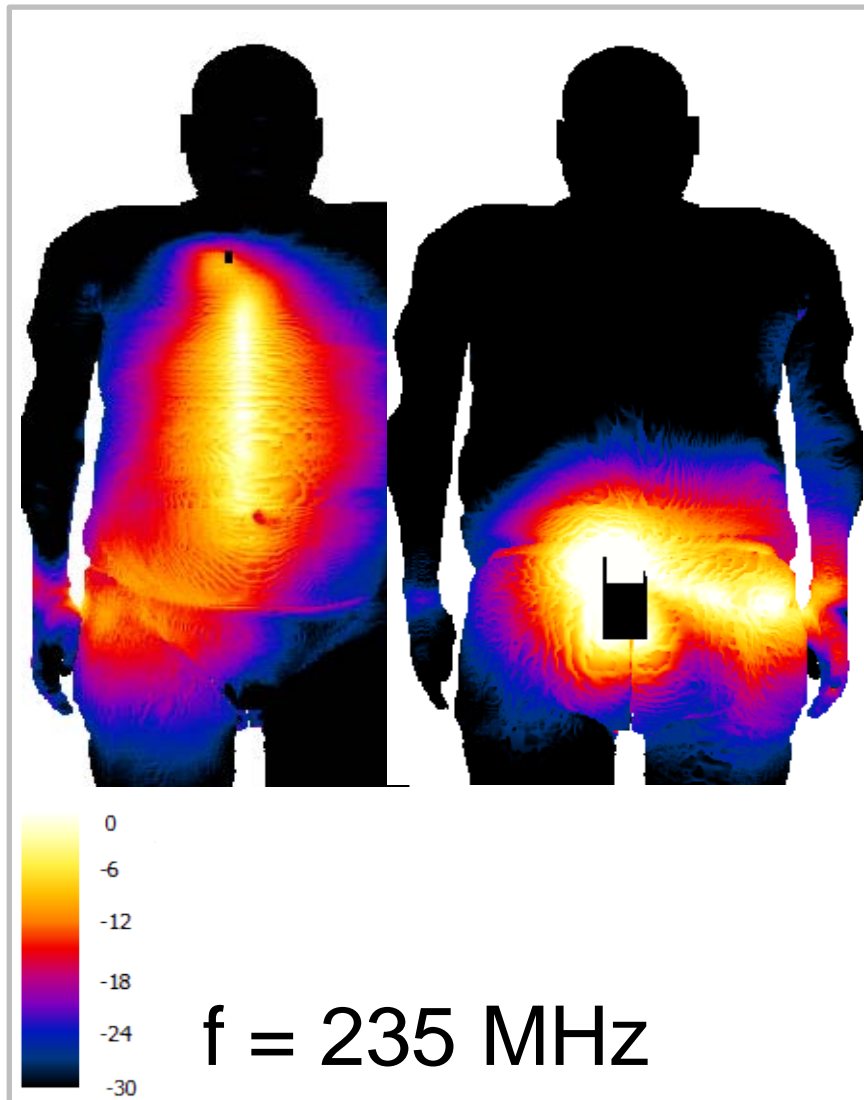


Radiated Power vs. Power Loss

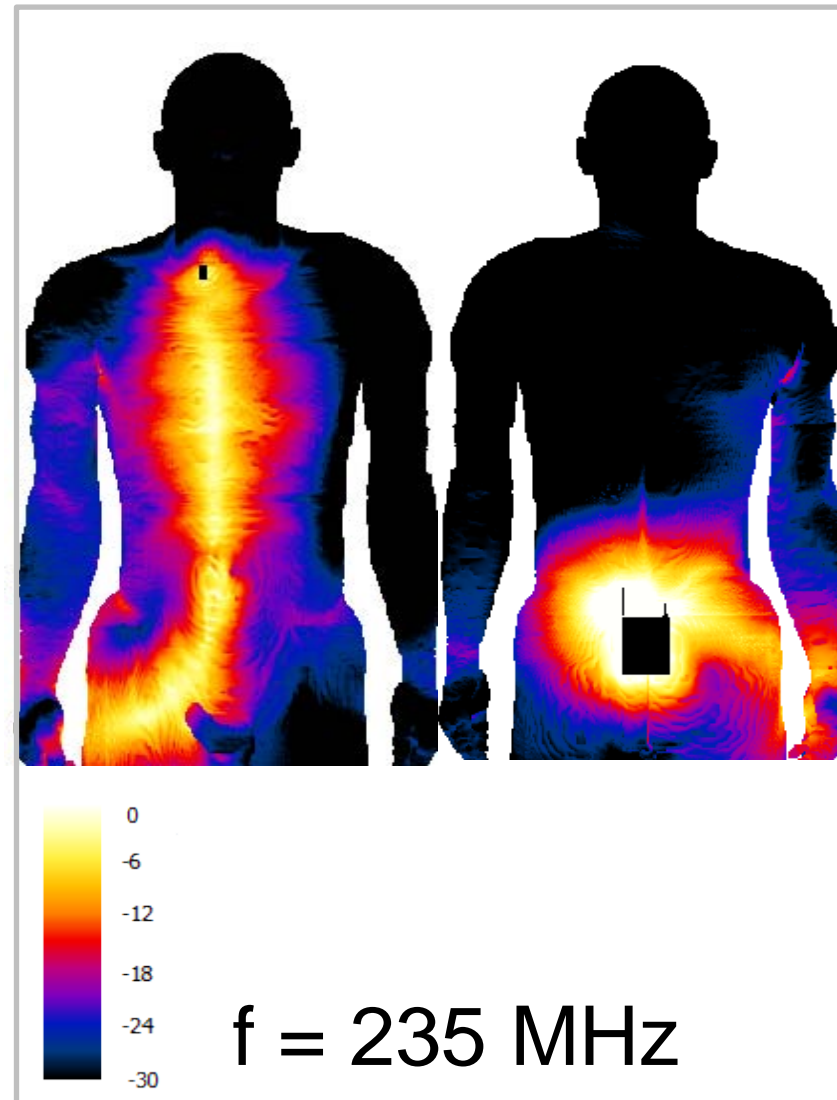


- PLoss: Power absorbed in the lossy tissues of the body
- Prad: Power radiated by the antenna
- $f > 3000$ MHz
 - Eartha, Duke, Fats: Prad $>$ Ploss

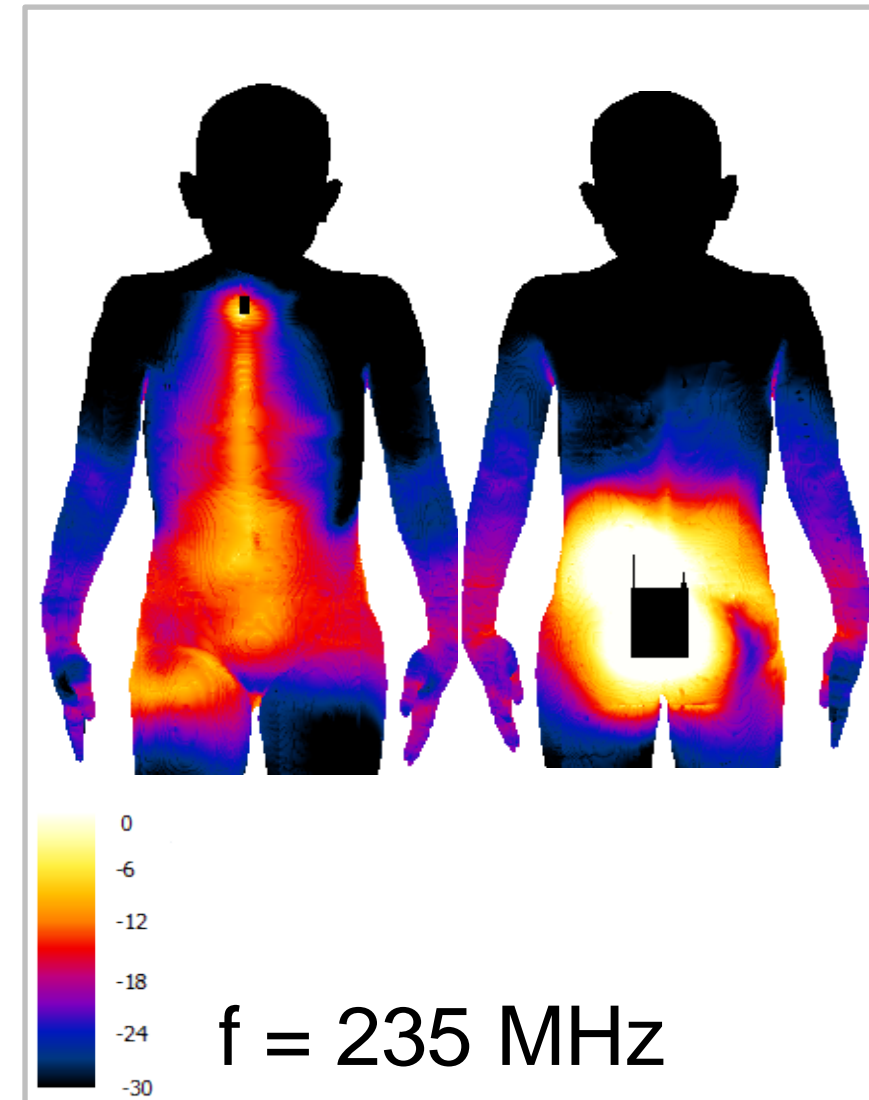
Surface SAR Distribution (W/kg) at 235 MHz



0 dB is 1 W/kg for 1 W Pin

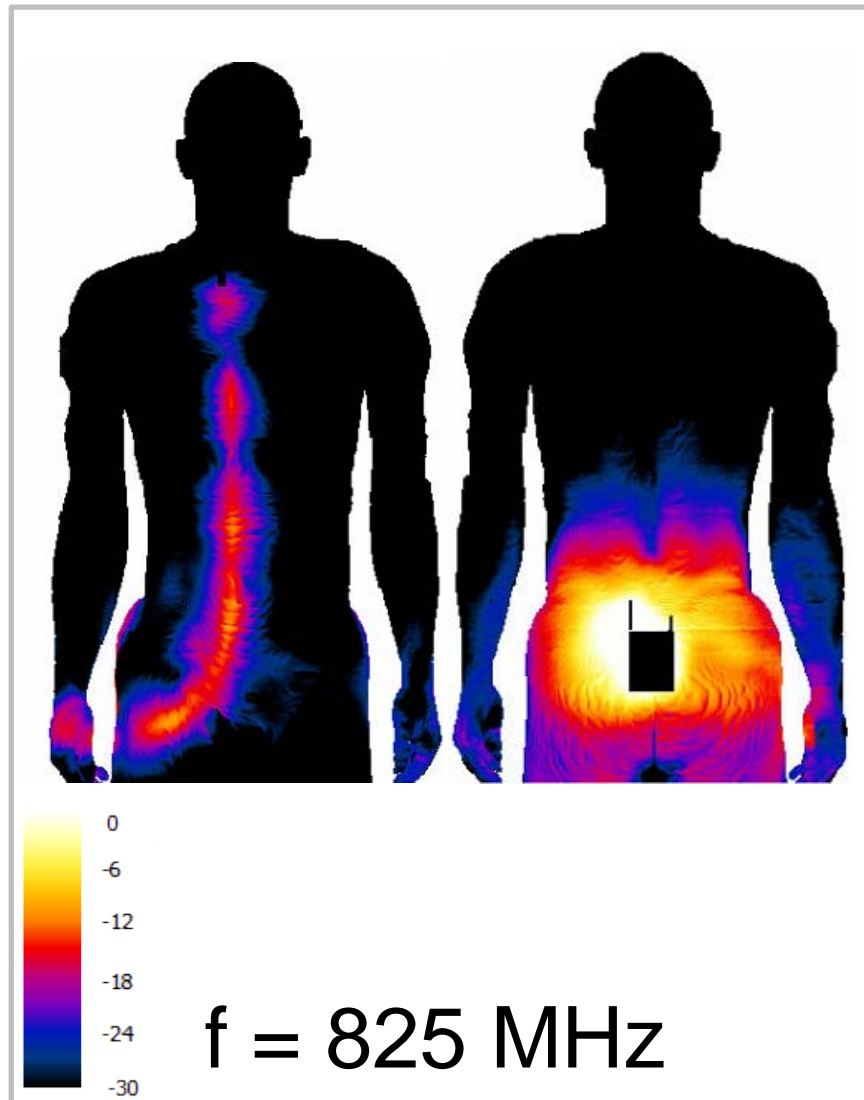


0 dB is 1 W/kg for 1 W Pin

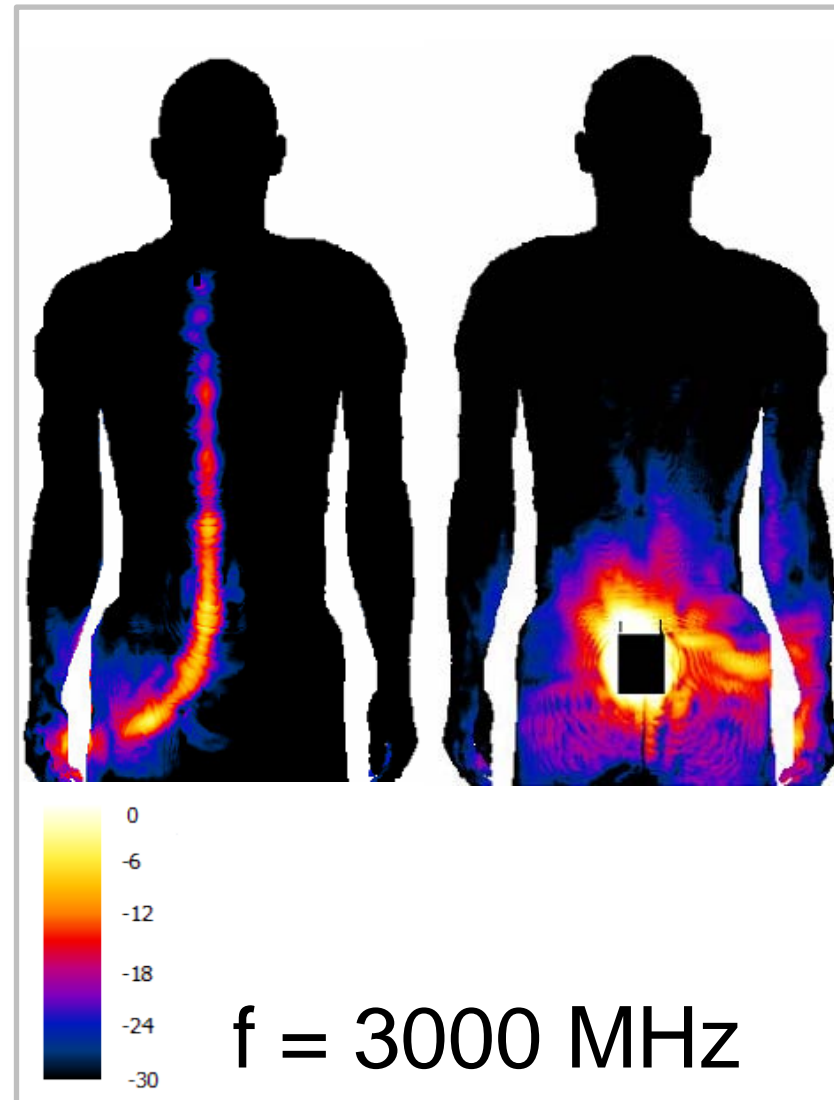


0 dB is 1 W/kg for 1 W Pin

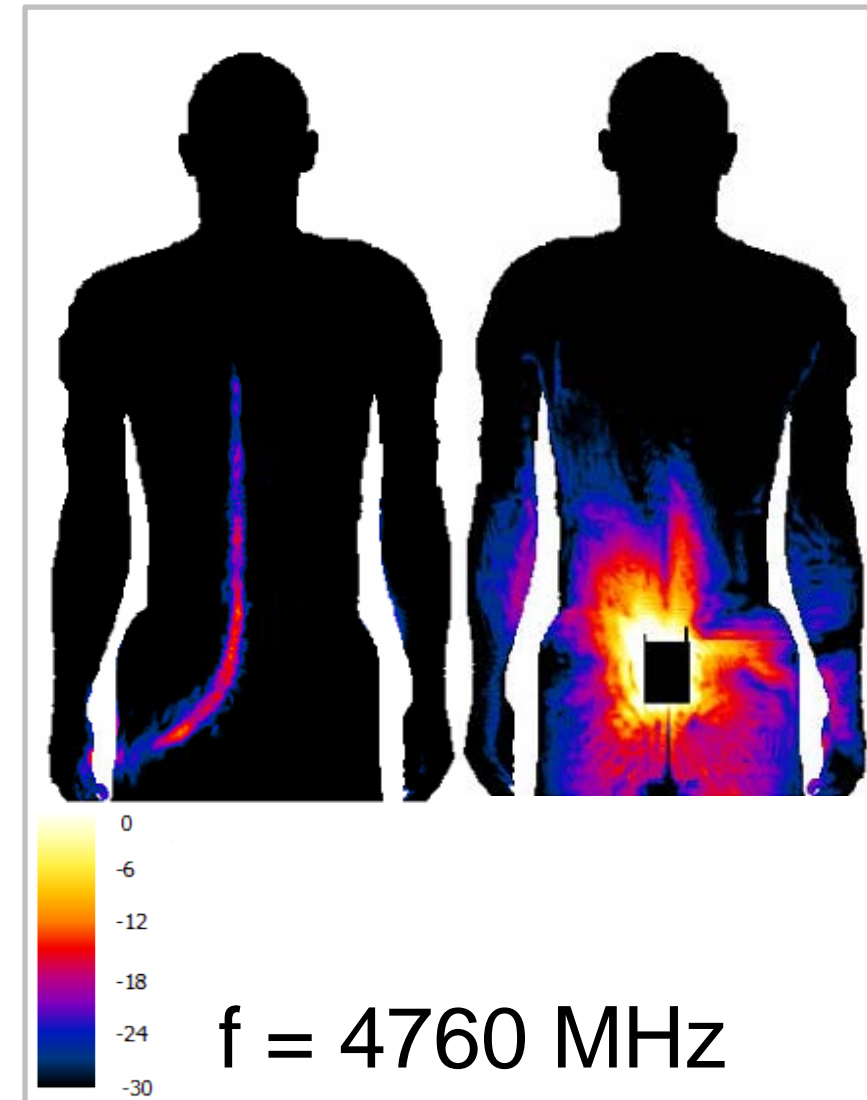
Duke: Surface SAR Distribution (W/kg)



0 dB is 1 W/kg for 1 W Pin

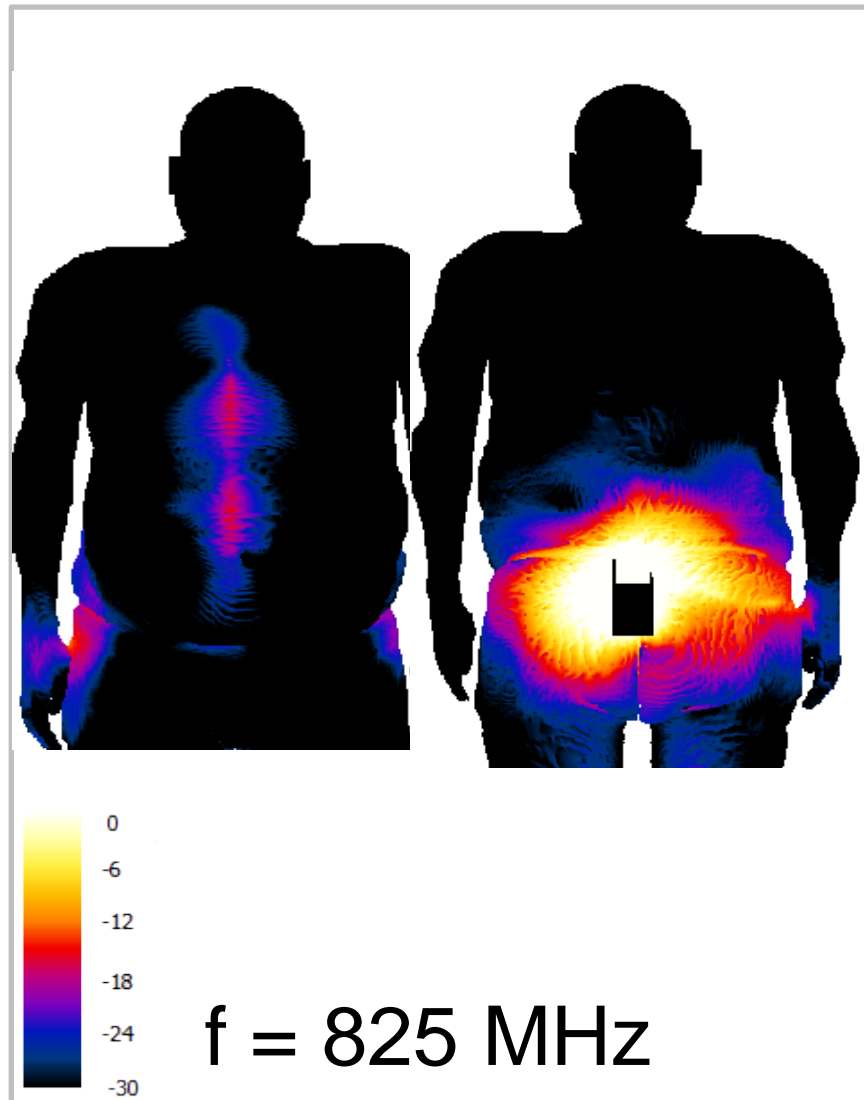


0 dB is 1 W/kg for 1 W Pin

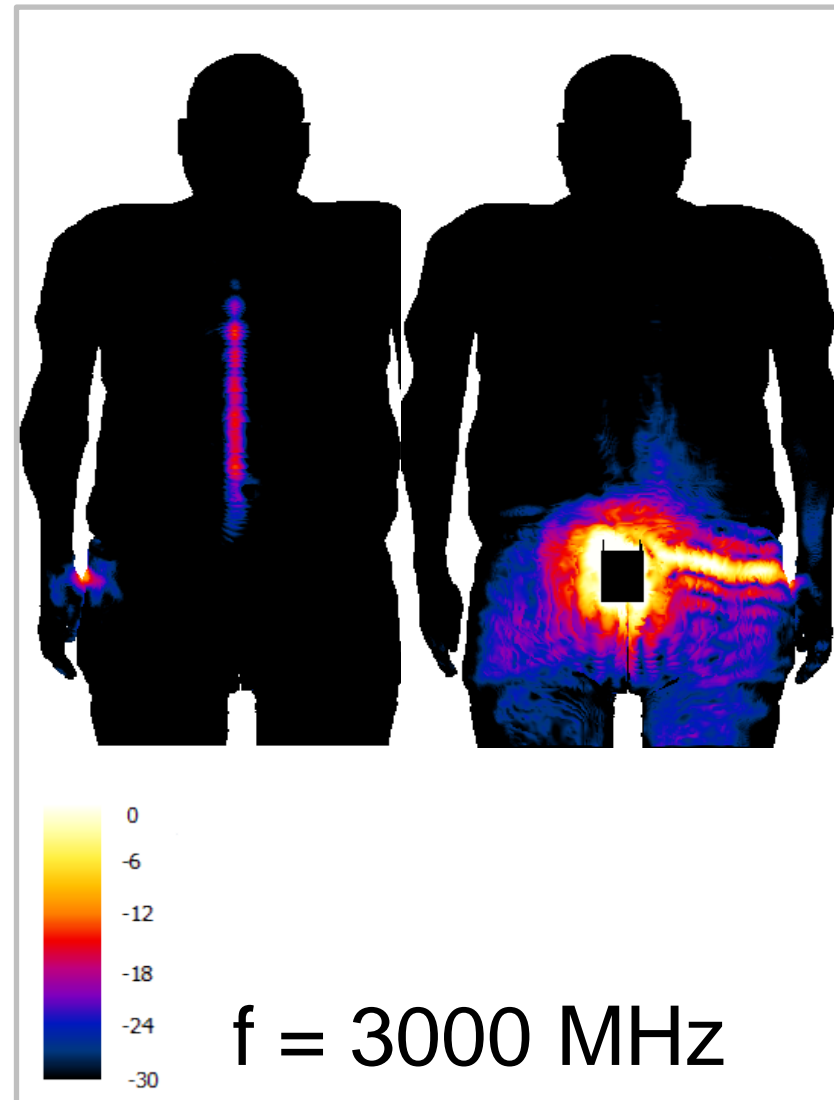


0 dB is 1 W/kg for 1 W Pin

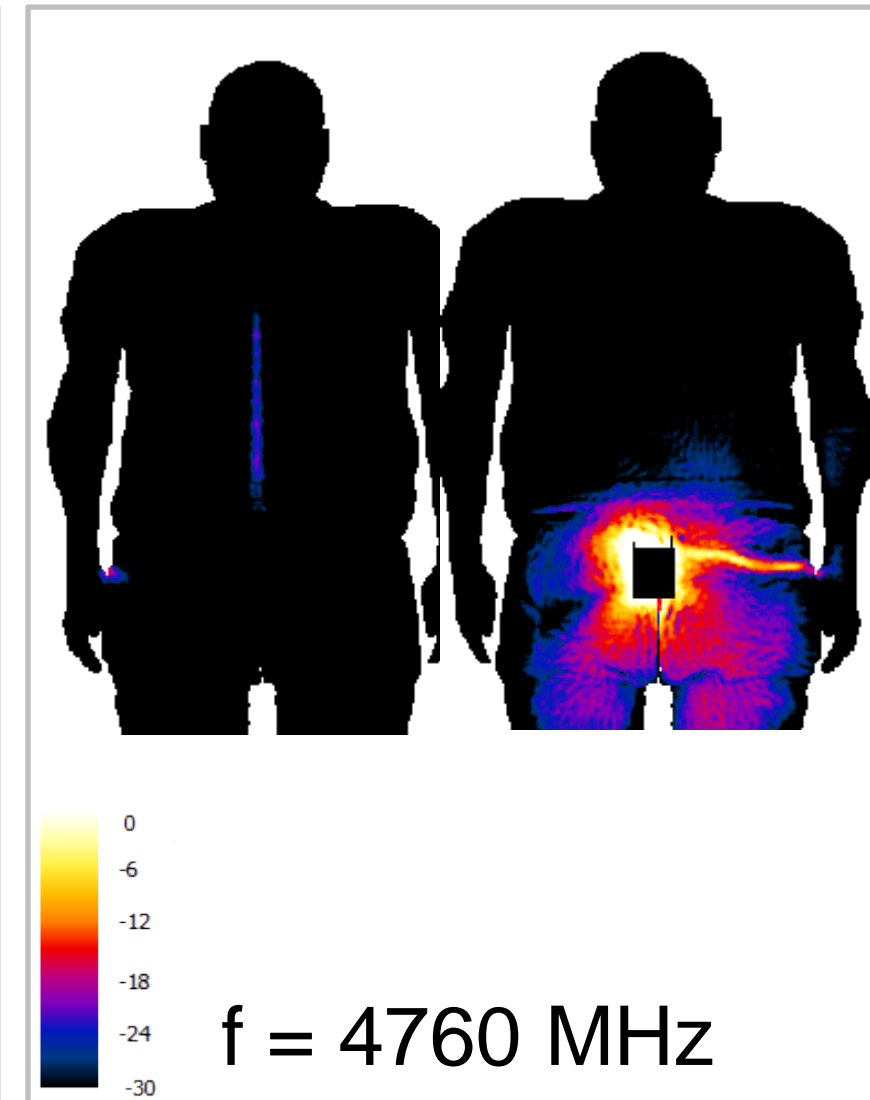
Fats: Surface SAR Distribution (W/kg)



0 dB is 1 W/kg for 1 W Pin

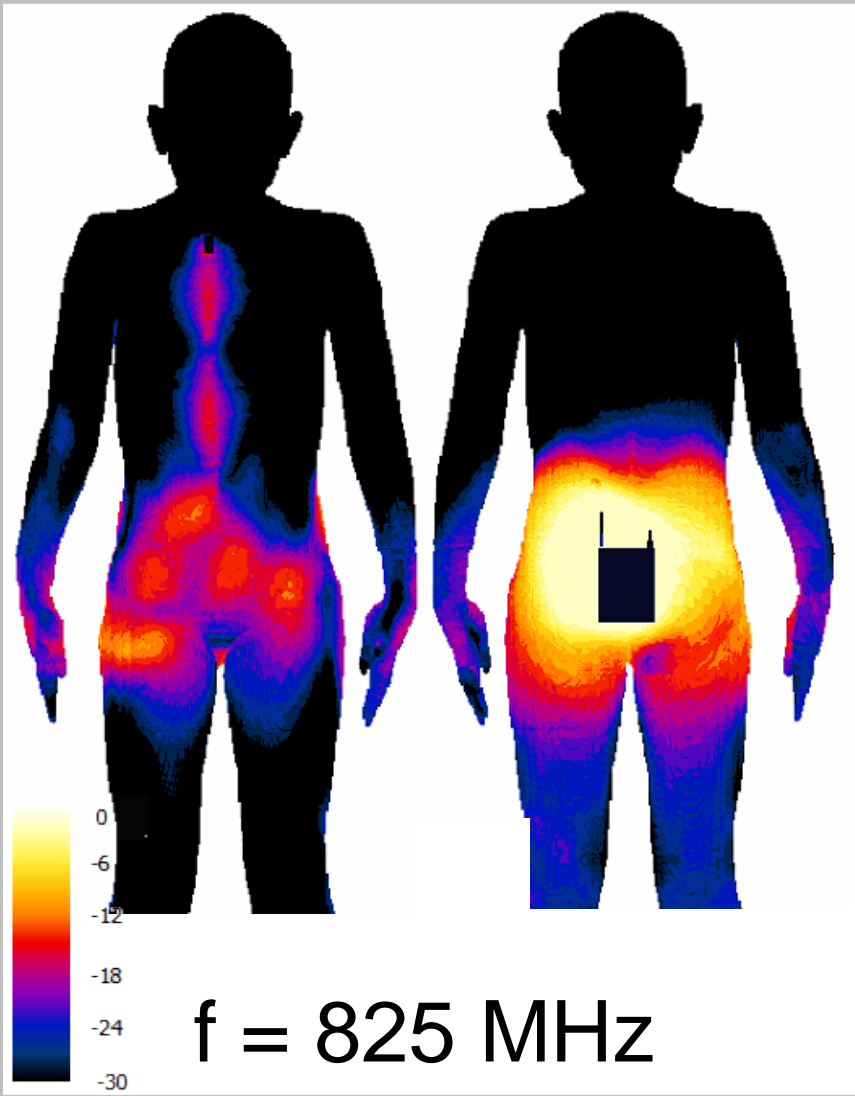


0 dB is 1 W/kg for 1 W Pin

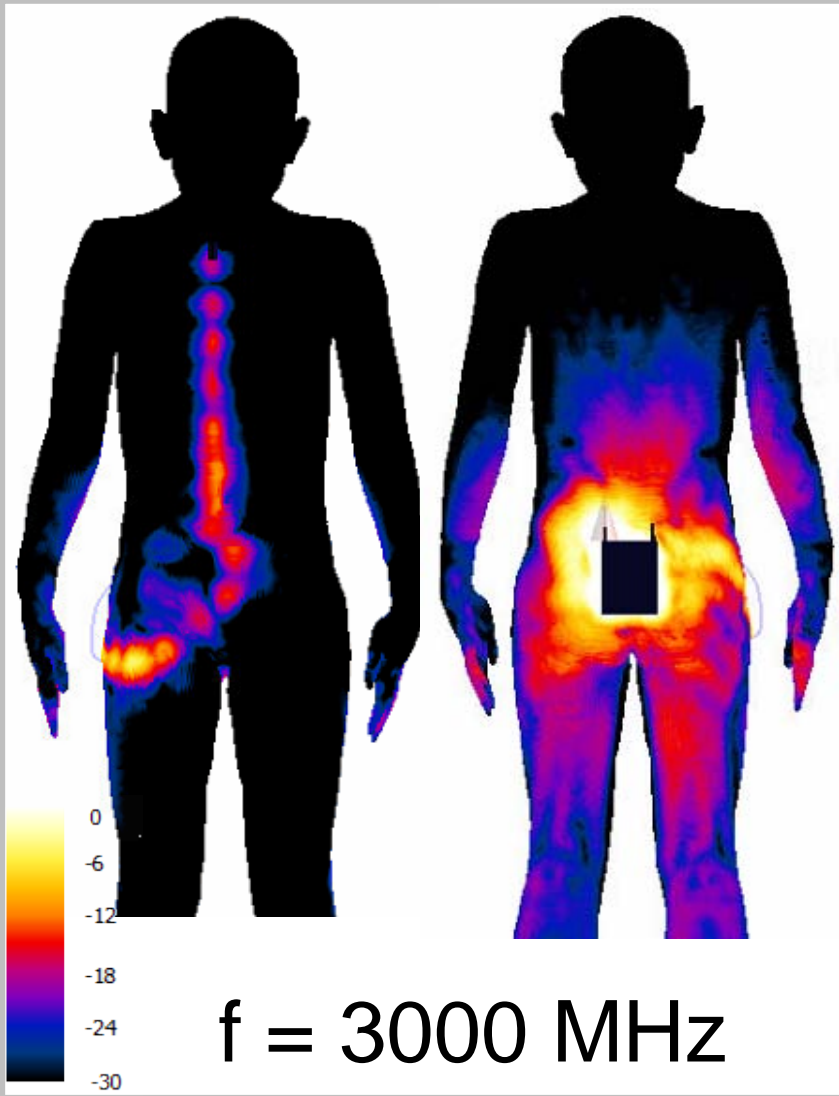


0 dB is 1 W/kg for 1 W Pin

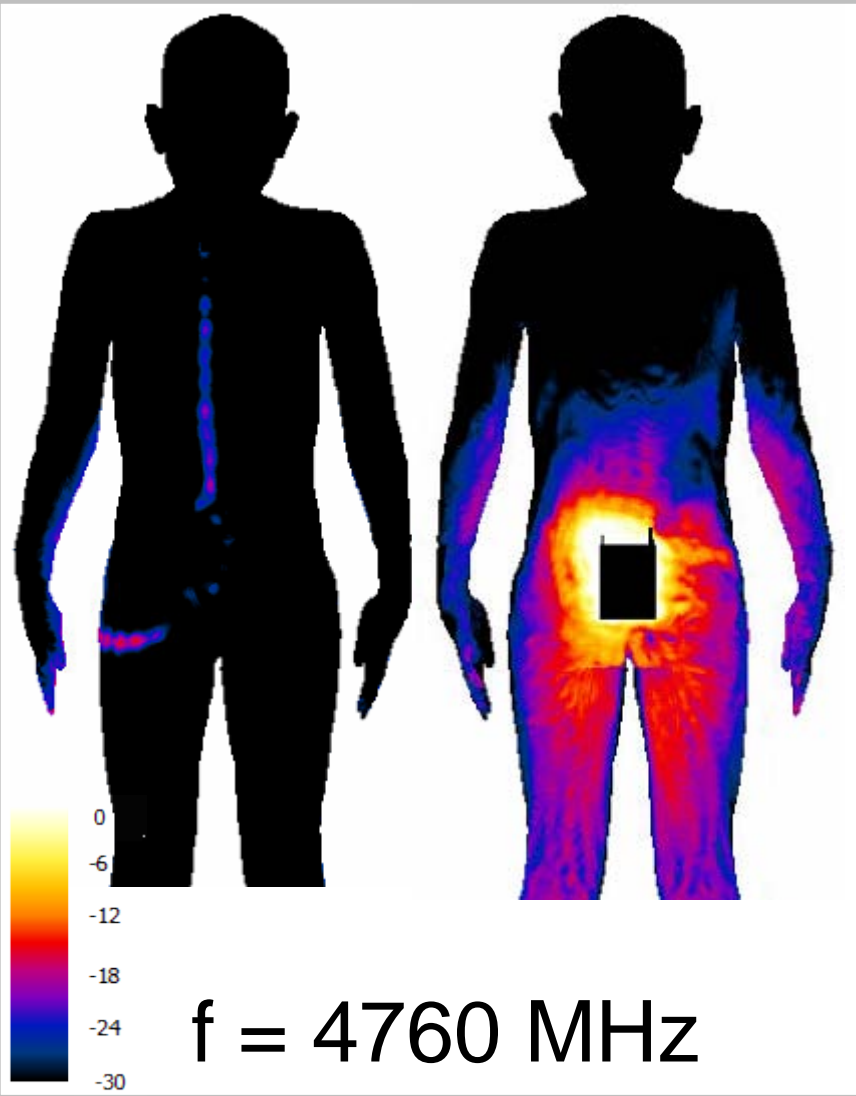
Eartha: Surface SAR Distribution (W/kg)



0 dB is 1 W/kg for 1 W Pin

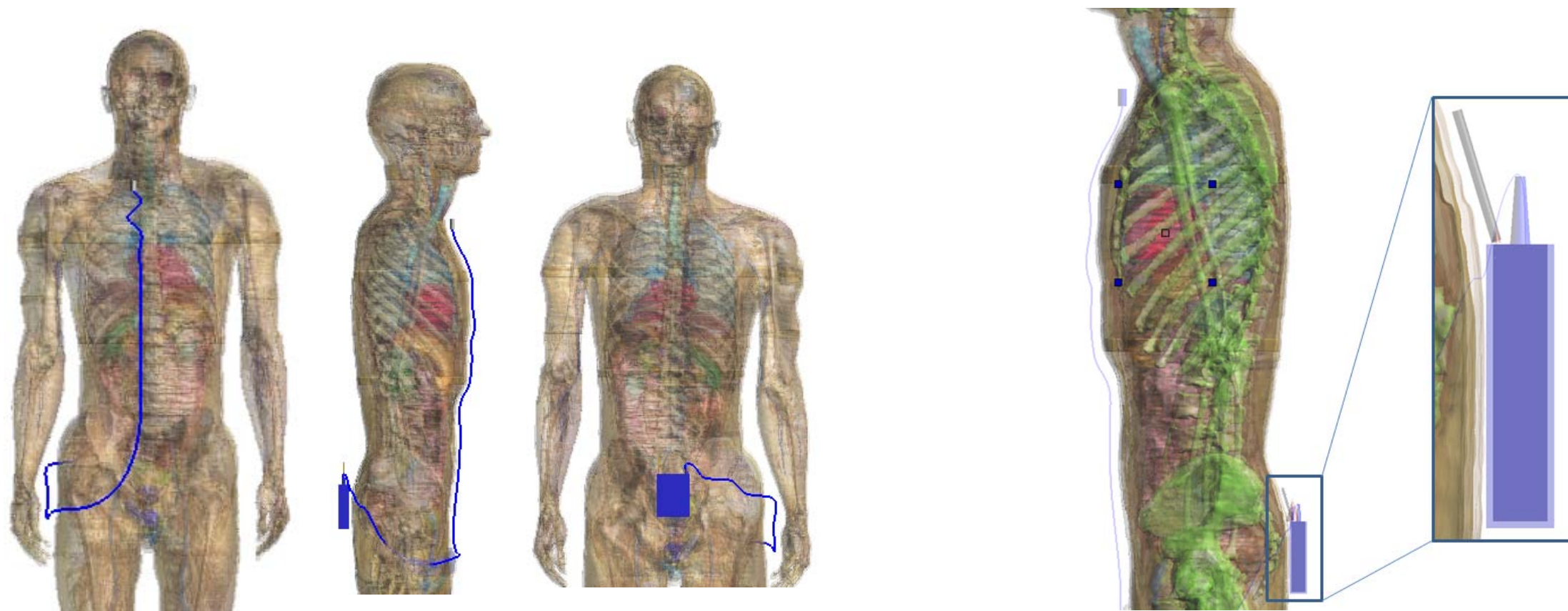


0 dB is 1 W/kg for 1 W Pin



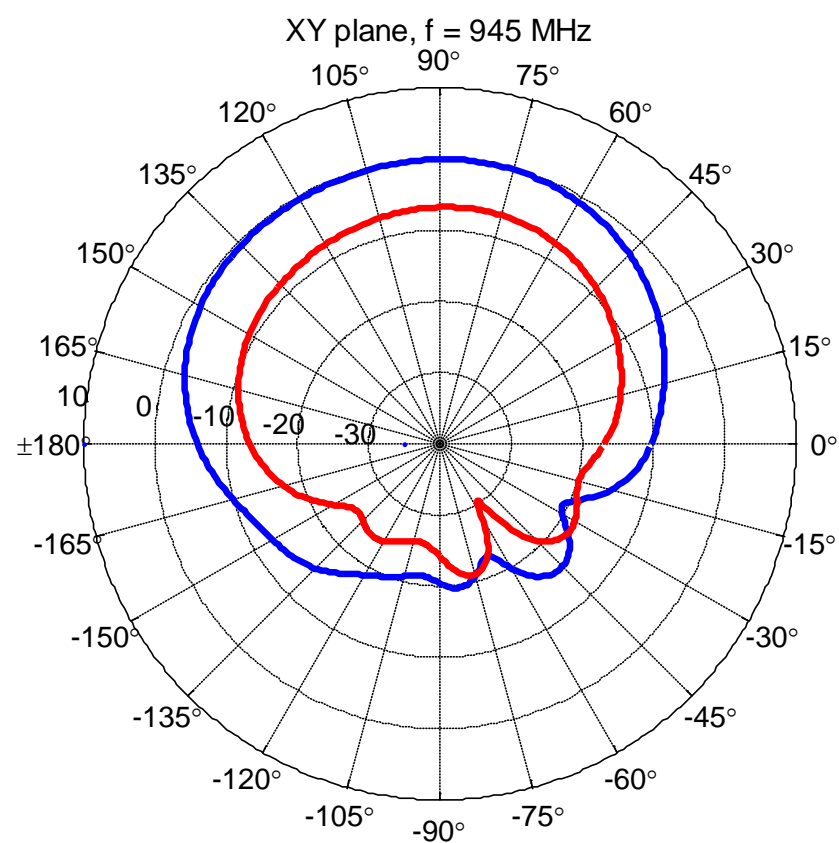
0 dB is 1 W/kg for 1 W Pin

Bodypack: Effect of Antenna – Body Distance

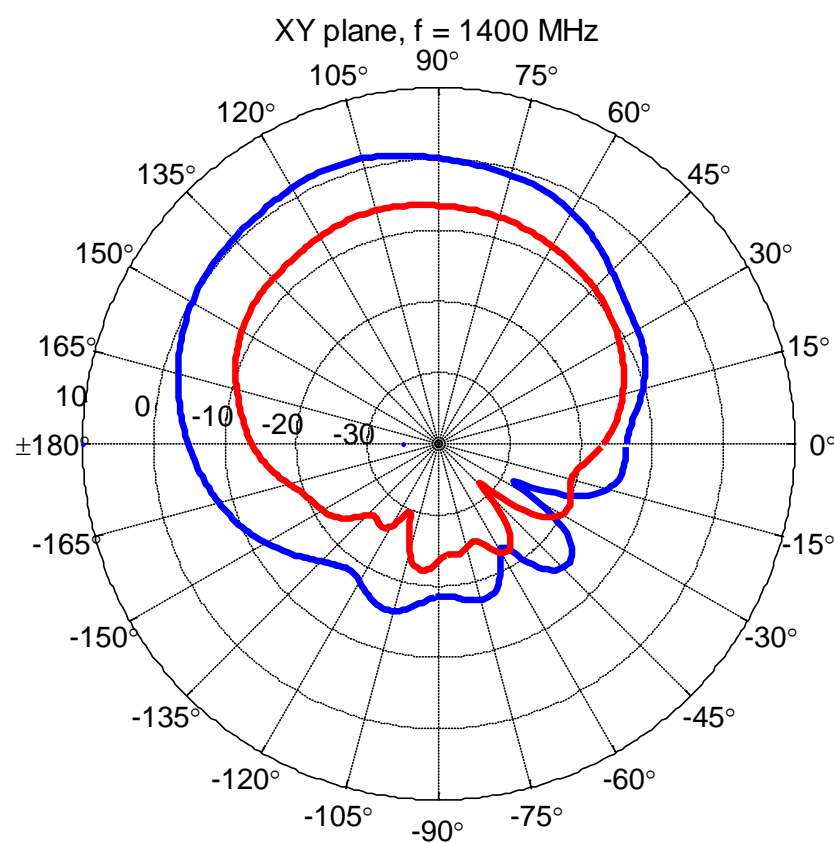


- Wire length ~ 1.2 m
- Antenna closer to body, leaning against body
 - old distance from 15 to 30 mm
 - new distance ~ 4 mm

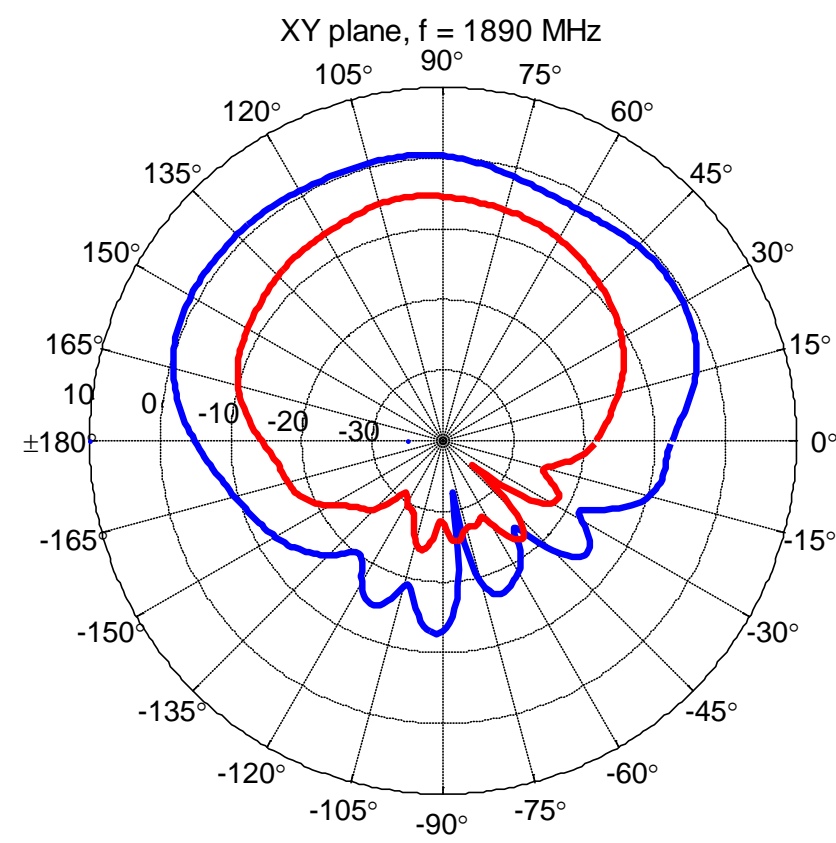
Body Pack: Effect of Antenna – Body Distance



— Duke Original — Duke Tilted



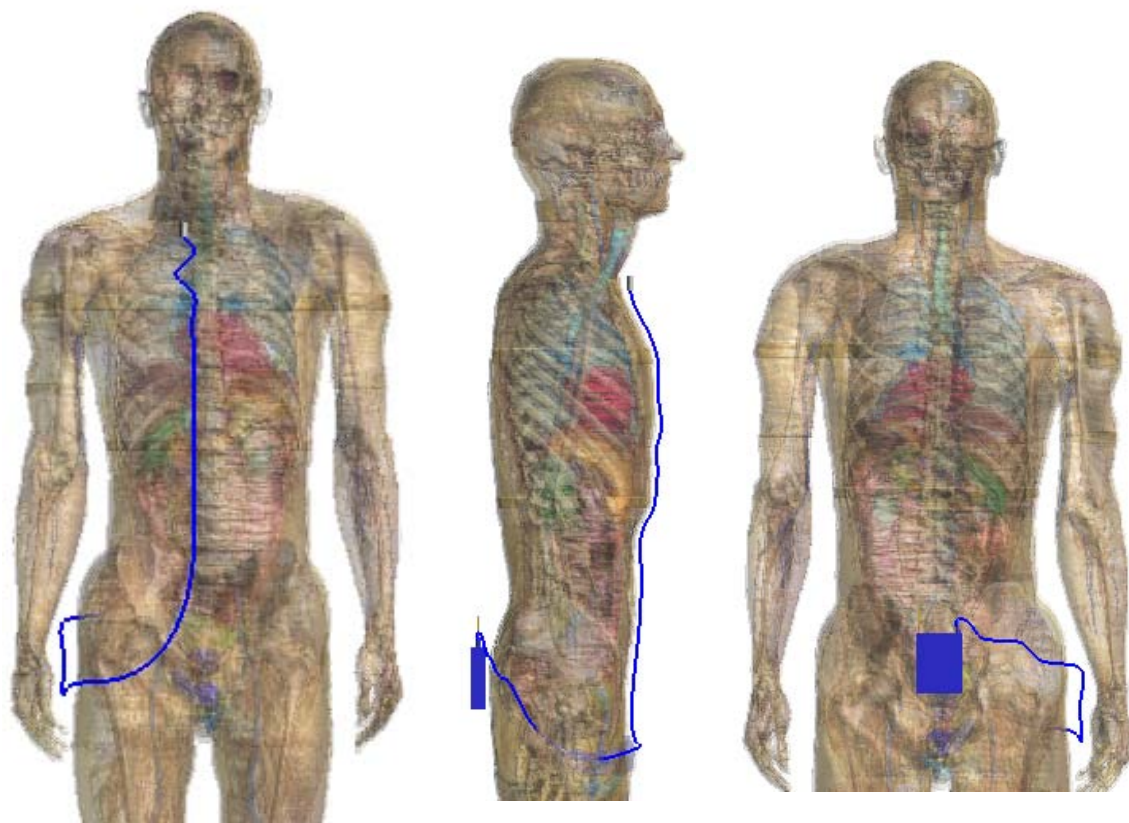
— Duke Original — Duke Tilted



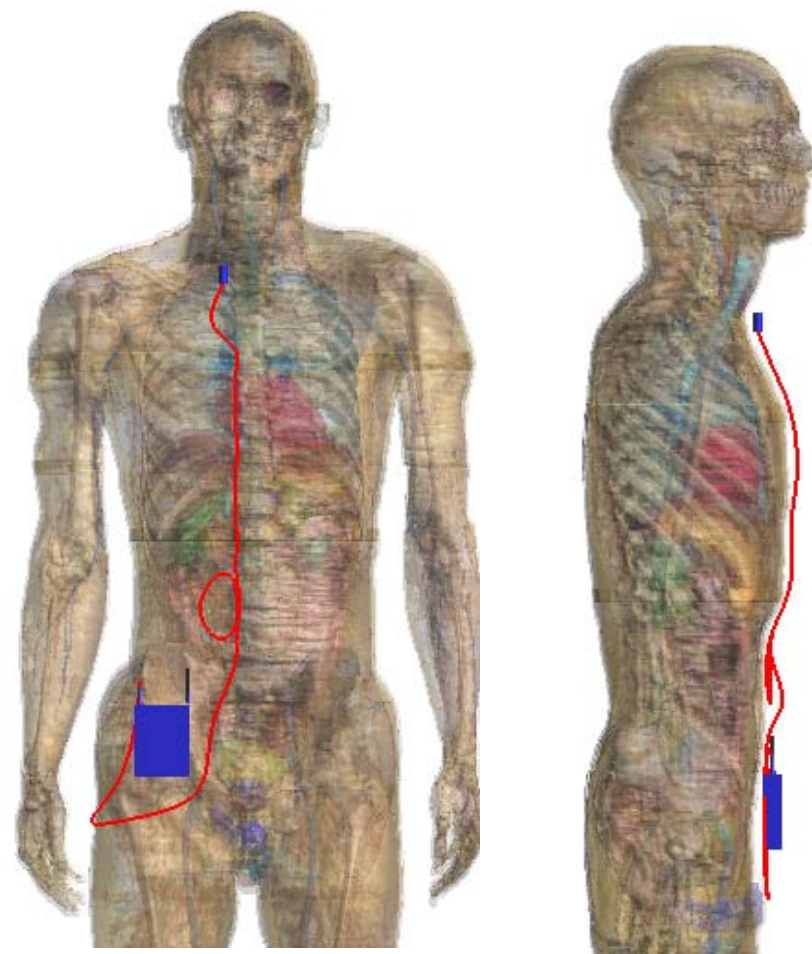
— Duke Original — Duke Tilted

Body Pack: Front Position vs Back Position

Back Position



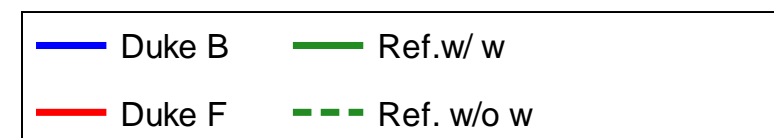
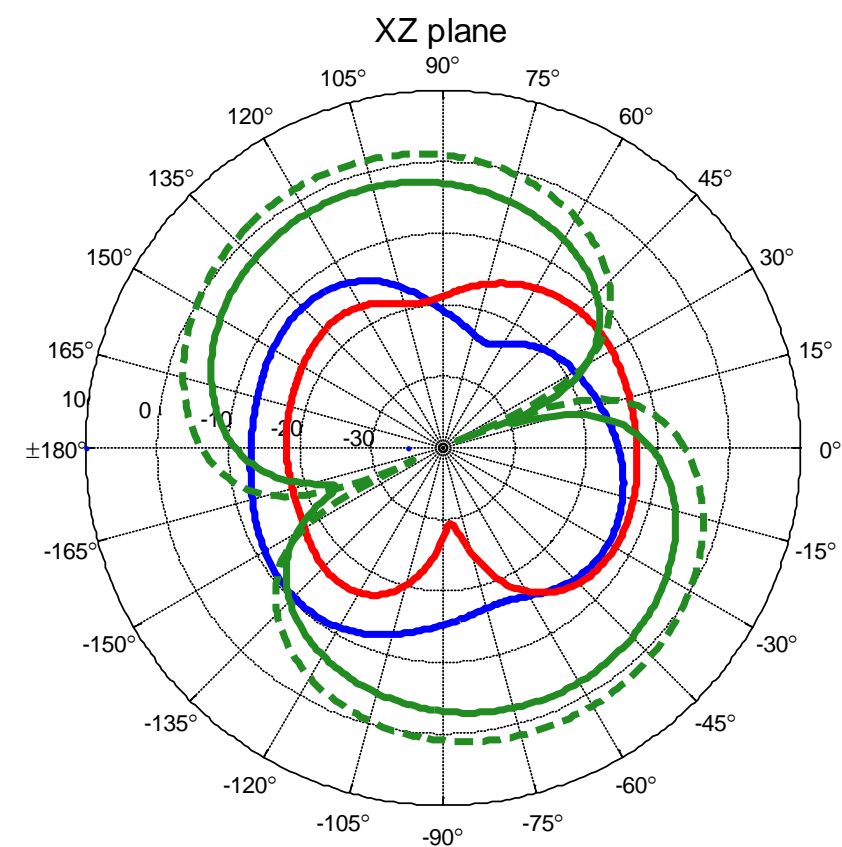
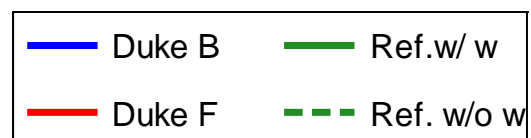
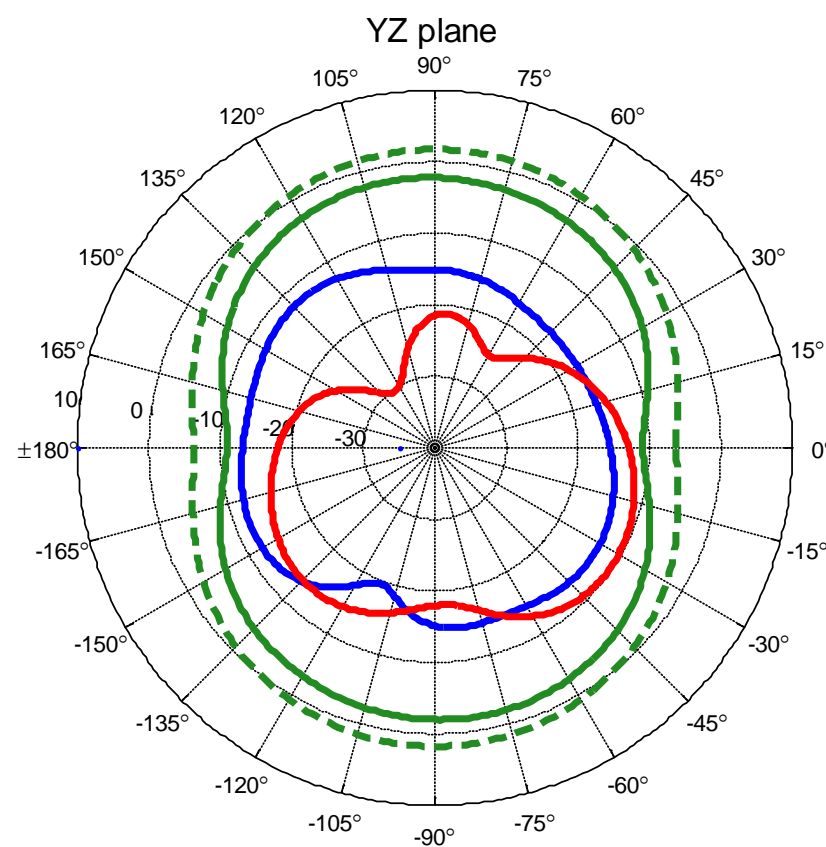
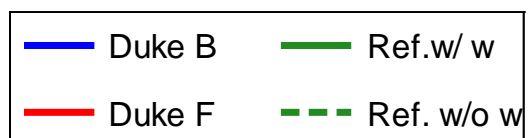
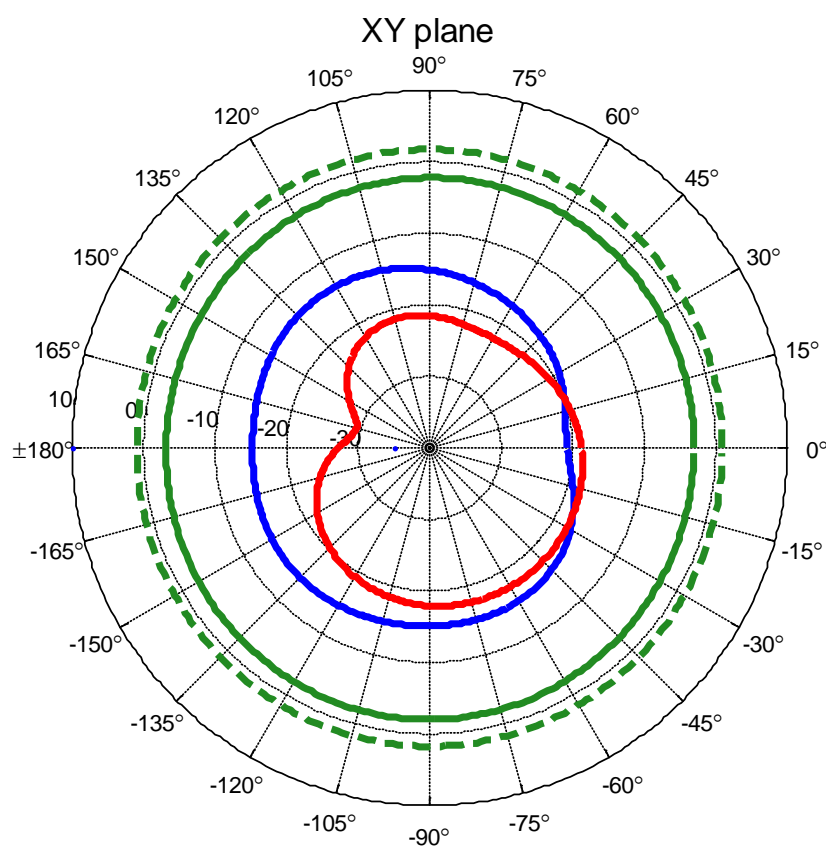
Front Position



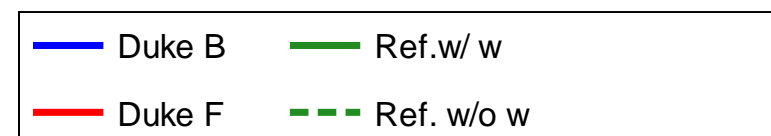
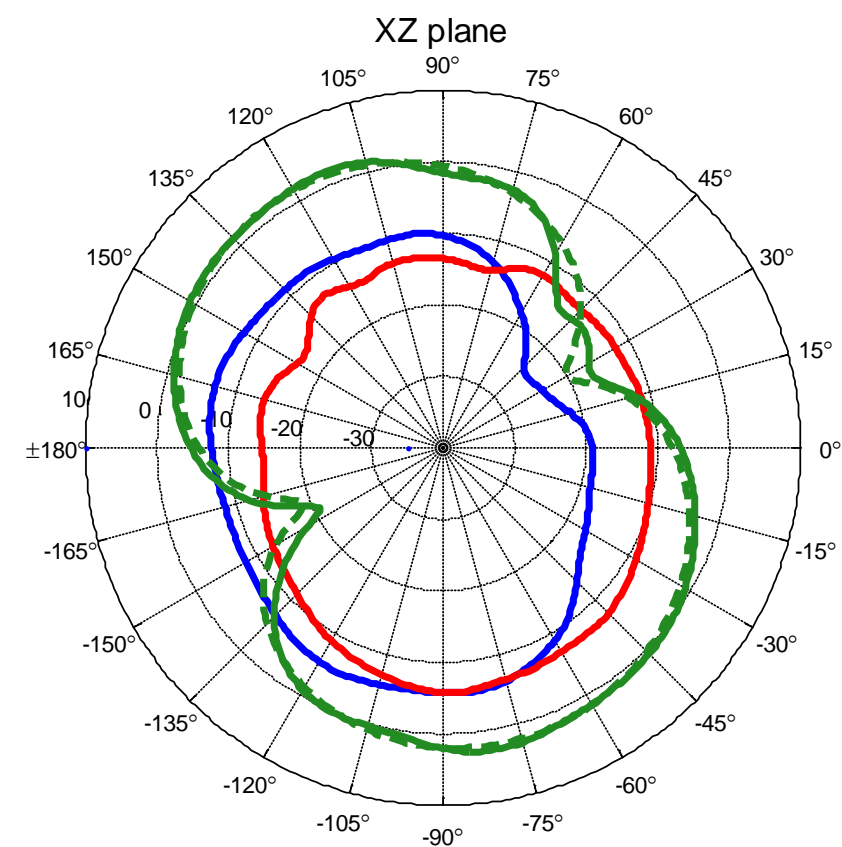
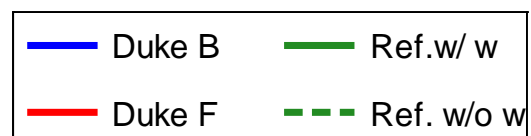
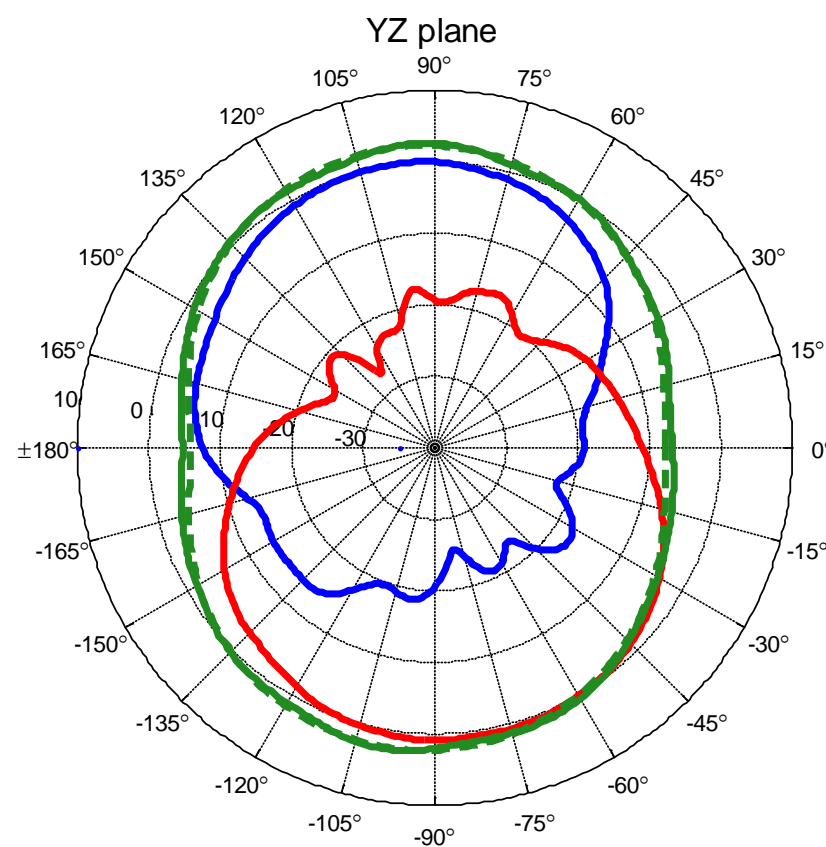
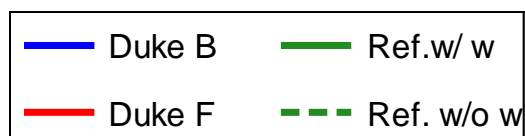
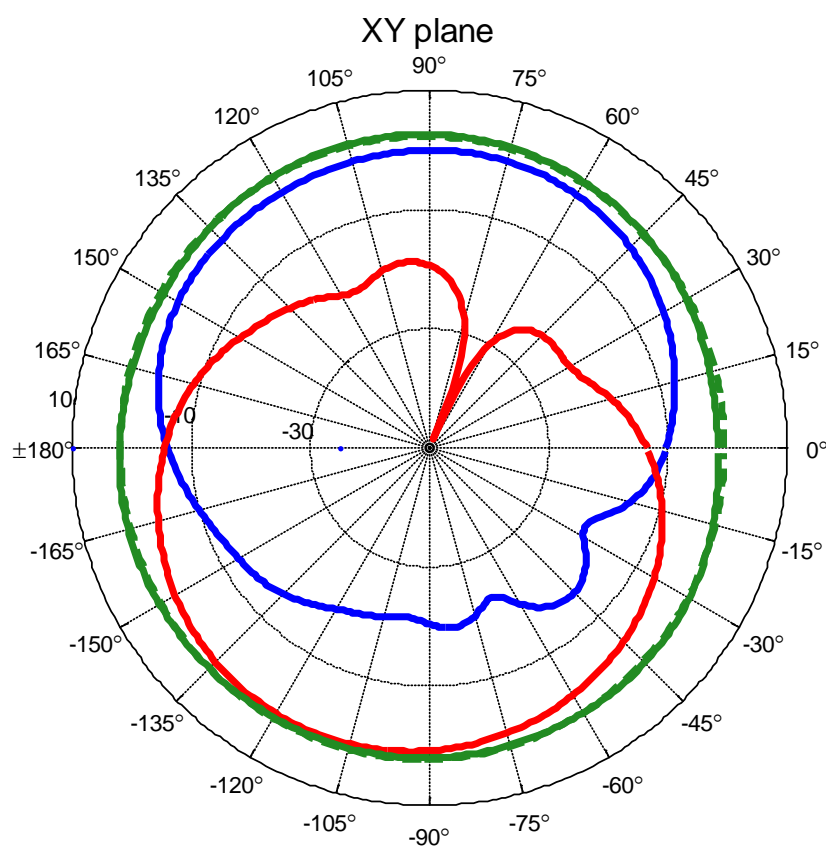
- Wire length ~ 1.2 m
- Tissue properties assigned for each frequency [1]

[1] Hasgall PA, Neufeld E, Gosselin MC, Klingeböck A, Kuster N, "IT'IS Database for thermal and electromagnetic parameters of biological tissues," Version 2.5, August 1st, 2014. www.itis.ethz.ch/database

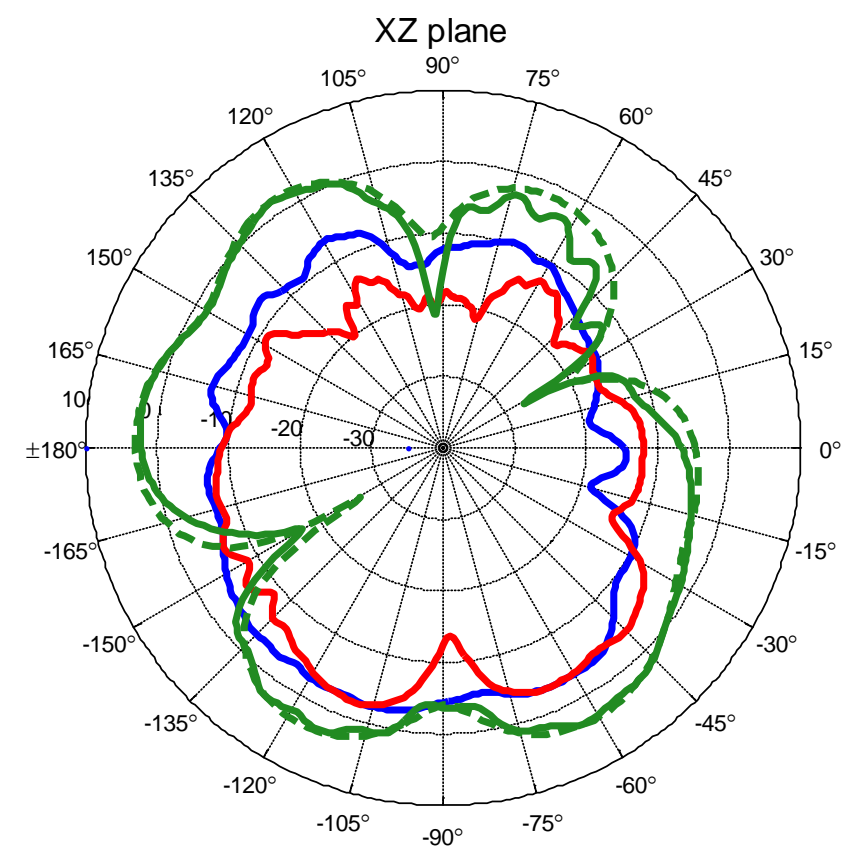
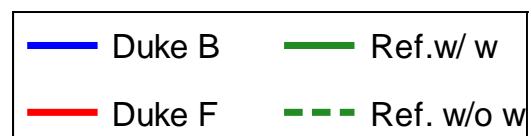
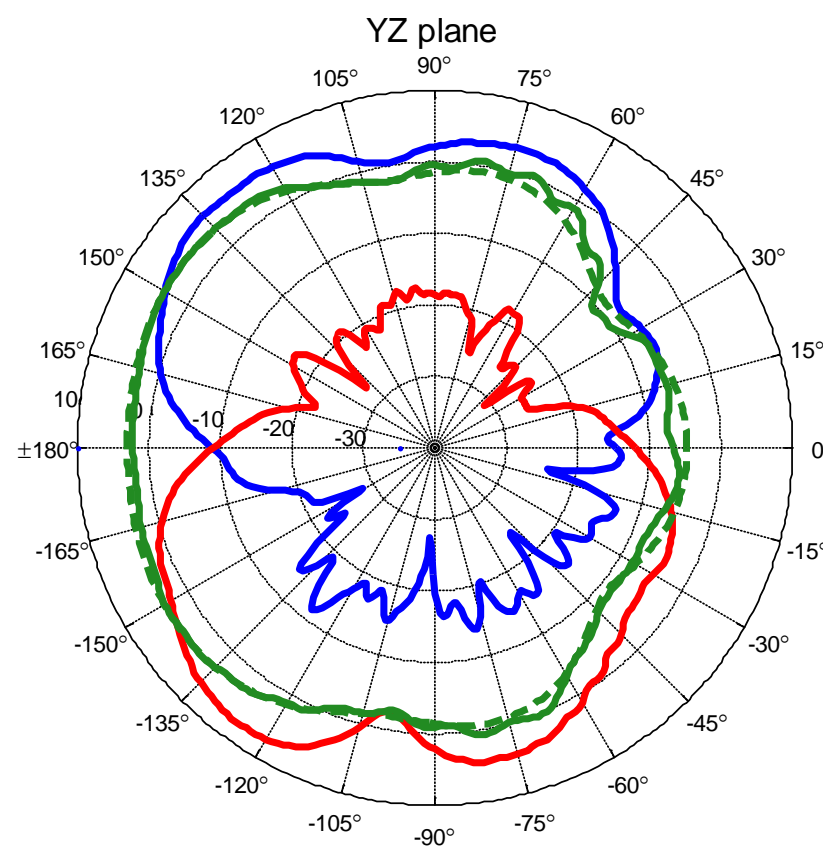
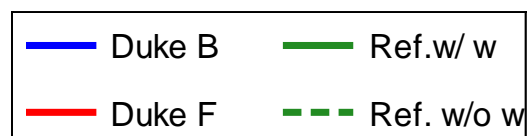
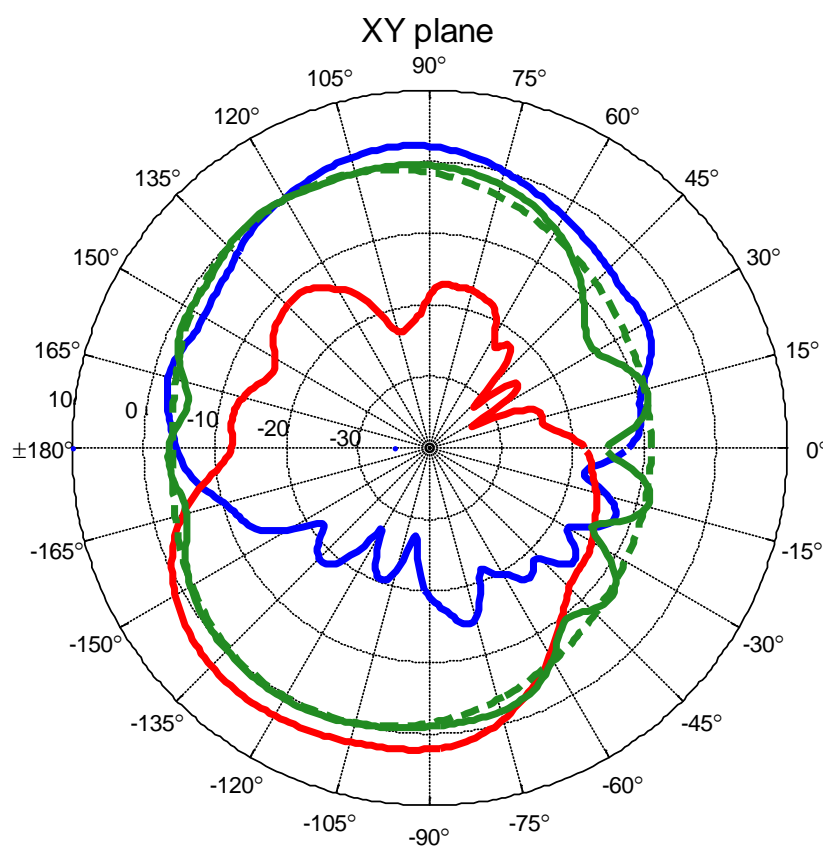
Front vs. Back, Band 1: 235 MHz



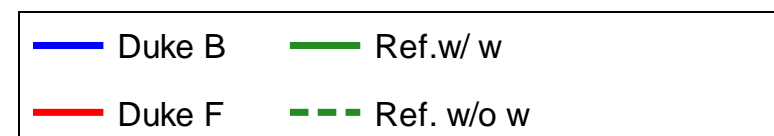
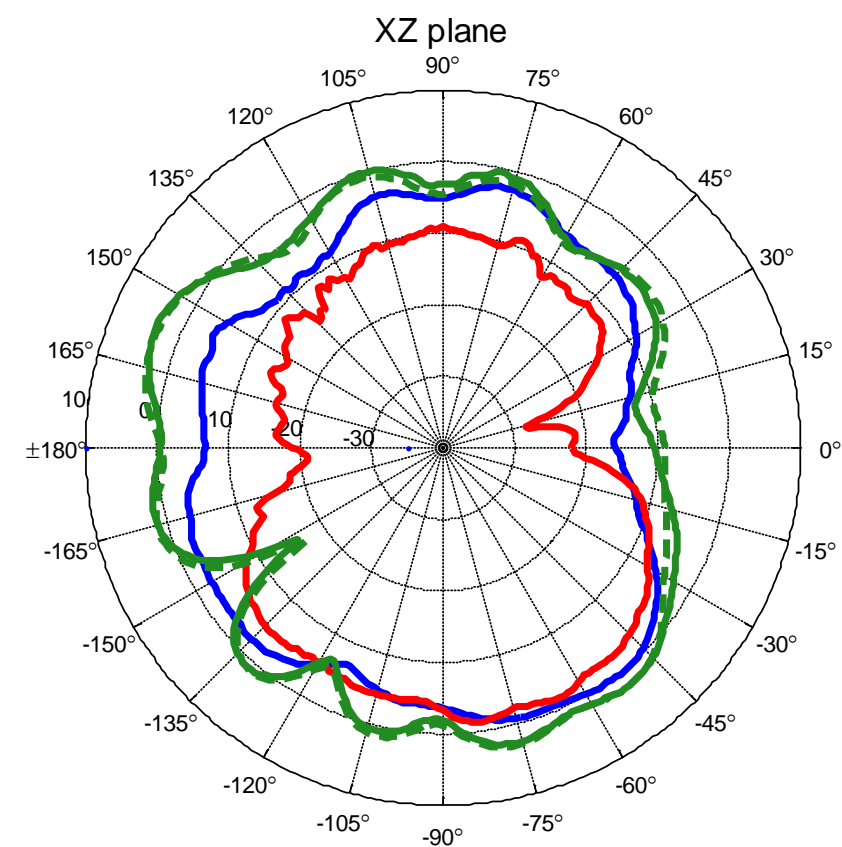
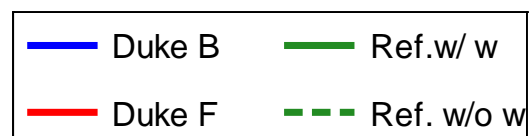
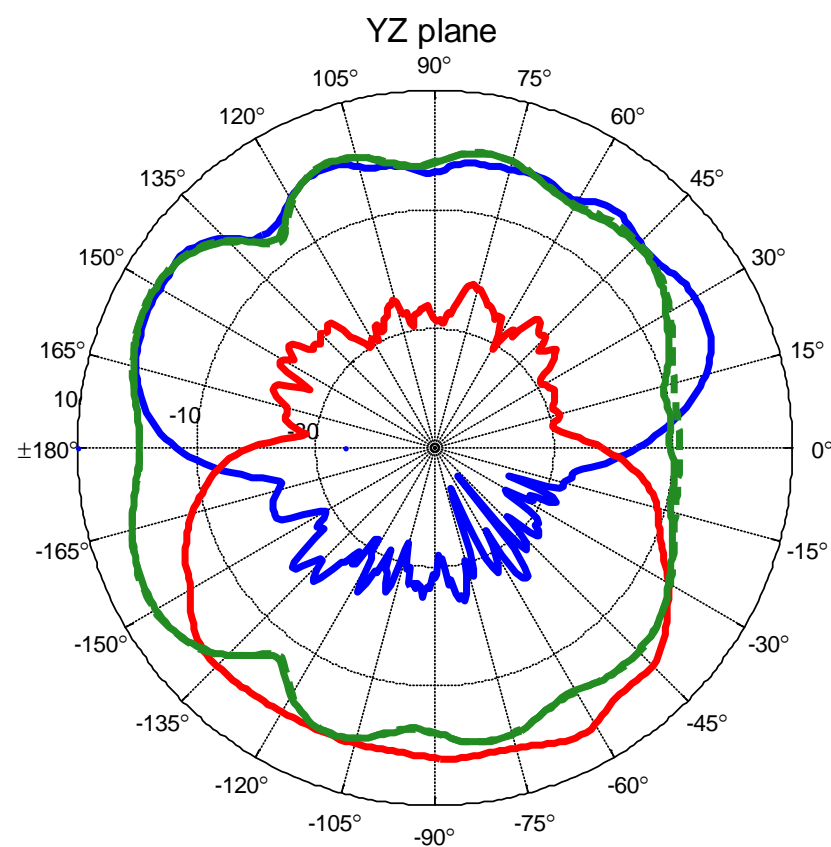
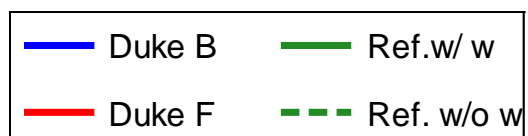
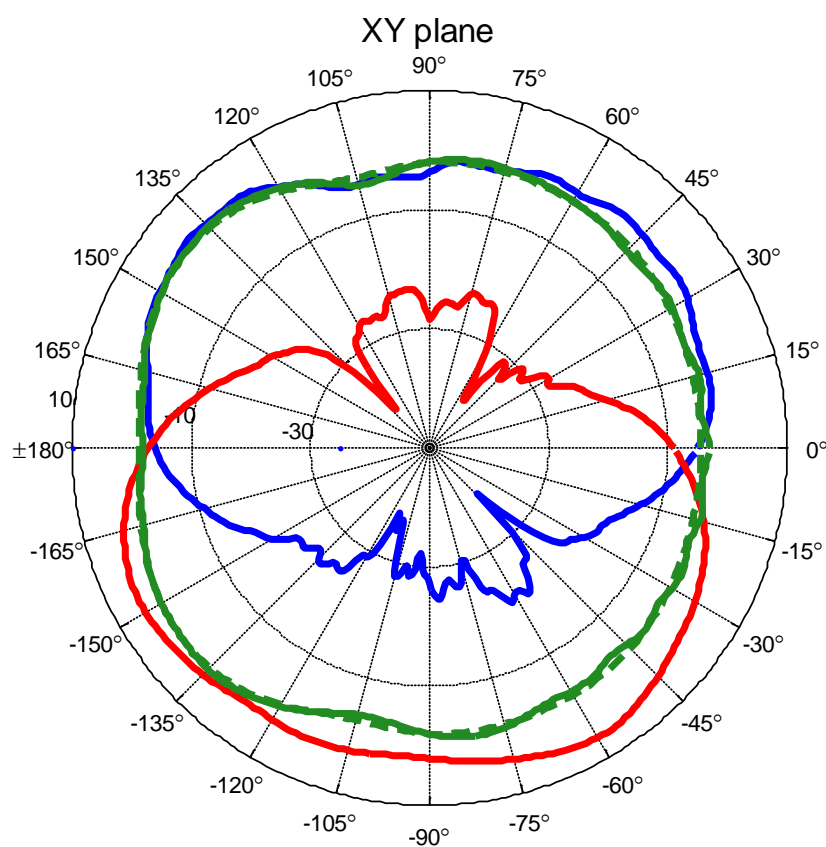
Front vs. Back, Band 2: 945 MHz



Front vs. Back, Band 3: 3000 MHz



Front vs. Back, Band 4: 6000 MHz



Conclusions

- Low frequencies:
 - Body acts like an absorber; radiation in favorable directions worse than FS
 - Body pack (BP) back -15 dB from FS
 - Hand held (HH) -5 dB @ the front, -10 dB @ the back, wrt FS
 - Shadowing less substantial
- Higher frequencies:
 - Deep null(s) in radiation pattern
 - Body acts like a reflector; gain may increase wrt FS in non-shadowed region
 - BP back 10 dB from FS
- Correlation of RP degradation with body size
- Radiated power: 70 % (BP), 90 % (HH) for $f > 3$ GHz

Conclusions

- Big influence of the distance microphone – body
 - BP radiation shows stronger absorption and shadowing than HH
 - BP tilted -10 dB wrt original distance
- Gain relative to 750 MHz
 - Hand Held: shadowing increases when wavelength becomes commensurate with head size
 - Body Pack: gain in the most favorable directions increases at high freq. However shadowing becomes more pronounced
- Shadowing is increasingly higher than reference for all scenarios as frequency grows
- Non-shadowed radiation may increase at higher frequencies due to reflections from the body (lower absorption at high frequencies)