



## Consider the Design and Analysis of Antennas for a modern Smartwatch

By  
Tracey Vincent



joins

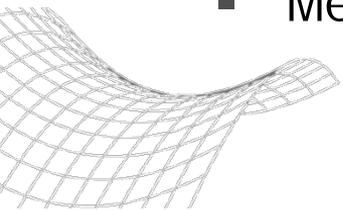


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# Smart watch design

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1. Overview of a modern smart watch.
2. Challenges posed for the antenna design engineer.
3. An example design.
4. Discuss some approaches in relation to:
  - Electromagnetic design and analysis
  - Mechanical design and co-design
  - Meeting regulatory standards

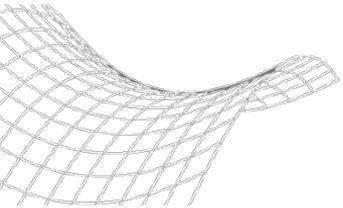


Examples developed in collaboration between CST, Magus and SIMULIA

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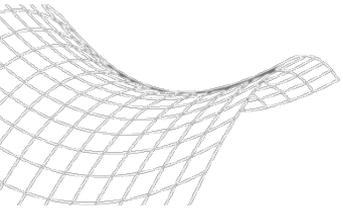
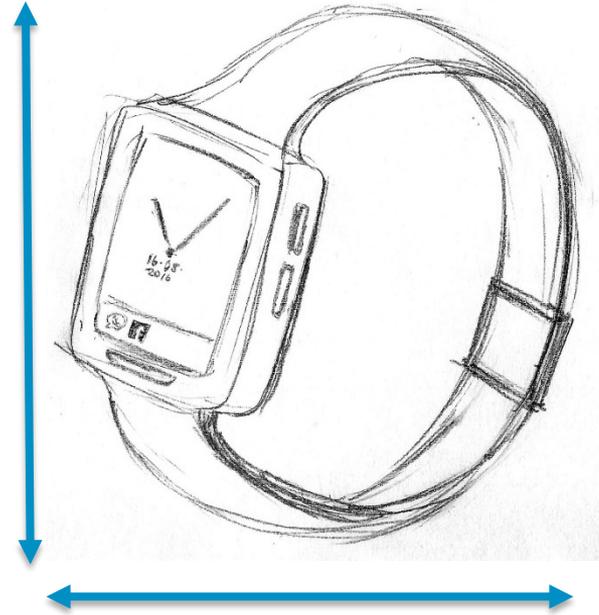
# A modern smart watch

- Casing and strap



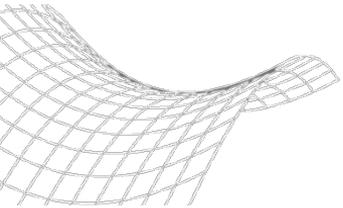
# A modern smart watch

- Casing and strap
  - Must be practical size



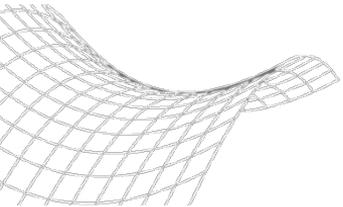
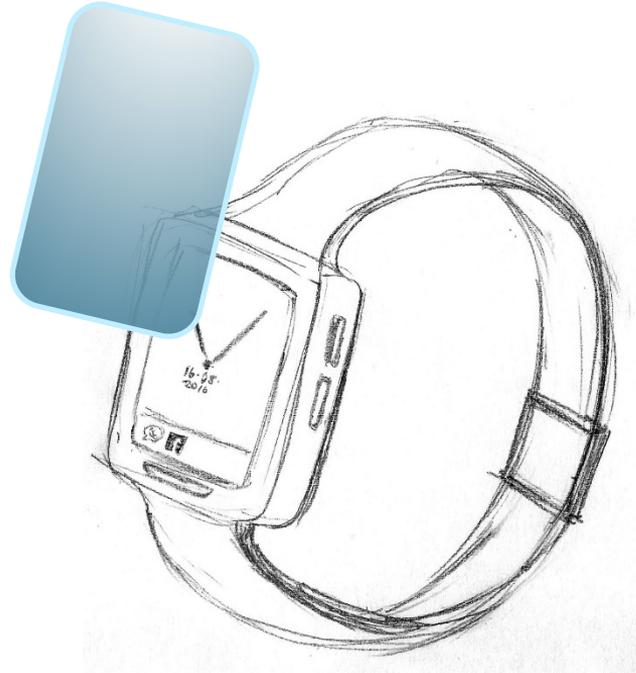
# A modern smart watch

- Casing and strap
  - Must be practical size
  - *Aesthetics and materials*



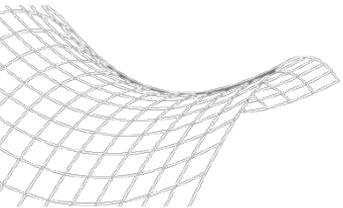
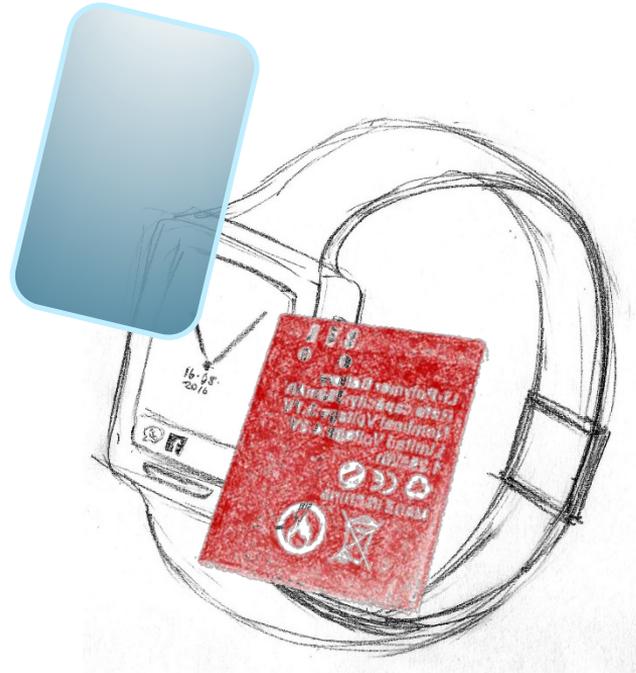
# A modern smart watch

- Casing and strap
  - Must be practical size
  - *Aesthetics and materials*
- Touchscreen



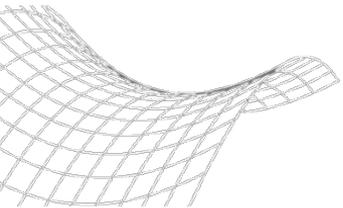
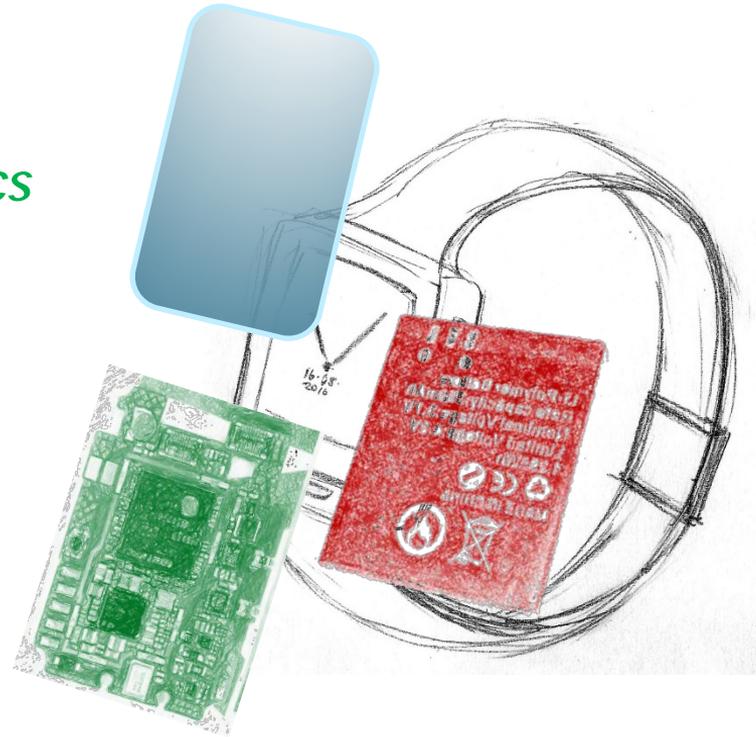
# A modern smart watch

- Casing and strap
  - Must be practical size
  - *Aesthetics and materials*
- Touchscreen
- Battery and charging



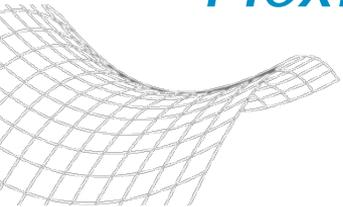
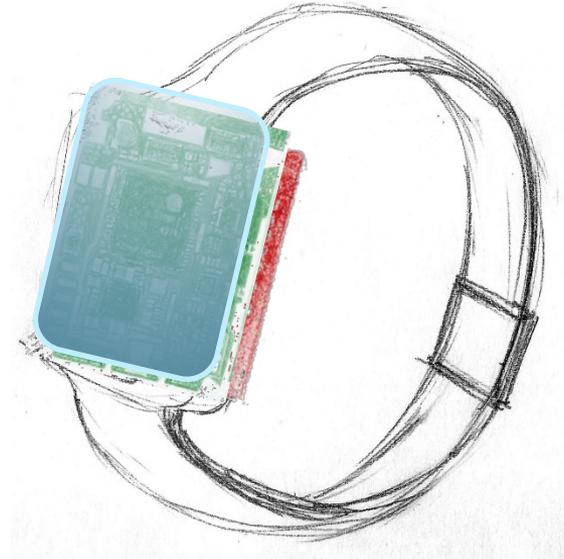
# A modern smart watch

- Casing and strap
  - Must be practical size
  - *Materials and aesthetics*
- Touchscreen
- Battery and charging
- Electronics



# A modern smart watch

- Casing and strap
  - Must be practical size
  - *Aesthetics and materials*
- Touchscreen
- Battery and charging
- Electronics
- *Flexibility and functionality*



# Concept design

- ▷ Modular strap.
- ▷ Connected to watch body.
- ▷ Interchangeable modules.
- ▷ User customization.



- ▷ Large screen.
- ▷ Differentiate touch and tap.

- ▷ Bluetooth, Wi-Fi, GPS and GSM capable

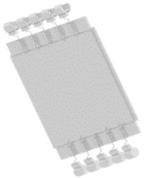
- ▷ Wireless charging required.



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# Concept design

- ▶ Standard mating connectors between modules / to watch body.
- ▶ Continuous ground plane, data and power lines



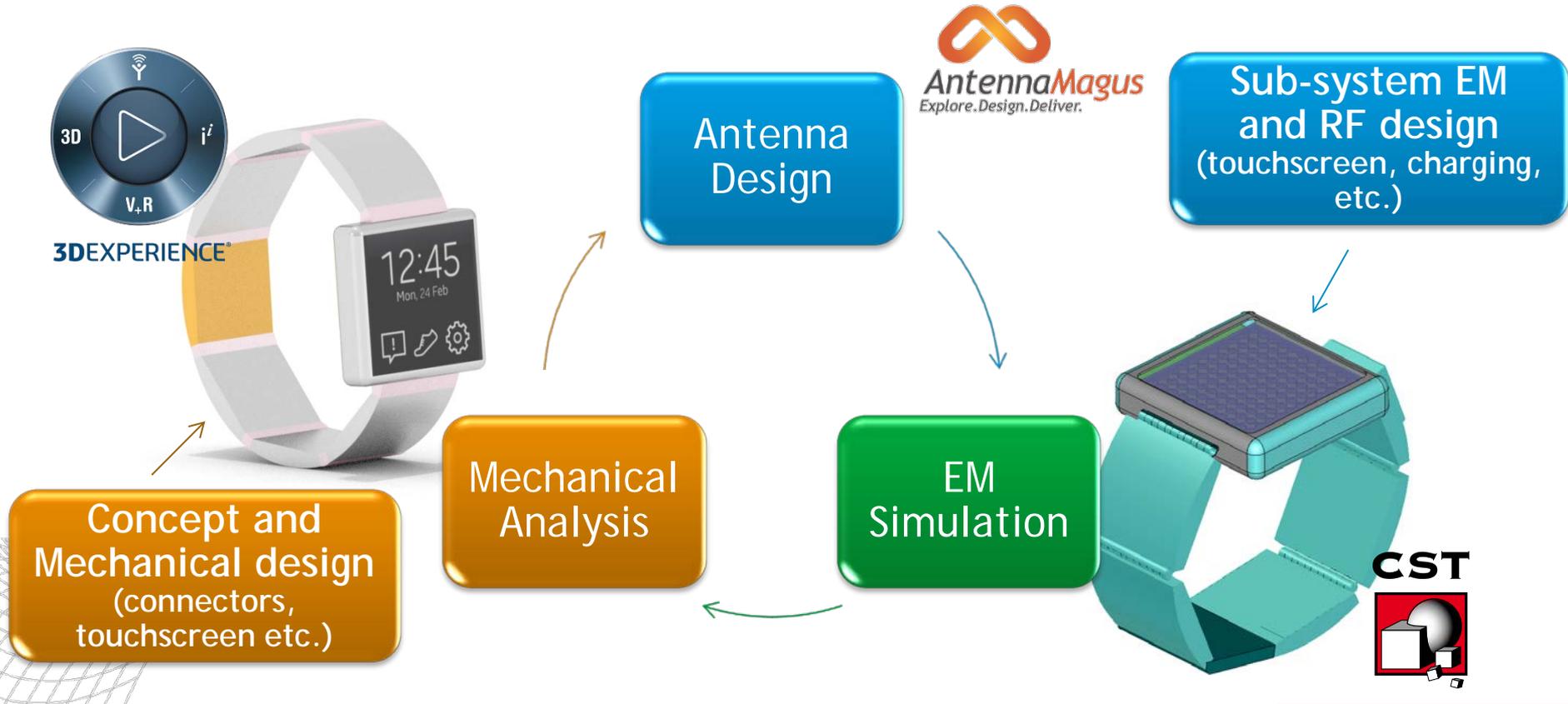
- ▶ Maximize data transfer rates achievable between strap modules (>1 Gb/s)
- ▶ Minimize interference risk
- ▶ Adhere to exposure standards
- ▶ Optimise for mechanical reliability and manufacture methods

- ▶ Aluminium/polycarbonate casing
- ▶ Polycarbonate strap/module housing

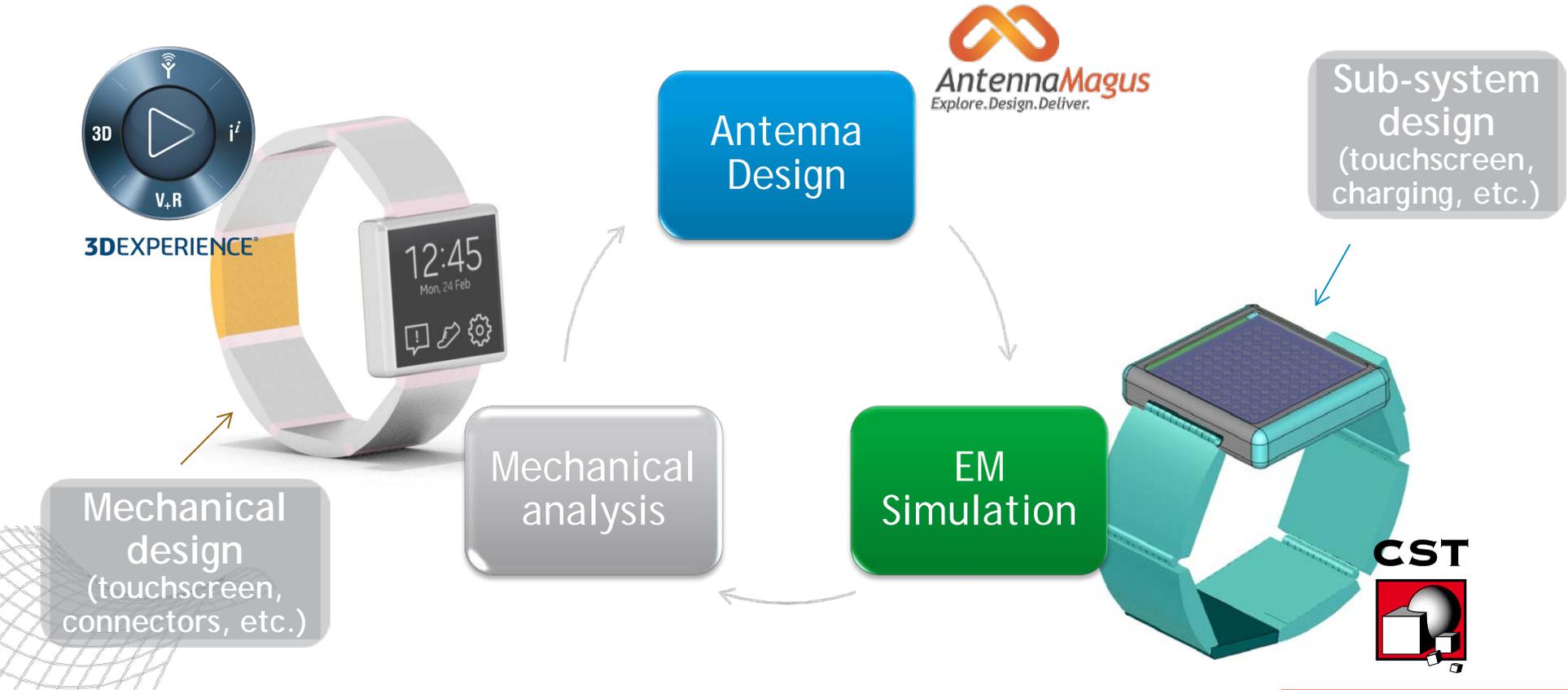


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# Design process



# Design process



# Concept design - Connectivity

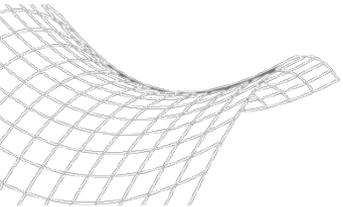
- WiFi (2.401 - 2.495 GHz)
- Bluetooth (2.4 - 2.485 GHz)
- GPS (1.563 - 1.587 GHz)
- GSM/Cellular (e.g. 880 - 960 MHz)
- $S_{11} < -10$  dB
- Best possible radiation efficiency



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# Antenna requirements

- Fit within the space available
- Efficient and well matched antennas (power use)
- Work alongside other electronics/systems
- Cater for different usage scenarios and environments
- Adhere to safety standards



# Antenna challenges: Space



# Antenna challenges: Space



*Freespace wavelength/2*



WiFi (2.401 - 2.495 GHz)

Bluetooth (2.4 - 2.485 GHz)

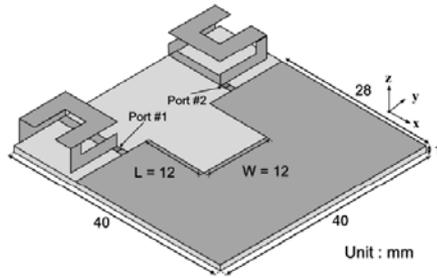
GPS (1.563 - 1.587 GHz)

GSM (880 - 960 MHz)

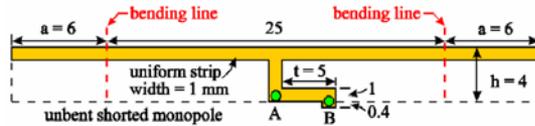
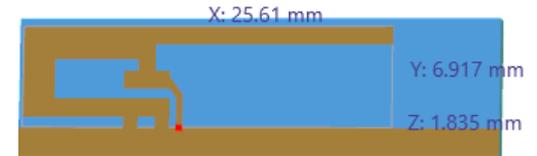
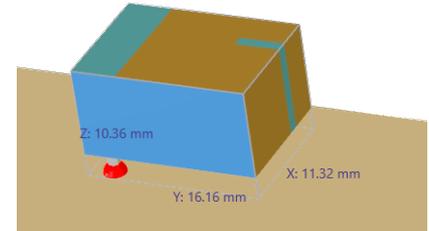
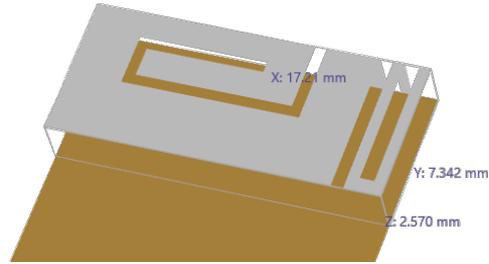


# WiFi and Bluetooth antennas

## Published papers

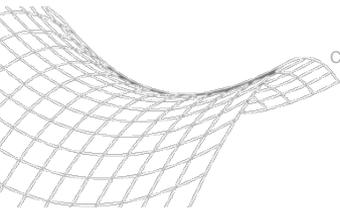
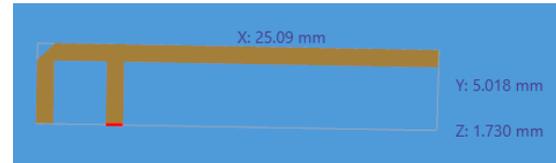


Design of a Compact UWB Diversity Antenna for WBAN Wrist-Watch Applications  
 \*Seungmin Woo, Jisoo Baek, Hyungsang Park, Dongtak Kim and Jaehoon Choi  
 Department of Electronics and Computer Engineering, Hanyang University 17  
 Haengdang-Dong,  
 Seongdong-Gu, Seoul, 133-791, Korea

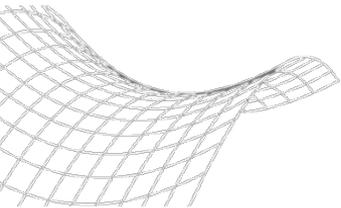
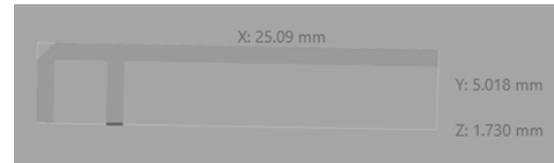
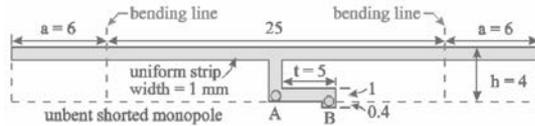
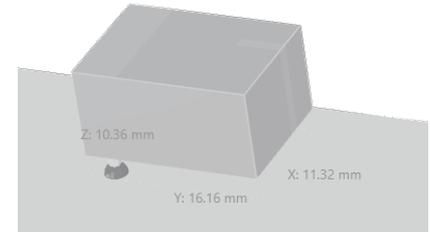
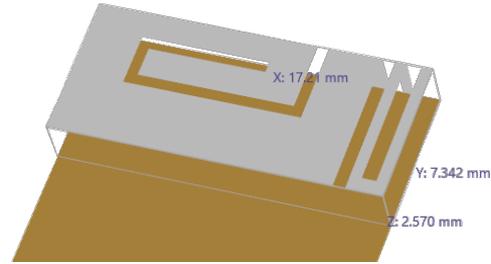
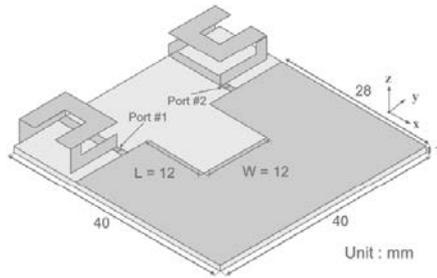


Conformal Bluetooth Antenna for the Watch-Type Wireless Communication Device Application

Chih-Hsien Wu\*(1), Kin-Lu Wong(1), Yuan-Chih Lin (1), and Saou-Wen Su (2)  
 (1)Department of Electrical Engineering  
 National Sun Yat-Sen University, Kaohsiung 804, Taiwan  
 (2)Technology Research and Development Center  
 Lite-On Technology Corp., Taipei 114, Taiwan

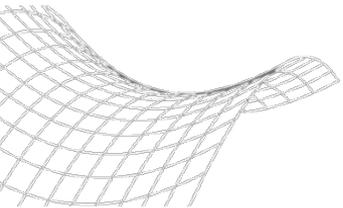


# WiFi / Bluetooth antenna - option 1

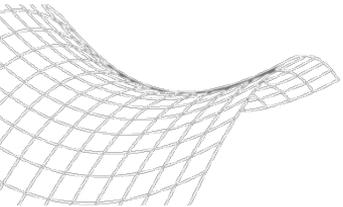
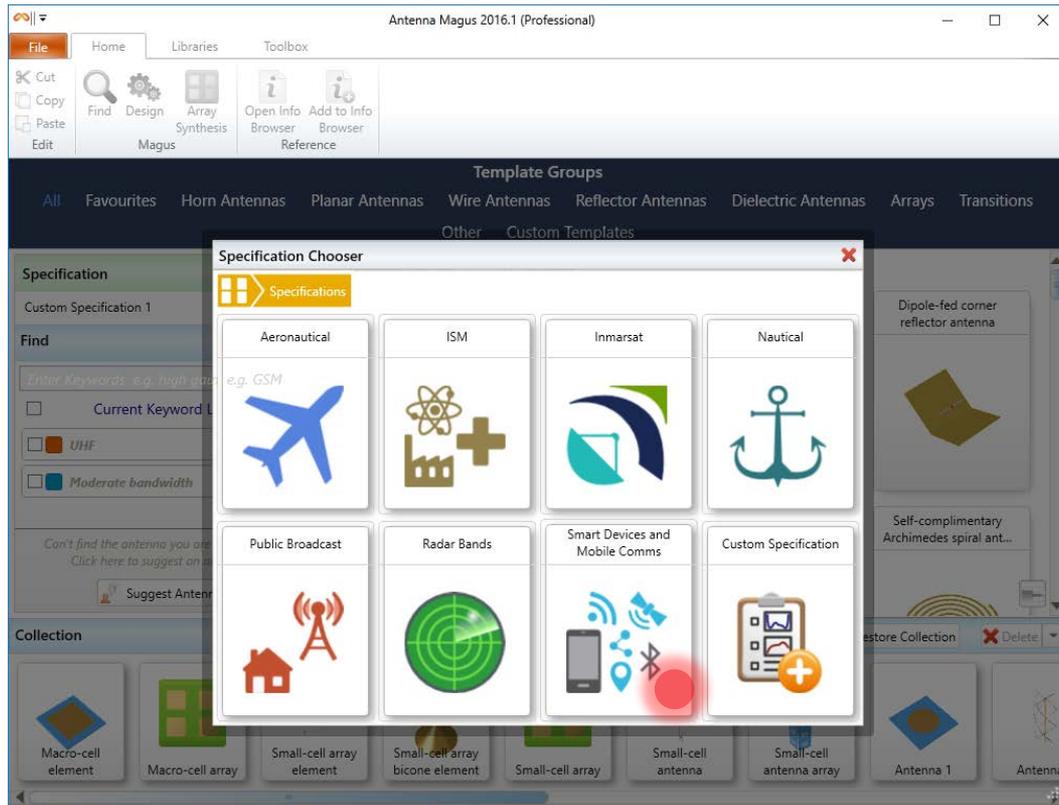


# WiFi / Bluetooth antenna - option 1

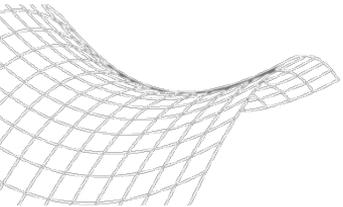
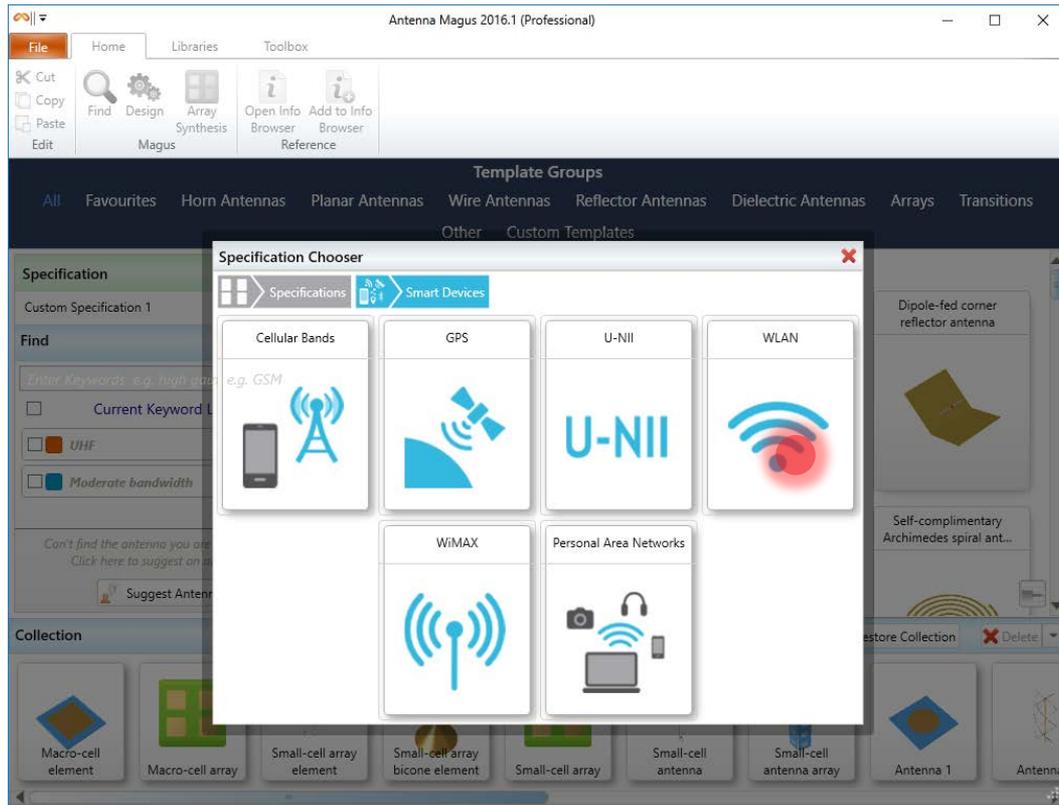
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# Choose application



# Choose application



# Choose application

The screenshot displays the Antenna Magus 2016.1 (Professional) software interface. The main window is titled "Antenna Magus 2016.1 (Professional)" and features a ribbon menu with tabs for "File", "Home", "Libraries", and "Toolbox". The "Home" tab is active, showing options like "Cut", "Copy", "Paste", "Edit", "Find", "Design", "Array Synthesis", "Open Info Browser", and "Add to Info Browser".

In the foreground, a "Specification Chooser" dialog box is open, displaying a list of WLAN 2.4 specifications. The dialog has tabs for "Specifications", "Smart Devices", and "WLAN", with "WLAN" selected. The list contains the following entries:

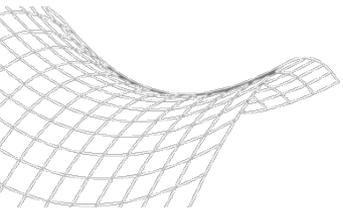
Name	About
WLAN 2.4 (802.11b/g/n)	WLAN 2.4 allows electronic devices to communicate with each other in the 2.4 GHz Industrial, Scientific and Medical (ISM) band over a short range and consists of 14 channels, while not all 14 channels are available for use in all countries. Due to the operation in the ISM 2.4 GHz band, interference with devices such as microwave ovens and bluetooth devices may occur.
WLAN 2.4 (802.11b/g/n)	WLAN 2.4 Channel 1 (of 14) spans the frequency range 2.401 - 2.423 GHz and overlaps with Channels 2, 3, 4 and 5. The set of non-overlapping channels containing this channel is 1, 6 and 11.
WLAN 2.4 (802.11b/g/n)	WLAN 2.4 Channel 2 (of 14) spans the frequency range 2.406 - 2.428 GHz and overlaps with Channels 1, 3, 4, 5 and 6. The set of non-overlapping channels containing this channel is 2, 7 and 12.
WLAN 2.4 (802.11b/g/n)	WLAN 2.4 Channel 3 (of 14) spans the frequency range 2.411 - 2.433 GHz and overlaps with Channels 1, 2, 4, 5, 6 and 7. The set of non-overlapping channels containing this channel is 3, 8 and 13.
WLAN 2.4 (802.11b/g/n)	WLAN 2.4 Channel 4 (of 14) spans the frequency range 2.416 - 2.438 GHz and overlaps with Channels 1, 2, 3, 5, 6, 7 and 8. The set of non-overlapping channels containing this channel is 4, 9 and 14.
WLAN 2.4 (802.11b/g/n)	WLAN 2.4 Channel 5 (of 14) spans the frequency range 2.421 - 2.443 GHz and overlaps with Channels 1, 2, 3, 4, 6, 7, 8 and 9. The set of non-overlapping channels containing this channel is 5, 10 and 14.
WLAN 2.4 (802.11b/g/n)	WLAN 2.4 Channel 6 (of 14) spans the frequency range 2.426 - 2.448 GHz and overlaps with Channels 2, 3, 4, 6, 7, 8, 9 and 10. The set of non-overlapping channels containing this channel is 1, 6 and 11.
WLAN 2.4 (802.11b/g/n)	WLAN 2.4 Channel 7 (of 14) spans the frequency range 2.431 - 2.453 GHz and overlaps with Channels 3, 4, 5, 6, 8, 9, 10 and 11. The set of non-overlapping channels containing this channel is 2, 7 and 12.

The background interface shows a "Specification" panel with "Custom Specification 1" selected, a "Find" section with search filters (Current Keyword, UHF, Moderate bandwidth), and a "Collection" panel with "Macro-cell element" and "Macro-cell" options. On the right, there are panels for "Arrays" and "Transitions" with various antenna models like "Dipole-fed corner reflector antenna" and "Self-complimentary Archimedes spiral ant...".

# Choose antenna

The screenshot displays the Antenna Magus 2016.1 (Professional) software interface. The main window is titled "Antenna Magus 2016.1 (Professional)". The interface is divided into several sections:

- File Menu:** Includes options like Cut, Copy, Paste, Edit, Find, Design, Array Synthesis, Open Info Browser, Add to Info Browser, Specification, Add to Collection, Export Mode, New Template, Edit Template, Delete Template, Import Templates, and Export Templates.
- Design mode:** A tooltip explains: "Design for specific objectives and investigate performance based on parametric changes. A new Prototype of the Template currently selected in the search results list will be added to the Collection."
- Specification:** Shows "WLAN 2.4 (802.11)".
- Find:** A search bar with the text "Enter Keywords e.g. high gain e.g. GSM". Below it, a "Current Keyword List" includes "Integrated antennas", "WLAN", and "Compact", all of which are checked.
- Template Groups:** A horizontal menu with categories: Planar Antennas, Wire Antennas, Reflector Antennas, Dielectric Antennas, Arrays, Transitions, Other, and Custom Templates.
- Search Results:** A grid of antenna templates. The "Dual-band planar inverted-F (PIFA) with..." template is highlighted with a blue border and a red glow.
- Collection:** A bottom bar showing "48 templates matched 2 / 3 keywords". It includes buttons for "Restore Collection" and "Delete". Below this are icons for various antenna types: Macro-cell element, Macro-cell array, Small-cell array element, Small-cell array bicone element, Small-cell array, Small-cell antenna, Small-cell antenna array, Antenna 1, and Antenna.



# Choose antenna

Antenna Magus 2016.1 (Professional)

File Home Libraries Toolbox

Cut Copy Paste Edit Find Design Array Synthesis Open Info Browser Add to Info Browser Specification Find Add to Collection Export Mode Export New Template Edit Template Delete Template Import Templates Export Templates

Design mode

All Favorites

Design for specific objectives and investigate performance based on parametric changes.

Specification

WLAN 2.4 (802.11n)

Find

Enter Keywords e.g. high gain e.g. GSM

Current Keyword List

- Integrated antennas
- WLAN
- Compact

Can't find the antenna you are looking for? Click here to suggest an antenna.

Suggest Antenna

Template Groups

Planar Antennas Wire Antennas Reflector Antennas Dielectric Antennas Arrays Transitions

Other Custom Templates

Planar dual-band monopole

Printed flat-plate dual-band laptop antenna

Dual-band planar inverted-F (PIFA) with...

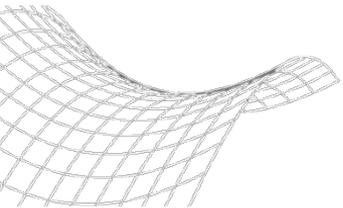
Ultra small integrated monopole

Collection

48 templates matched 2 / 3 keywords

Restore Collection Delete

Macro-cell element Macro-cell array Small-cell array element Small-cell array bicone element Small-cell array Small-cell antenna Small-cell antenna array Antenna 1 Antenna



# Automatic design

The screenshot displays the Antenna Magus 2016.1 (Professional) software interface. The title bar indicates the current design is a "Dual-band planar inverted-F (PIFA) with parasitic element".

**Specification:** WLAN 2.4 (802.11b/g/n) 1

**Prototype Designs and Tweaks:** WLAN 2.4 (802.11b/g/n) 1

**Design Parameters:**

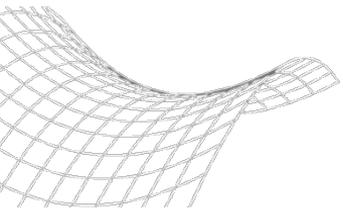
- Frequency Band 1:  $f_{01}$  = 2.45 GHz
- Frequency Band 2:  $f_{02}$  = 4.9 GHz

**Dimensions:** X: 17.21 mm, Y: 7.542 mm

**Right Panel (Performance Metrics):**

- Impedance vs frequency
- Radiation pattern ( $\varphi = 0^\circ$ )
- Radiation pattern ( $\varphi = 90^\circ$ )
- Radiation pattern 3D (first): WLAN 2.4 (802.11b/g/n) 1 [2.450 GHz]
- Radiation pattern 3D (second): WLAN 2.4 (802.11b/g/n) 1 [4.927 GHz]

**Collection:** A row of 11 antenna design thumbnails is shown, with Antenna 10 selected. The thumbnails are labeled Antenna 3 through Antenna 11.



# Adjust specification

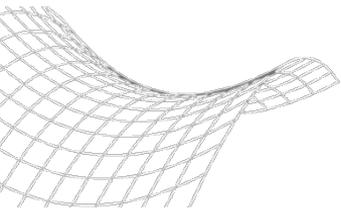
The screenshot displays the Antenna Magus 2016.1 (Professional) software interface. The main window title is "Dual-band planar inverted-F (PIFA) with parasitic element". The interface is divided into several sections:

- Specification:** Shows "WLAN 2.4 (802.11b/g/n) 1".
- Prototype Designs and Tweaks:** Lists "WLAN 2.4 (802.11b/g/n) 1" and "Design 2".
- Design Objectives - Group 2:** Contains settings for "Frequency Band 1" (1.6 GHz) and "Frequency Band 2" (2.45 GHz).
- Collection:** A row of antenna models from Antenna 3 to Antenna 10, with Antenna 10 selected.

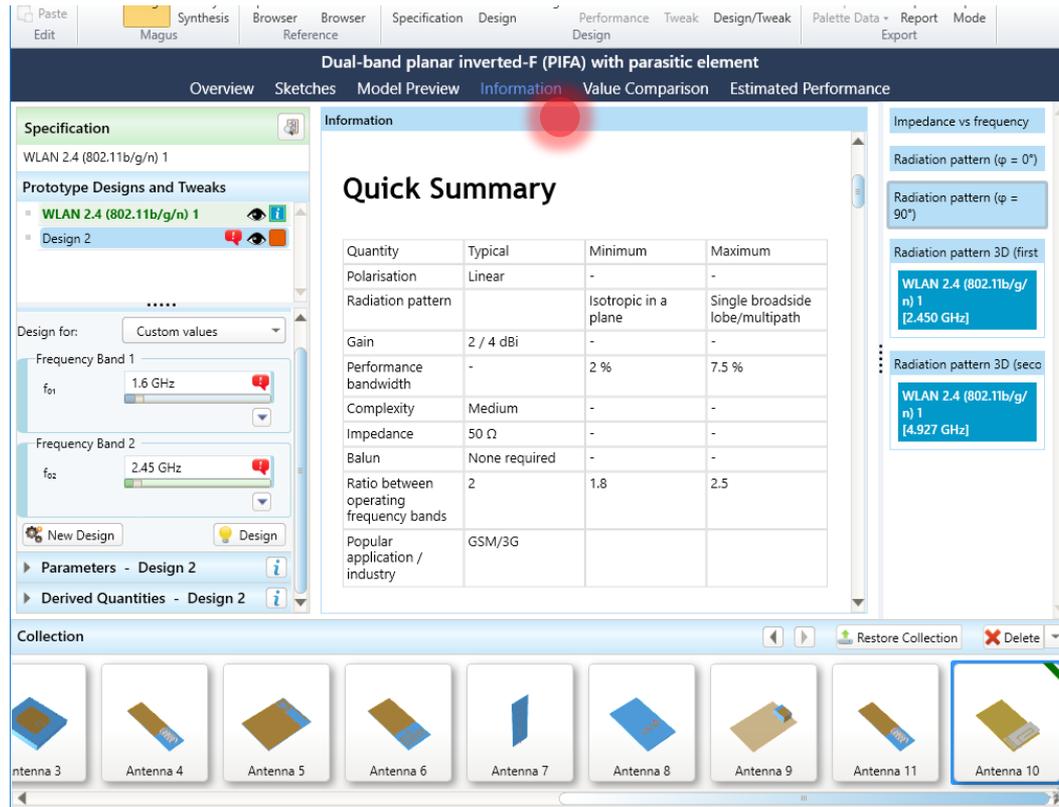
An error message is displayed in a tooltip over the 1.6 GHz frequency band:

*Set by User*  
Minimum: 300 MHz  
Maximum: 16.6 GHz  
The upper to lower frequency ratio 1.53125 is smaller than the minimum allowable ratio 1.8. (Error 91304)

On the right side, there are panels for "Impedance vs frequency", "Radiation pattern ( $\varphi = 0^\circ$ )", "Radiation pattern ( $\varphi = 90^\circ$ )", "Radiation pattern 3D (first)", and "Radiation pattern 3D (second)".



# Learn about the antenna limitations



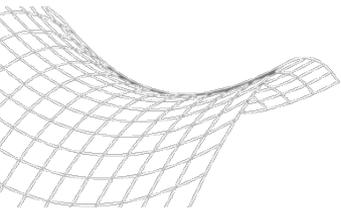
The screenshot displays the 'Information' tab of a software interface for a 'Dual-band planar inverted-F (PIFA) with parasitic element'. The 'Quick Summary' table provides key performance indicators for the design.

Quantity	Typical	Minimum	Maximum
Polarisation	Linear	-	-
Radiation pattern		Isotropic in a plane	Single broadside lobe/multipath
Gain	2 / 4 dBi	-	-
Performance bandwidth	-	2 %	7.5 %
Complexity	Medium	-	-
Impedance	50 $\Omega$	-	-
Balun	None required	-	-
Ratio between operating frequency bands	2	1.8	2.5
Popular application / industry	GSM/3G		

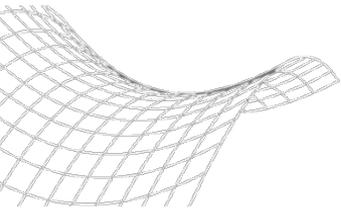
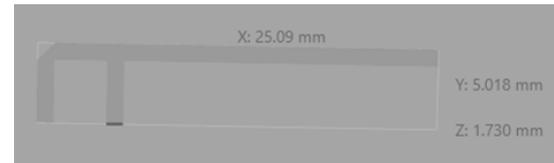
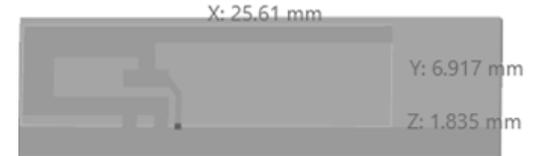
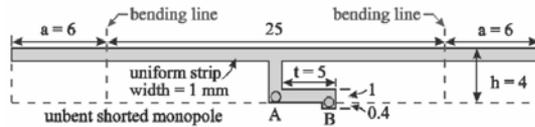
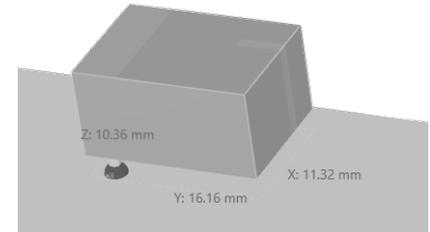
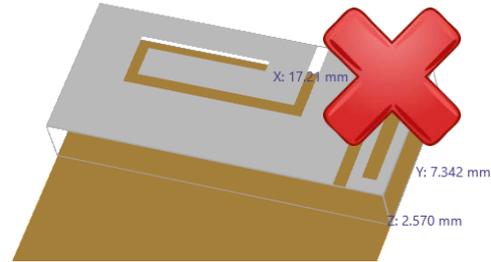
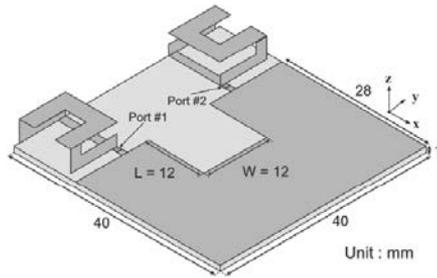
Design parameters shown in the interface include:

- WLAN 2.4 (802.11b/g/n) 1
- Prototype Designs and Tweaks
  - WLAN 2.4 (802.11b/g/n) 1
  - Design 2
- Design for: Custom values
- Frequency Band 1:  $f_{01}$  = 1.6 GHz
- Frequency Band 2:  $f_{02}$  = 2.45 GHz

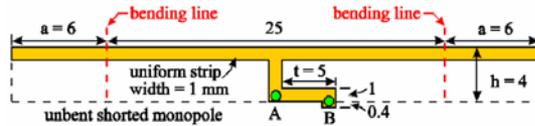
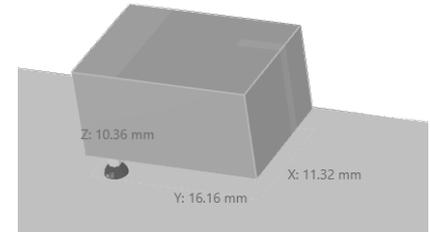
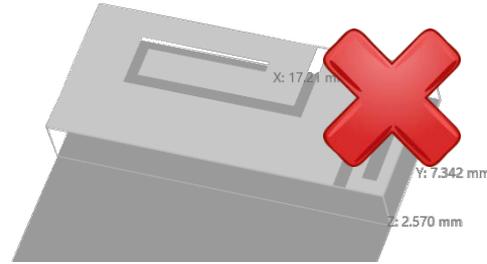
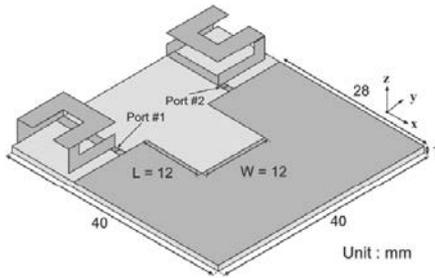
The 'Collection' bar at the bottom shows ten antenna designs, with Antenna 10 selected. A red circle highlights the 'Information' tab in the top navigation bar.



# WiFi / Bluetooth antenna - option 1

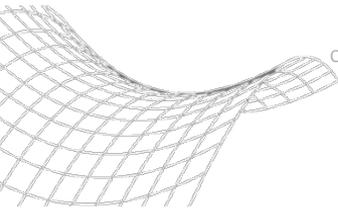
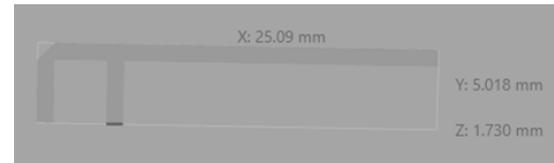
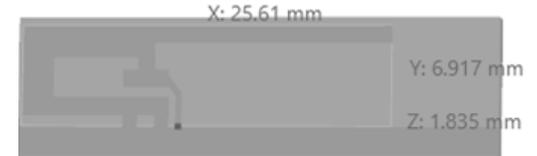


# WiFi / Bluetooth antenna - option 2

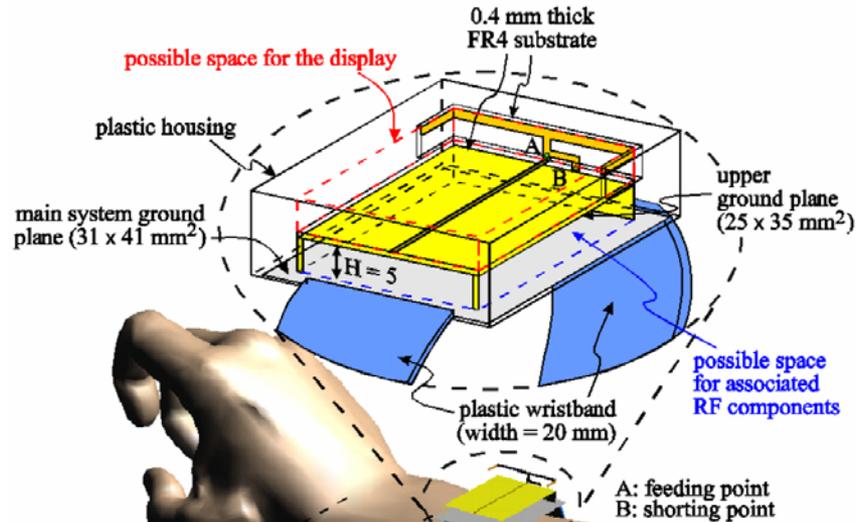


Conformal Bluetooth Antenna for the Watch-Type Wireless Communication Device Application

Chih-Hsien Wu\*(1), Kin-Lu Wong(1), Yuan-Chih Lin (1), and Saou-Wen Su (2)  
 (1)Department of Electrical Engineering  
 National Sun Yat-Sen University, Kaohsiung 804, Taiwan  
 (2)Technology Research and Development Center  
 Lite-On Technology Corp., Taipei 114, Taiwan



# WiFi / Bluetooth antenna - option 2

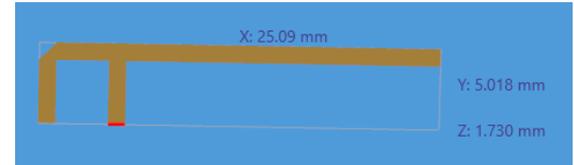
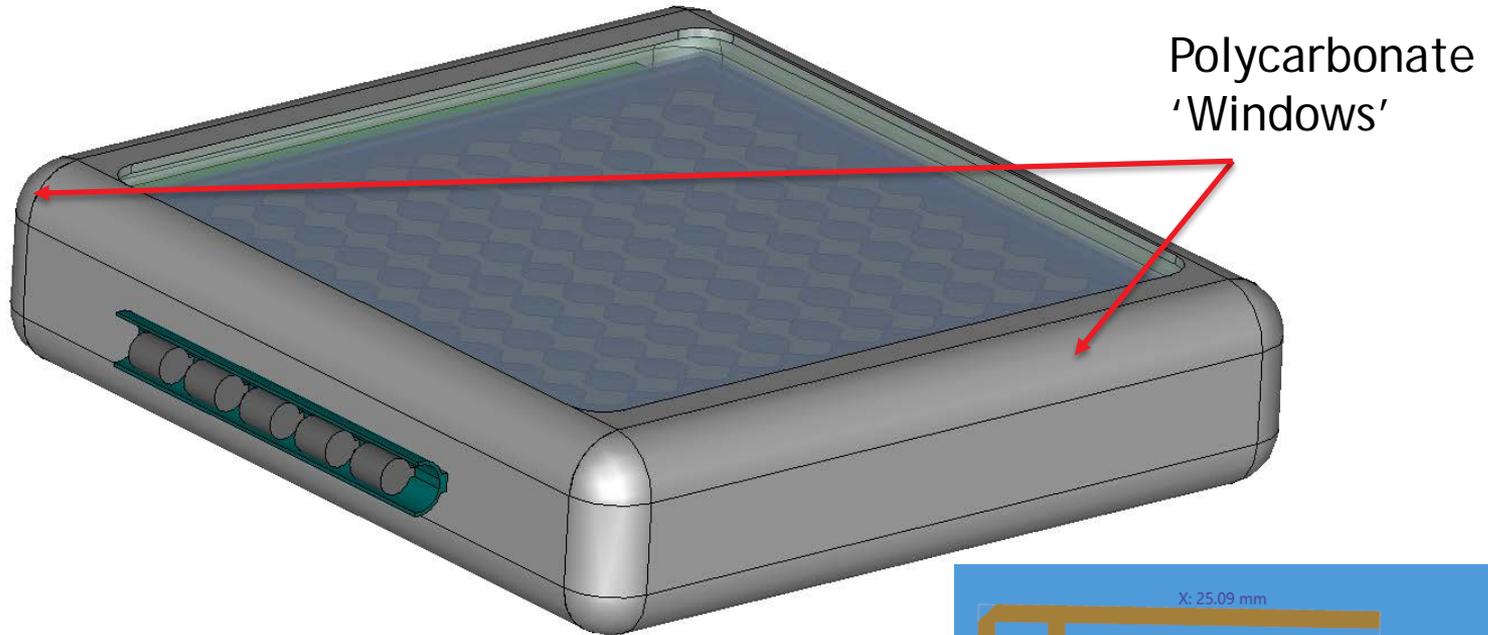


A watch-type wireless communication device at or near the user's wrist

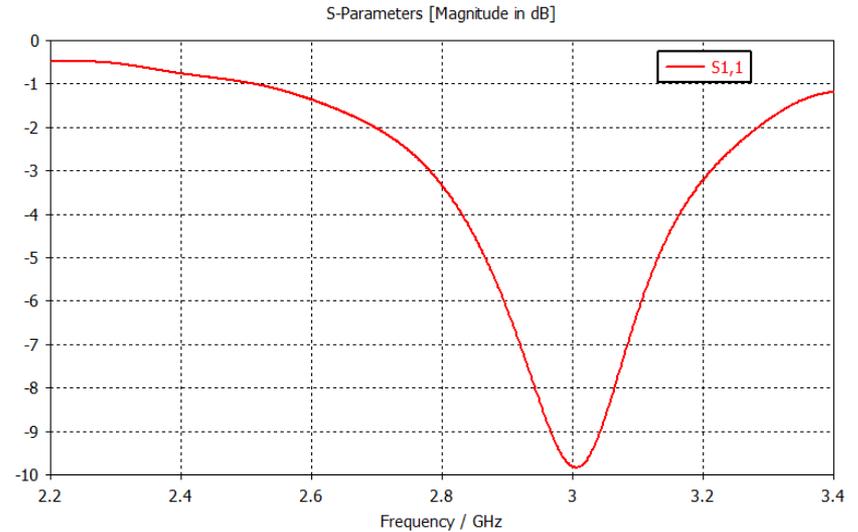
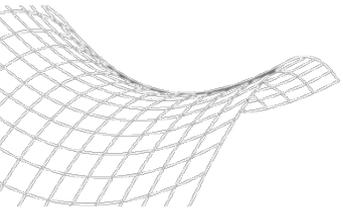
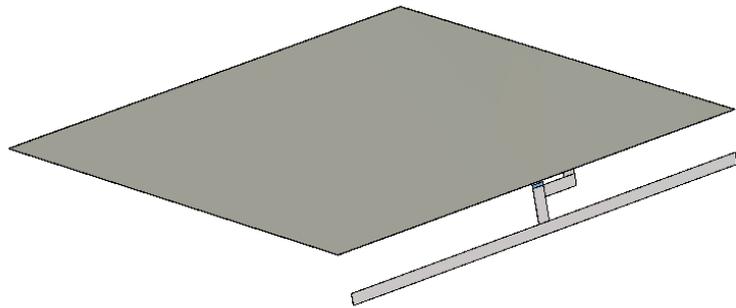
(a)

@2442 MHz	$\epsilon_r$	$\sigma$ (S/m)
Skin	38	1.46
Muscle	52.7	1.73
Bones	18.6	0.8

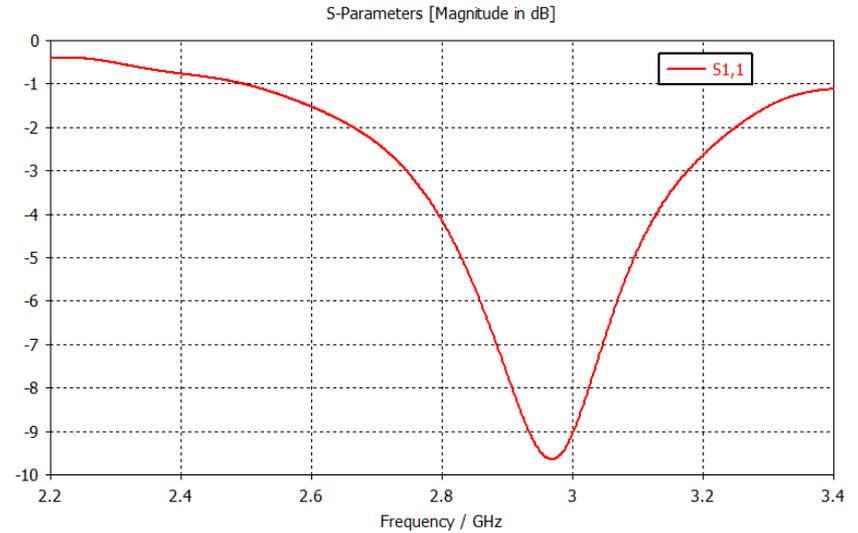
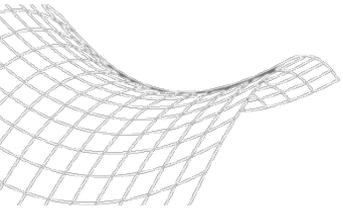
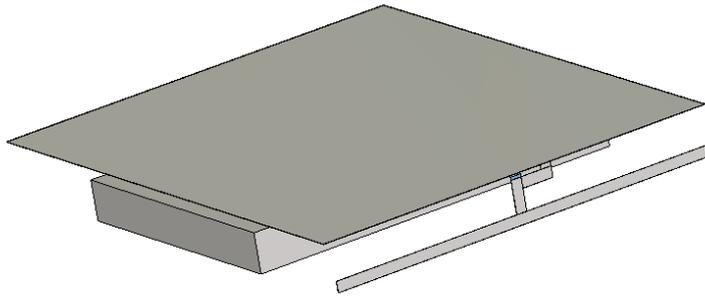
# WiFi / Bluetooth antenna - position



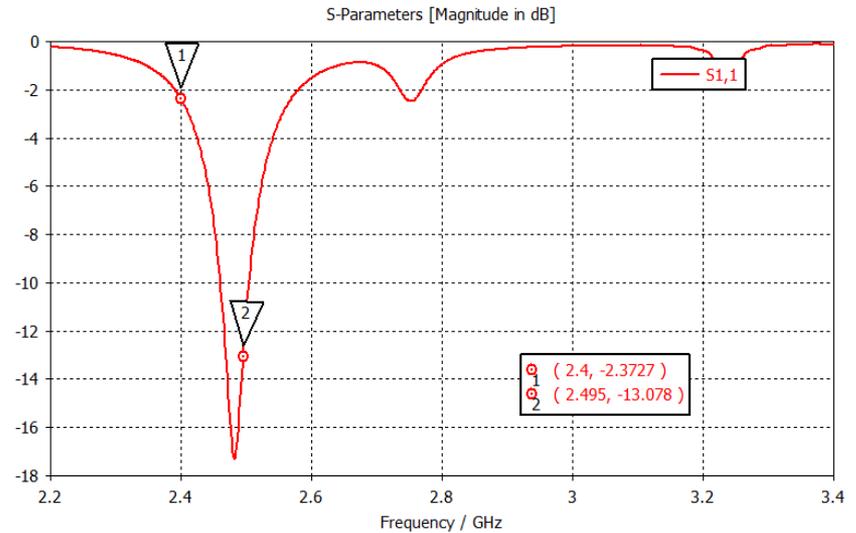
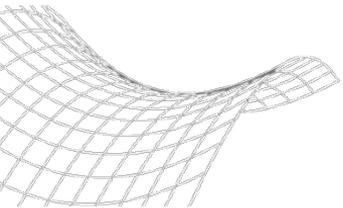
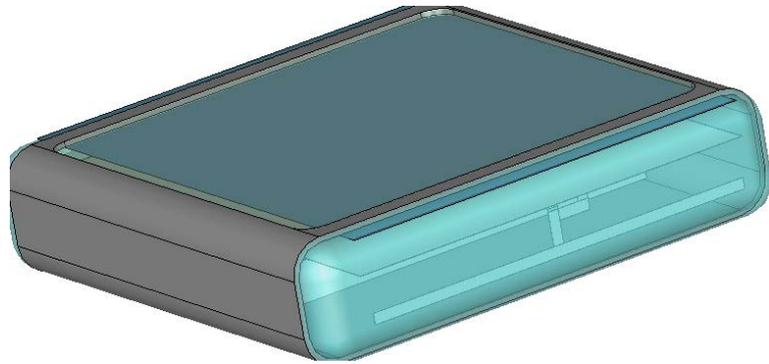
# WiFi / Bluetooth antenna - option 2



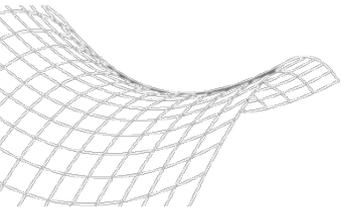
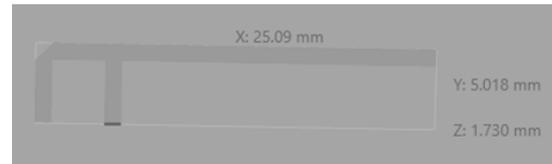
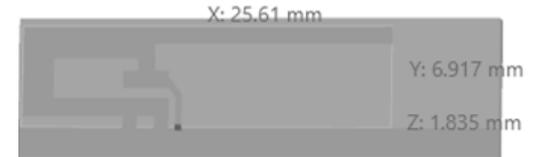
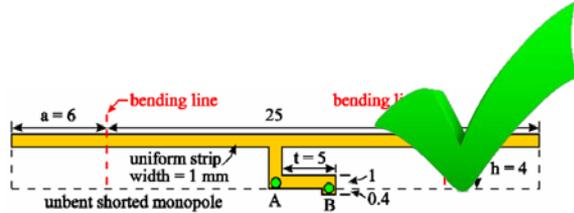
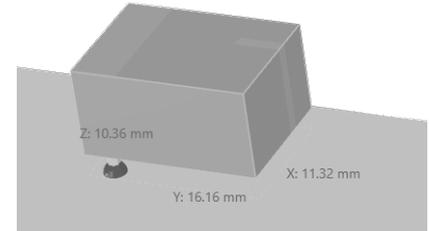
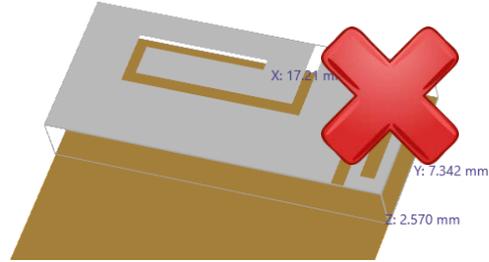
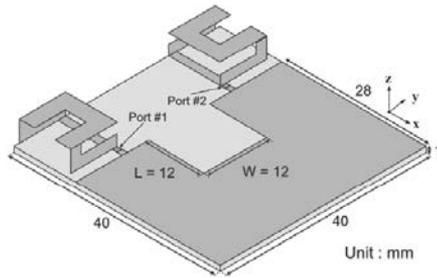
# WiFi / Bluetooth antenna - option 2



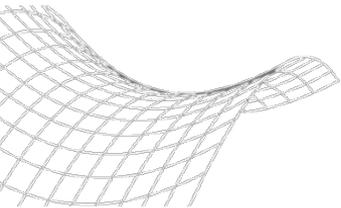
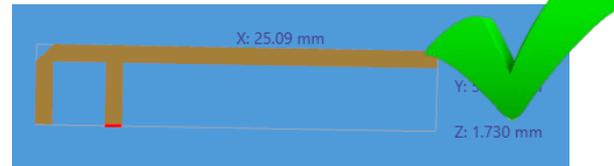
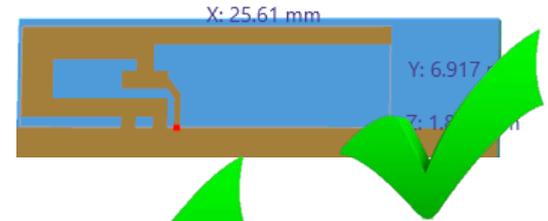
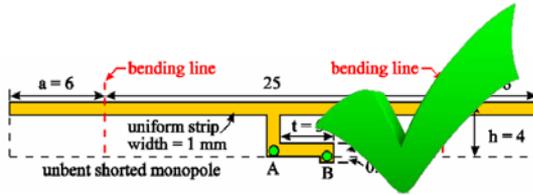
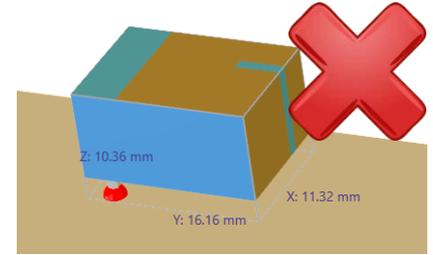
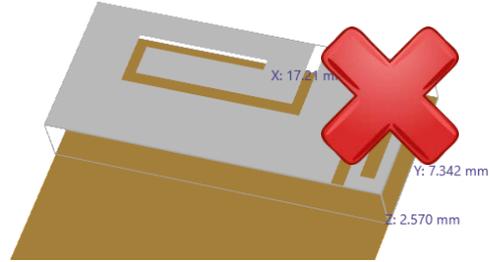
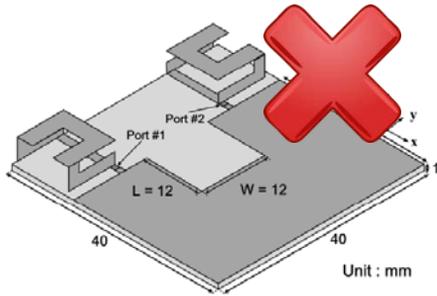
# WiFi / Bluetooth antenna - option 2



# WiFi and Bluetooth antennas

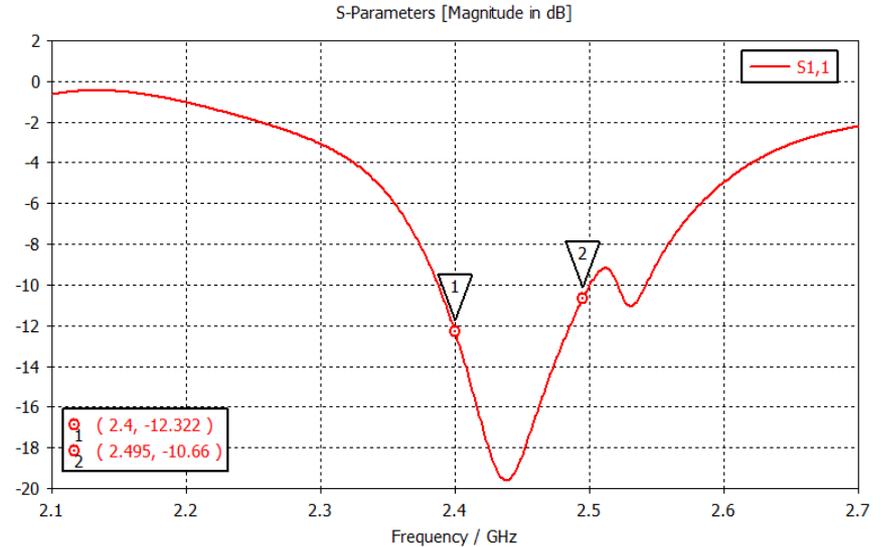
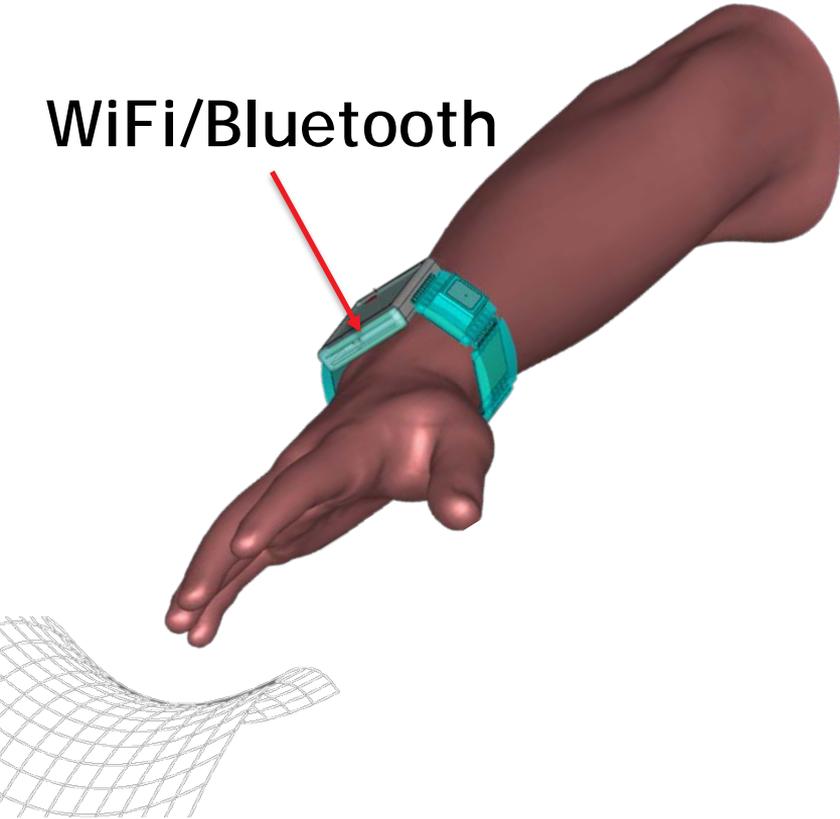


# WiFi and Bluetooth antennas



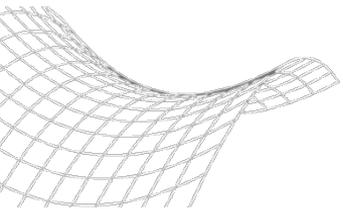
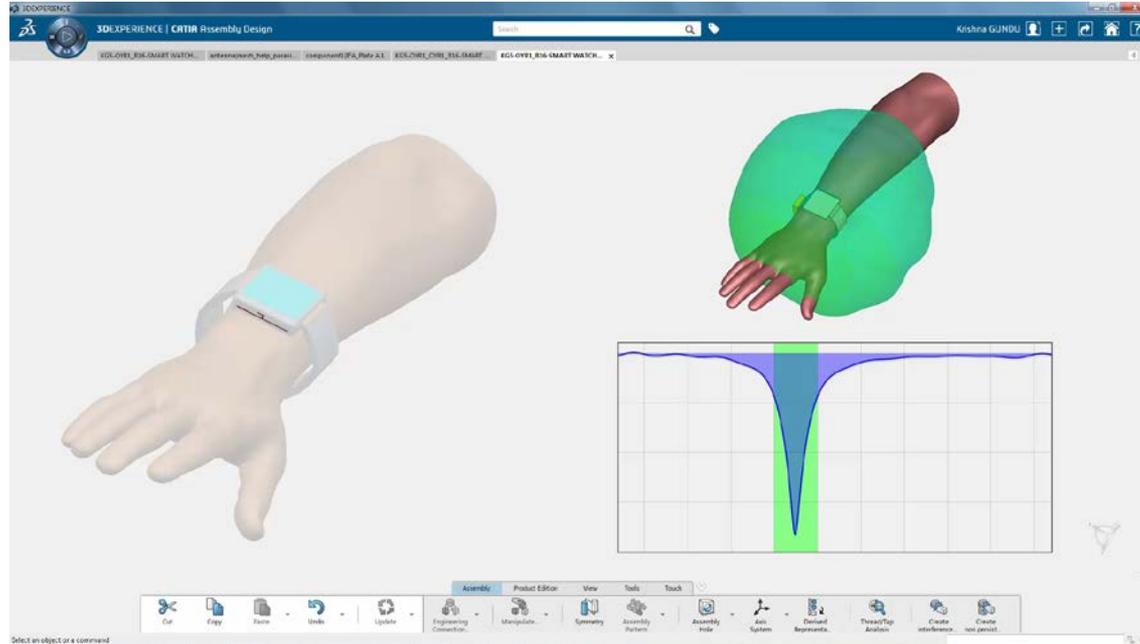
# WiFi and Bluetooth antenna

WiFi/Bluetooth



# WiFi and Bluetooth antennas

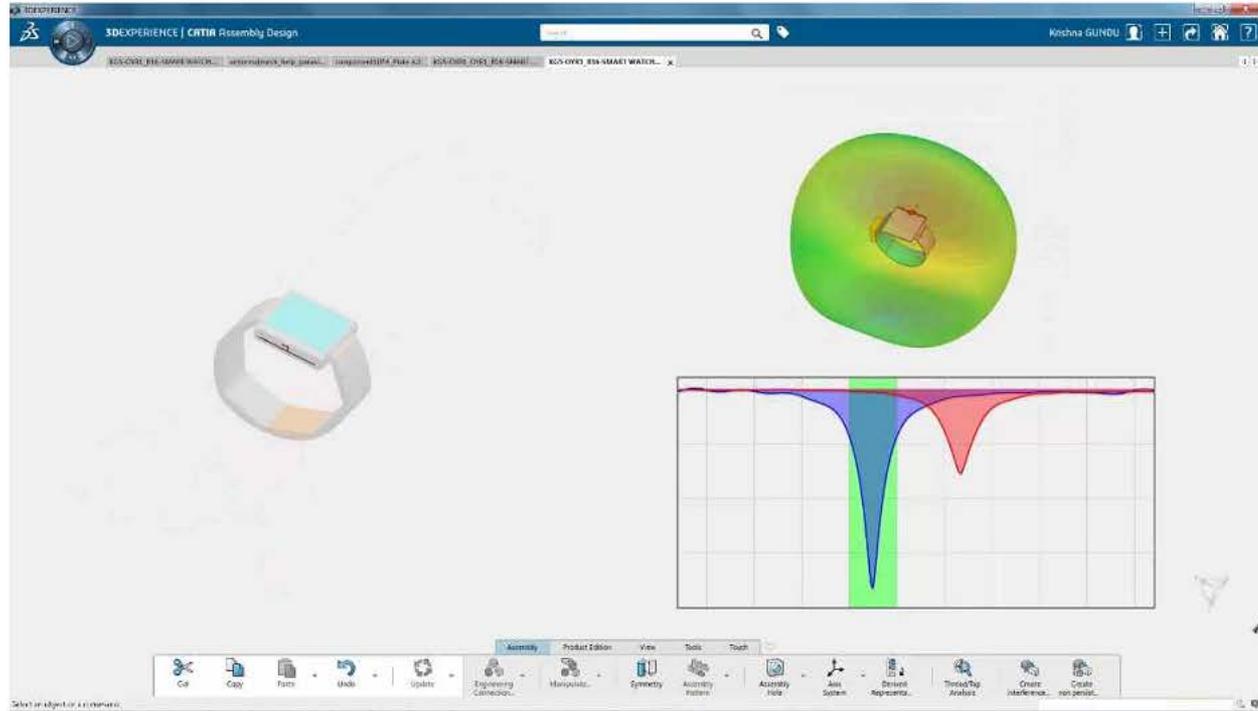
Watch on arm



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# WiFi and Bluetooth antennas

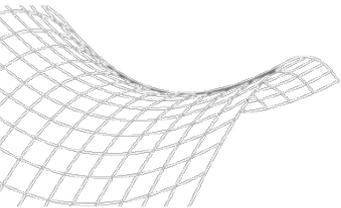
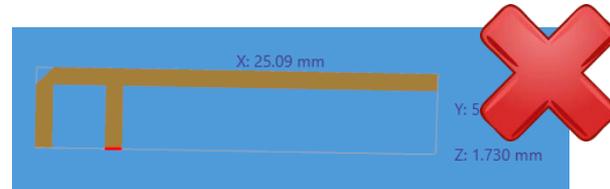
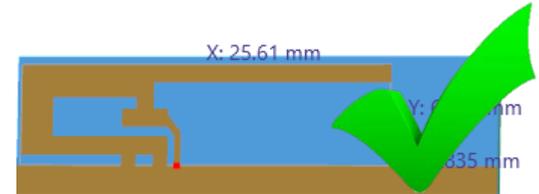
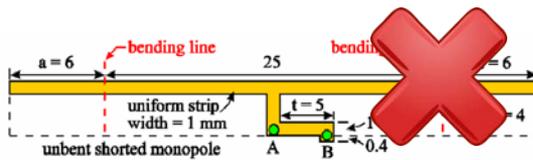
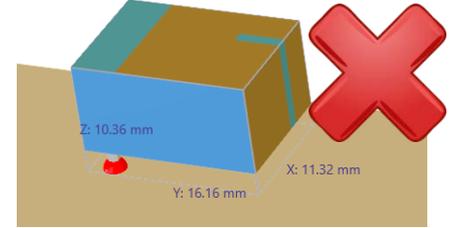
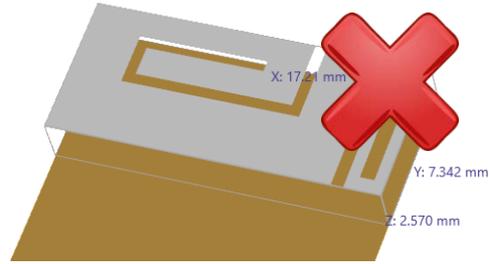
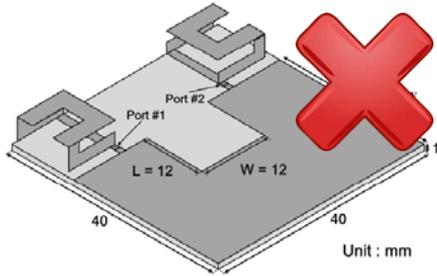
Watch off  
arm



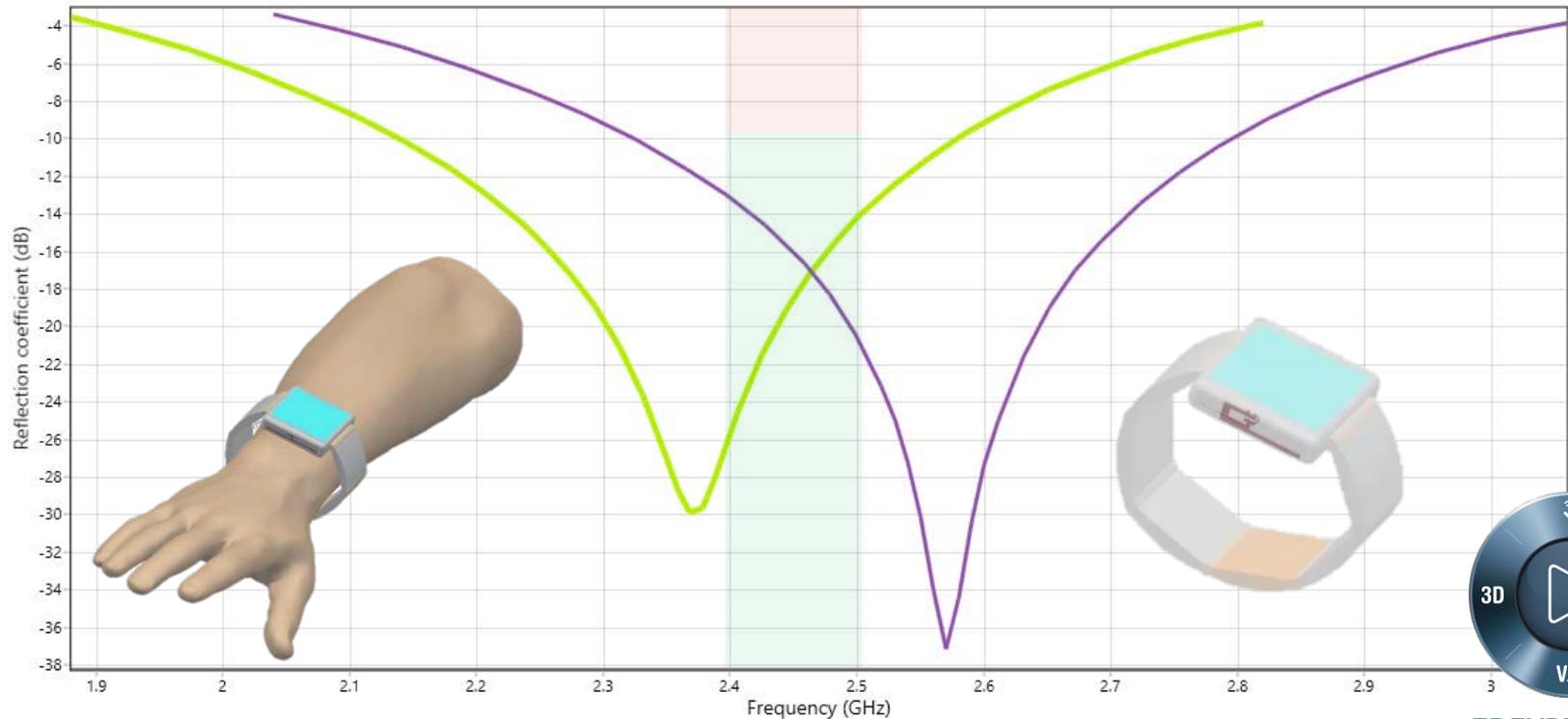
4



# WiFi and Bluetooth antennas



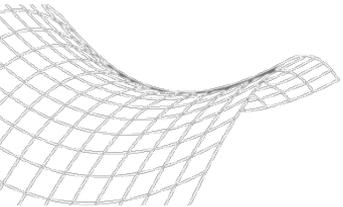
# WiFi and Bluetooth antennas



# GPS antennas

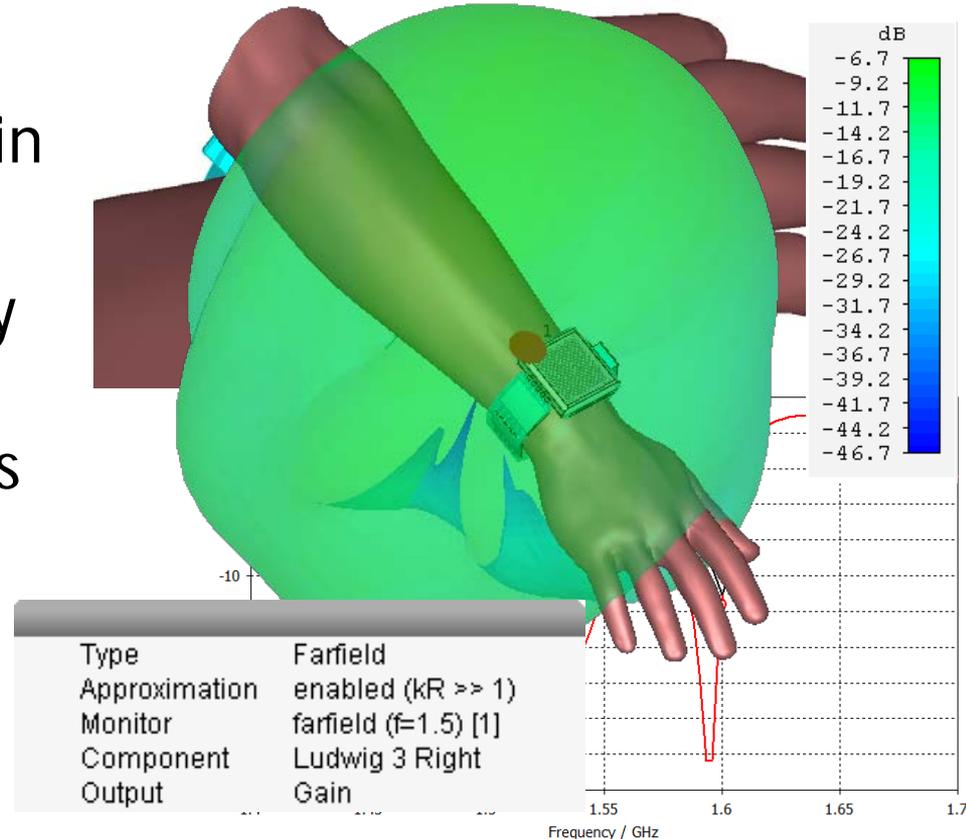
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- GPS signals are Circularly Polarised
- Traditionally patch antennas or helix variants are used for GPS applications
- Literature and Antenna Magus designs show that these antennas are too large

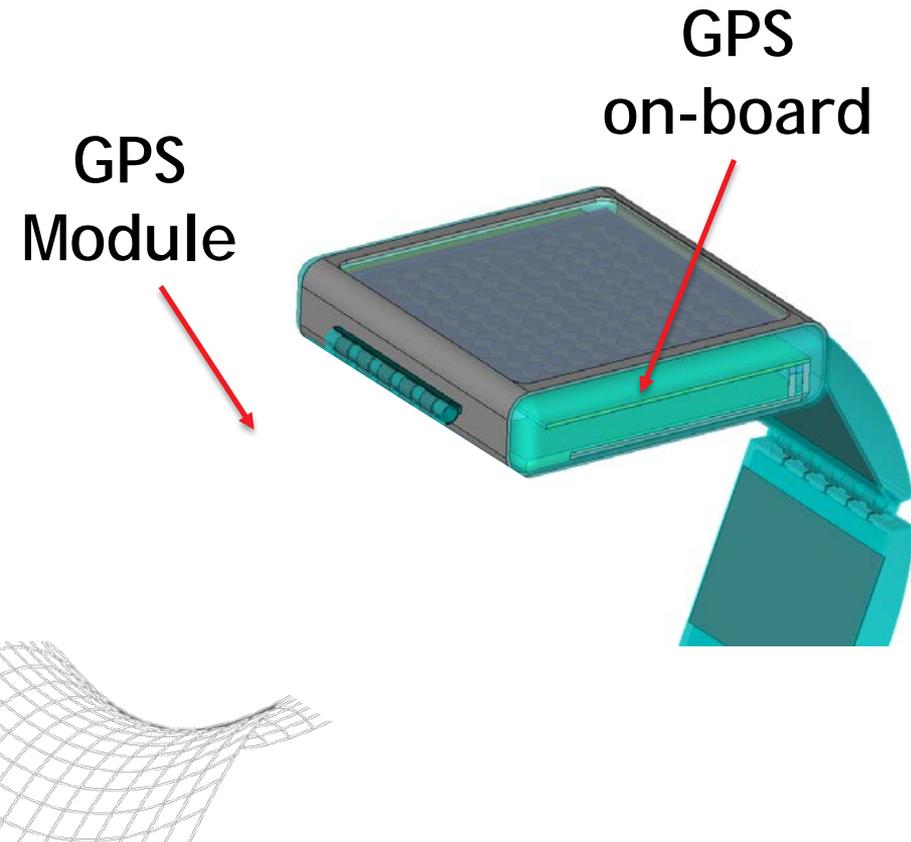


# GPS antennas

- Inverted-F type antenna designed for GPS housed in the watch body
- The GPS antenna is poorly matched and realised circularly polarised gain is poor
- Performance varies on or off the wrist



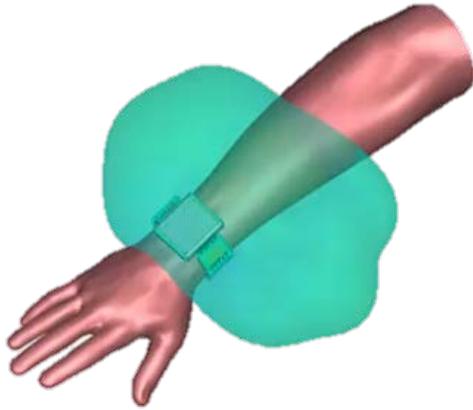
# GPS antennas



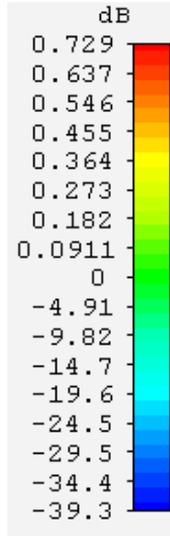
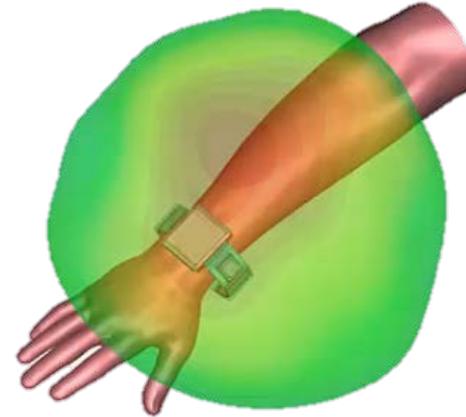
- We would like improved axial ratio and efficiency.
- A high-performance GPS strap module could be used
- Largely immune to usage scenario

# GPS antennas

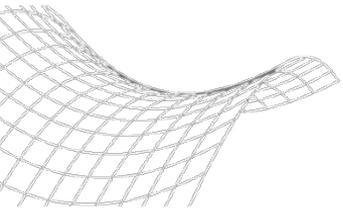
GPS on-board



GPS Module



Type	Farfield
Approximation	enabled ( $kR \gg 1$ )
Monitor	farfield ( $f=1.5$ ) [1]
Component	Ludwig 3 Right
Output	Gain



# What about GSM?

At lower frequencies (e.g. GSM 900) more space than is available in the casing is needed

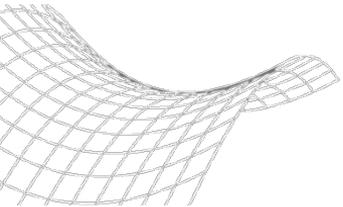
Published papers

## Antenna Designs of Smart Watch for Cellular Communications by using Metal Belt

Kun Zhao<sup>1,2</sup>, Zhinong Ying<sup>2</sup>, Sailing He<sup>1</sup>

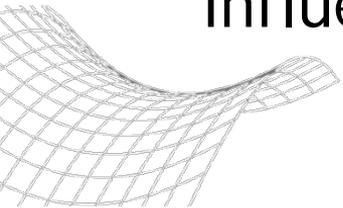
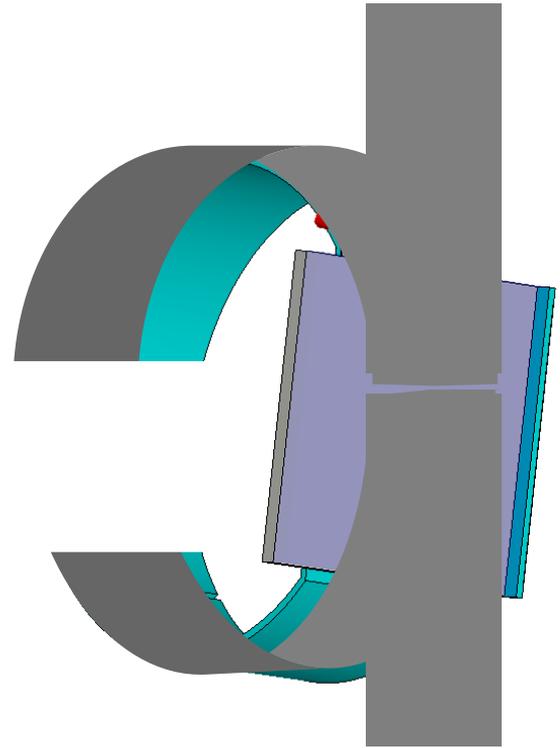
<sup>1</sup> Department of Electromagnetic Engineering, Royal Institute of Technology, Stockholm, Sweden

<sup>2</sup> Corporate Technology Office, Sony Mobile Communication AB, Lund, Sweden

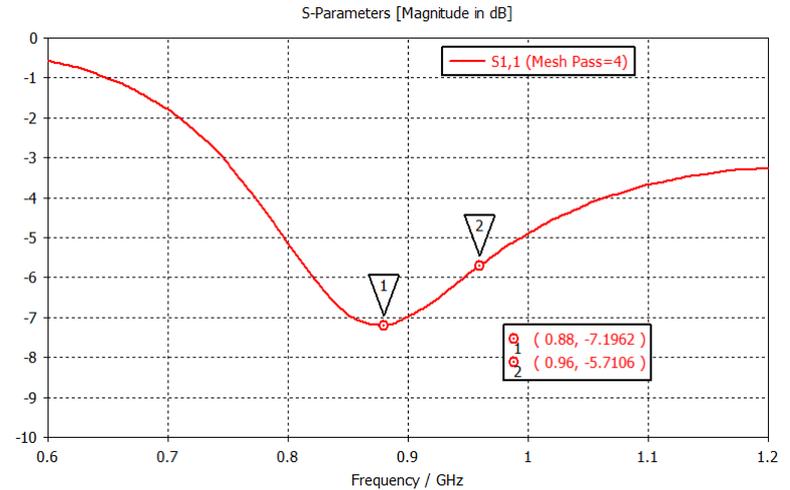
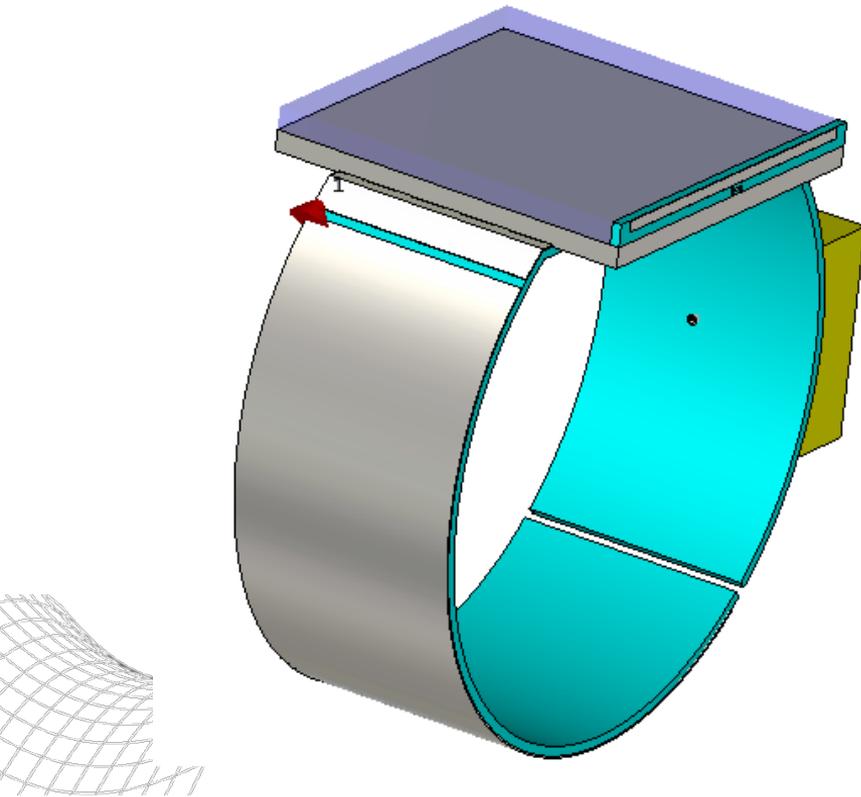


# What about GSM?

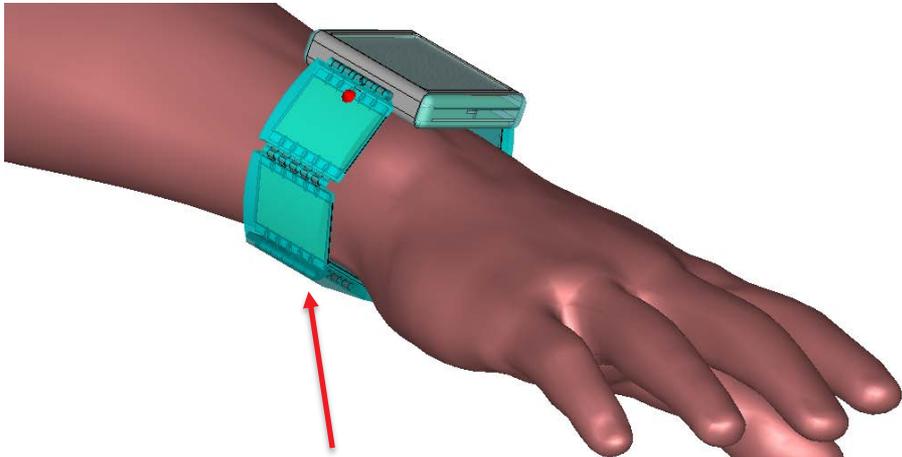
- Use the strap like a dipole
- Investigate and design by simulation with simplified 'canonical' models
- Will it work with the modular strap?
- How will electronics be influenced?



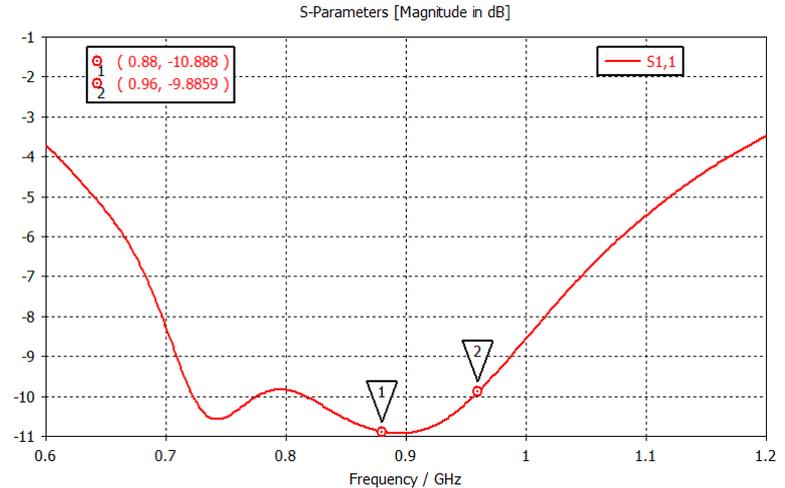
# What about GSM?



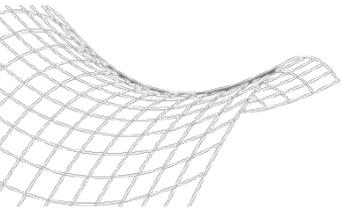
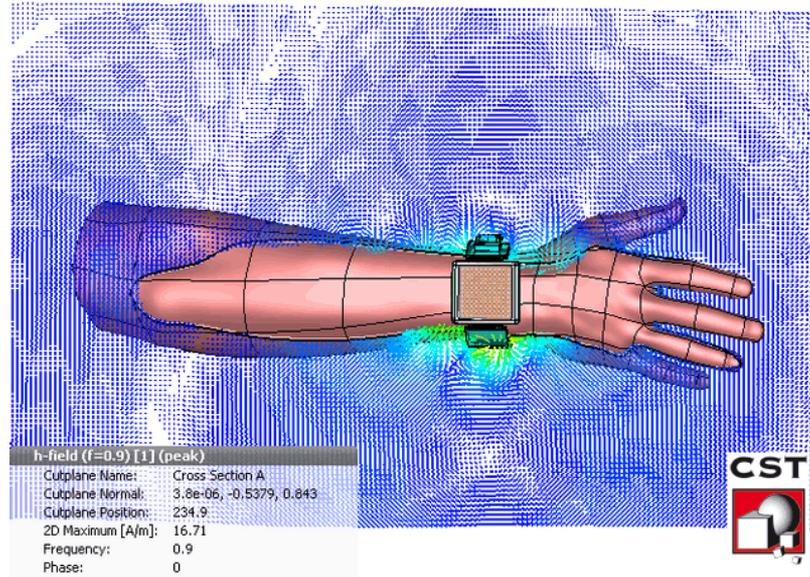
# What about GSM?



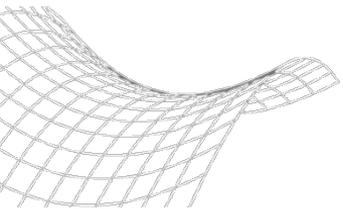
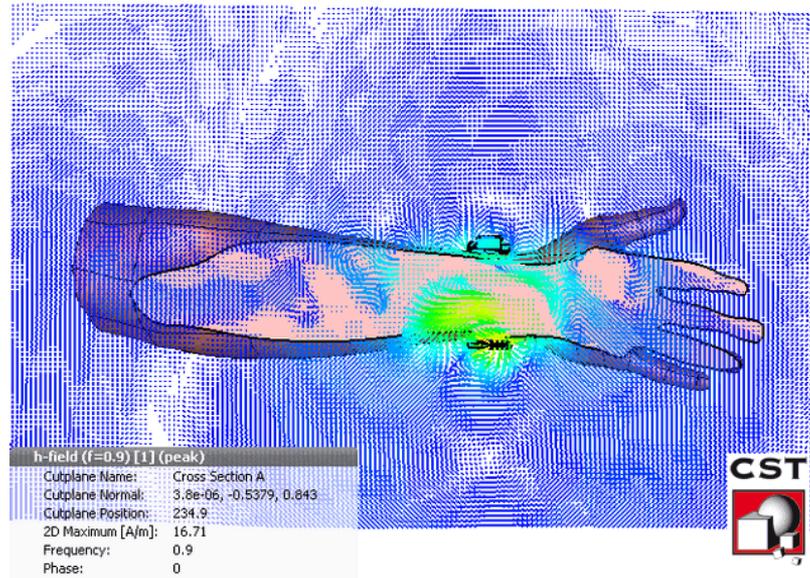
For GSM850/900 only 5 of the 6 strap modules should be connected to form the antenna



# Modelling the environment



# Modelling the environment

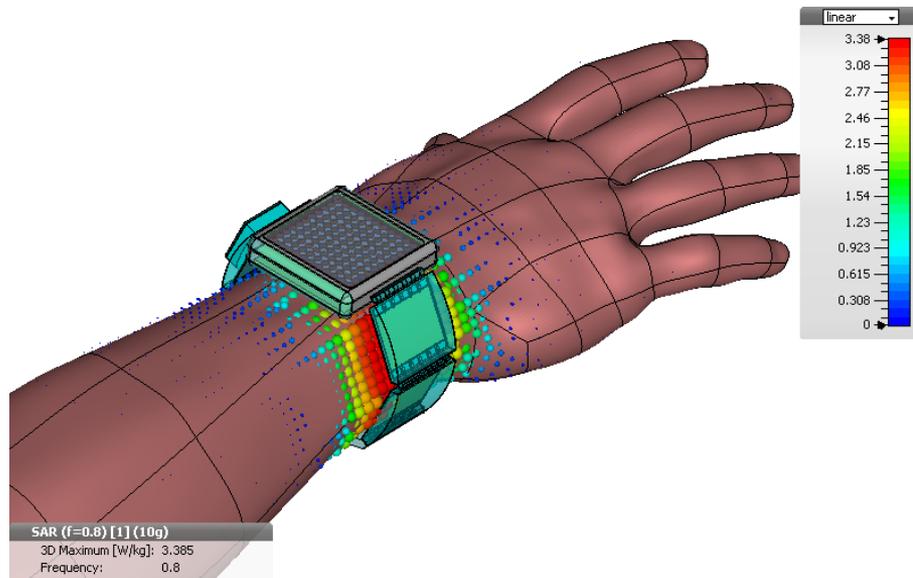


# Antenna challenges: Exposure

- European standard for limbs:
  - SAR (Specific absorption rate) should be less than 4 W/kg averaged over 10 g

## Transmitter:

- 2W peak power
- Active for 1/8<sup>th</sup> of every second
- 0.25W RMS input power



# Concept design

- ▶ Maximize data transfer rates achievable between strap modules (>1 Gb/s)
- ▶ Minimize interference risk



- ▶ Large screen.
- ▶ Differentiate touch and tap.

- ▶ Bluetooth, Wi-Fi, GPS and GSM capable

- ▶ Optimise mechanical reliability

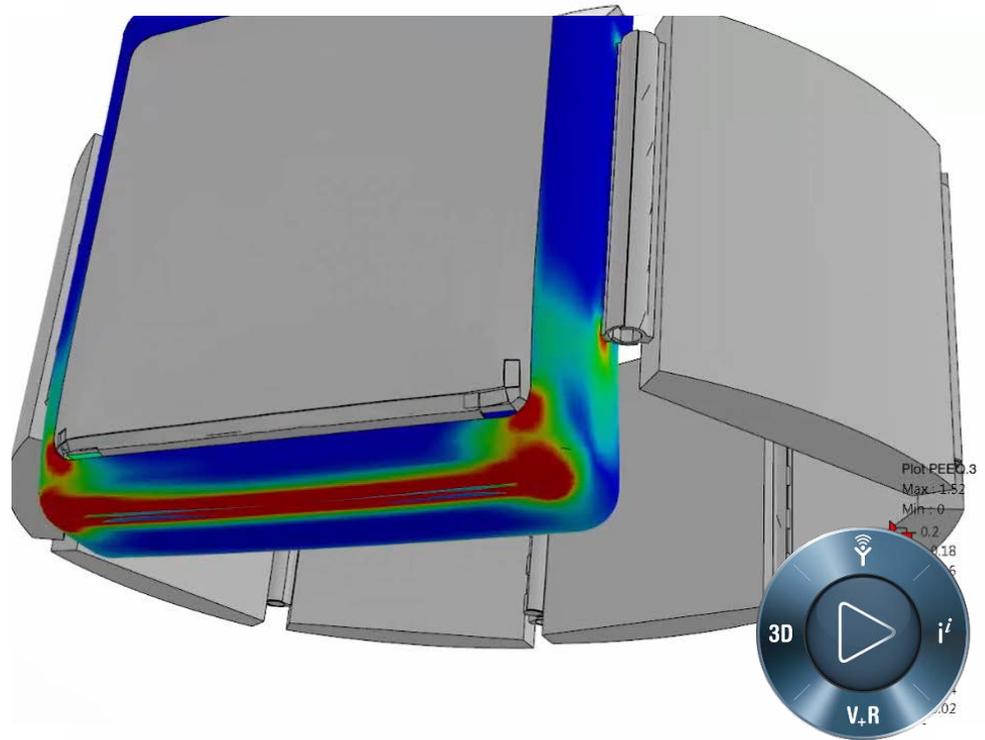
- ▶ Wireless charging required.



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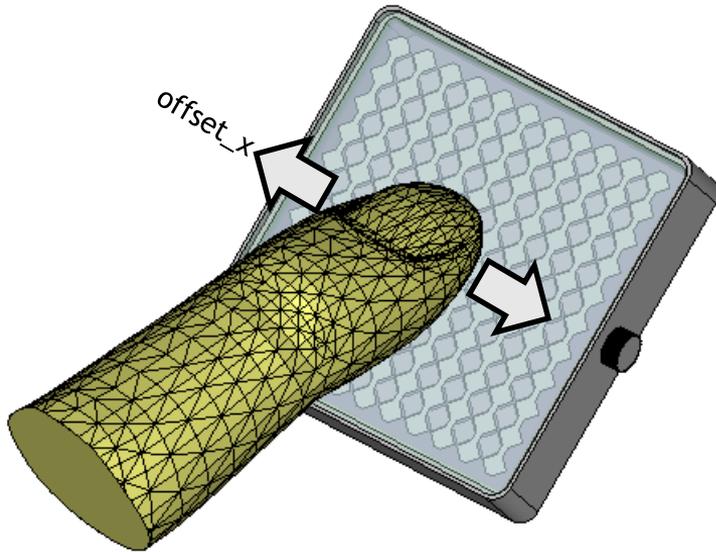
# Analysis - mechanical reliability

- Many studies and optimizations possible
  - Reliability of strap module connectors
  - Material choices and manufacture methods
  - Drop test simulation
  - Etc.

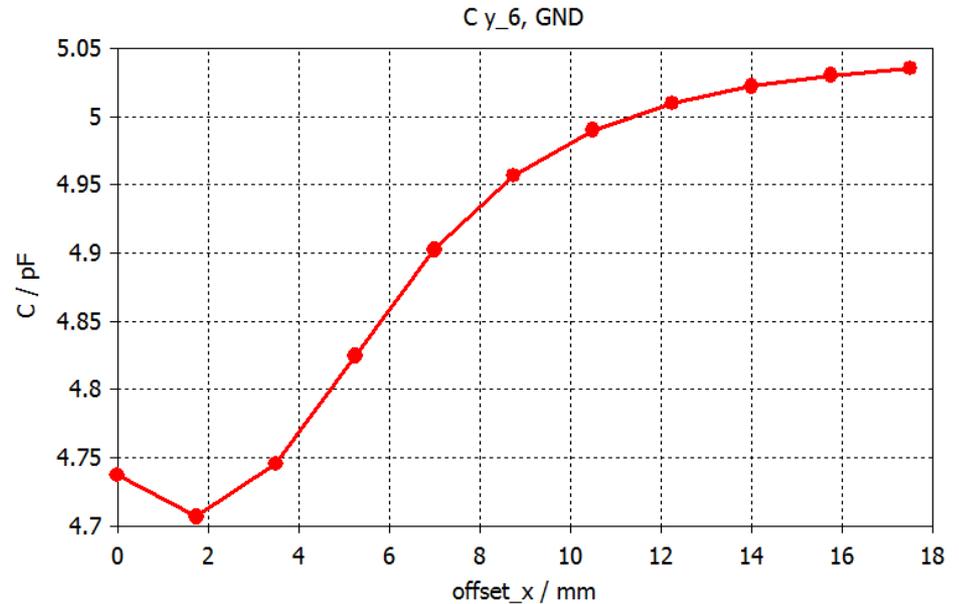


# Analysis - Touch Screen

Movement of finger

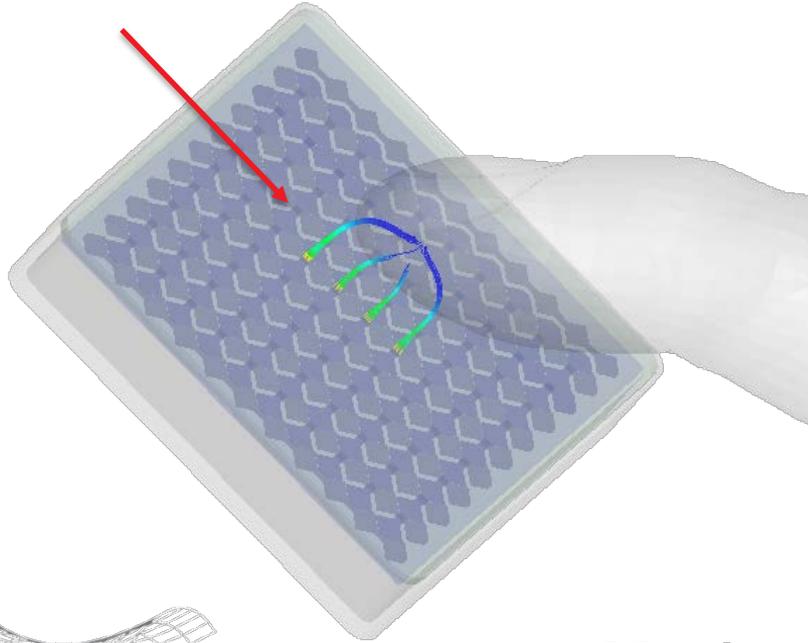


Capacitance Values



# Analysis - Touch Screen

Electric field lines



Considering deformation due to finger pressure on glass

Capacitance  
Undeformed

C x, y6
2.304e-012

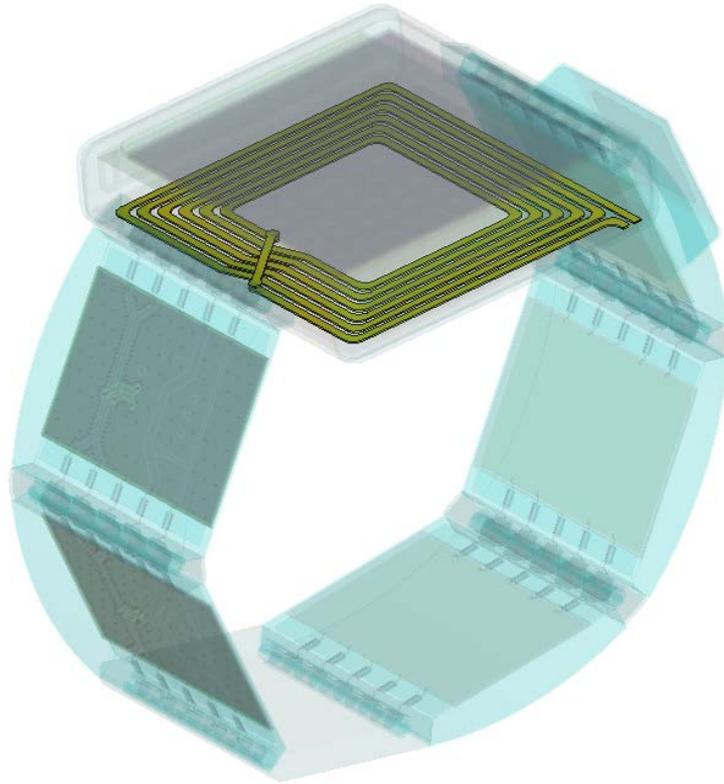
Capacitance  
Deformed

C x, y6
2.05785e-012

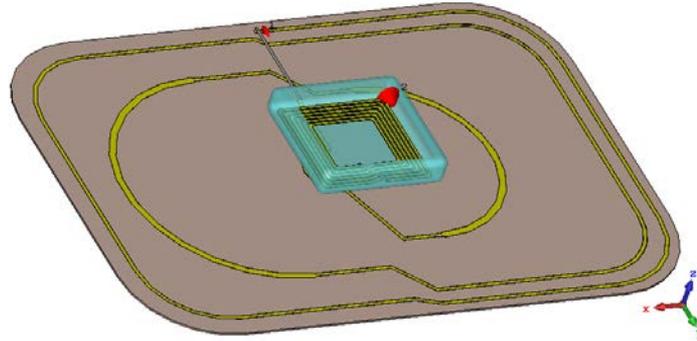
Mechanical and EM co-simulation

# Analysis - Wireless charging

---



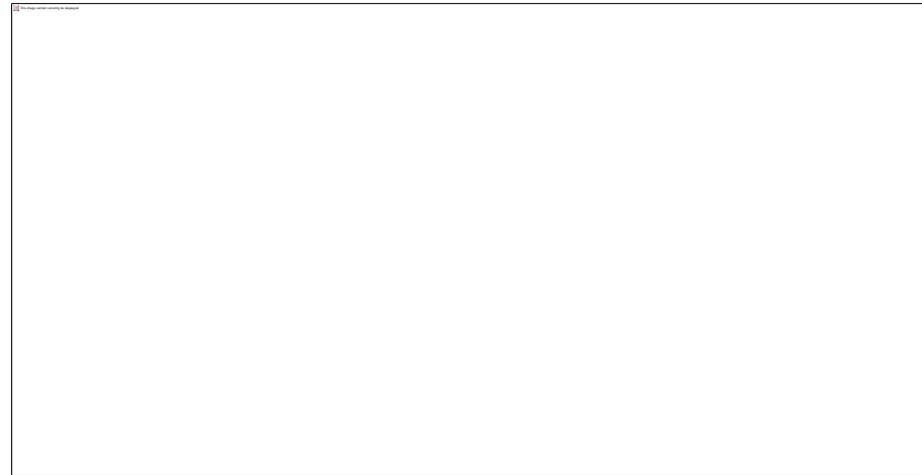
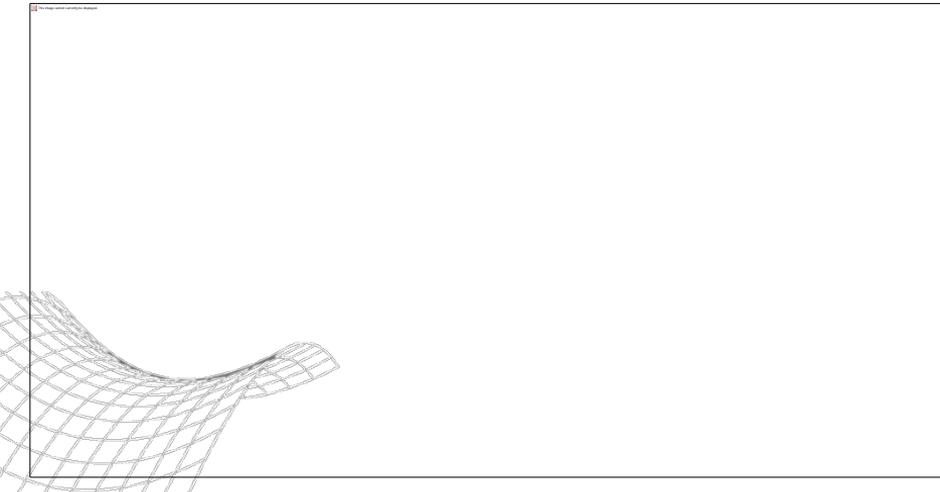
# Analysis - Wireless charging



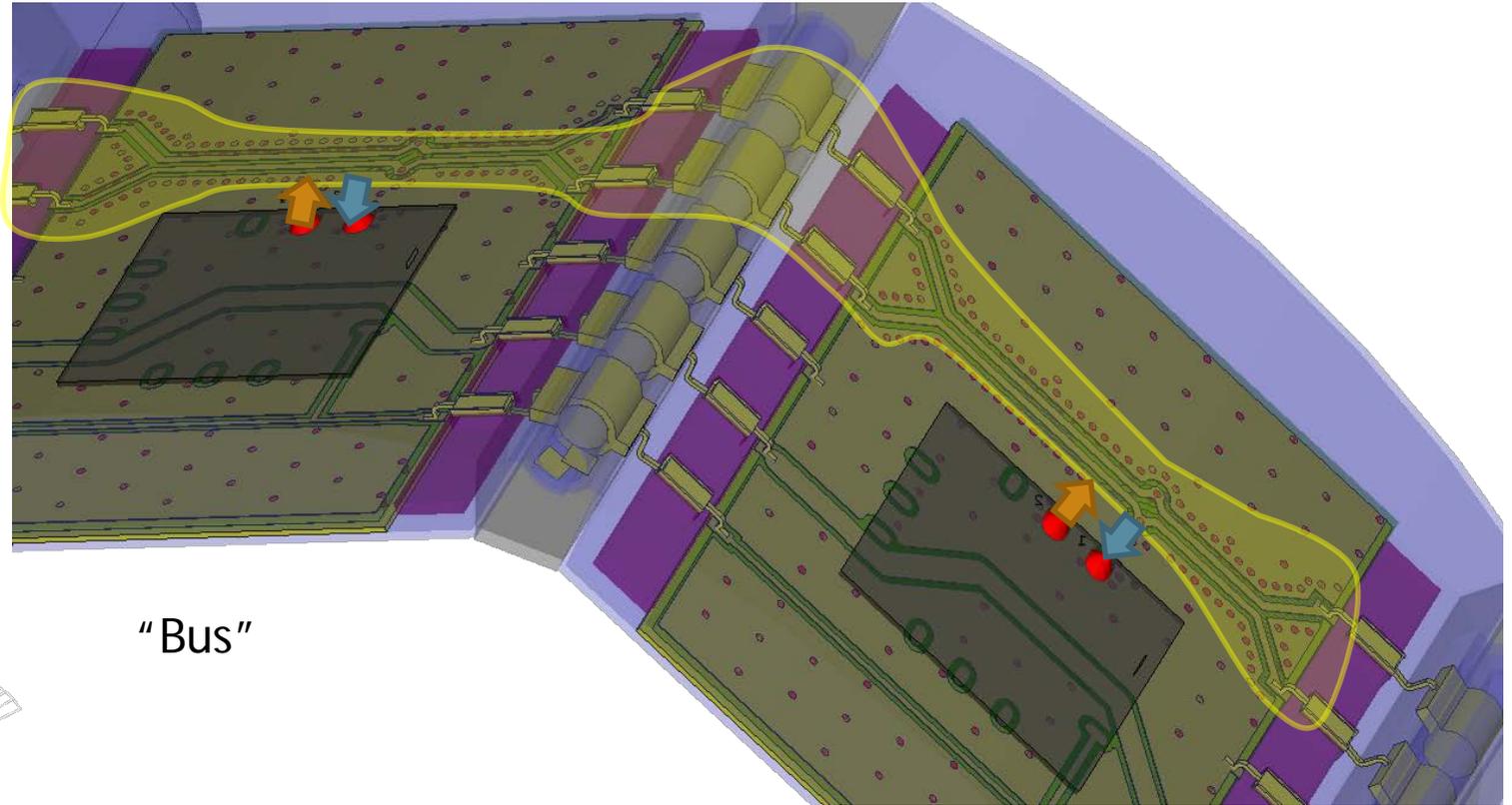
Magnetic Field  
@ 6.78MHz

YZ cut-plane

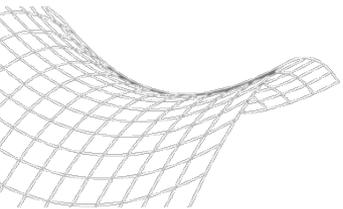
XZ cut-plane



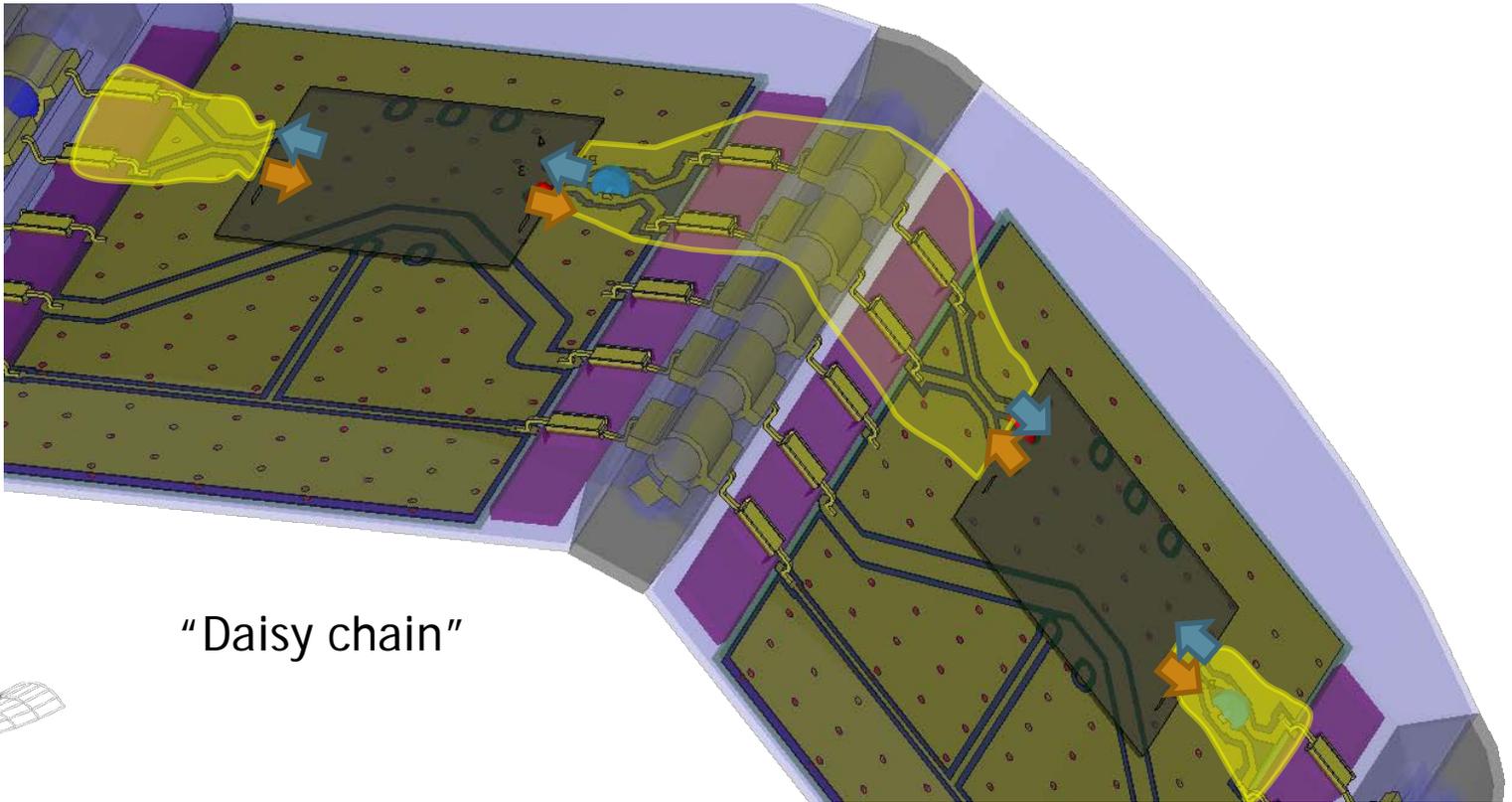
# Analysis - Modular electronics



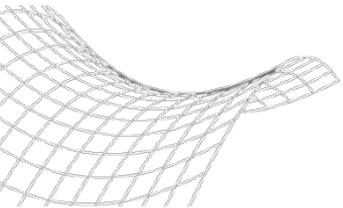
"Bus"



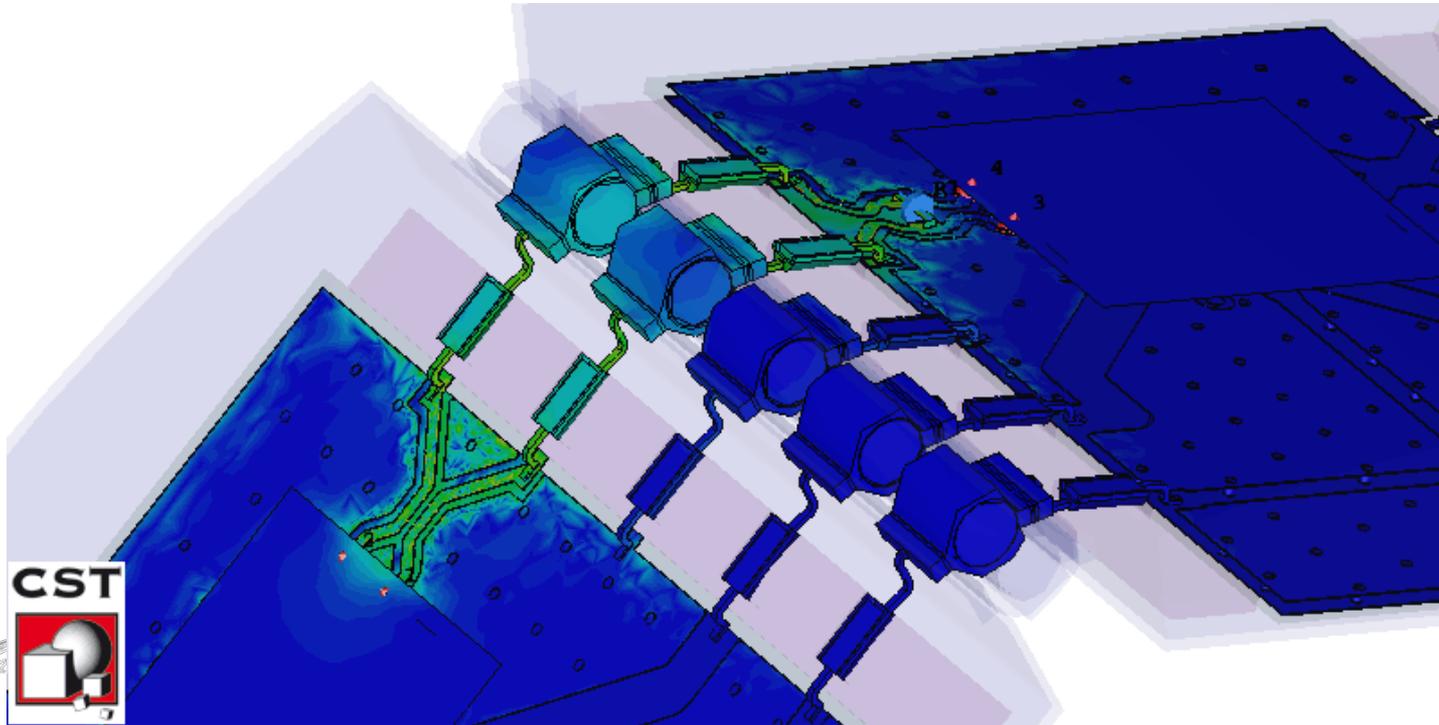
# Analysis - Modular electronics



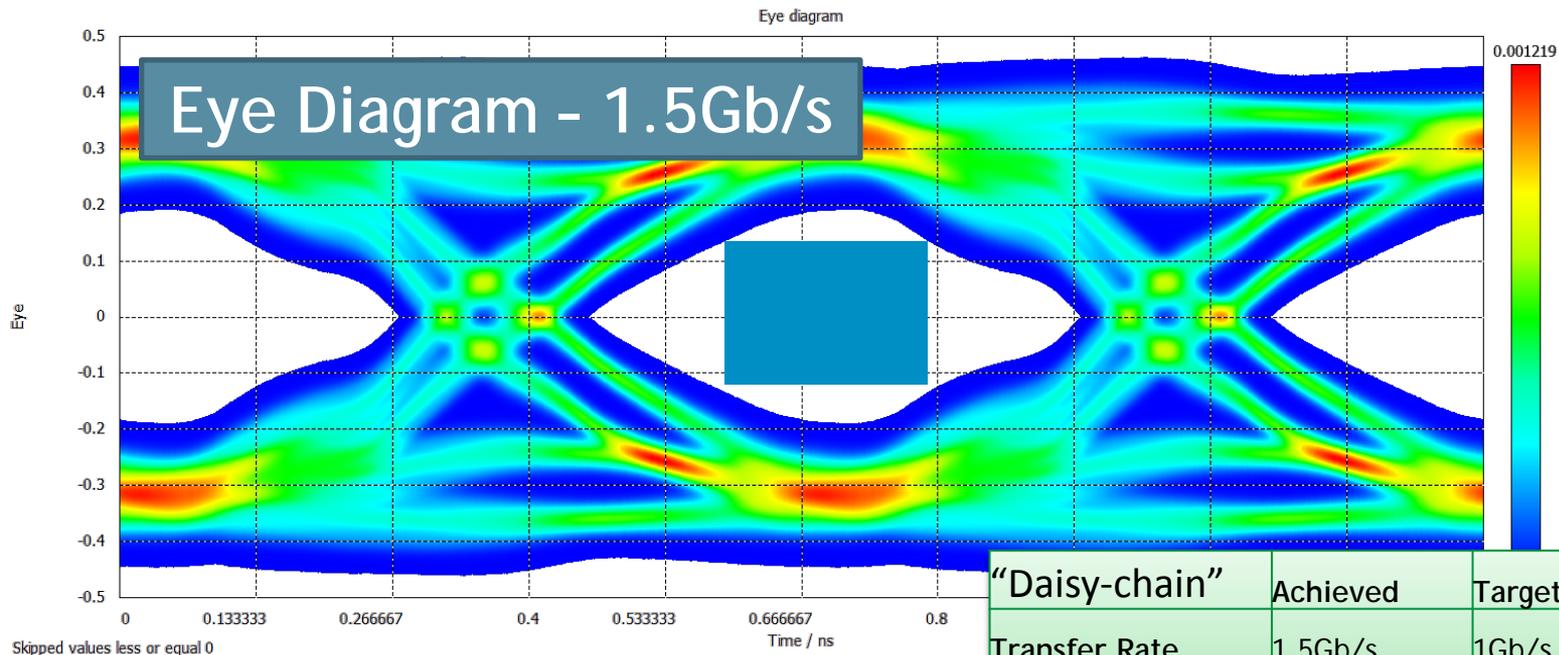
"Daisy chain"



# Analysis - Modular electronics



# Analysis - Signal Integrity



“Daisy-chain”

Achieved

Target

Transfer Rate

1.5Gb/s

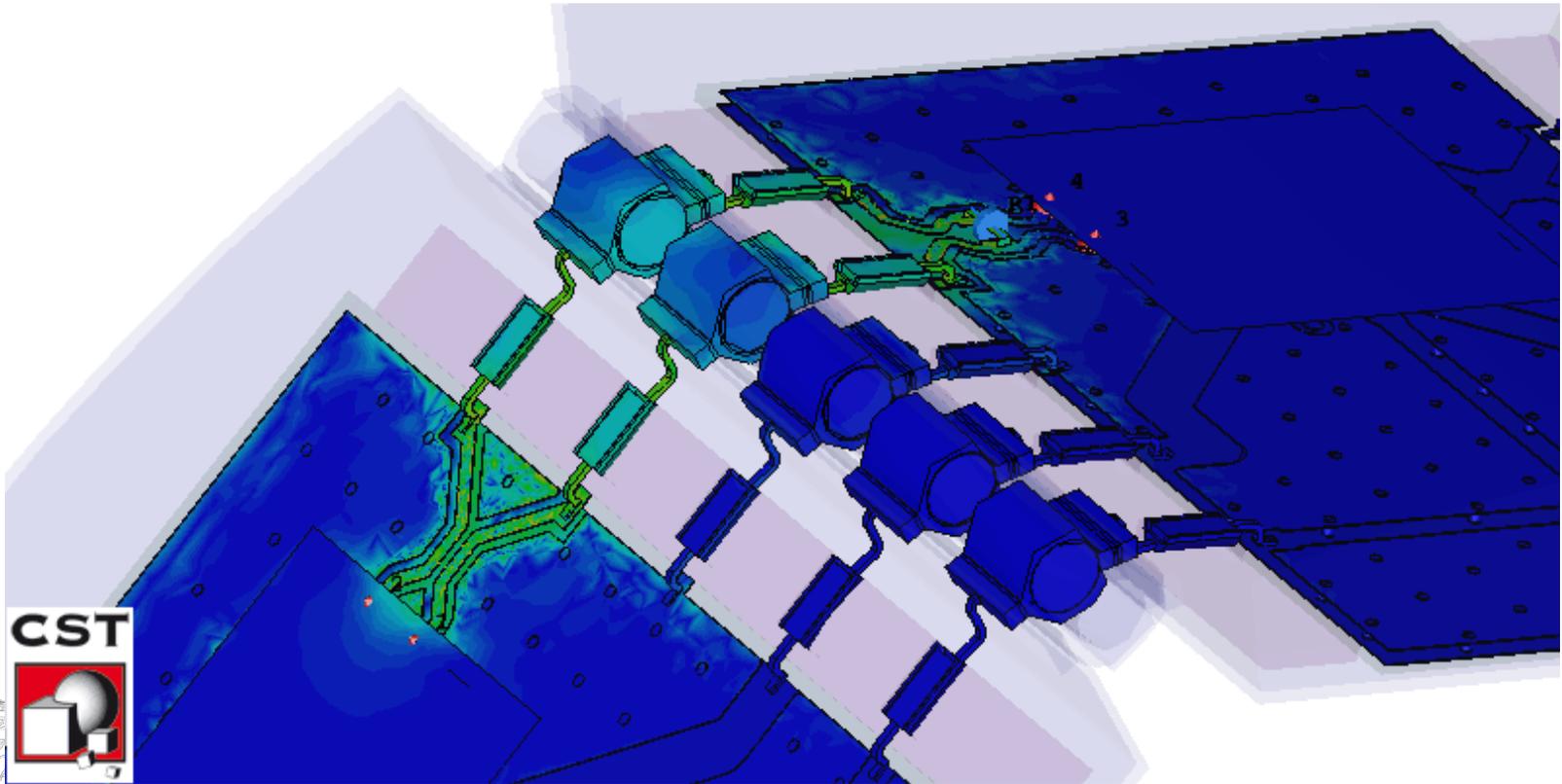
1Gb/s

Eye Opening

0.3mV

0.2mV

# Analysis - Signal Integrity

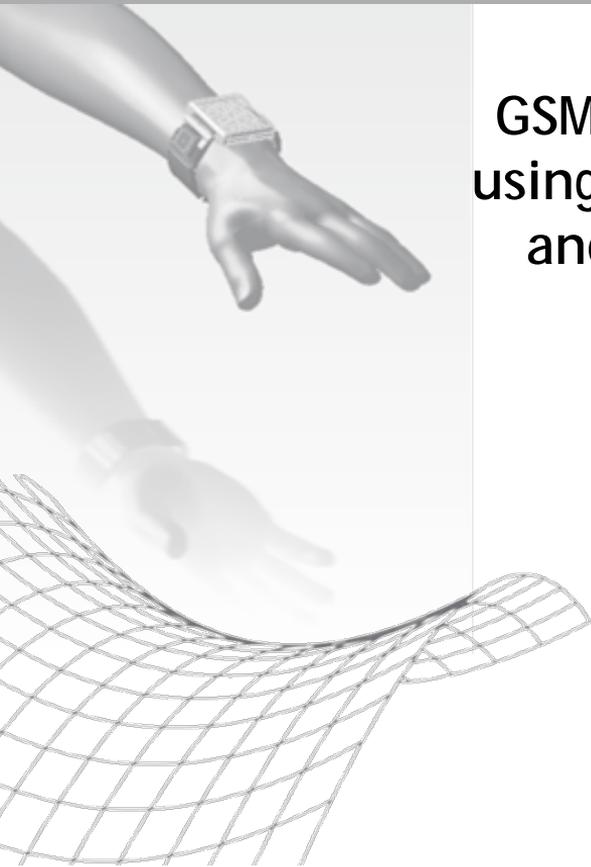


# Designing in a system

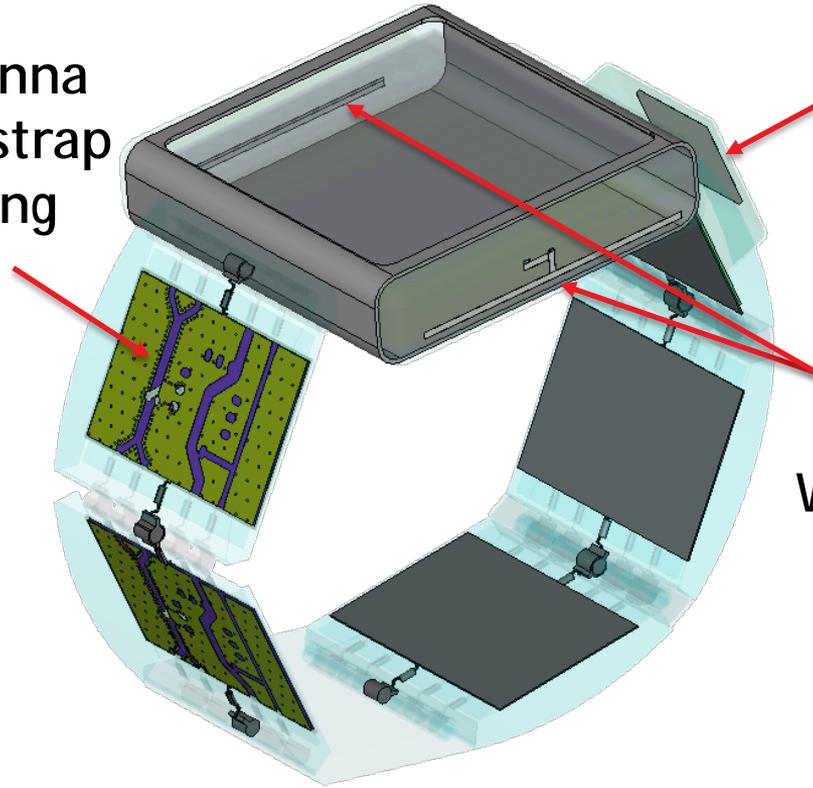


- Each antenna and subsystem design requires assumptions about other system components
- An understanding of the interaction between sub-systems and the shared impact of design choices takes time to evolve
- Each component design needs to be refined, leveraging understanding of this interaction
- An integrated, multi-disciplinary toolset is critical in this process

# First antenna concepts



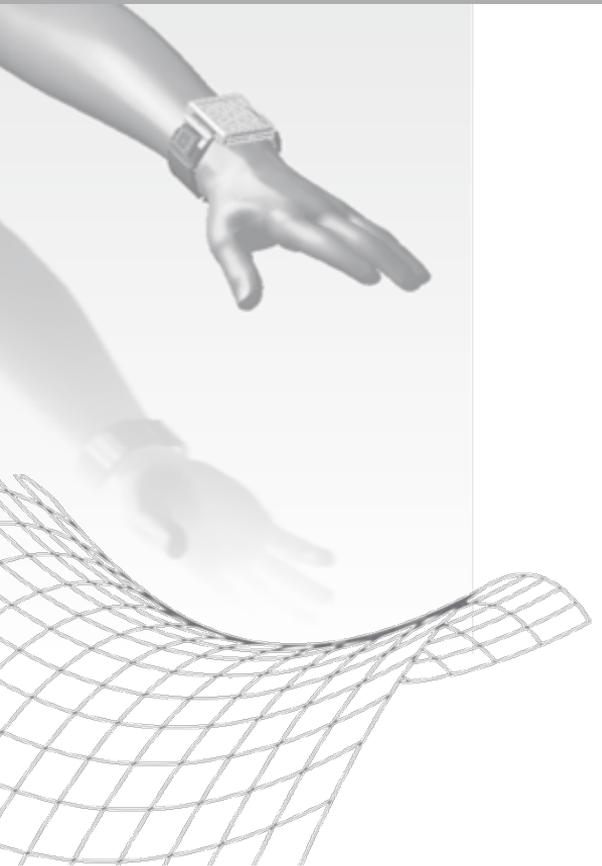
GSM antenna  
using the strap  
and casing  
body



High-  
performance  
GPS module

IFA-type  
antennas for  
Wifi/Bluetooth  
and GPS

# A first design concept



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# Thank you

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