How to select and design the right embedded antenna

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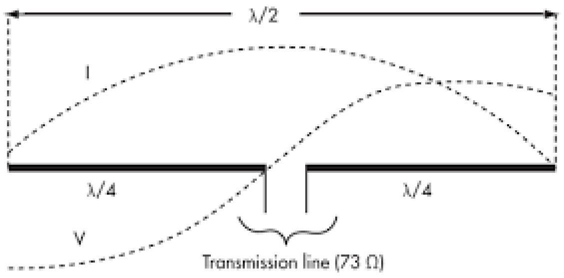
The IP&E Specialist

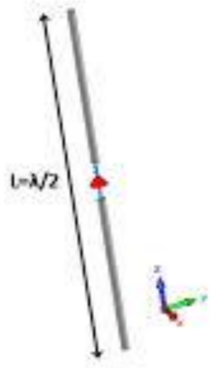
Agenda

- Introduction
- Typical embedded antenna types, pros and cons
- Design multiple antennas in a small device
  - Cellular
  - GNSS
  - Wi-Fi/Bluetooth
- Conclusions

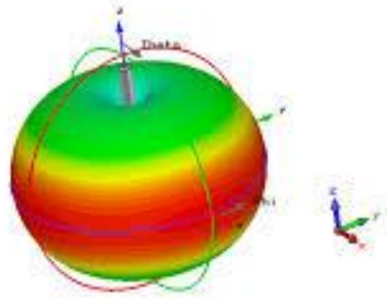
Common antenna types, electrical function



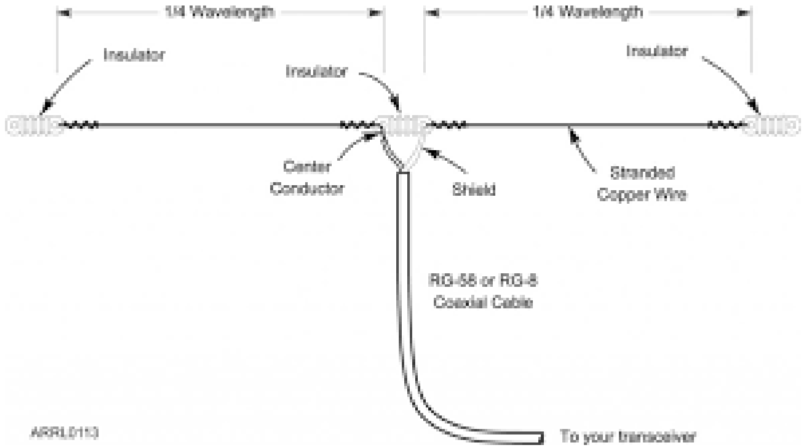
Half wave dipole

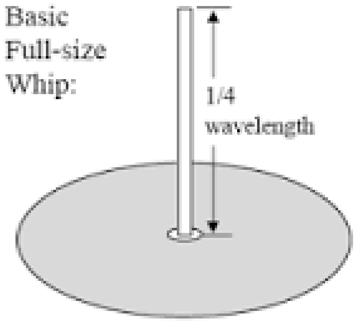


(a)

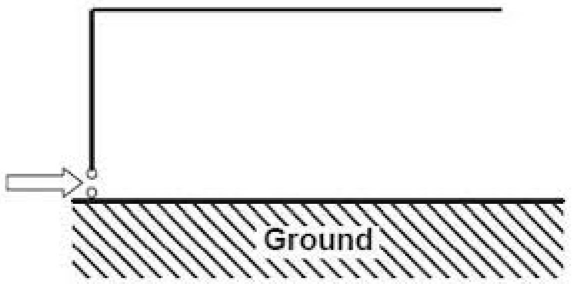


(b)



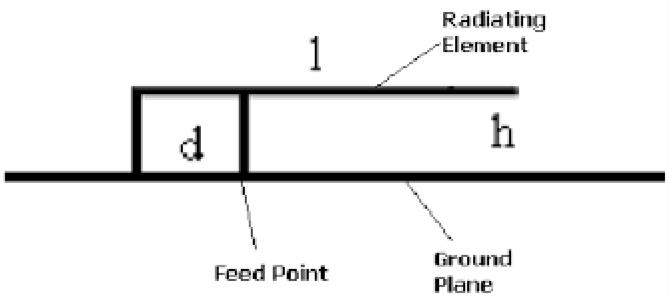


Quarter wave monopole

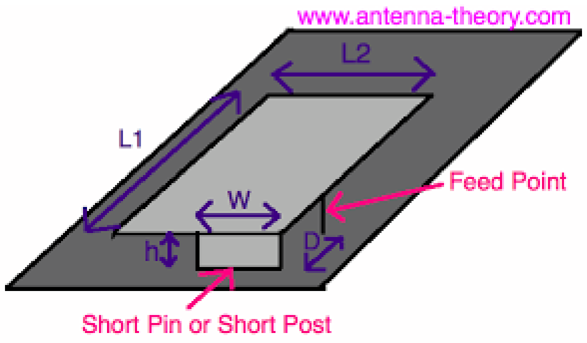


a) Inverted-L Antenna

Inverted L



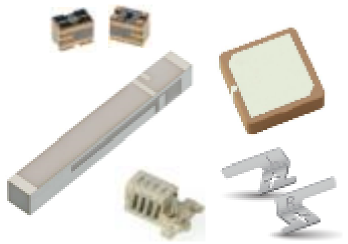
IFA



PIFA

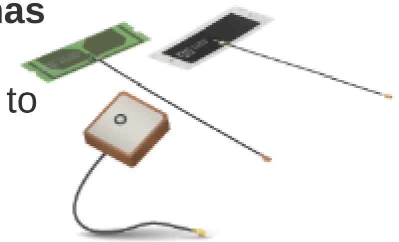
Typical Antenna Types

Embedded Antennas
(inside the device and mounted on the PCB)



Outdoor Antennas
(exposed to weather and harsh environments)

Internal Cabled Antennas
(inside the device and coaxial cable connected to the PCB)

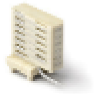
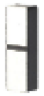
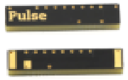


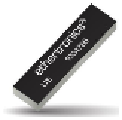
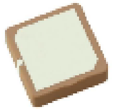
External Antennas
(outside of the device)

PCB Trace Antennas
(typically for 2.4 GHz applications)

Full Custom Solutions (for high volume projects where a catalog antenna doesn’t fit)

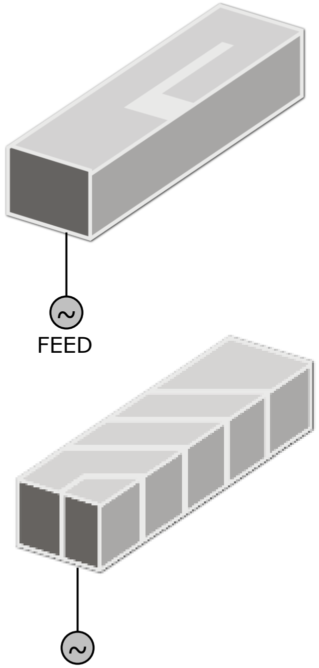
Embedded Antennas types

- Five common antenna solutions for embedded surface mount antenna applications are available.
  - Ceramic/Helical Monopoles  
  - Ceramic magnetic LOOP  
  - Ceramic/FR4 PIFA Multiband 


  - Stamped Metal PIFA  
  - Patch Antennas 

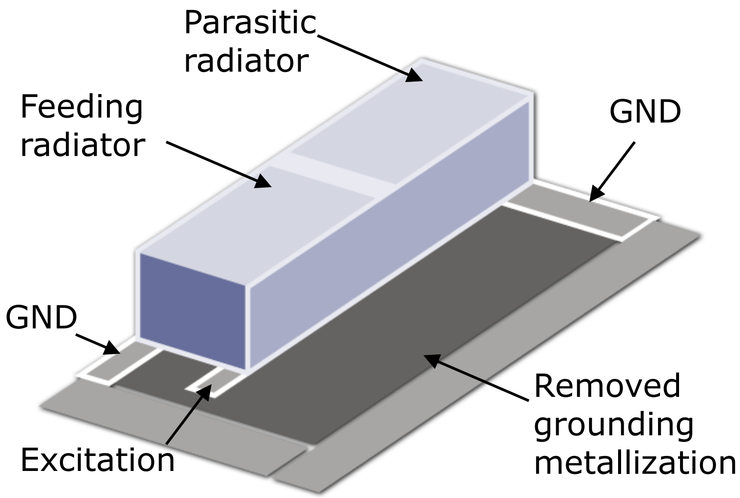
Monopole Chip Antenna vs Loop Antenna

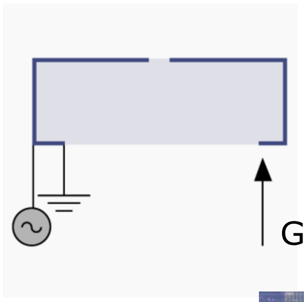
Monopole Antenna



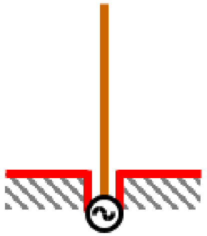
- Typical ceramic antenna structures are variants of monopoles and PIFAs and LOOP antennas
- Monopole antennas perform best on PCB corners
- Magnetic LOOP antennas perform best on PCB edge center position
- For small PCBs (< 40x40 mm) better use a monopole antenna

Loop Antenna

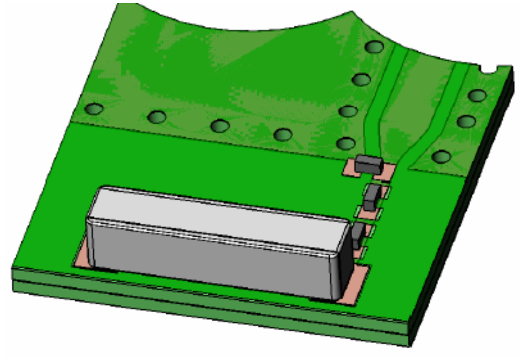




Ceramic Monopoles

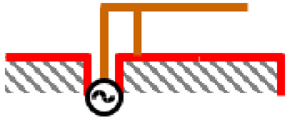


- Ceramic monopoles are the easiest embedded antennas to design-in. Some benefits and trade-offs of the monopole include:
  - Design-in is relatively straight forward and the easiest antenna to integrate
  - Impedance matching is accomplished with series/shunt component
  - Efficiency dependent on fundamental frequency and PCB dimensions
  - Placement limitations on PCB's due to ground plane dependence

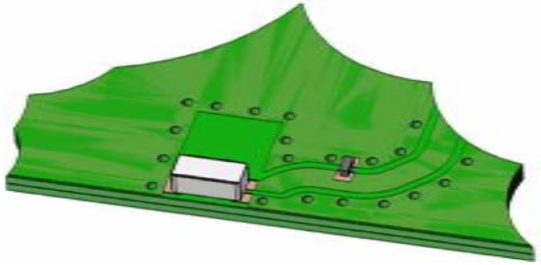


- Ceramic monopoles are *suitable for most devices*
- Ceramic monopoles are *ideally suited for PCB corner and edge locations*
- Ceramic monopoles must be tuned to surrounding mechanics
- Ceramic monopoles require larger ground clearance areas surrounding the antenna for radiation efficiency.
- Ceramic monopoles operate similar to a standard monopole, producing a dipolar radiation patterns.

Ceramic Loop



- Ceramic Loop Antennas offer a distinct advantage over the monopole design by:
  - Offering the highest radiation efficiency
  - Offers the greatest RF gains
  - Being more resilient to hand-loading effects



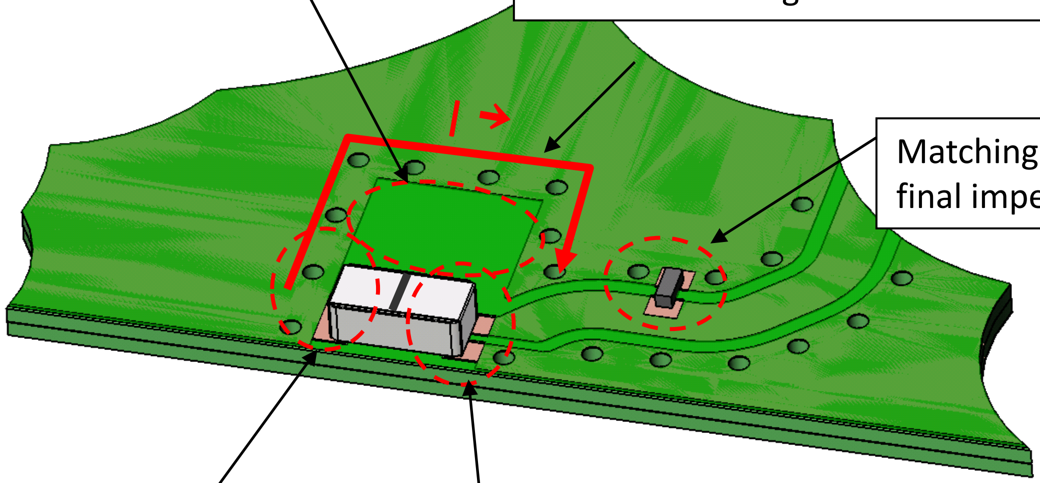
- Ceramic Loops are *the most engineering intensive embedded antenna solution*
  - An experienced RF Engineer is required to design-in the antenna

- Ceramic Loops are *best suited for hand-held applications* due to the high dielectric constant ceramic, immunity to body loading
- Ceramic Loops offer the smallest footprints available on the market

Loop Antenna - Function of GND Clearance area

GC area dimensions determine impedance bandwidth. Larger area results in wider BW.

GC area dimensions also determine the currents return path distance from grounded element back to feed. Bigger distance results in lower frequency due to increased loading effect.



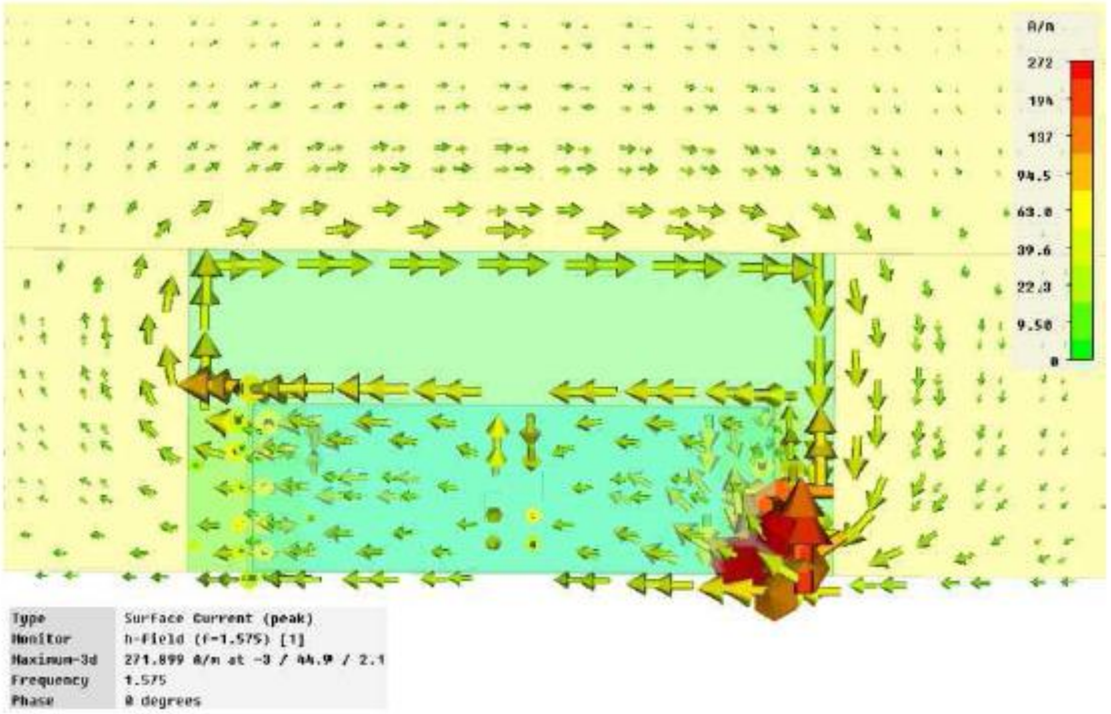
Matching circuits are used for final impedance optimization.

First element is excited by a feed electrode.
With GND-contact this element forms a PIFA type radiator.

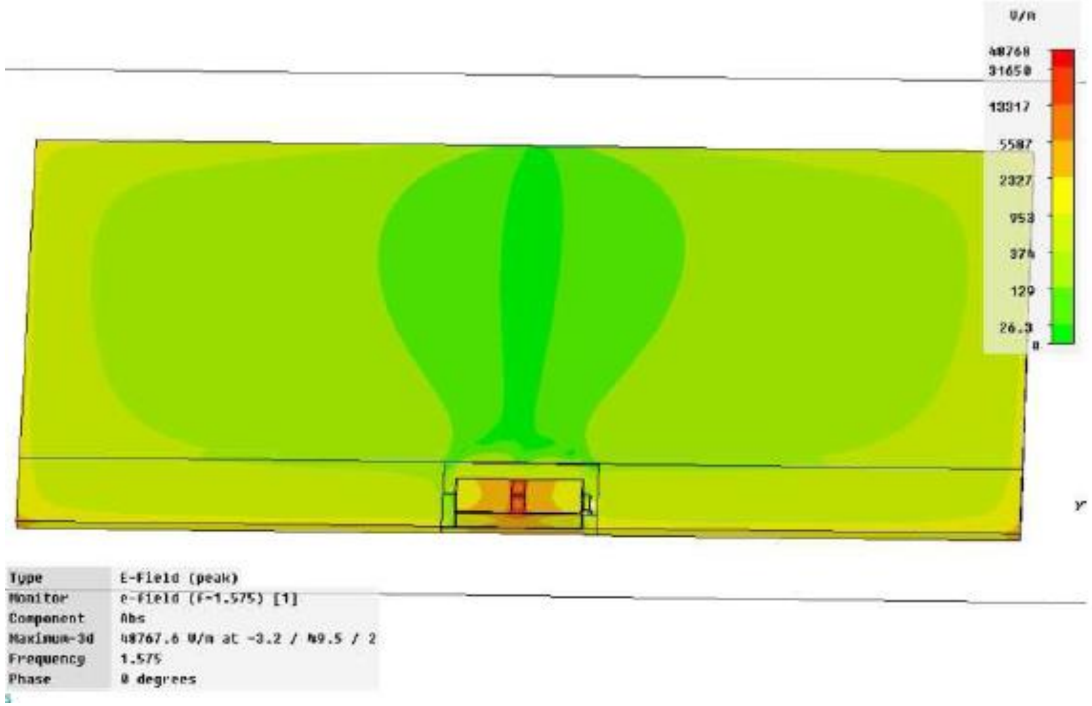
Second grounded element is coupled to feeding element via narrow gap in metallized surface. Amount of coupling determines how much the antenna resonance frequency is loaded.

Surface currents

Current flows from feeding element to loading element and across GC-area back to feed. Reinforces GC area return path tuning mechanism.



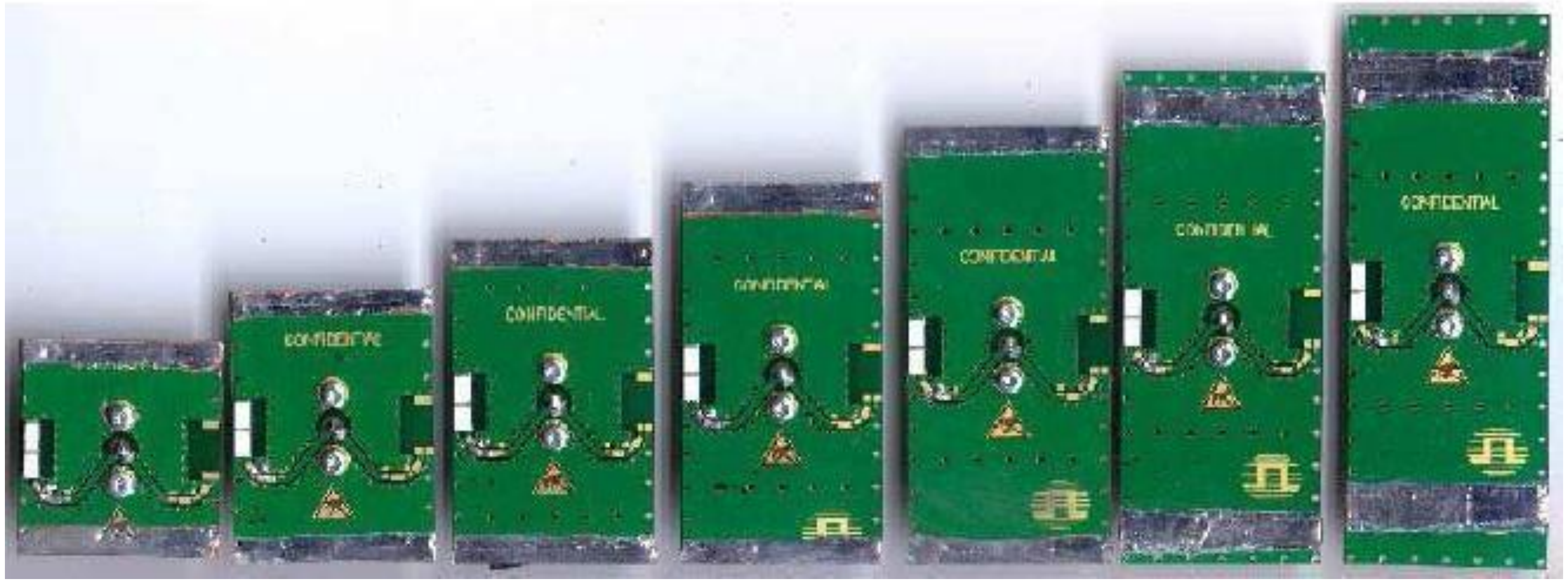
EM fields on board (PCB) – E-Field



- Whole PCB is “hot”
- E-Field maximums at board ends
  - Board edge radiates
  - Best radiation efficiency when board edge length is matched to operating freq wavelength
  - Longer PCB is usually ok but too short will reduce efficiency

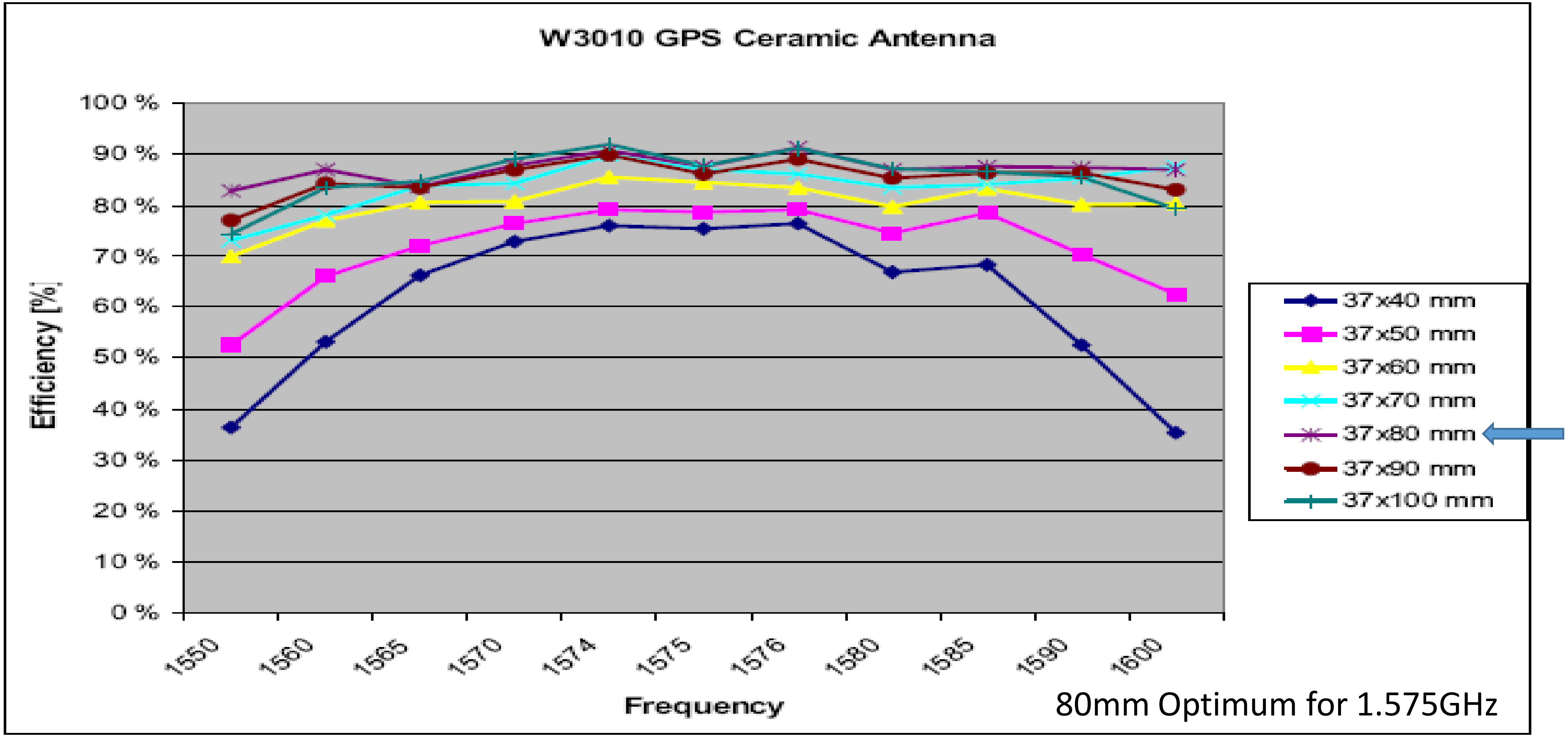
Loop Antenna – PCB length effects

- Ground planes are an integral part of antenna performance
- Pulse W3010 GNSS Antenna example
- 7 Board lengths: 40 to 100 mm



Example courtesy of Pulse Electronics

Loop Antenna – PCB length effects



80mm Optimum for 1.575GHz

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Example courtesy of Pulse

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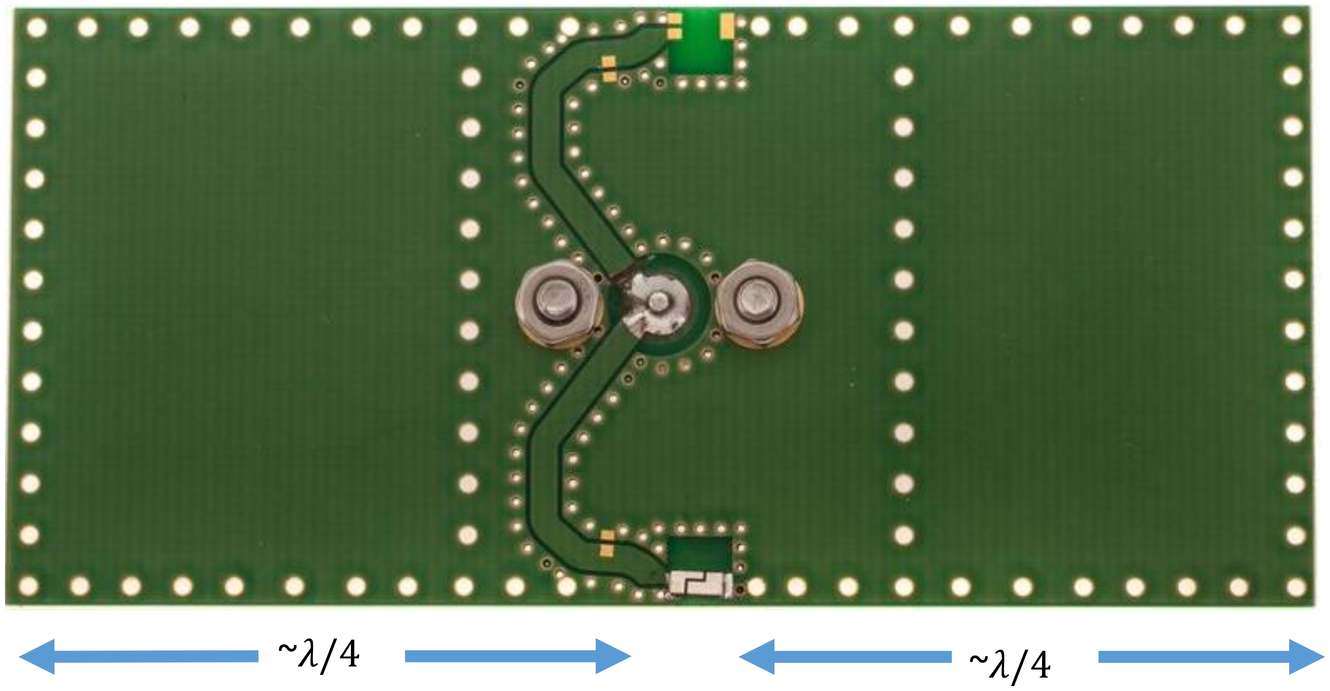
18 APRIL 2024
FHI Leusden

Loop Antenna – PCB length

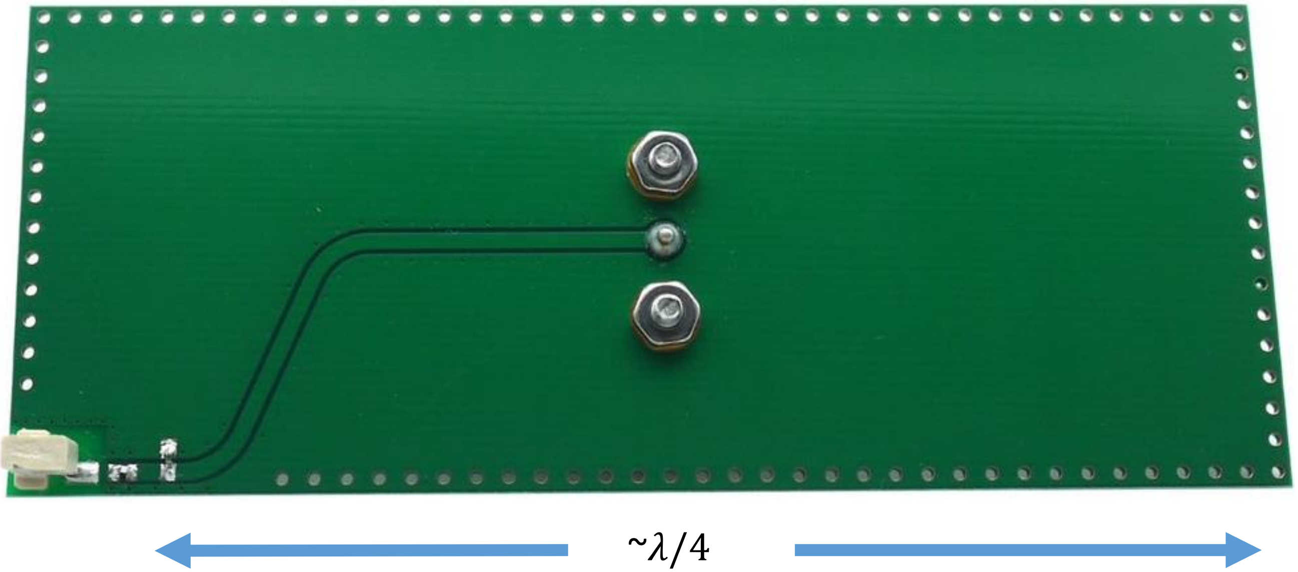


Some guidelines on ideal PCB lengths:

- 868 MHz (ISM): λ= 345 mm → $\lambda/2$= 172 mm
- 1.575 GHz (GPS): λ= 190 mm → $\lambda/2$= 95 mm
- 2.4 GHz (WiFi, BT): λ= 125 mm → $\lambda/2$= 62mm

- Ideal PCB lengths should be ~ $\lambda/2$, but in general not much smaller than $\lambda/4$. For shorter PCBs better use a Monopole Antenna

Monopole/PIFA Antenna – PCB length



Some guidelines on ideal PCB lengths:

- 868 MHz (ISM): λ= 345 mm → $\lambda/4$= 86 mm
- 1.575 GHz (GPS): λ= 190 mm → $\lambda/4$= 47 mm
- 2.4 GHz (WiFi, BT): λ= 125 mm → $\lambda/4$= 31 mm

- To be used typically for < $\lambda/4$ PCB lengths. For much longer PCBs better use a Loop antenna.

Designing multiple antennas in a small device

- Examples of commercially available Telematics Units, Asset Trackers, IoT devices,...

- LTE, 4G, 4.5G, 5G
- Wi-Fi 802.11ac
- BT 5.x (incl. BT LE)
- Hybrid V2X (DSRC and/or C-V2X)
- eUICC SIM (e-SIM)
- GPS, GLONASS, Galileo, Baidou

GPS | 4G | Bluetooth | W-LAN

- LoRaWAN communication
- Cellular 3G communication
- Wi-Fi hotspot
- Built-in GPS

Antenna design and positioning should be done starting by the most critical ones first:

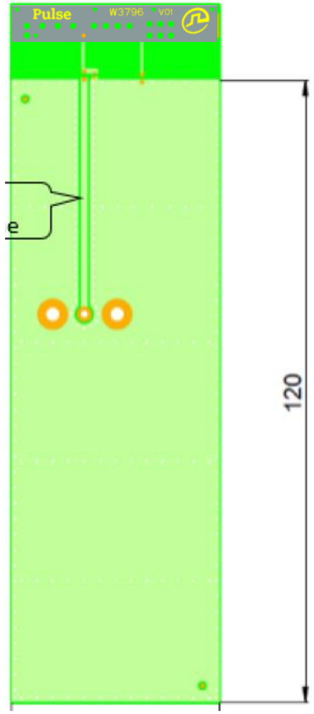
1. Cellular antenna
2. GNSS antenna
3. Wi-Fi/Bluetooth antenna

Think of antennas at the very early stage of your design!!!

Multiple antenna placement - Step 1→ 4G/5G

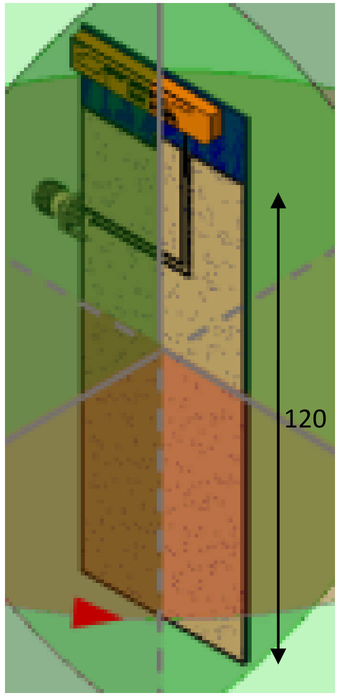
- PIFA Antenna, most common solution

Pulse W3796

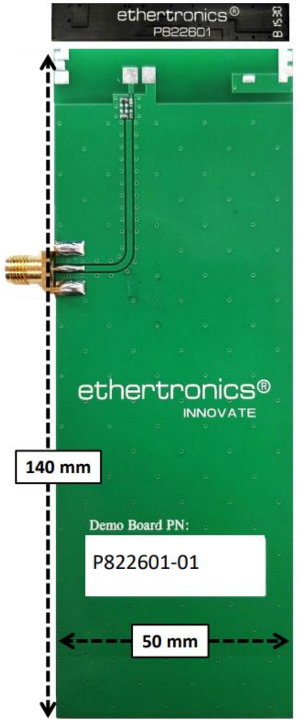


Taoglas PCS.06.A

TE 2108784-2



AVX P822601

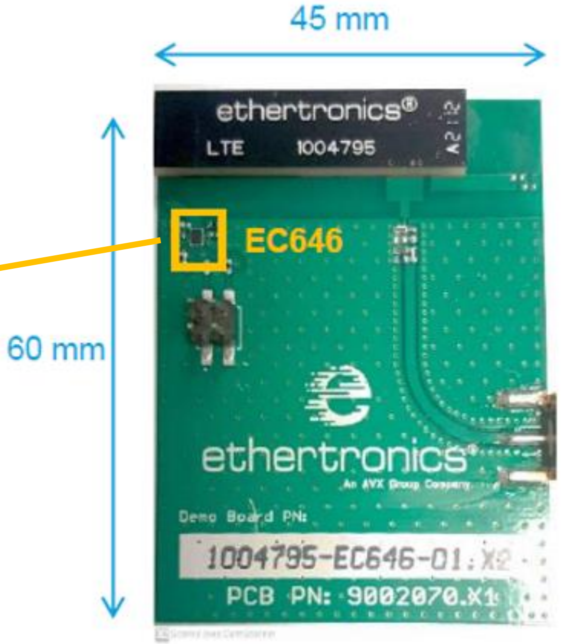


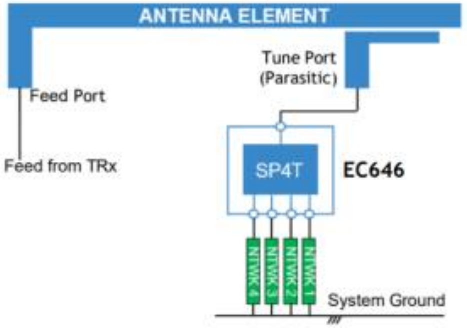
λ/4@700 MHz = 10.7 cm

For 5G applications λ/4@617 MHz = 12cm

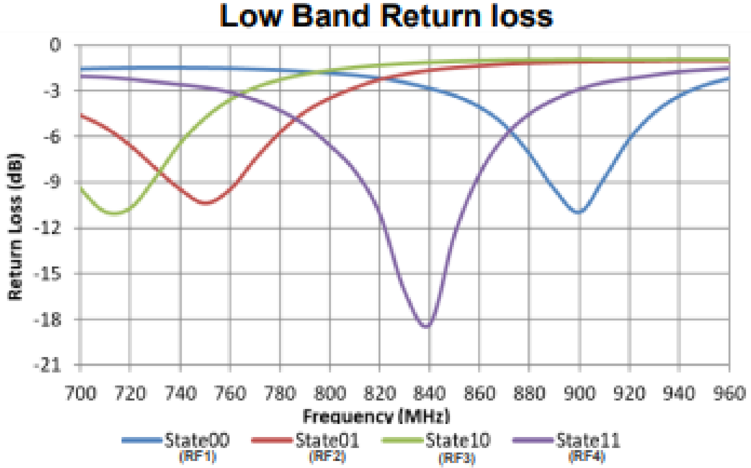
Kyocera AVX LTE Band Switching Example

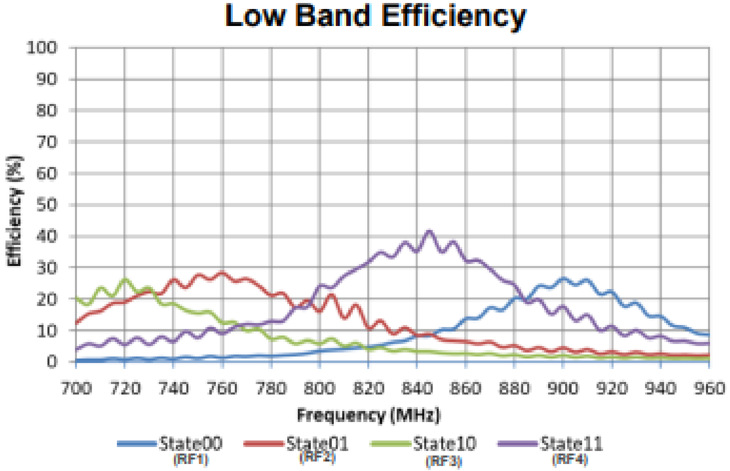
- For small PCBs





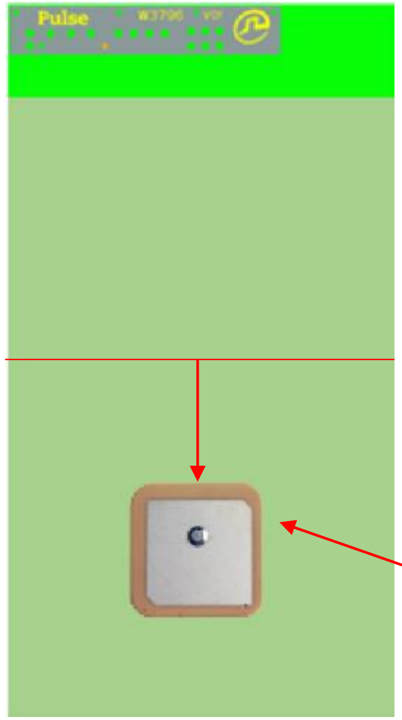
S0	S1	RF1	RF2	RF3	RF4
Low	Low	ON	OFF	OFF	OFF
Low	High	OFF	ON	OFF	OFF
High	Low	OFF	OFF	ON	OFF
High	High	OFF	OFF	OFF	ON



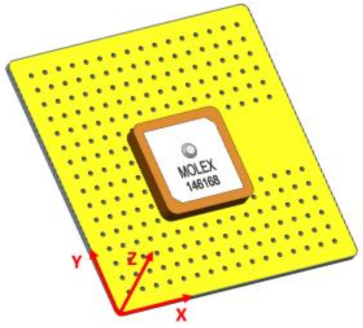


Multiple antenna placement - Step 2 → GNSS

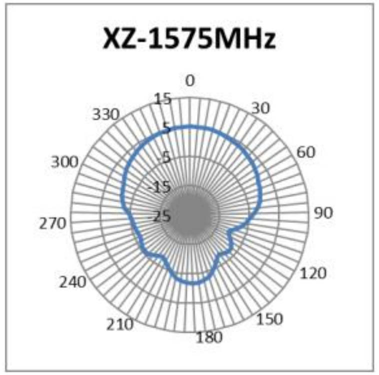
- Option 1 – Ceramic Patch antenna



- Typically available in sizes between 9 x 9 mm and 35 x 35 mm (most common being 18 x 18 mm and 25 x 25 mm).
- For fixed installations heading the sky gives best performance thanks to high gain and circular polarization
- Stacked-patches covering L1+L2/L5 frequencies for higher accuracy

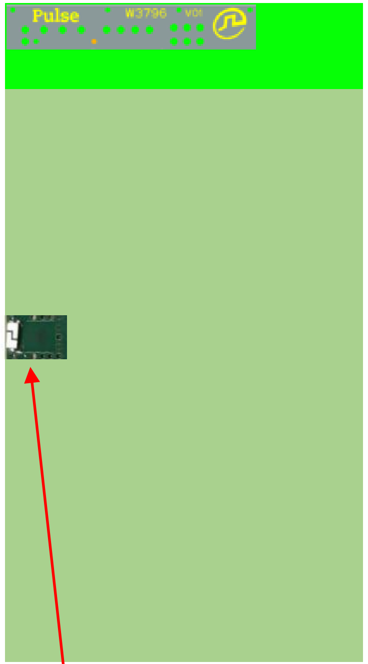


- To be positioned in the lower half of the PCB to provide spatial separation between cellular and GNSS antenna



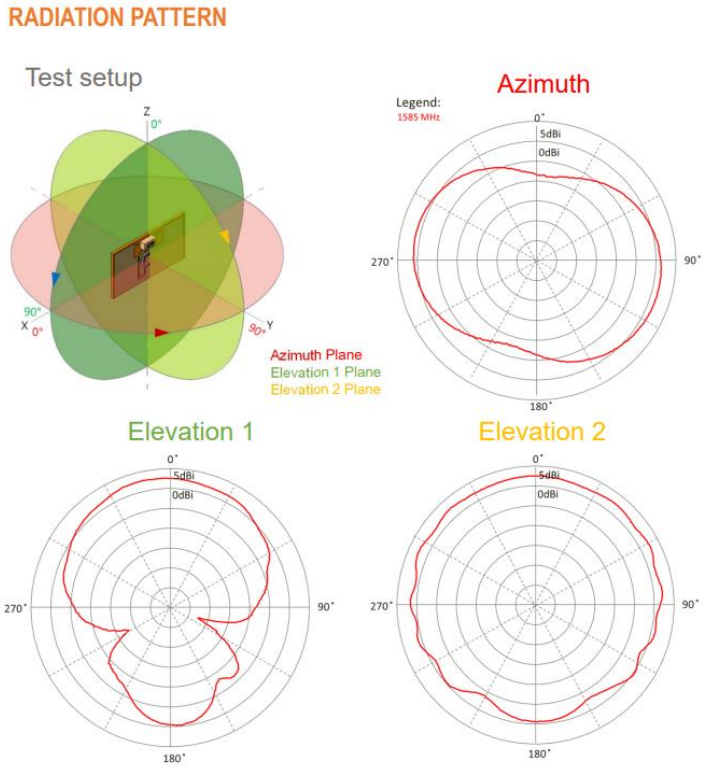
Multiple antenna placement → GNSS

- Option 2 – Ceramic loop antenna



- Omnidirectional pattern, ideal for application where installation is not controlled (e.g. wearables)
- Low profile and small footprint on the PCB, for densely populated boards
- Off-the+shelf antennas covering L1+L2+L5 frequencies (i.e. Kyocera AVX M830120, Pulse W3244,...)

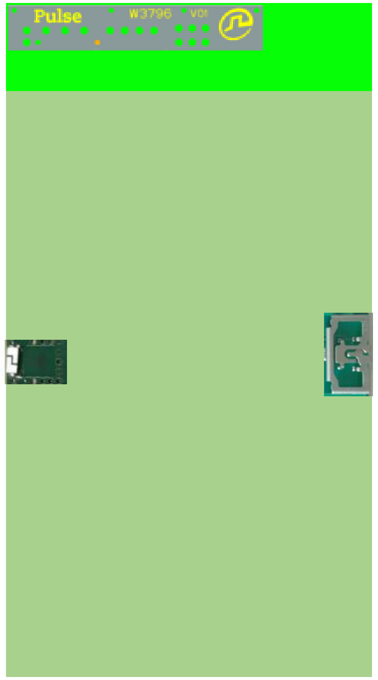
Example: TE 2108824-1



- To be positioned on the edge center

Multiple antenna placement – Step 3 → Wi-Fi/BT

- Loop antenna for best performance

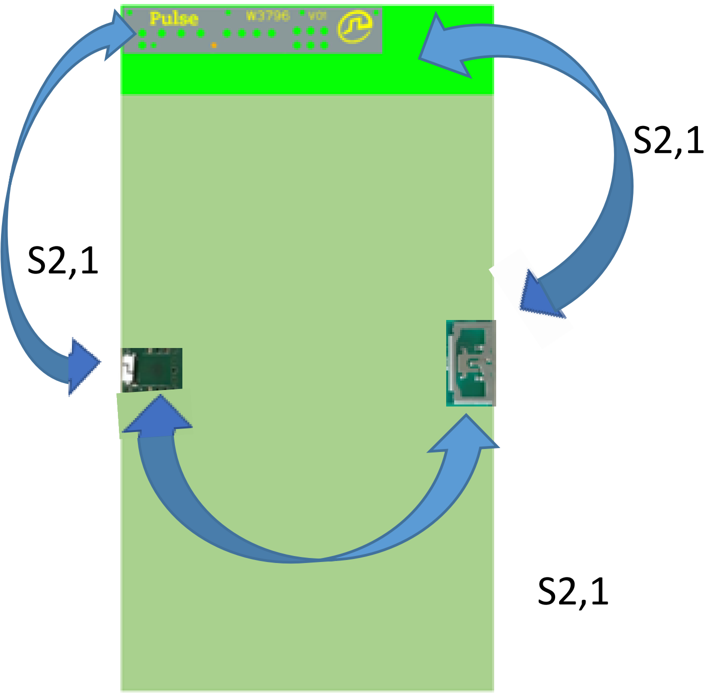


- Electrical size at Wi-Fi/BT frequencies makes it ideal for a loop antenna ($\lambda/2$= 62mm)
- Better performance and more immune to detuning compared to PCB antennas
- Ideal solution for wearable devices
- 2 options available:
  - Ceramic chip antenna
  - Stamp metal antenna

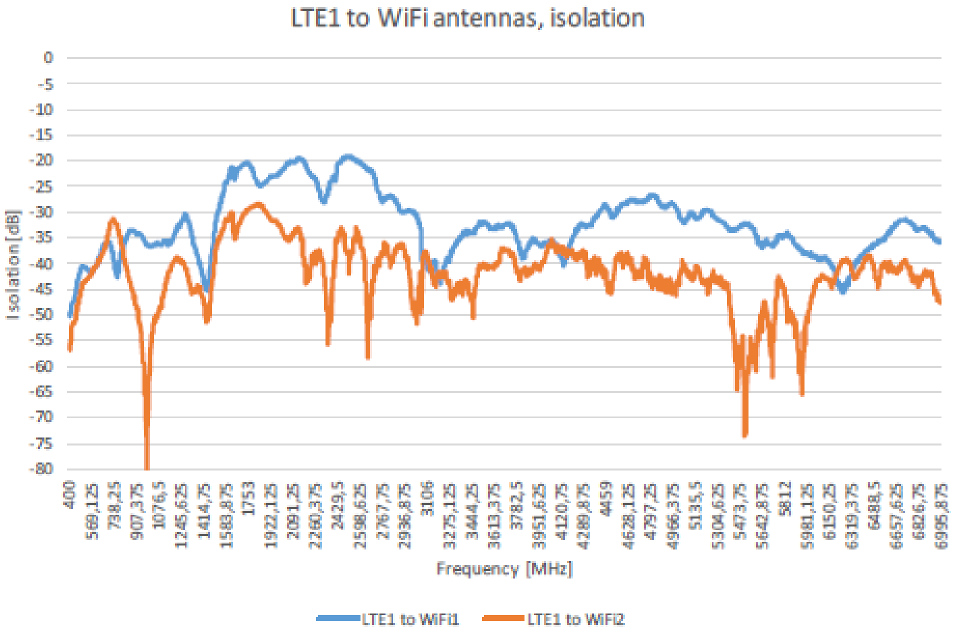
- To be positioned on to the edge center

Isolation

- Antenna-to-Antenna Coupling



- When designing multiple antennas in a single device it‘s important to measure antenna-to-antenna coupling, or S2,1
- Too low isolation reduce antenna efficiency since a portion of power is coupled to adjacent antennas instead of being radiated, or may create intereference (especially to GNSS receiver)
- Ideal case would be to have S2,1 < -15dB (< -20dB even better)



S2,1 measurement
Example courtesy of Pulse

Conclusions

- No embedded antenna will work for all device types
  - Monopole antennas better suited for small devices
  - Loop antennas give best performance if GND plane is big enough
- In case of multiple wireless technologies inside the same device start with the most complex
- Isolation between antennas should be measured and kept as low as possible (especially critical for GNSS)

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Thank you

- Visit us throughout the day to discuss your antennas and wireless modules needs. Stand 2
- Live antenna measurements with portable VNA
- Please send your questions and enquiries to:

  edoardo.genovese@de.ttiinc.com • ttieurope.com

- *Check our antenna stock on the TTI Europe website:*

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