Towards Miniaturisation of UWB Antennas

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Overview

- Introduction
- Antenna Size and Bandwidth
- Miniaturised Planar UWB antennas
  - Monopoles
  - Half Disc Monopole Antennas
  - Tapered Slot Antennas
- Discussion

Introduction – QMUL Antenna & EM Group

- The group was found in 1968
  - Currently: 5 Academic Staff, 8 RAs and 18 PhD students;
  - Funding over this RAE period: > 4M; Current EPSRC funding: >1.39M;
  - Wide links with industry and institutions
- Research topics
  - **Covering wide areas in antenna engineering and EM applications**
- Facilities:
  - 3 Anechoic Chambers (500 MHz – 350 GHz),
  - 2 CATRs (5GHz – 350GHz),
  - NSI 0.9m x 0.9m NF scanner.

Introduction – UWB Antennas

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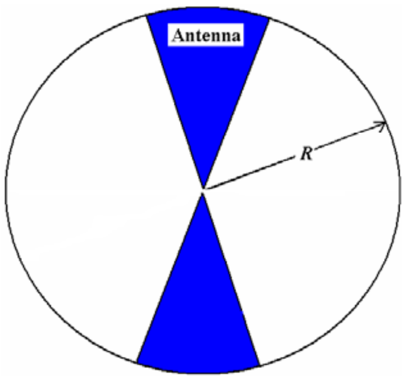
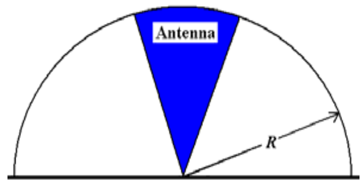
- **The quest for small UWB planar antennas**
  - Rapid development of UWB wireless communication systems has led to the increasing demand for miniature UWB antennas.
  - Provide flexibility to device designers and easily integrates into space-limited systems such as home-cinema equipment, Portable computers, PC peripherals, PDAs, mobile phones and UWB USB.
- **Main Effects of Size reduction on Antenna Performance:**
  - Gain, bandwidth and efficiency

Antenna Size and Bandwidth

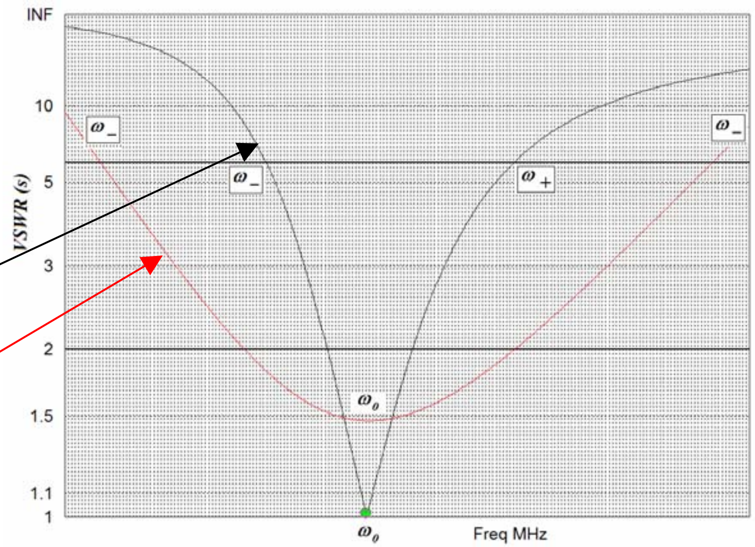




Ground Plane

R **is the radius of the boundary sphere around an antenna**

$$FBW = \frac{\Delta f_{3dB}}{f_{0dB}} = \frac{1}{Q}$$



Higher Q, narrower FBW

Lower Q, wider FBW

Antenna Size and Bandwidth

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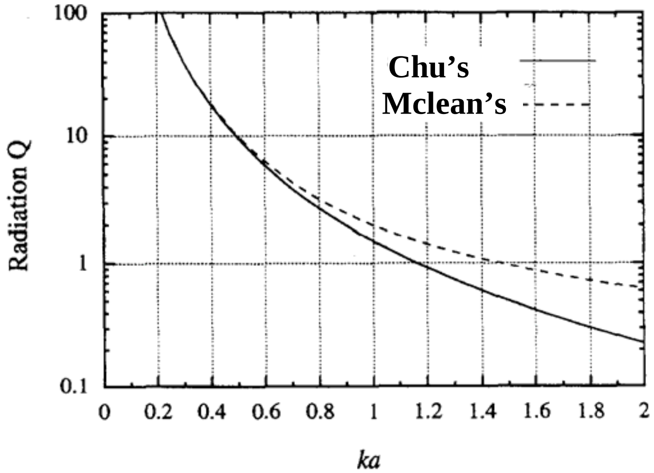
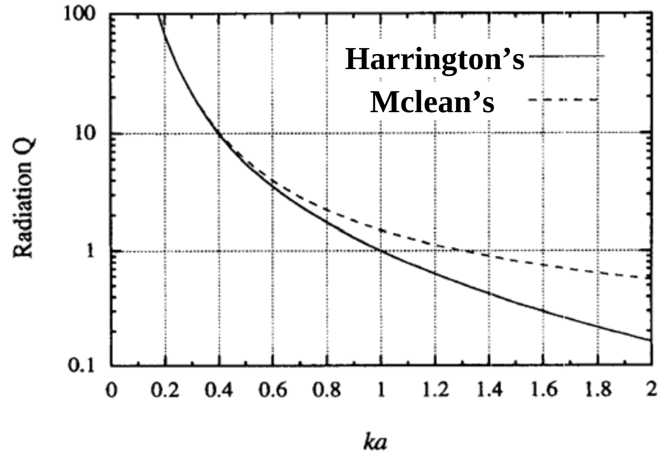
Minimum attainable radiation Q of a linearly polarized antenna

$$Q = \frac{1}{(kR)^3} + \frac{1}{kR}$$



Minimum attainable radiation Q of a circularly polarized antenna

$$Q = \frac{1}{2}\left(\frac{1}{(kR)^3} + \frac{2}{kR}\right)$$



The lowest values of Q is limited by the size of an antenna!

[1] L. J. Chu, "Physical Limitations of Omni-directional Antennas," *J. Appl. Phys*., Vol. 19, pp. 1163-1175, Dec. 1948
[2] R. F. Harrington, "Effect of antenna size on gain, bandwidth and efficiency," *J. Res. Nut. Bur. Stund.*, vol. 64-D, pp, 1-12, Jan./Feb. 1960.
[3] J. S. McLean, "A Re-Examination of the Fundamental Limits on the Radiation Q of Electrically Small Antennas," *IEEE Trans. Antennas Propagat*., Vol. 44, pp. 672-676, May 1996

Antenna Size and Bandwidth

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- **Both Chu-Harrington and McLean limits indicate that reducing the size of the antenna leads to the decrease of the bandwidth of the antenna.**

Challenge: Reducing antenna size while retaining UWB property!

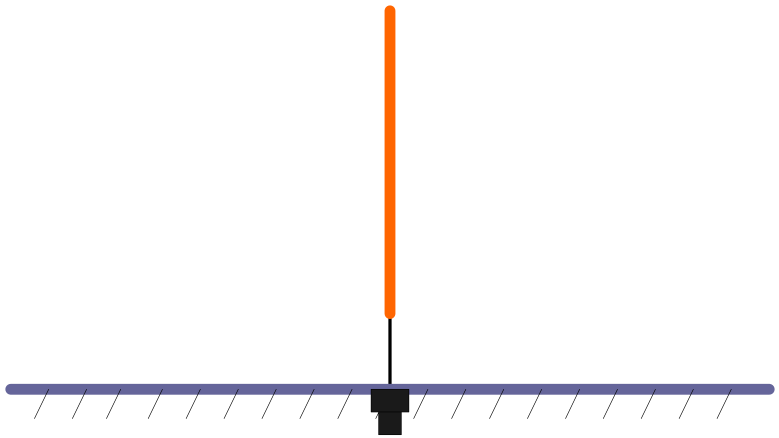
- **In practice, a variety of fat element monopoles were found to provide broad impedance bandwidth!**

Monopoles

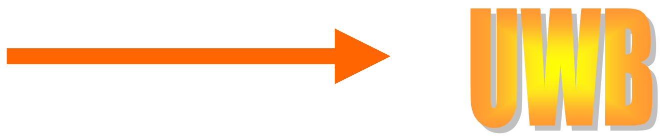
Classical Broadband Antennas

Straight wire monopole

Bandwidth: *≈10%*



Replacing the *wire element* with a *planar element*



Monopoles

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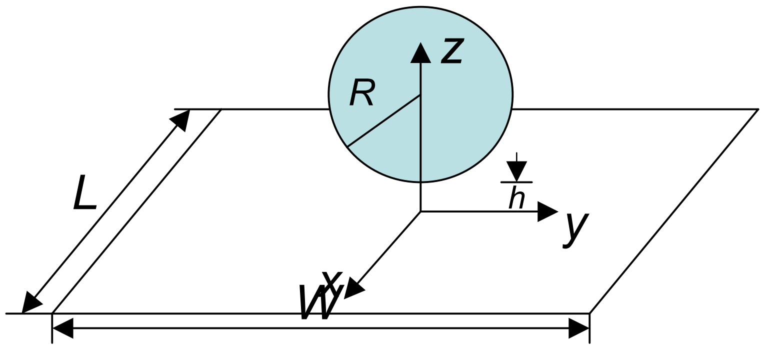
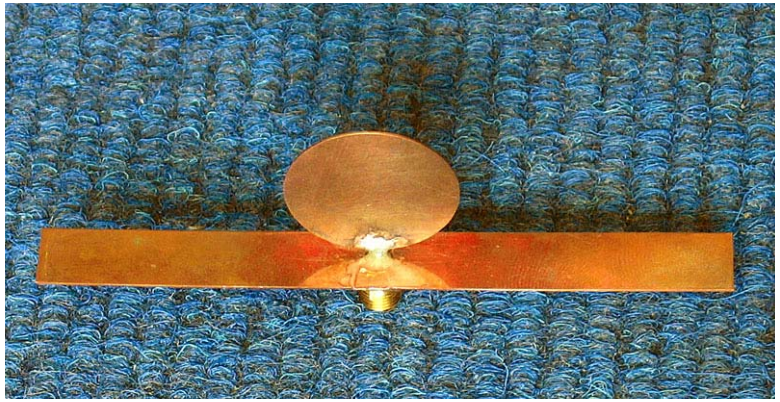
Circular disc monopole-- ***Vertical type***



Geometry of the antenna



R=12.5mm, *h*=0.7mm, *W*=100mm and *L*=10mm

wide bandwidth, satisfactory radiation properties, simple structure, low cost

Non-planar

Planar Monopoles

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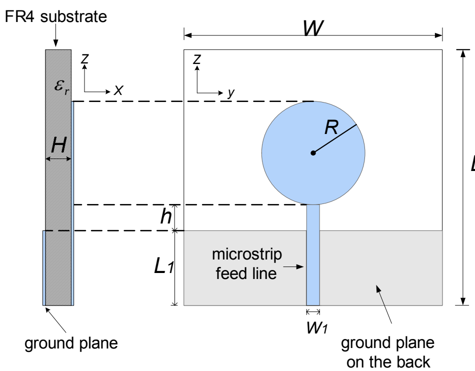
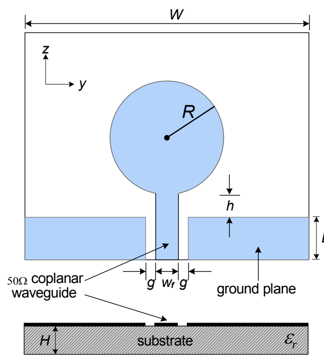
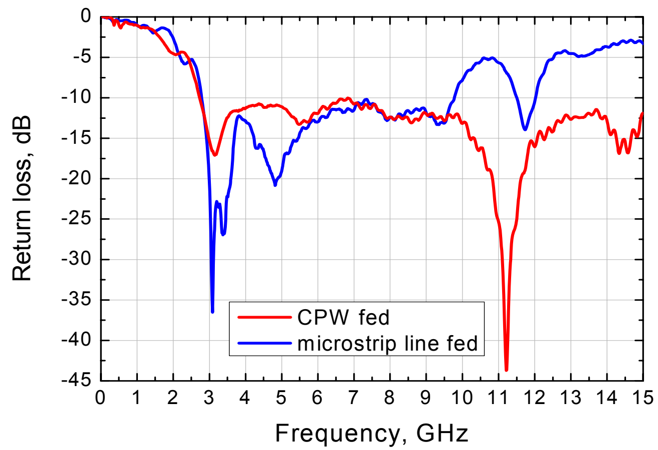
- Optimising the topology of planar antennas to reduce antenna size while retaining UWB.
- CPW-fed disc was found has a better impedance matching over microstrip-fed disc monopole.







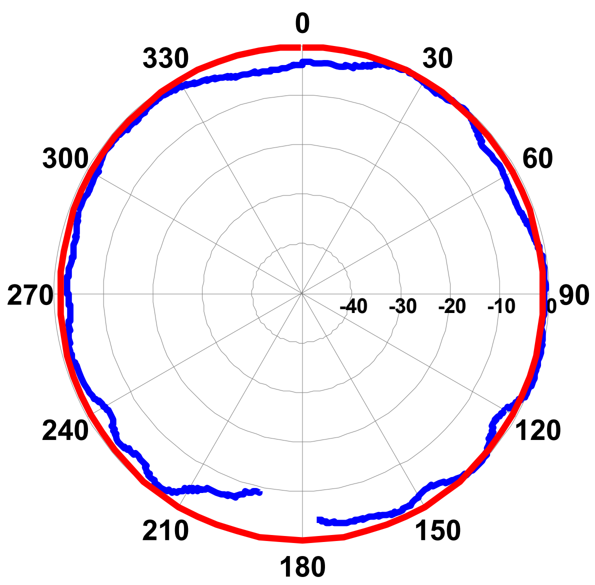
47mm×41mm with a dielectric constant of 4.7

CPW fed (2.73GHz-15GHz)
Microstrip fed (2.78GHz-9.78GHz)

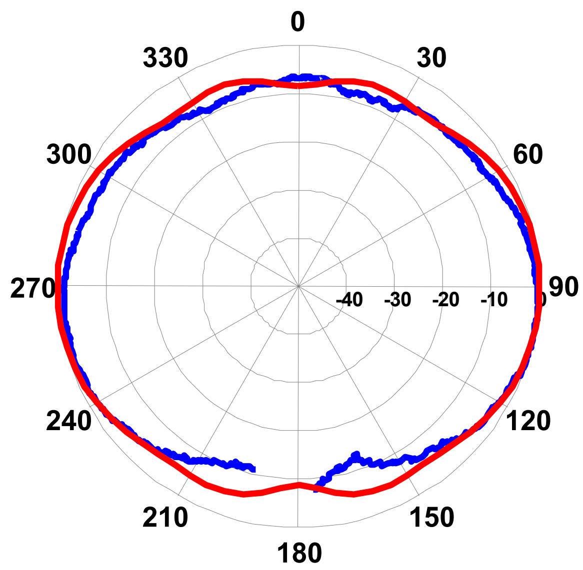
1.J. Liang, C Chiau, X. Chen and C.G. Parini, "Printed circular disc monopole antenna for ultra wideband applications", Electronic Letters, vol. 40, pp.1246-1248, September, 2004.

Radiation Patterns – CPW fed

- The *H*-plane pattern of the CPW-Fed disc monopole antenna is omni-directional at 3 GHz but distorted at 8.8 GHz



At 3 GHz



At 8.8 GHz

The simulated (red line) and measured (blue line) H-plane radiation patterns of CPW-Fed disc monopole antenna

Measurement of Monopoles

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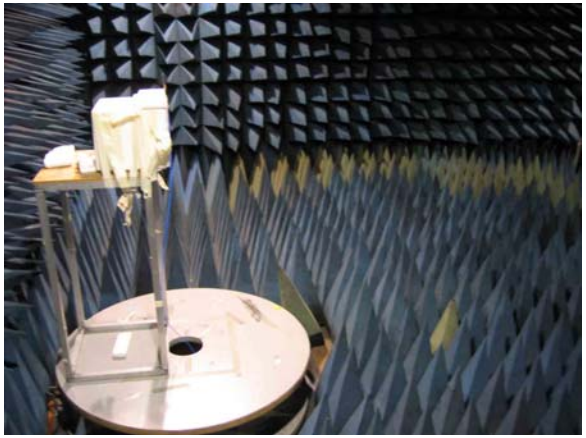
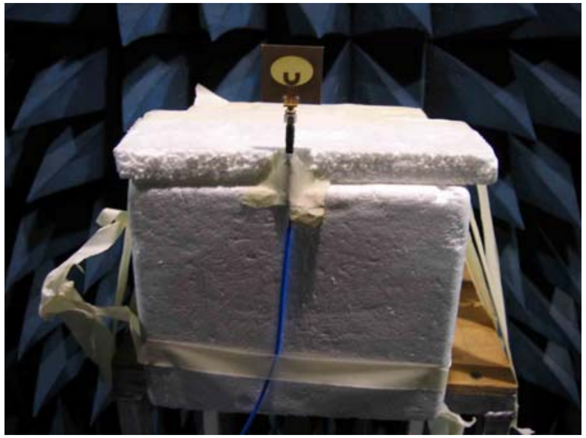
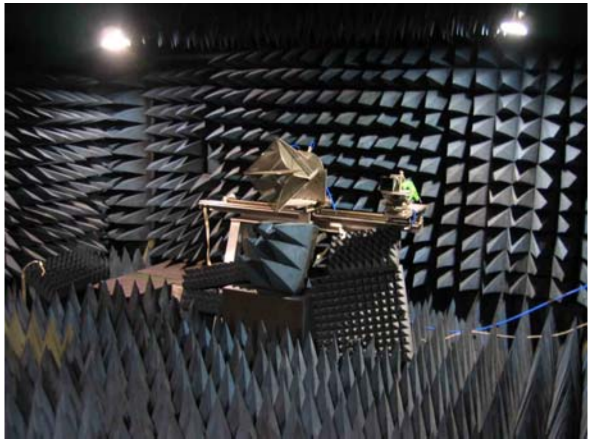
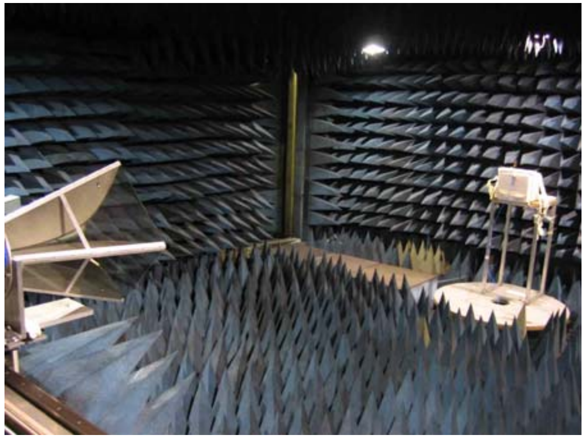
- Measurement set-up

Mechanism of UWB monopoles

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- How exactly a printed UWB monopole operates across the entire bandwidth?

Does a planar UWB monopole break Chu-Harrington's limit?

Mechanism of UWB monopoles

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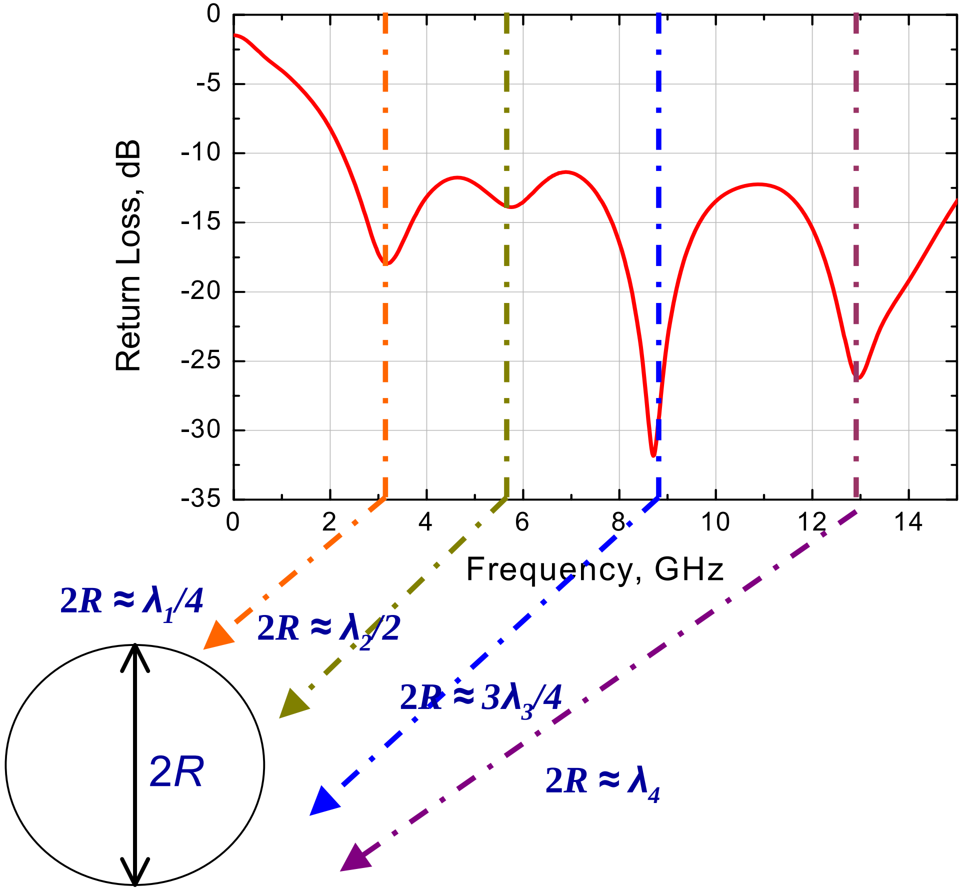
The disc supports multiple resonant modes

Simulated return loss curves



First resonant freq:

$2R \approx \lambda_1 /4$

Second resonant freq:

$2R \approx \lambda_2 /2$

Third resonant freq:

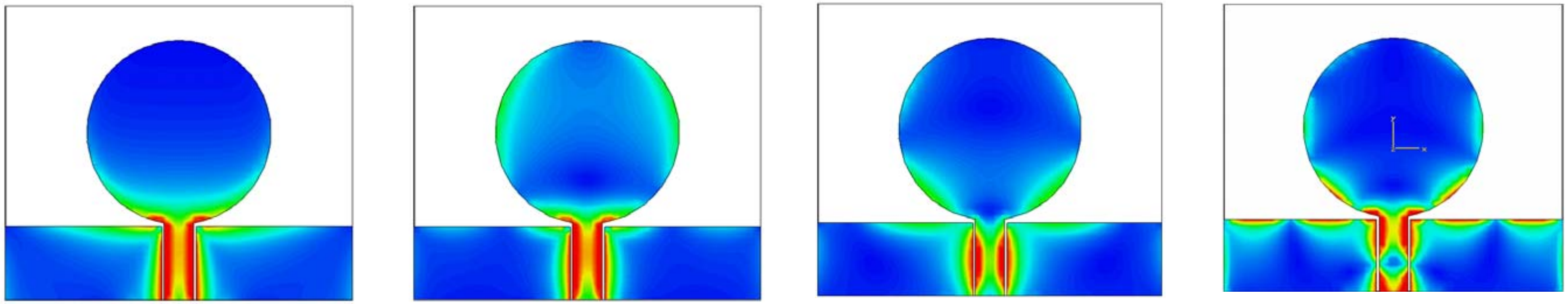
$2R \approx 3\lambda_3 /4$

Forth resonant freq:

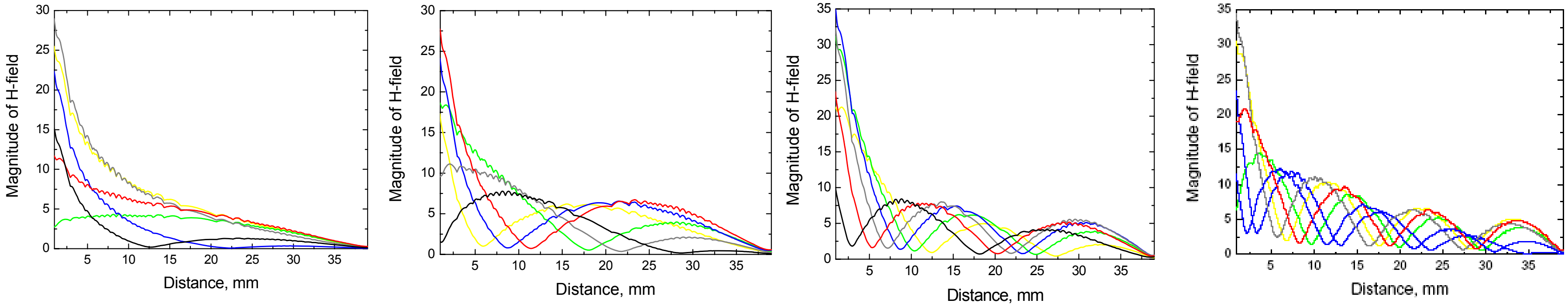
$2R \approx \lambda_4$

Mechanism of UWB monopoles

Current distribution



At 3GHz *At 5.6GHz* *At 8.6GHz* *At 12.8GHz*



H-field distributions along the edge of the half disc

Mechanism of UWB monopoles

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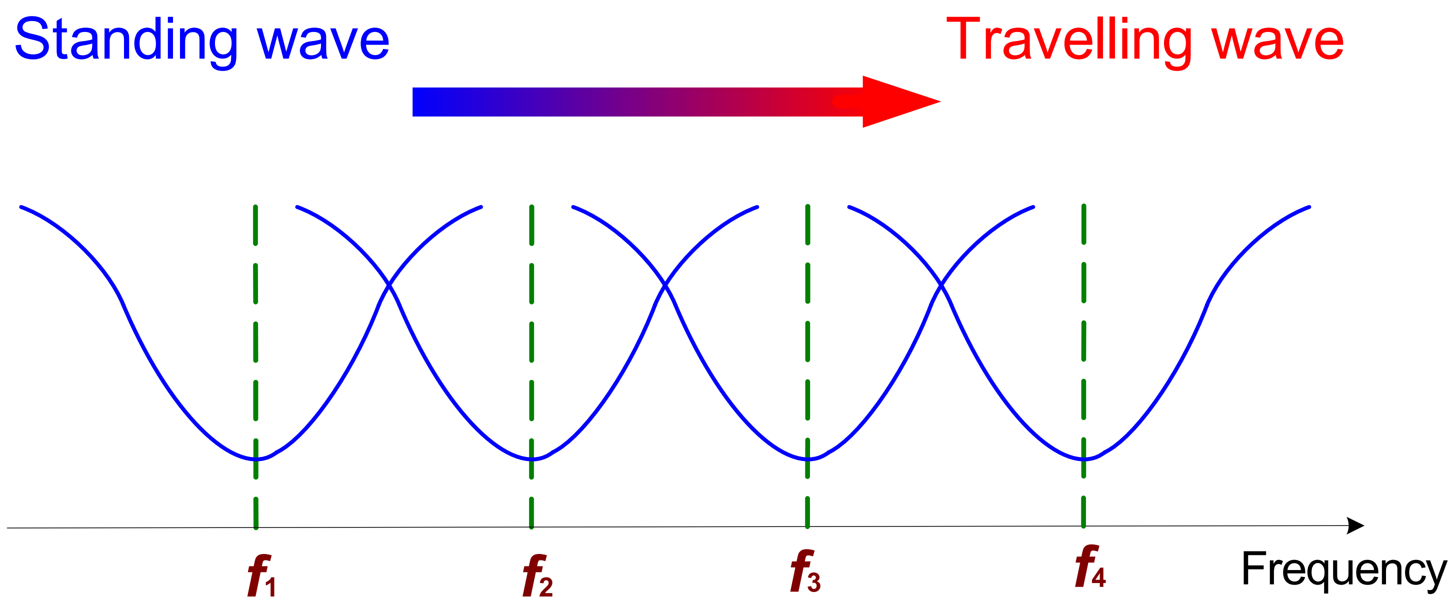
- Hybrid mode: standing wave + travelling wave
- Good feeding structure for traveling wave at high freq.



Slot Monopoles

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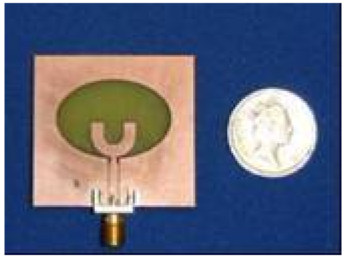
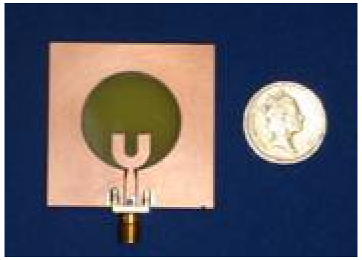
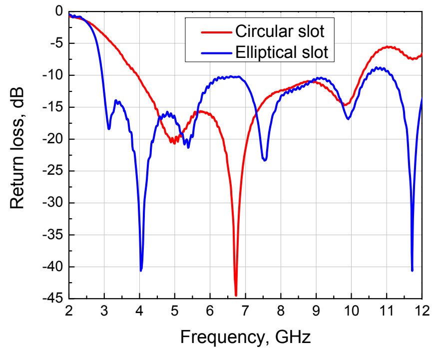
- Elliptical / circular slot antennas

CPW-fed:

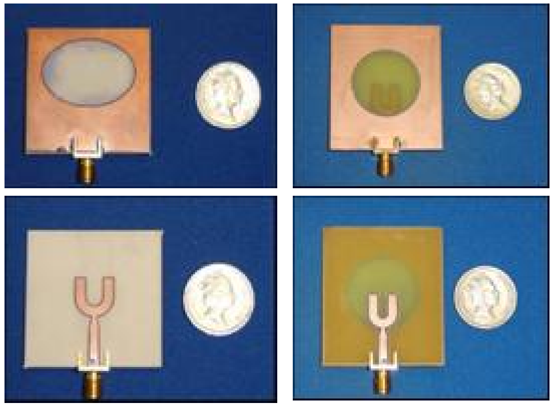


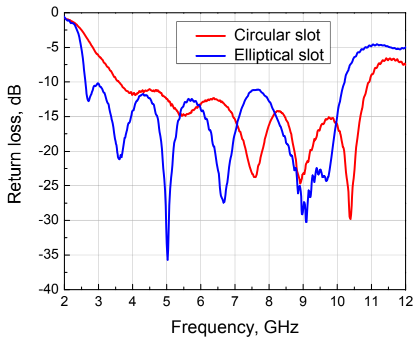




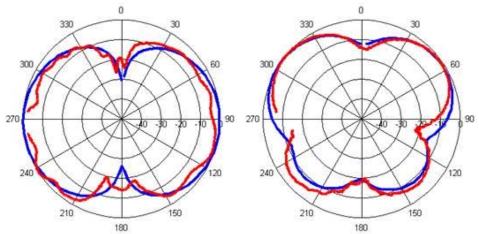
Measured return loss

Microstrip line fed:



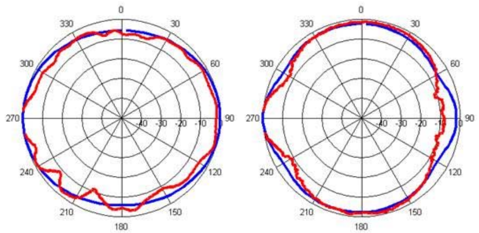


Measured return loss



E-Plane pattern

At 3.1GHz At 10GHz



H-Plane pattern

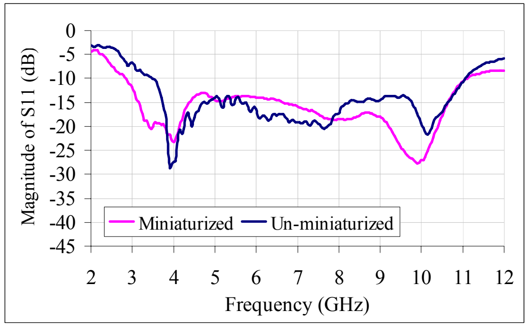
Half Monopoles

- Halve the disc antennas to achieve a 40% reduction in size.
- The miniaturisation improves the impedance bandwidth but reduces the gain and degrades the polarization purity in the upper frequency range.

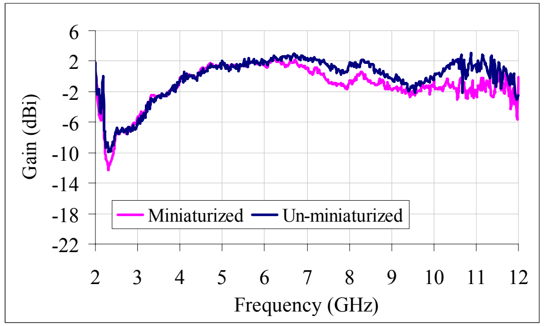
Original size:
17×17 mm with a LTCC dielectric constant of 7.8

Reduced size:
10×17 mm with a LTCC dielectric constant of 7.8

iWAT'07, M. Sun, Y.P. Zhang, NTU, Singapore



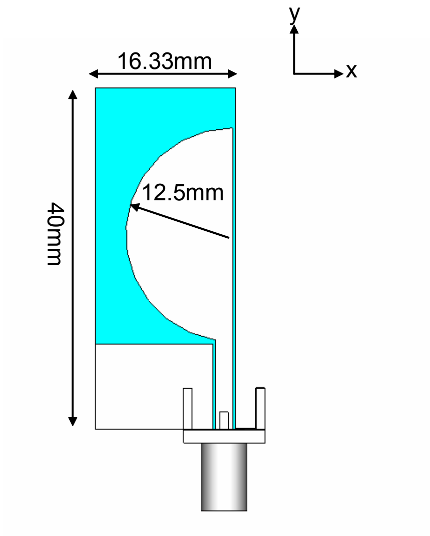
Measured return losses

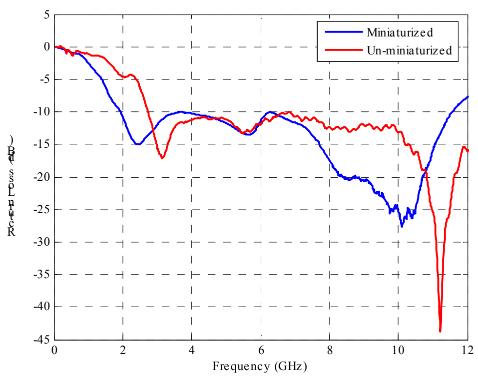


Measured gain

Half Monopoles

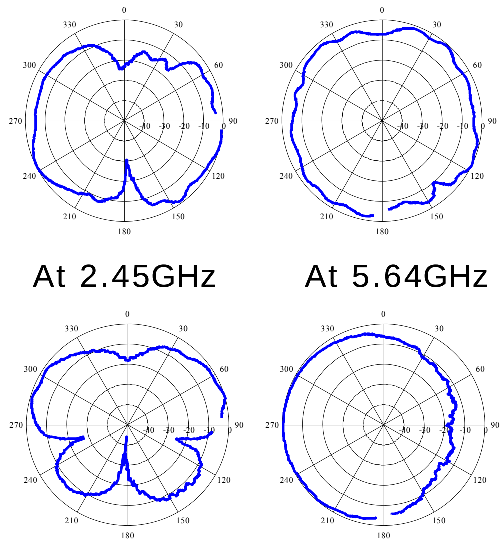
- In QMUL, The CPW-fed disc monopole was cut into half, the reduced antenna size is 16.33×40 mm with a dielectric constant of 3.
- The return loss is below -10 dB within 1.94-11.59GHz frequency band.





Measured return losses

half disc- blue line Full disc – red line

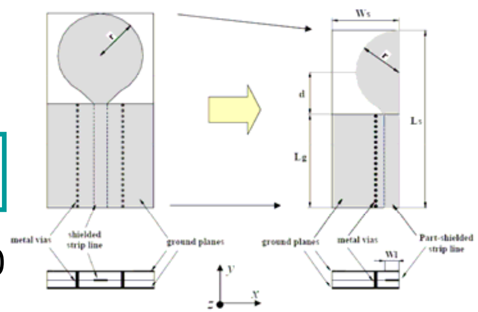


E-Plane pattern

H-Plane pattern

A similar design was proposed by B. Sanz-Izquierdo and J.C. Batchelor, University of Kent, LAPC 2007

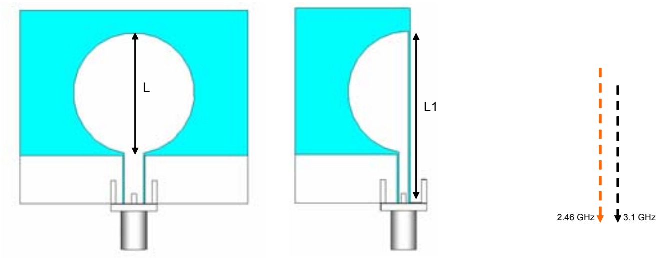
37 x 20mm



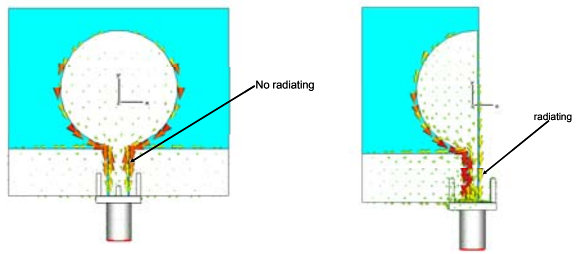
34.25 x 12.5mm

Half Monopoles

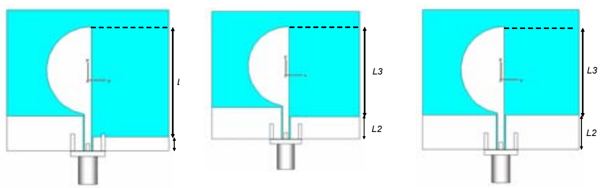
- Mechanism of the miniaturized antenna



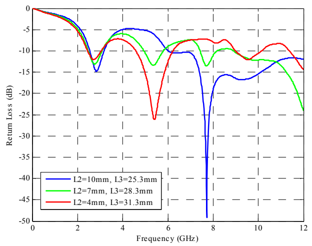
Firstly, the disc monopole antenna is simply chopped half



Current distributions



Further verification by introducing a ground plane on the other side with different length *L2*



The relationships between *L2*, *L3* and the first resonances

	L2=4mm, *L3*=31.3mm	*L2*=7mm, *L3*=28.3mm	*L2*=10mm, *L3*=25.3mm	*L*=25 mm (full disc)
First Resonance *f1*	2.72 GHz	2.76 GHz	2.84 GHz	3.01 GHz
wavelength λat *f1*	110.3mm	108.7mm	105.6mm	99.7mm
L3/λ	0.28	0.26	0.24	0.25

Tapered Slot Antennas

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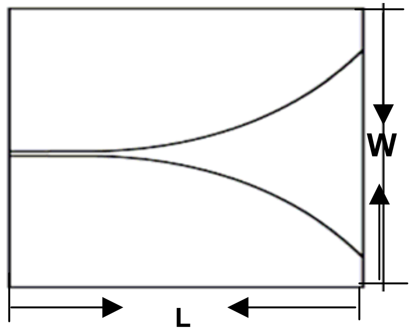
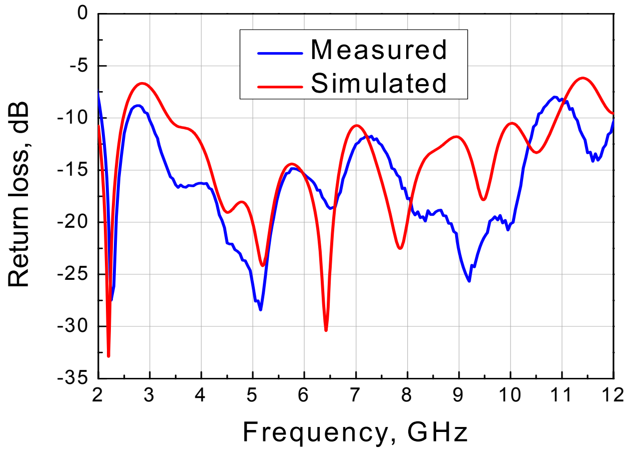
- As an travelling wave antenna, TSA has demonstrated multi-octave bandwidth.
- A typical TSA should have a aperture width of slot $W \geq \lambda_0/2$ and the length of the TSA L from 2 to $12\lambda_0$.
- It is not suitable for application when low-profile is essential.



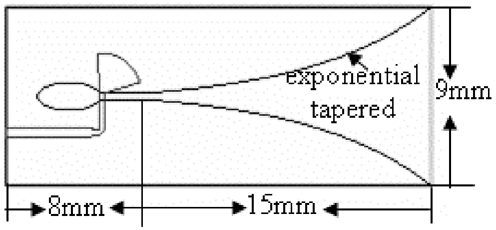
70.6mm×60mm



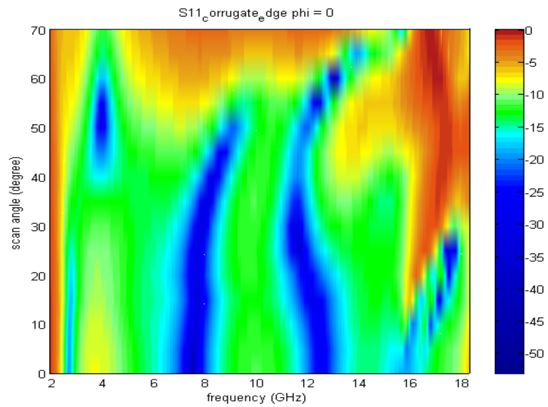
Measured: 3.3GHz—10.8GHz
Simulated: 3.0GHz—10.5GHz

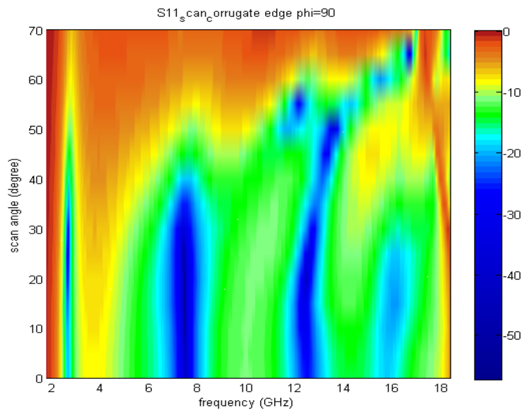
Miniature Tapered Slot Array Antenna

- The miniature tapered slot antenna in an array environment can obtain a bandwidth of 4-16GHz with wide scan angle. The element is only 0.12λin width and 0.3λin depth at 4GHz.
- The wideband impedance matching is achieved essentially due to the constructive effect of the mutual coupling among elements.



23mm×9mm





E- and H-plane Scanned Active Reflection Coefficient (dB) of the TSA array as the function of scan angle θ and frequency. The bandwidth achieved is approaching 4:1 from 4-16GHz

Conclusions

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- Planar monopoles are capable of supporting multiple resonance modes, overlapping of the evenly spaced modes leads to UWB characteristic – Chu-Harington limit no longer hold in multiple resonances!
- A remarkable more than 50% size reduction can be achieved for printed disc monopole antenna for UWB systems by simply halving the original antenna and tuning other parameters
- The small tapered slot antenna can achieve wideband performance in an array environment due to strong mutual coupling between elements.

Q&A

Thank You