Miniaturization of Ultra-wideband Antennas

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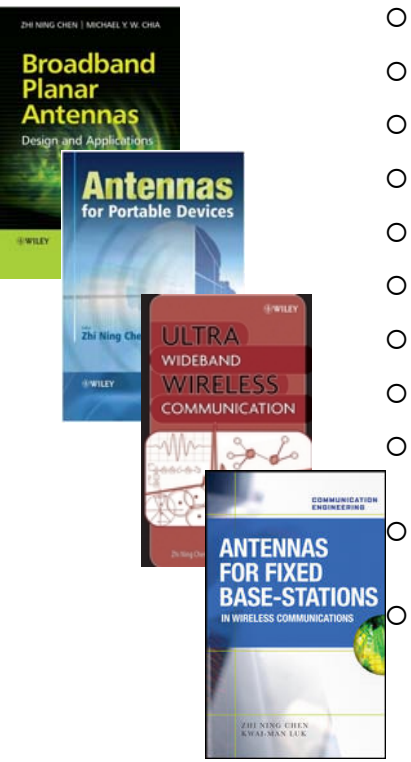
December 2008



Zhi Ning Chen (陈志宁) BEng, MEng, PhD & DoE

- IEEE Fellow
- IEEE AP-S Distinguished Lecturer
- Principal Scientist, Institute for Infocomm Research, Singapore
- Head of RF and Optical Department, Institute for Infocomm Research, Singapore
- Guest Professor at Shanghai Jiao Tong University, China
- Adjunct Professors at Southeast University, Nanjing University, Zhejiang University
- Adjunct Associate Professors at NUS, NTU, Singapore
- Academic Visitor, IBM Watson Research Center, USA
- Technical Advisors at Compex, Sensimesh
- JSPS Fellow, University of Tsukuba, Japan
- Research Fellow, City University of Hong Kong
- Associate Professor, Southeast University
- Associate Professor, Institute of Communications Engineering

- Books: 3; Papers : >220; Patents: 19; Licensing deals: 14

- International conferences:
  - Founder of iWAT; General Chair; TPC Chairs; IAC Chair
  - Keynotes; Invited talks; Short courses

Personal website: www1.i2r.a-star.edu.sg/~chenzn

In this talk…

- Introduction
- Miniaturized Antenna Design
- Conclusions

Introduction

- UWB & Promising Applications
- Challenges in UWB Antenna Design
- State-of-The-Art Solutions

Introduction:

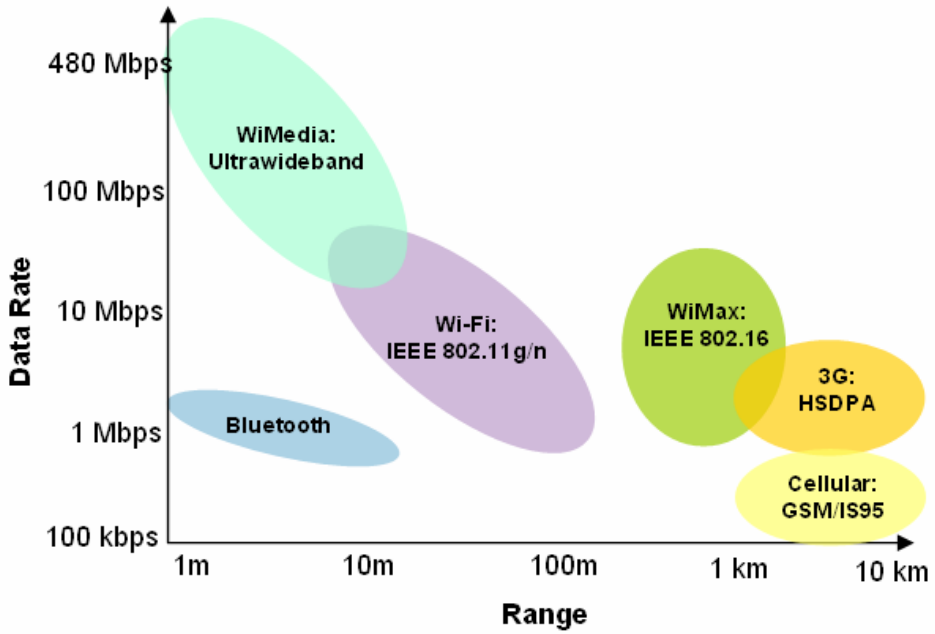
UWB & Promising Applications

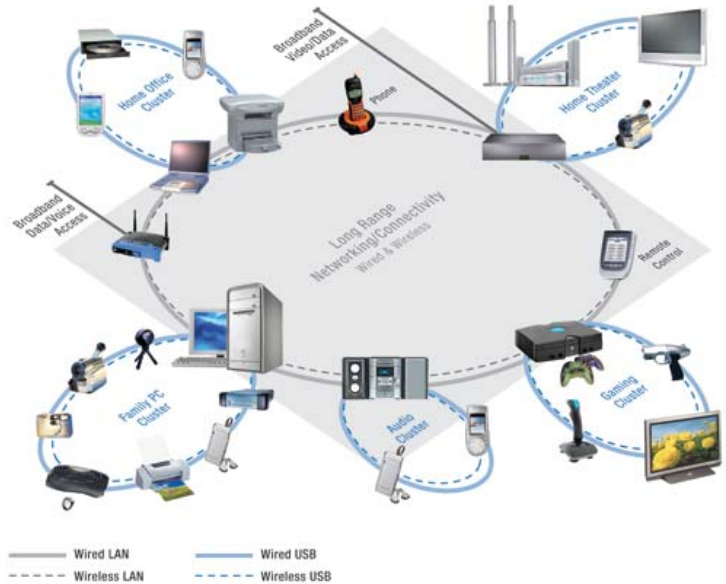
❖ UWB Radio Technology:

- ✓Emission mask (3.1-10.6 GHz)
- ✓Low emitted power (-41.3dBm)
- ✓Pulsed or Pulsed modulated

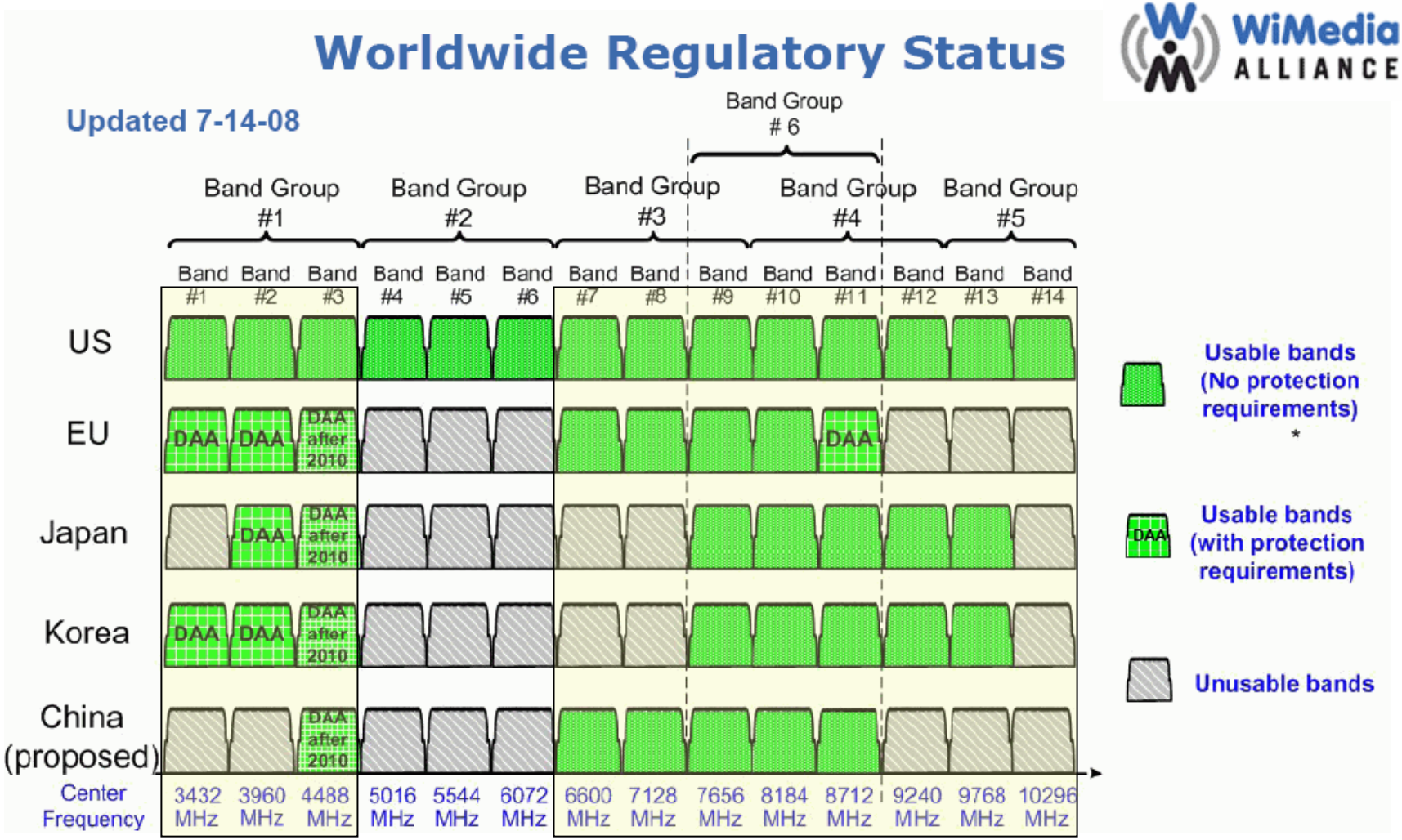
❖ Promising Applications:

- ✓Wireless connections with
  - ✓High date rate (>110Mbps)
  - ✓Short range (<3 m)
- ✓Consumer Electronics (WUSB & Next G Bluetooth)





Introduction:
Update of UWB Regulation



DAA: Detection And Avoid

Introduction:
Challenges in UWB Antenna Design

Ultra-wide bandwidth
Small size
Low cost

- **Impedance matching:**
  3.1-10.6 GHz, 3.1-4.8 GHz, 6-10.6 GHz
- **Radiation related--Stable**
  - **Gain:**
    Consistent at transmission/reception direction
  - **Beamwidth:**
    Consistent
  - **Polarization:**
    Unchanged
- **Phase:**
  Linear

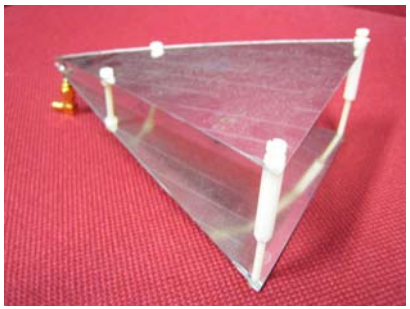
- **Physically small:**
  Embeddable/conformal/easy integration into circuits

- **Electrically small:**
  Overall size smaller than $\lambda/4$ or 25 mm (λ=100mm @3 GHz)

- **Functionally small:**
  Diversity/band-notch/…

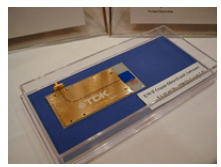
Introduction:
State-of-The-Art Solutions

3-D



2-D

smaller

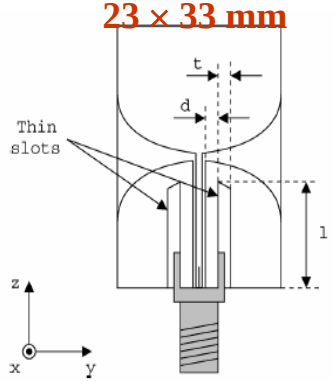


tiny

Planar design is very promising

Introduction:
State-of-The-Art Solutions: Planar Design

Ground independent
23 × 33 mm

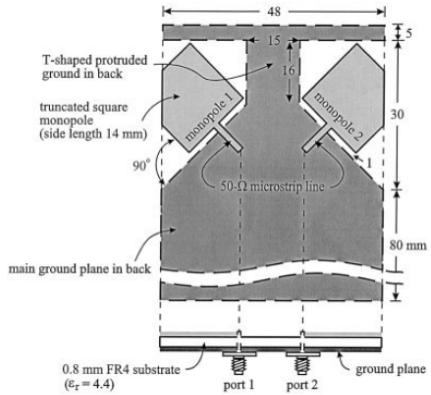


Kwon, D.-H.; Kim, Y.,
IEEE AWPL 2006

Embedded
11 × 45 mm

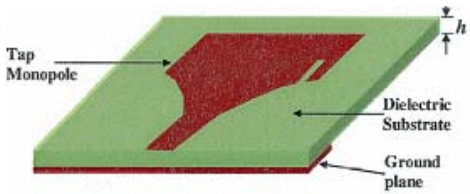
A. Kuramoto
1st EuCAP

Diversity
48 × 115 mm



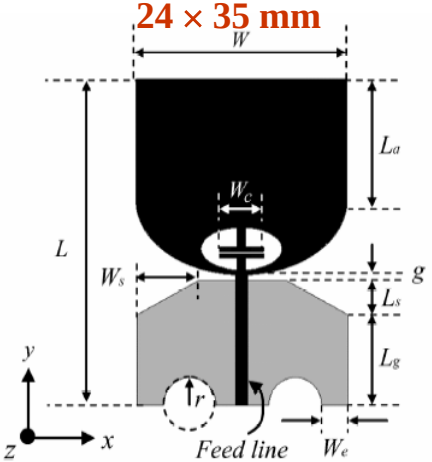
K.L. Wong, S.W. Su, Y.L. Kuo
MOTL 2003

Small size
(16 × 19mm)



A. A. Eldek
MOTL 2006

Band-notch
24 × 35 mm



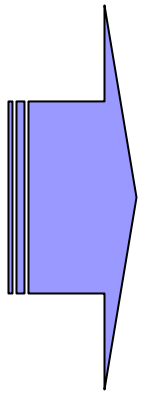
Hong, C.-Y., et al IEEE T-AP DEC 2007

LTCC
10 × 20 mm

M. Sun, et al APMC 2006

Miniaturized Antenna Design

Less ground plane effect



Miniaturized design for WUSB

Miniaturized diversity design

Miniaturized filtering design

Band-notched design

Design with stable gain

Design on LTCC

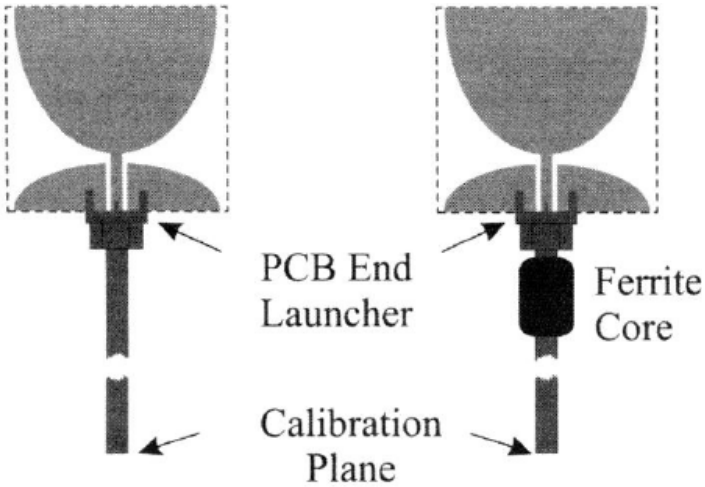
Size vs. Performance

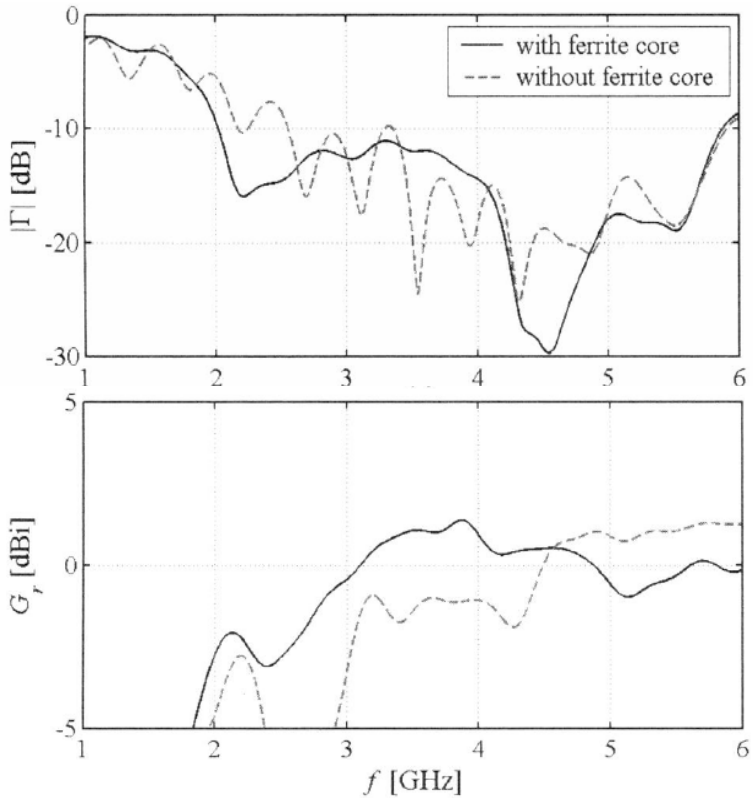
Miniaturized Antenna Design
-- Reduced Ground Plane Effect

Problem

Effect of changed size/shape of “Ground plane” of planar antenna on

- **Impedance response (matching/resonant frequency)**
- **Radiation patterns**

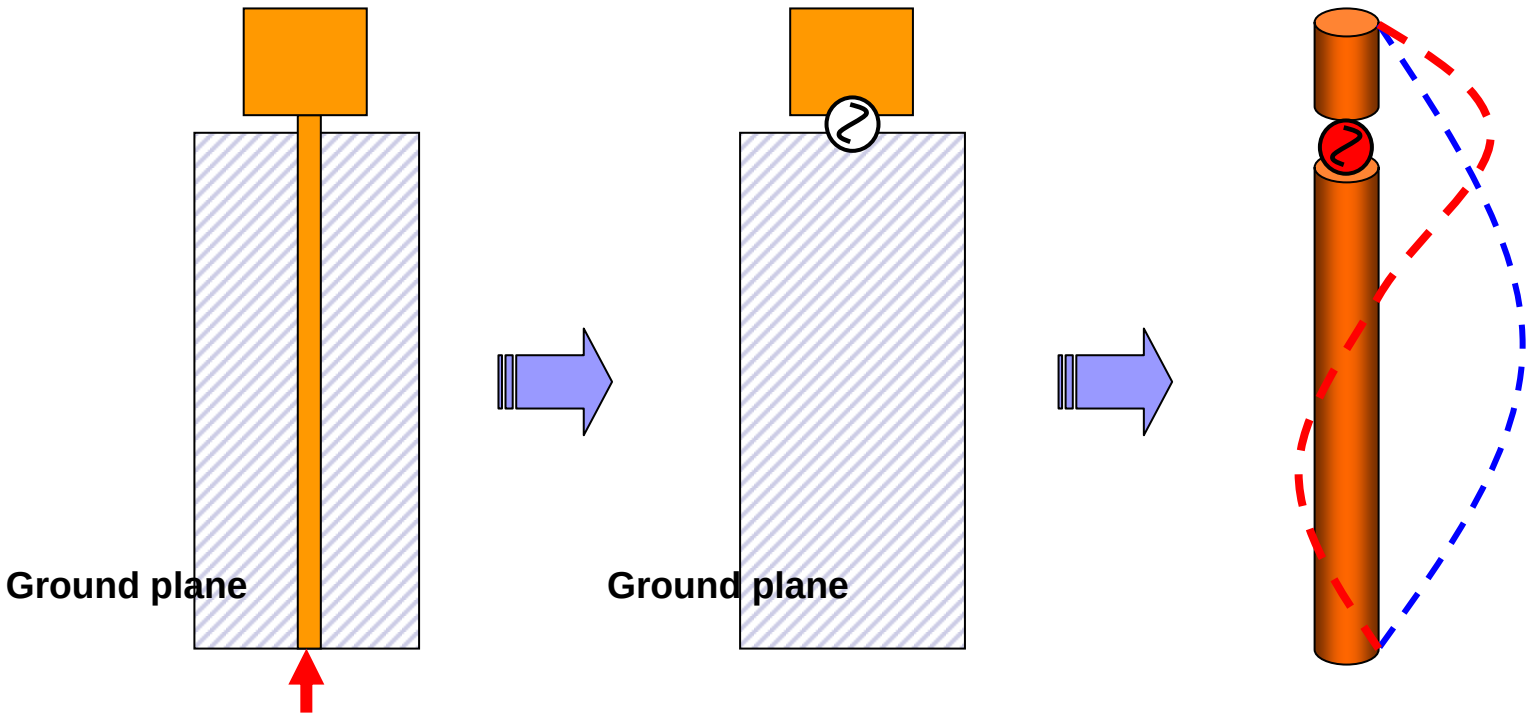




In test: accuracy
In installation: detuned

Hertel, T.W.; Cable-current effects of miniature UWB antennas, IEEE Antennas and Propagation Society International Symposium, 2005, Vol 3A, 3-8 July 2005 pp.524 - 527

Miniaturized Antenna Design
-- Reduced Ground Plane Effect

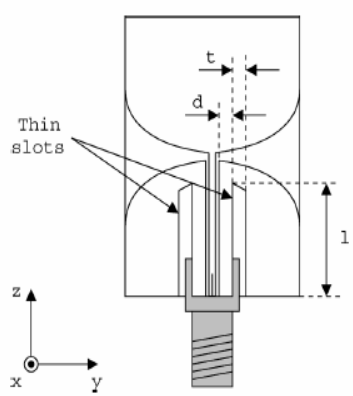


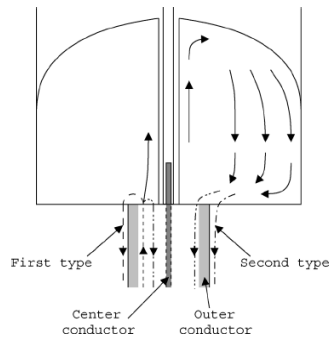
The “GP” is part of the antenna (asymmetrical unbalanced fed dipole)!

Miniaturized Antenna Design
-- Reduced Ground Plane Effect

Existing Solutions

- Differentiated antennas (dipole)
  - **But** Doubled size; positioned far from ground plane (reflector)
- Modified “ground plane” (monopole)
  - **But** ground plane large enough, just partially suppressed leakage current
- RF cable with chock
  - **But** for testing only; absorb power although without radiation from cable

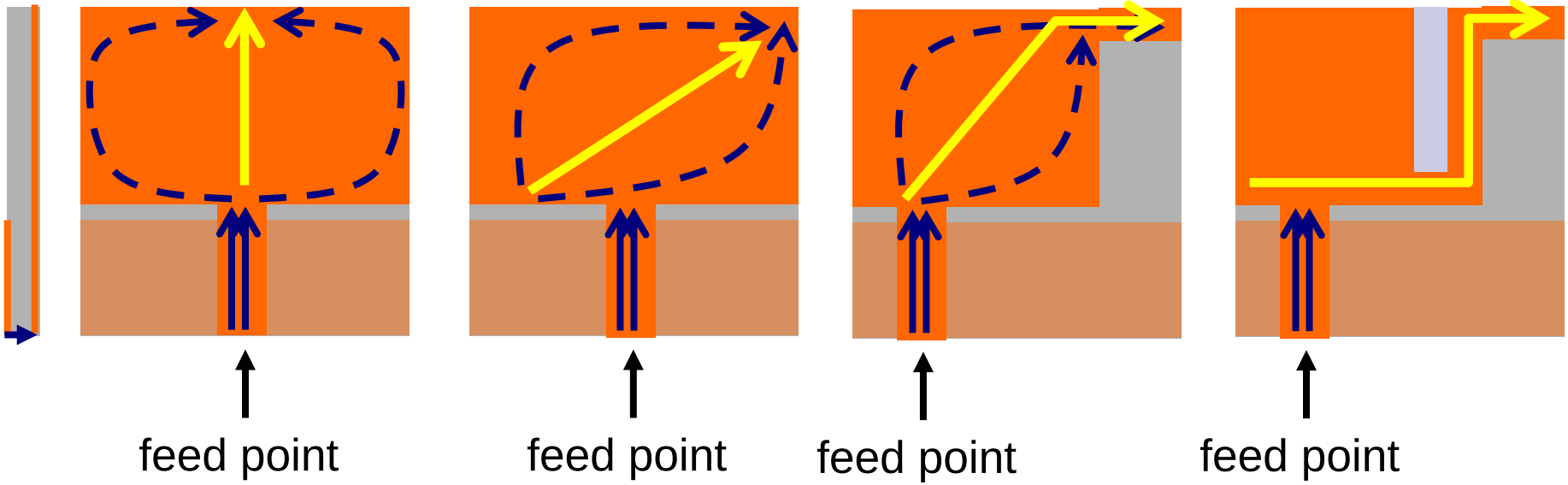


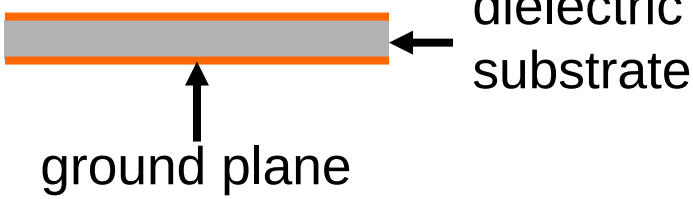


Kwon, D.-H.; Kim, Y.; “Suppression of Cable Leakage Current for Edge-Fed Printed Dipole UWB Antennas Using Leakage-Blocking Slots”, IEEE Antennas and Wireless Propagation Letters, Vol. 5, No. 1, Dec. 2006, pp.183 - 186

Miniaturized Antenna Design
-- Reduced Ground Plane Effect

Our solution

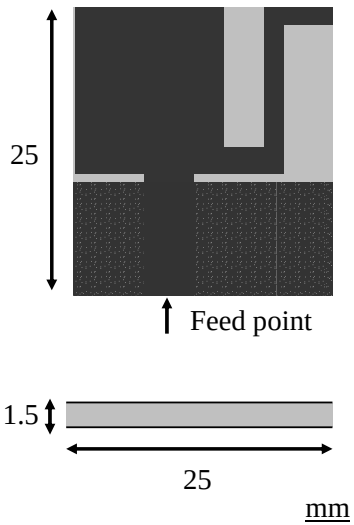


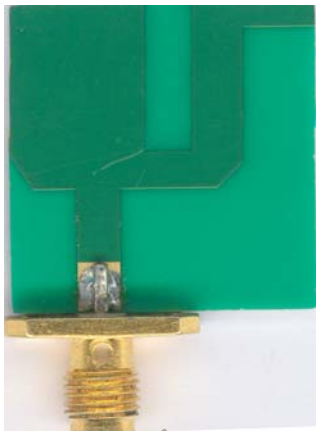


At low edge freq

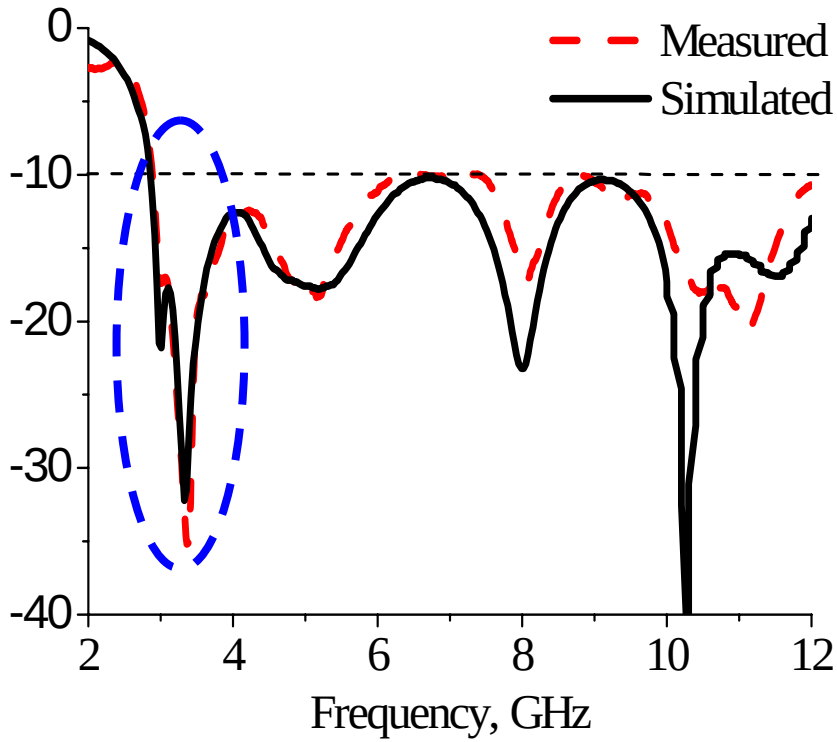
Z. N. Chen; See, T.S.P.; X. Qing; Ultra-Wideband Antennas with Miniaturized Size, Reduced Ground Plane Reliance, and Enhanced Diversity, iWAT 2008. International Workshop on Antenna Technology, 4-6 March 2008, pp. 24 - 27

Miniaturized Antenna Design
-- Reduced Ground Plane Effect





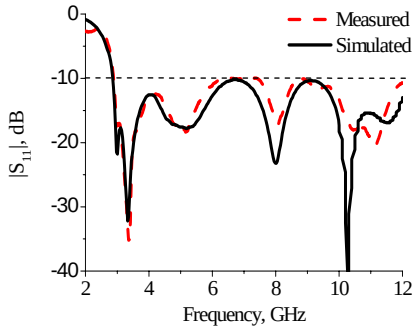
prototype

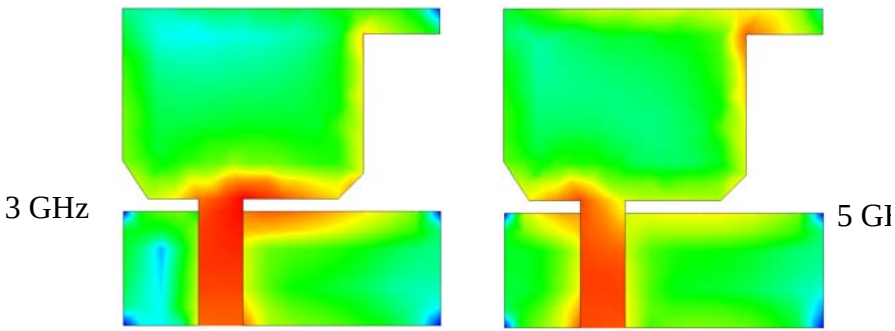


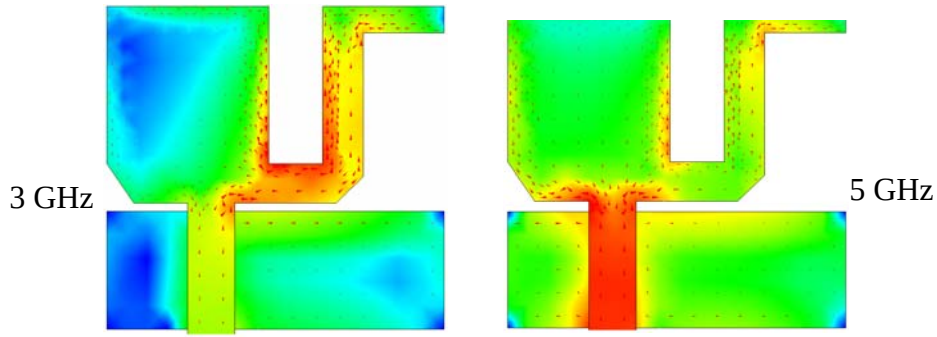
- **Simple method**
- **Stable impedance performance**
- **Less degraded radiation performance (radiation efficiency: 79~95%)**
- **GP size can be further reduced to 2 mm**

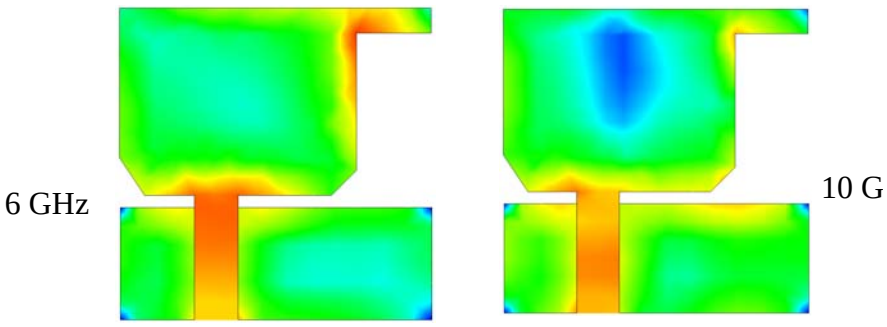
Zhi Ning Chen; See, T.S.P.; Terence S. P. See; Small Printed Ultrawideband Antenna With Reduced Ground Plane Effect, IEEE Transactions on Antennas and Propagation, Vol.55, No. 2, Feb. 2007, pp. 383 - 388

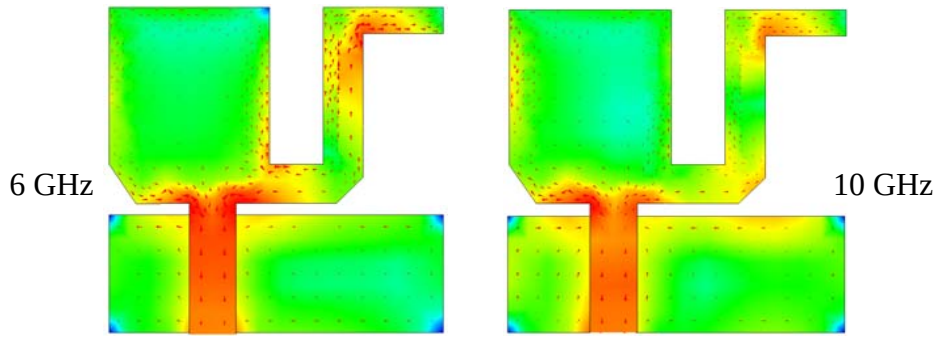
Miniaturized Antenna Design
-- Reduced Ground Plane Effect





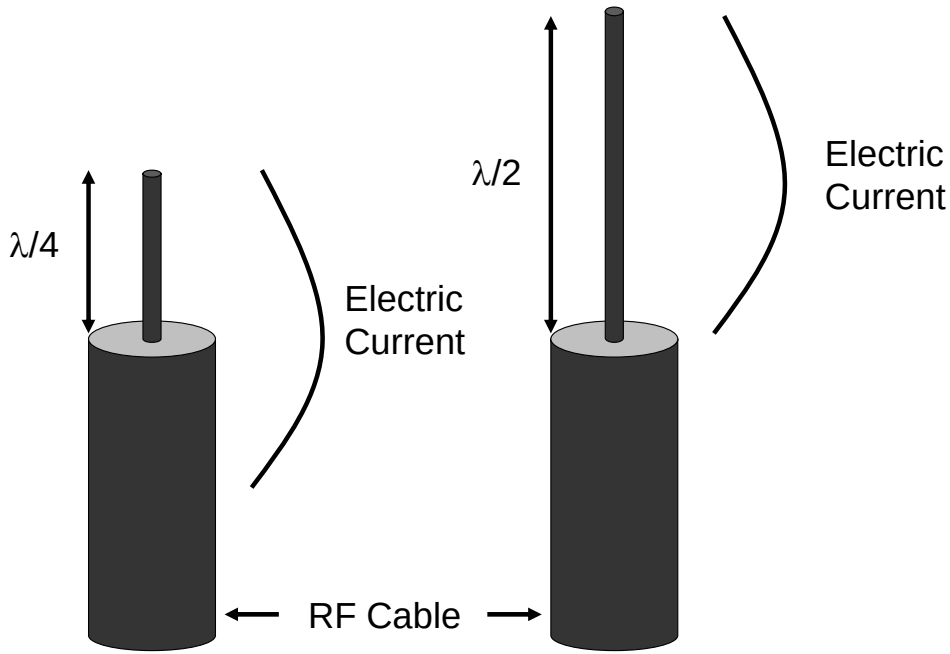






Zhi Ning Chen; See, T.S.P.; Terence S. P. See; Small Printed Ultrawideband Antenna With Reduced Ground Plane Effect, IEEE Transactions on Antennas and Propagation, Vol.55, No. 2, Feb. 2007, pp. 383 - 388

Miniaturized Antenna Design
-- Reduced Ground Plane Effect



Zhi Ning Chen; See, T.S.P.; Terence S. P. See; Small Printed Ultrawideband Antenna With Reduced Ground Plane Effect, IEEE Transactions on Antennas and Propagation, Vol.55, No. 2, Feb. 2007, pp. 383 - 388

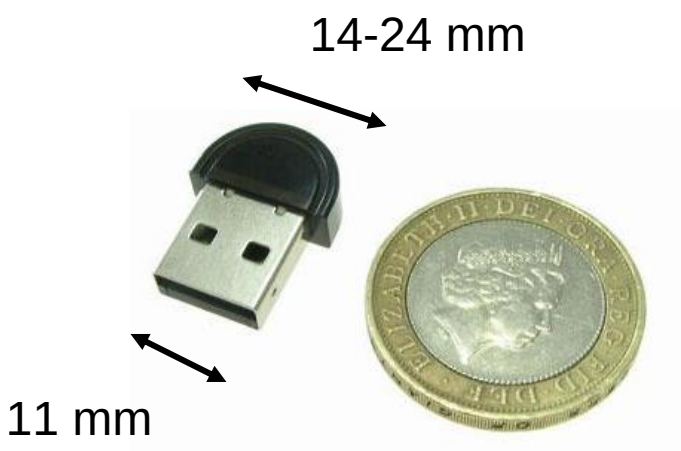
Miniaturized Antenna Design
-- For USB Dongles

Demand

- Wireless USB dongle

Problem

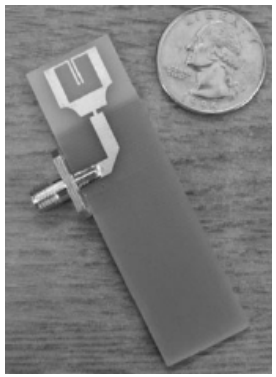
- Narrow with a width of ~11-24 mm
- Significant effect of ground plane length/shape



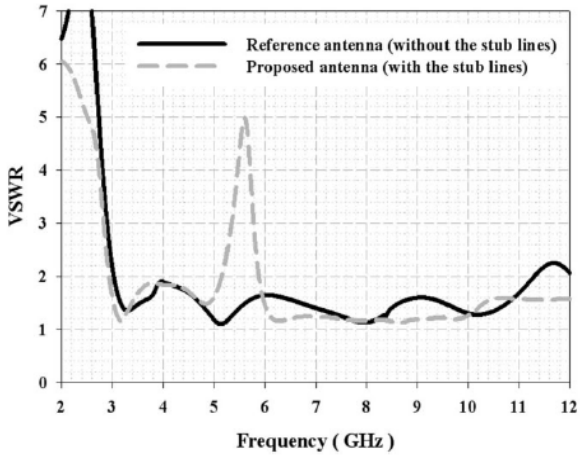
Nano

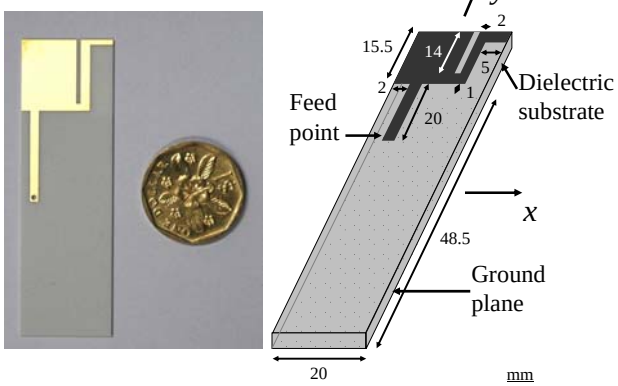
Miniaturized Antenna Design -- For USB Dongles

Solutions

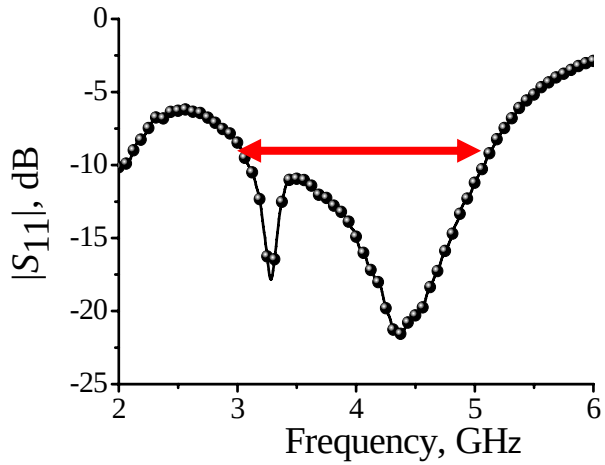


20mm×70mm
Strong GP effect





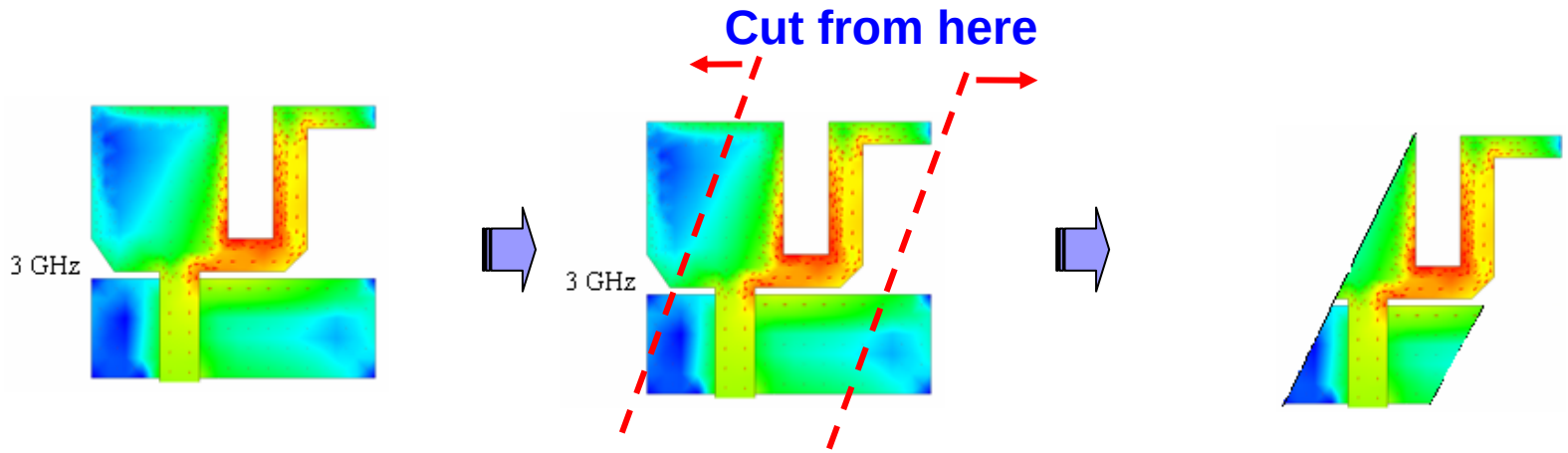
20mm× ~ mm
Less GP effect

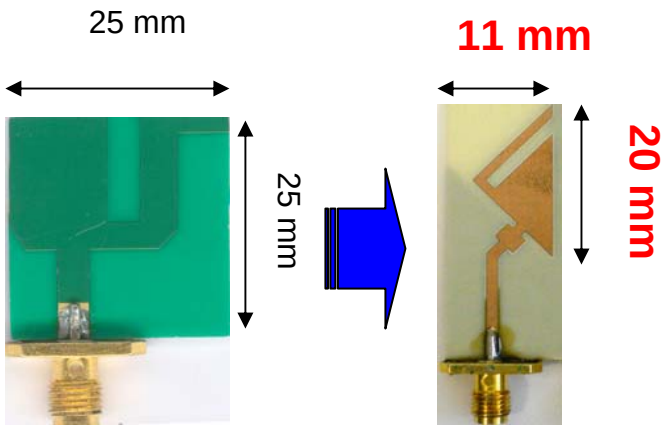


Jinwoo Jung, Hyeonjin Lee, Yeongseog Lim, “Band notched ultra wideband internal antenna for USB dongle application”, Microwave and Optical Technology Letters, Vol. 50, No 7, July 2008, pp.1789-1793

Chen, Z.N.; See, T.S.P.; Reduced Ground-Plane Effect UWB Antenna and Application for Laptop Computers (Invited), TENCON 2006. 2006 IEEE Region 10 Conference, 14-17 Nov. 2006 Page(s):1 - 4

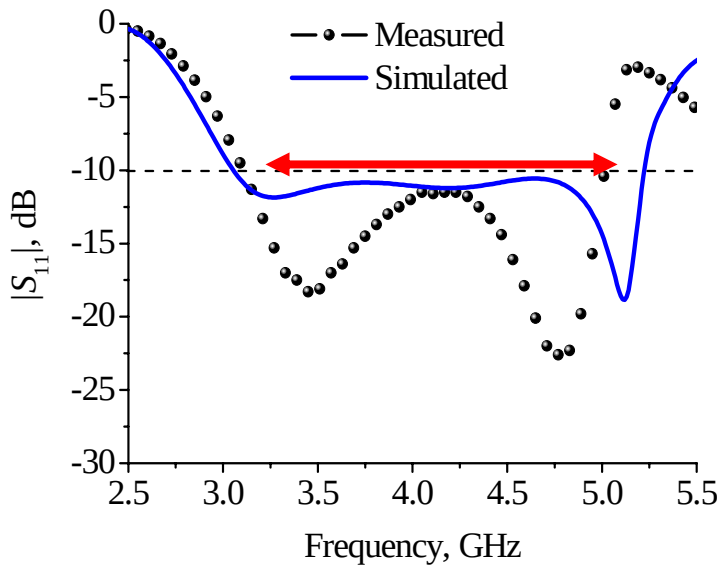
Miniaturized Antenna Design
-- For USB Dongles





11mm× ~ mm

Less GP effect



Zhi Ning Chen; UWB antennas with enhanced performances (invited), International Conference on Microwave and Millimeter Wave Technology, 2008. ICMMT 2008. Vol.1, 21-24 April 2008 pp.387 - 390

Miniaturized Antenna Design
-- Diversity Performance

Demand

- Reliability and robustness of UWB system in dense indoor environments

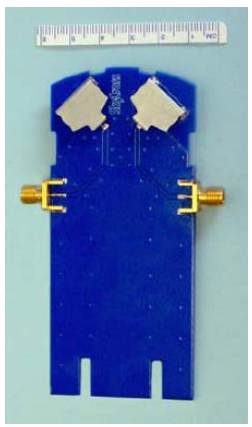
Problem

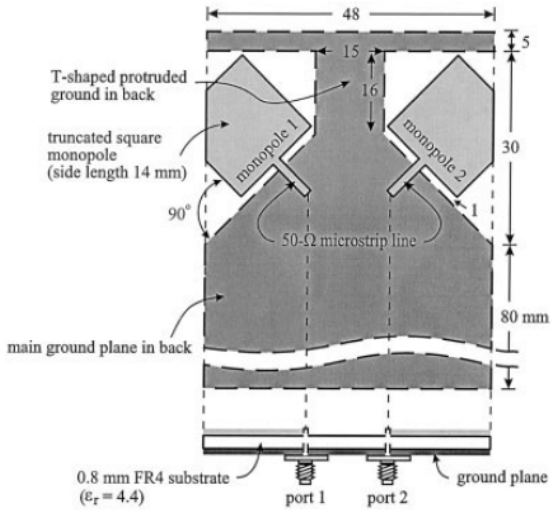
- Very limited space for two or more antennas with high enough isolation

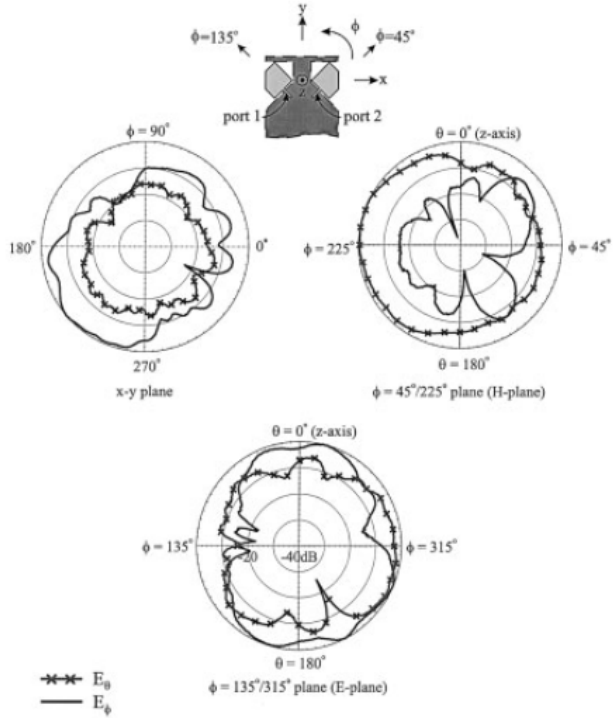
Solution

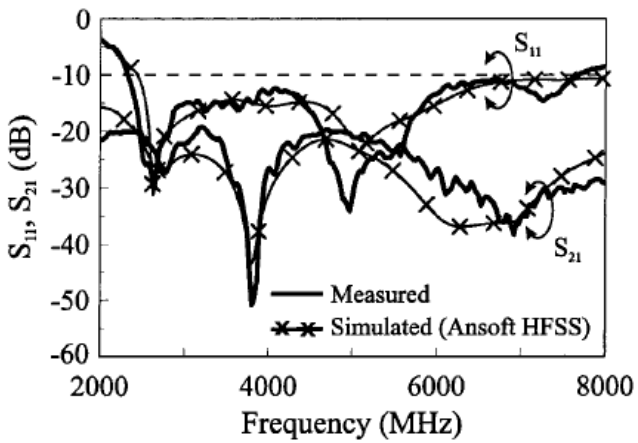
- Polarization
- Pattern
- But space

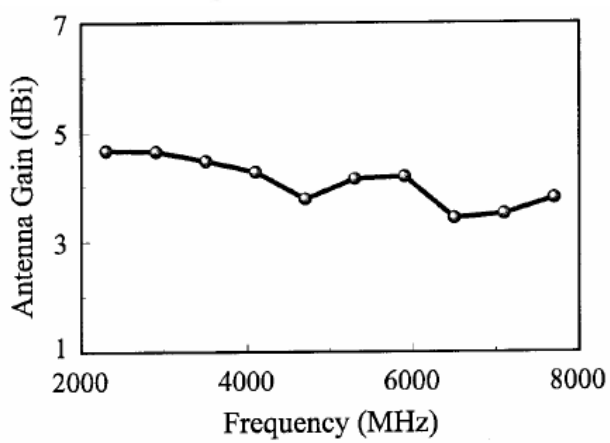
Miniaturized Antenna Design -- Diversity Performance





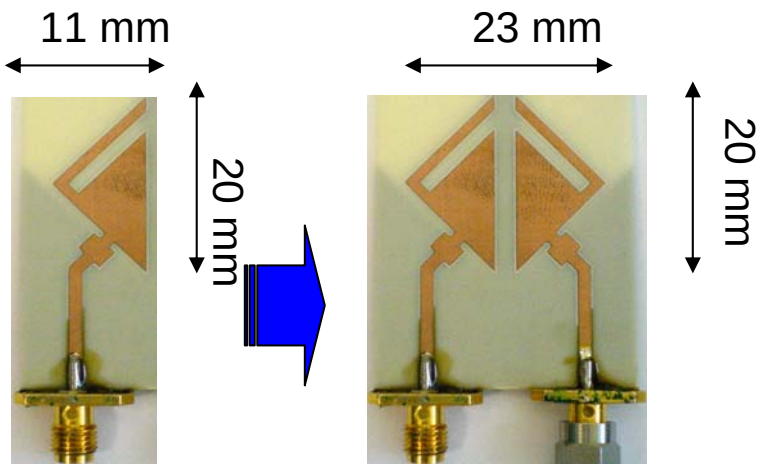


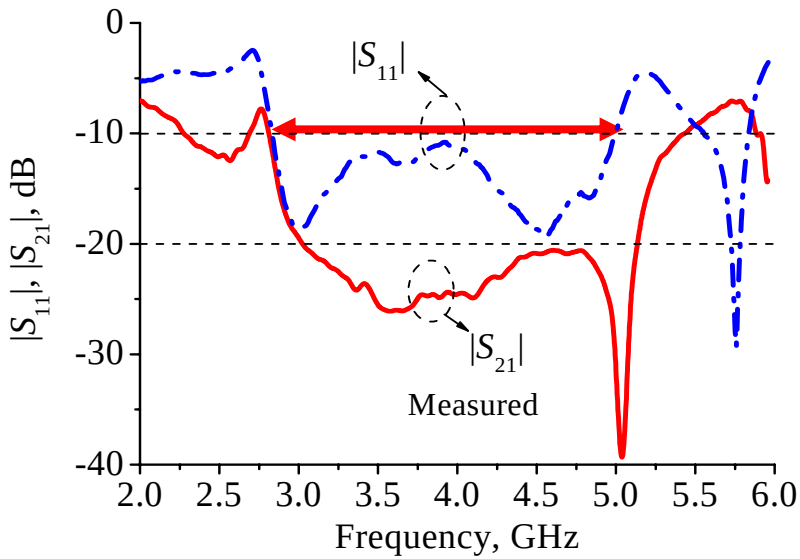


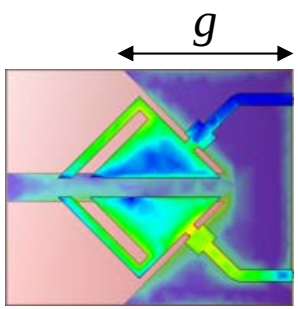


K.-L. Wong, S.-W. Su, Y.-L. Kuo, "A printed ultra-wideband diversity monopole antenna", *Microwave and Optical Technology Letters*, Vol. 38, No. 4, 20 August 2003, pp. 257-259

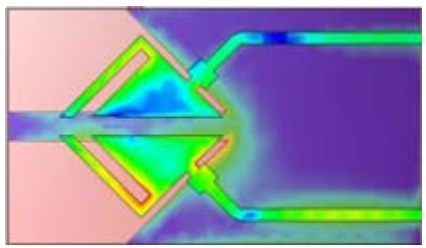
Miniaturized Antenna Design -- Diversity Performance



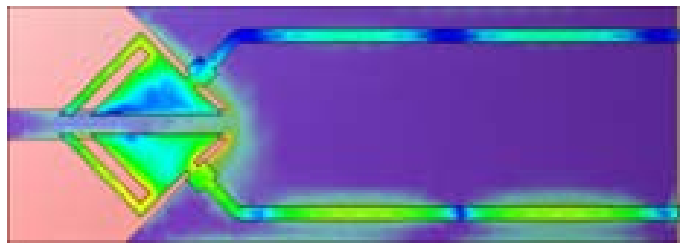




g=26.5 mm



g=46.5 mm



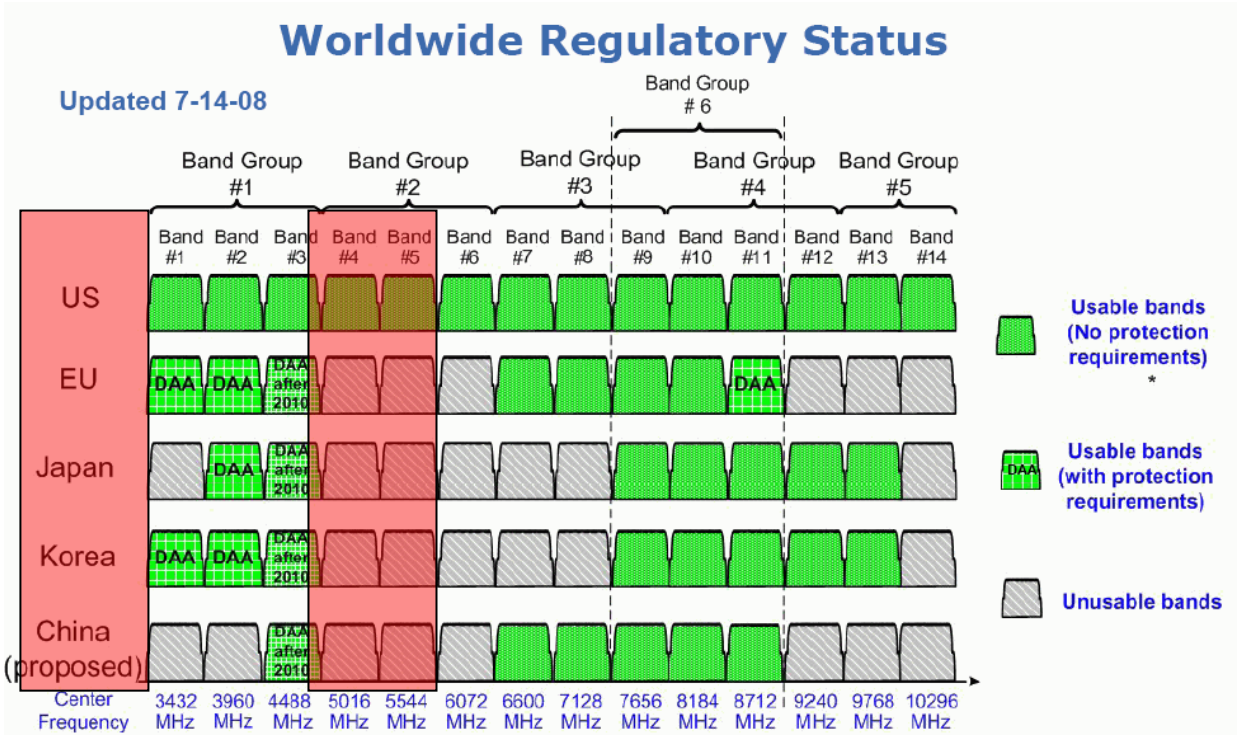
g=86.5 mm

Zhi Ning Chen; UWB antennas with enhanced performances (invited), International Conference on Microwave and Millimeter Wave Technology, 2008. ICMMT 2008. Vol.1, 21-24 April 2008 pp.387 - 390

Miniaturized Antenna Design
-- Filtering Antenna

Problem

- Possible out-of-band interference between UWB devices with other electric devices
- Additional filters with increased size of devices
- Embedded filter into radiator with low Q

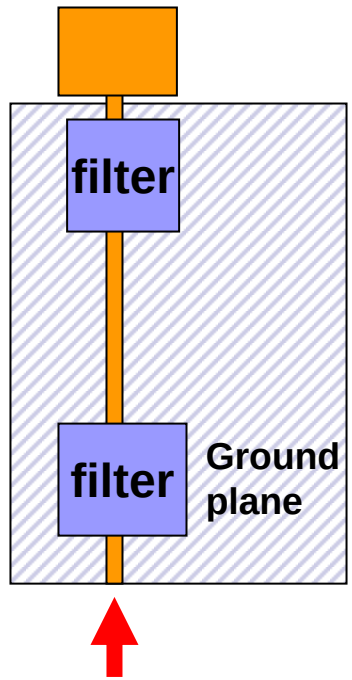


Miniaturized Antenna Design
-- Filtering Antenna

Solutions

- Additional bandpass filter before antenna: *large size*

- Co-design of filter and antenna with a common ground plane : *compact but challenging (low & high Q)*



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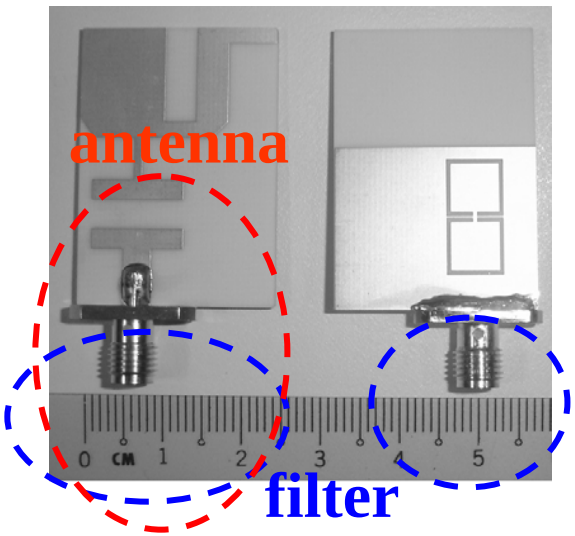
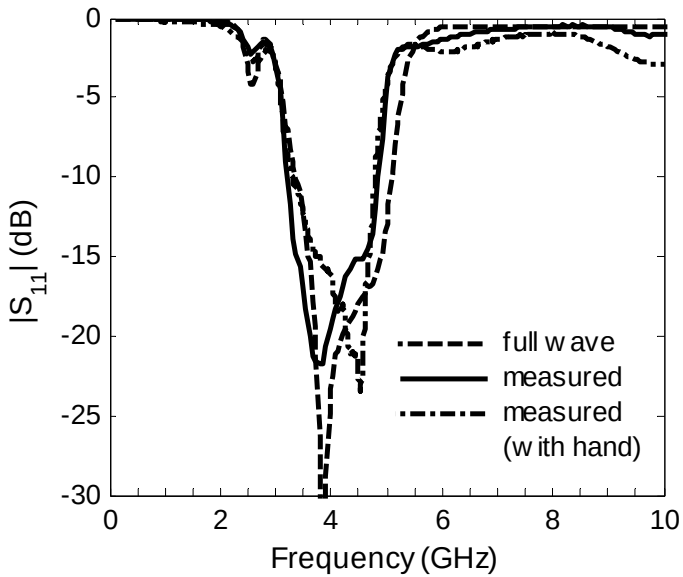
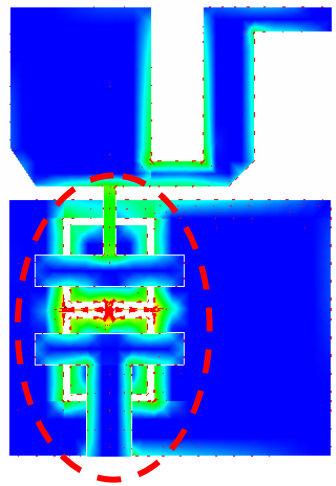






@3 GHz

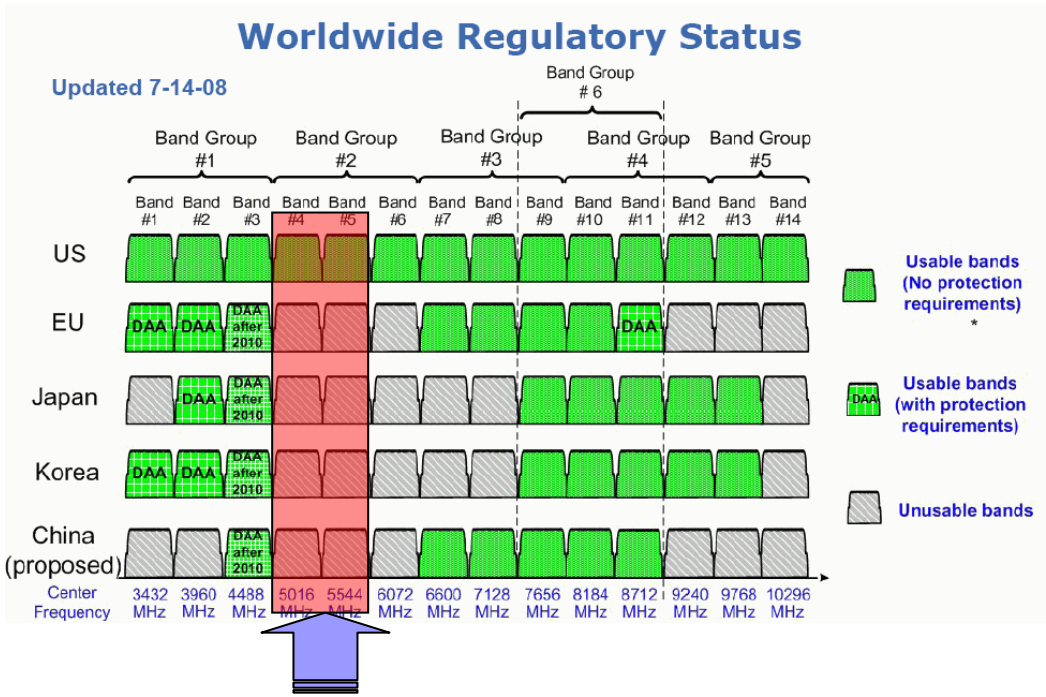
Miniaturized Antenna Design
-- Band-notched

Demand

- Possible interference between UWB devices with other electric devices in 5 GHz-band (4.9-5.875 GHz)

Problem

- Additional filters increase size of devices

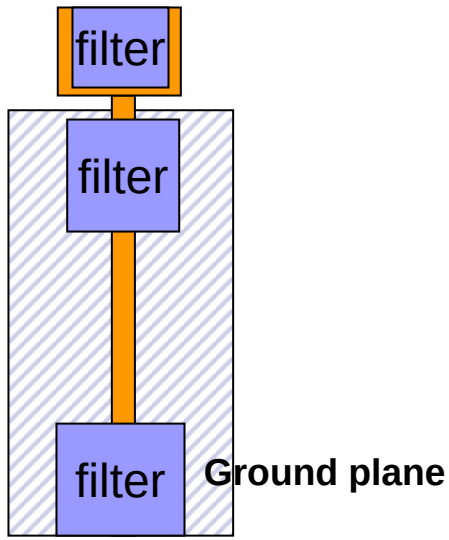


Public Security Band(WiMAX) WiFi (5.15-5.875 GHz)

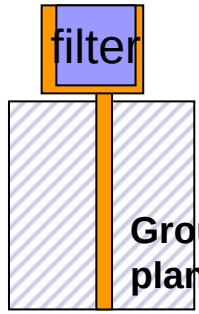
Miniaturized Antenna Design
-- Band-notched

Solutions

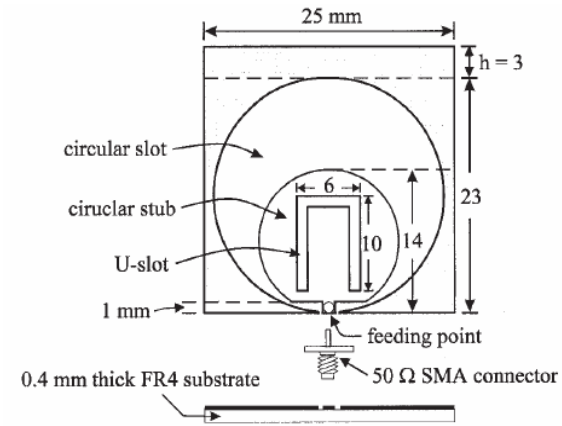
- Extra band-stop filter (before UWB antenna): *bulky size*
- Integrated filter into ground plane (in antenna): *strong coupling*
- Embedded filter into upper radiator: *low Q & bandwidth & rejection*

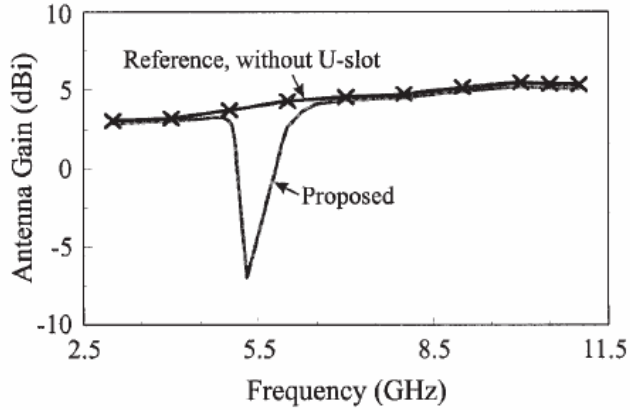


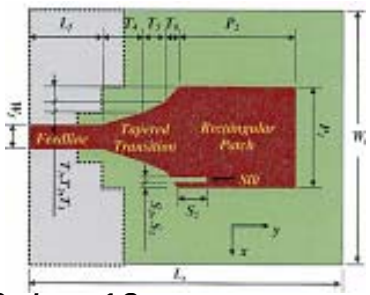
Miniaturized Antenna Design -- Band-notched

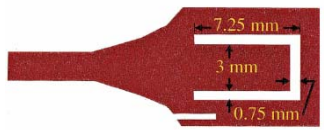


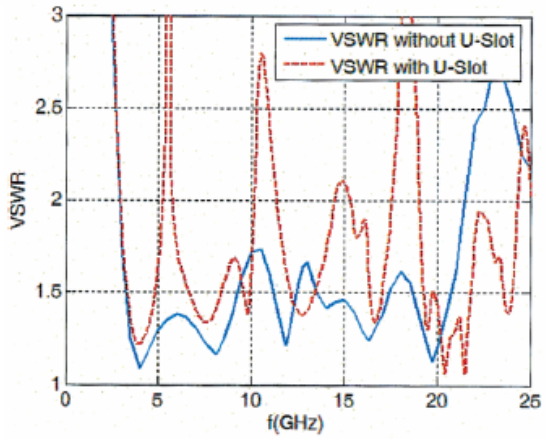
Solutions









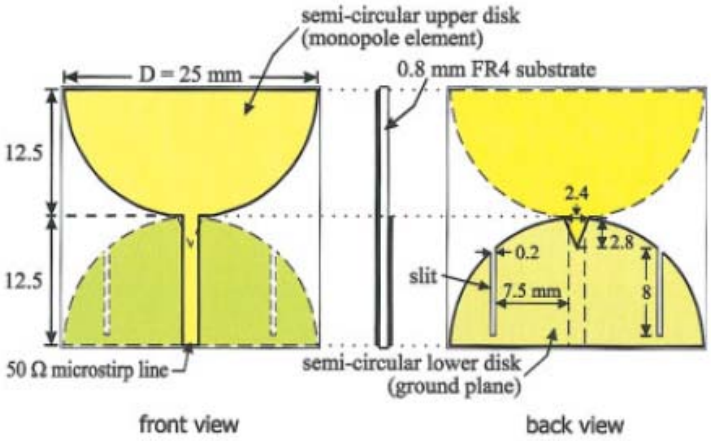


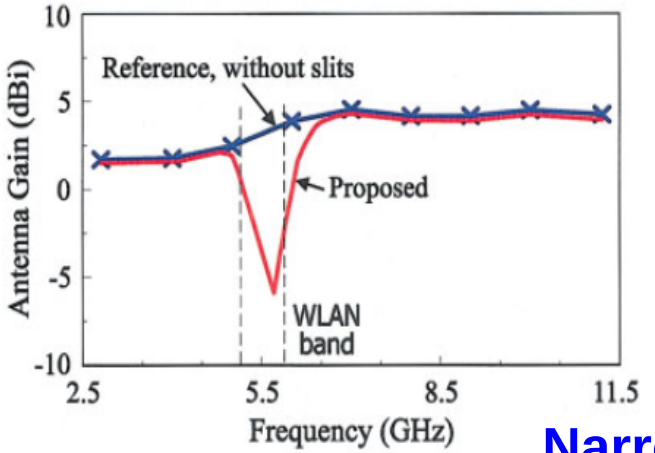
Ws =16, *Ls* =19mm;

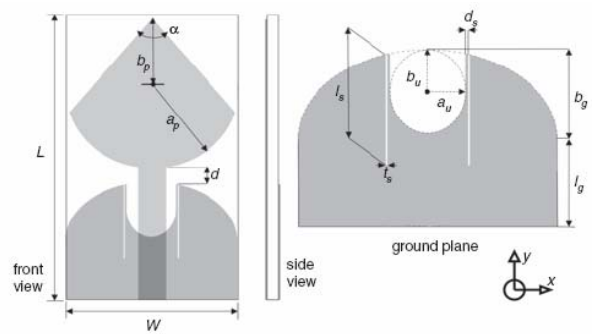
S. W. Su, K. L. Wong, and F.S. Chang, “Compact printed ultra-wideband slot antenna with a band-notched operation”, Microwave and Optical Technology Letters, Vol. 45, No. 2, 20 April 2005, pp.128-130

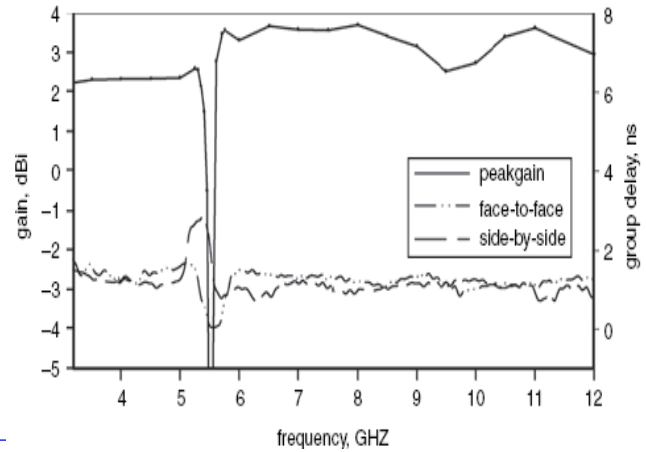
A. A. Eldek, “A small ultra-wideband planar tap monopole antenna with slit, tapered transition, and notched ground plane”, Microwave and Optical Technology Letters, Vol. 48, No. 8, August 2006, pp. 1650-1654

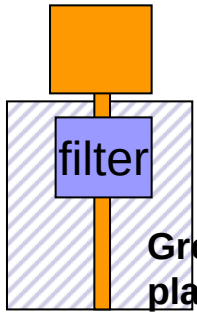
Miniaturized Antenna Design
-- Band-notched









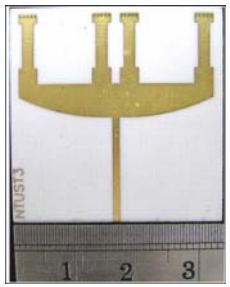


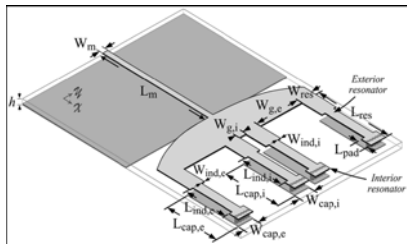
Narrow bandwidth

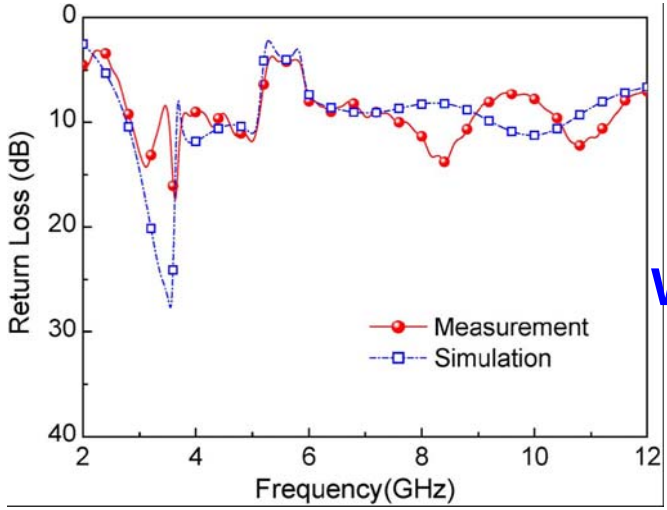
•Saou-Wen Su, Kin-Lu Wong, Fa-Shian Chang, “Compact printed ultra-wideband slot antenna with a band-notched operation”, Microwave and Optical Technology Letters, Vol. 45, No. 2, 20 April 2005, pp.128-130

•R. Gayathri, T.U. Jisney, D.D. Krishna, M. Gopikrishna and C.K. Aanandan, Band-notched inverted-cone monopole antenna for compact UWB systems, ELECTRONICS LETTERS 25th September 2008 Vol. 44 No. 20

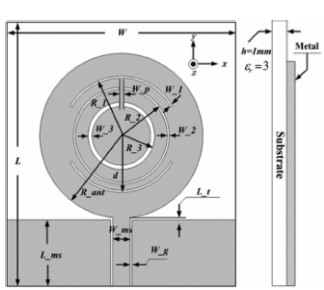
Miniaturized Antenna Design
-- Band-notched: Wideband/Multiband

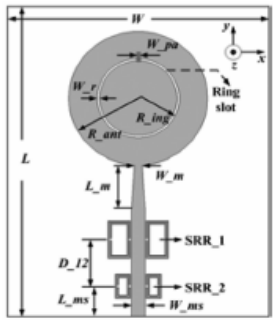


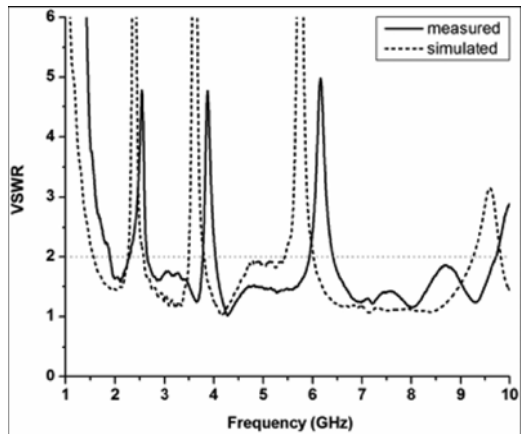




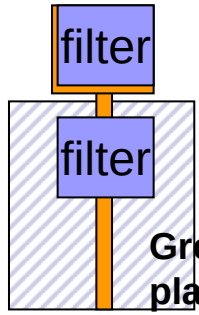
Wide bandwidth







Multiple bandwidth



•T.-G. Ma, R.-C. Hua, and C.-F. Chou, “Design of a Multiresonator Loaded Band-Rejected Ultrawideband Planar Monopole Antenna With Controllable Notched Bandwidth”, IEEE Trans antennas Propagat., Vol. 56, No. 9, Sept 2008, pp.2875-2883

•Y. Zhang; W. Hong; C. Yu; Z. Kuai; Y. Don; Planar ultrawideband antennas with multiple notched bands based on etched slots on the patch and/or split ring resonators on the feed line, IEEE Trans Antennas Propagat., Vol56, No9, Sept. 2008 pp.3063 - 3068

Miniaturized Antenna Design
-- Stable Radiation

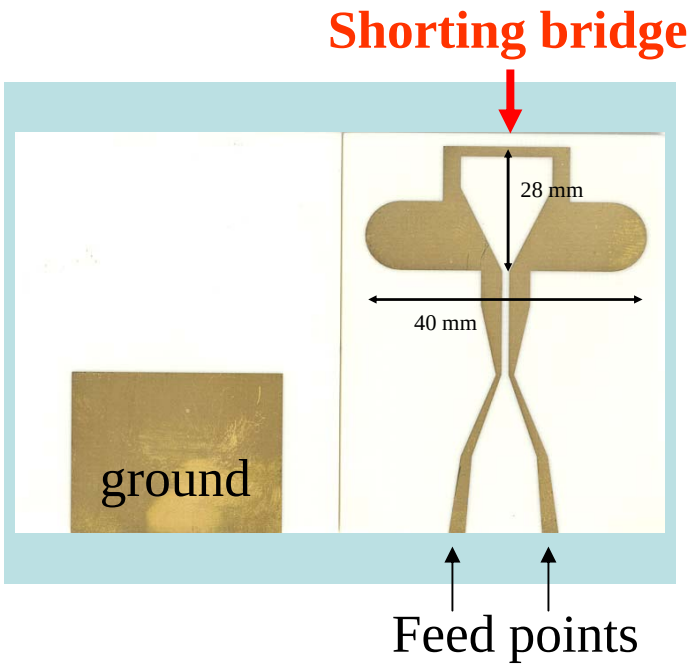
Problem

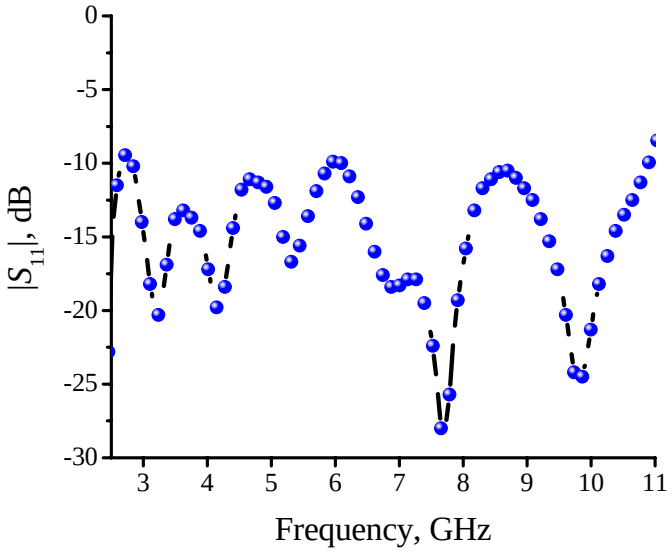
- Gain along T/R direction of interest changes across wide operation bandwidth (for P2P or P2MP)
  - Distorted waveform of pulses
  - Degraded receiver performance

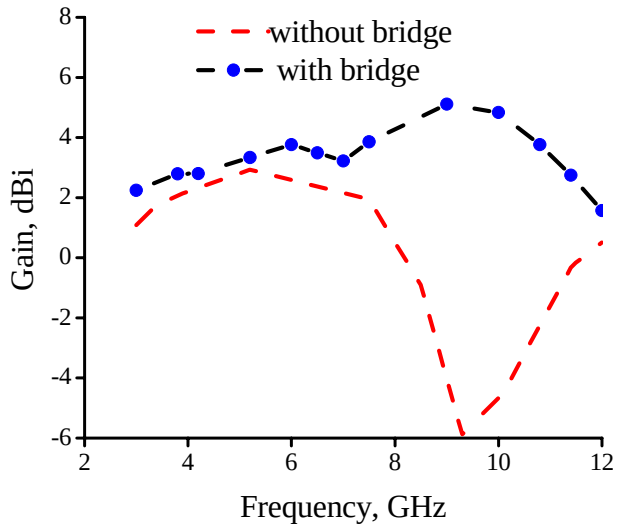
Solutions

- Combining different modes to compensate for the variation of the currents on antenna

Miniaturized Antenna Design -- Stable Radiation







X. N. Low and Z. N. Chen, "A compact planar dipole antenna with ultra-wideband performance," IEEE AP-S International Symposium on Antennas & Propagat., July 5-11, 2008 San Diego, USA

Miniaturized Antenna Design
-- Tiny Design

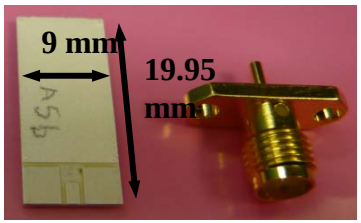
Problem

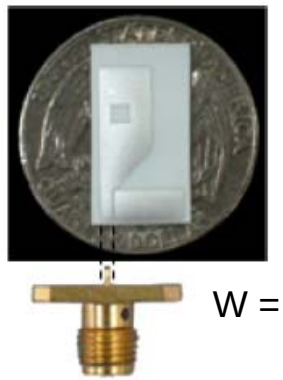
- Integration of antenna into ***very small*** devices such as sensors
- Integration of antenna into package

Solutions

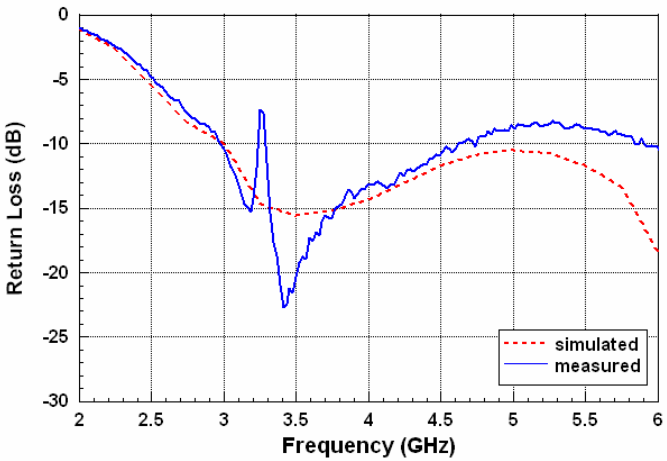
- Trade-off between performance and size
- **Using LTCC**

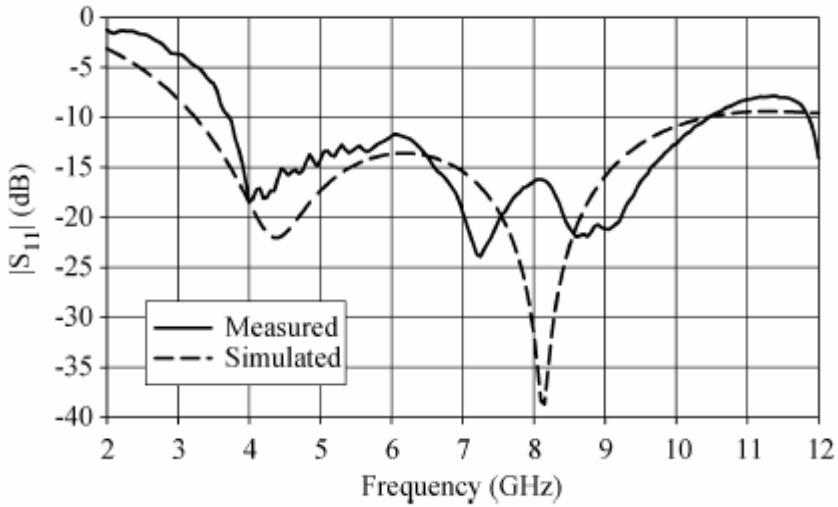
Miniaturized Antenna Design
-- Tiny Design





W = 8 mm, L = 17 mm





Ferro ceramic type with a dielectric constant of 5.9 and a loss tangent <0.002 below 10 GHz.

Sun Mei; Zhang Yue Ping; A Chip Antenna in LTCC for UWB Radios, IEEE Transactions on Antennas and Propagation, Vol. 56, No. 4, April 2008, pp.1177 - 1180

Conclusions

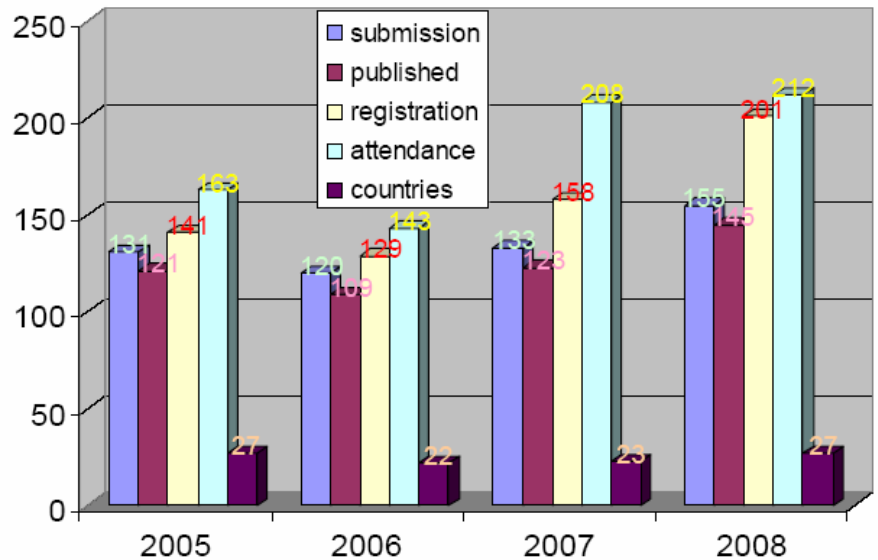
- **All designs are strongly driven by applications with specific requirements.**

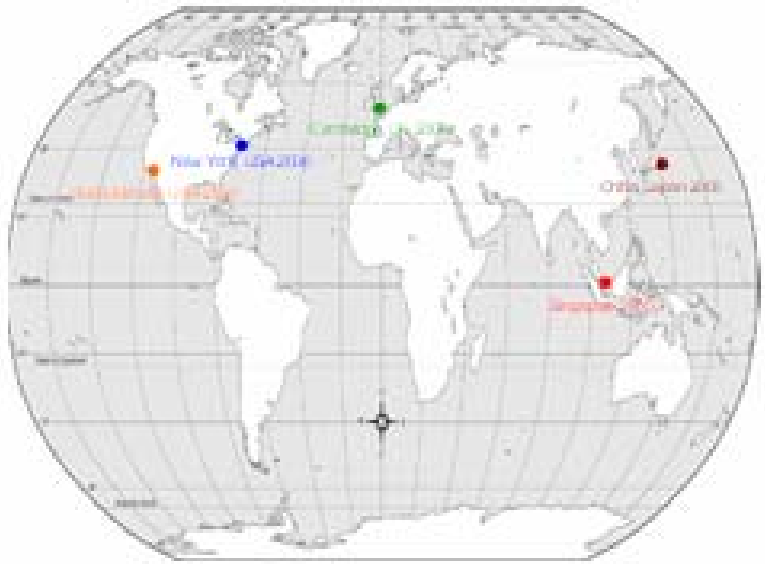
- **Desired UWB antennas for portable devices:**
  - ✓**Small/tiny size:** ***limited to area of ~12×12mm***
  - ✓**Reduced "groundplane" effect:** ***still challenging***
  - ✓**Diversity performance:** ***more work***
  - ✓**Filtering performance to suppress out-of-band interference:** ***just started***
  - ✓**Band-notch performance:** ***Shape rejection with enough bandwidth and/or multiple bands***

2009 IEEE International Workshop on Antenna Technology:

iWAT2009 : "Small Antennas and Novel Metamaterials"

March 2–4, 2009, Santa Monica, California





http://www.i2r.a-star.edu.sg/iwat/

THANK YOU !

Any questions or feedback, please contact me at

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www.i2r.a-star.edu.sg/~chenzn

Many thanks for all contributors to the work in this talk!