Frequency-Band Broadening of Microstrip Patch Antennas

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Preface[1] --- *Trends of Wireless Systems with Antennas*

Systems		Antennas	
@ **Miniaturization** *--- Portable*	→	*Meandering* *Folded* *Higher ε_r*	**Printed Technology**
@ **Integration** *--- System on chip*	→	*Active* *LTCC*	
@ **Multi-function** *--- Multi-mode*	→	*Multi-band* *Dual-polarized*	**Broad Bandwidth**
@ **Intelligentizing** *--- Pushbutton-type*	→	*Adaptive* *Smart* *MIMO*	**Signal Processing**

Preface$_3$ ---- *Structure Types of Printed Antennas*

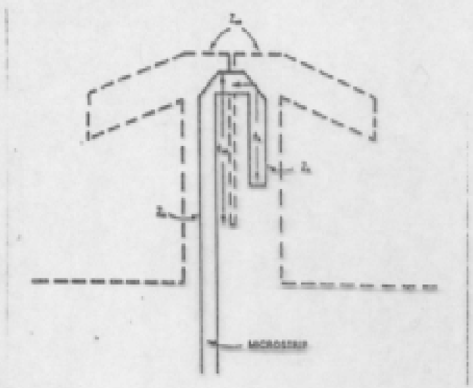
- **Wire Structure**
  - *Plate dipole*
  - *Meander-line*
  - *Spiral*
- **Patch Structure**
  - *Spiral*
  - *Microstrip patch* → Patch antennas
  - *Tapered slot-line*
  - *Co-planar waveguide*
- **Array Structure**
  - *Microstrip patch* → Patch antennas
  - *Strip grating* (dipoles)
  - *Frequency Selective surface* → with elements → Patch antennas
- **Aperture Structure**
  - *Frequency Selective surface*
  - *Fresnel zone plate*
  - *Reflectarray*
  - *Transmitarray*
  - (Reflectarray, Transmitarray) → elements → Patch antennas

Patch antennas

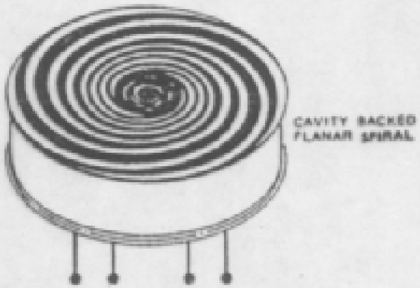
Preface 3 ---- *Structure Samples of Printed Antennas*

Wire Antennas

Printed Dipole

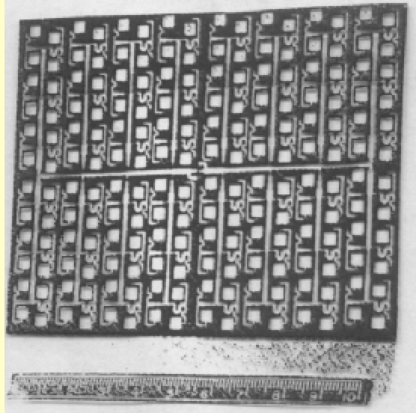


Printed Spiral

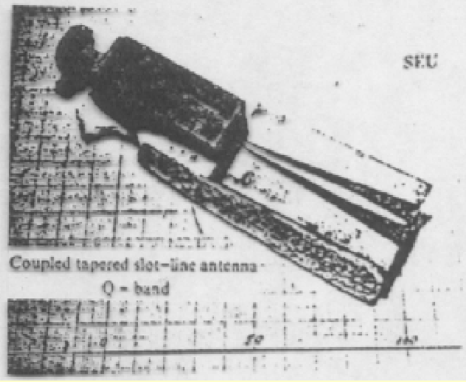


Microstrip-like Antennas

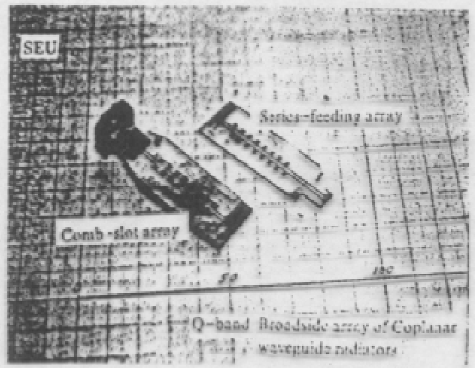
Patch



Tapered Slot-line

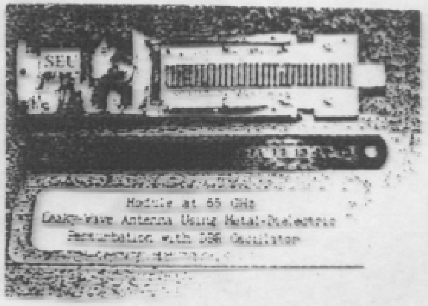


CPW Dipole

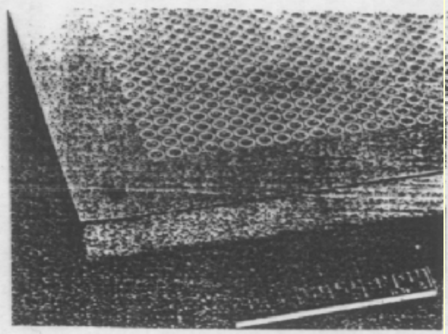


Printed Aperture Antennas

Grating



F S S



Fresnel Zone Plate

Preface$_4$ ---- *Historic Locus of Printed Antennas*

1950s Embryo
- *Strip-line (51)*
- *Micro-strip Line (52)*
- *Microstrip Antenna (53)*
- *Plate Antenna (55)*

1960s Pregnancy *Microstrip Circuits (MIC)*

1970s Baby
- *Practical Microstrip Ant. (72)*
- *Conformal Phased Array (74)*
- *Special Conference in N. M. (79)*
- *Vivaldi Antenna & TSA (74, 79)*
- *Frequency-Selective Surface (73)*

1980s Growth
- *Great Number of Papers ($10^{2\sim3}$)*
- *Many Monographs & Books(4^{+})*
- *Various Applications (BW? η_A?)*

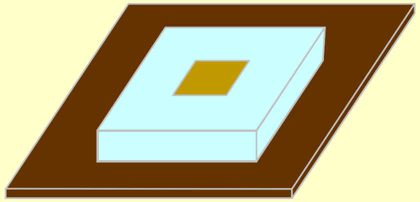
1990s Flourish
- *More Papers ($10^{3\sim4}$)*
- *More Monographs & Books(6^{+})*
- *Wide Applications (array tech.)*
- *Fresnel Zone Plate Antenna (91)*
- *Reflectarray Antenna (91)*

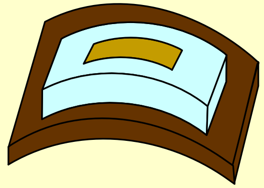
2000s Tiller
- *Structural Type*
- *Function & Performance*
- *Application Feature*
- *……*

Preface5 ---- *Features of MPA*

Structure

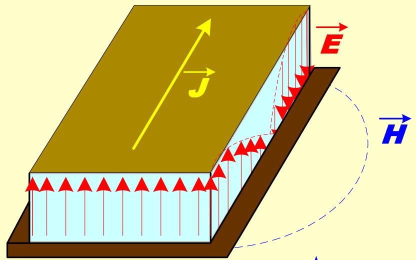
Low profile
Conformal

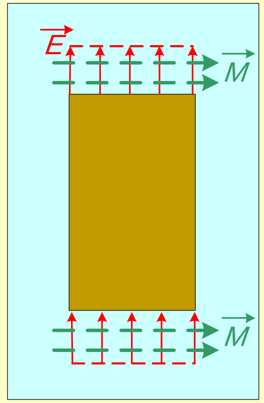




Fabrication

Uniform precision
Batch processing



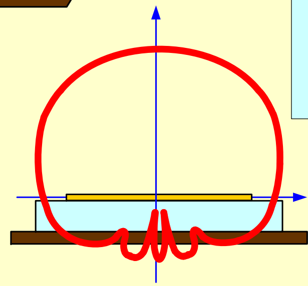


Principle

Resonant cavity mode
Slot-pair radiation

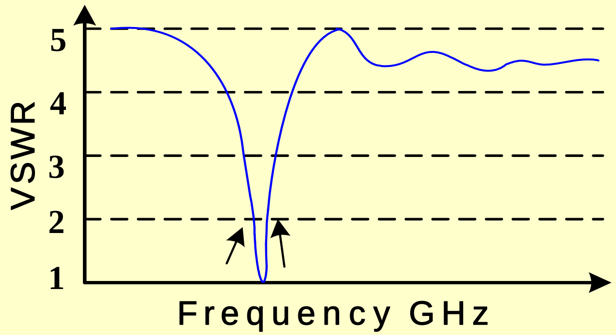
Pattern

Broadside
Unidirectional

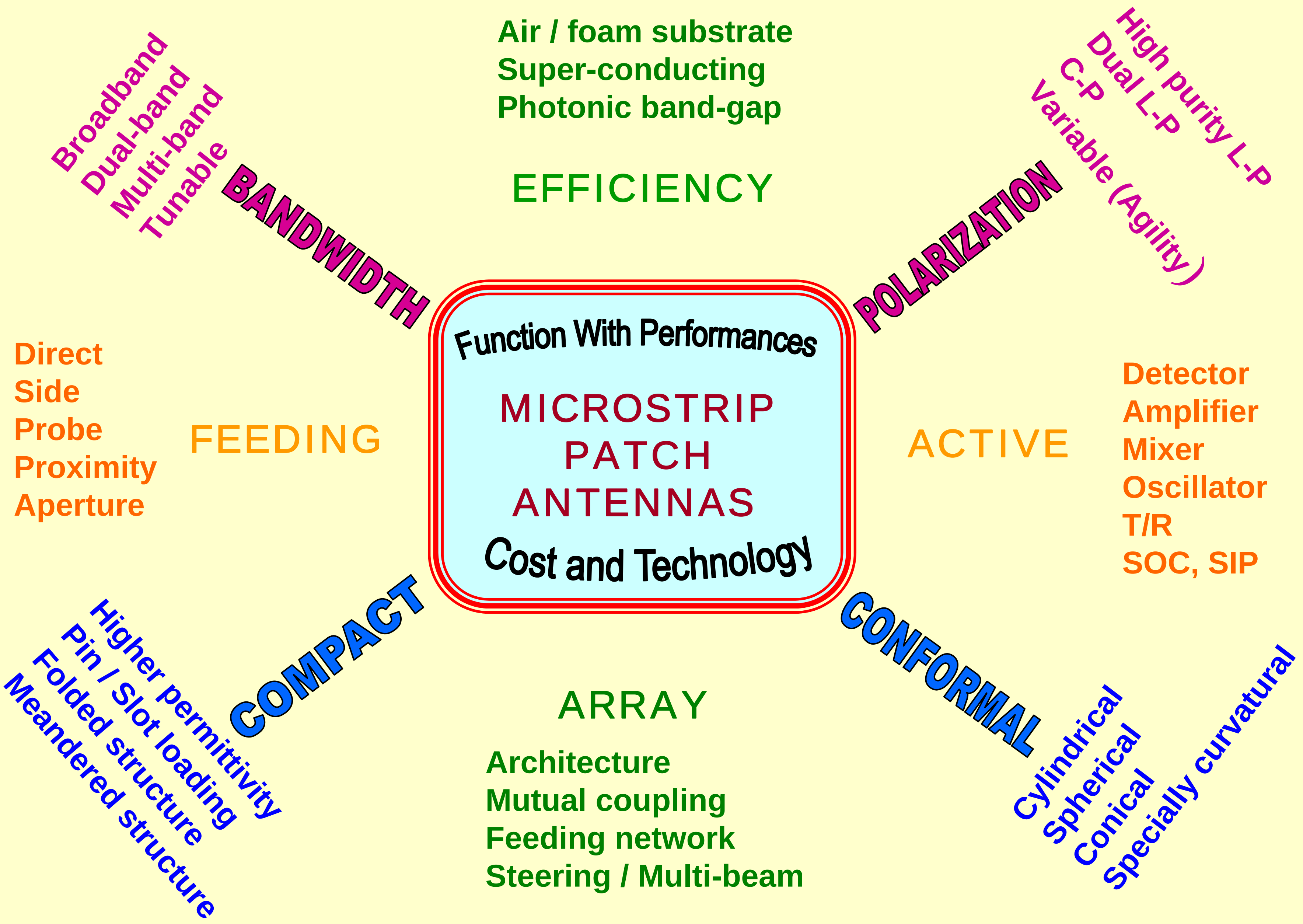


Shortcoming

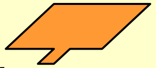
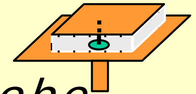
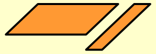
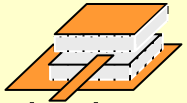
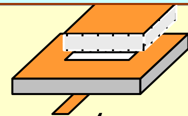
Narrower bandwidth
Lower efficiency



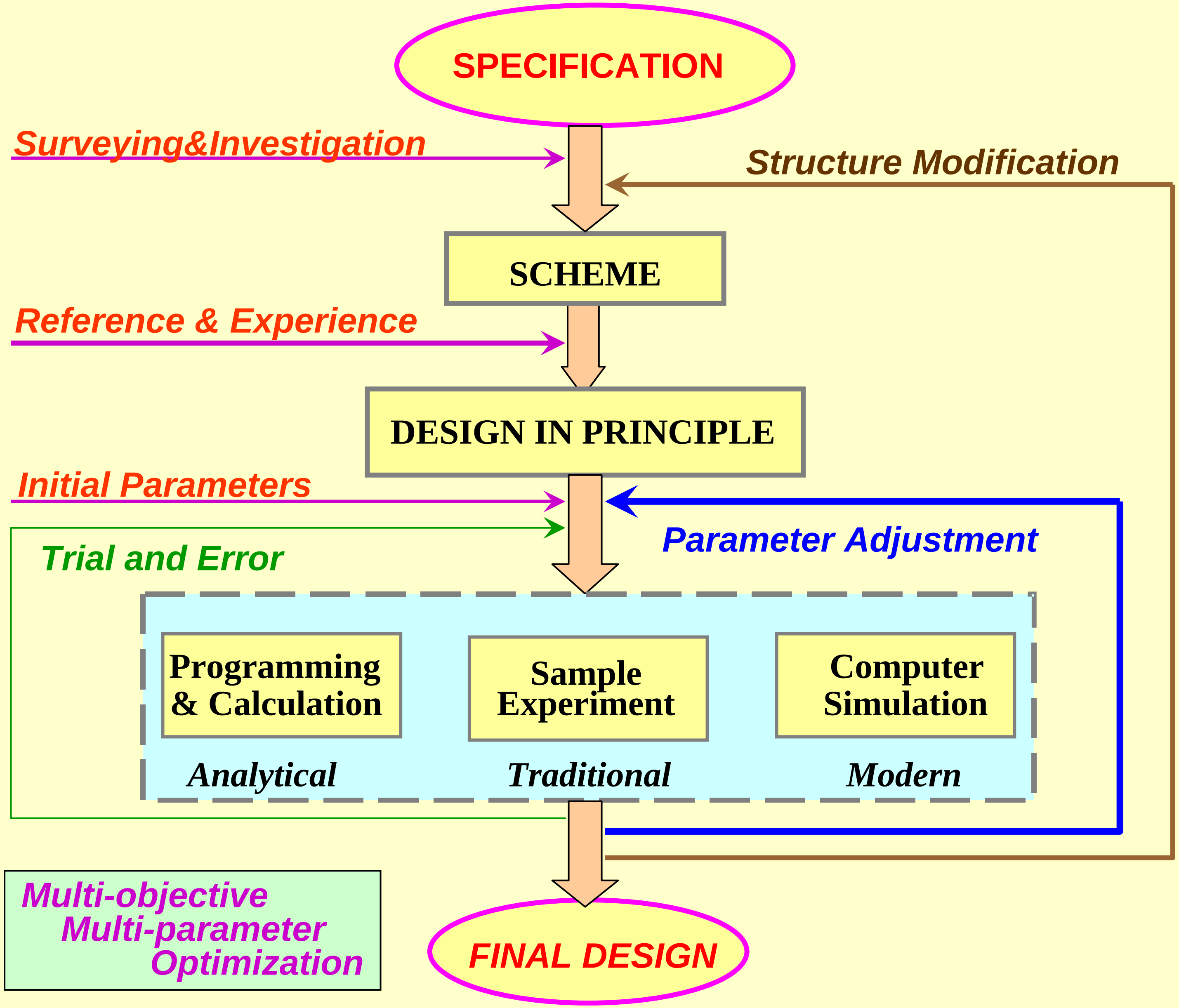
Preface 6 ---- *Eight Diagram of MPA*



Preface 7 ---- *Feeding Structure of MSA*

Type	Direct 	Probe 	Side 	Proximity 	Aperture 
Architecture **(*feeding*)**	***Co-planar ending***	***Isolated by ground plate***	***Co-planar passing***	***Quasi Co-planar***	***Isolated by ground plate***
Excitation **(*mechanism*)**	← ***Lumped*** →	***(Different polarity)***		← ***Distributed*** →	
Feeding **(*structure*)**	← ***Contacted*** → ***(Nonliner junction)***			← ***Un-contacted*** →	
Connector **(*input-port*)**	***Transition***	***Direct coaxial line***		← ***Transition or Direct networking*** →	
Adjustment **(*mechanically*)**		← ***Impossible*** →		← ***Possible*** →	
Thickness **(*relatively*)**	***Thin***	***3-D***	***Thin***	← ***Thick*** →	
Fabrication **(*technology*)**	***Printed***	***Mechanical***	***Printed***	← ***Printed / stacked*** →	
Performances **(*relatively*)**	← ***General*** → ***With matching compensation***		***Only for traveling wave array***	***Broader band***	***Broader band Higher gain Better pattern***

Preface 8 ---- General Design Flow-Chart



Contents

BroadBand Principle₁ ---- *Low 'Q'*

Specification of Frequency Bandwidth

The **Common Bandwidth** ***of*** **:** **Most important**

- *Impedance Matching* ---------------------- *for Narrow-band case*
- *Directive Gain*
- *Radiation Pattern parameters* ----------- *for Broad-band case*
- *Polarization parameters*

Principle 1. <*To reduce the Quality Factor "Q"*>

$$\uparrow BW \propto 1/Q \propto P_{dissipated} \begin{cases} \uparrow \text{loss} \propto 1/\text{efficiency} \Rightarrow \text{efficiency} \downarrow ; \\ \uparrow \text{radiation} \propto \text{volume} \uparrow . \end{cases}$$

To ⇧ volume of patch antenna	Restricted by-----
1. ⇧Patch size (↑W)	*Dominate mode resonance condition*
2. ⇧Substrate thickness (↓ε_r)	*Surface wave exciting/Probe radiating*
3. ⇧Coplanar parasitic elements	*Elements spacing in array*
4. ⇧Stacked parasitic element	*Coupling effectiveness*

Band Broadening$_2$ ---- *Suppress S-W*

Principle 2. *<To suppress the surface-waves>*

Surface-wave *is excited by* **inner-reflection inside dielectric**

Surface-wave ***results in*** { **Edge diffraction** / **Parasitic coupling** } **and then**

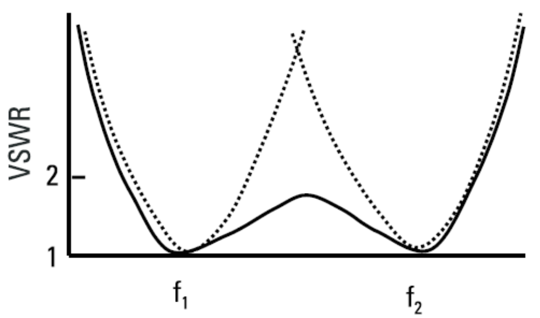
disturbs { ***Matching*** / ***Radiation*** } **properties**

Surface-wave ***may be suppressed by***
- ***Air-gap/Foam substrate***
- ***Decreasing (ε_r t)***
- ***Cavity-backed***
- ***Conductive fence***
- ***EBG structure***

Band Broadening$_3$ ---- *Multi-resonance*

Principle 3. *<To form multiple resonant response>*

Frequency-response Synthesis techniques:



*** Exciting multi-mode in the cavity**

----- by loading conducting post(s)

*** Adding magnetic currents of different f_R**

----- cutting shaped slot(s) on patch

*** Adjusting the configuration of patch**

----- adopting ridge(s) / notch(es) structure

*** Utilizing parasitic patches**

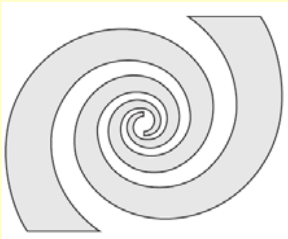
----- using co-planar bar(s) / stacked patch(es)

Band Broadening 4 ---- *Input-Matching*

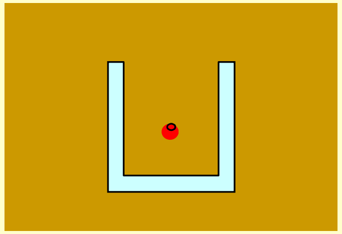
Principle 4. *<To match the input-impedance>*

* Control the patch impedance by internal-loading

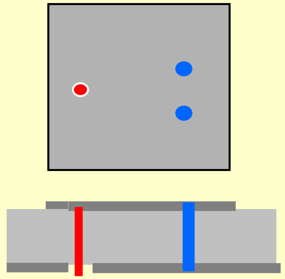
Shaped



Slotted

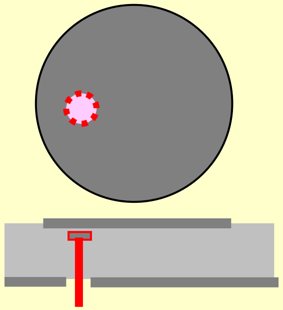


Shorted

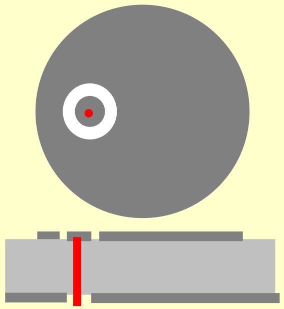


* Adjust the feed terminal by excitation-form

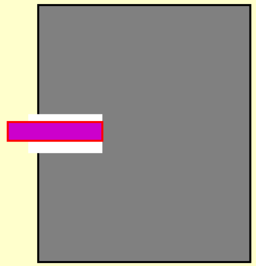
Disc-coupled probe



Slot-coupled probe



Inlaid-chock for strip

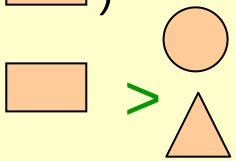


* Insert the matching network into feed-line

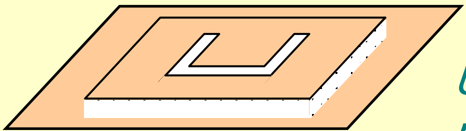
By means of Broadband-matching techniques
employing 'Branch & Stub'

Band Broadening 5 ---- *Summary*

BW % = Δ f / f₀ **for both** { ***VSWR ≤ 2.0:1 , 1.5:1 , 1.2:1*** / ***Pattern ~ Gain , X-polar*** / ***……*** }

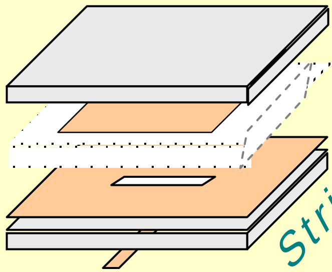
BW	*Technique*	*Feature*	*Problem*
<5%	.Low ε_r - thick substrate	***Foam /air-suspended***	***limited effect***
↓	.Larger width / length	(***for*** )	***higher-mode limitation***
10%	.Comparison in geometry		***pattern parameters***
↓	.Probe compensation	***Series resonance***	***auxiliary effect***
20%	.Co-planar bars	***Parasitic***	***limited size***
↓	.Stacked patches (SSFIP)	***Parasitic***	***structure & cost***
	.Slotted patch (U – type)	***Coincide***	***pattern parameters***
>40%	.L-probe patch	***Distributed feeding***	***Structural stability***

.Compound Tech.

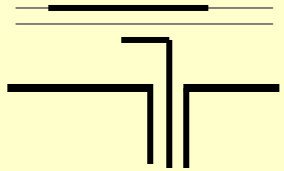


U-slotted patch

(*E-patch, H-slotted patch, H-patch, •••*)



Strip-Slot-Foam-Inverted-Patch



L-probe patch

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Band Broadening

Design Examples-8 *--- Double-layer*

Probe-fed patch --- Compound stacked

Dual-polarized patch --- SSFIP

Dual-polarized patch --- Aperture Coupled

Conclusion

Design Examples--*Double-layer Patch* 1

I. Probe-fed Compound StackedPatch -----

BW* ≈ *21 % in L-band* : *VSWR* ≤ *2.0:1 (50 Ω)

same $HPBW_E$ **(≈52°),**

***at 1.4* GHz : *SLL* < –*21*dB, *X-P* < –*20*dB.**

II. Dual-polarized SSFIP ----- element (array)

***BW* ≈ *8 % in L-band* : *VSWR* ≤ *2.0 (1.4) :1* (50 Ω) ; *I* = - *48 (-29)*dB,**

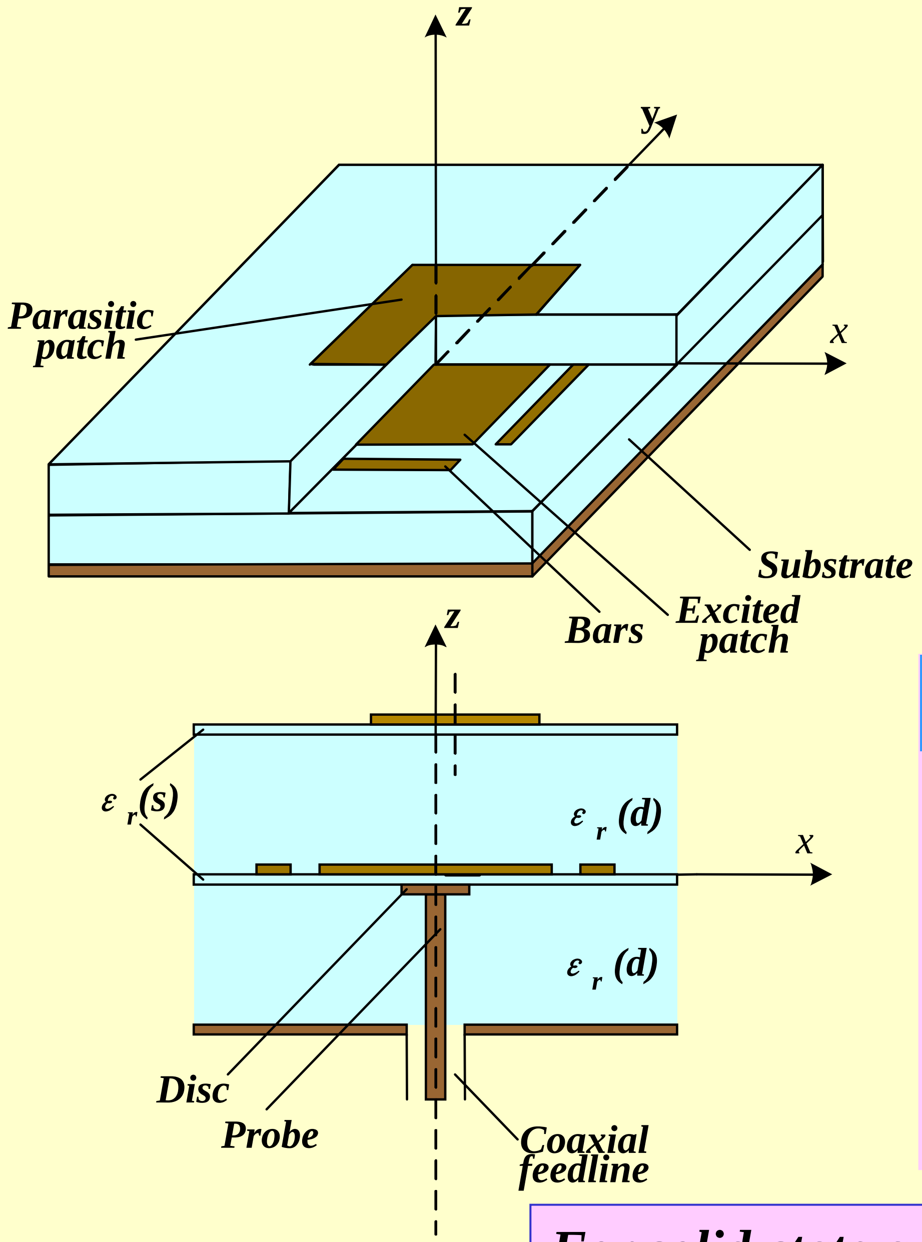
at f_0 **: *HPBW* ≈ *52°* ; *SLL* ≤ *-21* dB; *X-P* ≤ *-28* dB.**

III. Dual-polarized Aperture-coupled Patch -----

***BW* ≈ *22.1 (14.2)% in X-band* : *VSWR* ≤ *2.0 (1.3) :1* (50 Ω) ;**

***I* = *-34.6 (-35)*dB.**

I. Probe-fed Compound Stacked Patch



Compound Techniques:

- * Two pairs of parasitic bars surrounding the feeding patch
- * A stacked parasitic patch with offset by the current axis
- * A capacitive disc loading a probe fed by coaxial-line

Performances:

** BW≈21% at L-Band: VSWR≤ 2:1 with same E-plane patterns*

** at 1.4GHz : HPBW ≈52 °*
SLL< –21 dB
X-Polar< –20 dB

For solid-state active phased array

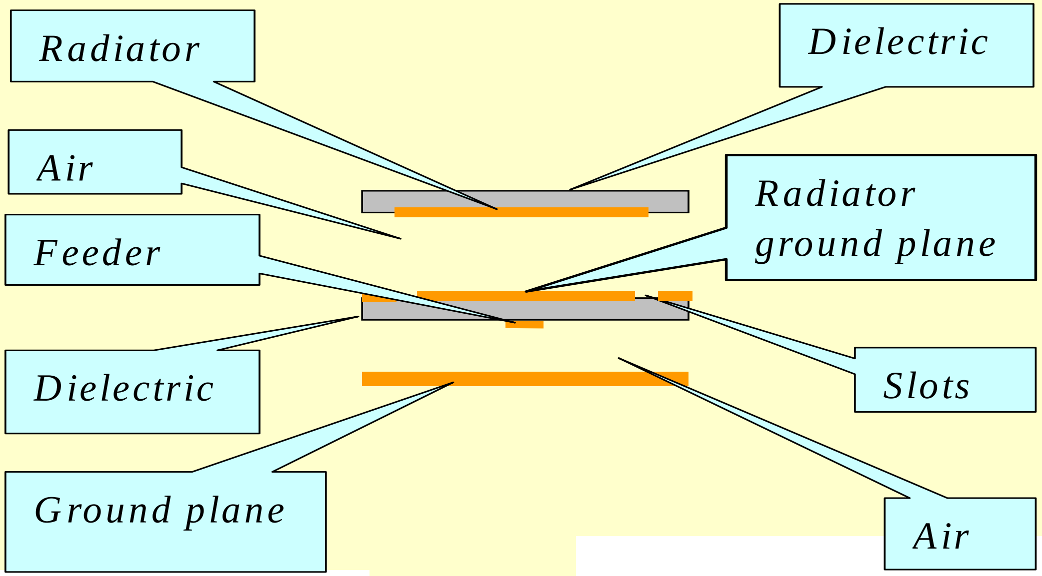
II. Dual-Polarized SSFIP

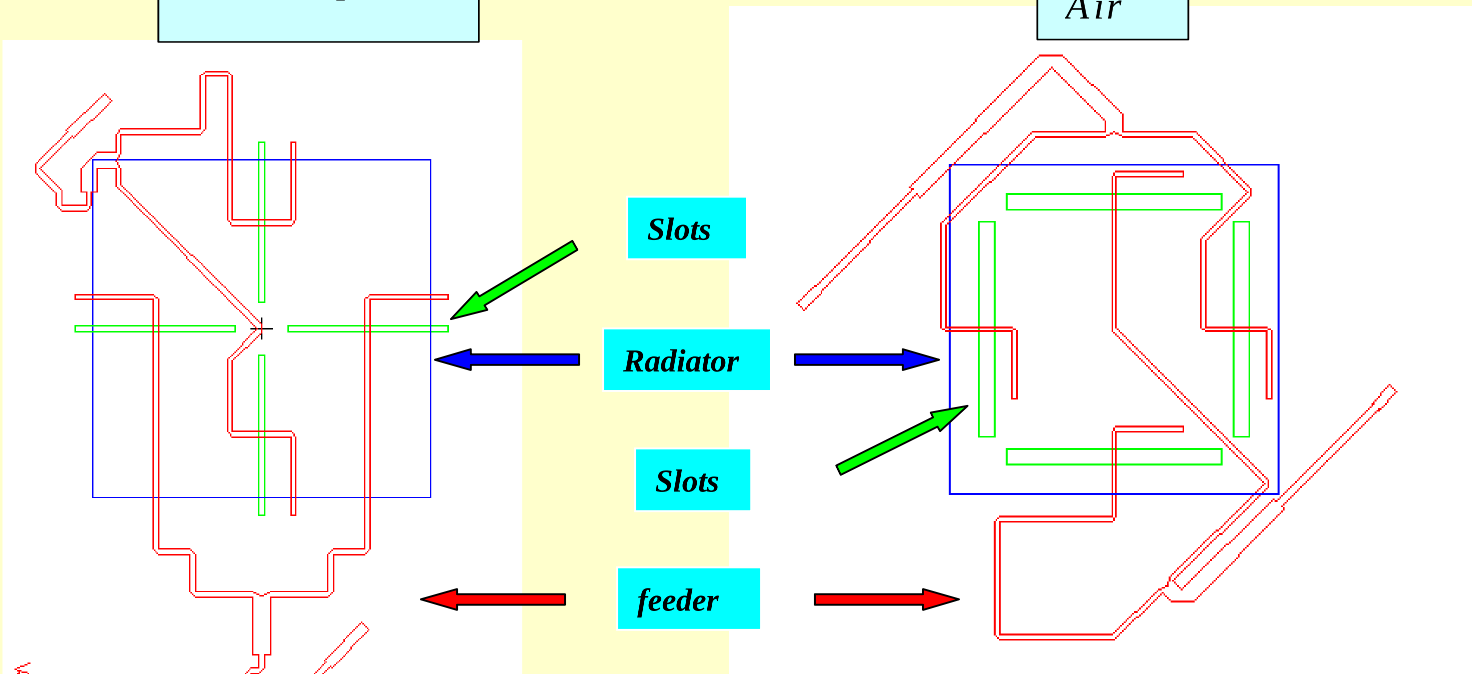
Structure

Bi-symmetry

↓

Input-isolation
&
Pattern-identity

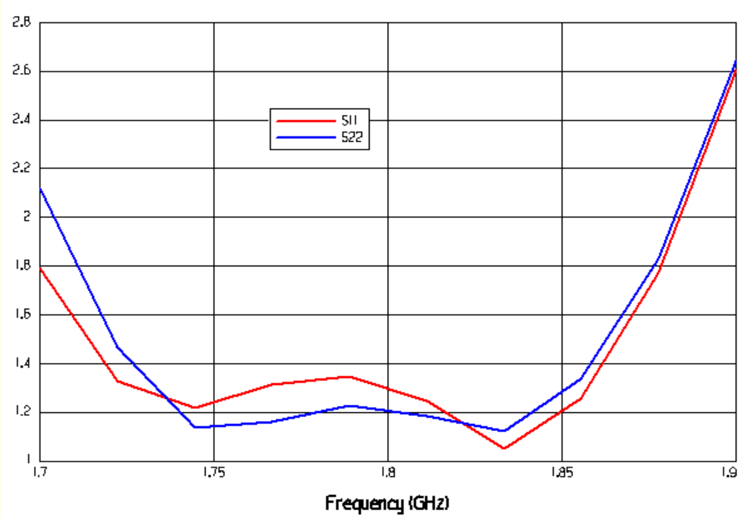




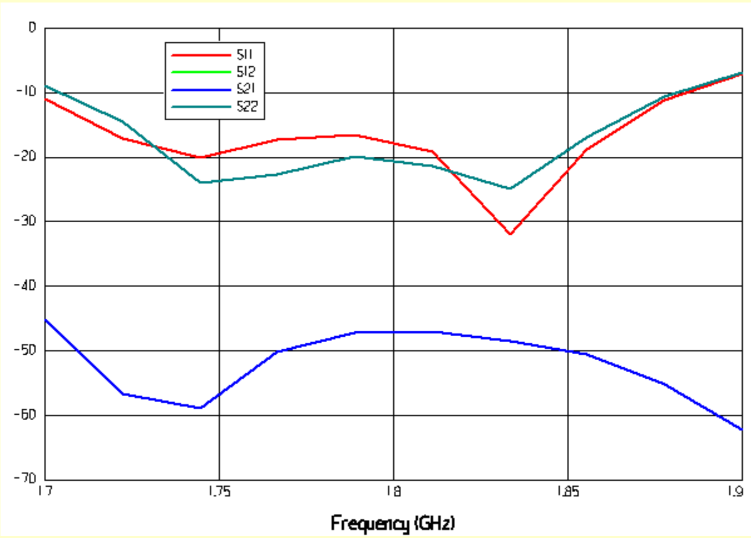
For Base-station of mobile communications

II. Dual-Polarized SSFIP

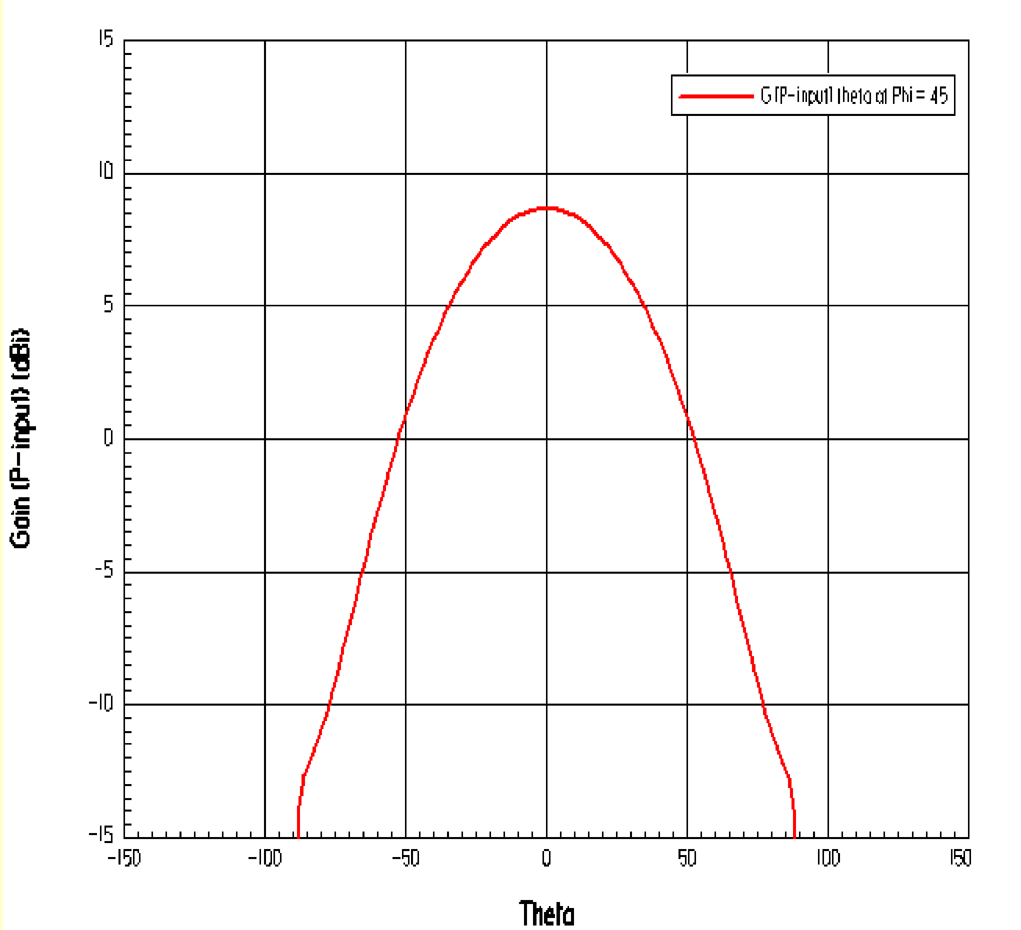
Curves



VSWR



Return Loss & Isolation (dB)



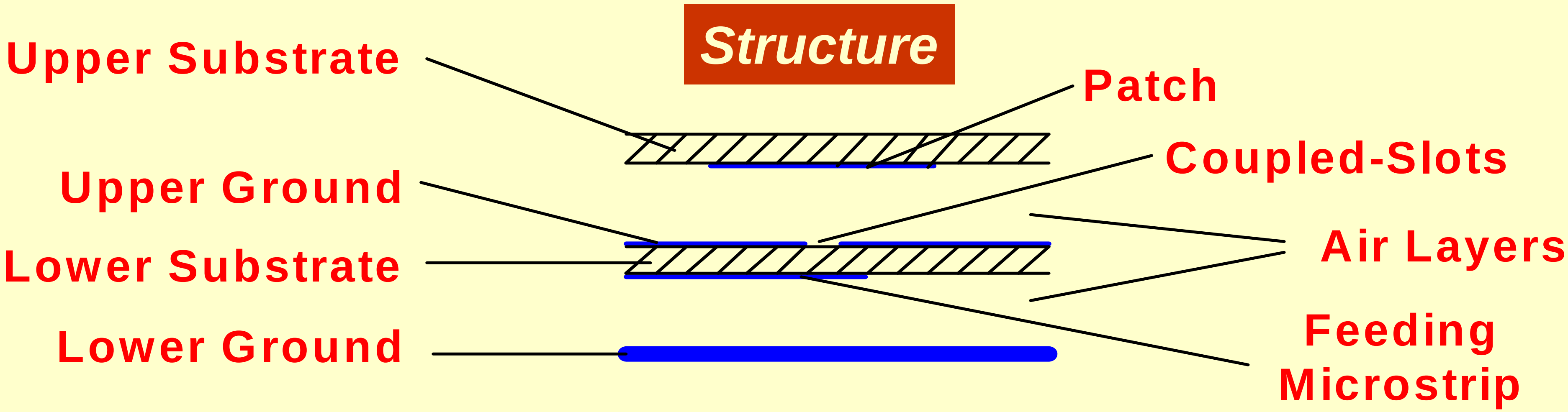
Vertical Pattern

II. Dual-Polarized SSFIP

Performances *With 7.9 % Bandwidth for*
- *VSWR≤ 2.0:1*
- *Isolation ≤ –48 dB*
- *Cross-Polar ≤ –28 dB*

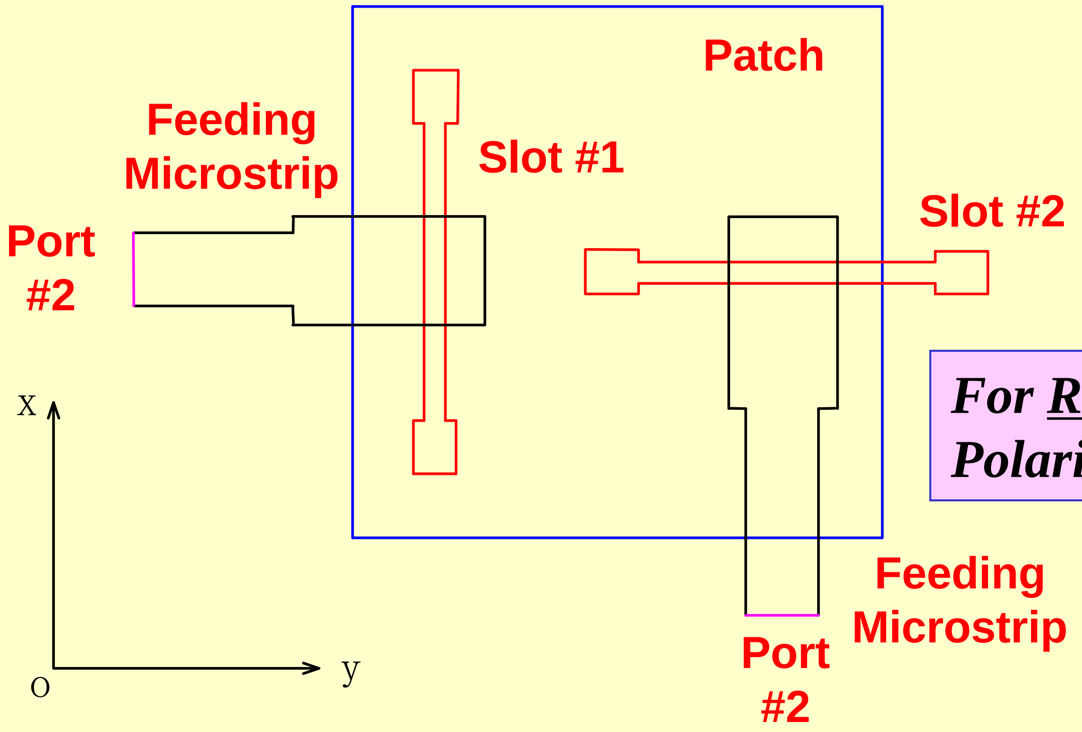
Antenna	*Element with two ports*			*Array of 6 elements*		
Frequency (GHz)	1.71	1.78	1.85	1.71	1.78	1.85
Gain (dBi)	8.2	9.0	9.3	15.2	15.5	15.8
X-Polar (dB)	-28	-33	-37	-28	-38	-31
VSWR (Port I) *(Port II)*	1.9 1.7	1.2 1.35	1.3 1.2	1.32 1.34	1.32 1.31	1.31 1.39
Isolation (dB) (*Ports & II)*	-48	-48	-50	-30	-37	-29

III. Dual-polarized Aperture-coupled Patch



Simple Feed

Broadband & Simplicity



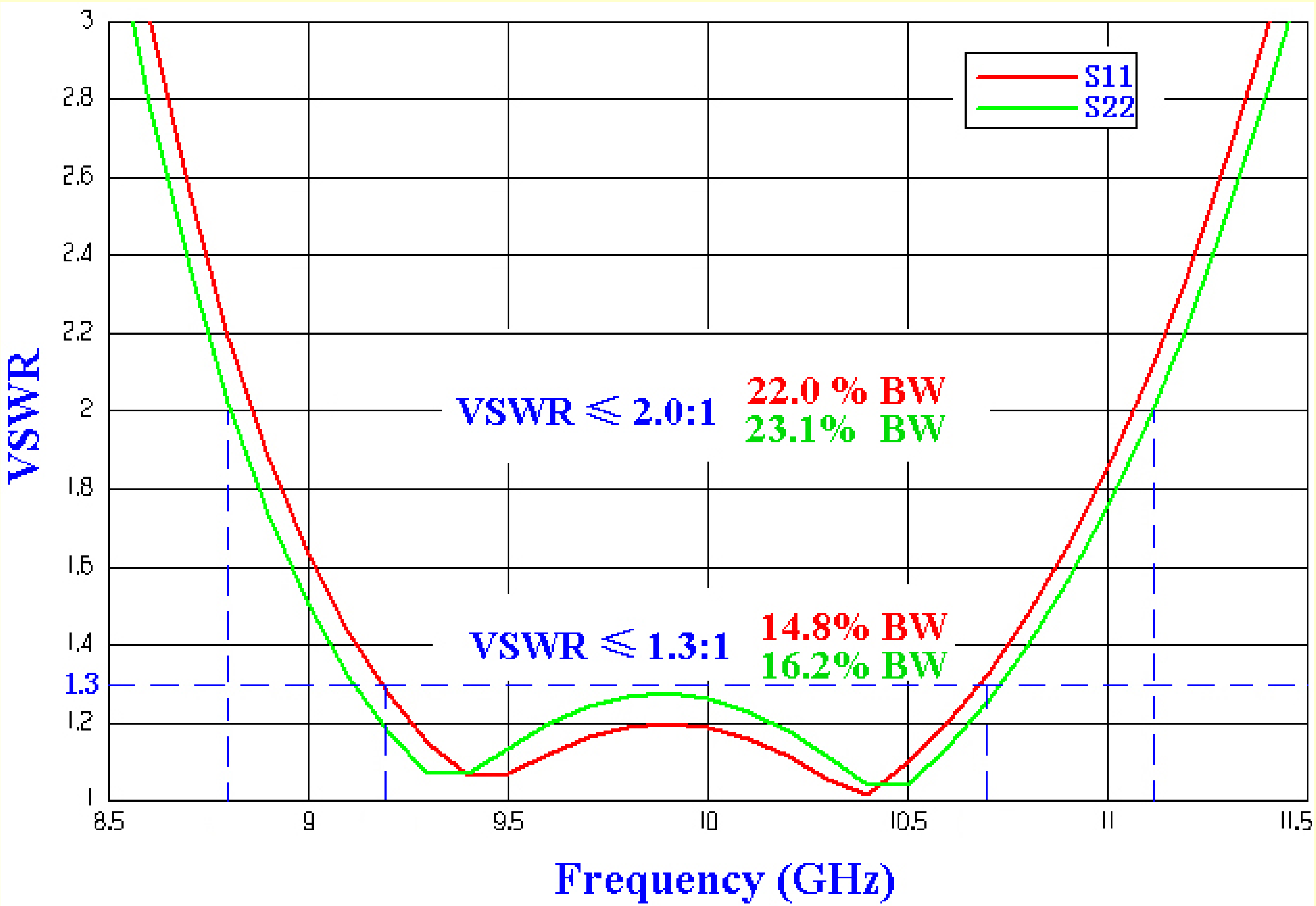
For Reflect-array with Polarized transform

III. Dual-polarized Aperture-coupled Patch

Matching

22.1 % Bandwidth for VSWR≤ 2.0:1

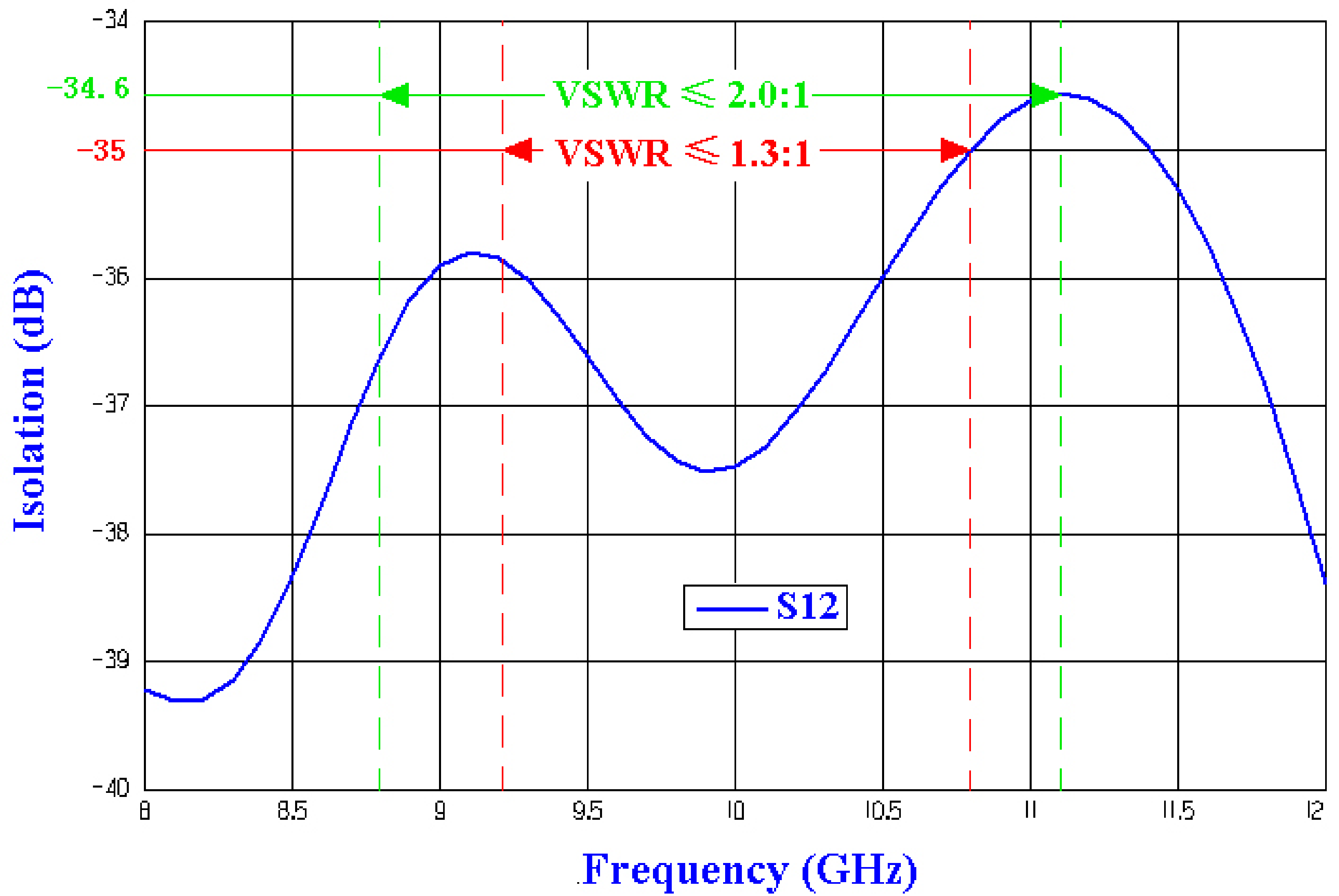
14.2 % Bandwidth for VSWR≤ 1.3:1



III. Dual-polarized Aperture-coupled Patch

Isolation

Isolation ≤ –34.6 dB in whole Bandwidth



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Band Broadening

DesignExamples-15 *--- Single-layer*

U-slotted patch --- Aperture coupled

Dual-band patch --- GSM+DCS

EBG-backed spiral --- Thin profile

Conclusion

Design Examples --*Single-layer Patch* 1

IV. Aperture-coupled U-slotted Patch -----

{ *BW ≈ 40 % in S, Ku-band* , *VSWR* ≤ *2.0:1* (50 Ω)
BW ≈ 30 % in Ku-band , *ΔG* ≤ *-3*dB, *X-P* ≤ *-18* dB .

V. Dual-band single-layer Patch-----

BW ≈ { *37% for DCS1800* ; *9.3 % for GSM900* } , *VSWR* ≤ *2.0:1* (50 Ω), *I* = *-15* dB;

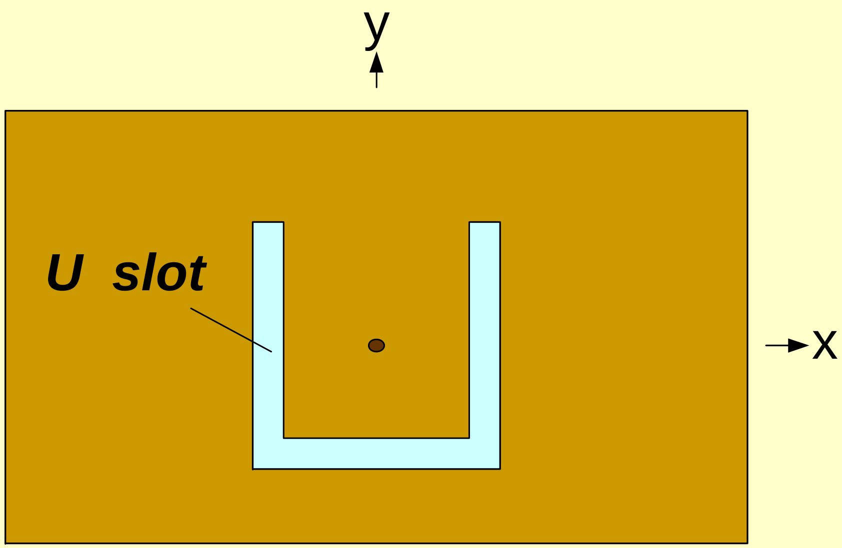
G ≥ { 5.6 dBi ; *10.2* dBi } ; *HPBW* ≈ { *107°* ; *58°* }

VI. PBG-backed Spiral----- *Relative to Spiral with PEC plate*

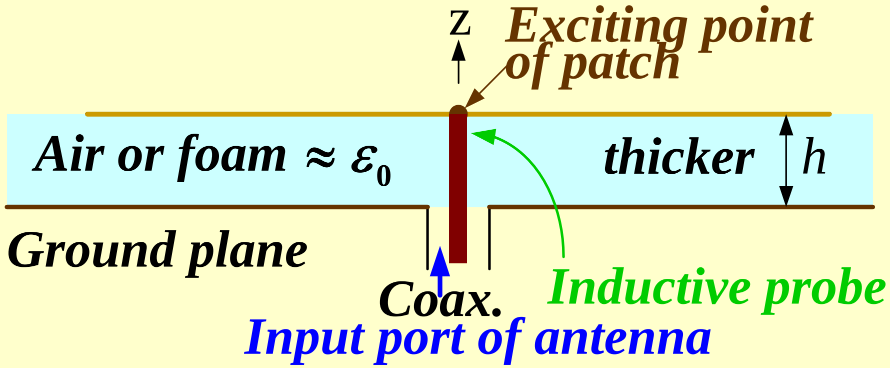
BW% ×1.23 ⇒ 65 % in X/Ku-bands , *VSWR* ≤ *2.0:1* (50 Ω *throughout Balun*)

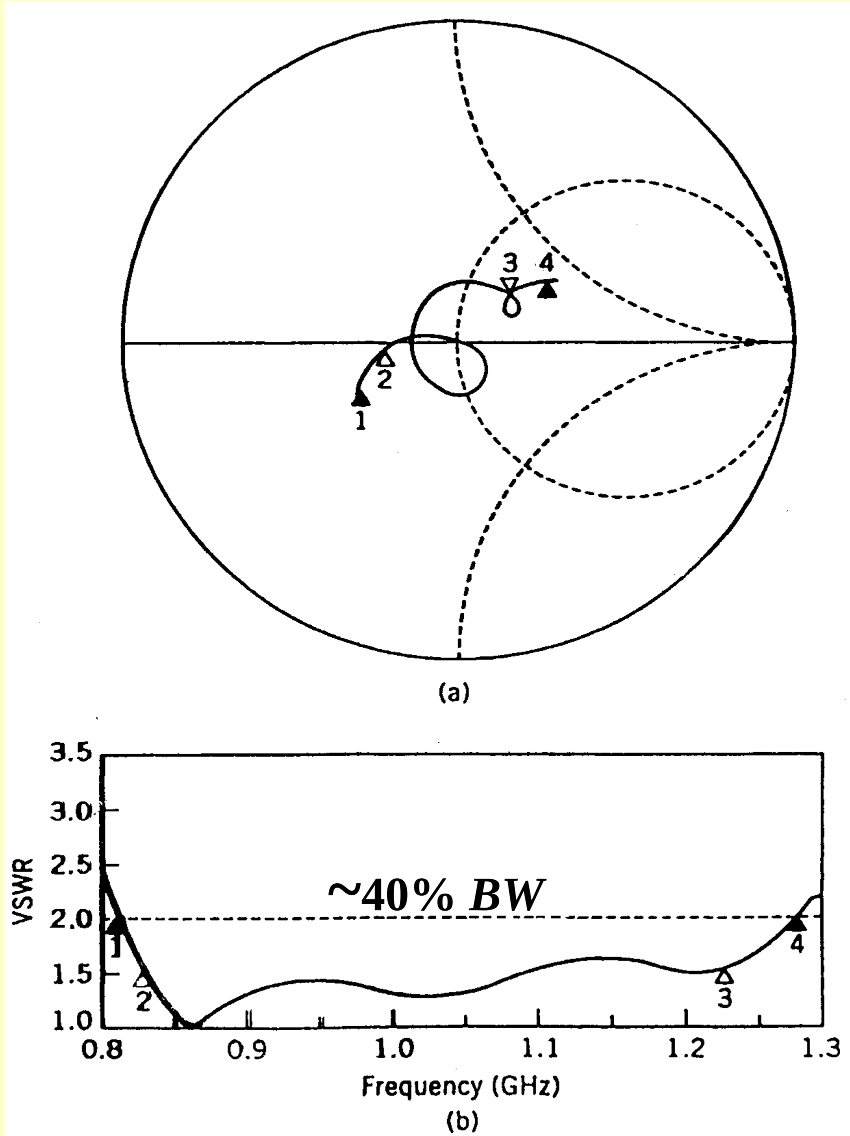
HPBW is same (≈ *90°*), G_{dB} *+1.3* dB, $(F/B)_{dB}$ *+8.9* dB .

@ Probe-fed U-slotted Patch- (Lee)



Capacitive U-slotted patch





1995 1997

From *K.F. Lee/W. Chen (Ed). "Advances in Microstrip and Printed Antennas" pp.64-65*

@ L-Probe proximity-fed U-slotted Patch- (Luk)

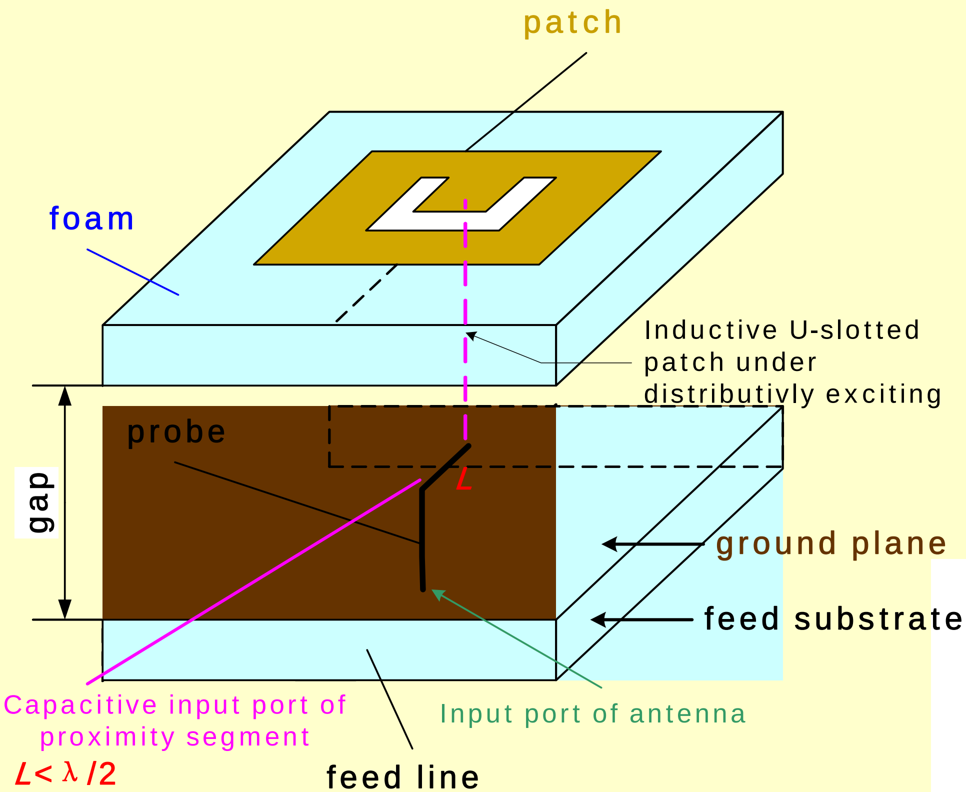


Fig. 1 Geometry of L-probe proximity fed U-slot patch antenna

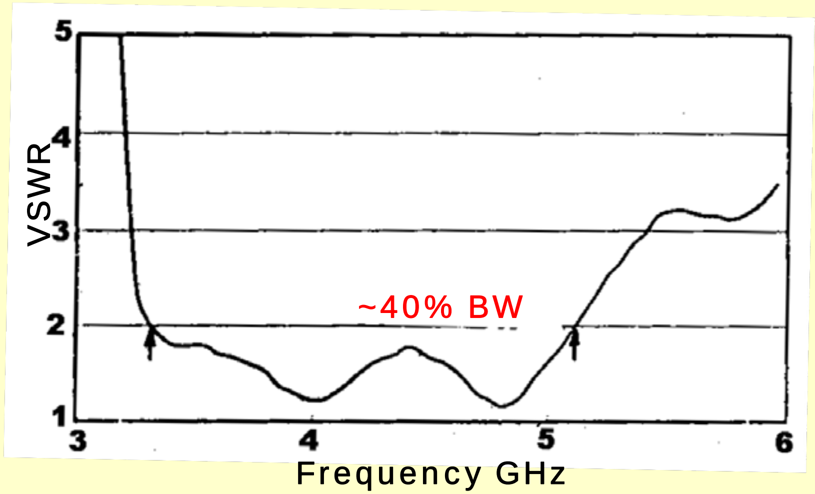


Fig. 2 VSWR against frequency

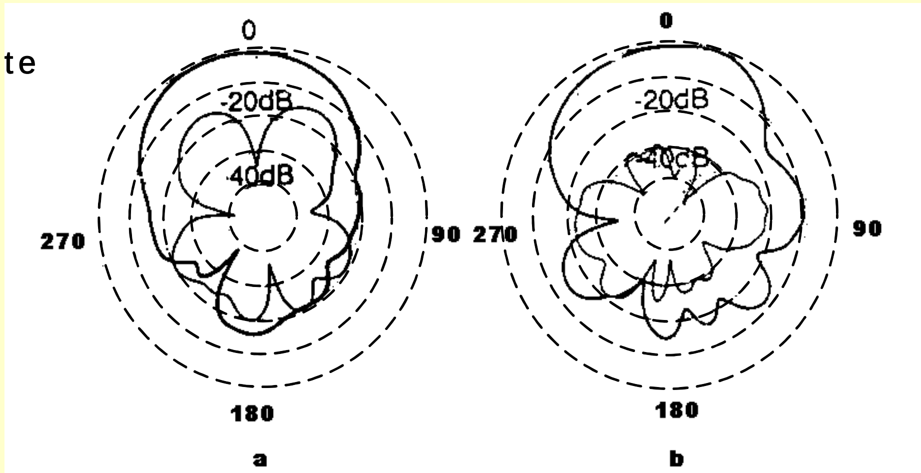


Fig. 3 Radiation patterns at 4.2 GHz

From *K.M. Luk et al. Electronic Letters(1998) 34(19) 1806-1807*

@ If Aperture-coupled U-slotted Patch exists?

◇ **Aperture-coupling separates Radiator & feed by ground plate**

*** Structure complanation ~ especially for array with feed network***

*** Interaction avoidance ~ isolation between radiation & transmission***

*** Design rationalization ~ using lower & higher εr substrates respectively***

◇ **Aperture-coupling had been widely applied to patch antennas**

*** Suitable for different kinds of patch antennas !***

*** Obvious merit to achieve impedance matching in a wideband !***

*** Why have not performed after the original (1995) paper until to 1999 ?***

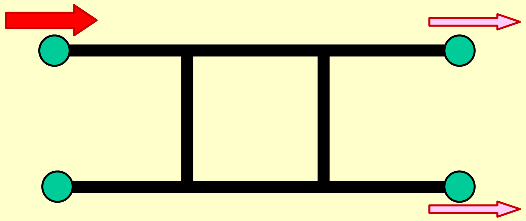
*** Be locked into a closed concept of capacitive impedance at excited point ?!***

@ Comparing lumped & distributed coupling

To perform a *Inductance* by shorter coupling-slot ? ----- *Failed !*

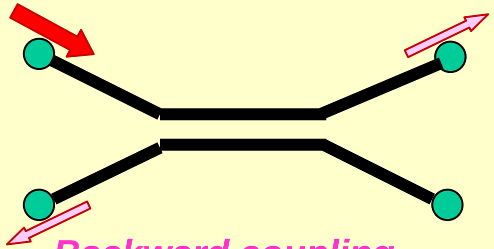
For a directional coupler constructed from two parallel transmission lines

Lumped coupling



Forward coupling

Distributed coupling



Backward coupling

opposite flow-direction for coupled output

Current on patch

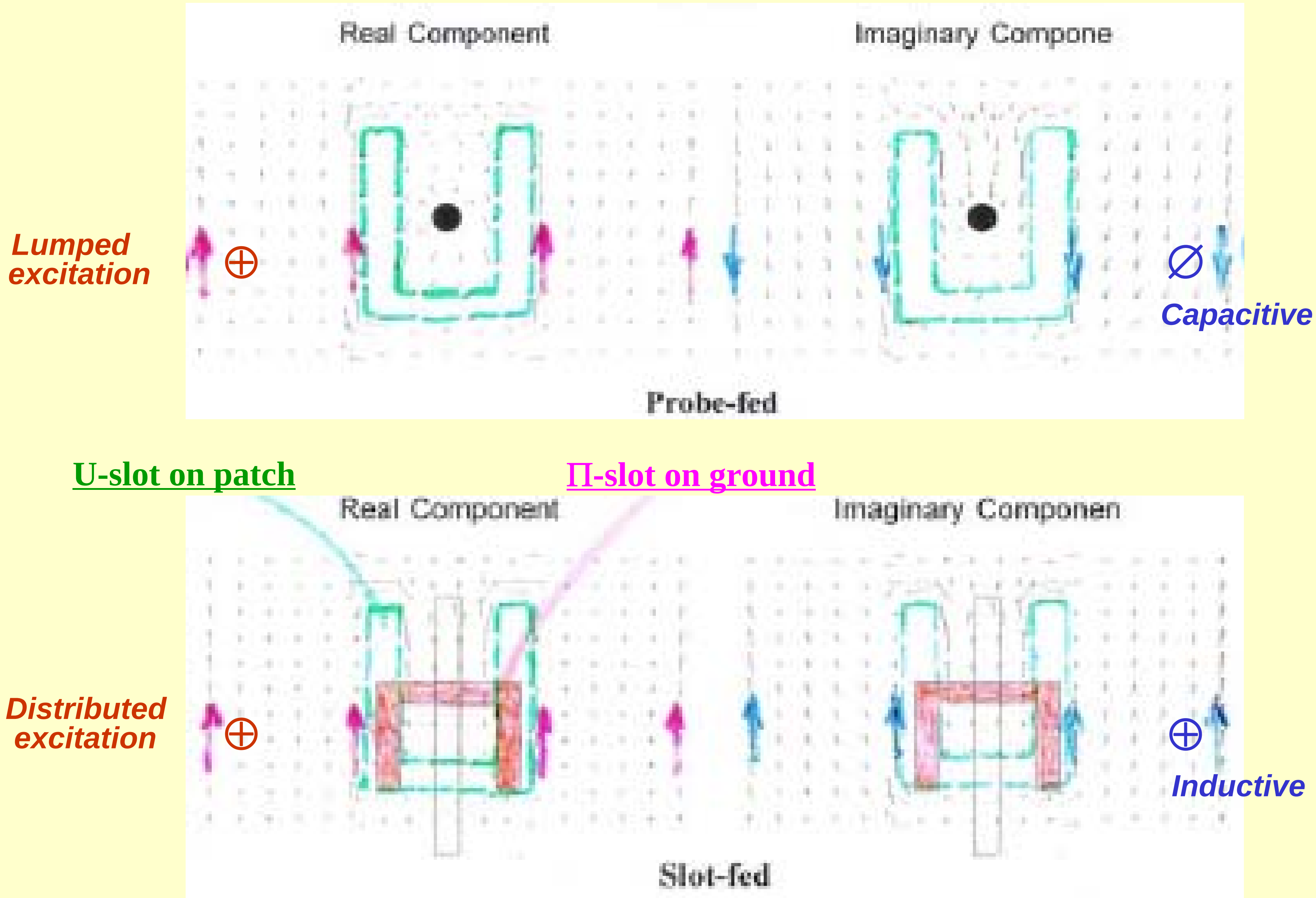
Current-direction corresponds to polarity of reactance

Capacitive Patch → ***Inductive coupling-slot < $\lambda/2$***

must be matched by

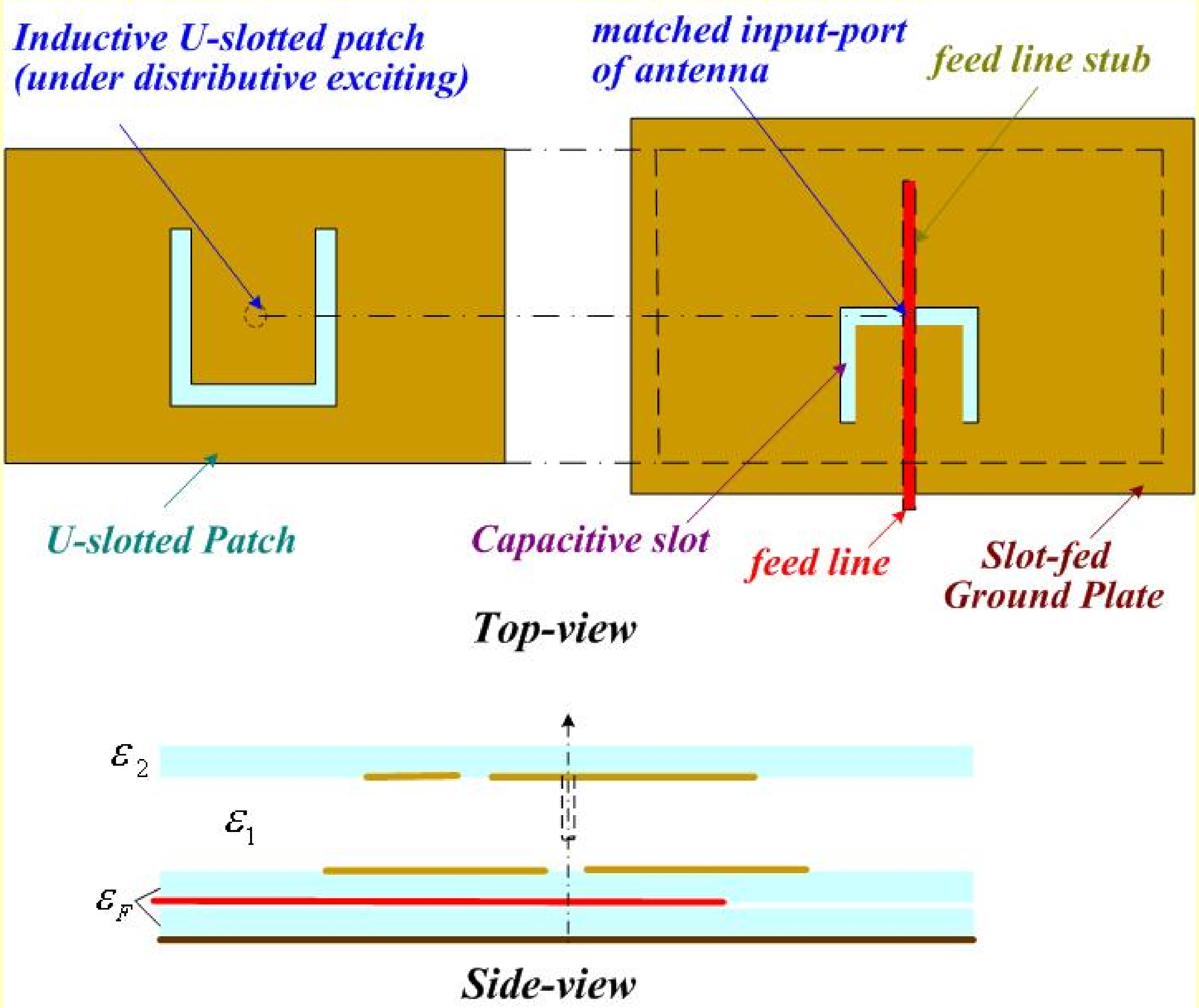
Inductive Patch → ***Capacitive coupling-slot > $\lambda/2$***

@ Comparison of curren polarity on patches



IV. Π-slot fed U-slotted Patch

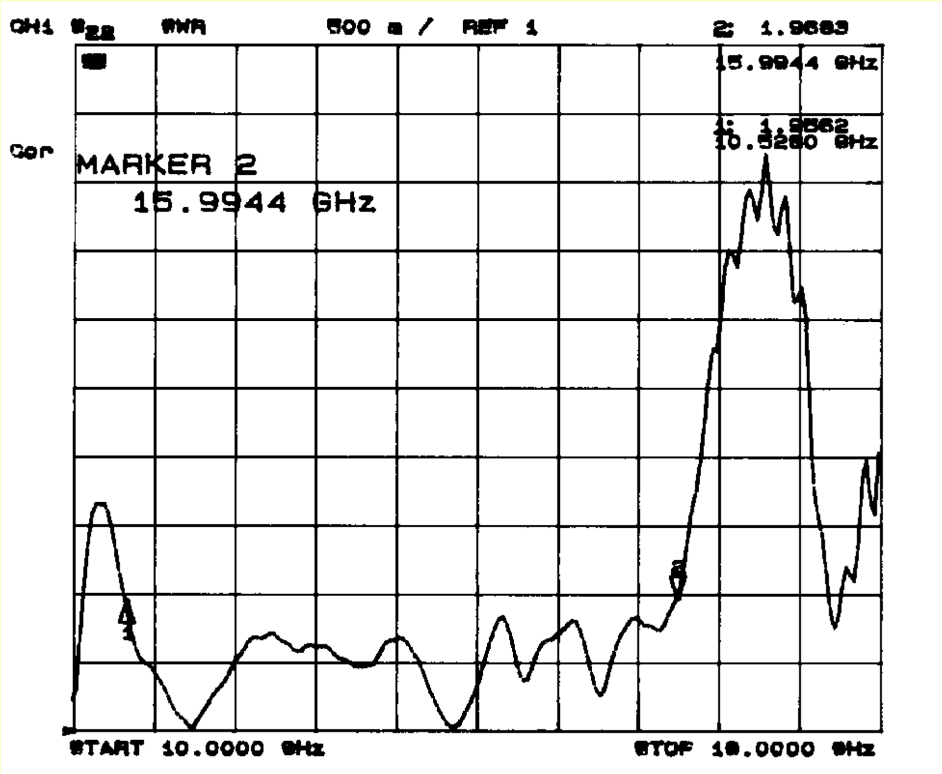
Structure



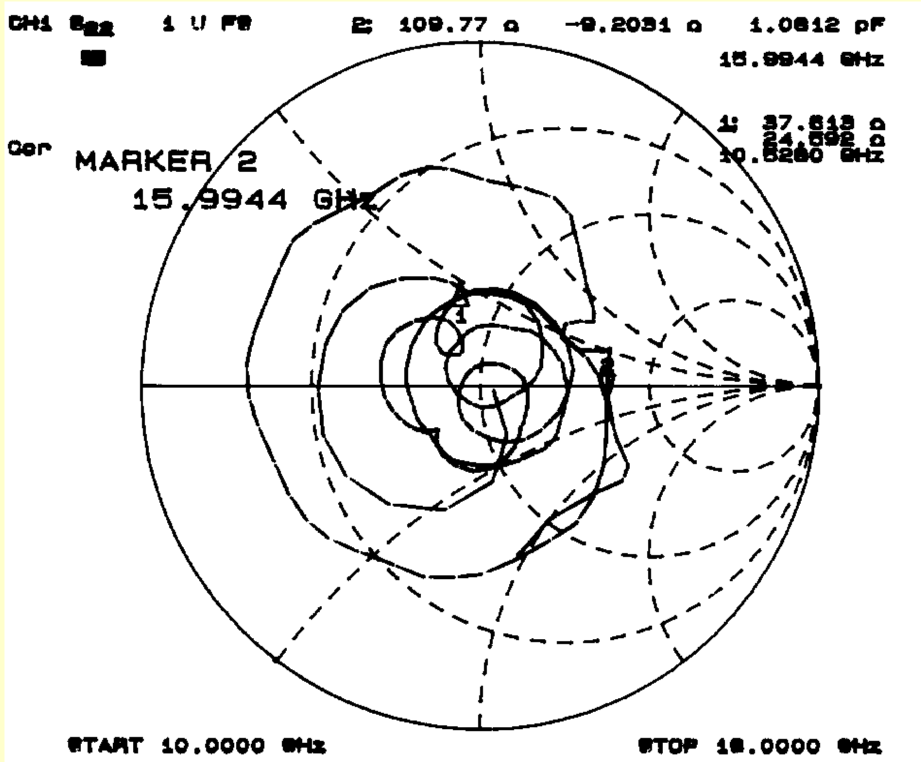
IV. Π-slot fed U-slotted Patch

Matching

Frequency response of slot-fed U-slotted patch antenna



Tested VSWR response

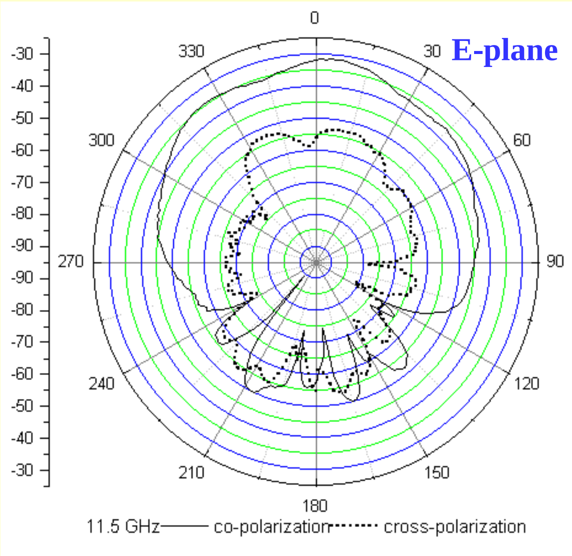


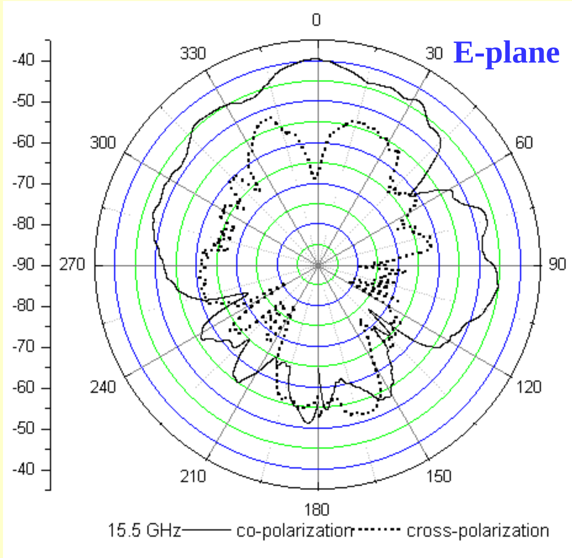
Tested impedance locus

40 % / 26 % Bandwidth for VSWR≤ 2.0:1 / 1.5:1 (50Ω) in Ku-Band

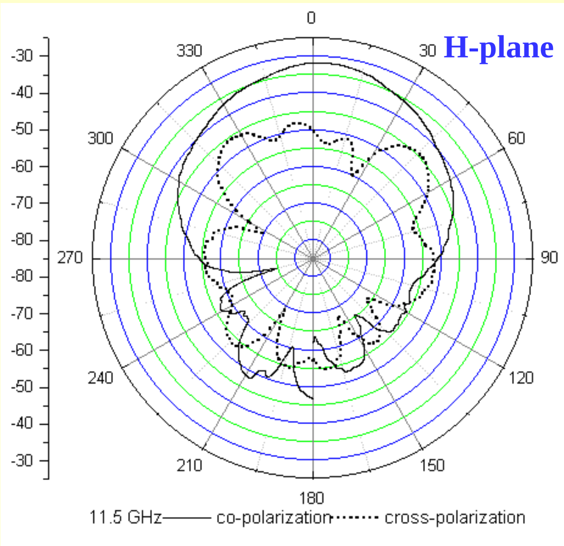
IV. Π-slot fed U-slotted Patch

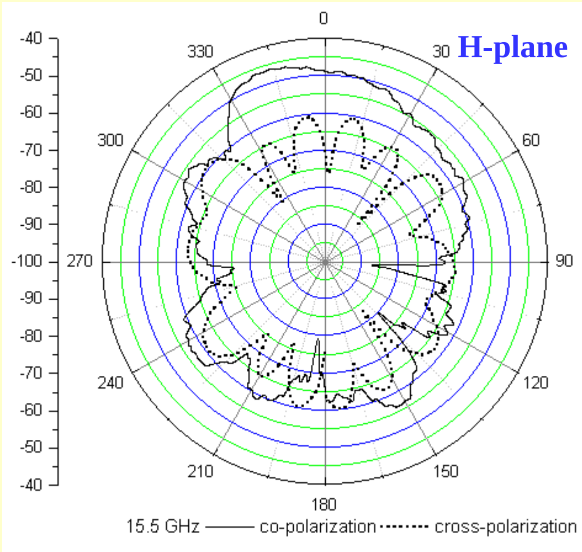
Pattern

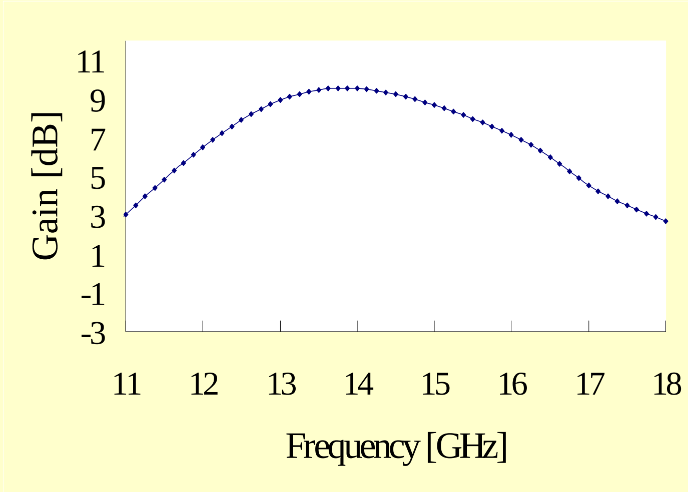




11.5 GHz **15.5 GHz**







30 % Bandwidth

for Pattern

$\Delta G \leq -3$dB

$X\text{-}P \leq -18$ dB

in Ku-Band

V. Dual-band Single-layer Patch

Principle

U-slotted patch → *move slot to patch edge* → **E- patch**

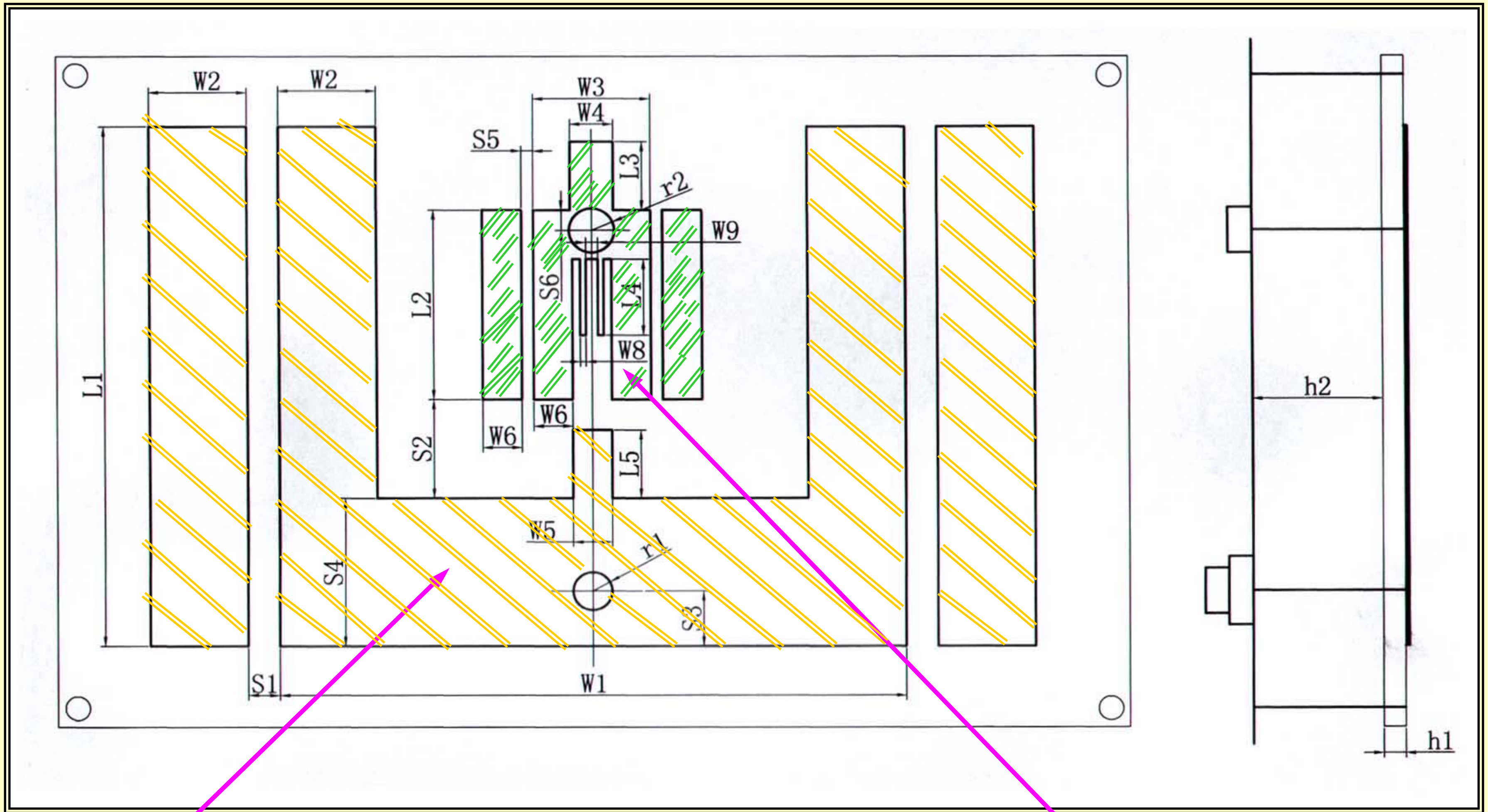
↓ *nested oppositely*

double E-patches → **Modified E-patches**

- *Parasitic bars --- decrease mutual coupling*
- *Ridged stubs --- adjust impedance matching*
- *Independent feeding --- by isolated probes*

V. Dual-band Single-layer Patch

Structure



GSM-900
(890~960) MHz

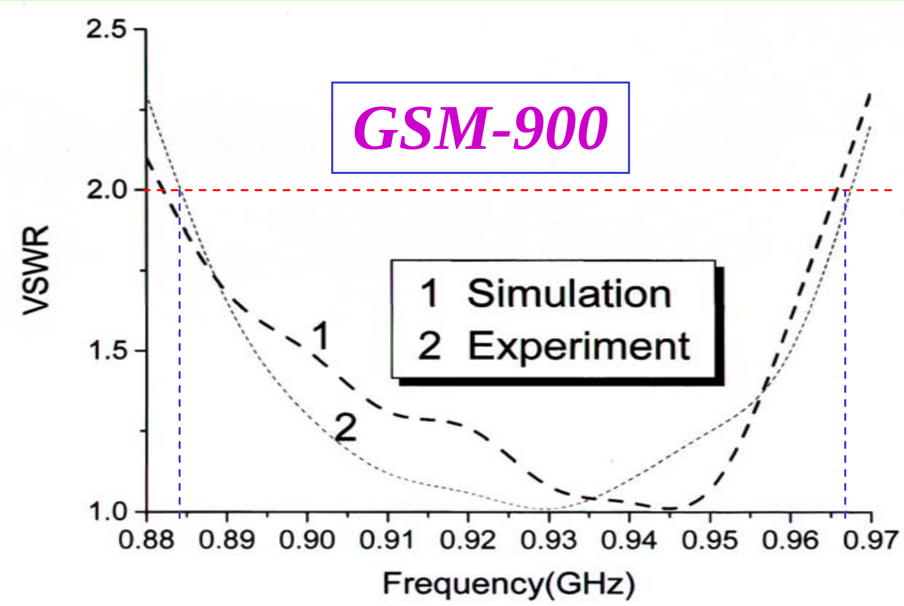
GSM-1800
(1710~1880) MHz

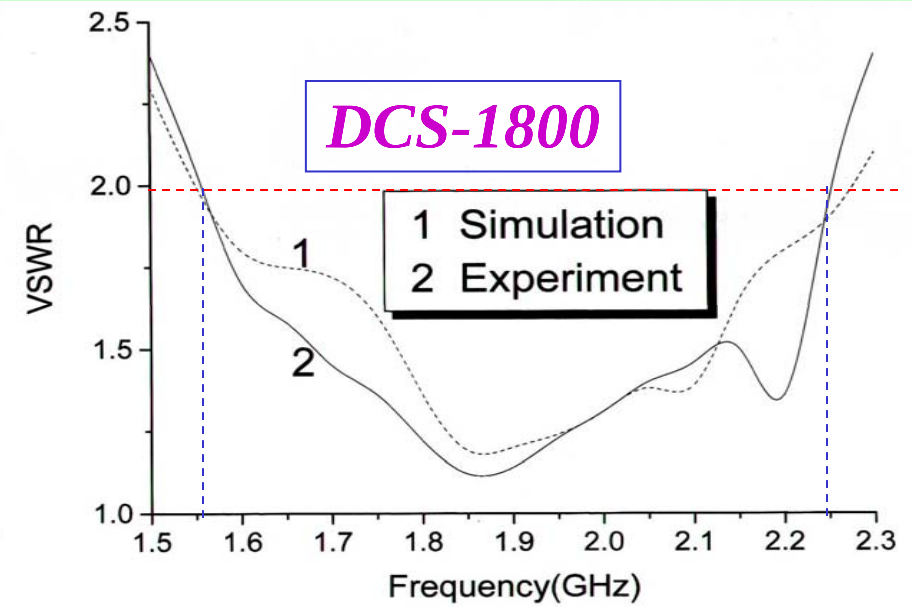
For wireless LAN in door

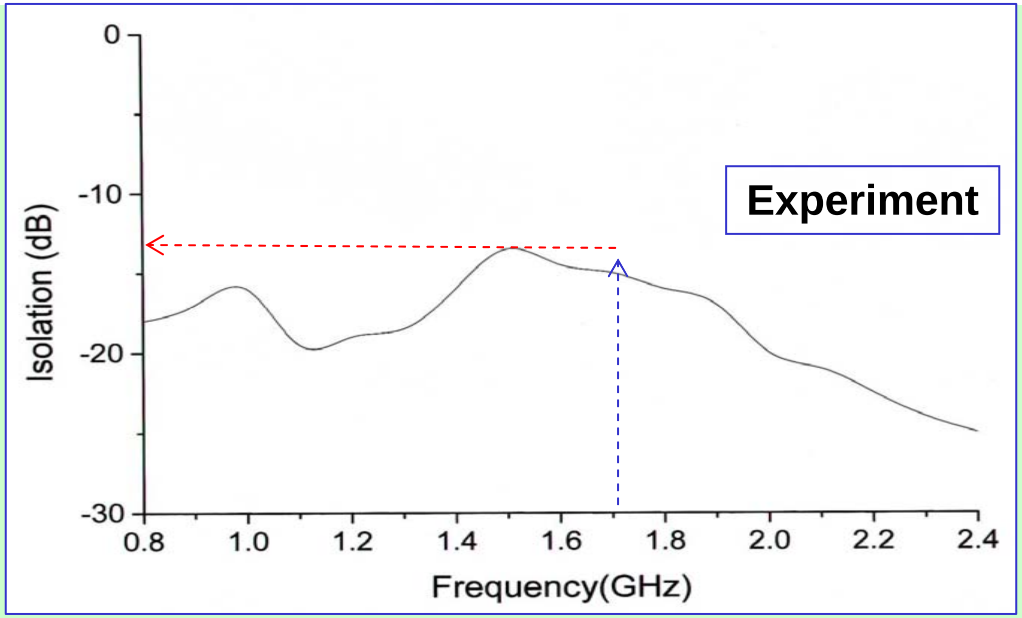
Patent

V. Dual-band Single-layer Patch

Curves







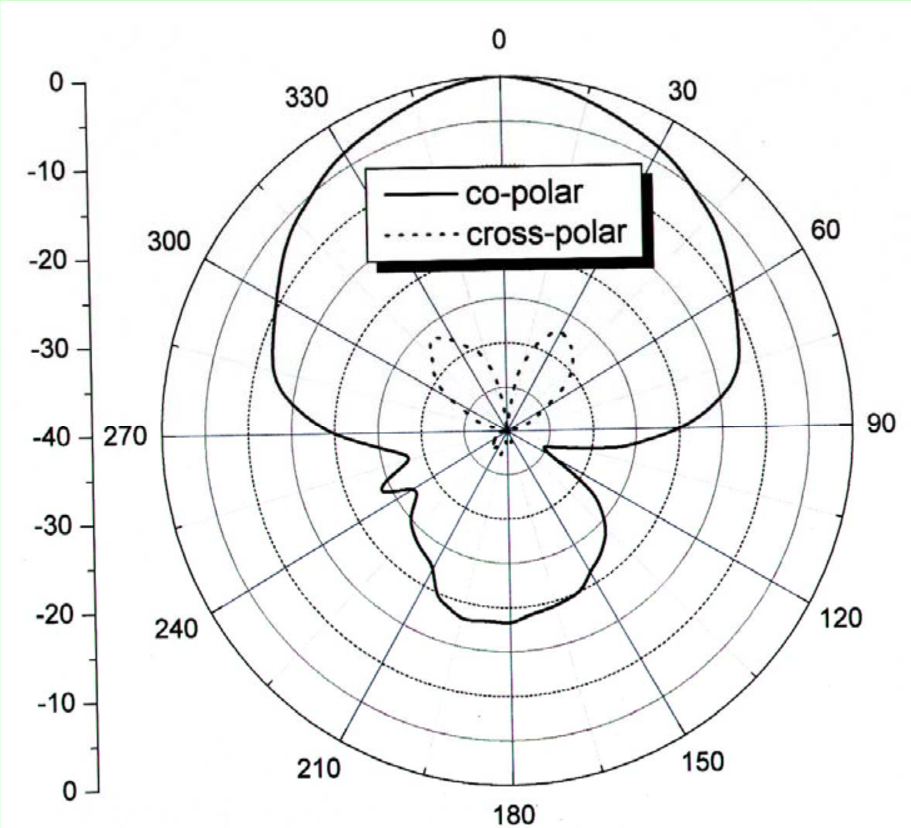
VSWR* ≤ *2.0 :1* (*50* Ω) *,

***I* ≤ *-13* dB,**

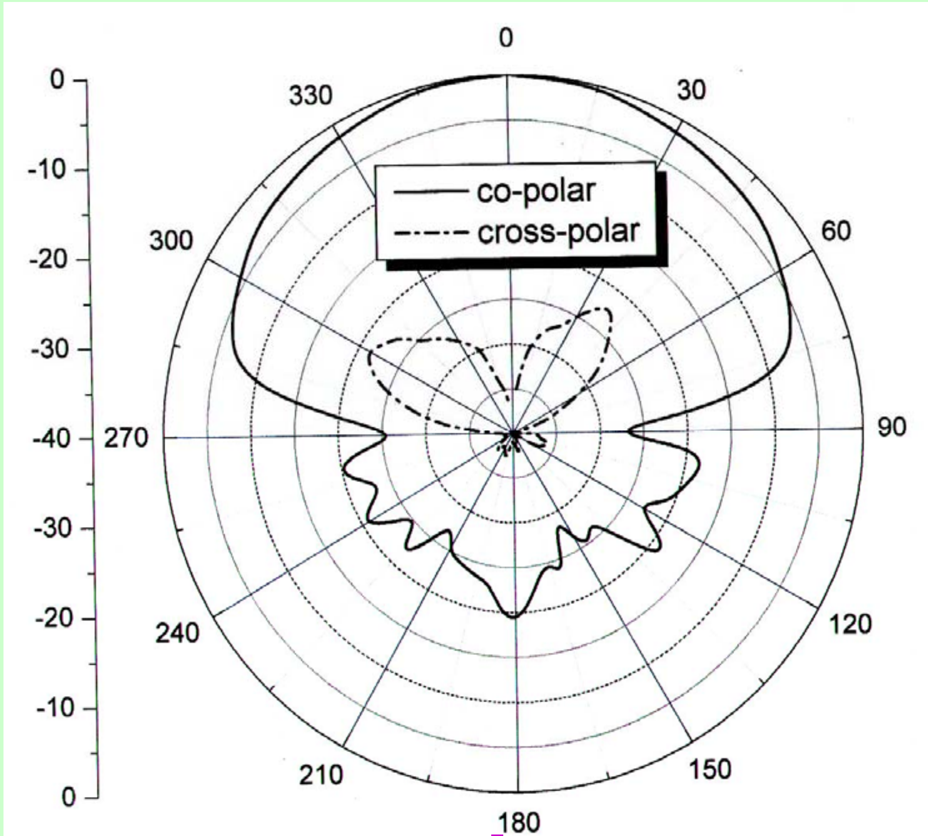
for BW* ≈ *9.3 % (GSM900)

37% (DCS1800)

V. Dual-band Single-layer Patch



900MHz **E-plane Pattern**



1800MHz **E-plane Pattern**

***G≥10.2* dBi/*5.6* dBi, *HPBW ≈58°/107°*;**

for BW ≈9.3 % (GSM900)

37% (DCS1800)

***X-P≤ -13.6*dB/-12.8dB *at f_0*.**

V. Dual-band Single-layer Patch

Data

GSM: 890~960MHz DCS: 1710~1880MHz	GSM900 *Simulation*	GSM900 *Measured*	DCS1800+ *Simulation*	DCS1800+ *Measured*
Frequency range (MHz)	881-964	885-966	1550-2280	1560-2269
Bandwidth (VSWR≤ 2:1)	9.22 %	9.00 %	40.56 %	39.38 %
Gain	10.4 dBi	9.8 dBi	5.94 dBi	6.15 dBi
3dB Beamwidth (H-plane) (E-plane)		59.6° 56.4°	106.0° 70.0°	108.8° 73.2°
Cross-polar (45°-plane)	-21.0 dB	-18.3 dB	-13.0 dB	-13.8 dB
Isolation	---------	>16.5 dB	----------	>15.3 dB

Multi-band & Multi-function Applicable

(885~966) MHz *covers*: GSM (890~960) MHz

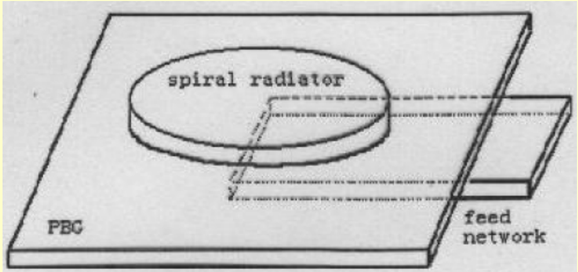
(1560-2269) MHz *covers*:

- GPS 1658 MHz
- DCS (1710~1880) MHz
- IMT-2000 (1850~1990) MHz
  (2110~2200) MHz
- PHS: (1900~1920) MHz
- UMTS: (1920~2170) MHz

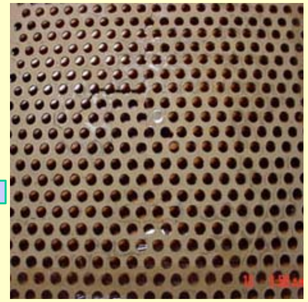
VI. Circular-Polarized Spiral backed on EBG

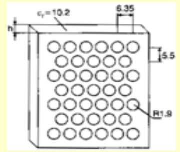
Structure

Spiral radiator:



EBG material:





Assembly

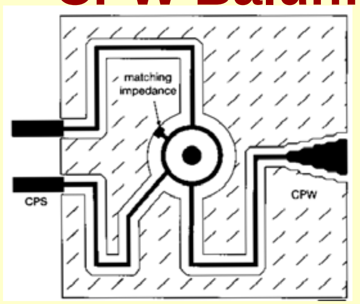
Feature in performance

- **Wide-band ~**
  depending on Max & Min radii
- **Circular-polar ~**
  natural and angle-independent
- **Lower gain ~**
  similar as one-wavelength loop

Trouble in structure

- **Ground screen ~**
  for uni-directive radiation
- **Long balun ~**
  for unbalanced feed
- **Lower efficiency ~**
  for reflection absorber

Wideband CPW Balun:



Patent

Feature for EMW propagation

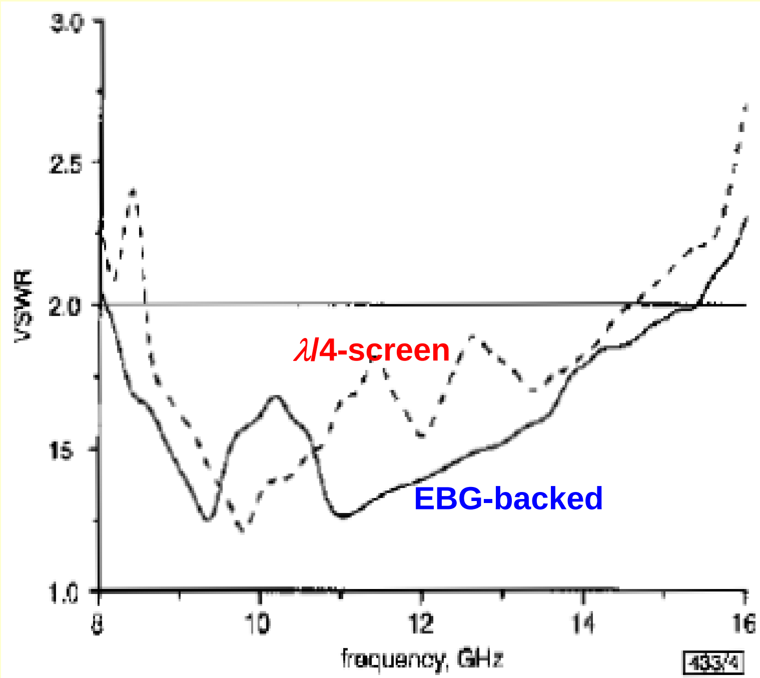
- **Band-gap material ~**
  suppress Surface-wave in stop-band
- **Gain enhancement ~**
  reduce loss & focus effect
- **Thinning structure ~**
  employ printed CPW-balun

Problem in development

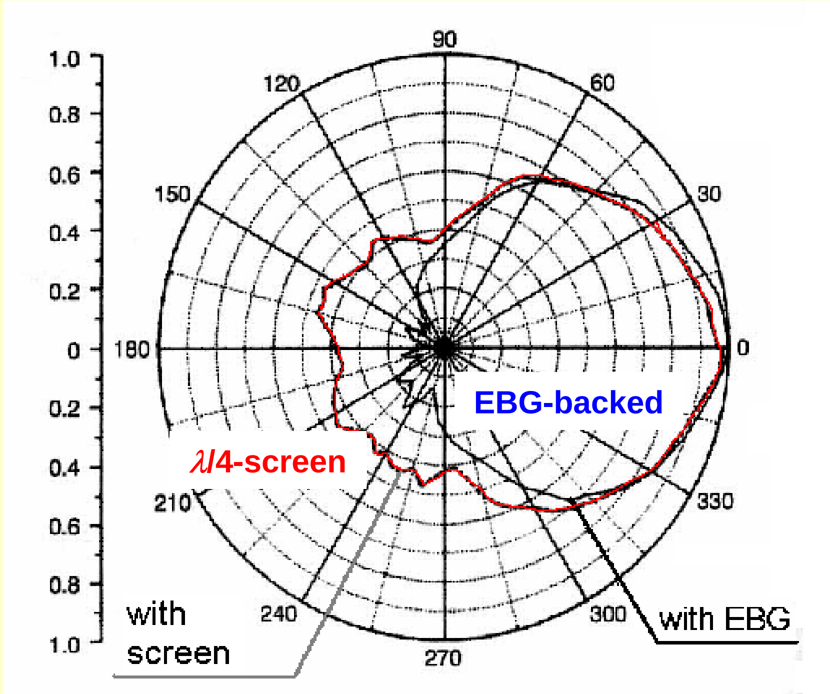
- **High quality dielectric ~**
  with high permittivity & low-loss
- **Wideband EBG material ~**
  angle/polar independent stop-band
- **Lower efficiency ~**
  precision in mechanical processing

VI. Circular-Polarized Spiral backed on EBG

Performances



VSWR response



Radiation pattern

<u>Compare to</u> that

backed on a ground plate

with the same sizes and $\lambda/4$ apart -----

***Bandwidth expends* × 1.23 ➡ 65 %**
***Gain enhancement* + 1.3 dB**
***Front/Back ratio* + 8.9 dB**

Contents

Conclusion

*** Printed antennas play important roles in various modern wireless systems.**

*** Microstrip patch antennas play major roles in the family of printed antennas.**

*** The main shortcoming of narrow-band for patch antenna has been relieved by means of *multi-resonance techniques.***

*** The band broadening for *compact patch* or *array of patches* is still a great challenge.**

*** Another rigorous challenge is to perform an *ultra-wide-band* compact patch antenna.**

Monographs & Books (I)

Microstrip Antennas (General)

< Microstrip Antennas > *I.J. Bahl & P. Bhartia, (1980) Artech House, Inc. (译).*

< Microstrip Antenna-----Theory and Design > *J.R. James, P,S. Hall & C. Wood, (1981) Peter Peregrinus Ltd.*

< Flat Radiating Dipoles and Applications to arrays > *G. Dubost, (1981) Research Studies Press Ltd.*

< 微带天线理论与工程 > *张钧、刘克成、张贤铎、赫崇骏，(1988) 国防工业出版社.*

< Handbook of Microstrip Antennas > *J.R. James & P.S.Hall, (1989) Peter Peregrinus Ltd.*

< 微带天线理论与应用 > *钟顺时，(1991) 西安电子科技大学出版社.*

< Millimeter-wave Microstrip and Printed Circuit Antennas > *P. Bhartia, K.V.S. Rao & R.S. Tomar, (1991) Artech House, Inc. (译).*

< Analysis, Design, and Measurement of small and Low-profile Antennas > Ed. by *K. Hirasawa & M. Haneishi , (1992) Artech House, Inc. (译).*

< Microstrip Antennas-----The Analysis and Design of Microstrip Antennas and Arrays > Ed. By *D.M. Pozar & D.H. Schaubert , (1995) IEEE Press.*

Monographs & Books (II)

Microstrip Antennas (Modern)

< Broadband Patch Antennas > *J.-F. Zurcher & F.E. Gardiol, (1995) Artech House, Inc.*

< CAD of Microstrip Antennas for Wireless Applications > *R.A.Sainati , (1996) Artech House, Inc.*

< Advances in Microstrip and Printed Antennas > Ed. By *K.F. Lee & W. Chen , (1997) John Wiley & Sons, Inc.*

< Design of Nonplanar Microstrip Antennas and Transmission Lines > *K.-L. Wong, (1999) John Wiley & Sons, Inc.*

< Microstrip Antenna Design Handbook > *R.Garg, P. Bhartia & I. Bahl , (2001) Artech House, Inc.*

< Compact and Broadband Microstrip Antennas > *K.-L. Wong, (2002) John Wiley & Sons, Inc.*

< Broadband Microstrip Antennas > *G. Kumar, K.P. Ray (2006)* ***Artech House, Inc.***

THE END

Thanks!