# Printed Antennas

**Alfonso Muñoz Acevedo, José-Manuel Fernández González**
**alfonso@gr.ssr.upm.es, jmfdez@gr.ssr.upm.es**
**Universidad Politécnica de Madrid**
**(Technical University of Madrid, UPM)**

POLITÉCNICA



# Outline

POLITÉCNICA

## Microstrip printed antennas

1. **Structure, basic characteristics, limitations, applications**
2. **Substrate selection**
3. **Different feeding methods of a patch antenna**
4. **Patches shape analysis: rectangular, square, circular, slot**
5. **Polarization**
6. **Performance techniques: Bandwidth and Beamwidth**

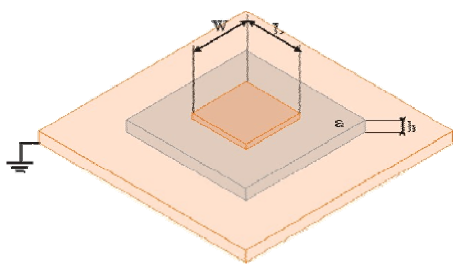
# Item 1.
# Structure and basic characteristics, limitations, applications



## *1. Structure and basic characteristics*

In planar antennas, we use patch designed **in microstrip technology**.

- ***Patches***
  - Metallic laminate of resonant size (0.25λ - 1λ)
    - patch length = 0.5λ ⇒ resonant in the fundamental mode
    - Very thin (thickness : 10 – 50μm ⇒ typically: 18μm y 35μm )
  - The patch resonate in one of its dimension (length) and radiate in the other (width)
- ***Substrate***
  - dielectric sheet that support the patch
    - thickness : 0.005λ - 0.2λ
  - Dielectric constant generally $1 \leq \varepsilon_r \leq 12$
- ***Ground plane***
- ***Excitation or feeding***
  - provide the RF energy to the patches




ANTENNA DESIGN AND MEASUREMENT TECHNIQUES - Madrid (UPM) – March 2009

# Limitations

| Advantages | Drawbacks |
|---|---|
| ➢Low profile, reduced weight and volume<br>➢**Low cost**<br>➢**Robust mechanism** (fabricated in rigid surfaces)<br>➢**Easy to fabricate (photolithography technology)**<br>➢Versatile (frequency, polarization, radiation pattern,…)<br>➢Compatible with active devices<br>➢Easy to fabricate arrays<br>➢Can be adapted to curved surfaces | ➢High Q (> 50) ⇒ **narrow band** : 1%-5%<br>➢**Spurious radiation** (due to the transmission line, wave surfaces, edge effects, …) ⇒ that damage the antenna performances<br>➢Use quality substrate<br>➢Power limitation ⇒low power<br>➢Input impedance: difficult to calculate and to adjust in the design<br>➢Cross polarization⇒ **poor polarization purity** (high crosspolar)!⇒ Relation (CP/XP) > 20 dB<br>➢**Reduced efficiency** in arrays (losses in the feeding network**)** |



# Applications

Frequency range : 100 MHz – 50 GHz

Printed antennas are used as isolated radiating element and especially in arrays

## *Typical applications:*

- ➢Mobile communications (base stations, telephone, automobile)
- ➢Antennas in planes (navigation, altimeter)
- ➢Satellite communications
- ➢Radars (Phased arrays) with electronic beamforming
- ➢Biomedical (heat applications in medicine)
- ➢Telemetry (sensors)
- ➢Security systems, identification and control (alarm, toll)

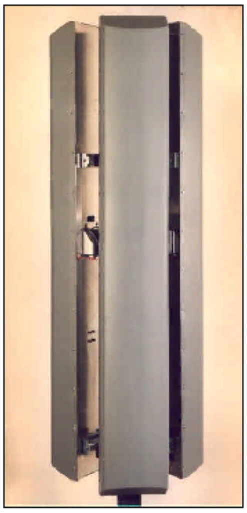
# *Base station antenna GSM900/DCS1800/UMTS for mobile communication*

***GSM:*** **Global System for Mobile Communications (870 – 960 MHz)**

***DCS:*** **Digital Cellular System (1710 – 1880 MHz)**

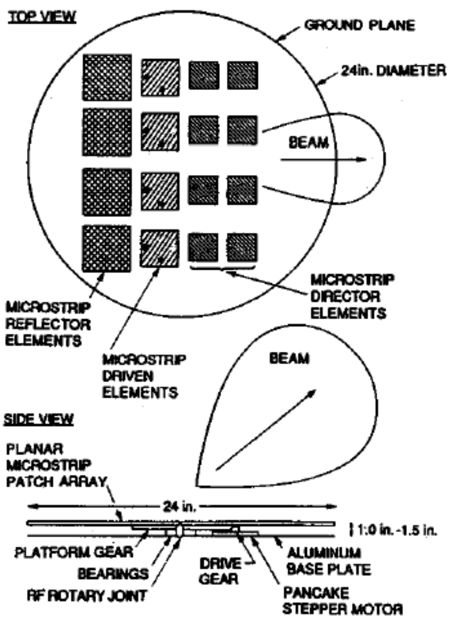
***UMTS:*** **Universal Mobile Telecommunications System (1885 – 2170 MHz)**

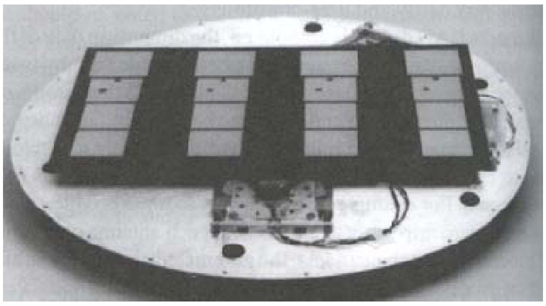
| | |
|---|---|
| **Frequency Range** | **870 ÷ 960 & 1710 ÷ 2170 MHz** |
| **Gain** | 17.5 dBi |
| **VSWR** | < 1.3 ÷ 1 GSM900<br>< 1.5 ÷ 1 DCS/UMTS |
| **Polarization** | Dual Slant ± 45 |
| **Horizontal Beamwidth** | 60° |
| **Vertical Beamwidth** | < 8° |
| **Donwtilt** | 4° Both bands independently<br>(6°under request) |
| **Sidelobe supression** | > 15 dB |
| **Isolation between polarizations** | >30 dB |
| **Front Back Ratio** | > 25 dB |
| **Power rating** | 2 x 500 w GSM900<br>2 x 200 W DCS&UMTS |
| **Impedance** | 50 Ω |

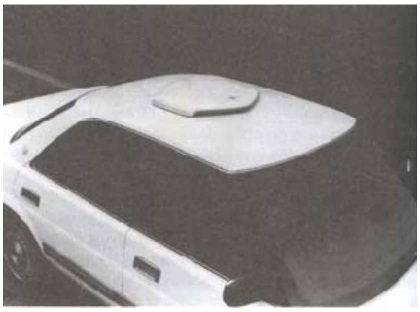




# *Mobile communication by satellite*

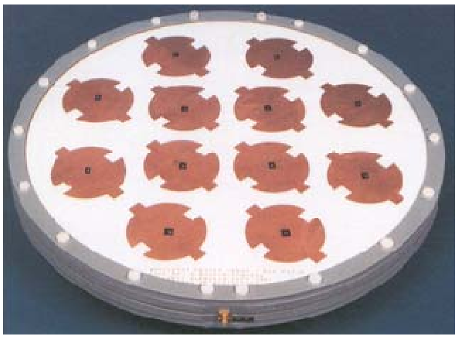


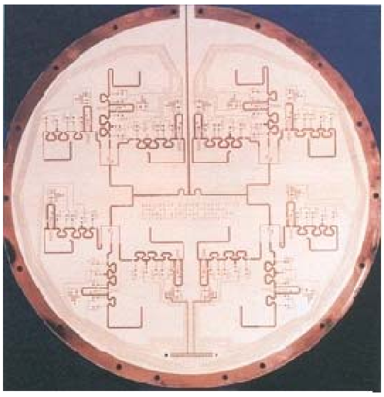





- Array antennas with mechanical scanning

# *Mobile communication by satellite*



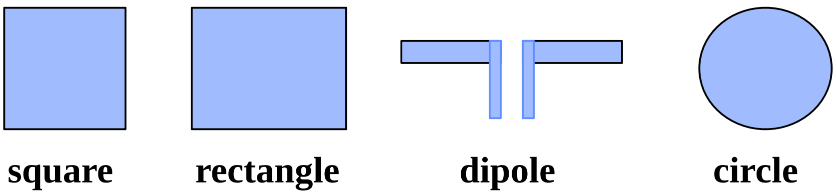


- Array antennas with electronic scanning

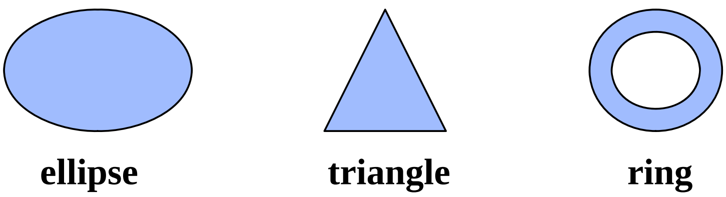


# *Layout configuration*

➢**Patch shapes usually used:**




➢**Other patch shapes:**



# Item 2.
# Substrates

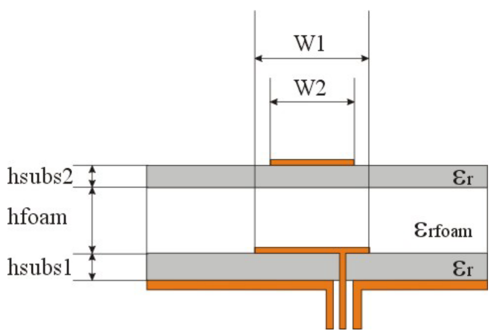


## *2. Substrate selection (I)*

**Characterization of a substrate:**

- **Thickness *h***
- **Material: permitivity and permeability** $\varepsilon_r$ , $\mu_r$
- **Dielectric losses: tan(δ)**

| | |
|---|---|
| If the substrate thickness is reduced | Bandwidth is reduced |
| | Resonant frequency increase |
| | Patch resonant length is reduced |
| To increase the bandwidth | Increase the thickness substrate |
| | Increase the patch resonant length L |
| | Small dimensions of the ground plane |



# Substrate selection (II)

➢ **The materials that better adapt to the printed microstrip antennas design are the ones of $\varepsilon_r \leq 5$ (near 1, as "foam" o air): higher radiation efficiency, wider bandwidth, low losses**

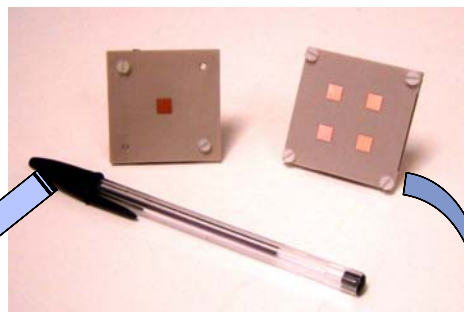
| | **Thickness *h*** | $\varepsilon_r$ |
|---|---|---|
| To diminish the line radiations | thin | high |
| small dimension of antennas | thin | high |
| Low losses (surface waves,…) | thin | low |
| To increase bandwidth | thick | low |
| Higher radiation efficiency | thick | low |
| Less sensibility versus tolerances | thick | low |

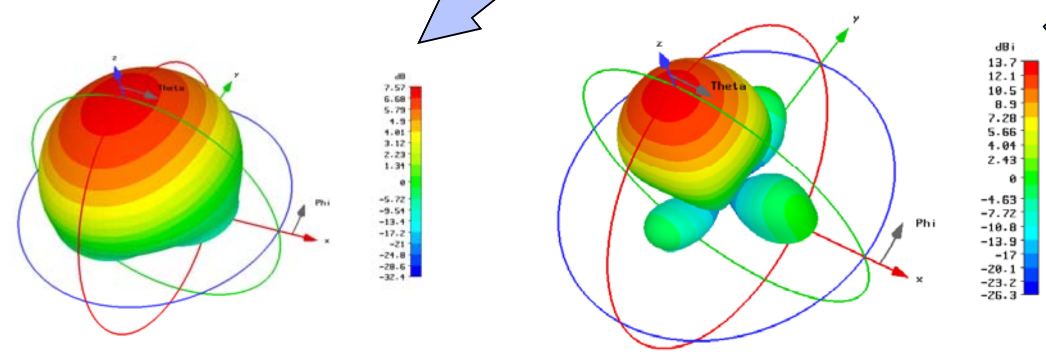
➢ **Better thick substrates and low dielectric constant $\varepsilon_r$**
**¿How to solve the contradictions ?**
➢ **Multilayer configuration ⇒ bandwidth techniques**



# Radiation pattern

- ➢ For one radiating element:
  - Typical gain: 5-7 dB
  - -3dB beamwidth: 60°- 90°
- ➢ Dielectric effect
- ➢ Finite ground plane effect



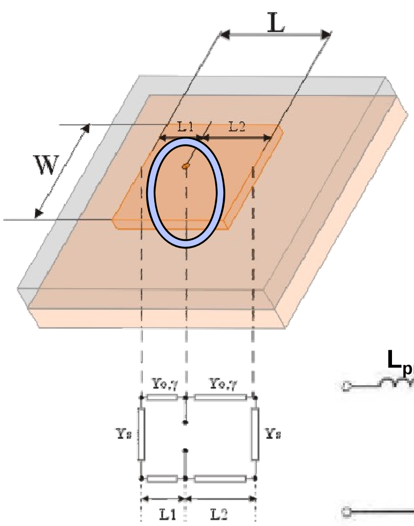


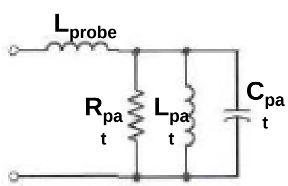
# Item 3.
# Feeding techniques



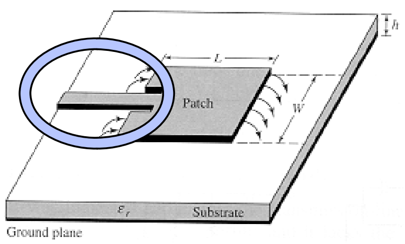
## *3. Different feeding methods of a patch antenna(I)*

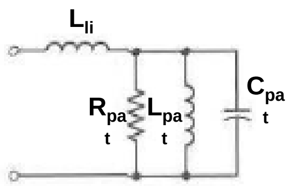
### Probe feed




### Microstrip line feed

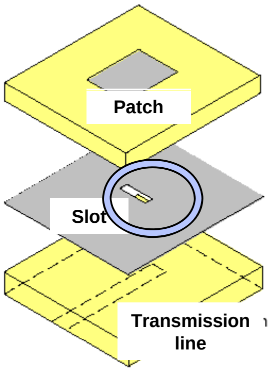


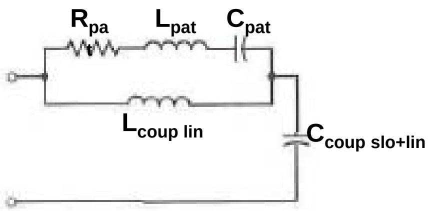




➢**The microstrip lines and the coaxial probes radiated more with low $\varepsilon_r$ substrate ⇒ affect to worse the cross polarization level and the side lobe levels.**

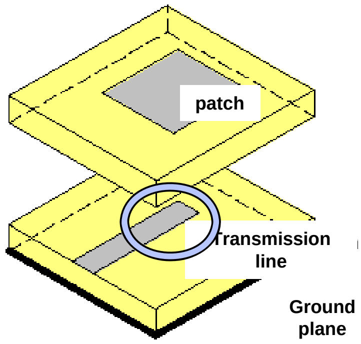
# *Different feeding methods of a patch antenna(II)*

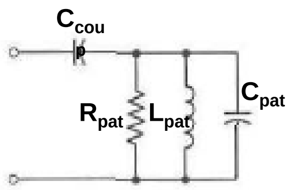
## Slot coupling feed




## Proximity coupling feed :

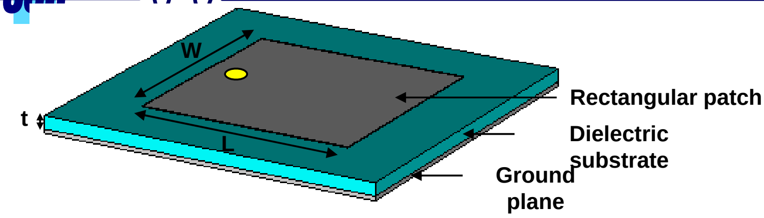


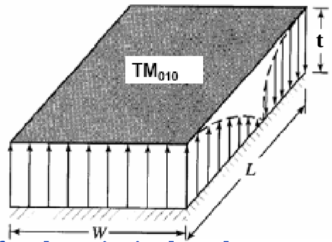






# Item 4.
# Patches and their shapes

# Rectangular

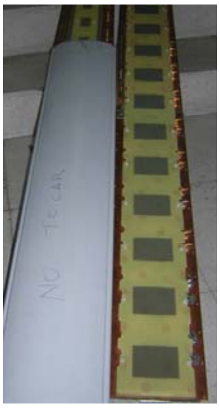



Field lines for the principal mode: $TM_{010}$ mode

- The patch resonate in one of its dimension (length L) and radiate in the other (width W).
- Polarization : linear, circular, dual
- The input impedance is:
  - In the edge : 180Ω - 300Ω
  - In the center : 0Ω

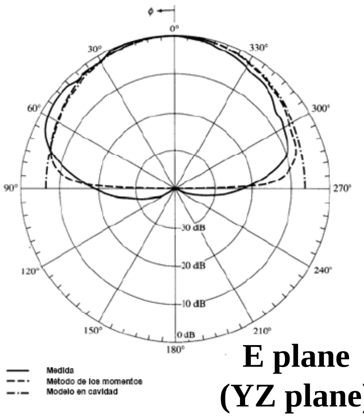
$$Rin \approx \frac{1}{2 \cdot G} \cdot \cos^2(\beta \cdot L1)$$



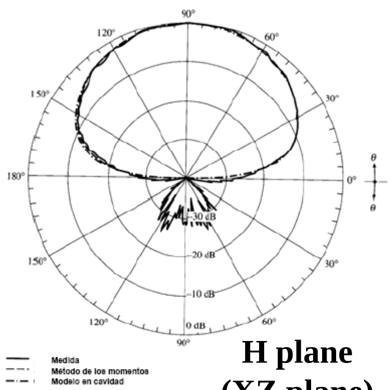
65° & 90° Sectorial antenna



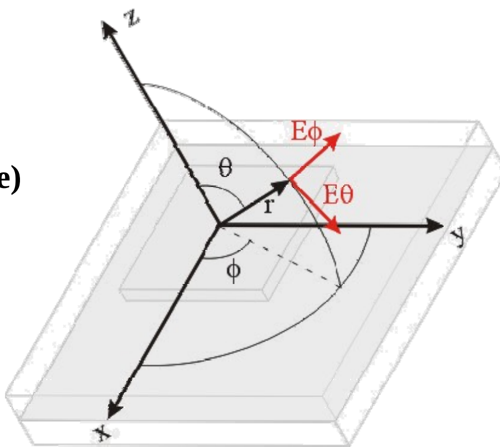
# Rectangular




**E plane (YZ plane)**

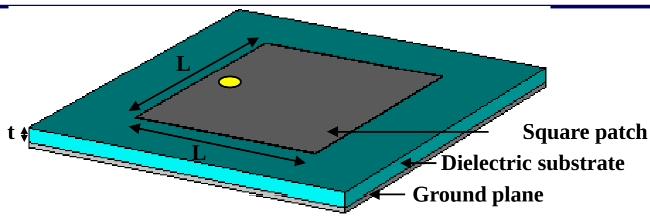



**H plane (XZ plane)**



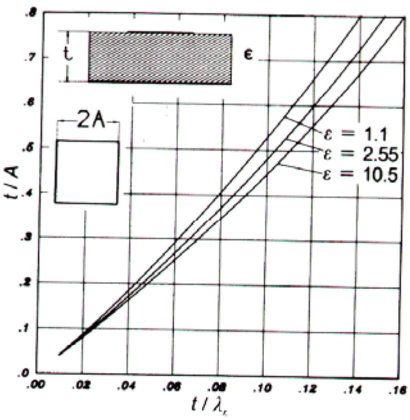

$$D = \frac{\frac{r^2}{2 \cdot \eta_0} \cdot Re(\|E_\theta\|^2 + \|E_\phi\|^2)|_{\theta=\theta_{max}}}{Pr/4 \cdot \pi}$$

# Square




➢Polarization : linear, circular, dual

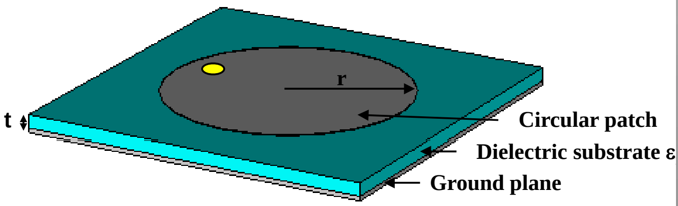
➢Generate high cross polar XP levels ⇒ dual polarization or circular polarization.

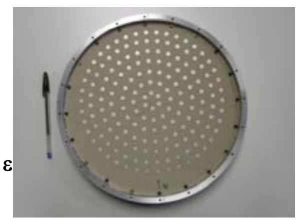


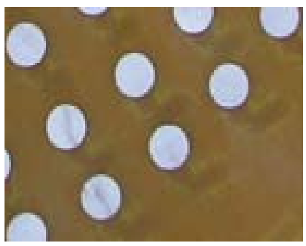

**90° sectorial Antenna with ± 45°double linear polarization for Personal Communications System (PCS 1850-1990 MHz)**



# Circular



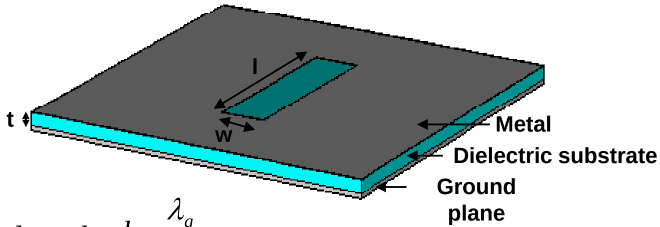


**Antenna for TV reception via satellite (DBS) at 12 GHz**

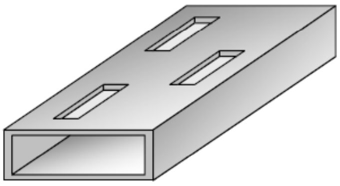
➢Polarization : linear, circular, dual

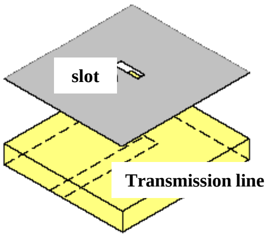
➢Generate high cross polar XP ⇒ dual polarization or circular polarization.

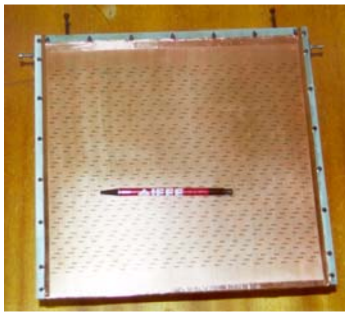
# Slot




- Slot length: $l = \frac{\lambda_g}{2}$
- Coupling level is determined by l
- Slot width: $w = \frac{l}{10}$
- Polarization: linear, circular, dual
- Excited by field coupling





Antenna for TV reception via satellite (DBS) at 12 GHz

Antenna for TV reception via satellite (DBS) at 12 GHz



# Item 5

# Polarization

ANTENNA DESIGN AND MEASUREMENT TECHNIQUES - Madrid (UPM) – March 2009

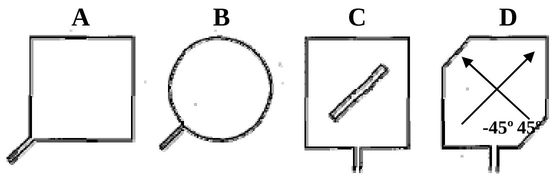
# 5. Polarization

- A conventional microstrip patch with unique feed produce a **linear polarization** radiated field.
- Polarization change with diffractions and reflections
- One can obtain **circular polarization**:
  - For an unique element:
    - Unique feeding and specific shapes
    - Multiple feeding
  - For arrays antennas:
    - Sequential rotation
- One can obtain **dual polarization**:
  - For a unique element:
    - Multiple feeding and specific shapes



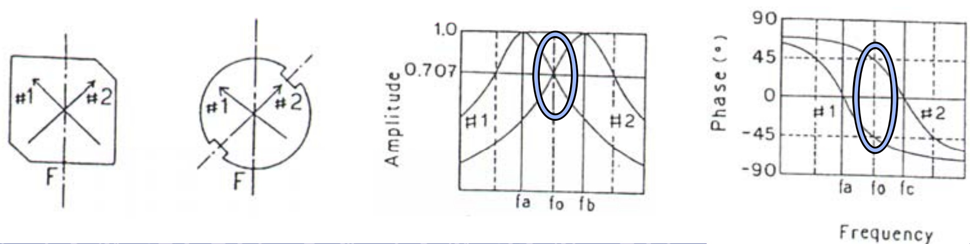
# Circular Polarization: unique excitation

➢Circular polarization, unique excitation:



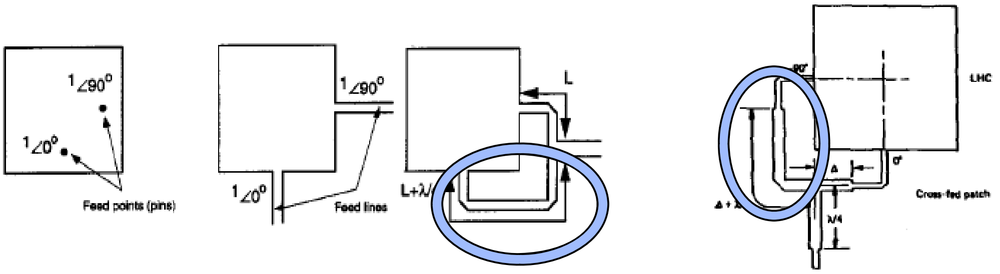

| | |
|---|---|
| A) nearly rectangular | C) Square with slot |
| B) nearly elliptical | D) Corners truncated square |

- **Based on the excitation of 2 orthogonal modes, almost degenerated (similar resonant frequencies).**
- **Patch shape: geometry deviation with degenerated modes.**
- **The excitation point is critical to generate the 2 modes with identical amplitude.**
- **The circular polarization condition is achieved to an intermediate frequency between the two resonances (narrow bandwidth!).**



# Circular polarization: double feeding (I)

➢**Circular polarization, 2 excitation points:**

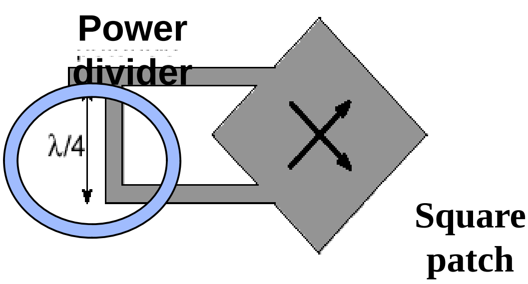


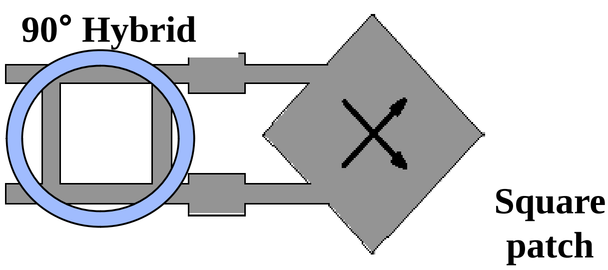

- Symmetrical patch: circular or square.
- 2 excitation points separated of 90° and a difference phase of 90°.
- Achieve a wider bandwidth.
- The same configuration for the dual polarization.

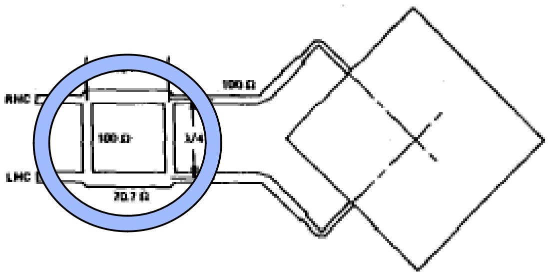


# Circular polarization: double feeding (II)

- **The difference phase is achieved using a feeding network with different length or using hybrid circuits that achieve the same effect.**

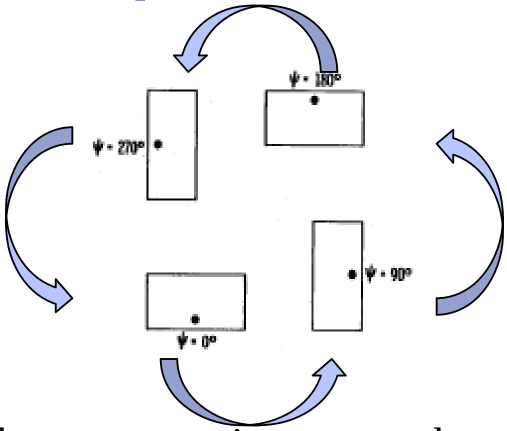


# *Circular polarization: Arrays*

➢**Circular polarization, sequential rotation:**




**Physical rotation**

**Phase shift**

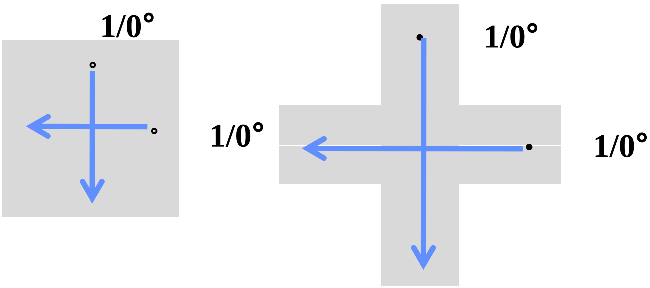
- One must rotate, between contiguous patches:
  - Physical orientation: 90º
  - Phase shift: 90º
- Achieve a wider bandwidth.
- Drawbacks: dimension

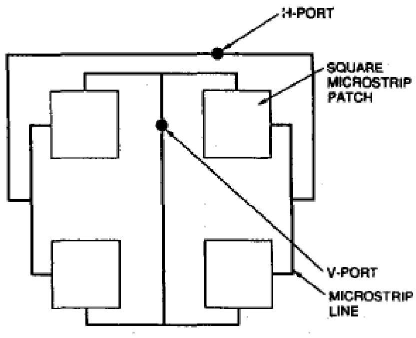


# *Dual polarization*

- Microstrip patch antennas with **dual linear polarization** allow to duplicate the communication capacity of a band reusing it in polarization. This is relevant in
  - ➢ Mobile communication antennas
  - ➢ Satellite communication systems
- The square or circular patch shape is the usual geometry for this kind of polarization:
  - ➢ Drawback: generated high crosspolar level for dual or circular polarization
- A microstrip patch antenna is able to radiate signals of dual linear polarization:
  - ➢ If it is excited by 2 orthogonal feeding points
  - ➢ 2 independent feedings that correspond to 2 individual orthogonal linear polarizations.

# *Dual polarization*




**Dual polarization arrays**

- The 2 feeding points are excited in completely independent manner with same amplitude and phase.
- In microstrip arrays antennas, the dual polarization is obtained interconnecting double polarized patches in series.



# Item 6.

# Bandwidth and beamwidth design techniques

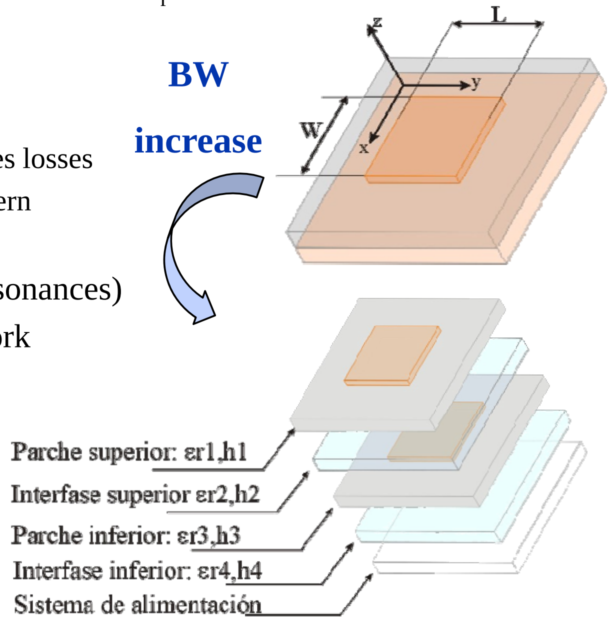
# 6. Bandwidth techniques

•The bandwidth can be enhanced:

- The easiest and direct method to enhance the bandwidth is: increasing the antenna volume: thicker substrate with low dielectric constant $\varepsilon_r$.
  - Advantages:
    - –Increase the bandwidth
    - –Increase efficiency
  - Drawbacks: thick substrate ⇒ surface waves losses
    - –Decrease the power of the radiation pattern
    - –Increase the side lobe levels (SLL)
- With parasitic coplanar patches (more resonances)
- With an external matching feeding network
- Piled patches
- With multilayer configurations

  ⇒ more resonance

  ⇒ bandwidth



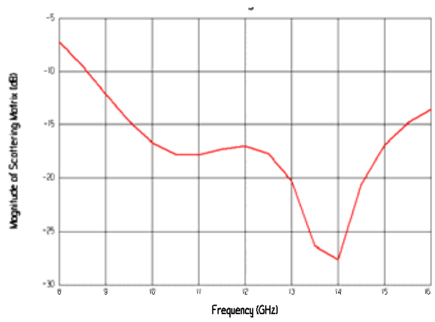



# Input matching BW

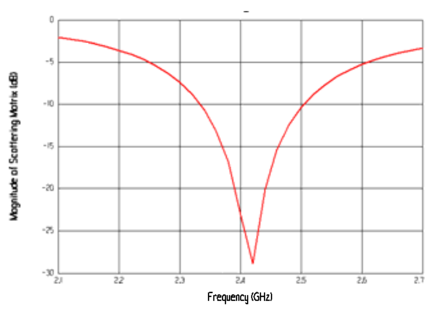
- The bandwidth is defined for several characteristics
  - Input impedance
  - Polarization (Axial ratio)
  - Radiation pattern variation
- For a simple patch and thin dielectric (⇒ 1-2%, for VSWR < 2 (-10 dB))
- It can be detuned by fabrication tolerances, temperature change, radome presence, etc.
- For a lot of applications, we need wider bandwidth

**High BW for input impedance**

$$Q = \frac{\omega_0 \cdot W_T}{P_d + P_c + P_r}$$




**Wide bandwidth**




**narrow bandwidth**

# Beamwidth techniques

- Diminish the width W (radiated dimensions) of the patch ⇒ increase the beamwidth in azimuth.
- Substrate thickness diminish ⇒ decrease the beamwidth in azimuth.
- The finite ground plane have an influence in the radiation pattern. It reduces the beamwidth because of the effect of the ground plane edge diffraction.
- With parasitic coplanar patches to the radiating element:
  - The radiation pattern is modified as:
    - The separation distance between these parasitic elements and the radiating element change.
    - The width of the parasitic elements.

**If we separate more the parasitic elements with the radiating element and we increase the width of the parasitic elements.**

⇓

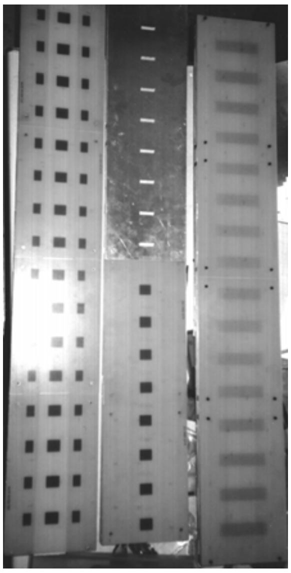
**increase the beamwidth in azimuth**



# Beamwidth techniques

- With parasitic coplanar patches to the radiating elements
  - Example: Sectorial antennas for DECT 3500 systems
  
  (Digital Enhanced Cordless Telecommunications)
  - Frequency: 3400-3600 MHz
  - 16 elements
  - Polarization : linear vertical

| | -3dB beamwidth in azimuth: |
|---|---|
| Sectorial 60° | 60º±5º |
| Sectorial 90° | 90º±5º |
| Sectorial 120° | 120º±5º |



**120º 90º 60º**

# *References*


[1] J.R. James, P.S. Hall, “Handbook of Microstrip Antennas”, IEE Electromagnetic waves series, Peter Peregrinus Ltd, 1989.

[2] R. Garg, P. Barthia, I. Bahl, A. Ittipiboon, “Microstrip antenna design handbook”, Ed. Artech House, 2001.

[3] A Derneryd, “Linearly Polarized Microstrip Antennas”, IEEE Trans. Antennas and Propagation, AP-24,pp.846-851, 1976.

[4] I.J. Bahl, P. Bhartia, “Microstrip Antennas”, Artech House, Dedham,1980.

[5] K. Hirasawa, M. Haenishi, “Analysis, Design and Measurements of small and low profile antennas”, Ed. Artech House, London, 1992.

[6] C.A. Balanis, “Antenna Theory, Analysis and Design”, Ed. John Wiley & Sons, New York, 1997.

[7] K.F. Lee, W. Chen, “Advances in Microstrip and Printed Antennas”, John Wiley, 1997.

[8] J.F. Zürcher, F.E. Gardiol, “Broadband Patch Antennas”, Ed. Artech House, 1995.

[9] D.M. Pozar, “Microstrip antenna aperture-coupled to a microstripline”, Electronics Letters, vol. 21, pp. 49-50, January 1985.

[10] D. M. Pozar, D.H. Schaubert, “Microstrip Antennas: The Analysis and design of Microstrip Antennas and Arrays”. IEEE Press, 1995.

[11] E. Aloni, R. Kastner, “Analysis of a dual circularly polarized microstrip antenna fed by crossed slots”, IEEE Transactions on Antennas and Propagation, vol. 42, n°8, pp. 1053-1058, August 1994.

[12] J. Torres Martín, “Diseño, Análisis, Construcción y Medida de antenas para el sistema PCS de Telefonía Móvil”, Proyecto fin de carrera, 2004.

[13] M. Martínez-Vázquez, “Antenas Integradas para Terminales Móviles de Tercera Generación”, Tesis Doctoral, Valencia 2003.