Active antennas for mobile terminals

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Simulation of a large array including mutual coupling

* Source: Institut für Hochfrequenztechnik, Technische Universität Braunschweig

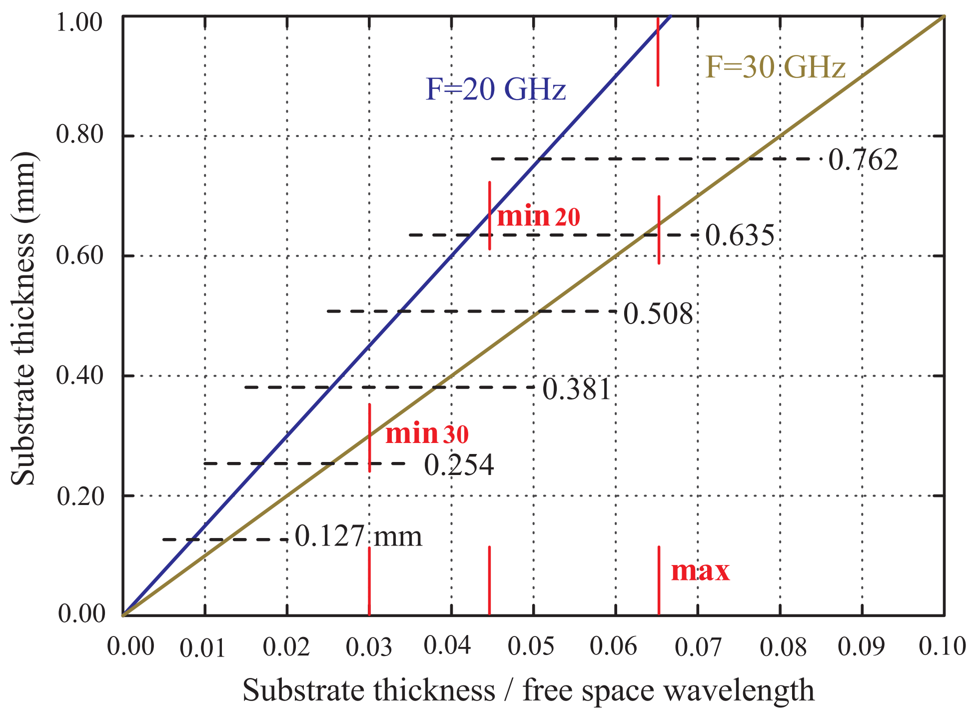
Partner associated with DLR in the complementary project SANTANA (Smart ANTennA termiNAl)

1 ATM-Sat specifications

Low Earth Orbit (LEO) satellite system

Parameter	Value
Uplink-frequency	30 GHz
Downlink-frequency	20 GHz
Bandwidth (antenna)	500 MHz
Polarisation (radiation)	Circular
Antenna gain	35 dBi
Radiation pattern beamwidth (at -3 dB)	~ 5°
Side lobes level	< -20 dB
Cross-polarisation	< -20 dB
Maximum scan angle	60°
Antenna beams	1 transmit beam 2 receive beams

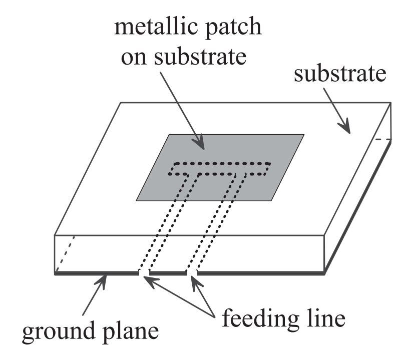
Thickness of the substrate supporting the radiating elements: selection criteria



- - - - - - standard thicknesses of commercial substrates

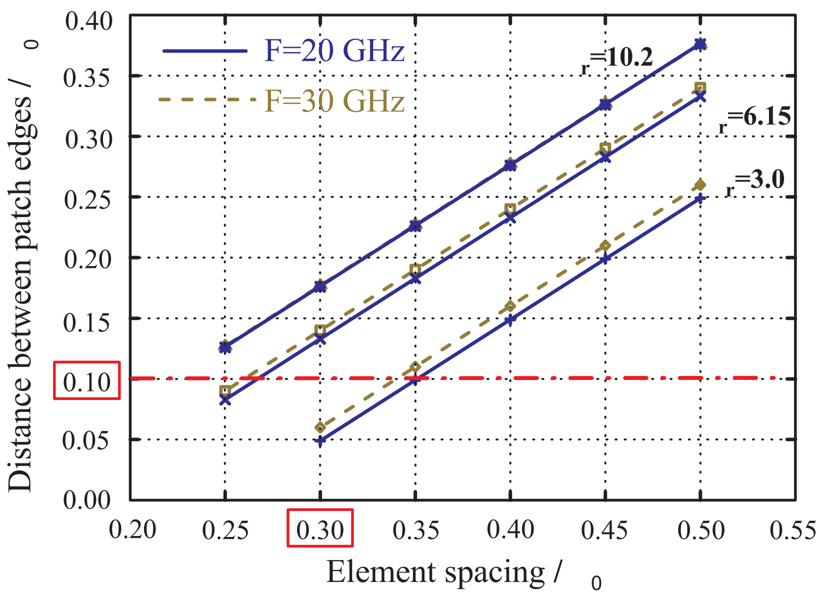
- min: minimum relative thickness required to meet the targeted bandwidth
- max: maximum relative thickness recommended to avoid the occurrence of a scan blindness within the scan angle range
- Targeted bandwidths = 1 GHz

⇒ 5.0 % at 20 GHz
3.5 % at 30 GHz



2.1 Guiding principles and goals

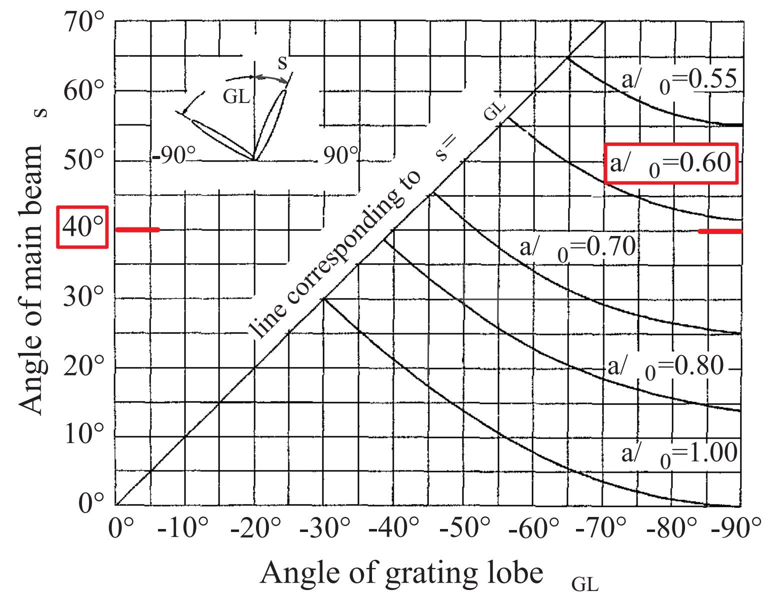
Permittivity ε_r of the substrate supporting the radiating elements



minimum relative distance between patch edges to limit mutual coupling effects

square patch dimension estimated by cavity model

Angular locations of the main beam and the first grating lobe



a: element spacing in a conventional array

a: subarray spacing if elements are sequentially rotated

λ_0: free space wavelength

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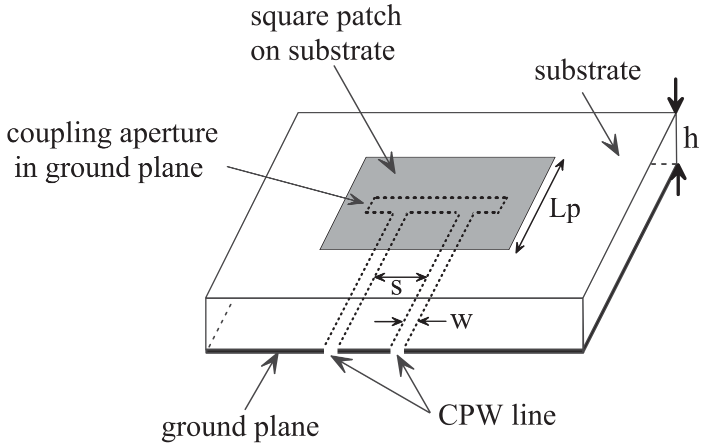
2.2 Coplanar-waveguide-fed aperture-coupled patch and substrate selection

Elementary radiator



patch fed by a CPW line
through an aperture (capacitive coupling)

At 30 GHz: patch edge Lp = 1.6 mm
CPW: strip s =0.5 mm, gap w = 0.1 mm (impedance=50 Ω)

with the substrate parameters: permittivity = 6.15
thickness h = 0.508 mm

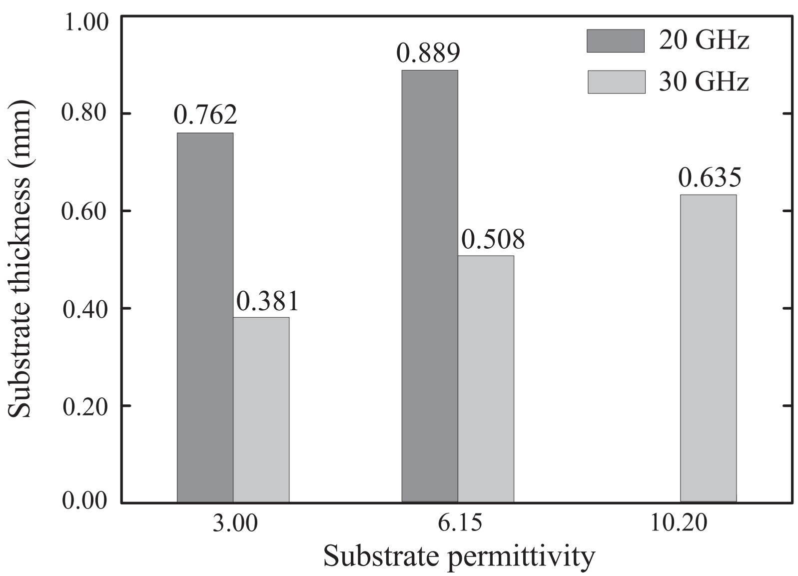
Advantages

- CPW * lines allow the use of a single substrate between the patch and its feed line
  - facilitate the fabrication
  - improve the feeding quality
- Aperture coupling is a non-contacting feeding
  - easy to implement and reliable
- Square patch preferred to maximise the circular polarisation purity

* coplanar waveguide

2.2 Coplanar-waveguide-fed aperture-coupled patch and substrate selection

Substrate thicknesses enabling to meet the targeted bandwidths with different permittivities*



- $\varepsilon_r = 6.15$
  minimum permittivity to be selected to reduce the subarray spacing to 0.6 λ_0

* isolated radiator considered

- Operating bandwidths = 500 MHz

  ⇒ 2.5 % at 20 GHz
  1.7 % at 30 GHz

- Design goal

  Return loss lower than -10 dB over **1 GHz**

  ⇒ 5.0 % at 20 GHz
  3.5 % at 30 GHz

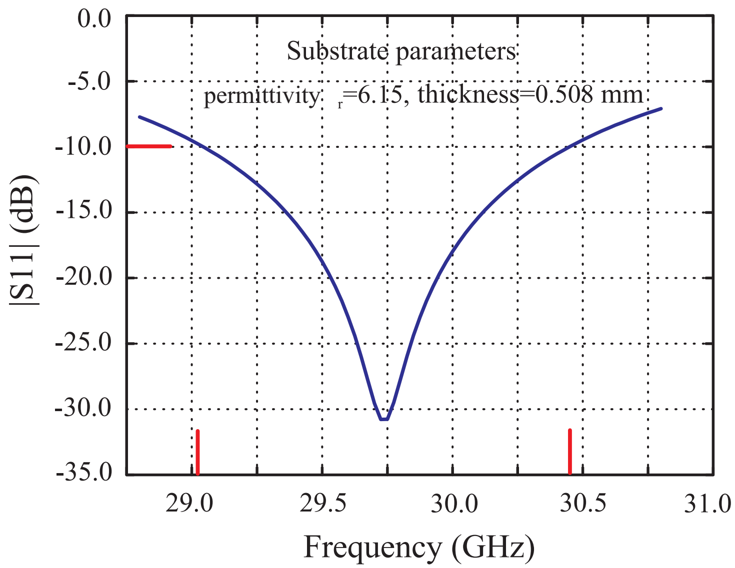
  to take into account the degradations due to

  – fabrication and material tolerances
  – beam scanning
  – mutual coupling

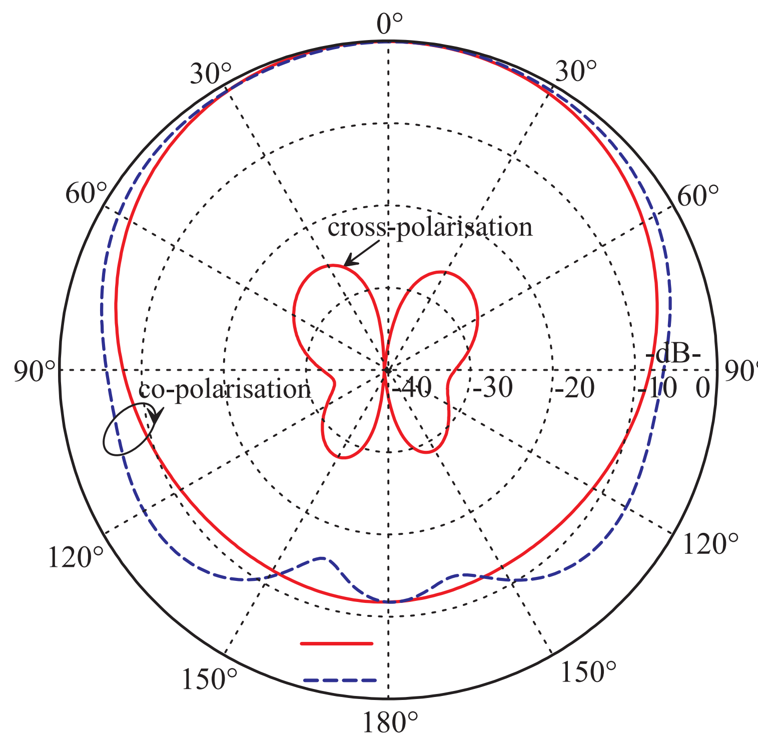
λ_0: free space wavelength

Isolated, linearly-polarised patch operating at 30 GHz

Return loss



Radiation patterns in the principal planes



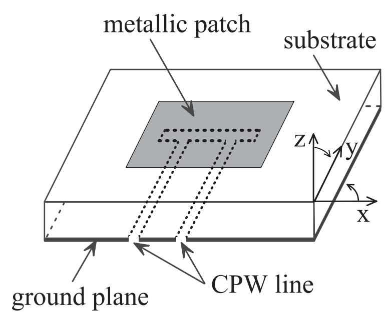
finite ground plane

Bandwidth=1.4 GHz = 4.7 %

Resonant frequency=29.75 GHz

Radiation efficiency=95 %, gain=5.5 dB

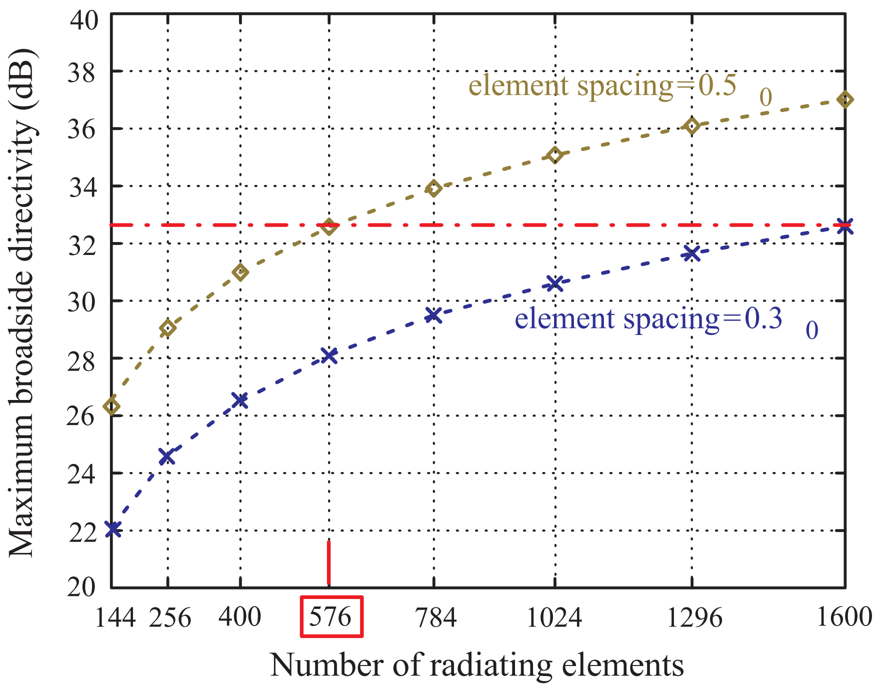
Half-power beamwidth=105° for ϕ=0°
135° for ϕ=90°



radiation characteristics stable over the bandwidth
5 dB ≤ gain ≤ 5.8 dB, cross-polarisation ≤ -23 dB

2.3 Array radiation characteristics

Maximum broadside directivity D_0 of square arrays



- Realistic design goal: broadside antenna efficiency = 60%

$\Rightarrow$ broadside realised gain ~ 30 dB

Good estimation for large arrays

$$D_0 = \left(\frac{4\pi}{\lambda_0^2}\right) A$$

A , antenna geometric area

λ_0 , free space wavelength

- Targeted broadside directivity ~ 32 dB

⇩

Antenna surface

18×18 cm² at 20 GHz
12×12 cm² at 30 GHz

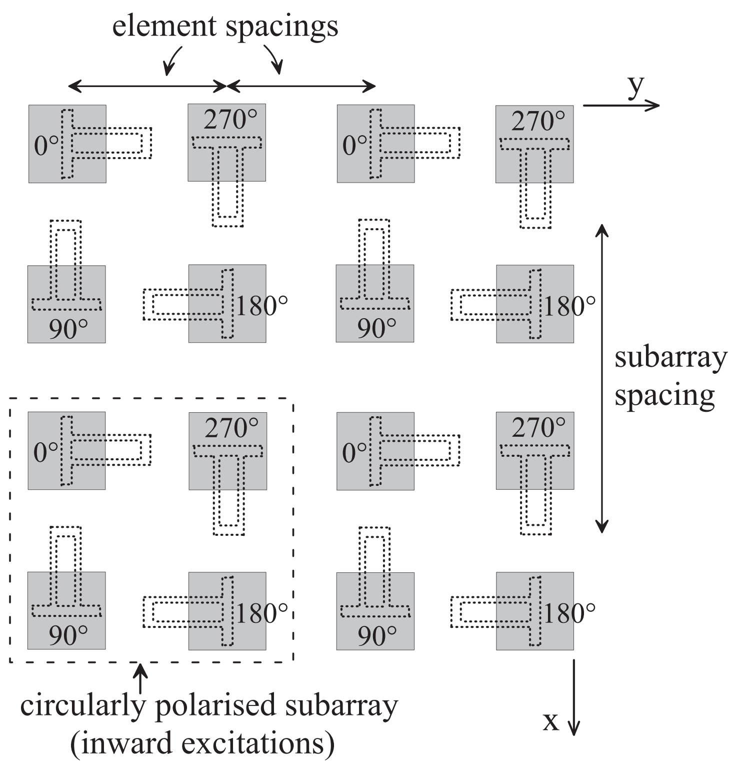
2.3 Array radiation characteristics

Arrays of sequentially rotated elements

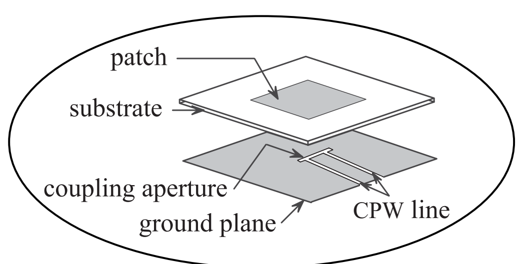
- Sequential rotation of elementary radiators used to generate the circular polarisation
  - Geometrical rotation and electrical phase shift applied to each element in a subarray
  - Different element arrangements possible within a subarray (inward, outward or in-out excitations)
  - Subarrays can also be sequentially rotated to improve the axial ratio

- Subarrays should be spaced as close as possible to widen the scan angle range
  ⇒ coupling effects must be taken into account

Detail of a large array: module of 16 patches

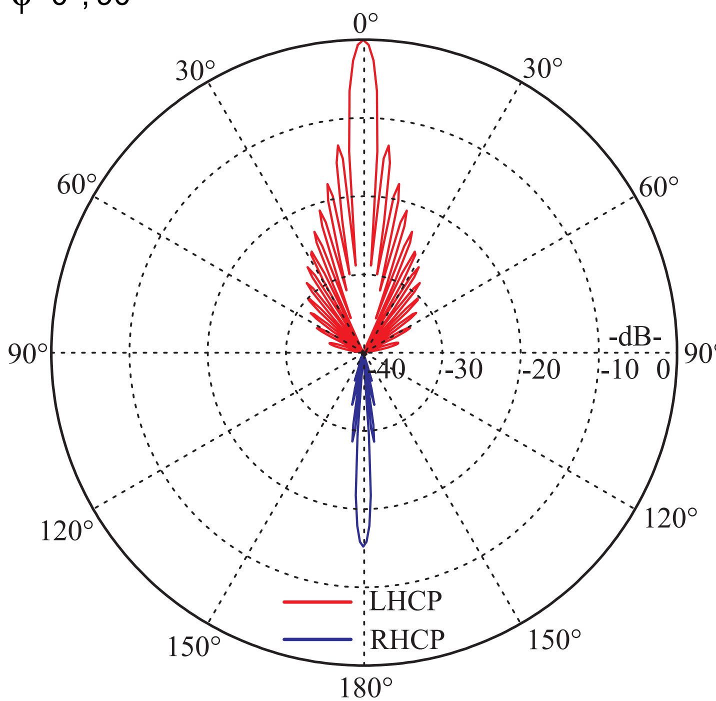


Single element



Radiation characteristics of a 1600-element circularly polarised array at 30 GHz

Principal planes
ϕ=0°, 90°



Radiation patterns

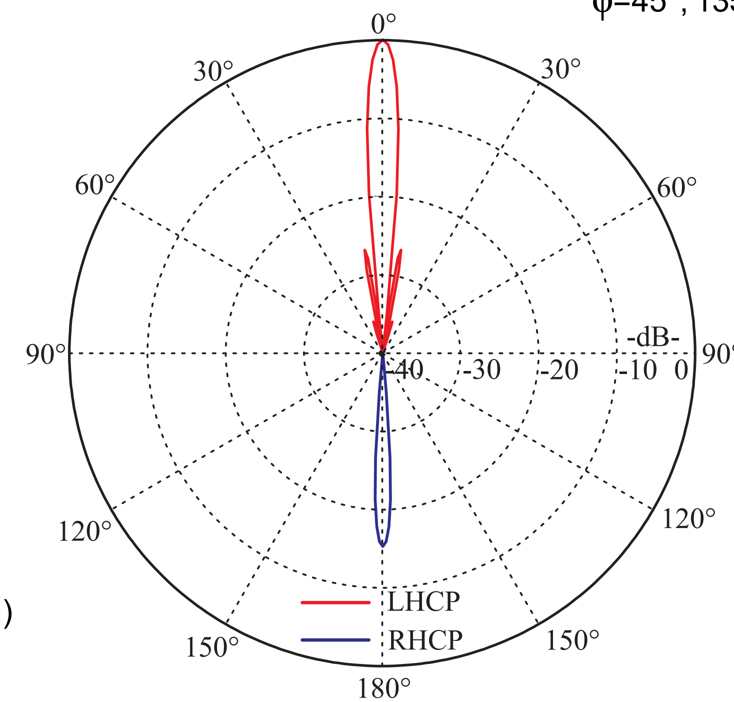
Scan angle
(ϕ_s=0°,θ_s=0°)

gain = 32 dB

Efficiency = 92 %
(radiation)

Axial ratio = 0.15 dB
(over half-power beamwidth)

Diagonal planes
ϕ=45°, 135°

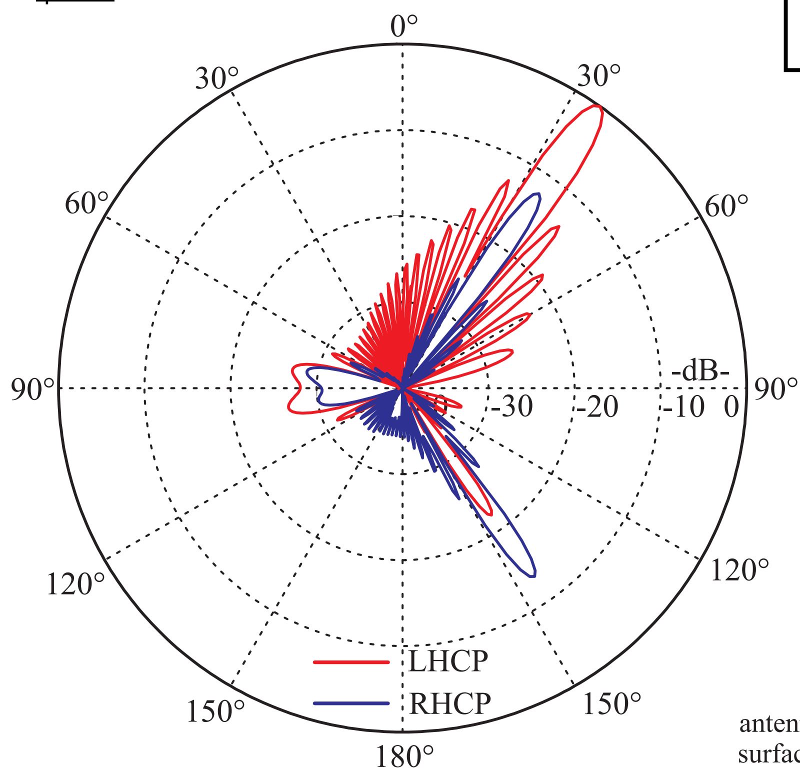


- Substrate parameters
  permittivity ε_r = 6.15
  thickness h = 0.508 mm
- 40×40-element array
  element spacing=0.35 λ_0 within subarrays
  subarray spacing=0.6 λ_0
- Only patches are sequentially rotated
- LHCP: left-hand circular polarisation
  RHCP: right-hand circular polarisation

Radiation characteristics of a 1600-element circularly polarised array at 30 GHz

Radiation patterns – Beam scanned in a principal plane

$\phi=0°$

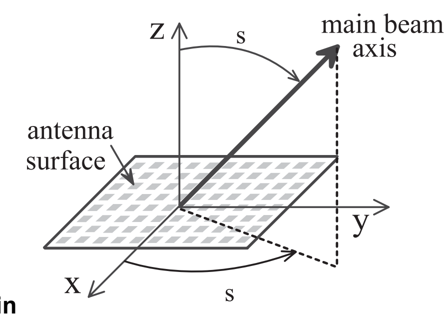


Scan angle
$(\phi_s=0°,\theta_s=35°)$

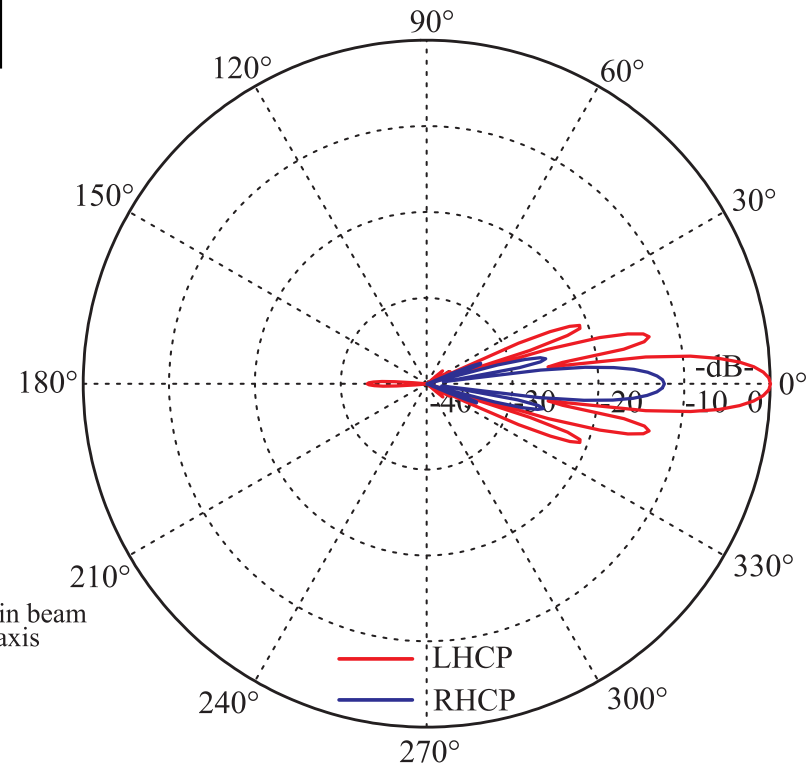
gain = 30.5 dB

Efficiency = 85 %
(radiation)

Axial ratio = 4.3 dB



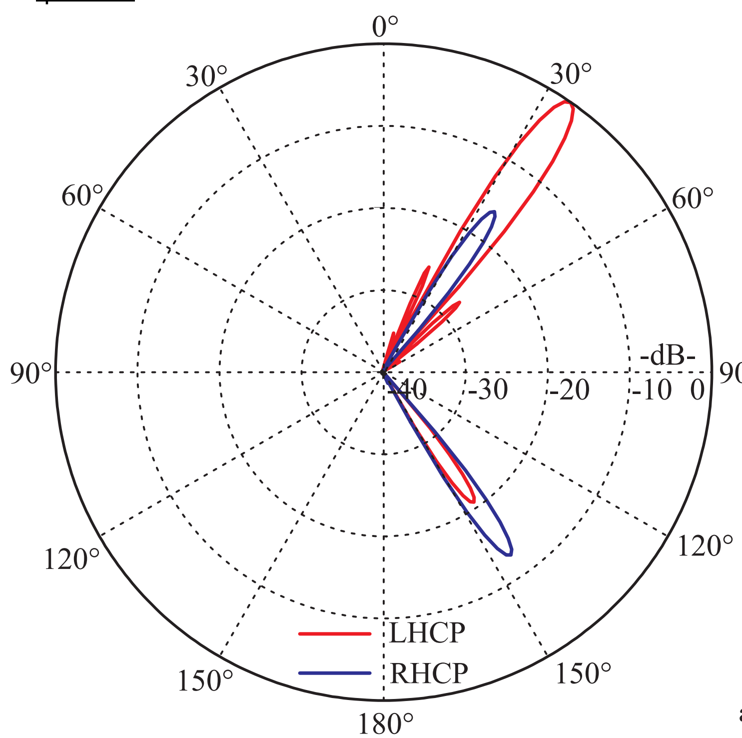
$\theta=35°$



Radiation characteristics of a 1600-element circularly polarised array at 30 GHz

Radiation patterns – Beam scanned in a diagonal plane

ϕ=45°

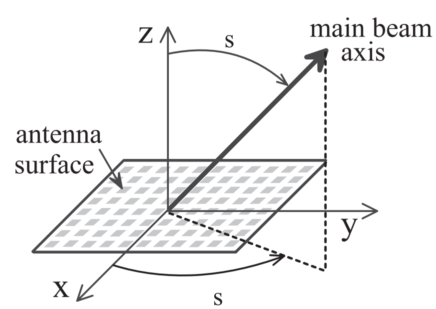


Scan angle
(ϕ_s=45°,θ_s=35°)

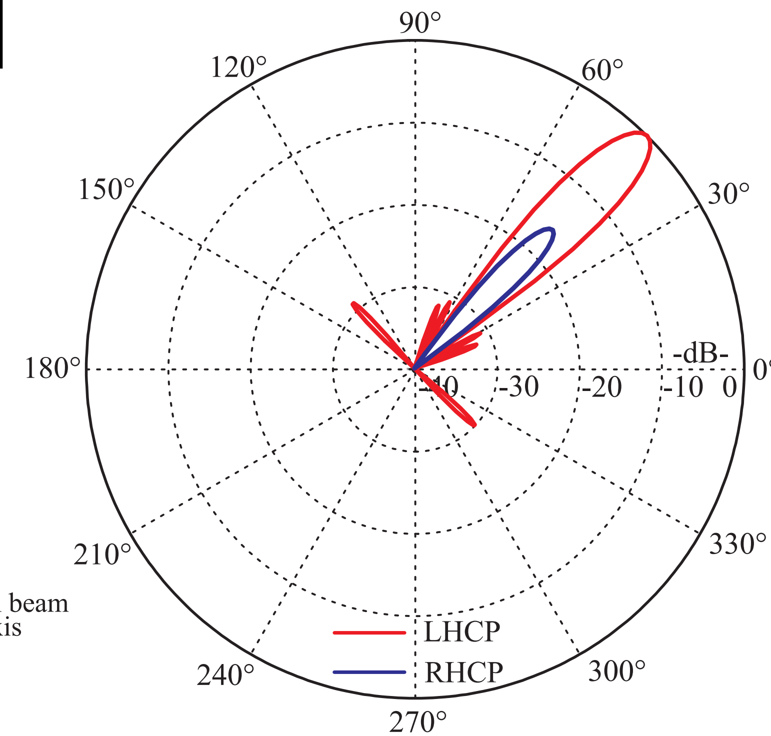
gain = 30.7 dB

Efficiency = 86 %
(radiation)

Axial ratio = 2.7 dB



θ=35°



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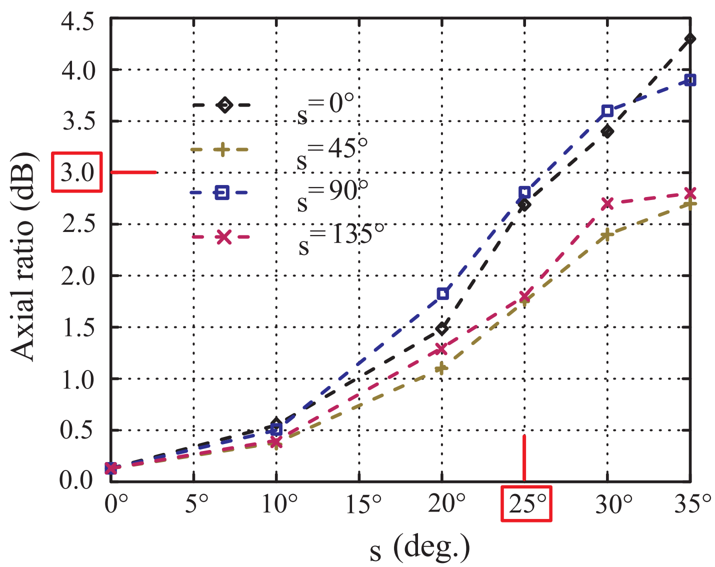
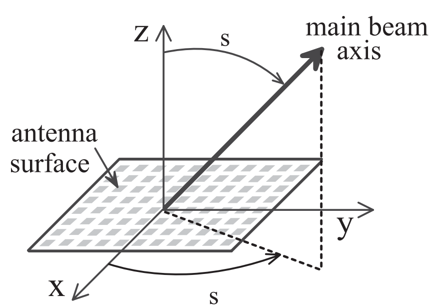
Radiation characteristics of a 1600-element circularly polarised array at 30 GHz

<u>Circular polarisation quality</u>





<u>Record</u>

- For a scan angle θ_s varying up to (±) 35°

– Axial ratio ≤ 4.3 dB (< 3 dB for $\theta_s \leq 25°$)
– Cross-polarisation ≤ -12 dB
– Side lobes ≤ -13 dB
– Radiation efficiency ≥ 83 %
– 30.5 dB ≤ Gain ≤ 32 dB (1600 elements)

with element spacing=0.35 λ_0 (within subarrays)
subarray spacing=0.6 λ_0

Only patches are sequentially rotated

- Lower cross-polarisation expected when performing additionally a sequential rotation on the subarrays
  ⇒ reduced axial ratio, higher maximum scan angle

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3 RF electronics and system parameters

Different options to perform the transmit, receive and calibration functions

RF aspects	Options	Comments
Receiver	Homodyne architecture	relevant choice for monolithic integration
	Heterodyne architecture*	conventional approach, good performance, space required, medium cost
Transmitter	Direct conversion	profitable only if integrated solutions exist
	Dual conversion*	feasible right now, digital modulation possible and preferable
Components	LO built with discrete components 1 Local Oscillator signal, distributed*	simplest option
Calibration	Internal calibration	optimum practical choice but expensive
	External calibration	cost-effective but bulky
	Calibration based on mutual coupling measurements	may be interesting but experimental testing required

* options compatible with a short-term fabrication (requisite components presently on the market)

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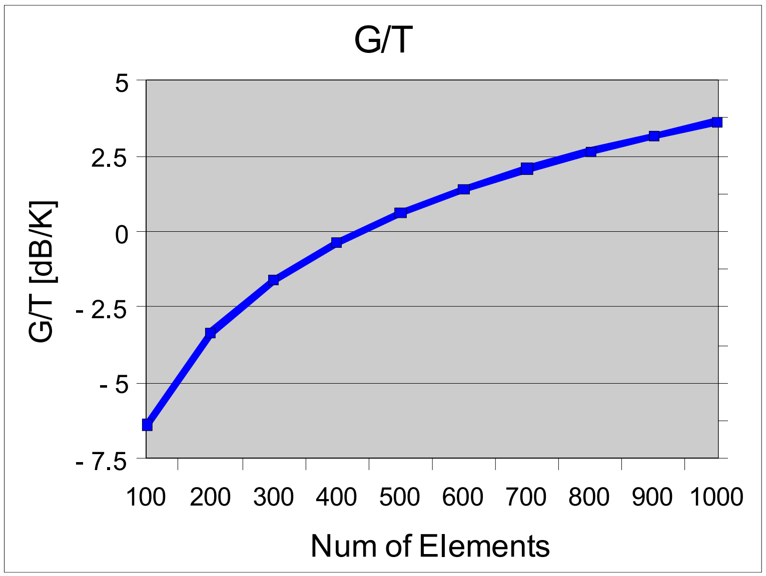
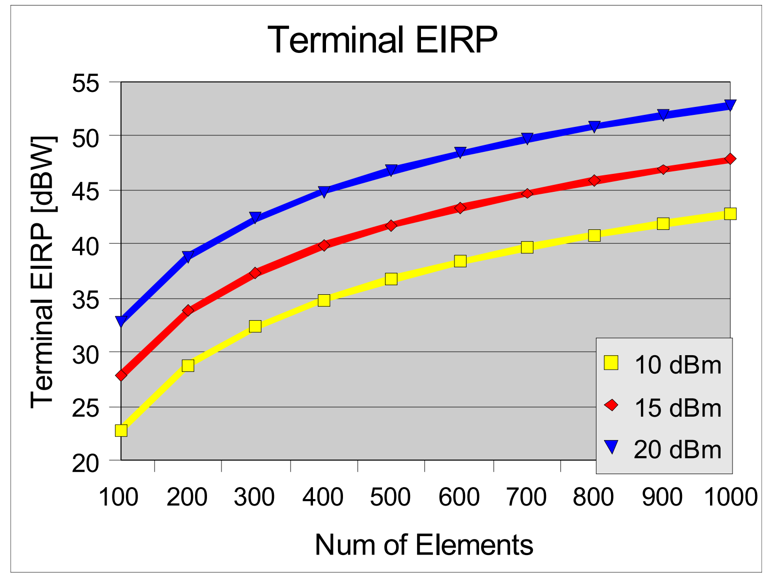
System parameters

Receiver



Transmitter



Assumptions

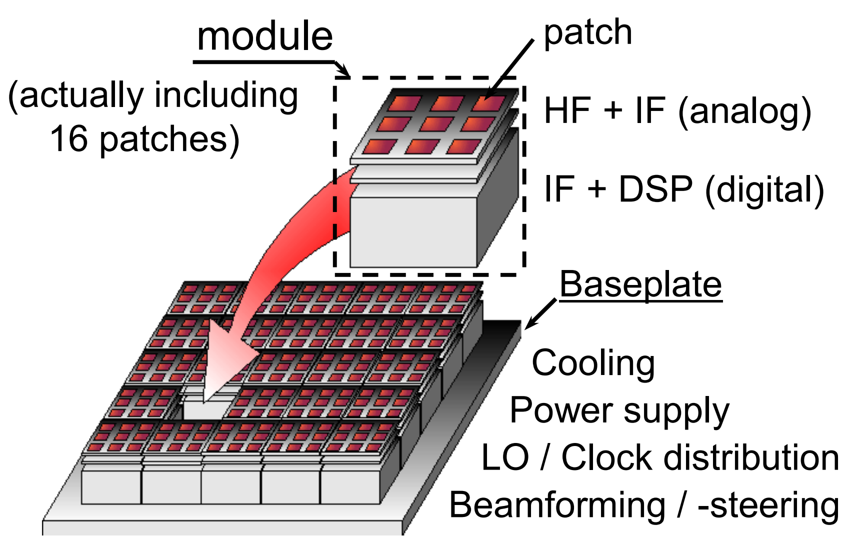
Antenna Noise Temp.: 290K
Receiver Noise Figure: 4 dB

Antenna efficiency: 60%
Element spacing: 0.5 λ_0

Element power: 10/15/20 dBm

4 Terminal architecture and construction

Packaging architecture

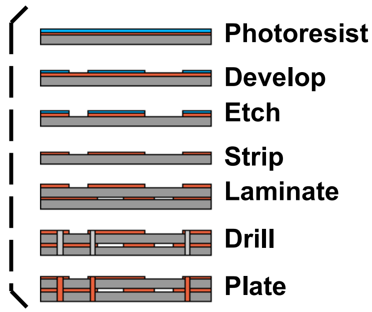
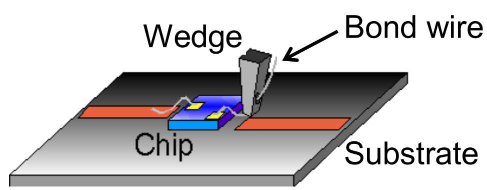
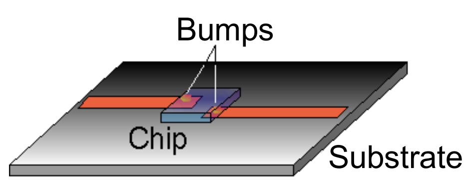


complete active antenna ≡ minimum 36 modules

Terminal antenna construction (a)

Proposals	Comments
Modular construction	array subdivided into modules, module ≡ 2×2 subarrays
Hybrid Tile- / Brick-architecture (for the module)	• RF parts of receiver/transmitter • IF/BB circuitry • AD/DA converters
Cross-module functions implemented at the module-base level	• DC-supply power • Local-Oscillator signals • Clock signals • DSP functions • Heat sink facilities

Terminal antenna construction (b)

	Proposals	Comments
MCM technology	**Multichip-module laminate** Fabrication steps → 	(+) robust and reliable construction (+) most cost-effective technology
Interconnections	**Wire bonding**  (present standard technology)	(+) ready for implementation (–) space-consuming (–) fully automated fabrication not possible
	Flip-chip  (next-generation technology)	(+) fast, high-volume automated production (+) most mechanically rugged method (+) compactness (–) all needed chips not currently available

(+) advantages, (–) drawbacks

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5 Manufacturing guidelines

Technological recommendations for fabricating full-scale terminals

- Receive and transmit functions performed by 2 separate antennas
  - Heterodyne receiver
  - Dual conversion transmitter
- Modular, hybrid architecture
- Multichip-module-laminate technology
- Flip-chip interconnections
- Digital beamforming

Further comments

- Iterative and progressive 3-step implementation suggested
  - module (16 elements)
  - intermediate building block (256 elements)
  - full-size terminal
- Factors limiting the antenna dimension
  - efficiency of the heat-sink process
  - performance and cost of components available when realising the complete active antenna
- An up-market-oriented product is targeted