Antenna Technologies for Wireless Solutions

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September 10, 1998

Careful Antenna Selection is Smart

- Stand alone antennas are not “smart”.
- Careful selection of the antenna is “smart”.
- Antennas are often the after thought of a system design.
- Optimum antenna performance can enhance the smartness of the system.
  - A smart antenna system makes an antenna appear to be smart.
  - A quality antenna can make the system appear smarter.

Antenna Selection Criteria

- Decision to employ Smart Antenna system depends on:
  - Cost of increased capacity:
    - Justifiable?
  - Size/weight:
    - Zoning issues
    - Mounting requirements
  - Form Factor:
    - Zoning issues
    - Wind loading
  - System performance requirements:
    - Horizontal & Vertical pattern shape, gain, polarization, interference & isolation issues, bandwidth and ports

Fixed vs Mobile Requirements

- Many antenna performance considerations are the same for fixed and mobile applications
  - Seasonal changes
  - Movement of nearby objects
- Adjustment can be made to each to improve system performance
  - Fixed my require greater performance margins

Contents

- Antenna Array Theory
- Type of Antenna Radiators
- Important Array Characteristics
- Dual Slant Polarized Arrays
- Dual Band?Dual Slant Antennas
- Arrays Used to Increase Capacity

Radiation Patterns Are Generated Using Complex Sum

Complex sum is used to generate the far field radiation pattern

$$E(\theta,\phi) = E_{el}(\theta,\phi)\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} A_{mn}\, e^{jk\left[md_x \sin\theta\cos\phi + nd_y \sin\theta\sin\phi\right]}$$ 2-D array

$$E(\theta) = E_{el}(\theta)\sum_{m=0}^{M-1} A_m\, e^{jk\left[md_x \sin\theta\right]}$$ 1-D array (linear)

where:

M=Number of radiating elements in the x direction

m=The m[th] element in the x direction

k=constant ($2\pi/\lambda$)

j=square root of -1

d_x=Element spacing in the x direction

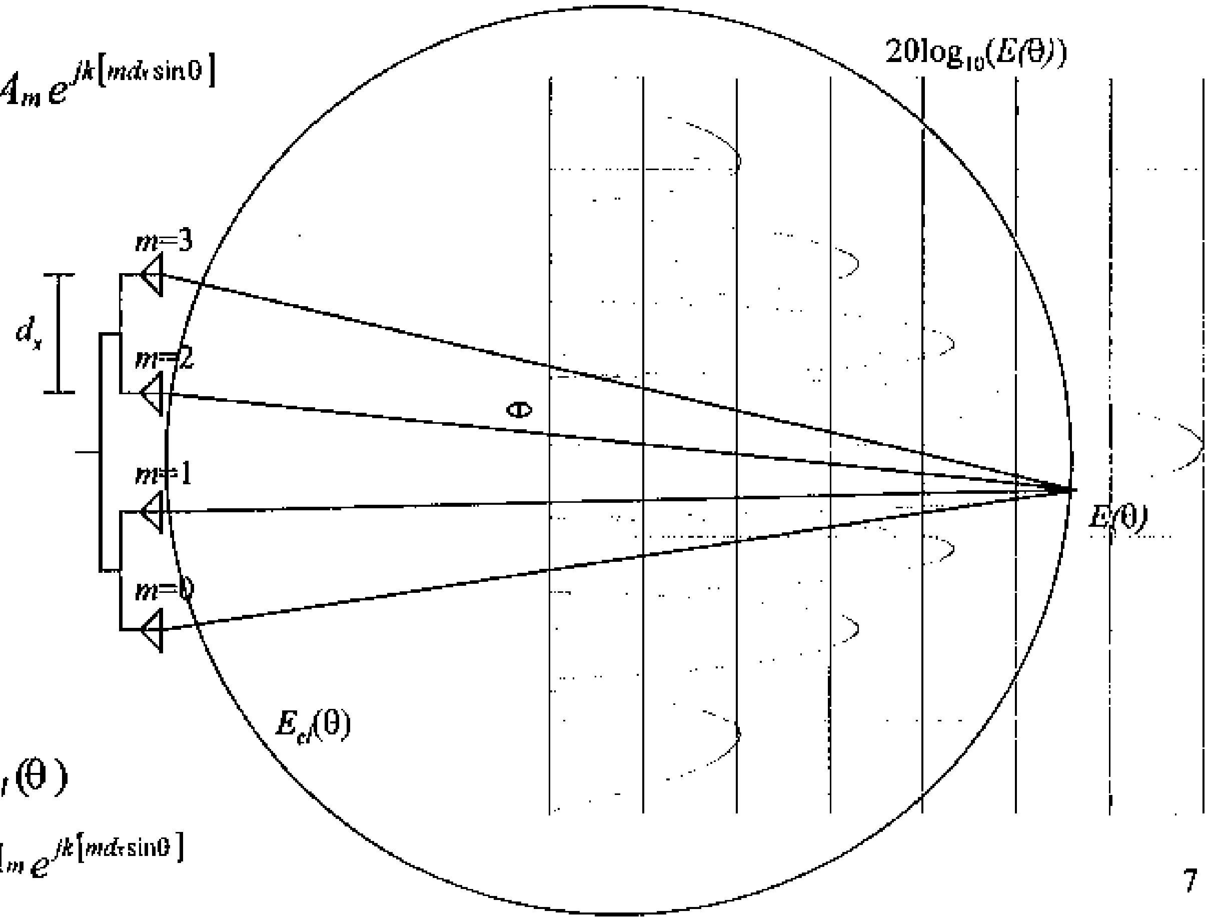
Am=Complex excitation of the m[th] element (contains scan information)

$E(\theta)$=Complex far field radiation voltage at angle θ of array.

$Eel(\theta)$=Complex far field radiation voltage at angle θ of the radiating element of the array.

Element and Array Factor Affect Antenna Radiation Pattern

$$E(\theta) = E_{el}(\theta)\sum_{m=0}^{M-1} A_m e^{jk[md_x \sin\theta]}$$



$$ElementFactor = E_{el}(\theta)$$

$$ArrayFactor = \sum_{m=0}^{M-1} A_m e^{jk[md_x \sin\theta]}$$

Element Factor Can Help Suppress Unwanted Slidelobes

$$E(\theta) = E_{el}(\theta)\sum_{m=0}^{M-1} A_m e^{jk[md_x \sin\theta]}$$

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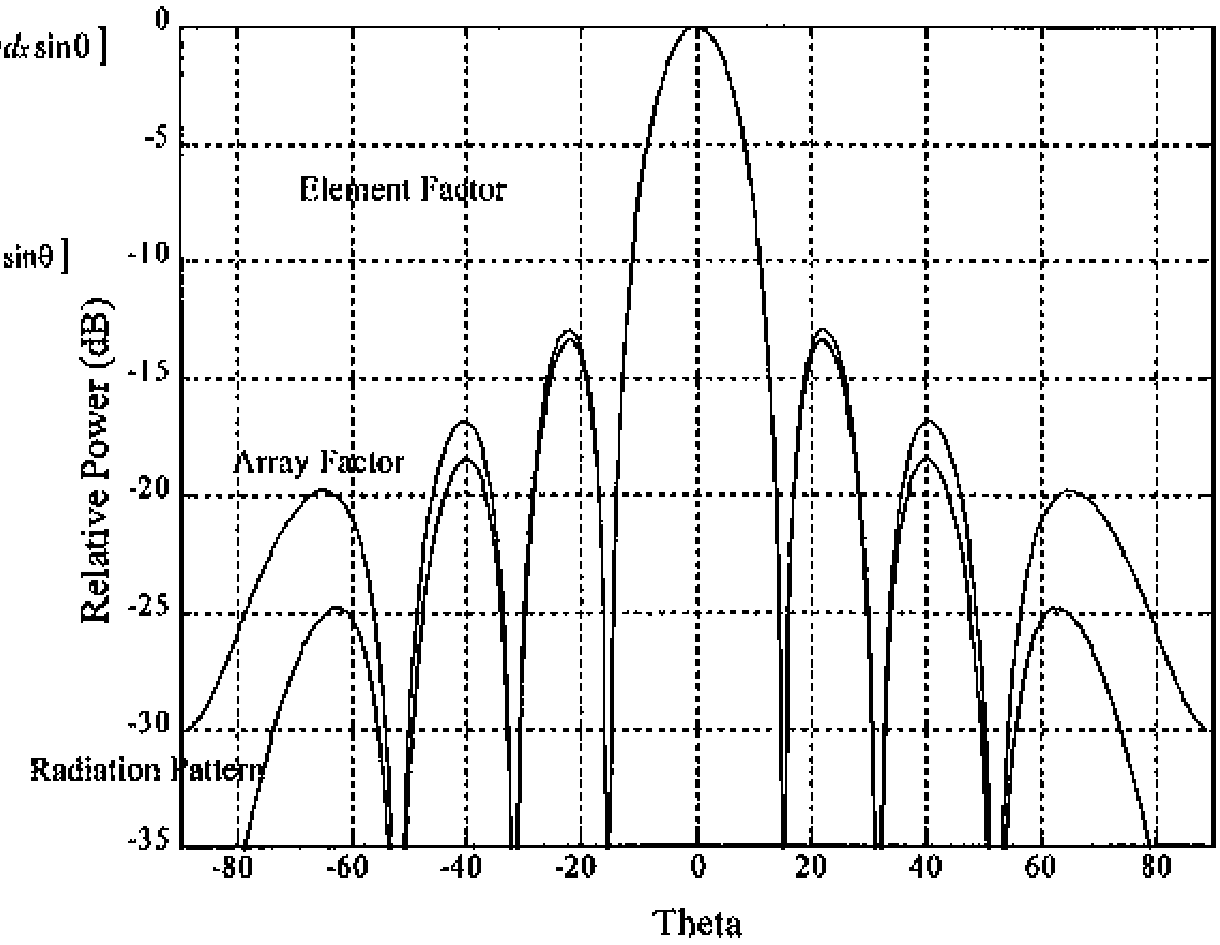


Typical Radiating Element Types (Element Factor)

Type	Advantages	Disadvantages
Dipole	-Broadband -Easy to achieve broad horizontal beamwidth	-Front-to-back ratio -Non-conformal form factor
Log-periodic	-Excellent front-to-back ratio -Horizontal beamwidth consistency -Broadband performance -Fast pattern roll-off in horizontal plane	-Non-conformal form factor
Microstrip patch	-Conformal form factor -Fast pattern roll-off in horizontal plane -Simple to fabricate -Horizontal beamwidth consistency	-Traditional patch offers narrow bandwidth -Broadband tuning/design is typically required
Travelling wave	(Primarily used in omni directional antennas) -Simple to fabricate	-Narrow pattern bandwidth due to colinear array design

Array Factor Affects Radiation Beam Characteristics

- **Grating lobes**
  - **Result from too wide of element spacing or periodic mismatches**
  - **Reduces antenna gain (energy goes into grating lobe)**
  - **Degrade more at high frequency end of the band**
- **Amplitude Tapering**
  - **Shapes beam and slidelobes (does not move beam location)**
  - **Broadens beamwidth slightly**
  - **Reduces antenna gain**
- **Phase adjustments**
  - **Combination of phase and amplitude for null-fill effects**
  - **Shape beam (phase spoiling)**
  - **Tilt or point main beam (phase slope)**

Important Array Characteristics

- Bandwidth
- Input impedance match
- Efficiency
- Gain
- Radiation pattern
  - Field of view (coverage)
  - Number of beams
- Power handling
- Polarization
  - Cross polarization level
  - Dual slant port-to-port isolation
- Passive intermodulation (PIM)
- Construction/Reliability

Bandwidth of an Antenna

- The bandwidth of an antenna is defined as the frequency band over which the antenna specifications are met.
  - Numerical definitions (example):
    - Band edges:
      - RX: 1850-1910 MHz
      - TX: 1930-1990 MHz
    - Percent bandwidth
      - RX: 3.2 percent centered at 1880 MHz I.e. [(60/1880)x100]
      - TX: 3.1 percent centered at 1990 MHz
- It is typically more difficult to obtain optimum performance as bandwidth is increased.

Input Impedance Match

- The input impedance match defines how well the antenna matches the characteristic impedance of the system (typically 50 ohms).
- If a mismatch occurs then a reflected wave is generated and maximum energy transfer is not achieved.
- Input impedance match is often specified by:
  - Voltages Standing Wave Ratio = VSWR = $\frac{\left(1+\left|\Gamma\right|^2\right)}{\left(1-\left|\Gamma\right|^2\right)}$
  - or
  - Return loss = $-10\log\left(\left|\Gamma\right|^2\right)$

Input Impedance Mismatch Affects Energy Transfer

- Reciprocity applies to the mismatch of a passive antenna
  - Receive and Transmit energy are both reduced

VSWR	Return Loss (dB)	Reflection Coefficient (Γ)	Reflected Power %	Mismatch Loss (dB)
1.00:1	-∞	.000	0.00	0.00
1.25:1	-19.1	.111	1.23	0.05
1.50:1	-14.0	.200	4.00	0.18
1.75:1	-11.3	.273	7.44	0.34
2.00:1	-9.5	.333	11.11	0.51
2.25:1	-8.3	.385	14.79	0.70

Radiation Efficiency Consideration

- Radiation efficiency is affected by impedance mismatches and I^2R (ohmic) material losses.
- Transmission medium is an important factor (feed circuitry & radiating element)
- Microstrip
  - substrate characteristics (printed circuit vs air loaded)
  - trace protection issues
- Coaxial cable
  - solder joint transitions
  - can be lossy
- Radome losses
- Mismatches within antenna

Antenna Efficiency Is Directly Related To System Performance

- Losses and mismatches in the antenna decrease the system carrier-to-noise ratio.

$$\frac{C}{N} \propto \frac{G}{T} = \frac{D\left(1-|\Gamma|^2\right)}{T_{LOOK}\left(1-|\Gamma|^2\right)+290\left[\left(F_{OHMIC}-1\right)+\frac{\left(F_{LNA}-1\right)}{G_{OHMIC}}\right]}$$

<u>Where:</u>

C=Received carrier power
N=Received noise power
G=Gain of the receive antenna
D=Directivity of the receive antenna
T_{LOOK}=Noise the antenna sees from the direction it is pointed
F=Noise factor
G_{OHMIC}=Ohmic loss of the system (antenna)
Γ=Complex reflection coefficient

Note:
1 dB of ohmic loss can result in a C/N degradation of 1.5 dB

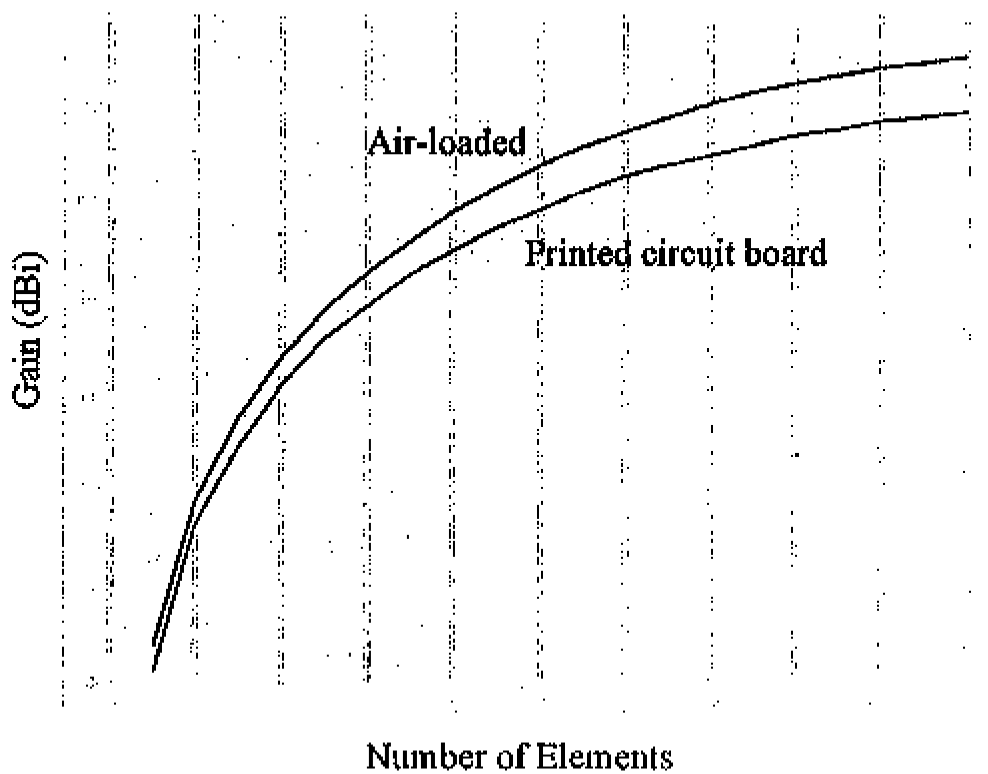
Several Radiation Pattern Characteristics To Consider

- Directivity
  - $D=4\pi$(max power radiated/total power radiated)
- Gain
  - $G=D-Loss_{I^2R}-Loss_{(1-|\Gamma|^2)}$
- 3 dB beamwidth
- Co- and cross-polarization
- Sidelobes
- Front-to-back and Front-to-side ratios
- Consistency of performance from unit to unit

Increase in Gain Requires Larger Antenna or Lower Loss

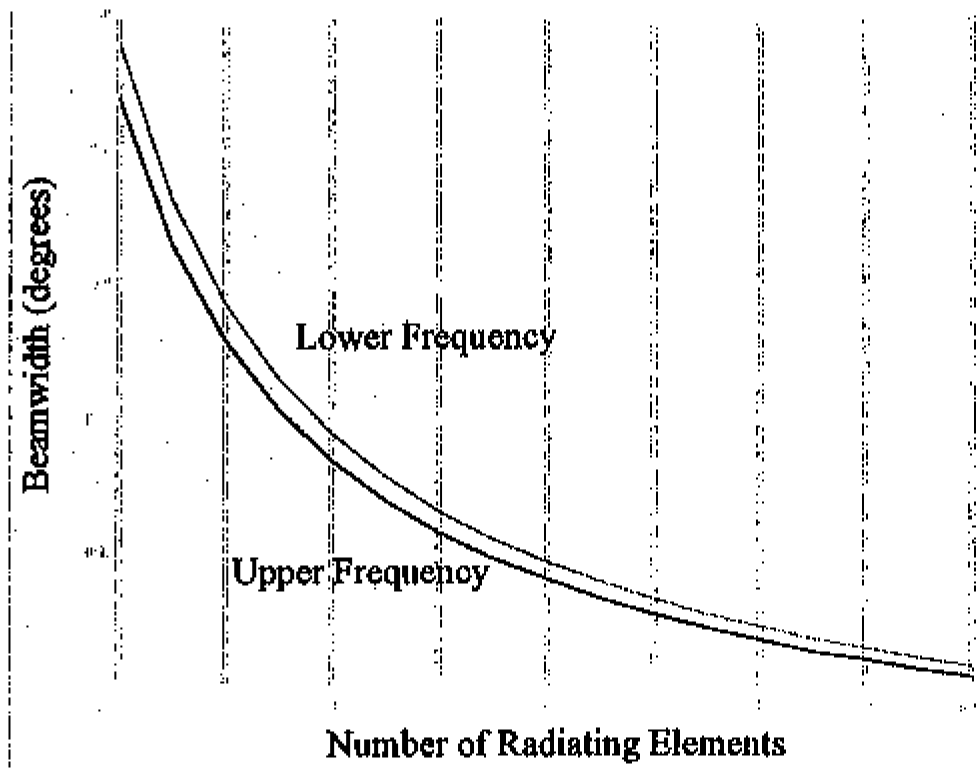
- Graph shows gain comparison between air-loaded and printed circuit board antenna designs.

Note:
1) Element spacing is constant.
2) Closer spacing will result in lower gain.
3) Losses are included.
4) Based on current antenna designs at Ball.
5) Low loss printed circuit board material is used.



Beamwidth is Effected By Number of Radiating Elements

- Beamwidth changes as a function of frequency
- As frequency increases:
  - Beamwidth narrows
  - Directivitiy increases
- Antenna Loss does not affect beamwidth



Example:

PCS Band Antenna Length (approx) :	12	18	24	30	36	42	48	55	61 (inches)
Cellular Band Antenna Length (approx):	24	36	48	60	72	84	96	108	120 (inches)

Assumptions:

1) 0,9λ elements spacing is used,
2) Elements are in a line

Antenna Power Handling Considerations

- Amount of heat dissipated in the antenna can be a result of:
  - Lossy transmission medium
    - Feed network
    - Radiating element efficiency
  - Internal mismatches
  - High current density
- Heat can degrade long term antenna performance

Poor Passive Intermodulation Can Degrade System Capacity

- Passive Intermodulation (PIM) can reduce the system capacity.
- Poor PIM is a result of non-linearities in a transmission medium ("diode effect").
- The following design guidelines should be used to minimize PIM generation:
  - Employ electromagnetically coupled techniques for transitions within the antenna
  - Avoid metal to metal contacts when possible
  - Minimize solder joints or other similar processes
  - Minimize parts in antenna fabrication

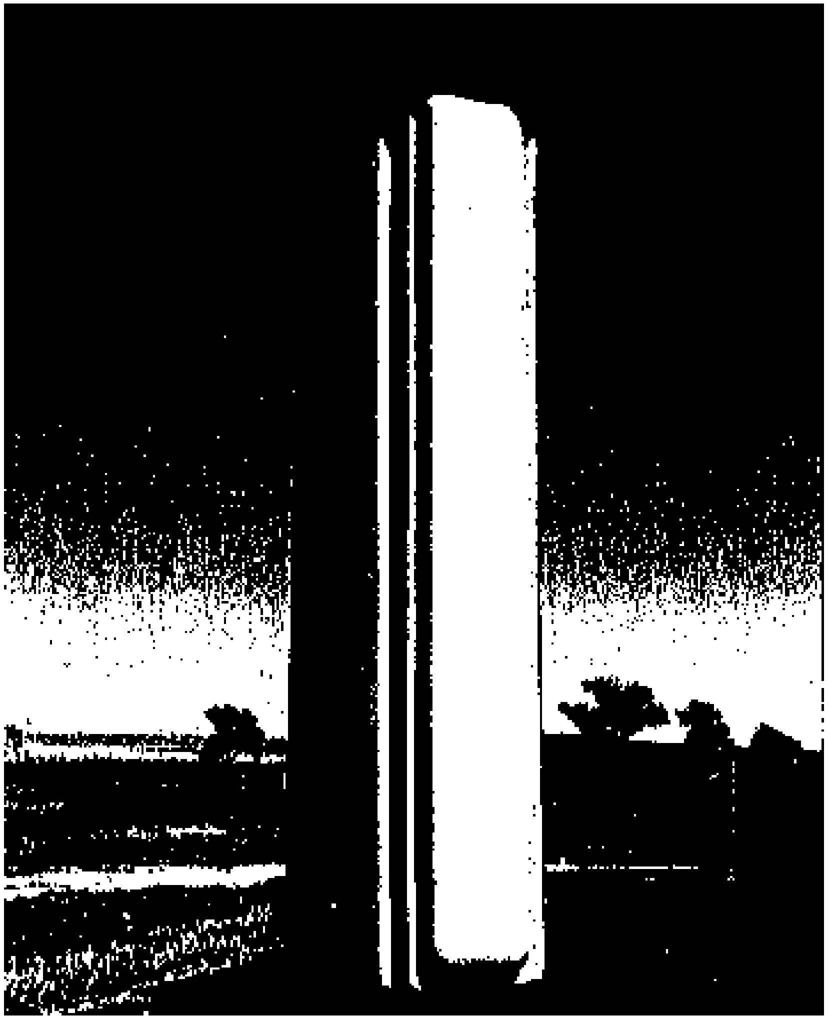
Array Construction Approach is Critical to Performance

- Proper material selection will add long term performance:
  - Radome:
    - UV stabilized materials
    - Water absorption of material (long term)
    - Method used to fasten radome to groundplane, end caps, or mounting bracketry
  - Circuit boards:
    - Water absorption will de-tune antenna
    - Lossy materials will degrade over time due to RF heating
  - Metals:
    - Proper treatment when necessary
    - Avoid dissimilar metal to metal contacts

Dual Slant Polarized Arrays

- Typically used to minimize zoning issues.
- Dual slant performance is better than H/V for most applications.
- Things to look for in a dual slant antenna:
  - Identical geographical coverage between polarizations
  - Pattern and gain consistency for various polarization angles across entire frequency band (co- and x-pol)
  - Good port-to-port isolation (<- 30 dB is desirable)
  - Front-to-side and Front-to-back ratio performance
  - Reliability; typically more complex feed network is required
  - Passive Intermodulation (PIM); transitions and solder joint quality can effect PIM performance

UniPak™ Polarization Diversity package



Dual Band/Dual Slant Antennas

- Dual Band/Dual Slant antennas help solve various problems:
  - Zoning issues
  - Dual frequency use with one antenna
  - Reduced wind loading
  - Reduced installation costs
- Minimum antenna size is achieved when dual band radiating element is implemented
- All Dual slant antenna comments previously shown also apply.

Arrays Used To Increase Capacity

- Switched beam arrays
- Adaptive arrays
  - Active phased array
  - Passive Column arrays
- Orthogonality of adjacent beam polarizations

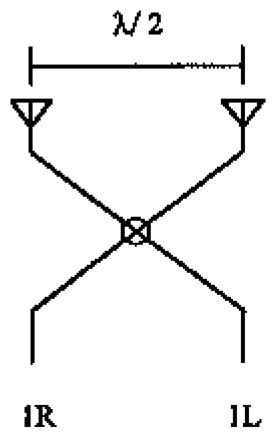
Switched Beam Arrays Can Be Employed To Increase Capacity

- Butler Matrix array
  - 2, 4, 8, … -way
  - Planar and cylindrical configurations
  - Multiple fixed beams
- Blass Matrix
- Rotman Lens

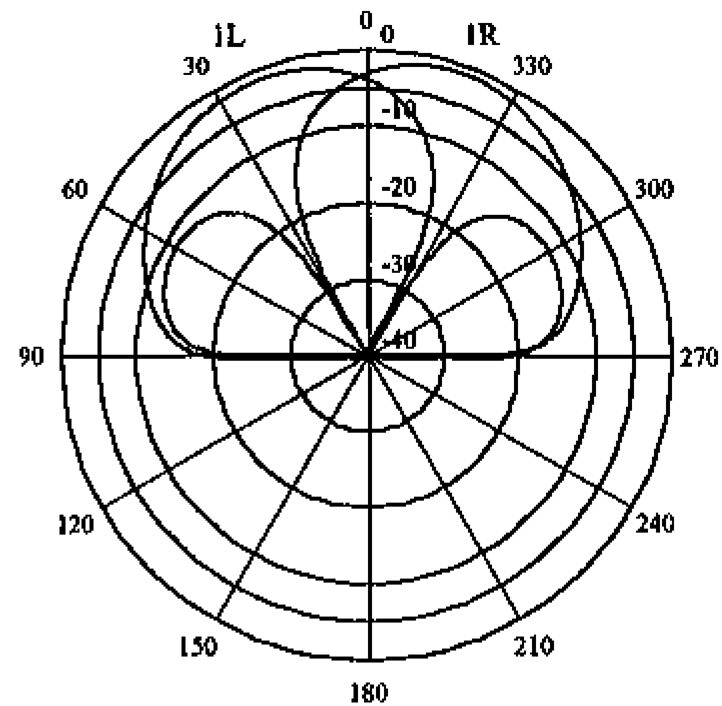
Butler Array Trade-Offs

- Advantages
  - Gain of whole aperture
  - Isolation between adjacent beams
  - Narrow horizontal beamwidth capability
  - Can shape into cylindrical form factor
  - Can be conformal form factor
- Disadvantages
  - Cross overs in feed network if more than 4 ports are required
  - Feed network loss
  - Wind loading can be high

2-Port Butler Matrix Is Shown



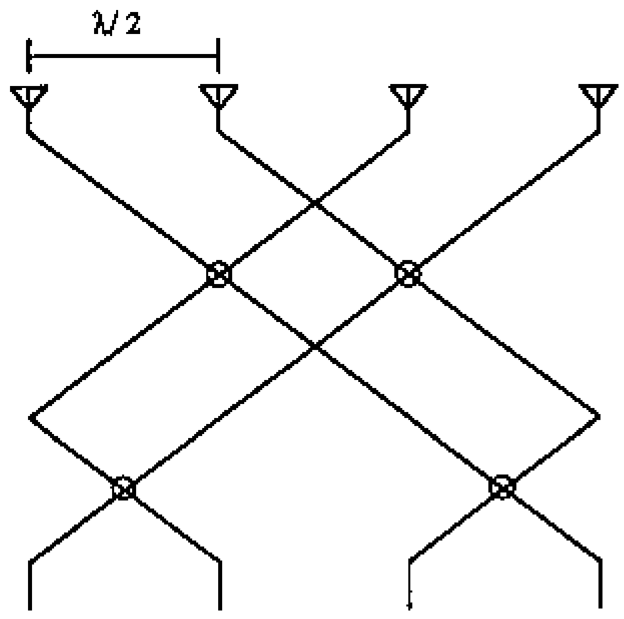
Butler Matrix Feed Topology



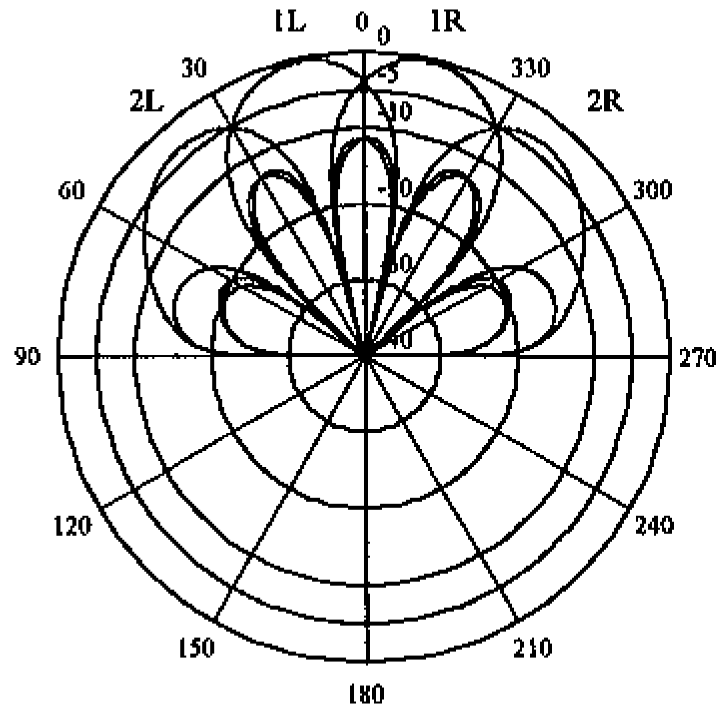
Antenna Radiation Pattern of 2 Port Butler

Note: Various combinations of ports can provide other beam locations and shapes.

4-Port Butler Matrix Provides 4 Beams Without Additional Processing



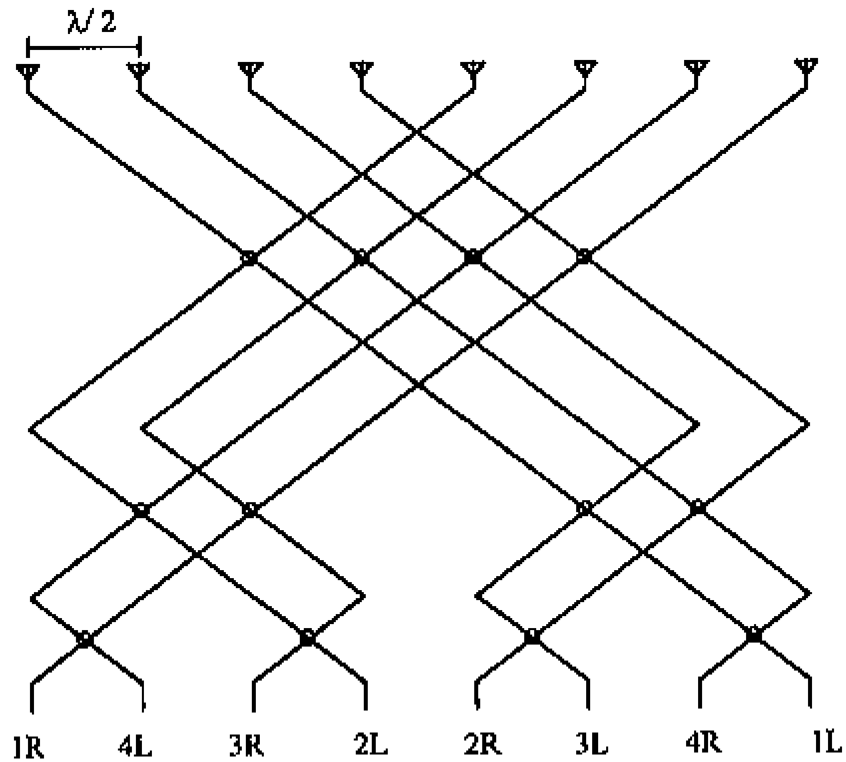
Butler Matrix Feed Topology



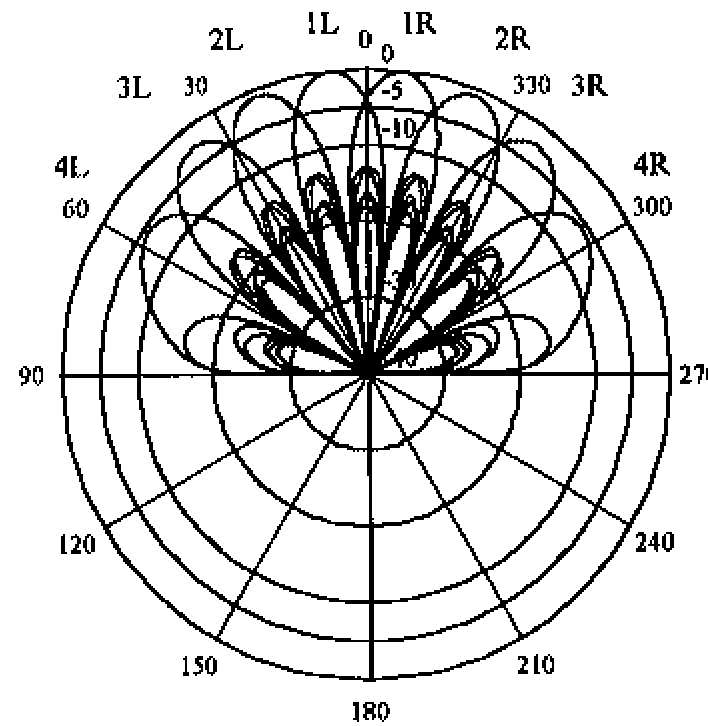
Antenna Radiation Pattern of 4 Port Butler

Note: Various combinations of ports can provide other beam locations and shapes.

8-Port Butler Matrix Requires Cross-Over Feed Lines



Butler Matrix Feed Topology



Antenna Radiation Pattern of 4 Port Butler

Note: Various combinations of ports can provide other beam locations and shapes.

8-Port Butler Matrix Array Is Shown

Photo of internal layers of 8 port Butler Matrix array

Adaptive Array Approach

- Can be a very powerful approach to increase system capacity.
  - Implementation of DSP technology is required
- Antennas that can be used are:
  - Phased arrays
  - Columns of arrays
  - Multi-Beam arrays
  - Others

Adaptive Array Approaches (con't)

- Advantages
  - Beam shape versatility
  - Null steering
  - Change pattern real time
- Disadvantages
  - Phased arrays are costly (phase shifter, attenuators, control circuitry at the antenna, one feed network per port, Gain is reduced with multiple beam are form from a single port phased array)
  - Radiation pattern shape versatility is dependent on number of elements or columns

Summary

- Antennas play a key role in the wireless solution.
  - Zoning/Mechanical/RF Performance
- A well designed antenna can assist in increasing capacity performance.
  - RF performance parameters are main factor
- The type of antenna used in a ‘smart system’ is closely tied to the ‘smart radio.’