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# Review of the AirCell/Boeing Cross-Polarization ATG Band Sharing Proposal

## WT Docket 03-103

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Dr. Jay Padgett
Senior Scientist
Telcordia Technologies/ Applied Research
Wireless Systems and Networks
jpadgett@telcordia.com

# Overview

- The latest AirCell/Boeing cross-polarization proposal is not new, and suffers from the same flaws as the previous version.
- The severe reverse link interference problem seen in AirCell's earlier (June) analysis has been "fixed" by reducing traffic capacity by a factor of 12 in the simulation, for the airport scenario.
- Even minimal cross-polarization isolation cannot be reliably maintained.
- Cross-polarization interference will occur in an ATG environment, causing SINR degradation that will prevent delivery of reliable broadband ATG service.
- Band-sharing via cross-polarization would require common infrastructure designs and joint admission controls among competing ATG providers.

# The "AirCell/Boeing" Cross-Polarization Sharing Proposal is Not New

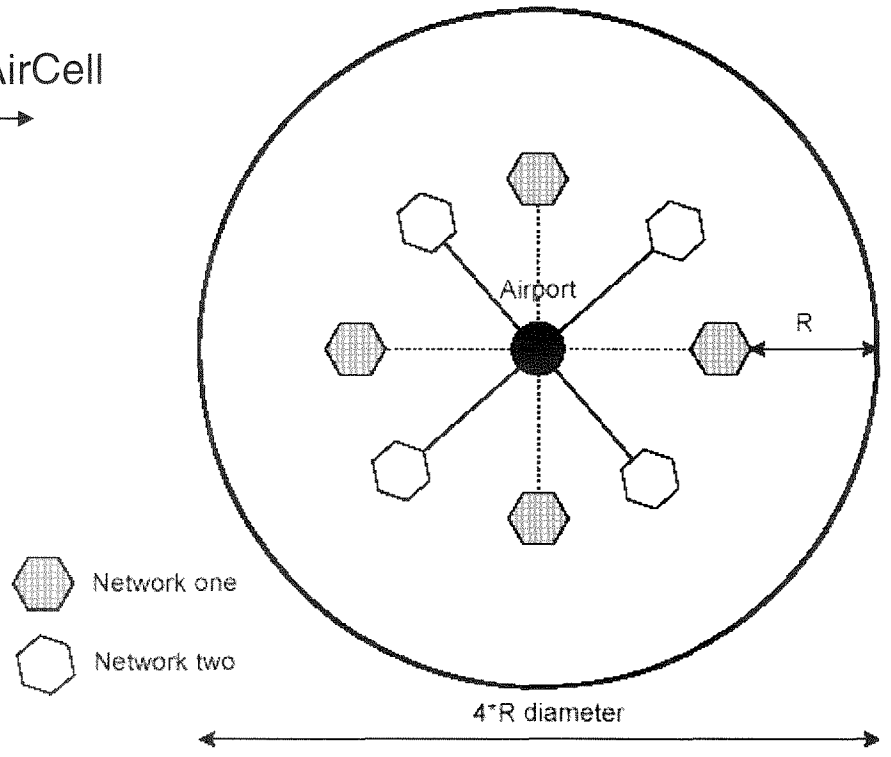
- AirCell proposed cross-polarization in June[1]
  - Assumed 12 dB of polarization isolation
  - Cited 1997 flight test data (that doesn't support claim)
  - Provided analysis that shows intolerably high noise rise (interference on the reverse link) in the airport environment, even with the 12 dB constant polarization isolation
- In October, AirCell/Boeing made "new" proposal[2] which differs in some respects from earlier proposal
  - Two systems required to provide nearly identical coverage (close or co-located base stations; identical BS antenna patterns)
  - Traffic capacity of the "airport scenario" reduced by a factor of 12 to "solve" the noise rise problem
  - Cites new (but inadequate) source of test data as evidence

[1] AirCell Ex Parte Letter of Jun. 29, 2004

[2] AirCell Ex Parte Letter of Oct. 26, 2004

# AirCell's June "Airport Scenario"

Reproduced from AirCell June 29 paper →




- R = 12.5 miles (scenario includes 25-mile radius around airport).
- 3 sectors/cell per system x 4 cells/system x 3 aircraft/sector = 36 aircraft per system at 75% loading.
- AirCell simulation results showed very high interference into base stations of both systems (next slide).

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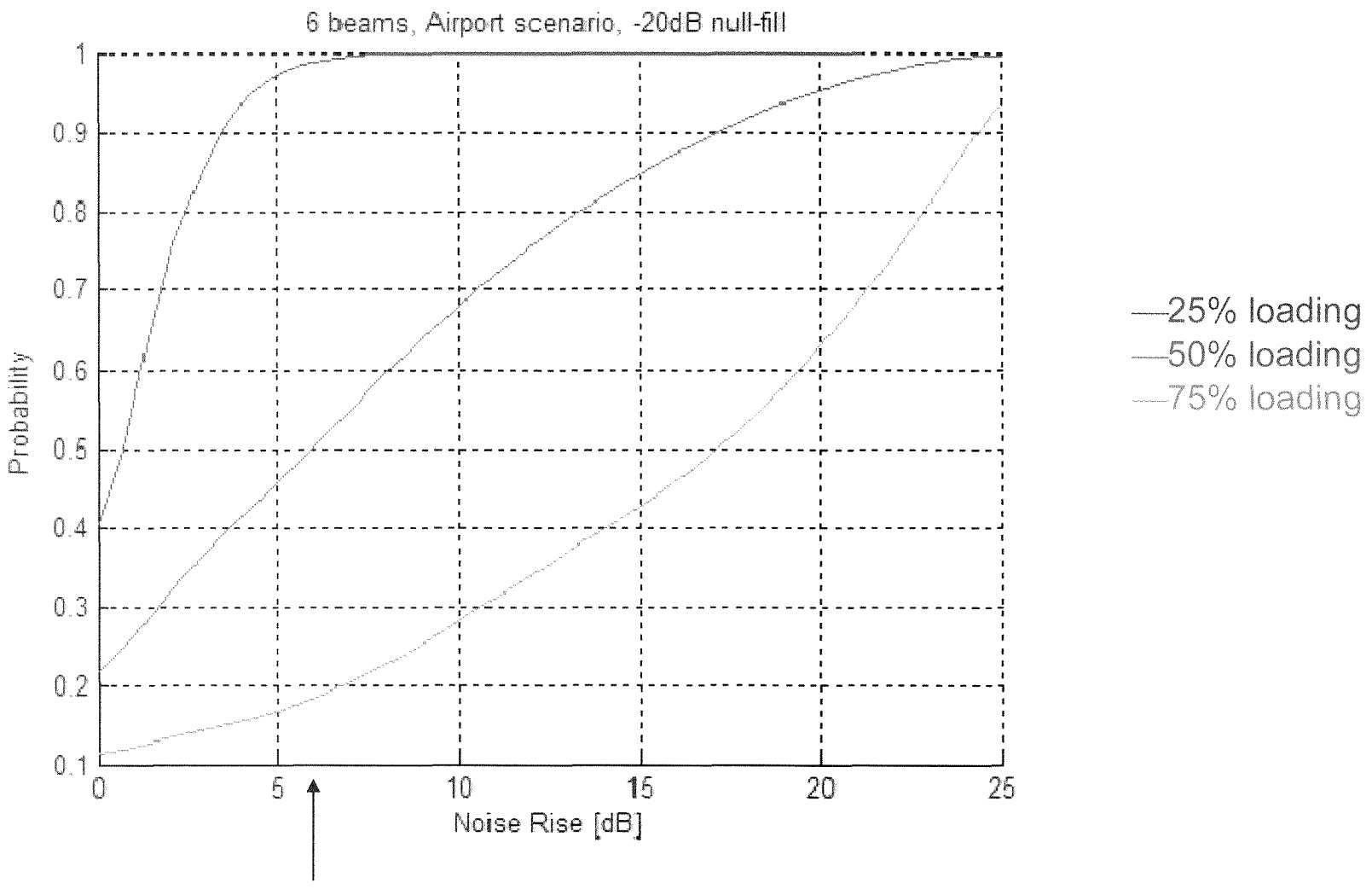
# Noise Rise CDF from AirCell (June) Fig. 6.23




**typical CDMA maximum-load design point (~6 dB) for 75% loading**

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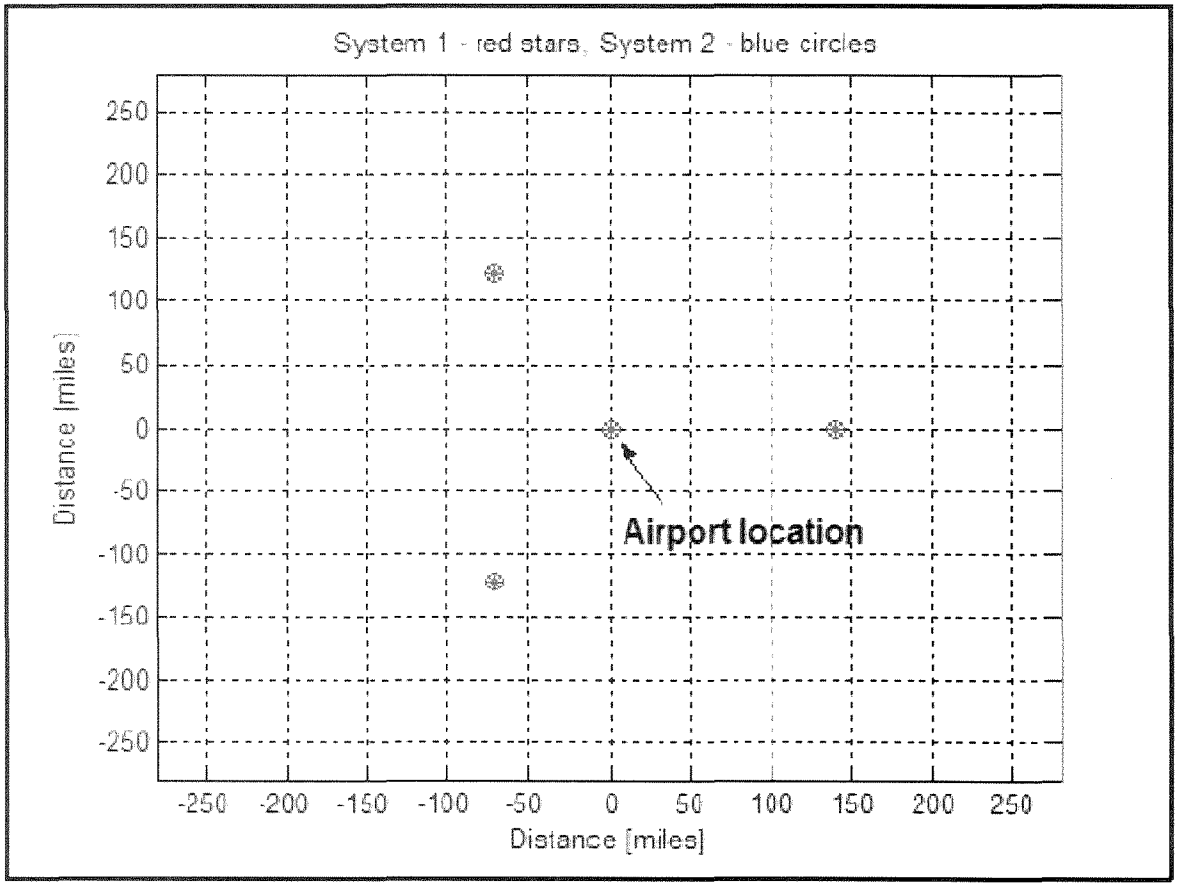
# AirCell Redefines the ATG Model to "Solve" the Interference Problem – Resulting in 12-Fold Reduction in Traffic




Reproduced from AirCell October 25 Presentation to FCC, WT Docket 03-103.

**Revised "airport scenario" is not a reasonable model for an actual airport environment**

- 1 cell/system x 1 sector/cell (omni) x 3 aircraft/sector = 3 aircraft/system at 75% loading. Each aircraft transmits 48 kbps average on reverse link
- Next nearest cell is about 140 miles from airport

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# Polarization Isolation Cannot Be Reliably Maintained

- There is nothing in the record to support AirCell's claim that 12 dB of cross-polarization isolation is achievable
  - October proposal reference provides only a single graph for a single test run
  - No explanation of test procedure or equipment parameters
  - Subsequent inquiry by FCC Staff revealed that base was transmitting alternating V and H polarizations, with aircraft receiving on H pol
  - No statistical summary of results was provided
  - Measurements were not made under representative conditions for ATG: dish antenna at base; low-flying (5000 ft) aircraft
  - Measurements were intended to determine polarization isolation for aircraft-to-cellular base station interfering path, not ATG path

# Polarization Isolation Cannot Be Reliably Maintained

- Even if the antennas are "polarization-pure", environmental factors will cause cross-coupling between V and H polarizations
  - reflections
  - aircraft pitch and roll
  - altitude differential between aircraft and base station (most pronounced at cruise altitude)
- Polarization isolation will be highly variable, and therefore is not a reliable means of limiting inter-system interference
- There is no apparent means of regulating, testing, monitoring, or enforcing polarization isolation (vis-à-vis other accepted isolation techniques such as operating on different frequencies)

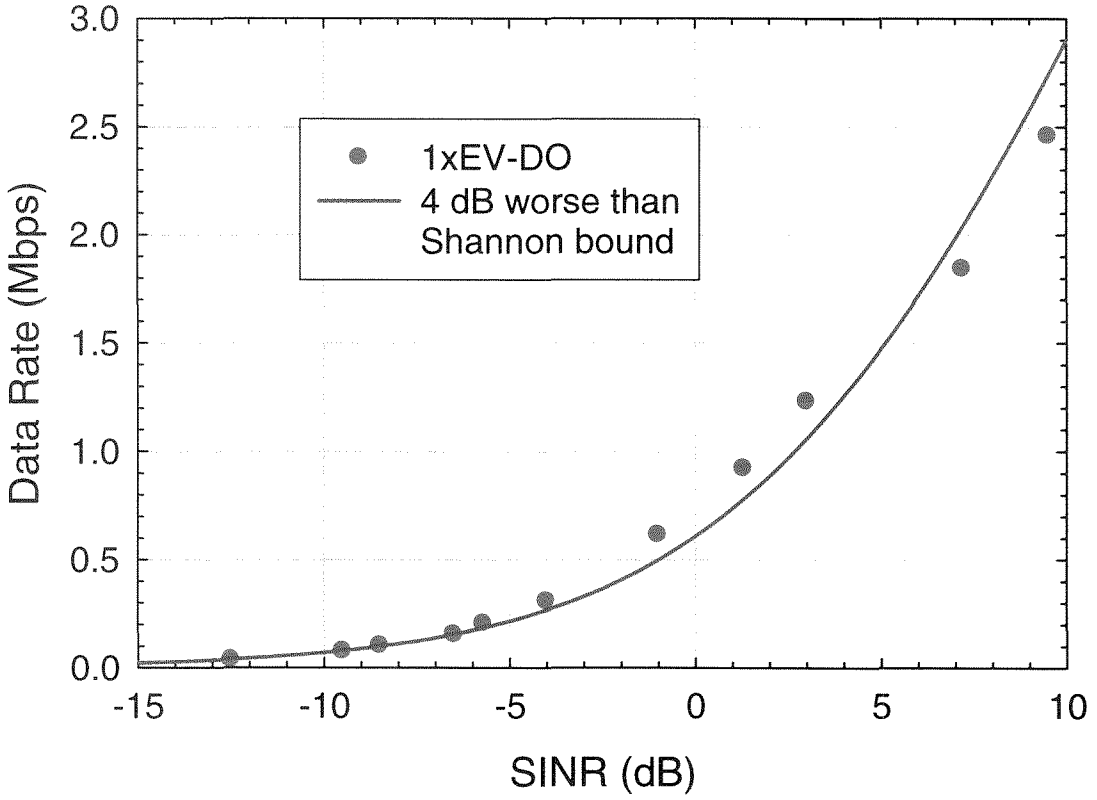
# Summary of Free-Space Polarization Cross-Coupling

- "Vertical" and "horizontal" polarization orientations cannot be maintained with propagation in three dimensions
- Follows from basic principles of radio wave propagation; applies to any antenna type and will cause cross-polarization interference.
- Problem is most severe at steep elevation angles
  - Aircraft at cruise altitude in the vicinity of a base station
  - Aircraft near airports with small horizontal distances
- V-to-H and H-to-V interference are not symmetric
  - With H-pol aircraft antenna, paths to both H and V at base depend on aircraft bearing and heading
  - With V-pol aircraft antenna, paths to H and V at base depend on aircraft bearing only
- Cross-polarization interference will be different for each aircraft/base station pair and will change as the aircraft moves

[See background slides for more detail]

# Cross-Polarization Would Prohibit Delivery of Broadband ATG Service

- High data rate requires high SINR (see below)
- Cross-polarization interference will significantly degrade the SINR in uncontrollable and unpredictable ways
- AirCell's own results show that cross-polarization interference can prevent sharing using even relatively low data rates

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# Joint Design and Operation Would Be Required Between V- and H-Polarized Systems

- Coverage per sector (net path loss to base) would need to be nearly identical
  - Total path isolation is reduced, dB for dB, by any variation in the relative patterns of the V- and H-pol base station antennas. This is not taken into account in AirCell's analysis
  - Example: H-H loss 100 dB, V-V loss 96 dB, H(ac) – V(base) XPI = 12 dB. Forward link at H-pol aircraft S/I = 8 dB, not 12 dB. Also causes 4-dB disadvantage to V-pol reverse link (power control)
  - This requirement would (as noted by AirCell) mean that V- and H-pol base stations need to be essentially co-located and have identical antenna patterns
- Reverse link admission control would need to be jointly managed between the two systems to have any chance of controlling the noise rise at the base station receiver. Some type of cooperation rules or "etiquette" would be necessary
- In some respects, the two systems would need to operate as one
- Even so, service would be unreliable

# The AirCell/Boeing Analysis is Severely Flawed

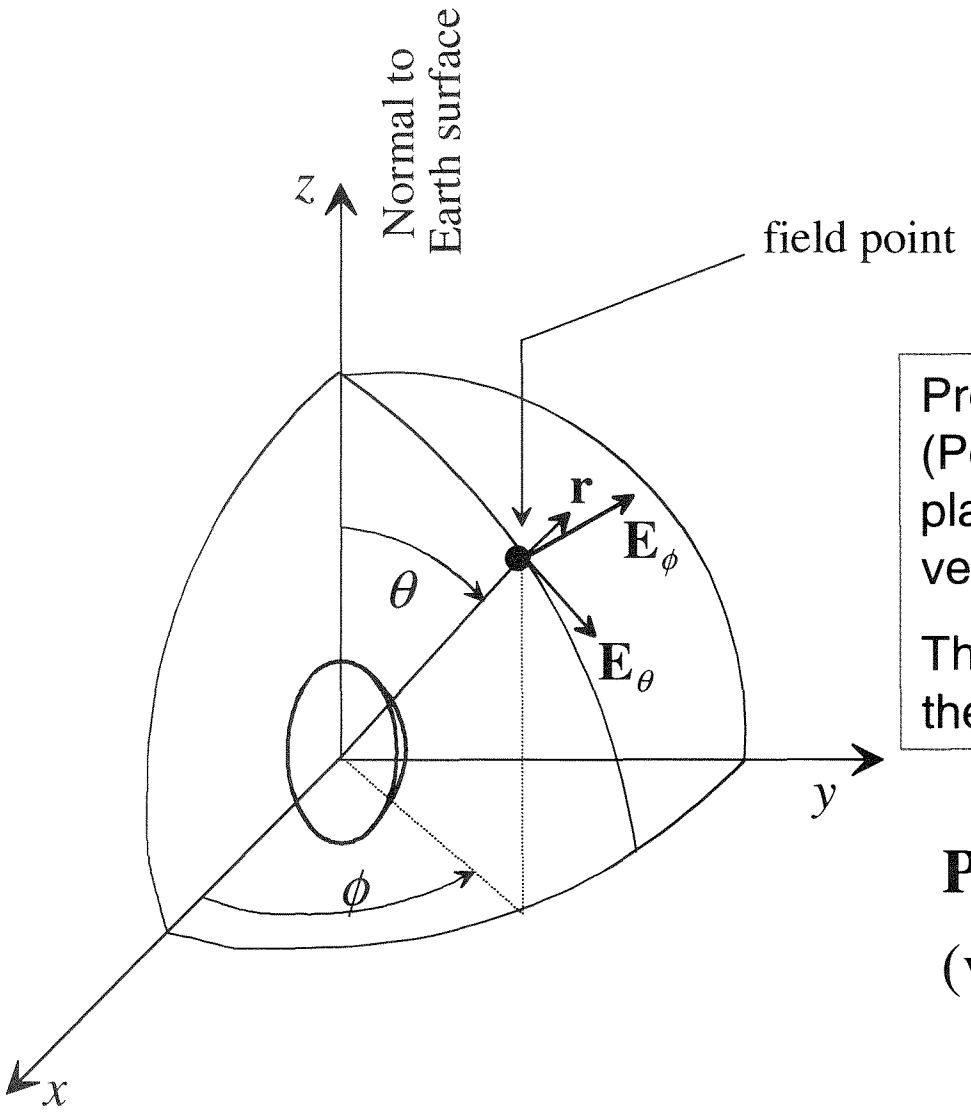
- Does not model polarization isolation; assumes 12 dB based on limited and inappropriate test data
- Assumes co-located base stations with perfectly aligned antennas
- Assumes identical service profiles and air interfaces for both systems
- Does not model a realistic airport scenario
- Assumes low power operation (200 mW aircraft EIRP) and correspondingly low rate reverse link transmissions (48 kbps average per aircraft)
- Ignores real-world path effects (fading, antenna pattern variations)
- Does not include sensitivity analysis to explore the impact of changes in these assumptions, such as sharing between unlike systems, or support for broadband transmissions on the reverse link

# Summary

- The AirCell/Boeing proposal is not new. It is simply a repackaging an earlier band-sharing proposal that is severely flawed. The recent presentations "solve" the airport-scenario interference problem by reducing traffic load by more than 90%.
- There is nothing in the record to support AirCell's claim that 12 dB of polarization isolation is achievable.
- In fact, cross-polarization isolation cannot be reliably maintained at any level, and the FCC would not be able to ensure compliance with such a requirement.
- Cross-polarization interference will occur in an ATG environment, preventing provision of high-quality broadband service.
- Isolation of 12 dB, even if it could be reliably achieved, would be inadequate to protect ATG systems from mutual interference.
- The AirCell/Boeing proposal would require two competing ATG providers to effectively design and operate their systems jointly.

# Background Slides

# Plane Wave Propagation in Free Space




Propagation direction (Poynting vector) is normal to plane containing the *E*-field vector.

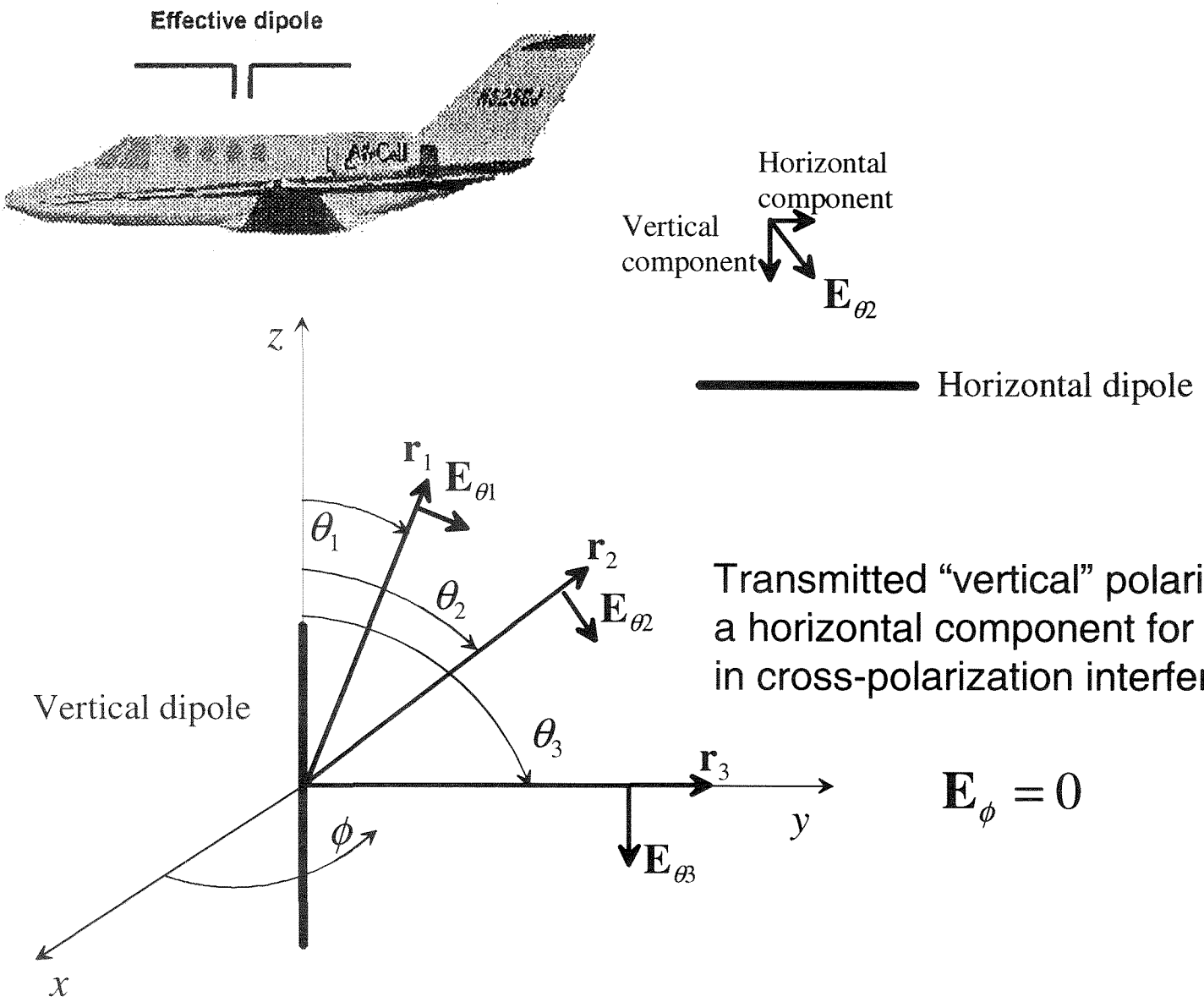
This holds ***independent*** of the specific antenna pattern.

$$\mathbf{P} = \mathbf{E} \times \mathbf{H} \quad \text{watts/m}^2$$

(vector cross product)

Antenna Boresight

# Cross-Polarization Interference in Free Space




Transmitted "vertical" polarization projects a horizontal component for $z \neq 0$, resulting in cross-polarization interference.

$$\mathbf{E}_{\phi} = 0$$

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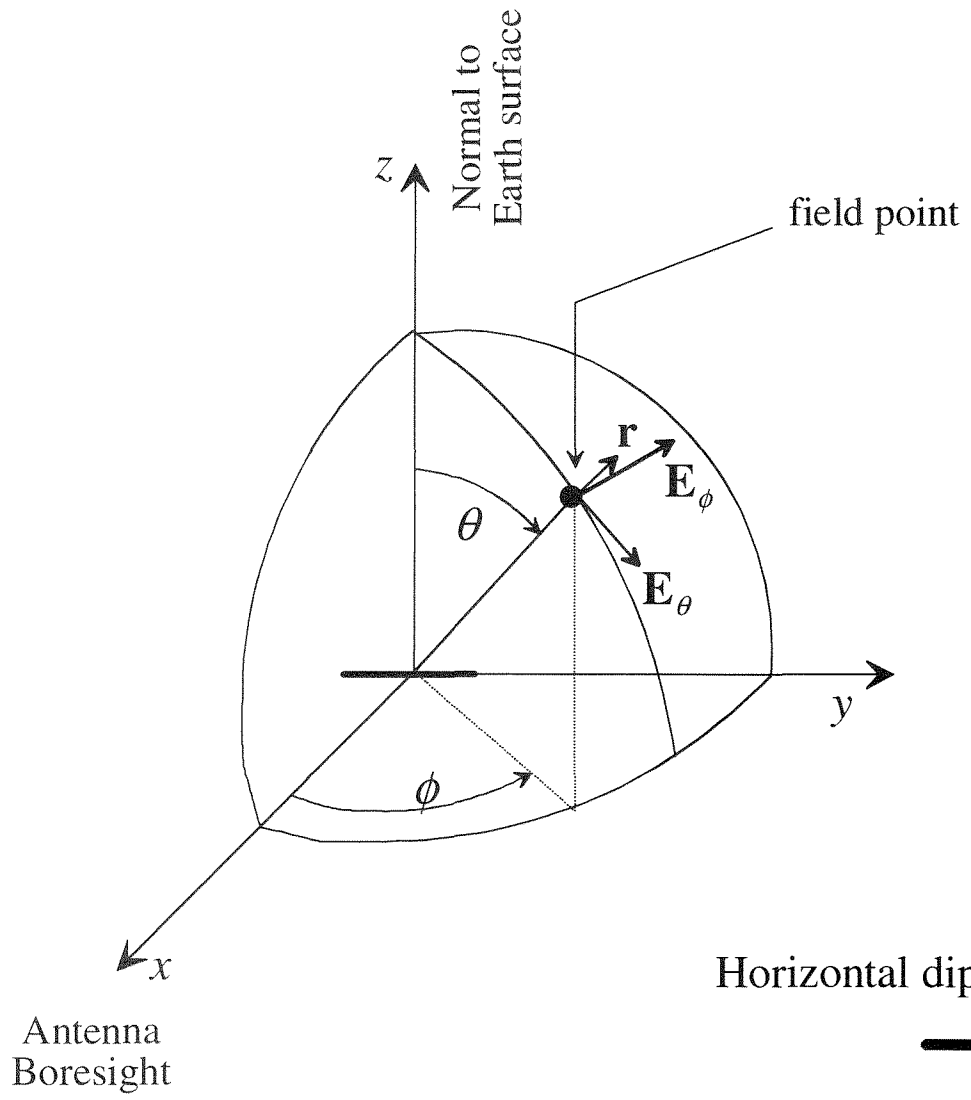
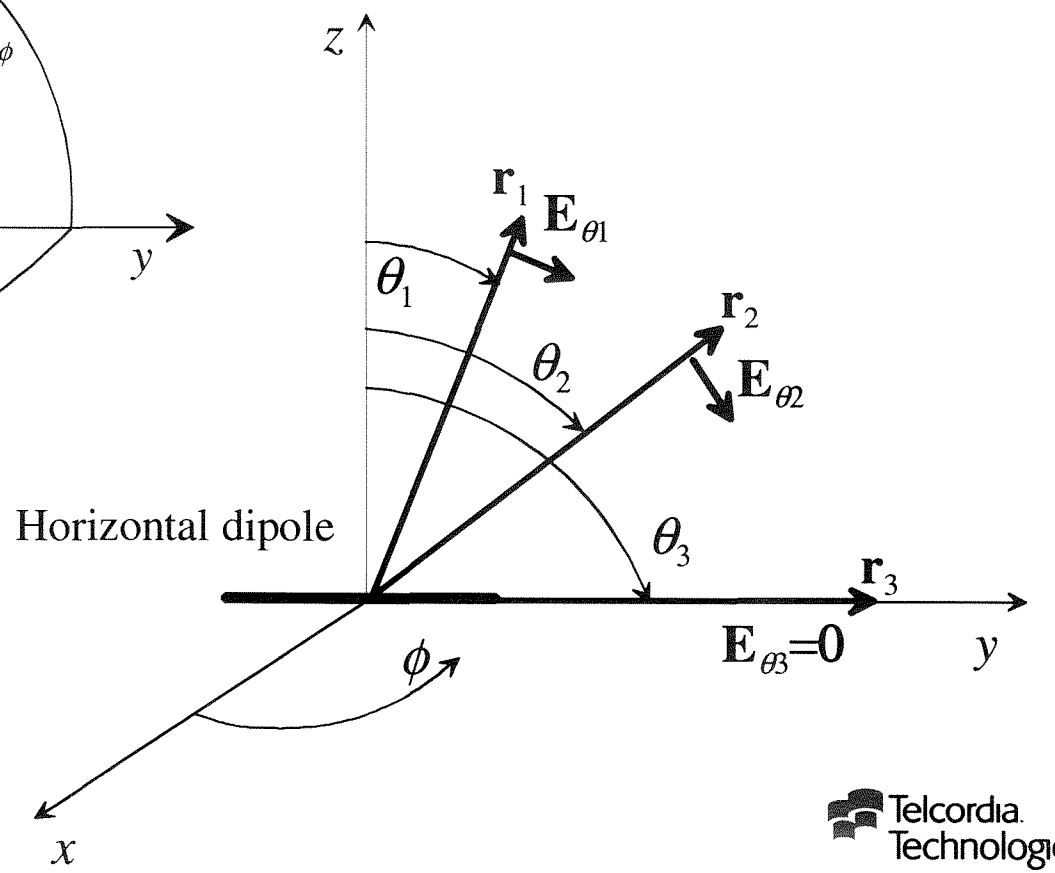
# Horizontal Dipole




$\mathbf{E}_\phi \neq 0$, in general

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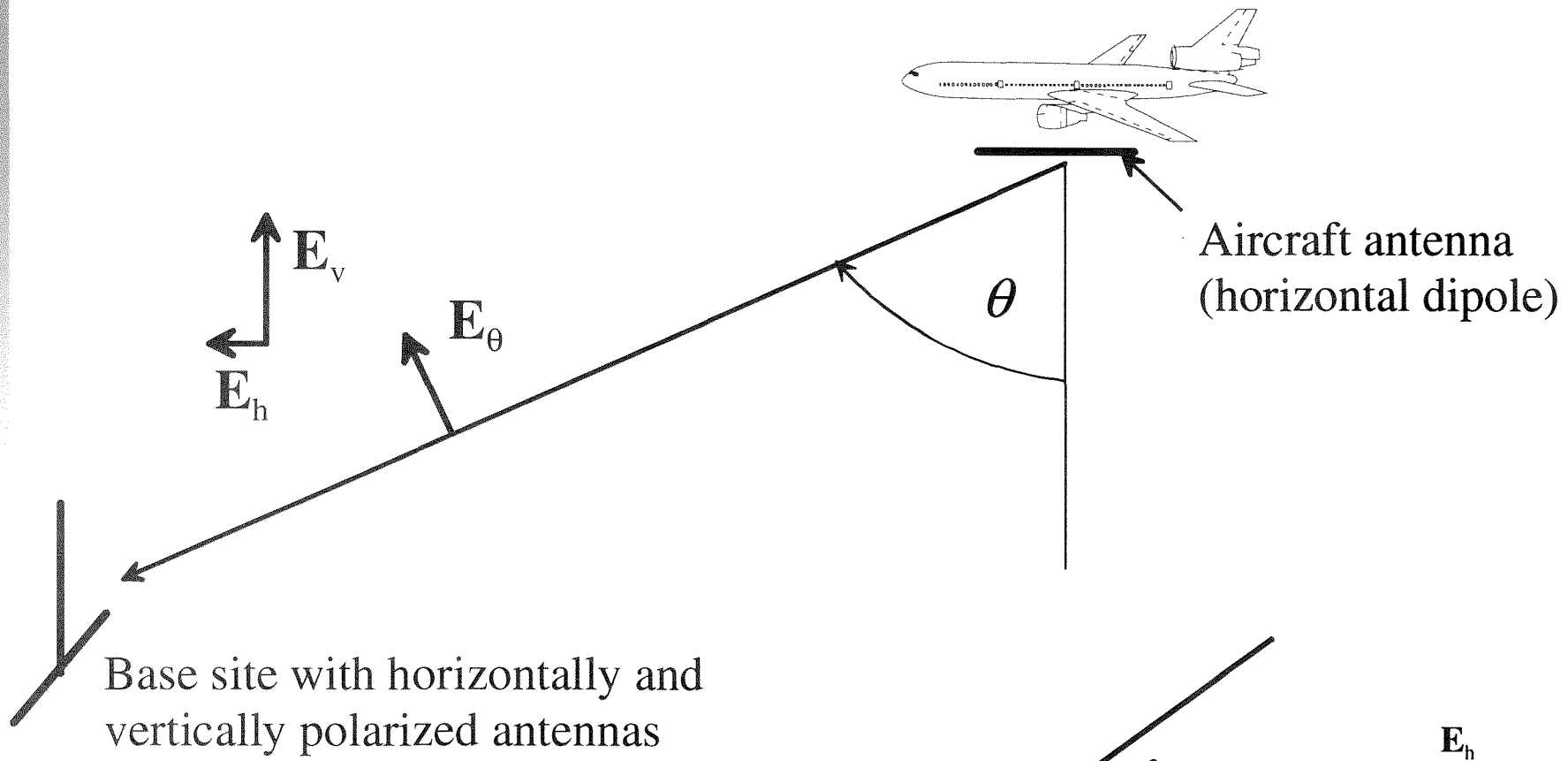
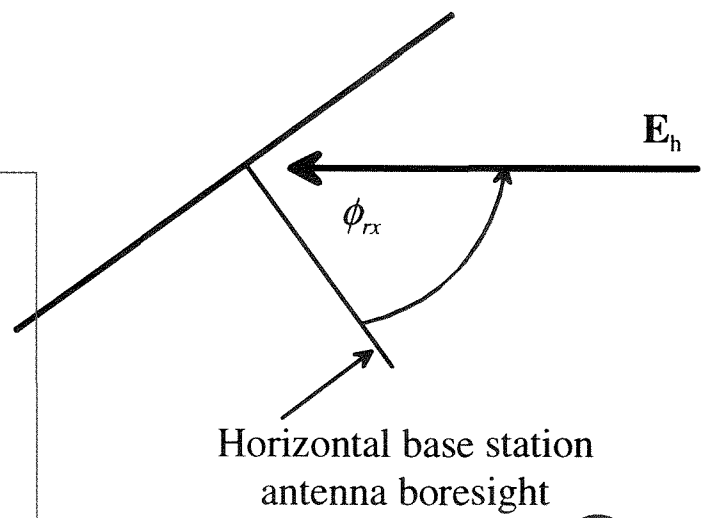
# Horizontally-Polarized Aircraft Antenna




- $\mathbf{E}_h$ and $\mathbf{E}_v$ depend on the aircraft heading relative to the base station location.
- The projection of $\mathbf{E}_h$ onto the horizontally polarized base station antenna depends on the aircraft bearing relative to the antenna orientation.

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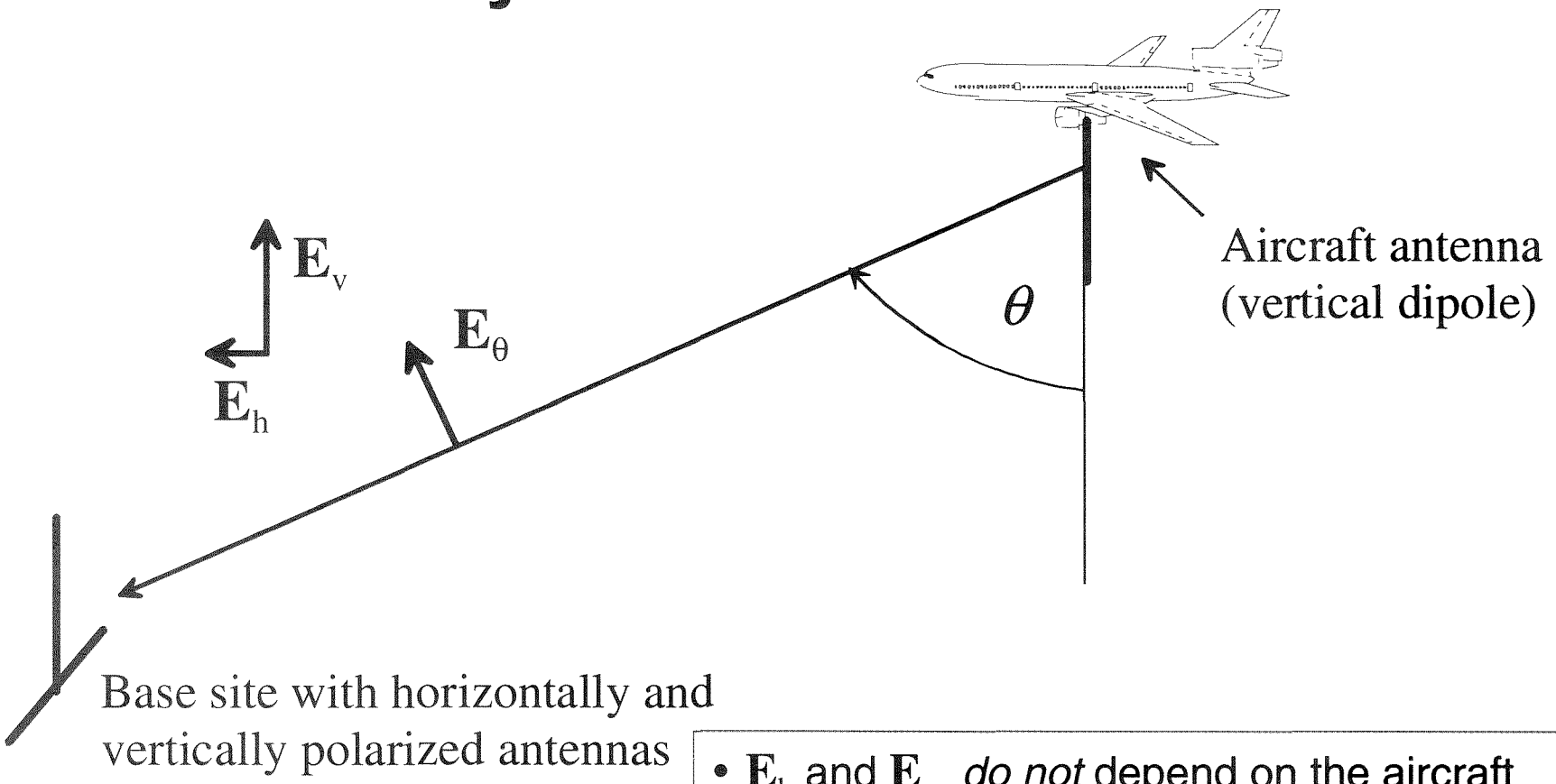
# Vertically-Polarized Aircraft Antenna




- $\mathbf{E}_h$ and $\mathbf{E}_v$ *do not* depend on the aircraft heading relative to the base station location.
- The projection of $\mathbf{E}_h$ onto the horizontally polarized base station antenna still depends on the aircraft bearing relative to the antenna orientation.

# CDMA Reverse Link Noise Rise and Pole Capacity

***Simplifying Assumptions for Illustration***

- Single cell (or sector)
- Same power $S$ received at base station from each mobile (power control)
- Same SINR requirement for each user

$$SINR = \frac{S}{N + \underbrace{(K-1)S}_{\text{interference from the other mobiles}}} \rightarrow S = \frac{N}{\frac{1}{SINR} + 1 - K}$$

$N$ = receiver noise

$K$ = number of active mobiles in the cell

**Pole capacity:** $K_{pole} = \frac{1}{SINR} + 1 \quad (S/N \rightarrow \infty)$ $\qquad S = \frac{N}{K_{pole} - K}$

$P_{tot} = KS + N$ Total RF power at receiver

**Noise rise:** $\frac{P_{tot}}{N} = K\frac{S}{N} + 1 = \frac{1}{1 - K/K_{pole}}$

The noise rise expression is general, and applies for multiple cells (with out-of-cell interference) and for different rate and SINR requirements for each mobile.

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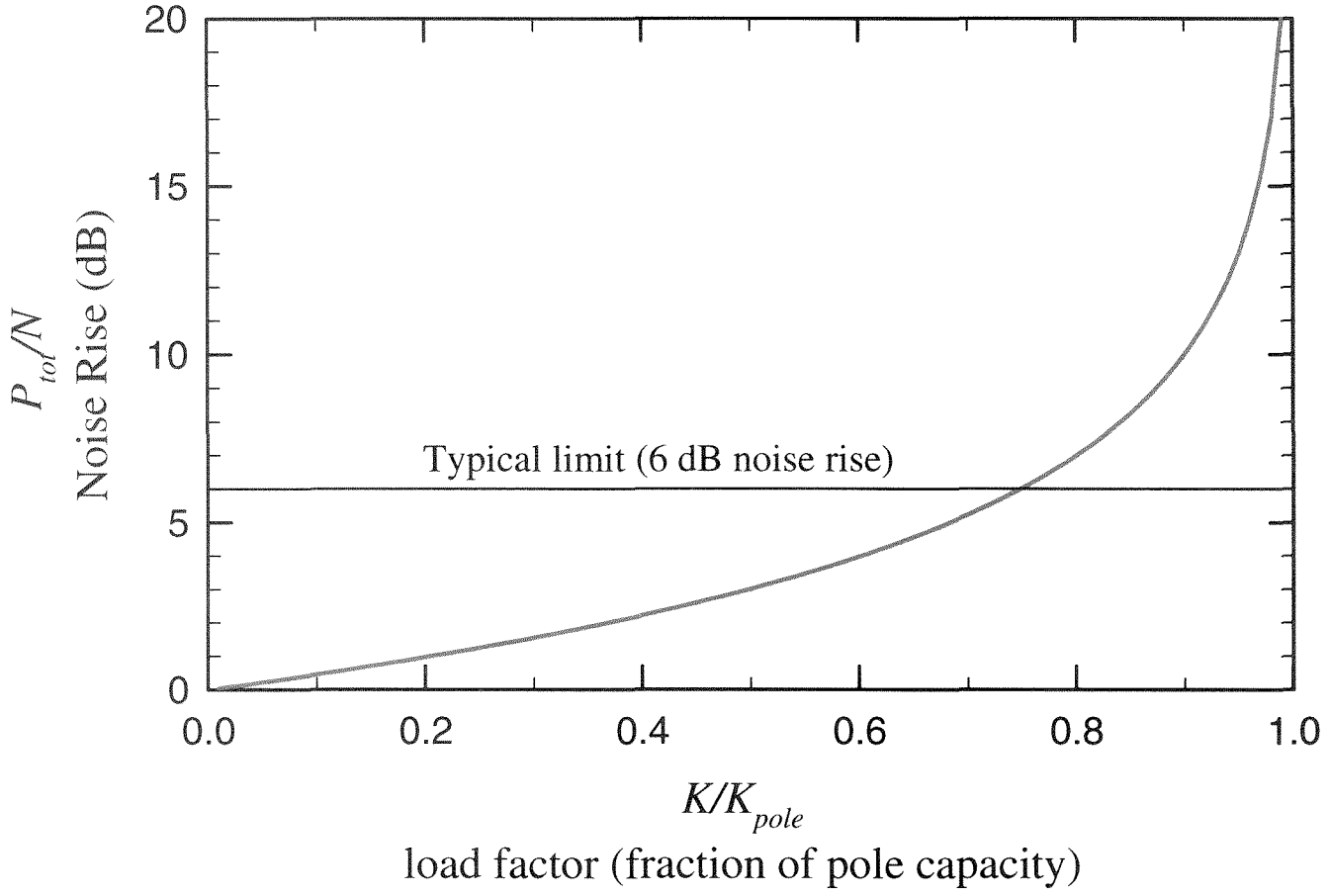
# CDMA Reverse Link Load Curve




**It is important to limit the noise rise to maintain:**

- Receiver front-end amplifier linearity
- System stability
- Reasonable transmit power levels

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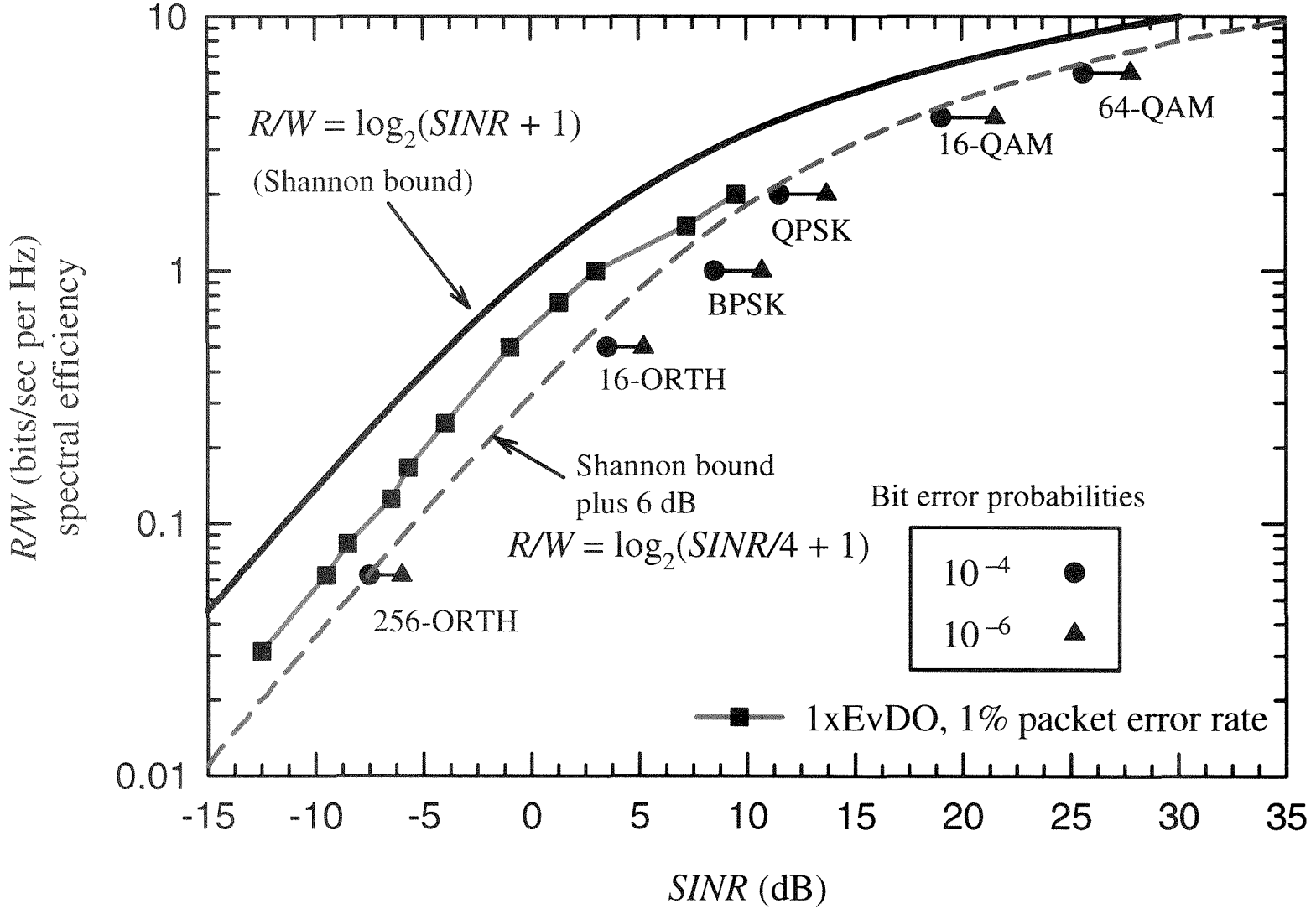
# Higher Throughput Requires More Power

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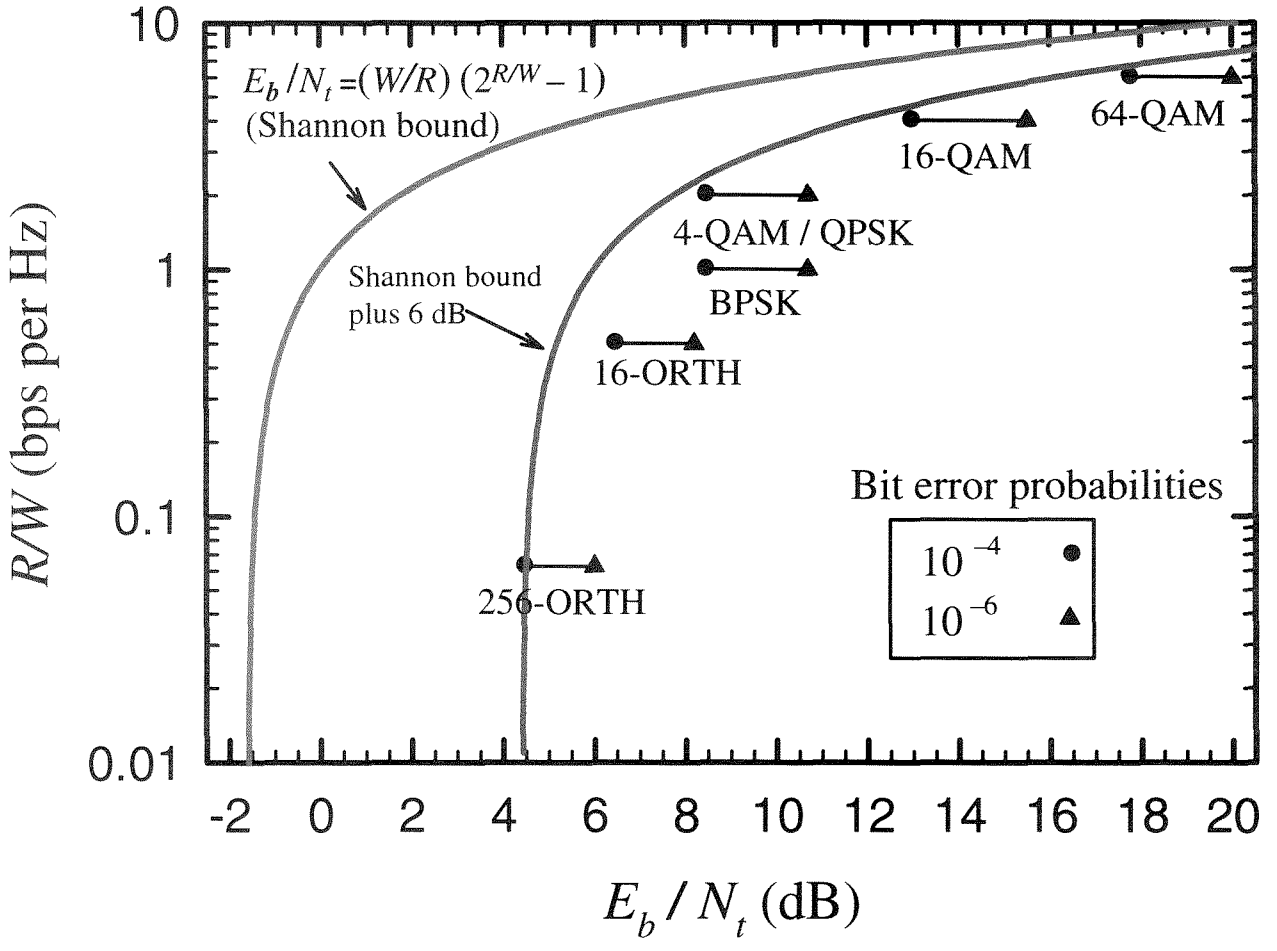
# Modulation Efficiency vs. $E_b/N_t$




$$\frac{E_b}{N_t} = \frac{W}{R} \cdot SINR$$