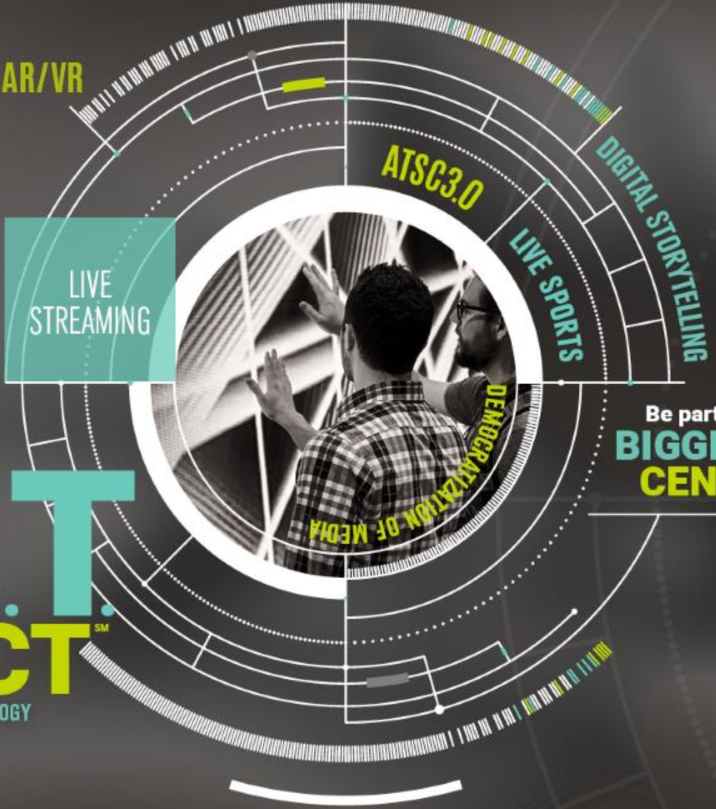

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ATSC 3.0 – Boosting the Signal Strength - MISO

John L. Schadler

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Continuation

"Antenna Technology For ATSC 3.0 – Boosting the Signal Strength"

More, More, More

Fundamentally changing the way U.S. Broadcast TV is delivered.

Merging internet with broadcast with

- More flexibility
- More services
- More robust delivery
- More platforms

More bits to more places

More signal strength

How much signal strength is required?

Usage cases: Outdoor Fixed, Mobile; Indoor Gateway, Nomadic…

95 dBu

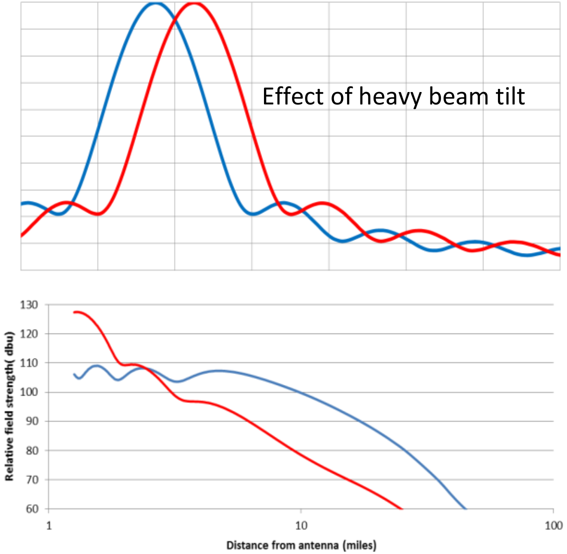
25 Mbit Deep indoor mobile to small handheld receiver

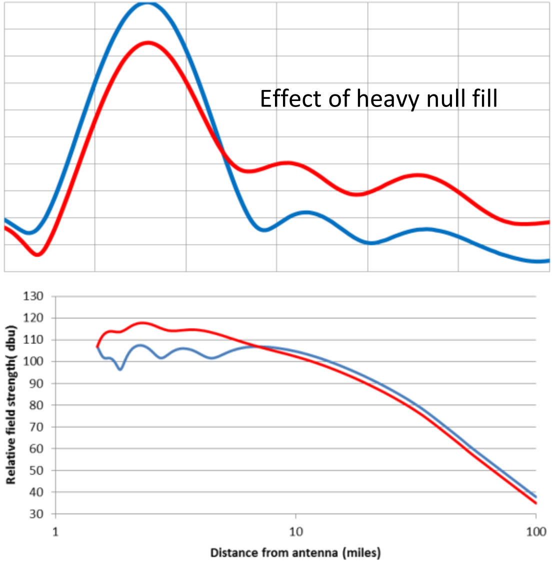
Outdoor reception of the Bootstrap signal

48 dBu

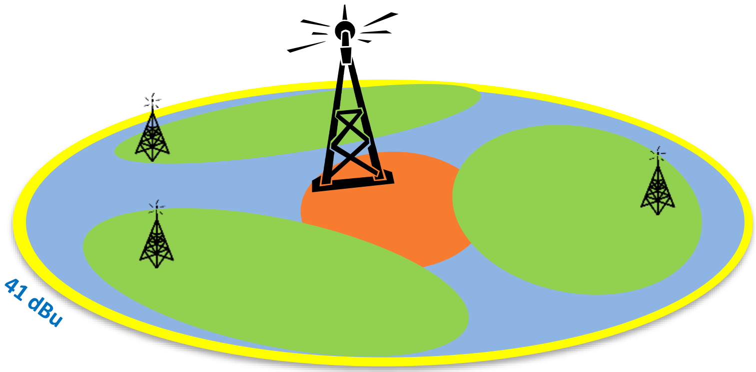
Review

1. ~~Increase transmitter power~~
2. Increase beam tilt
3. Increase null fill
4. Add a SFN





Addition of SFNs

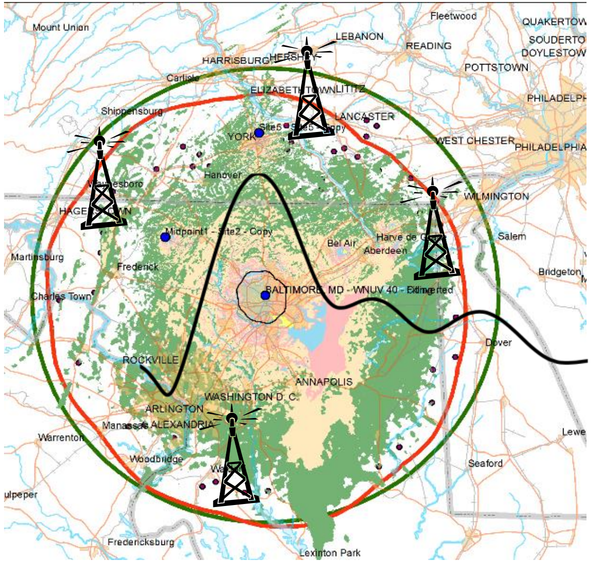


Review

Most effective way to design for service and provide even distribution of high signal strength – High null fill + SFNs

“FutureFill” + SFN

- Saturate in the vicinity of the main antenna by increasing the null fill
- Add SFN sites around coverage perimeter to boost the signal strength outside of the high null fill area



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Today

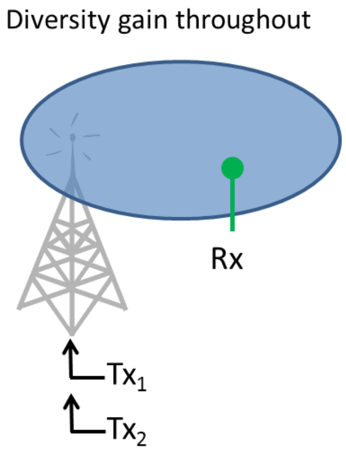
Boosting the signal strength with MISO diversity

- ATSC 3.0 MISO scheme – TDCFS
  - Transmitting two uncorrelated signals to a single receiver
  - Cost effective
    - Increase the complexity of the transmitter – not the receiver
      - ATSC 3.0 SFN sites will serve many receivers
        - Economical to add equipment cost at the transmit site rather than the receiver
        - Receiver remains small and affordable

MISO deployment

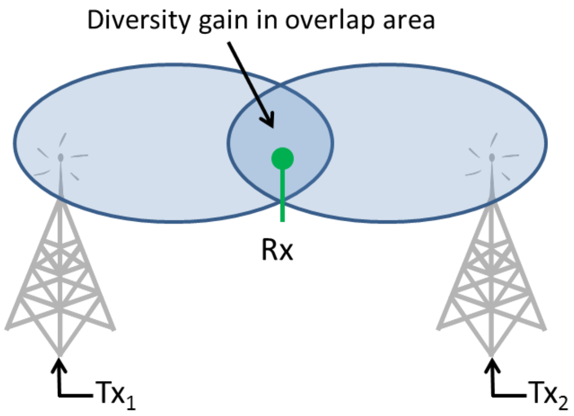
- TDCFS can be deployed in either a co-located or distributed configuration

Co-located



- Diversity gain throughout the coverage area

Distributed



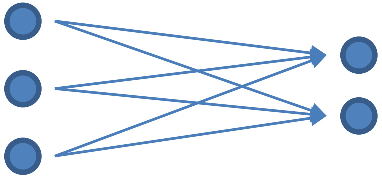
- Does not require any new RF equipment within the existing SFN

Boosting the signal strength – Diversity gain

Diversity gain ≡ Boosting the RSS

Max diversity gain is based on the total number of independent signal paths

M transmit antennas



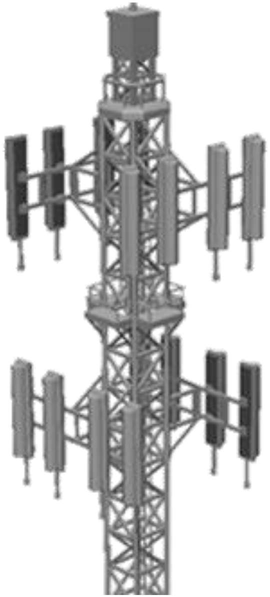
N receive antennas

$$1 \leq G_d \leq G_{max} = M * N$$

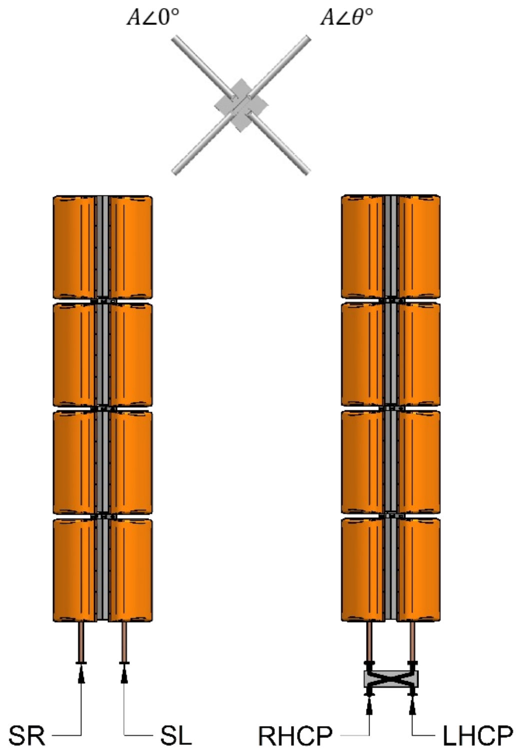
3 dB improvement in RSS can be achieved when 2 x 1 MISO diversity is applied

Co-located Diversity Implementation

- Traditionally
  - Spatial diversity
    - Separate antennas
    - Difficult to implement
      - Space limitations
  - Polarization diversity
    - Co-located antenna elements
    - Orthogonal polarizations
    - Modes of operation
      - Slant linear
      - RH / LH CP



Dual input broadcast antenna array



Which mode of polarization diversity operation is best for ATSC 3.0 MISO?

Polarization diversity – Figure of Merit

- Max diversity gain depends on spreading the power evenly between the polarizations
- Figure of merit
  - Cross Polarization Discrimination (XPD)
    - The ratio between the available power in the vertical and horizontal polarizations

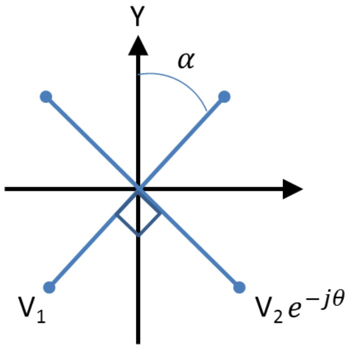
$$XPD = \frac{\langle |R_v|^2 \rangle}{\langle |R_h|^2 \rangle}$$

For optimal diversity gain XPD=0dB

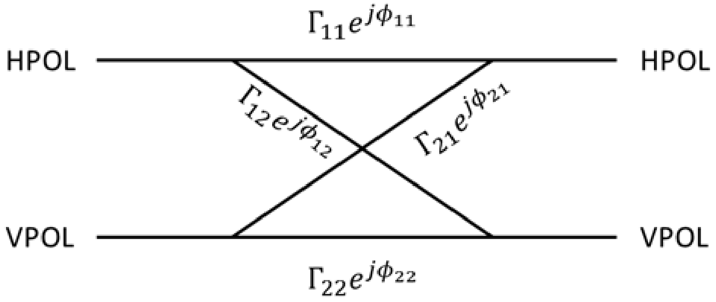
Compare the static response XPD for slant linear and RH/LH CP

Transmission Channel

Dipole modeling



Channel modeling



Γ – random variable used to model the multipath fading

Φ- random phase introduced by the channel

Pair of orthogonal crossed dipoles oriented in space by a tilt angle α

Four channel links between the transmitter and receiver

$$\begin{pmatrix} V_h \\ V_v \end{pmatrix} = \begin{bmatrix} sin\alpha & -cos\alpha \\ cos\alpha & sin\alpha \end{bmatrix} \begin{pmatrix} V_1 \\ V_2 e^{-j\theta} \end{pmatrix}$$

$$\begin{pmatrix} R_h \\ R_v \end{pmatrix} = \begin{bmatrix} \Gamma_{11} e^{j\phi_{11}} & \Gamma_{12} e^{j\phi_{12}} \\ \Gamma_{21} e^{j\phi_{21}} & \Gamma_{22} e^{j\phi_{22}} \end{bmatrix} \begin{pmatrix} V_h \\ V_v \end{pmatrix}$$

Cross Polarization Discrimination

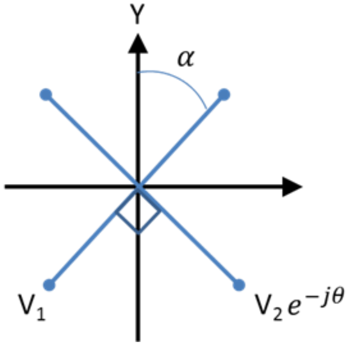
$$XPD = \frac{\left\langle \begin{array}{c} V_1^2[\Gamma_{21}^2 sin^2\alpha + \Gamma_{22}^2 cos^2\alpha + 2\Gamma_{21}\Gamma_{22} sin\alpha cos\alpha cos(\phi_{21} - \phi_{22})] + V_2^2[\Gamma_{22}^2 sin^2\alpha + \Gamma_{21}^2 cos^2\alpha + 2\Gamma_{21}\Gamma_{22} sin\alpha cos\alpha cos(\phi_{21} - \phi_{22})] \\ +2V_1V_2 cos\theta[\Gamma_{21}\Gamma_{22}(sin^2\alpha - cos^2\alpha)cos(\phi_{21} - \phi_{22}) + (\Gamma_{22}^2 - \Gamma_{21}^2) sin\alpha cos\alpha] \end{array} \right\rangle}{\left\langle \begin{array}{c} V_1^2[\Gamma_{11}^2 sin^2\alpha + \Gamma_{12}^2 cos^2\alpha + 2\Gamma_{11}\Gamma_{12} sin\alpha cos\alpha cos(\phi_{11} - \phi_{12})] + V_2^2[\Gamma_{12}^2 sin^2\alpha + \Gamma_{11}^2 cos^2\alpha + 2\Gamma_{11}\Gamma_{12} sin\alpha cos\alpha cos(\phi_{11} - \phi_{12})] \\ +2V_1V_2 cos\theta[\Gamma_{11}\Gamma_{12}(sin^2\alpha - cos^2\alpha)cos(\phi_{11} - \phi_{12}) + (\Gamma_{12}^2 - \Gamma_{11}^2) sin\alpha cos\alpha] \end{array} \right\rangle}$$

The definition yields $XPD = \frac{\langle |R_v|^2 \rangle}{\langle |R_h|^2 \rangle} = \frac{A\langle \Gamma_{21}^2 \rangle + B\langle \Gamma_{22}^2 \rangle}{A\langle \Gamma_{11}^2 \rangle + B\langle \Gamma_{12}^2 \rangle}$ where

$$A = V_1^2 sin^2\alpha + V_2^2 cos^2\alpha - 2V_1V_2 sin\alpha cos\alpha cos\theta$$

$$B = V_1^2 cos^2\alpha + V_2^2 sin^2\alpha + 2V_1V_2 sin\alpha cos\alpha cos\theta$$

The different types of polarization diversity can be described by the coefficients A and B



Polarization	V1	V2	α	θ	A	B
Slant Left	1	0	-45	0	0.5	0.5
Slant Right	1	0	45	0	0.5	0.5
RHCP (Slant 45)	0.707	0.707	45	90	0.5	0.5
LHCP (Slant 45)	0.707	0.707	45	-90	0.5	0.5
RHCP (H/V)	0.707	0.707	0	90	0.5	0.5
LHCP (H/V)	0.707	0.707	0	-90	0.5	0.5

Dual Polarization Slant Linear or CP for ATSC 3.0 MISO?

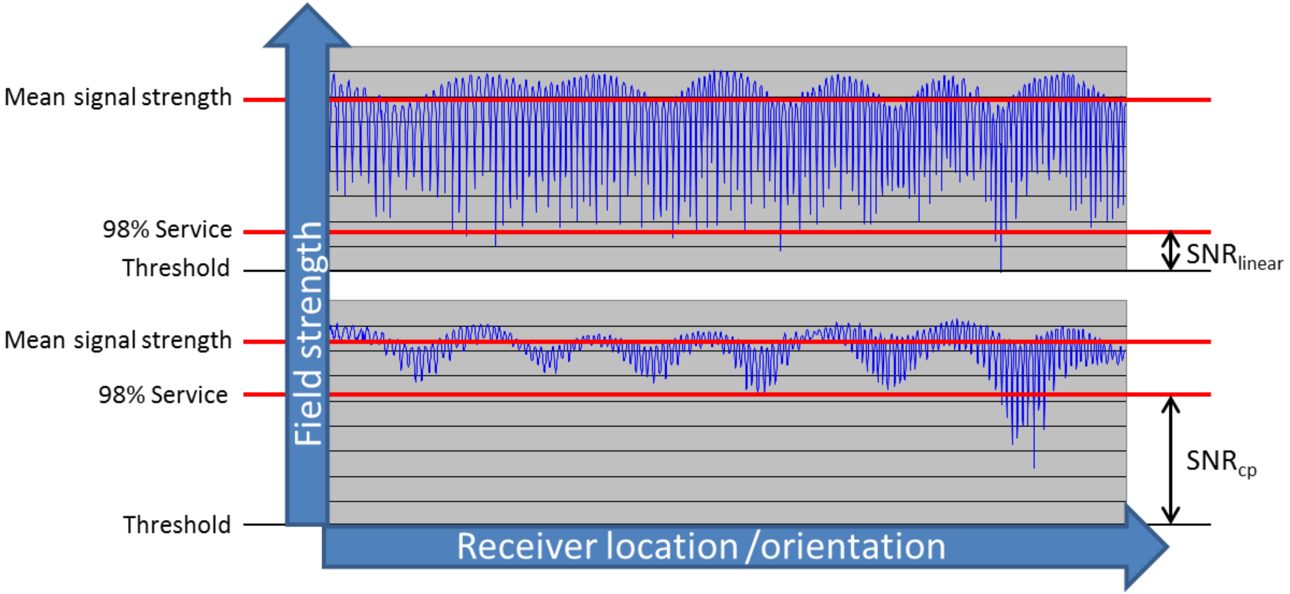
Since the A and B coefficients are the same in all 6 cases, the equations that describe the XPD are identical in all 6 cases

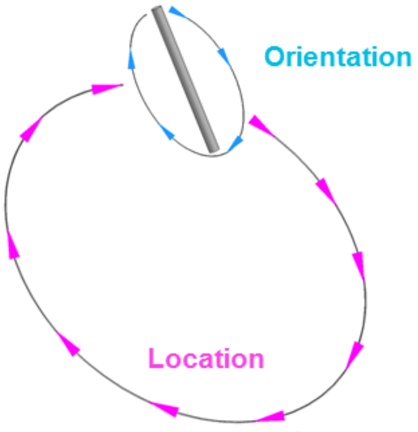
Slant linear and circularly polarized antennas transmit the same average performance in a static MISO system. The expected diversity gain of SL / SR linear and RH / LH CP are on average the same.

Dual Polarization Slant Linear or CP for ATSC 3.0 MISO?

- Analysis assumes
  - For CP we increased the transmitter power 3dB to maintain the same ERP
  - The receiver is stationary
  - Independent of any margin improvement observed by transmitting CP to a linearly polarized receive antenna in motion

What is Margin Improvement?





$$MI = SNR_{cp} - SNR_{linear}$$

Margin Improvement with Circular Polarization

Starting over a decade ago – extensive testing to quantify the benefit of transmitting CP to a linearly polarized receiver in motion

- Controlled environments
- Field tests in ME and FL
- Indoor / Outdoor / Vehicle
- Measurements based on RSS and BER
- Different amounts of VPOL

Margin Improvement with Circular Polarization

All measurements have confirmed that transmitting circular polarization to a linearly polarized receiver in motion in a heavy scatter environment provides 5 to 7 dB of margin improvement (MI) over transmitting a linearly polarized signal to the same receiver.

Margin Improvement and Diversity Gain

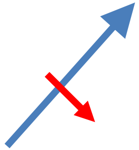
- G_d and MI are independent
  - 5-7dB MI is observed when transmitting a single CP signal to a linear receiver in motion
  - Adding a second independent path (MISO) does not change this but adds 3dB of G_d

The total system gain of dual RH / LH CP MSIO diversity system transmitting to a linearly polarized mobile receiver in motion in a heavy scatter environment is as high as 8-10dB.

Cross Polarization Isolation

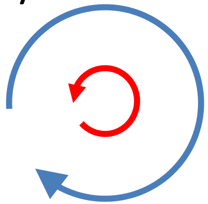
- A new antenna specification to consider
- So far we have assumed the transmit signals are completely uncorrelated
- Imperfect antennas couple energy

SR/SL Linear



$$I = f(cross\ polarization)$$

RH/LH circular



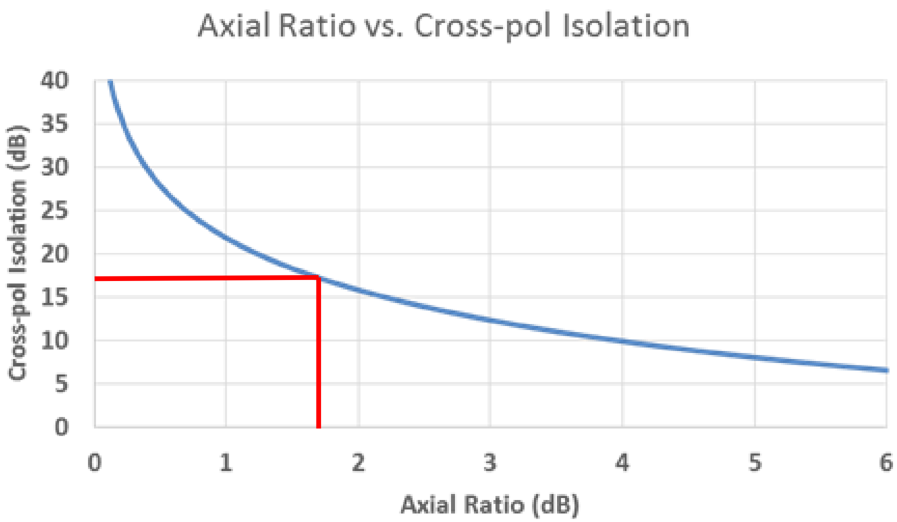
$$I = f(axial\ ratio)$$

All waves can be decomposed into two components with orthogonal polarization states

- Studies : 17 dB of cross pol isolation is sufficient to reach 99% of desired data rate

Isolation Between Polarizations for CP Antenna

$$I = 10log\left[\frac{\frac{1}{2}+\frac{AR}{AR^2+1}}{\frac{1}{2}\left(\frac{1}{\left(\frac{AR+1}{AR-1}\right)^2}+1\right)+\frac{AR}{AR^2+1}\left(\frac{1}{\left(\frac{AR+1}{AR-1}\right)^2}-1\right)}\right]$$



Specification

AR<1.7dB for RH/LH CP MISO

Conclusion

- Employing MISO diversity gain can add up to 3 dB in the system gain
- On average slant linear and circularly polarized antennas transmit the same average performance in a stationary MISO diversity system
- This is independent of any margin improvement observed by transmitting CP to a linearly polarized receive antenna in motion
- Transmitting CP to a linearly polarized receiver in motion in a heavy scatter environment can add 5 to 7 dB of margin improvement
- Total ATSC 3.0 system gains employing RH/LH CP diversity can be 8 to 10dB if you choose to increase your TPO by 3dB.
- The axial ratio specification of a RH / LH co-located system considered for diversity should be < 1.7dB.

** The use of LH CP will require an FCC rule change*

Thank you

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