Offset Quadruple-Ridge Orthomode Transducer, Mode Splitter/Combiner

X-Band OMT Design Review   October 1, 2009

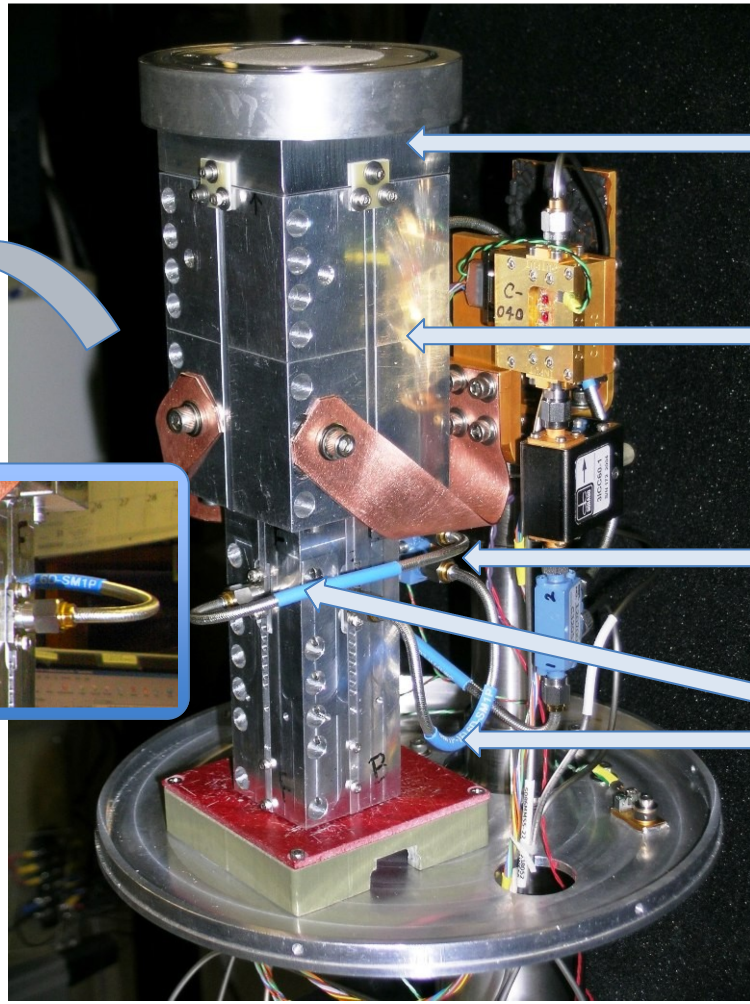
Gordon Coutts

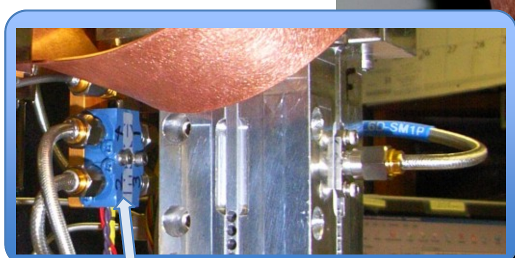
Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

Introduction

Low-Band EVLA Circular Polarizers

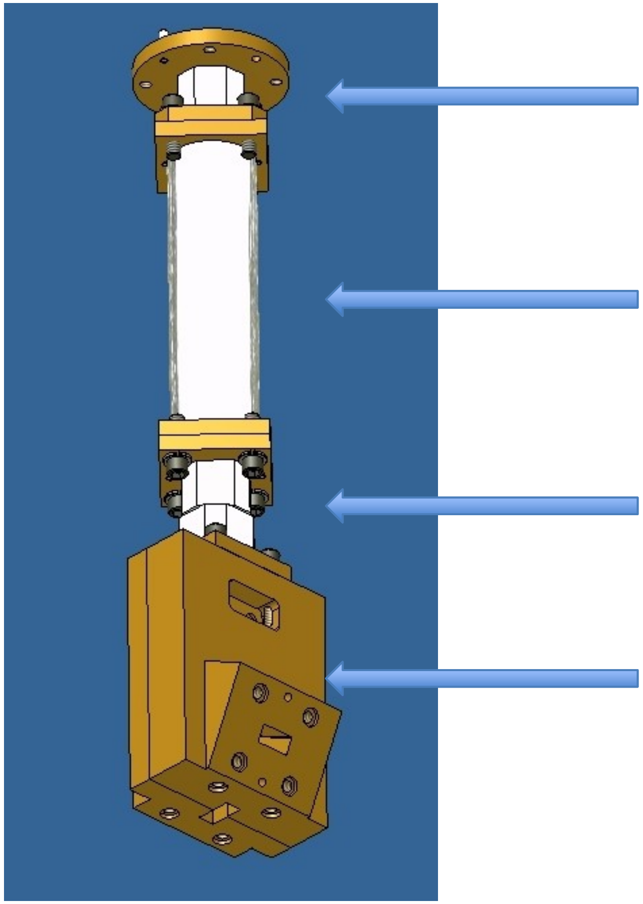




Quadrature Hybrid

- Circular to Square Transition
- Quadruple-Ridge OMT (separates orthogonal linearly polarized signals)
- Quadrature Hybrid
- Phase-Matched cables connecting the OMT to the hybrid

High-Band EVLA Circular Polarizers



- Circular to Square Transition
- Sri's corrugated waveguide Phase Shifter
- 45 Degree offset mode splitter
- Bøifot OMT (separates orthogonal linearly polarized signals)

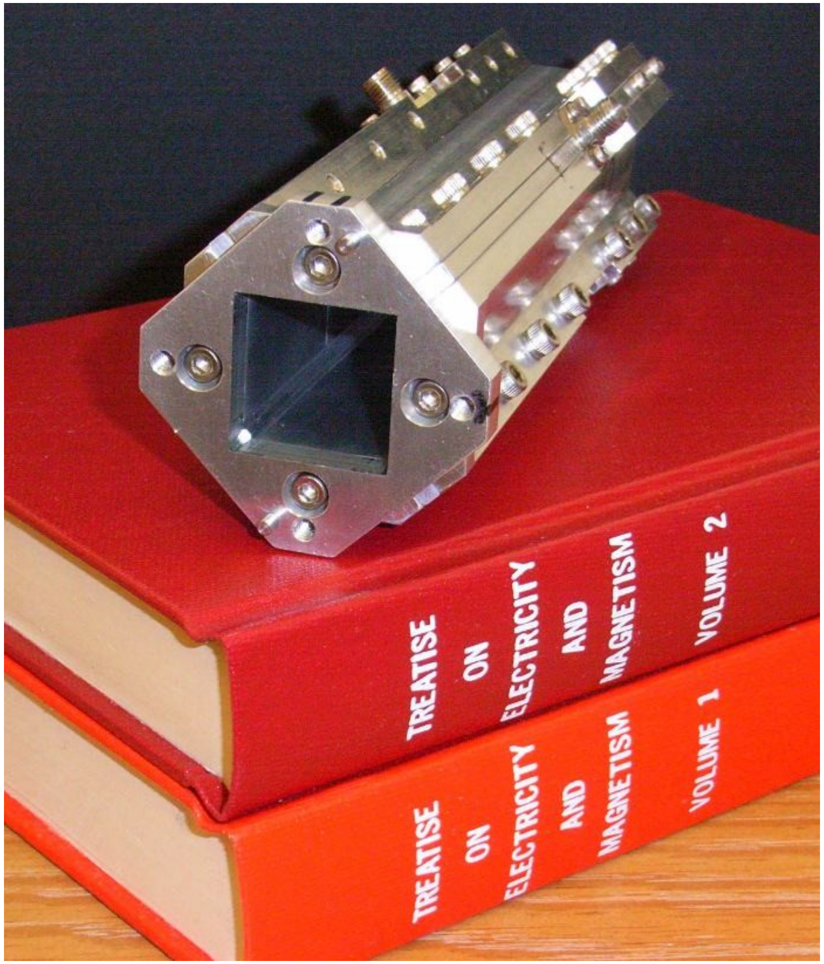
X-Band Design Challenges

- Two options using conventional technology from existing EVLA receivers:
  – Cascaded Bøifot OMT/ mode splitter/ phase shifter
    - This would scale to an impractically large size at X-band
  – Direct scaling of the C-Band Polarizer to work at X-Band
    - This would result in very small dimensions (20 mil chamfer, 30mil ridge gap)
    - Manufacturing tolerances would be a significant percentage (of the order of 10%) of the scaled dimensions
    - Narrow ridge dimensions would not readily accommodate set screws/coaxial feeds
    - Phase matching to an external hybrid would be extremely difficult due to the required cable length adjustments (1.9mil/degree at 12GHz)

Proposed X-Band OMT Design

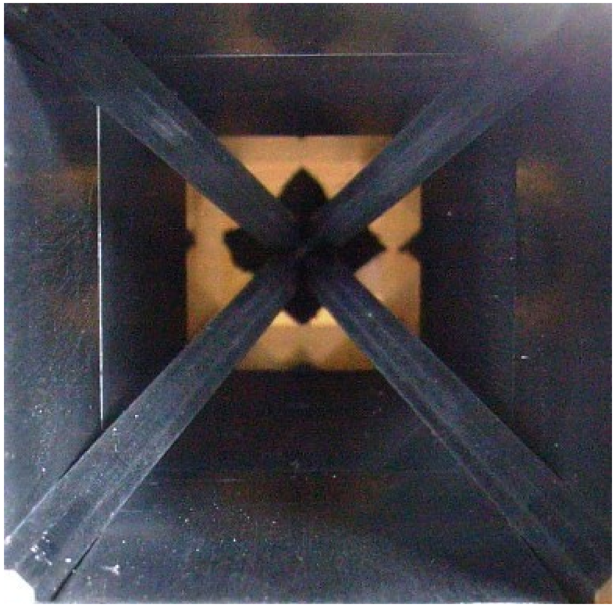
Novel X-Band OMT Design

- The new X-Band OMT uses a 45 degree offset quadruple-ridge design
- The novel polarizer design combines concepts from low-band and high band circular polarizer designs
- The OMT combines the function of the '45 degree twist' mode splitter and Bøifot OMT used in the high frequency designs

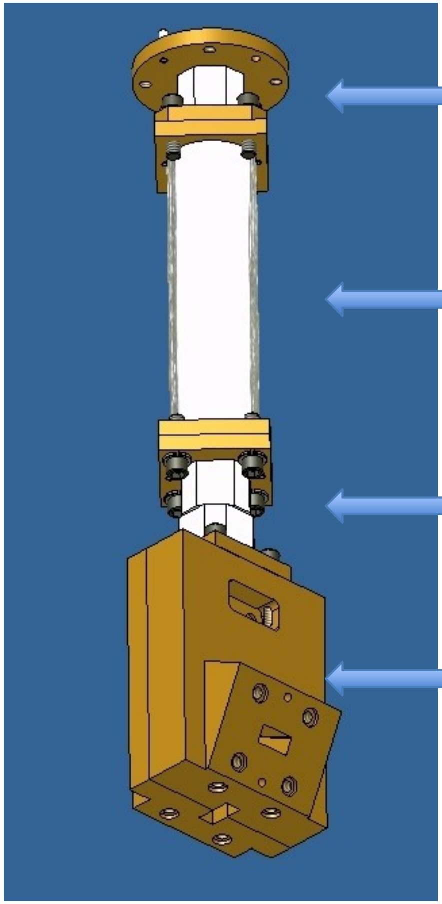


Novel X-Band OMT Design

- Ridges are offset from the square waveguide input by 45 degrees
- Square Waveguide Input: 0.947” x 0.947”
- Detects circularly polarized signals when used in conjunction with Sri’s waveguide phase shifter
- No external quadrature hybrid or phased matched cables in this design

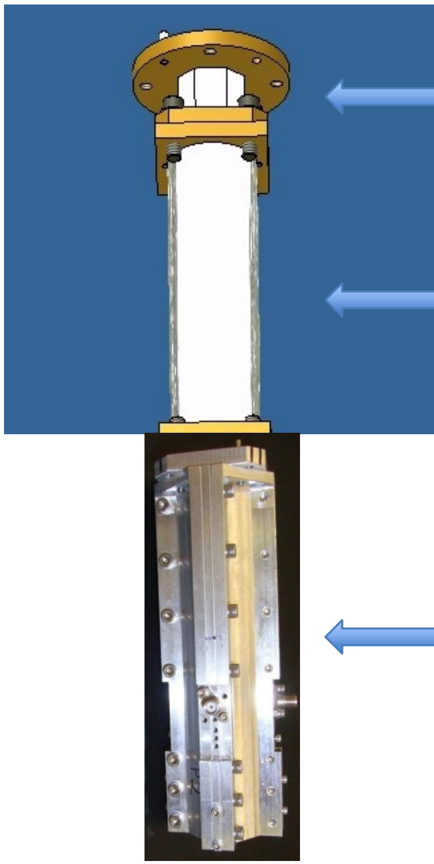


High-Band EVLA Circular Polarizers



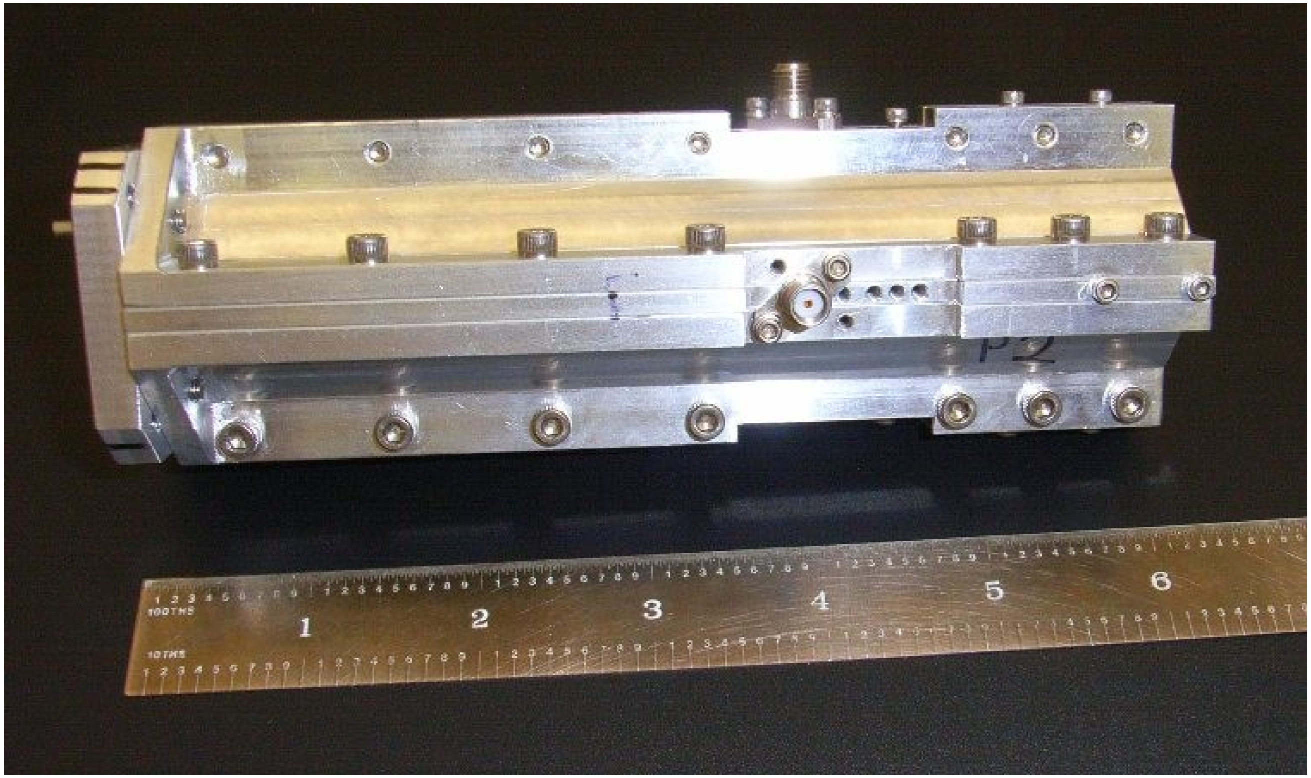
- Circular to Square Transition
- Sri's corrugated waveguide Phase Shifter
- 45 Degree offset mode splitter
- Bøifot OMT (separates orthogonal linearly polarized signals)

Proposed EVLA X-Band Circular Polarizer



- Circular to Square Transition
- Sri's corrugated waveguide Phase Shifter
- 45 Degree offset quadruple-ridge OMT

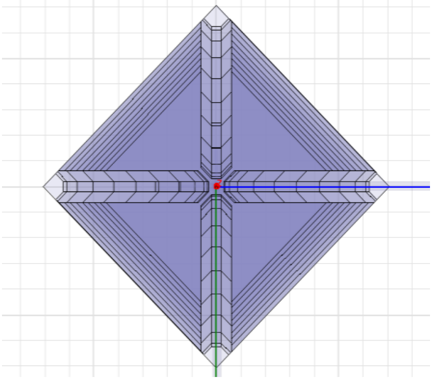
Compact Design of X-Band OMT

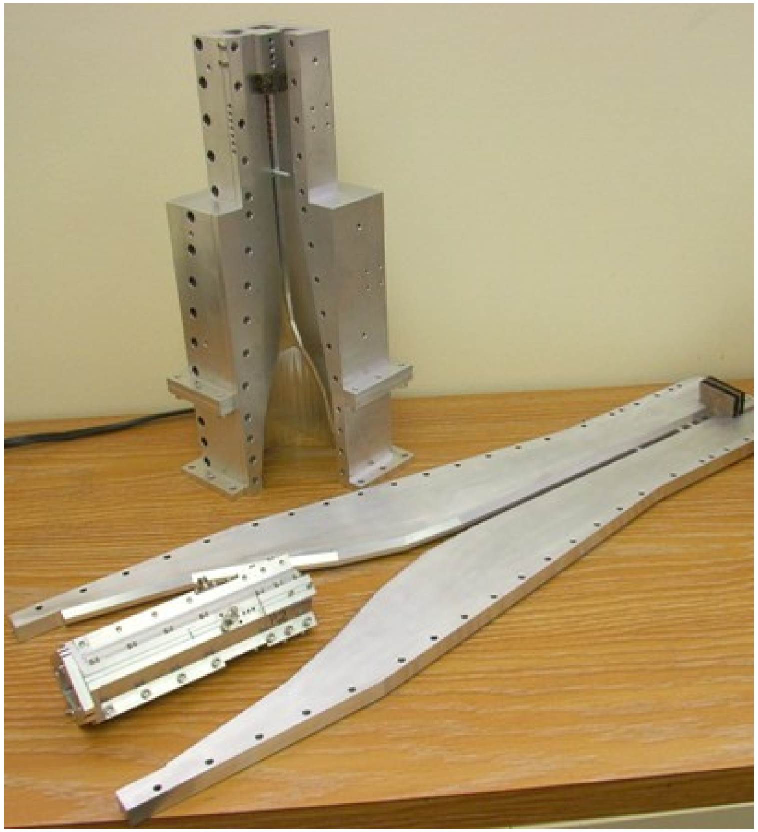


- Compact design: OMT Length is 6.12”

X-Band OMT Dimensions

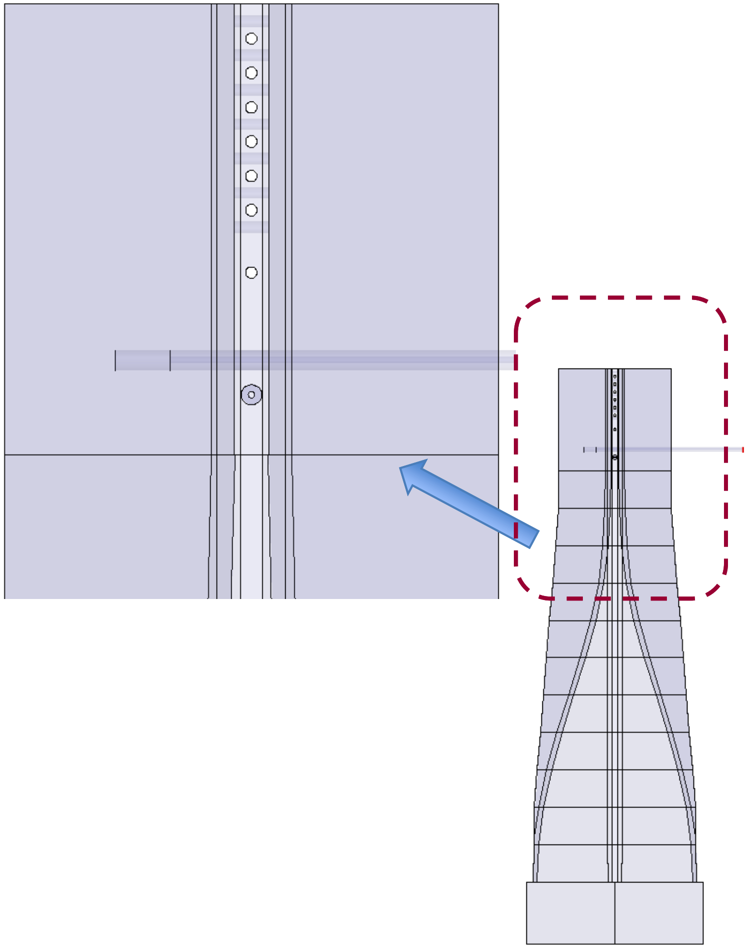
- Chamfer profile similar to C-band OMT for manufacturability
- 125 mil Ridge Width
- 62 mil Ridge Gap
- 40 mil Chamfer flat section
- Locator block sets ridge gap and maintains symmetry





X-Band OMT Dimensions

- The quadruple-ridge waveguide dimensions:
  - optimum impedance at low-band edge
  - Eliminate higher order modes
- 0.047” semi-rigid coaxial feeds
- 62.5mil spaced shorting pins for impedance matching and TE11 trapped-mode resonance suppression
- One 2-56 set screw for each sorting pin, with set screws for adjacent pins on opposing ridges



Theory of Operation

Circularly Polarized Electromagnetic Waves

- LCP (Astronomy Definition)

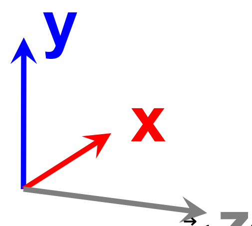
$$\vec{\mathcal{E}}(z,t) = E_0 \left\{ \hat{x}\cos(\omega t - k_0 z) + \hat{y}\cos\left(\omega t - k_0 z + \frac{\pi}{2}\right)\right\}$$

$$\vec{E} = E_0(\hat{x} + j\hat{y})e^{-jk_0 z}$$

- RCP (Astronomy Definition)

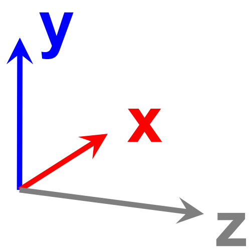
$$\vec{\mathcal{E}}(z,t) = E_0 \left\{ \hat{x}\cos(\omega t - k_0 z) + \hat{y}\cos\left(\omega t - k_0 z - \frac{\pi}{2}\right)\right\}$$

$$\vec{E} = E_0(\hat{x} - j\hat{y})e^{-jk_0 z}$$



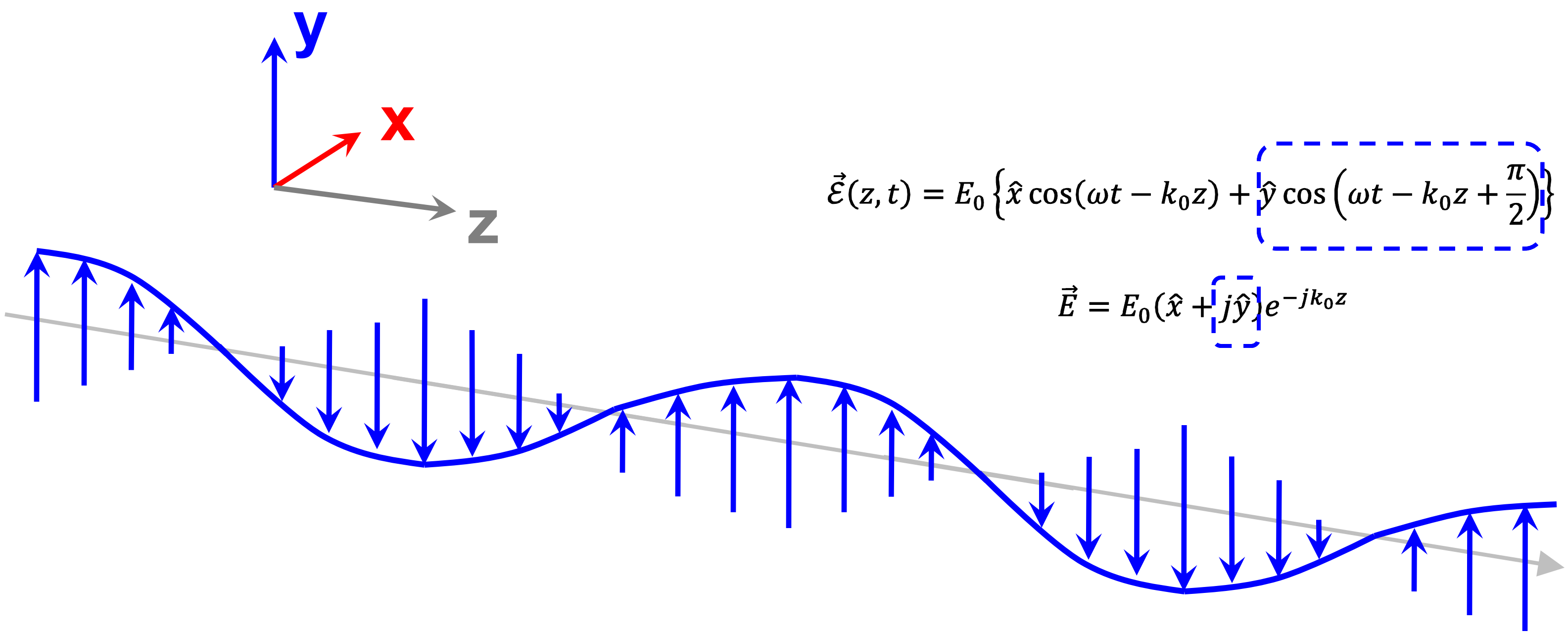
$$\vec{\mathcal{E}}(z,t) = E_0\left\{\hat{x}\cos(\omega t - k_0 z) + \hat{y}\cos\left(\omega t - k_0 z + \frac{\pi}{2}\right)\right\}$$

$$\vec{E} = E_0(\hat{x} + j\hat{y})e^{-jk_0 z}$$



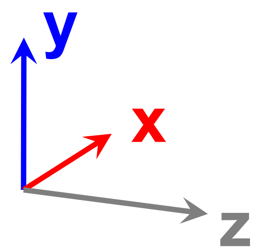
$$\vec{\mathcal{E}}(z,t) = E_0 \left\{ \hat{x}\cos(\omega t - k_0 z) + \hat{y}\cos\left(\omega t - k_0 z + \frac{\pi}{2}\right) \right\}$$

$$\vec{E} = E_0(\hat{x} + j\hat{y})e^{-jk_0 z}$$



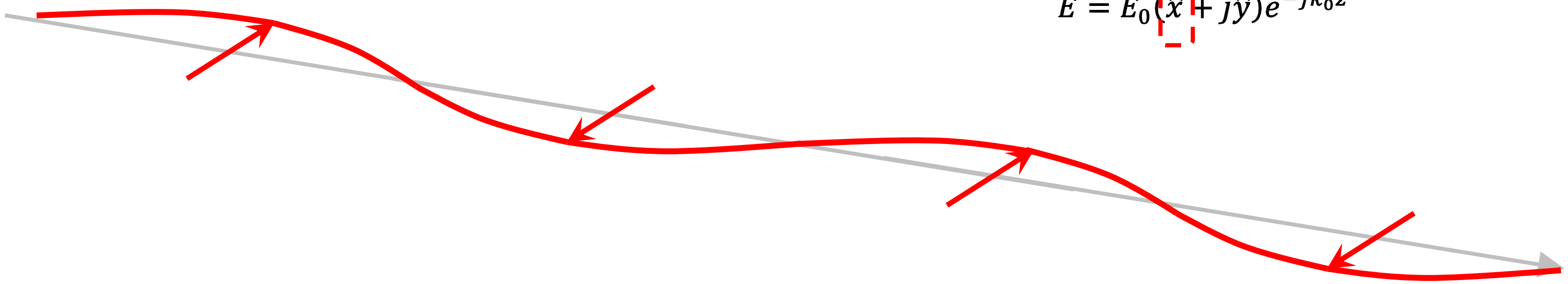
$$\vec{\mathcal{E}}(z,t) = E_0\left\{\hat{x}\cos(\omega t - k_0 z) + \boxed{\hat{y}\cos\left(\omega t - k_0 z + \frac{\pi}{2}\right)}\right\}$$

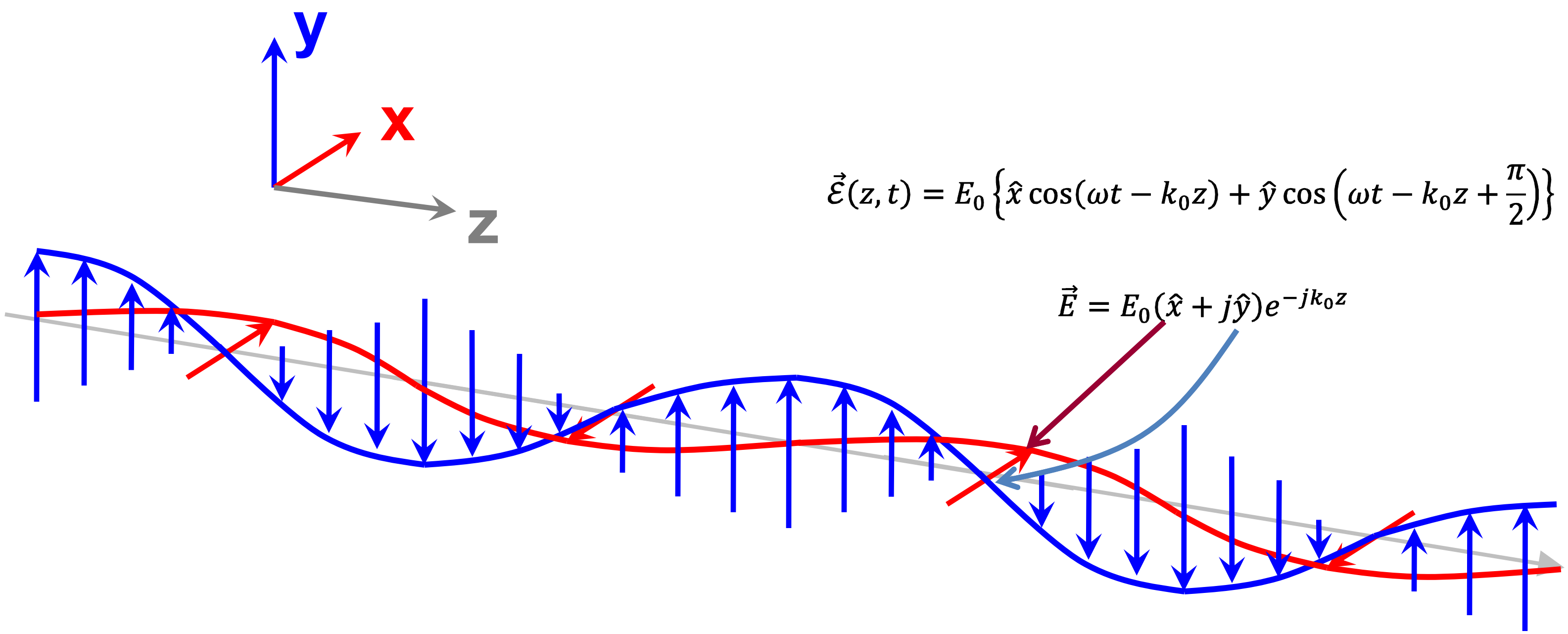
$$\vec{E} = E_0(\hat{x} + \boxed{j\hat{y}})e^{-jk_0 z}$$



$$\vec{\mathcal{E}}(z,t) = E_0\left\{\boxed{\hat{x}\cos(\omega t - k_0 z)} + \hat{y}\cos\left(\omega t - k_0 z + \frac{\pi}{2}\right)\right\}$$

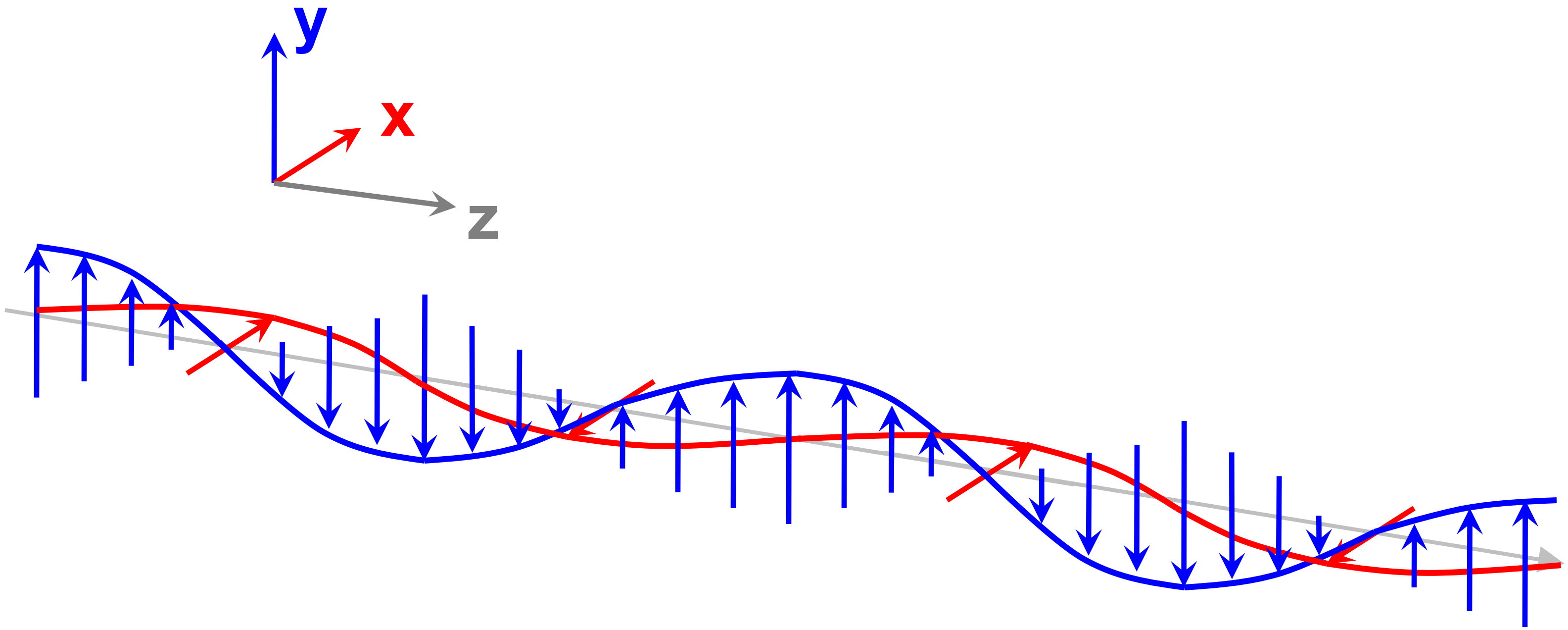
$$\vec{E} = E_0(\boxed{\hat{x}} + j\hat{y})e^{-jk_0 z}$$

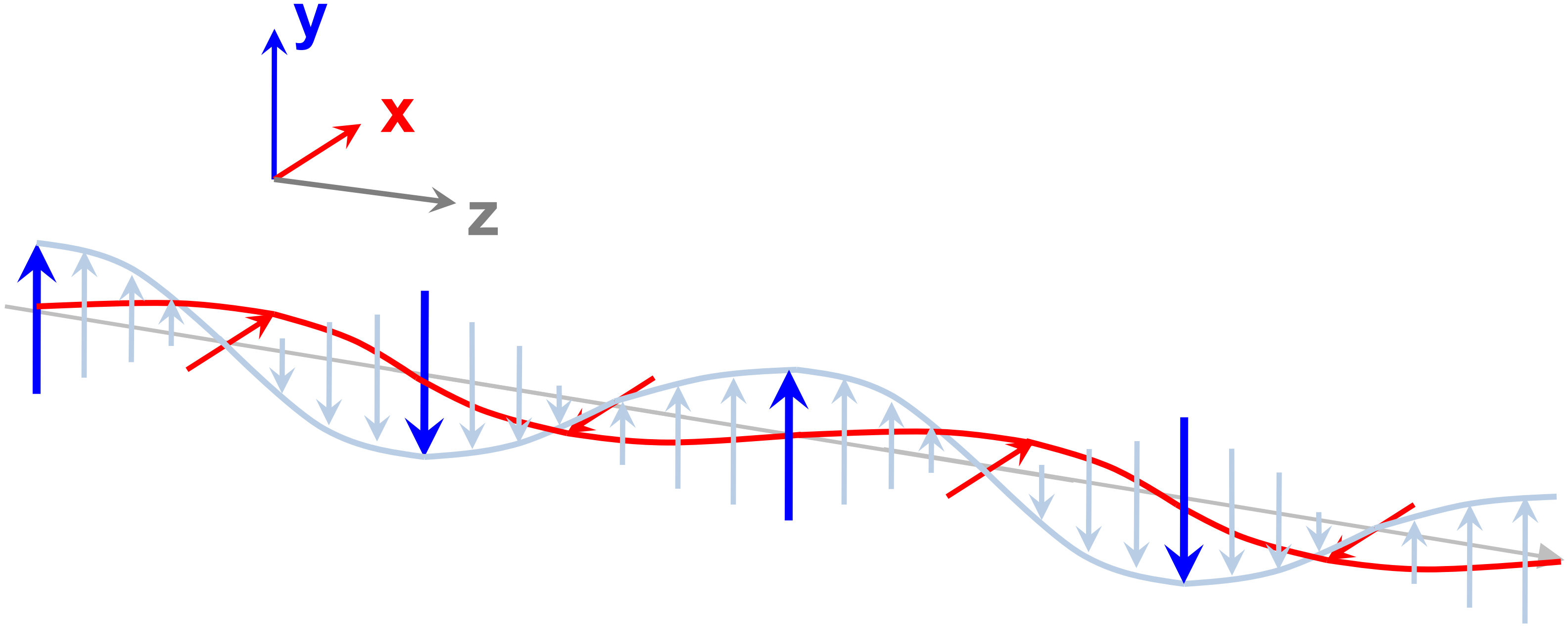


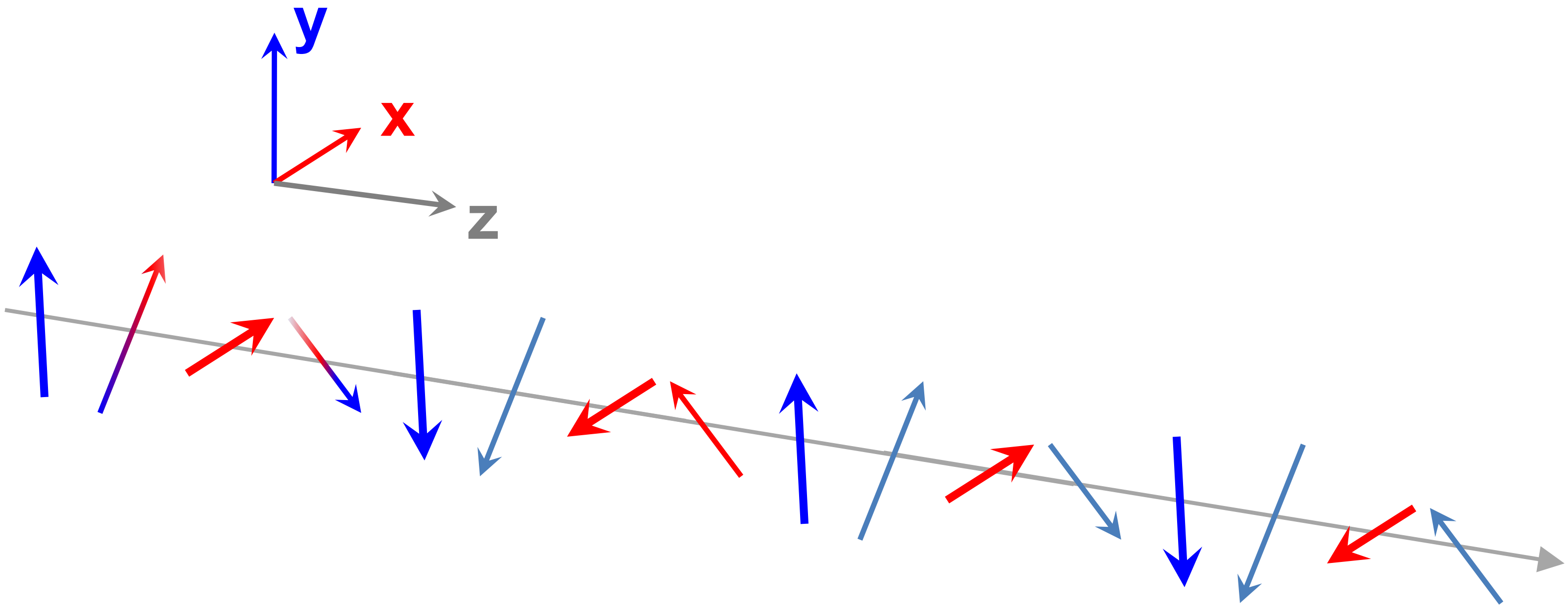


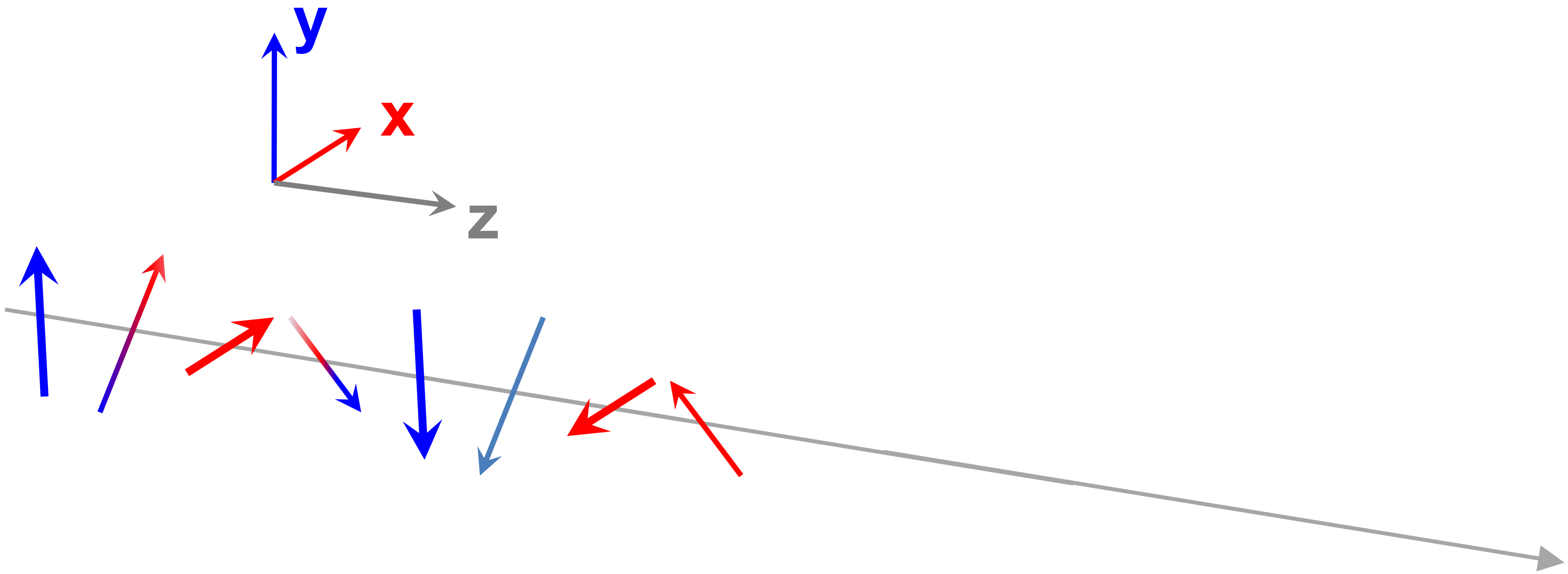
$$\vec{\mathcal{E}}(z,t) = E_0\left\{\hat{x}\cos(\omega t - k_0 z) + \hat{y}\cos\left(\omega t - k_0 z + \frac{\pi}{2}\right)\right\}$$

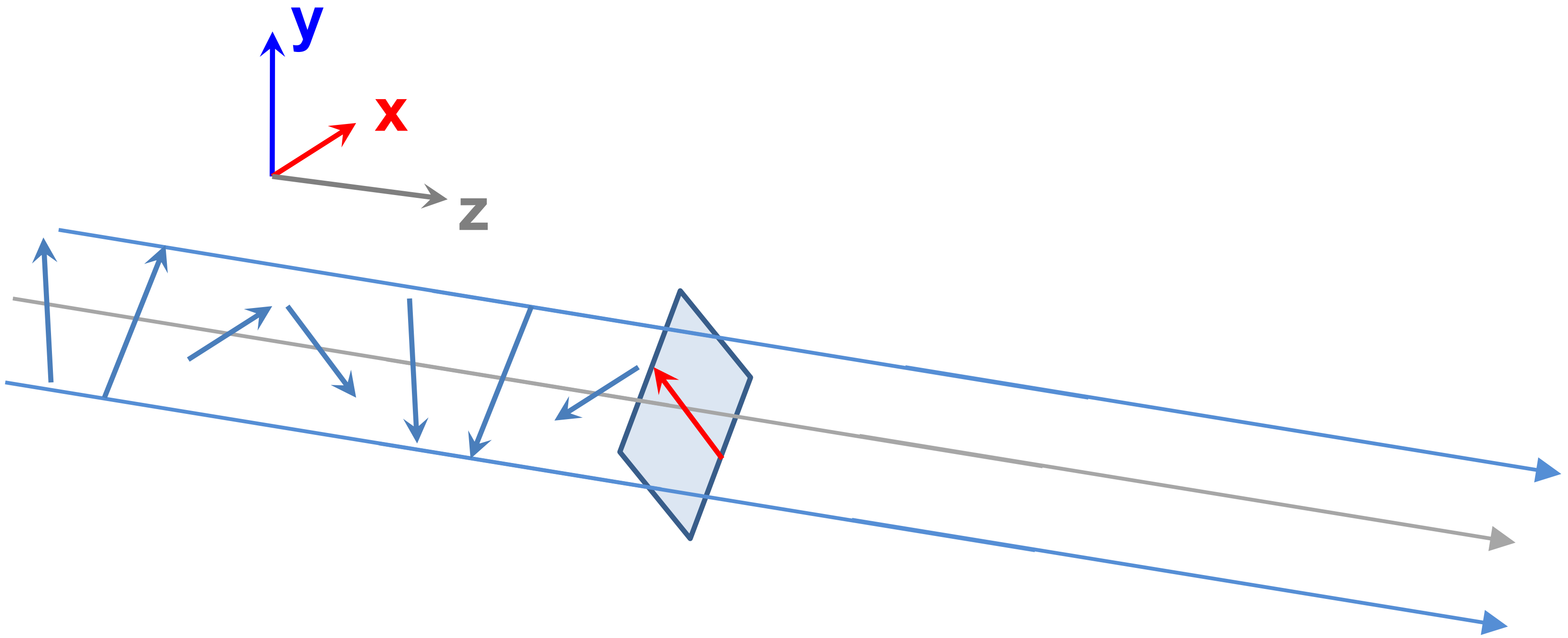
$$\vec{E} = E_0(\hat{x} + j\hat{y})e^{-jk_0 z}$$

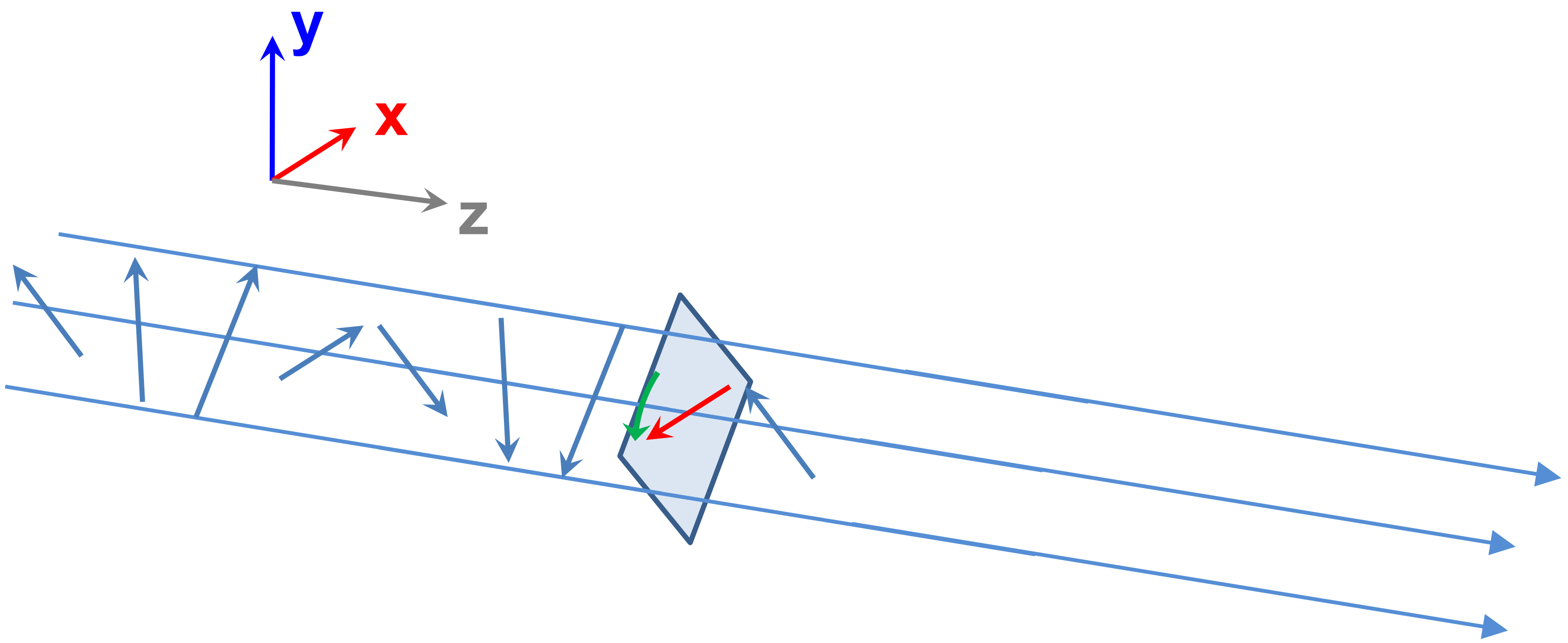

y
x
z

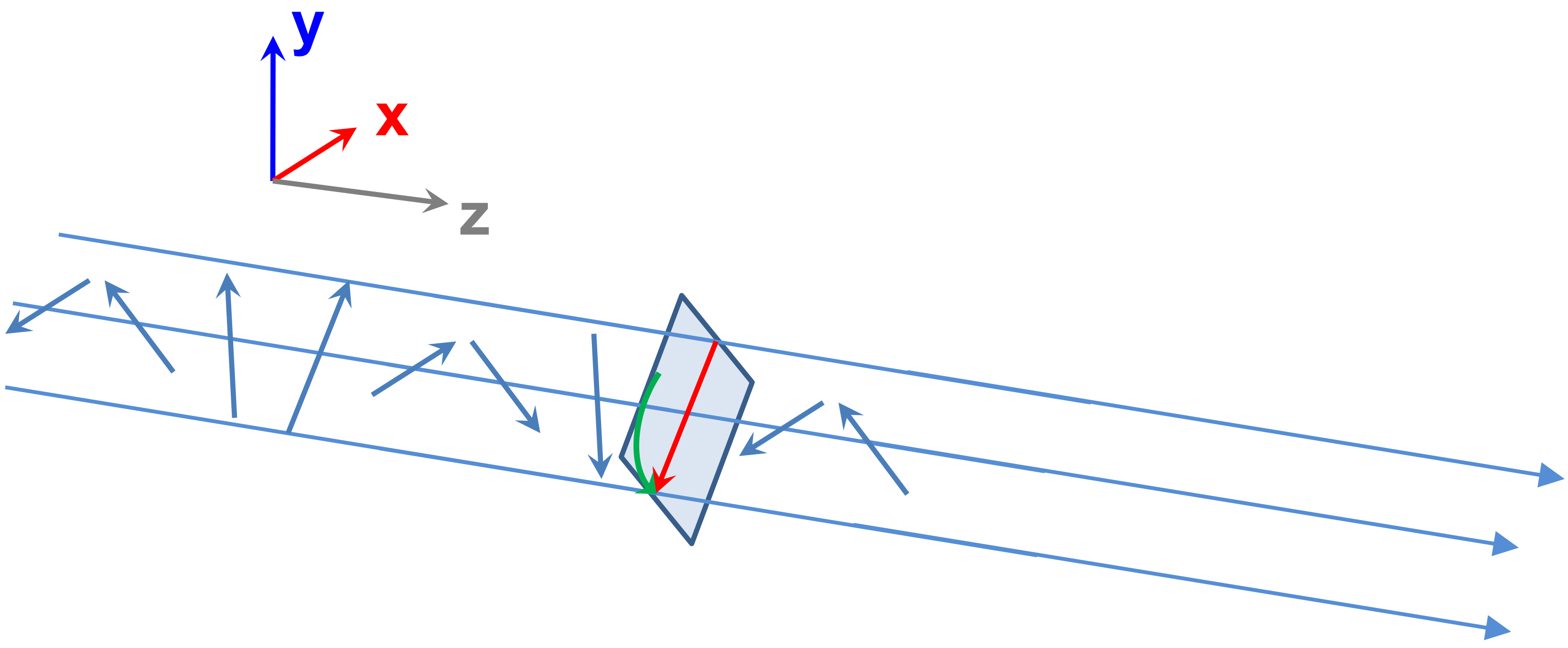

y
x
z

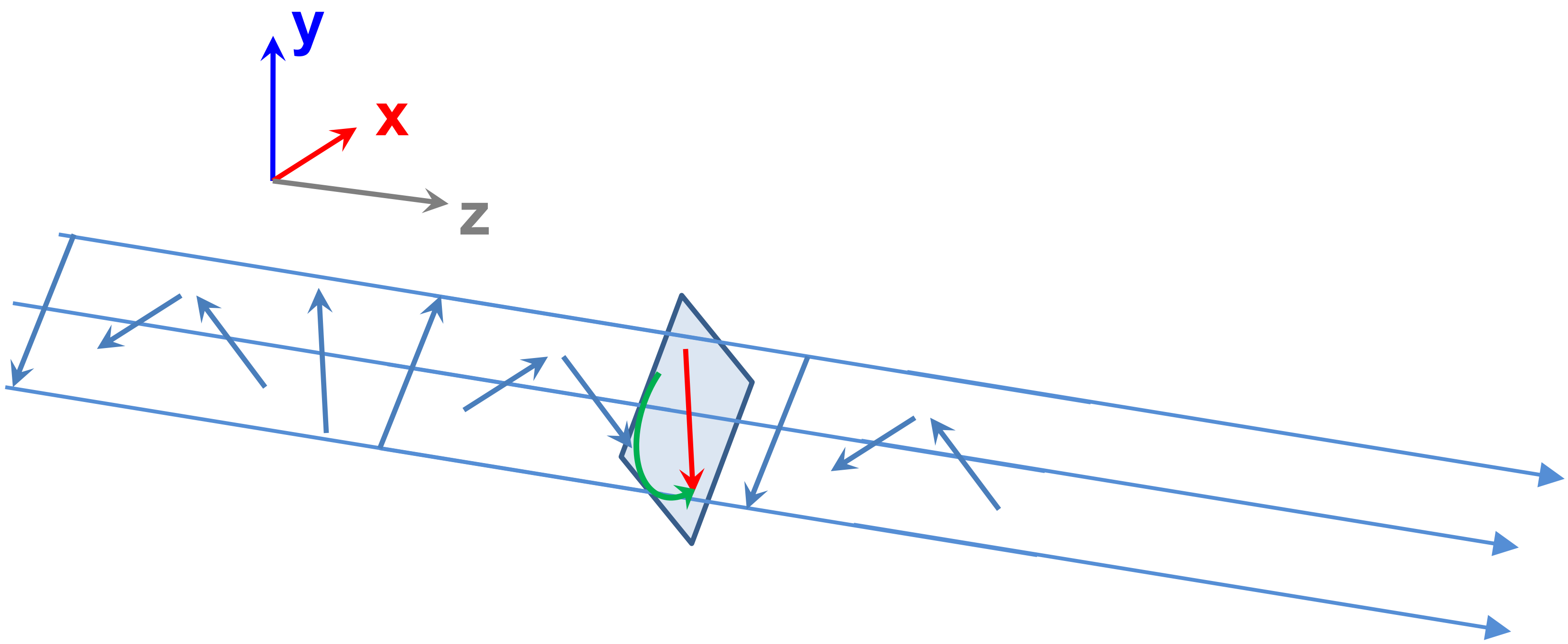

y
x
z

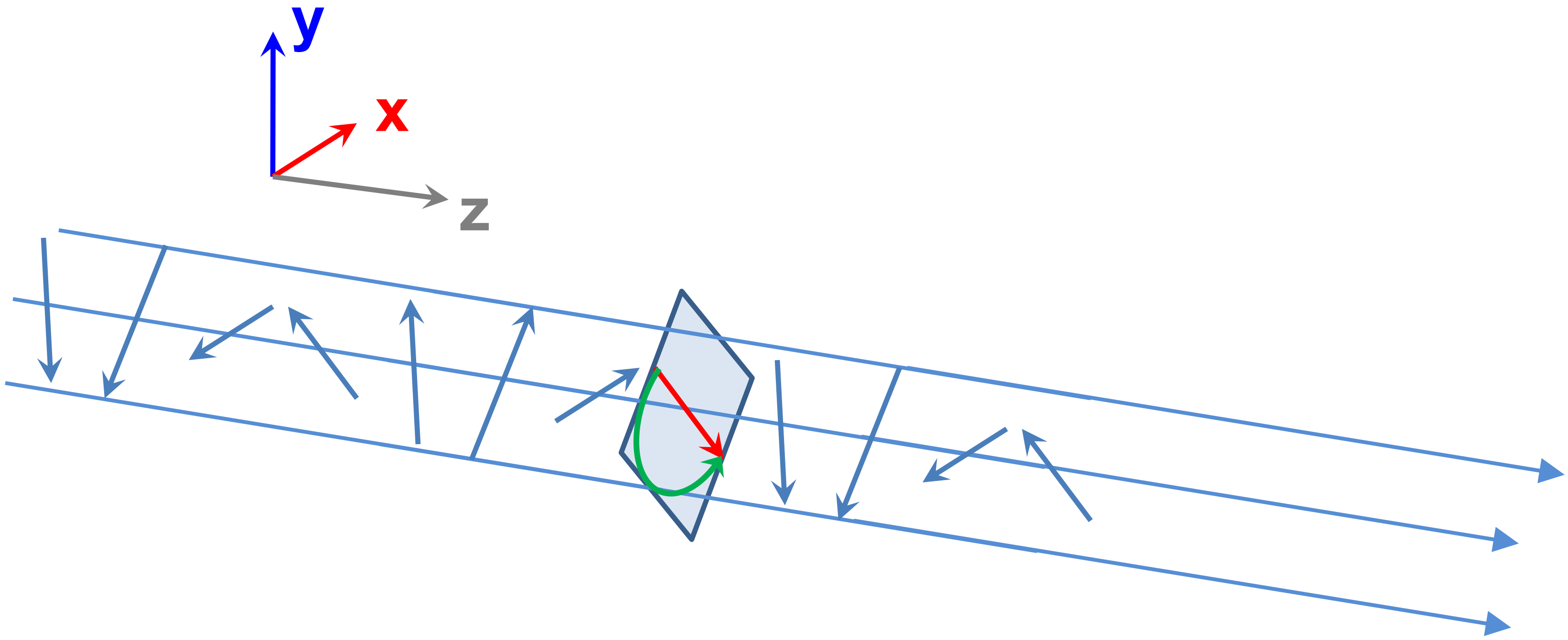

y
x
z

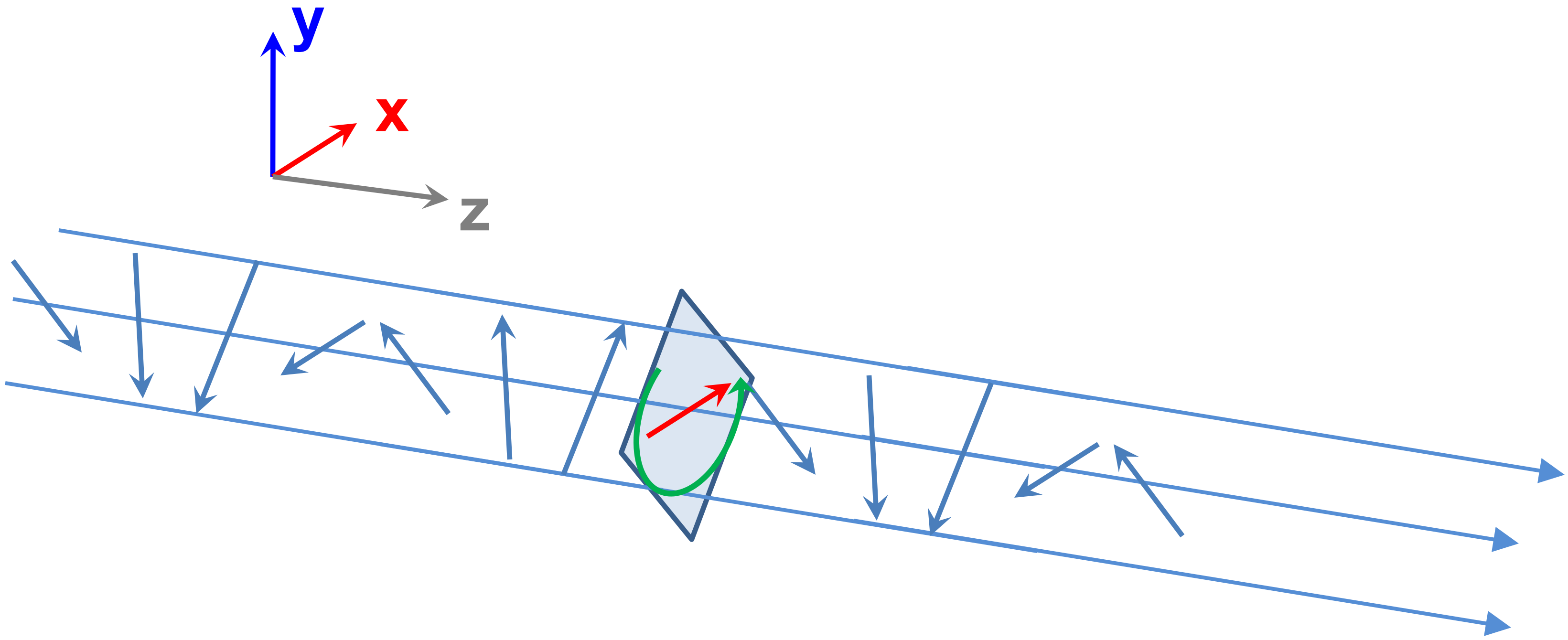

y
x
z

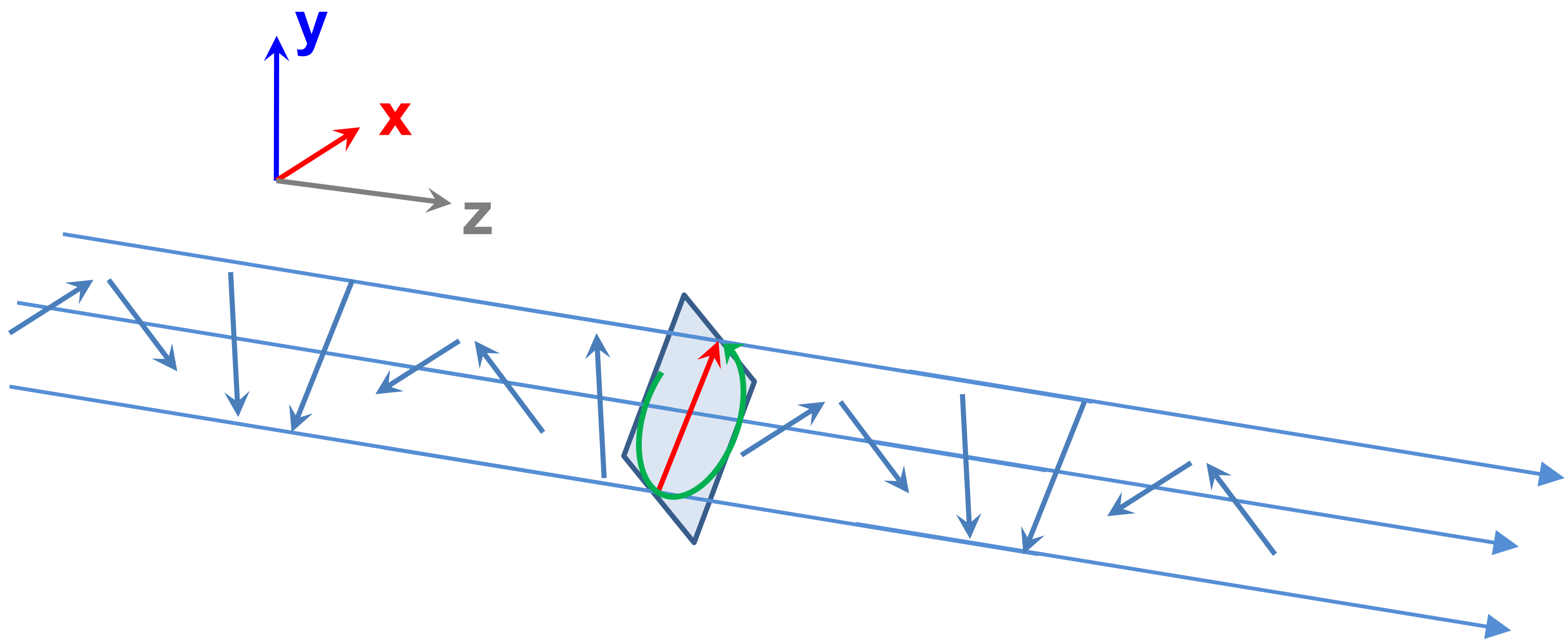

y
x
z

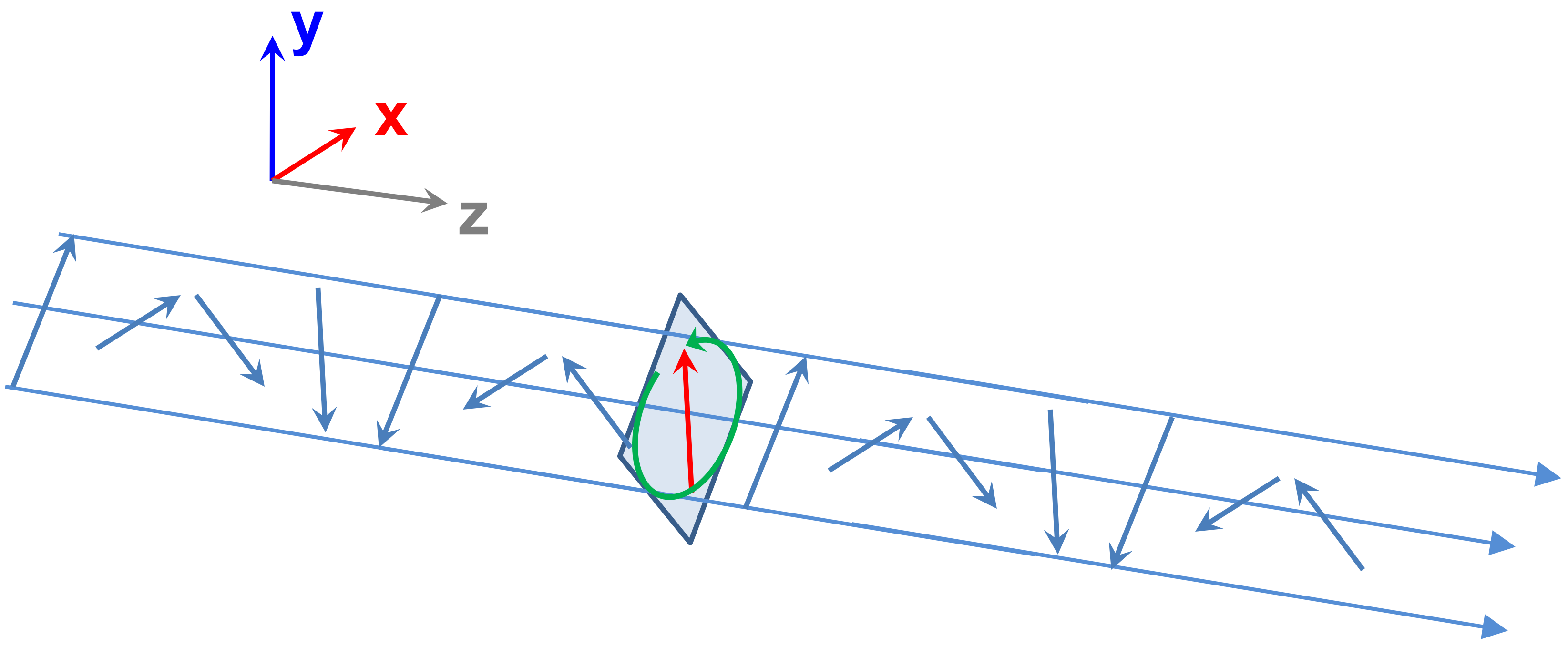

y
x
z

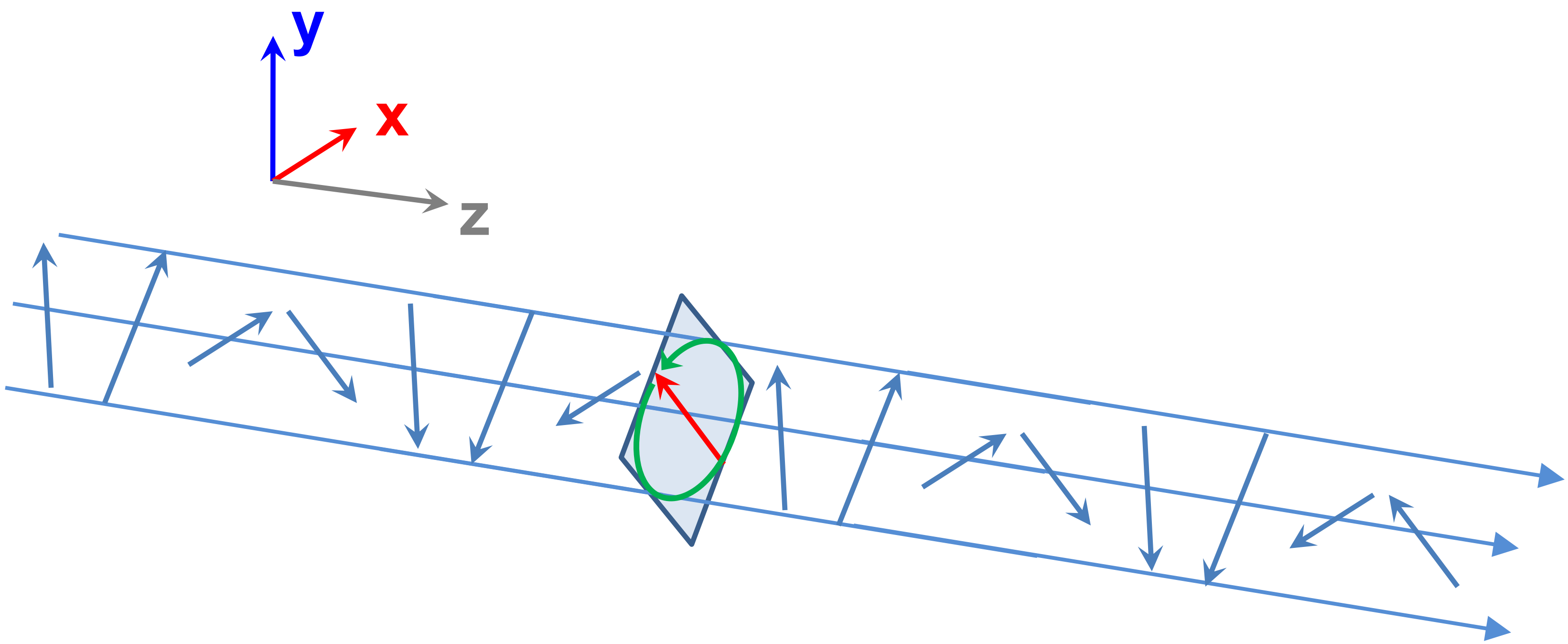

y
x
z

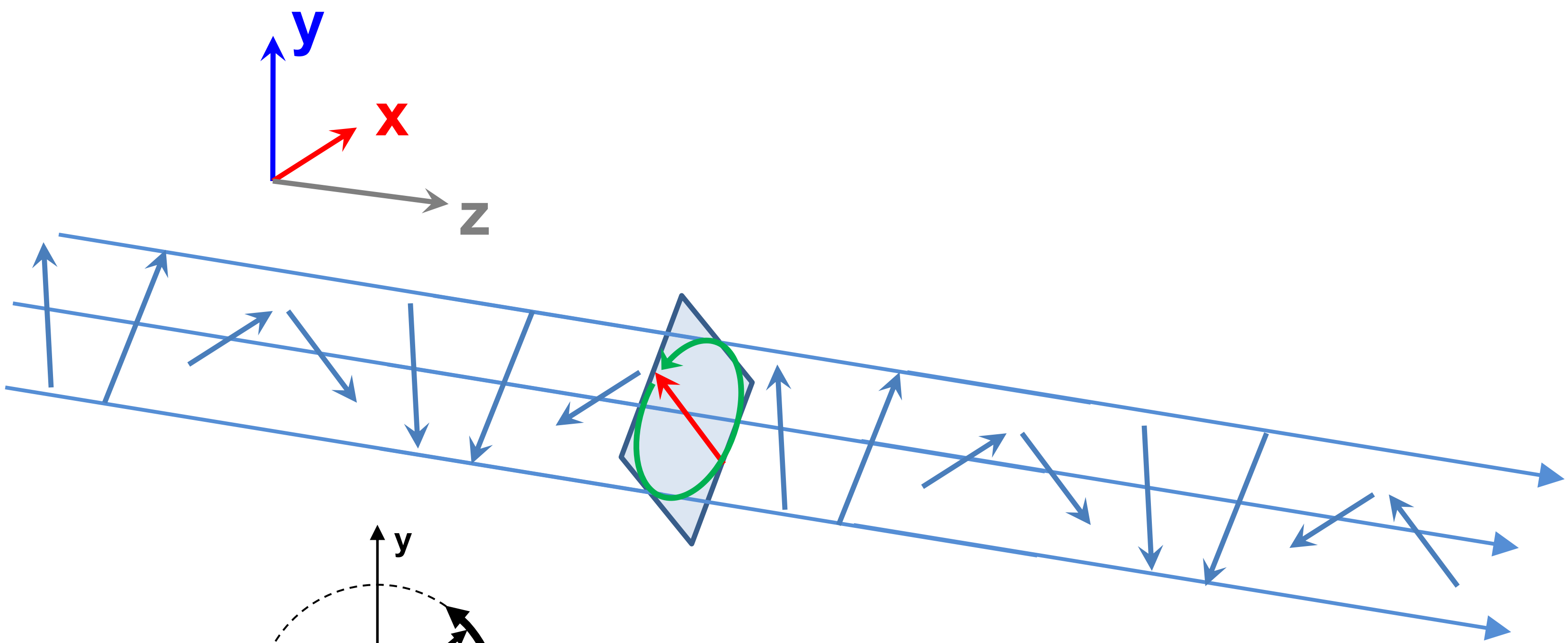

y
x
z

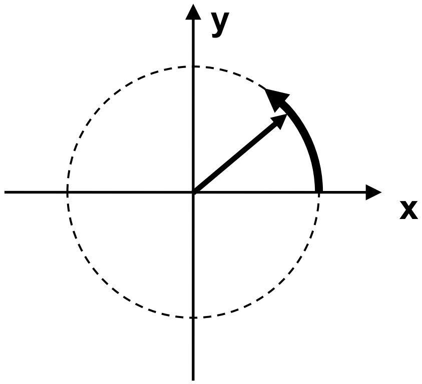

y
x
z


y
x
z


y
x
z


y
x
z

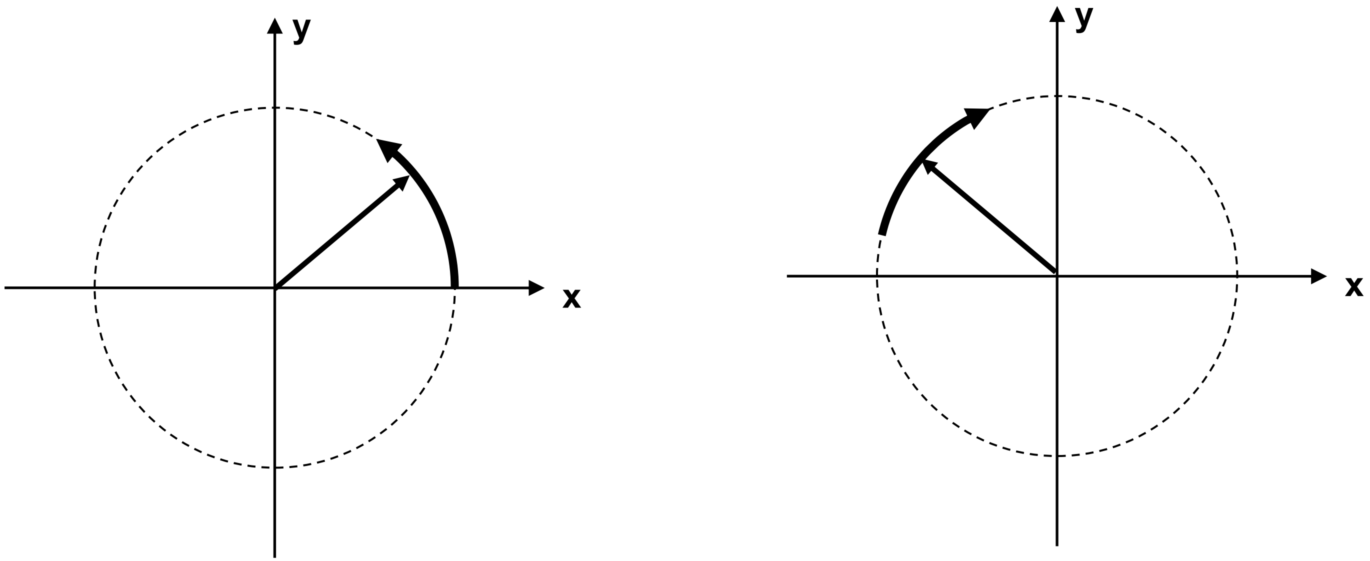




LCP signal

Theory of Operation

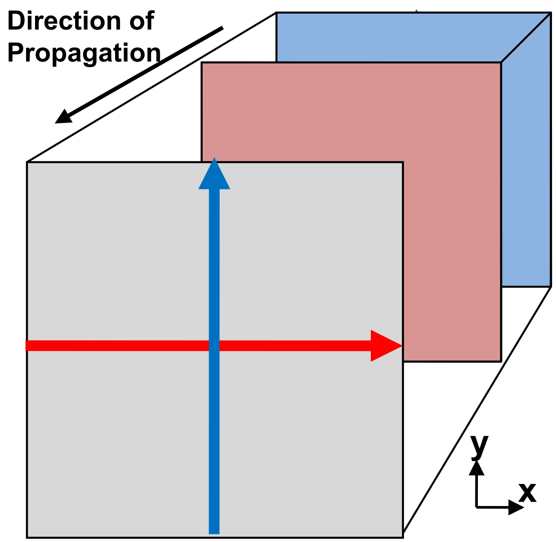
Apparent motion of electric field vector of circularly polarized electromagnetic waves as viewed from the receiver (astronomy definition).



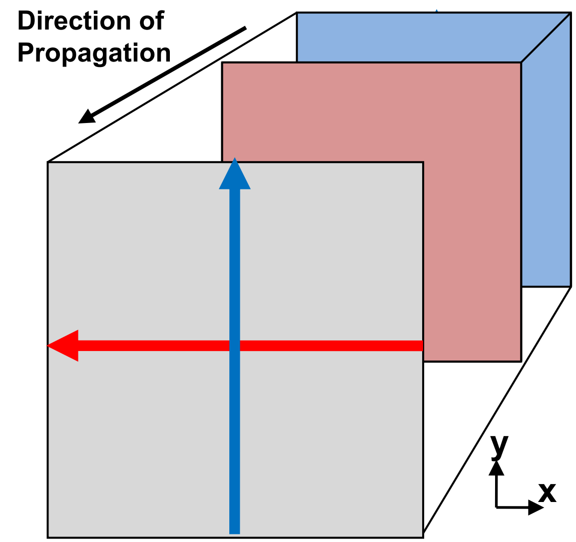
LCP signal

RCP signal

Theory of Operation: Phase Shifter

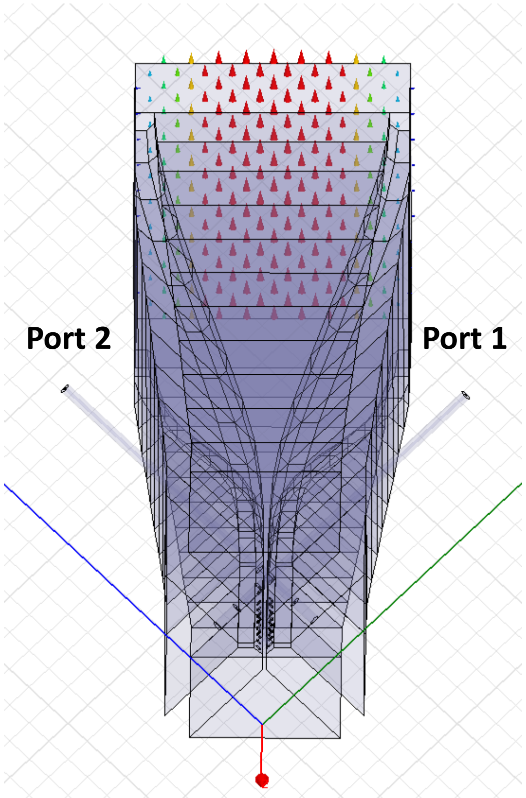


LCP signal



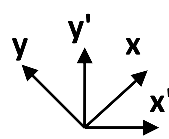
RCP signal

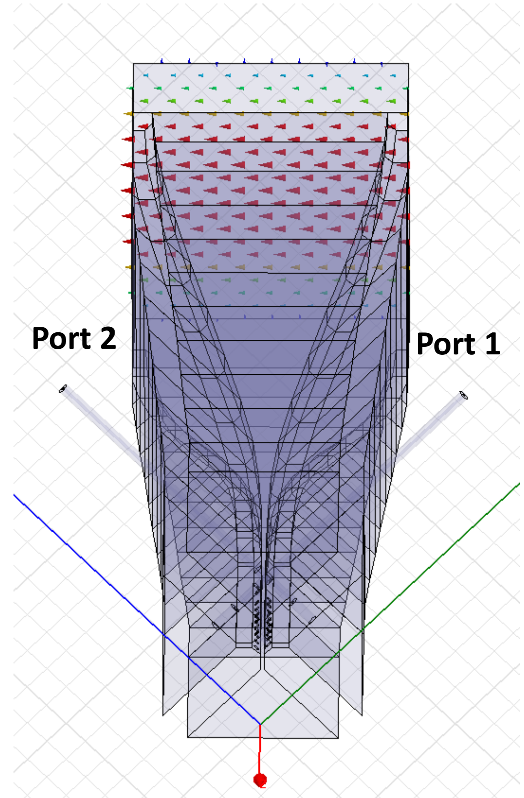
Theory of Operation: OMT



TE'_{10}

(mode 1)

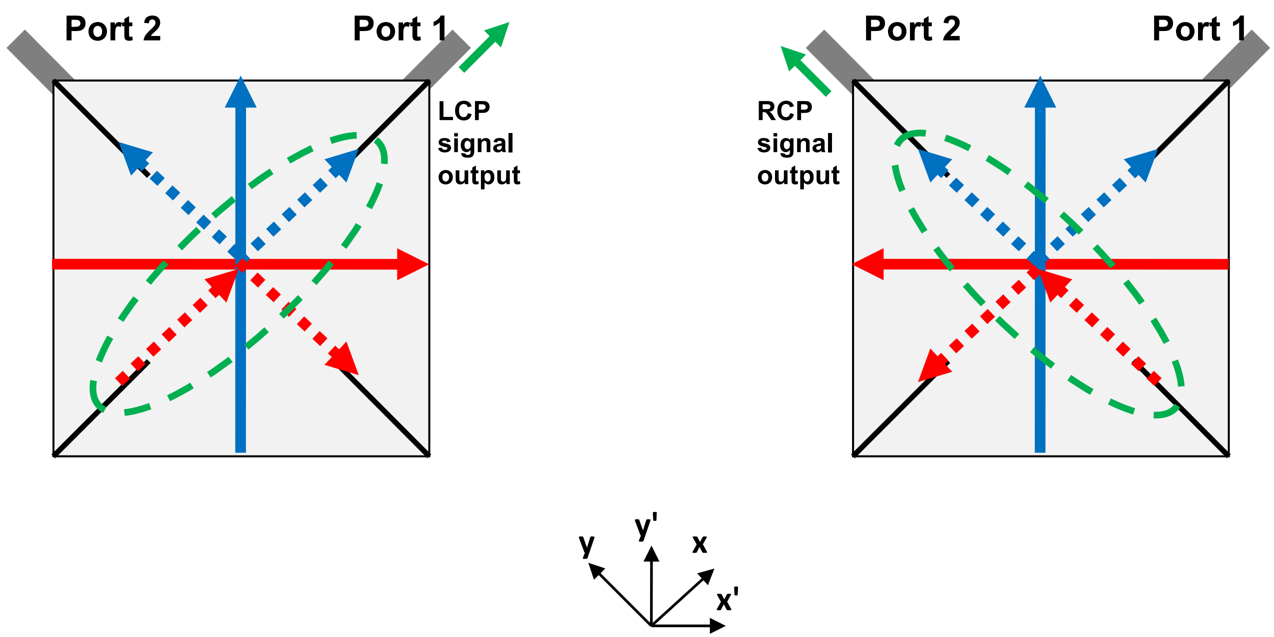




TE'_{01}

(mode 2)

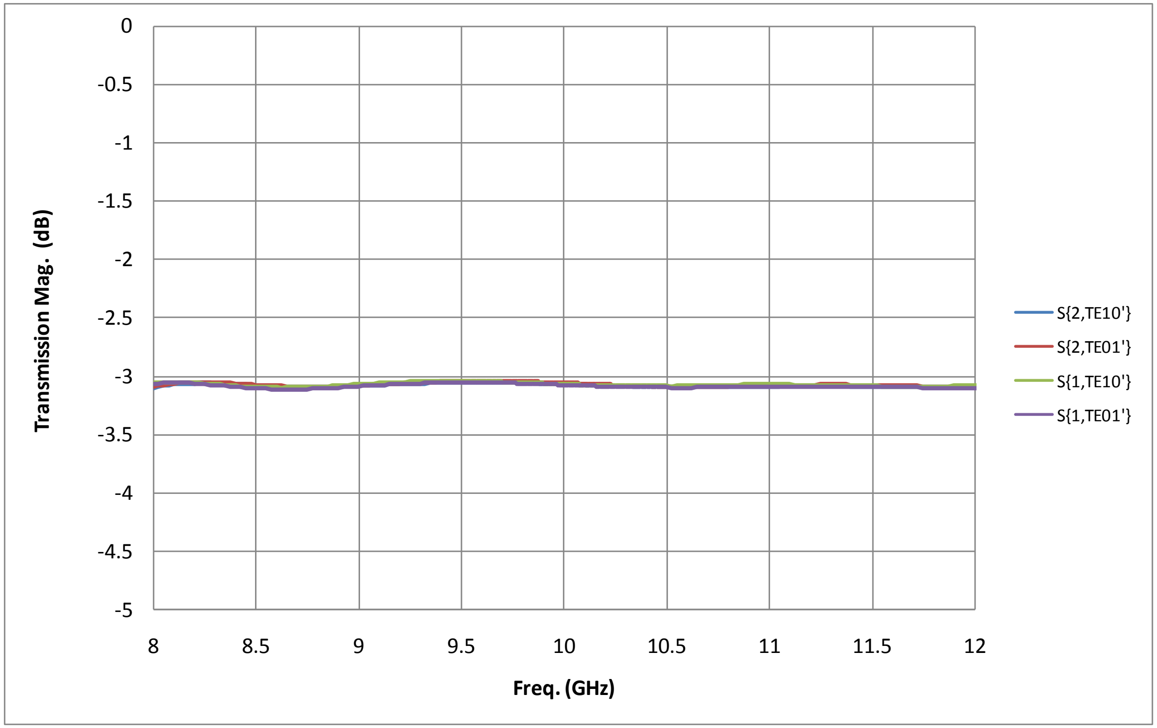
Theory of Operation: OMT



LCP signal

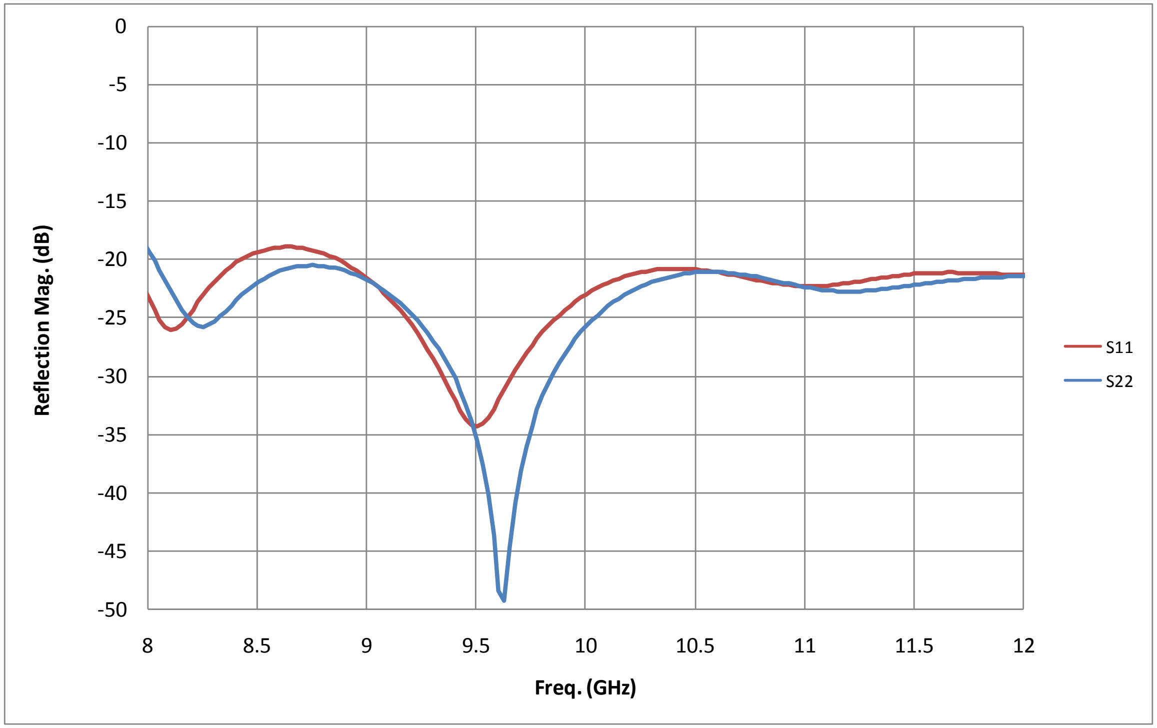
RCP signal

HFSS Simulated OMT Performance



- HFSS simulated modal transmission S-parameter magnitude from OMT input to the coaxial OMT output ports

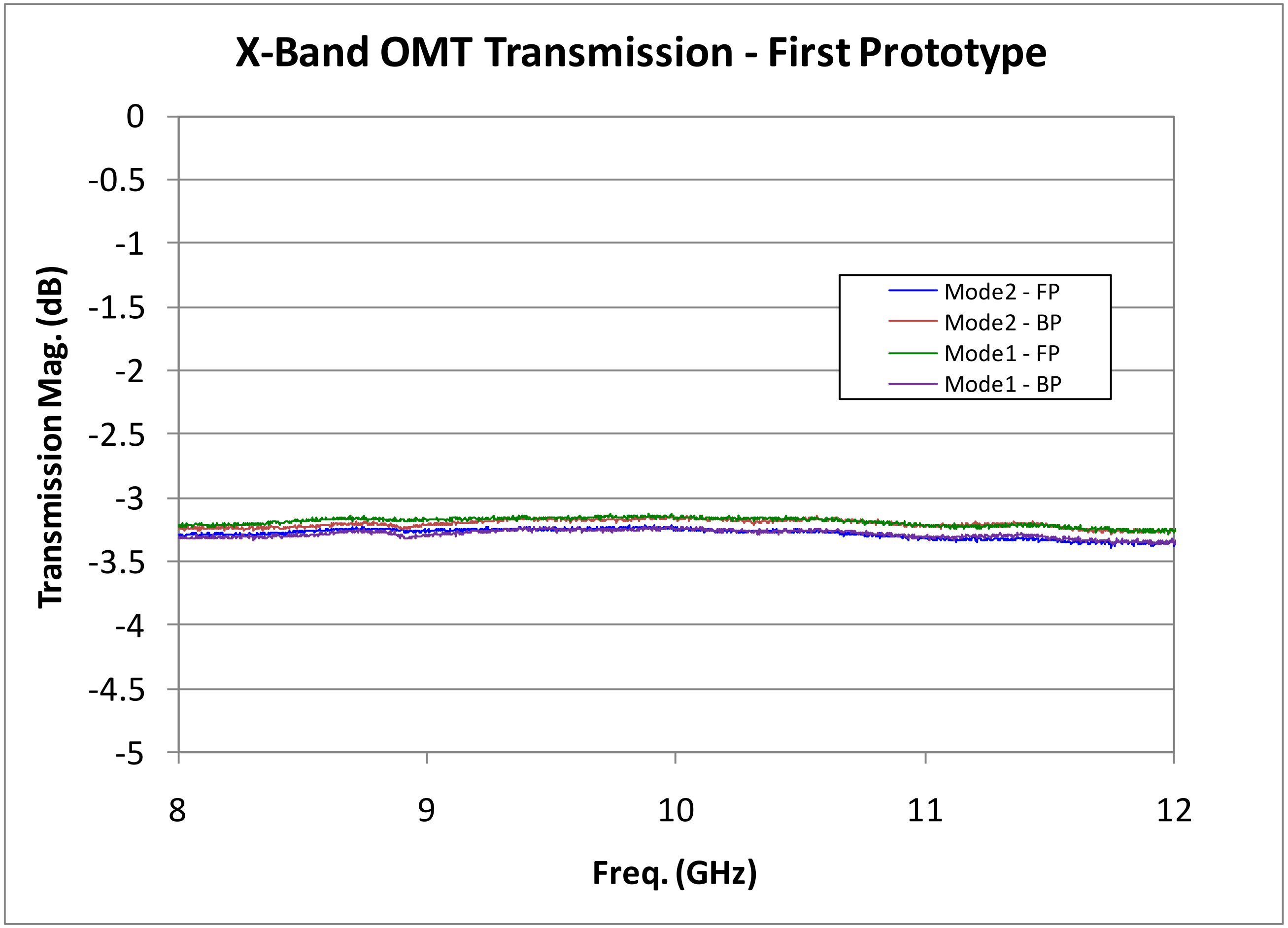
HFSS Simulated OMT Performance



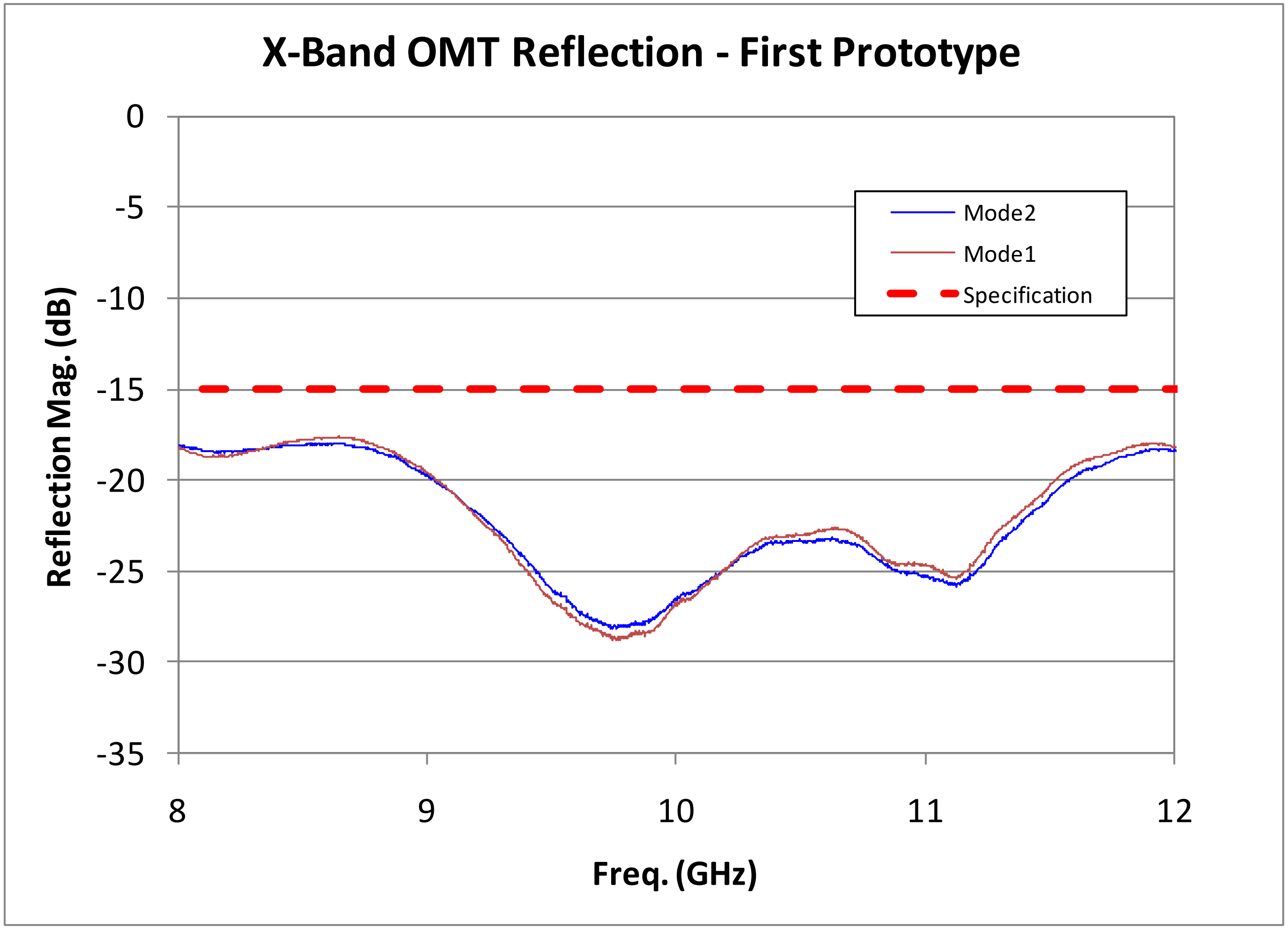
- HFSS simulated reflection OMT S-parameters

Measured X-Band OMT Performance

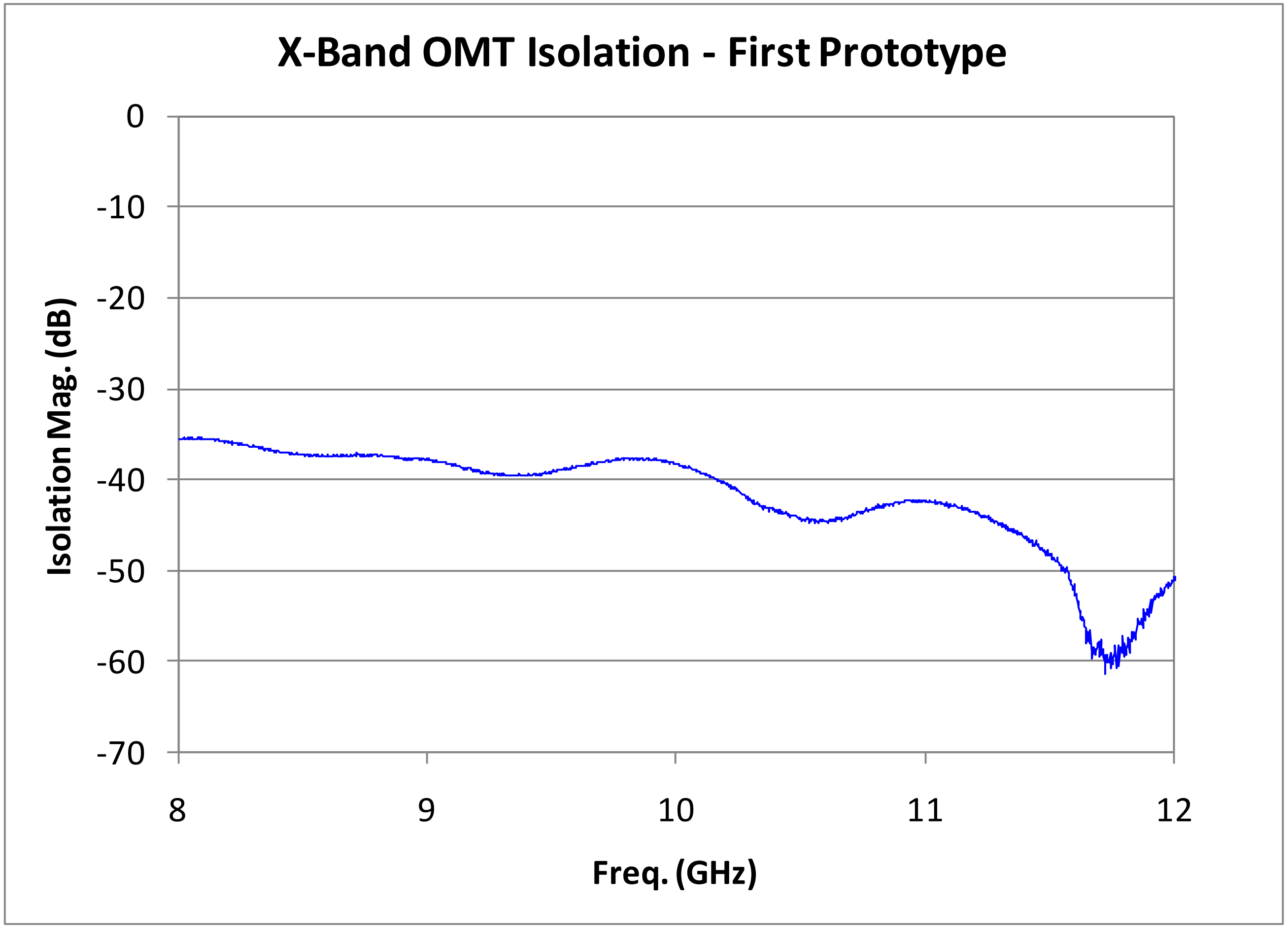
Measured OMT Performance



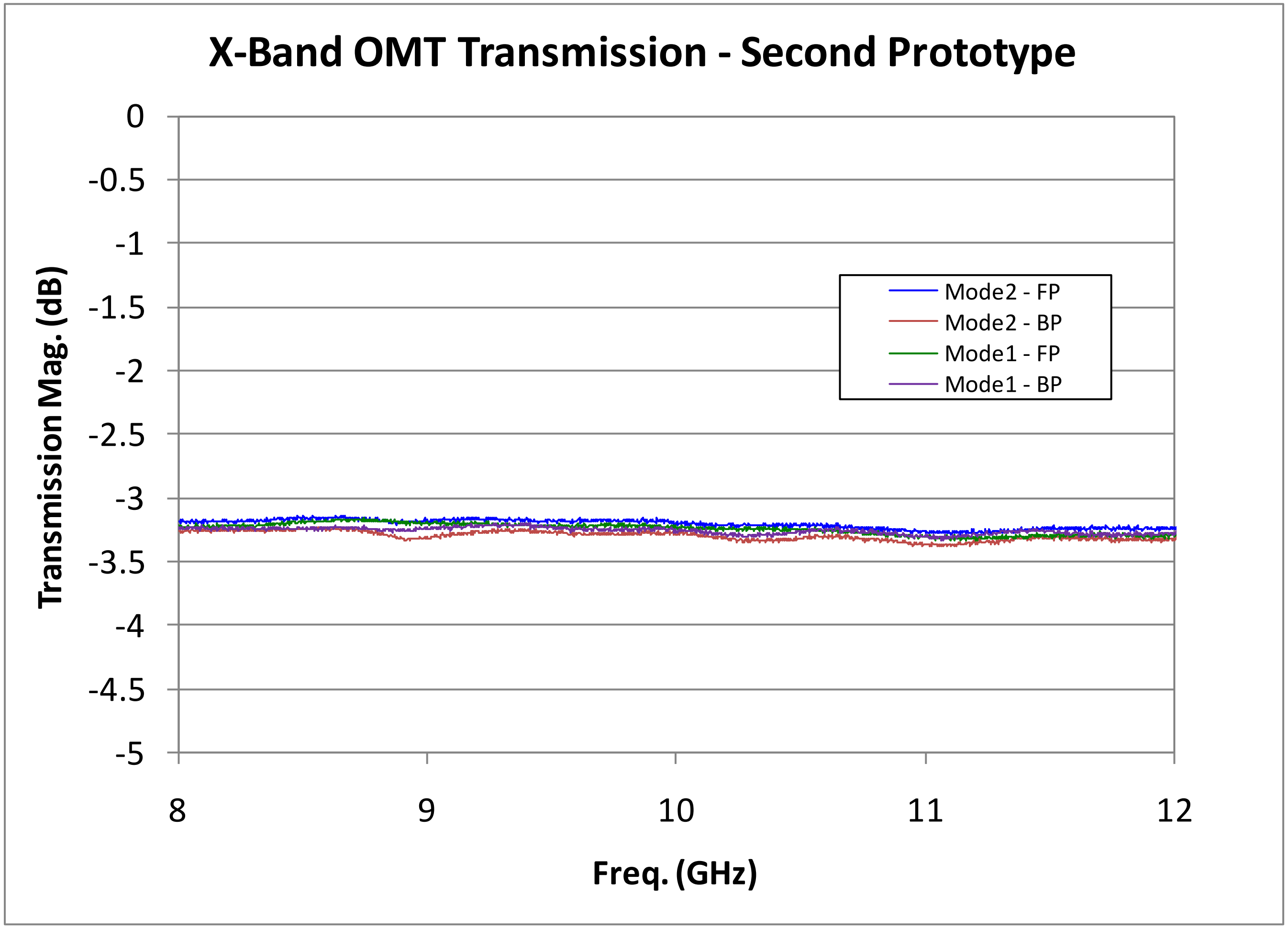
Measured OMT Performance



Measured OMT Performance

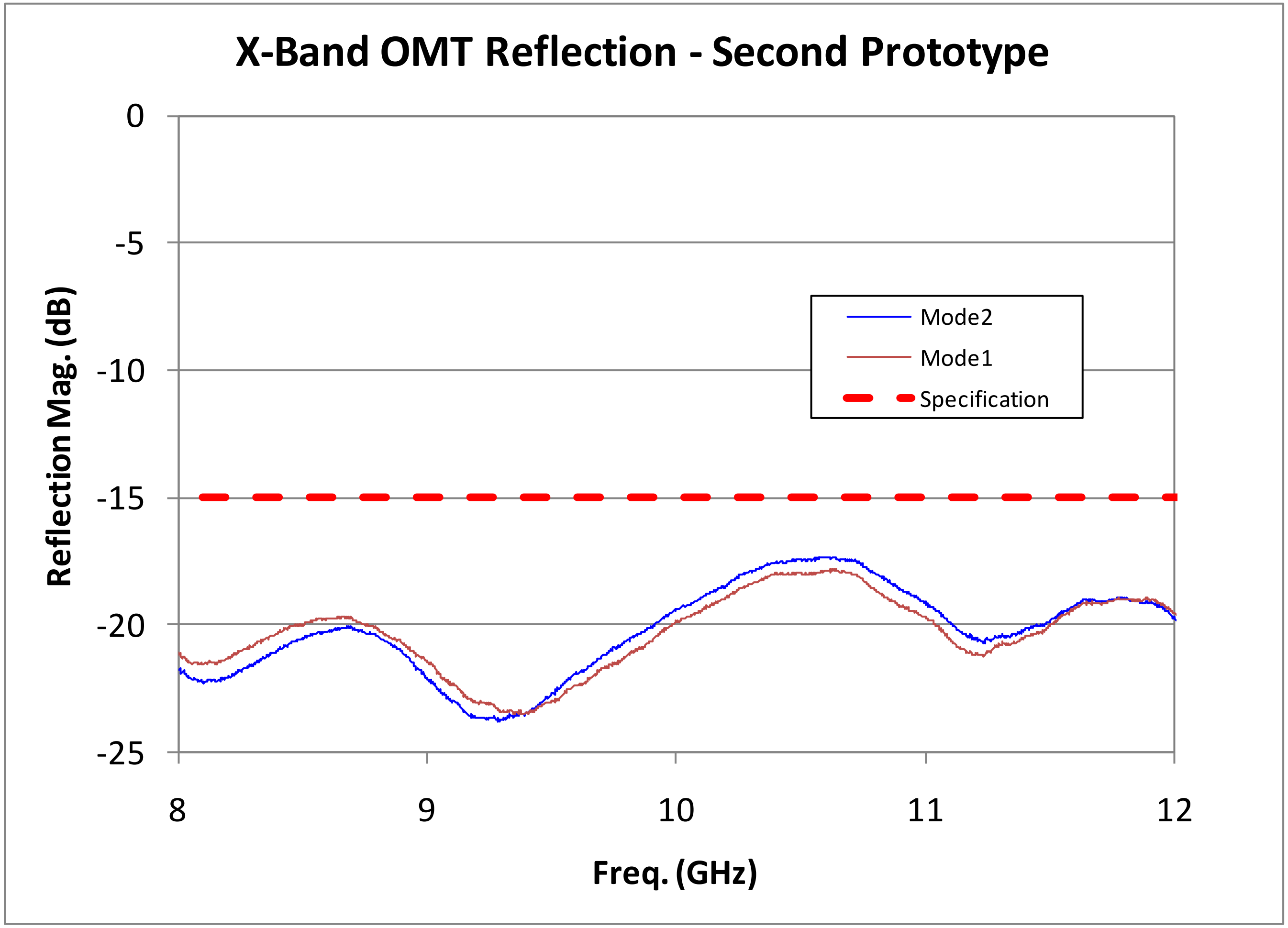


Measured OMT Performance

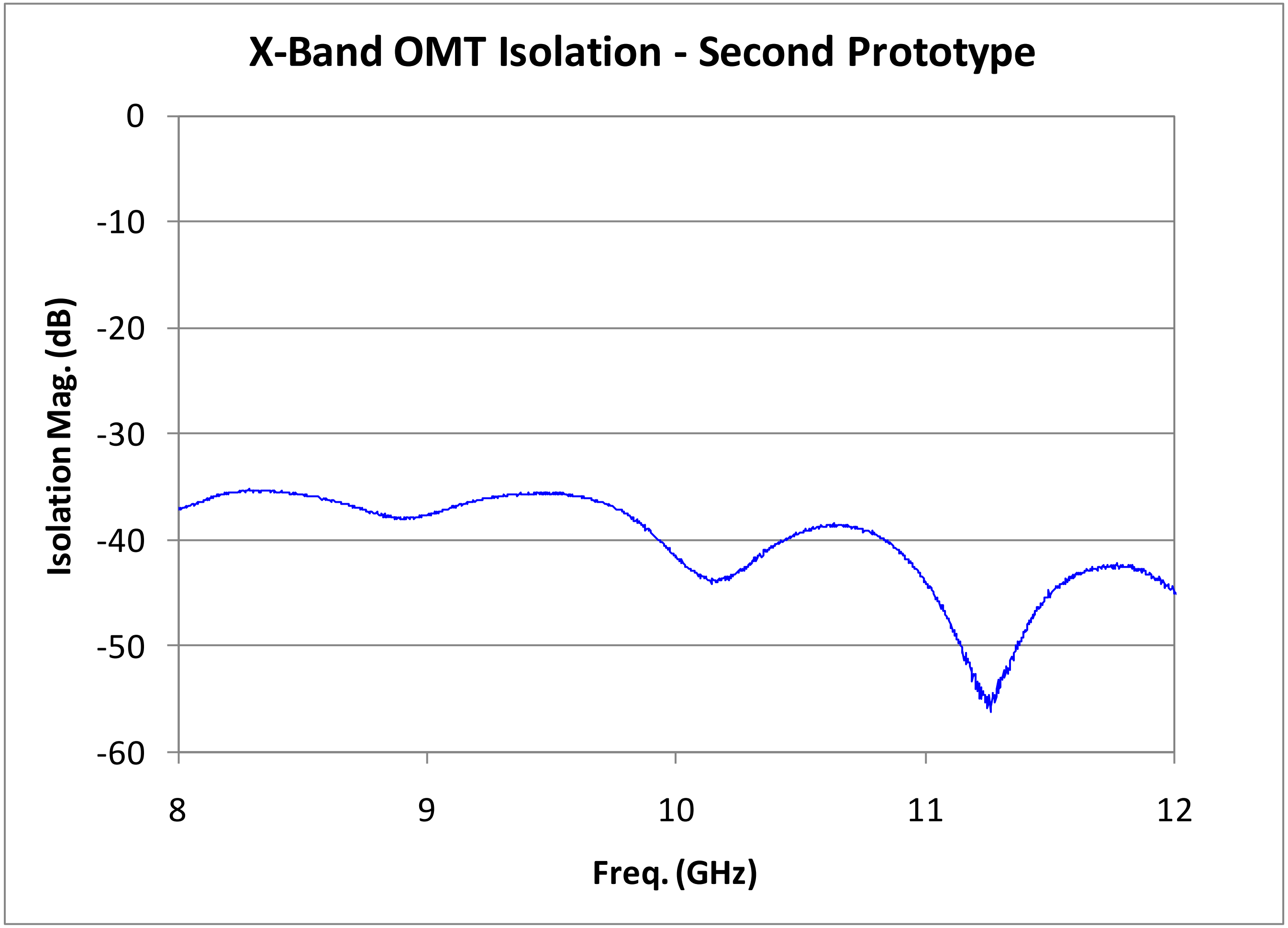


EVLA

Measured OMT Performance



Measured OMT Performance

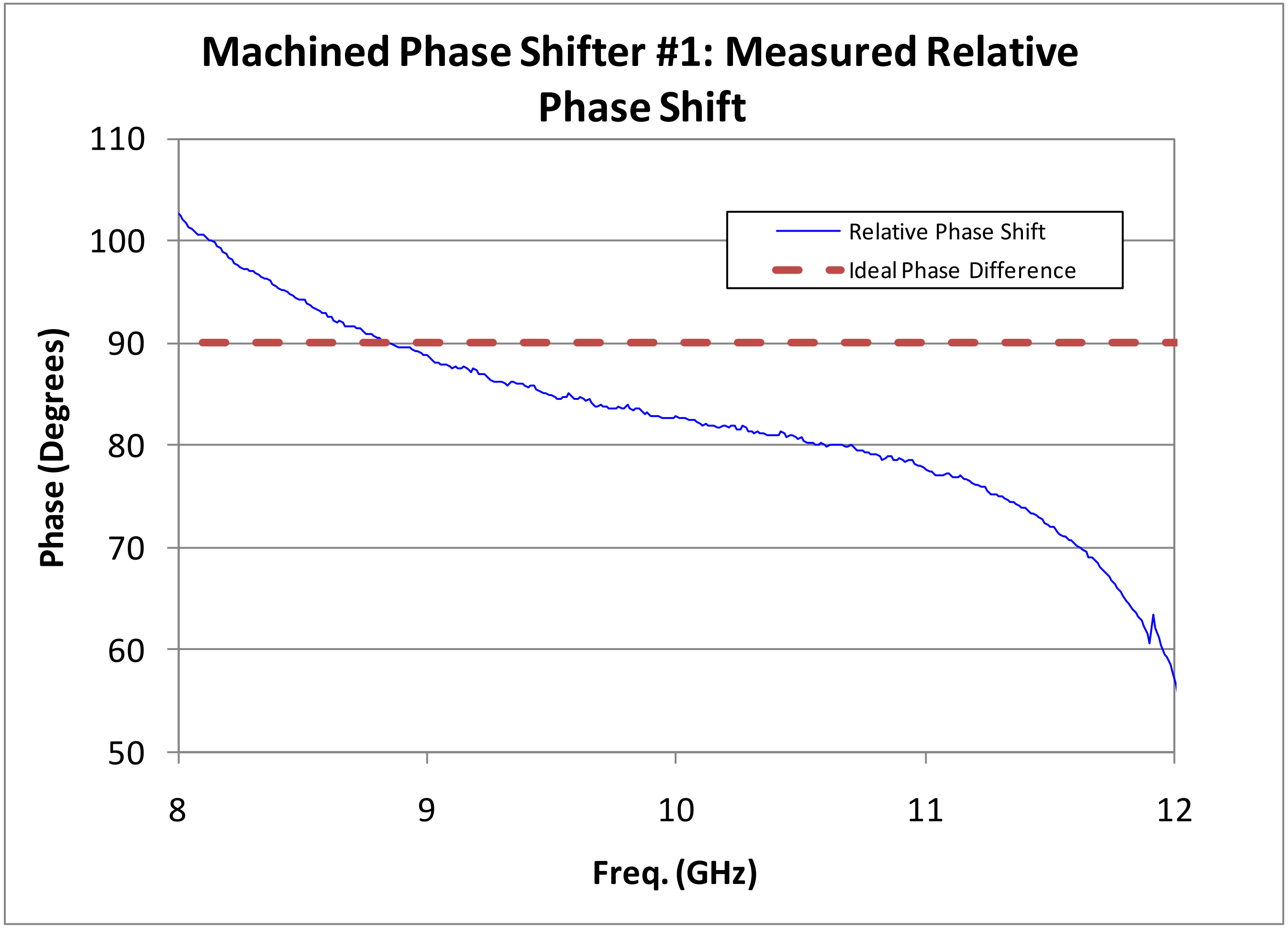


Measured Circular Polarization Performance using Machined Prototype Phase Shifters

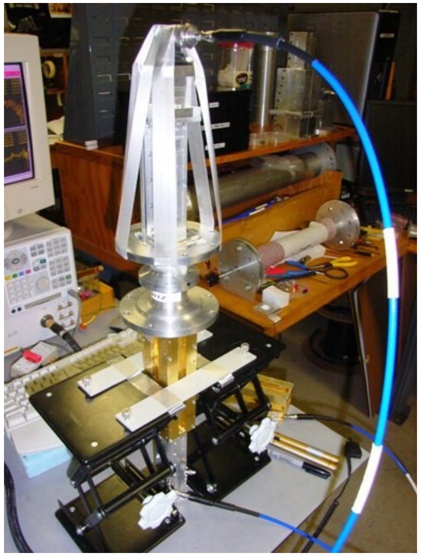
Machined Phase Shifters

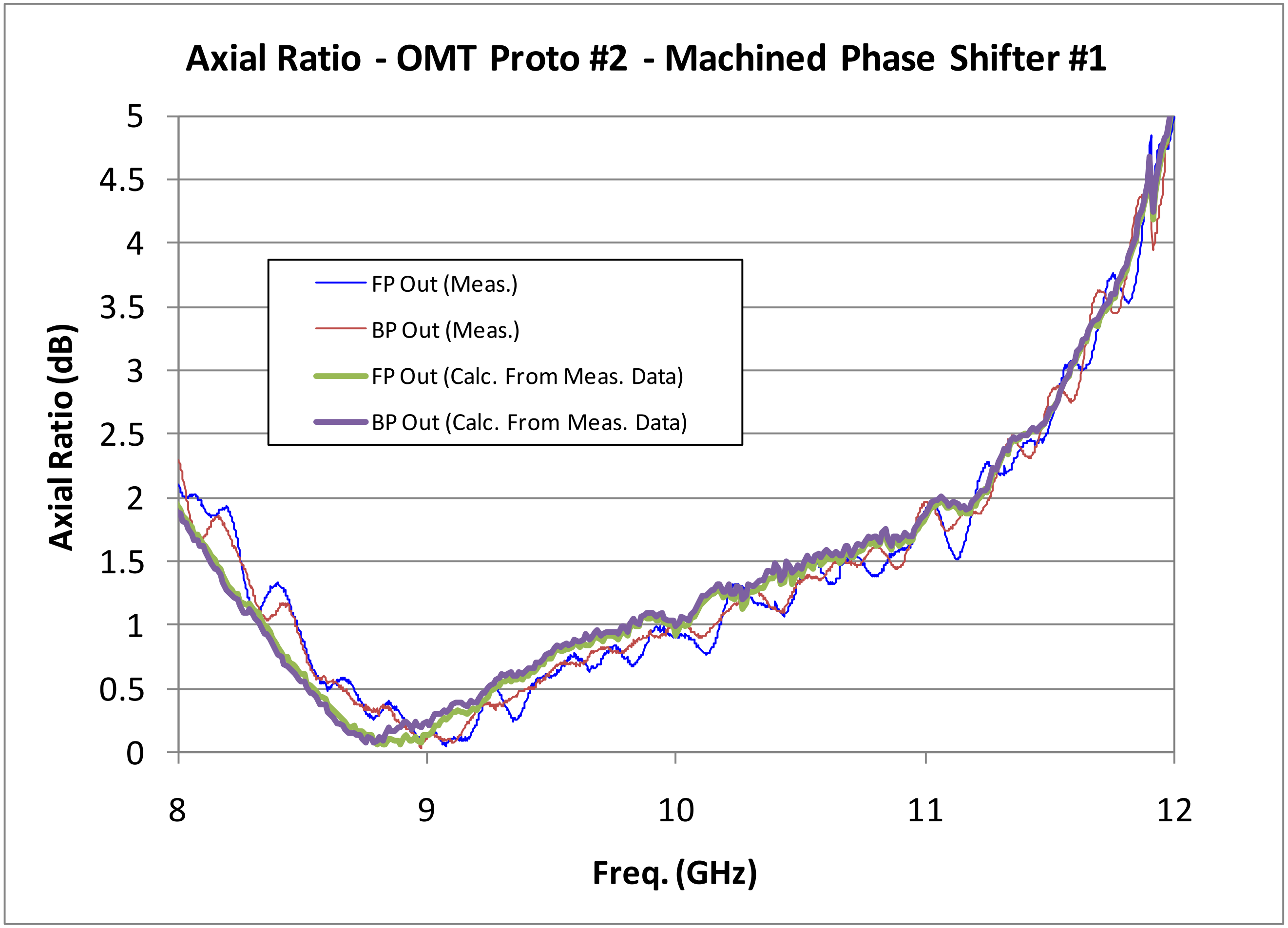
- Prototype X-Band phase shifters were fabricated in-house
- Used to evaluate circular polarization performance of the new X-Band OMT
- The X-Band OMT was connected to the phase shifter and measured using the PNA

Machined Phase Shifter Measured Performance

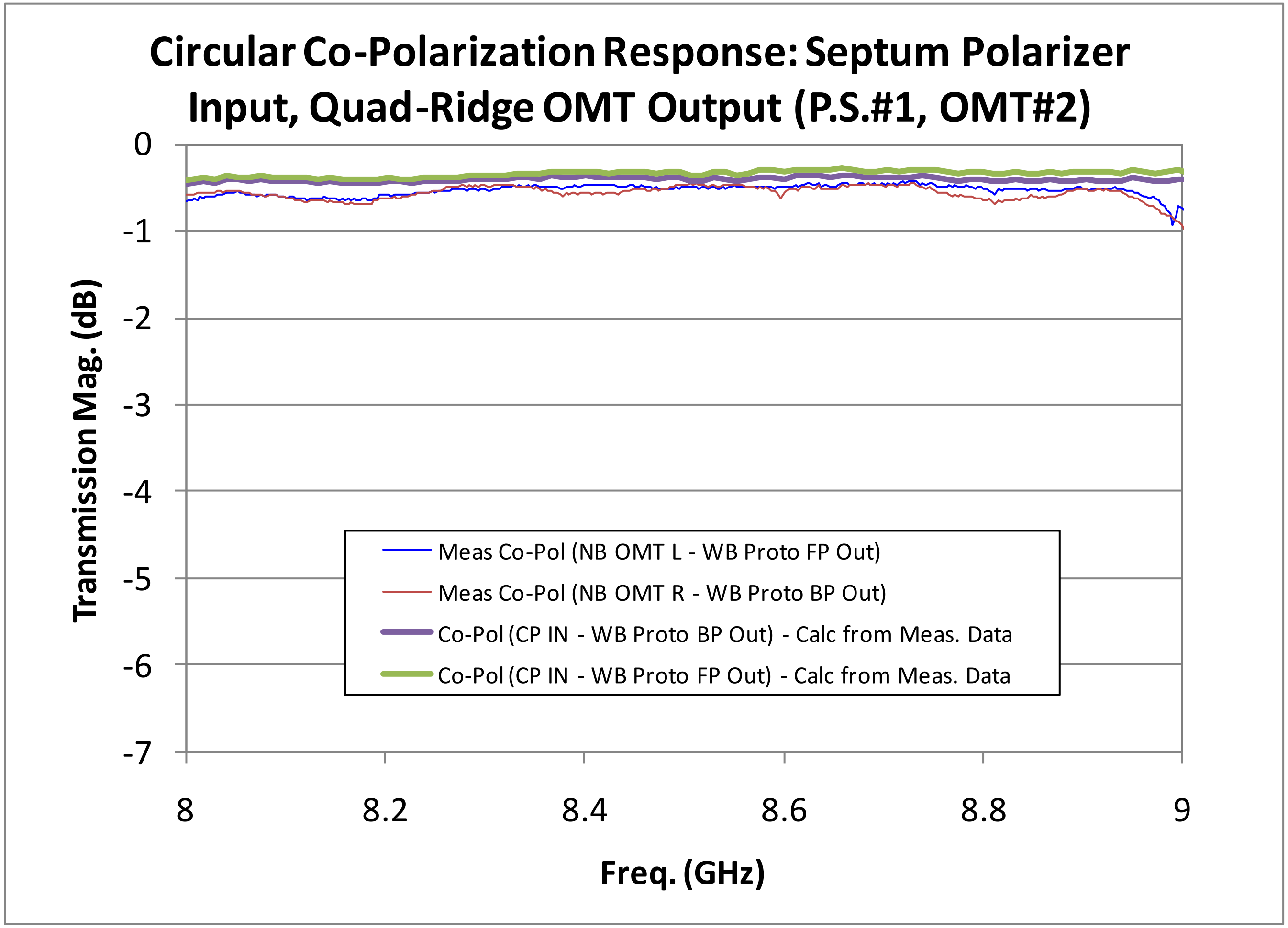


Measured Axial Ratio Performance

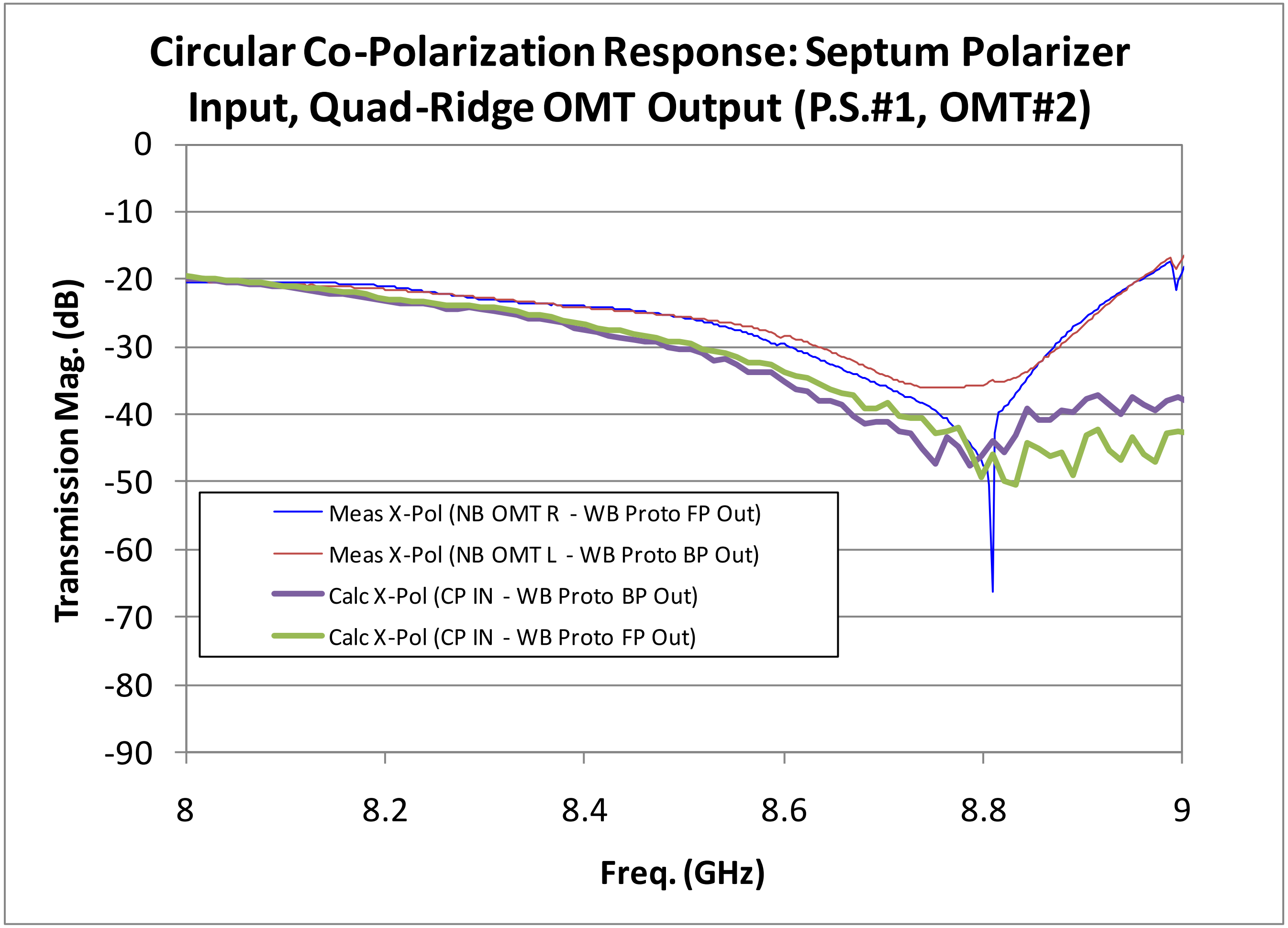




Circular Polarization Performance

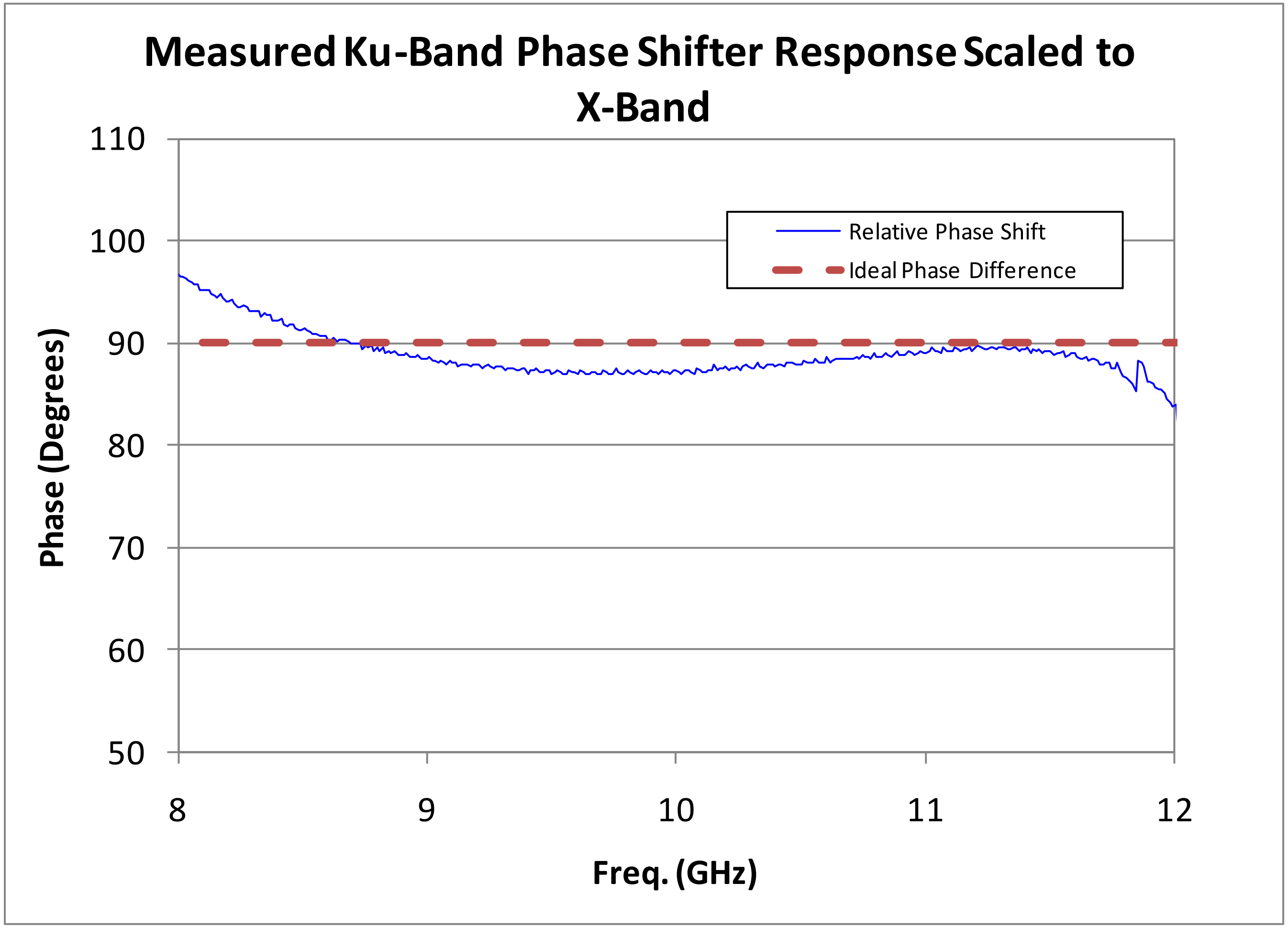


Circular Polarization Performance

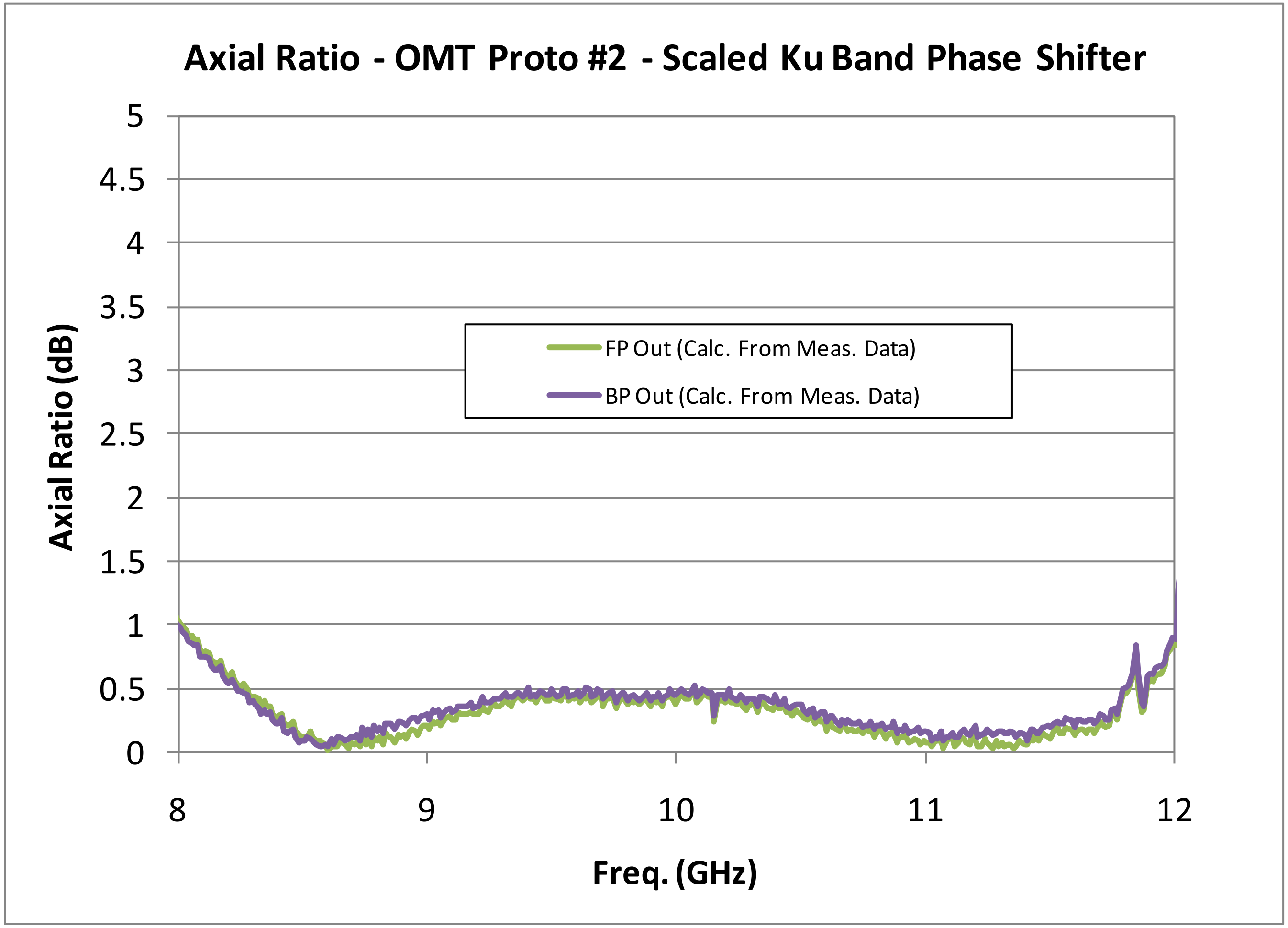


Measured Circular Polarization Performance using Scaled Ku-Band Phase Shifter Experimental Data

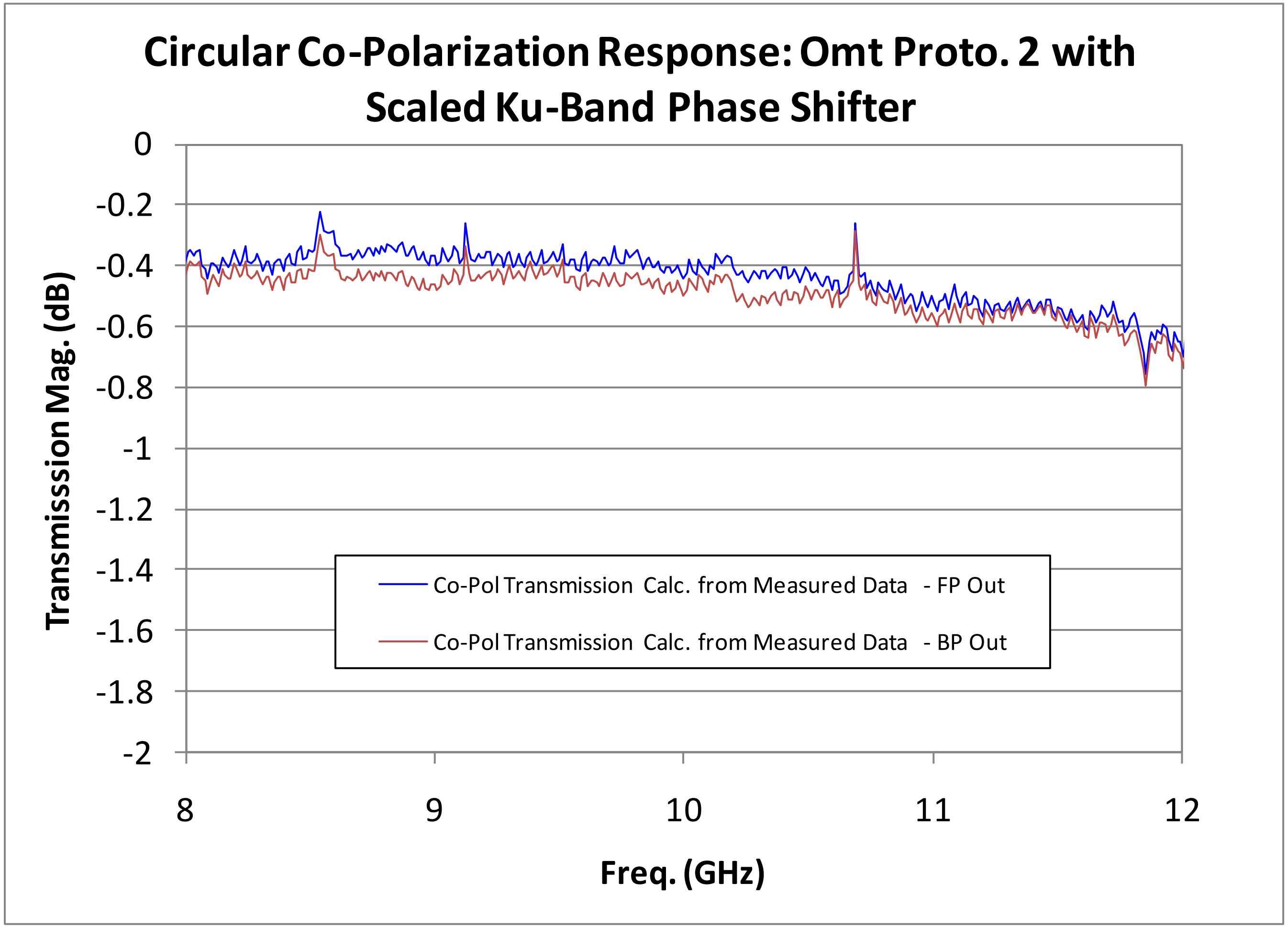
Scaled Phase Shifter Performance



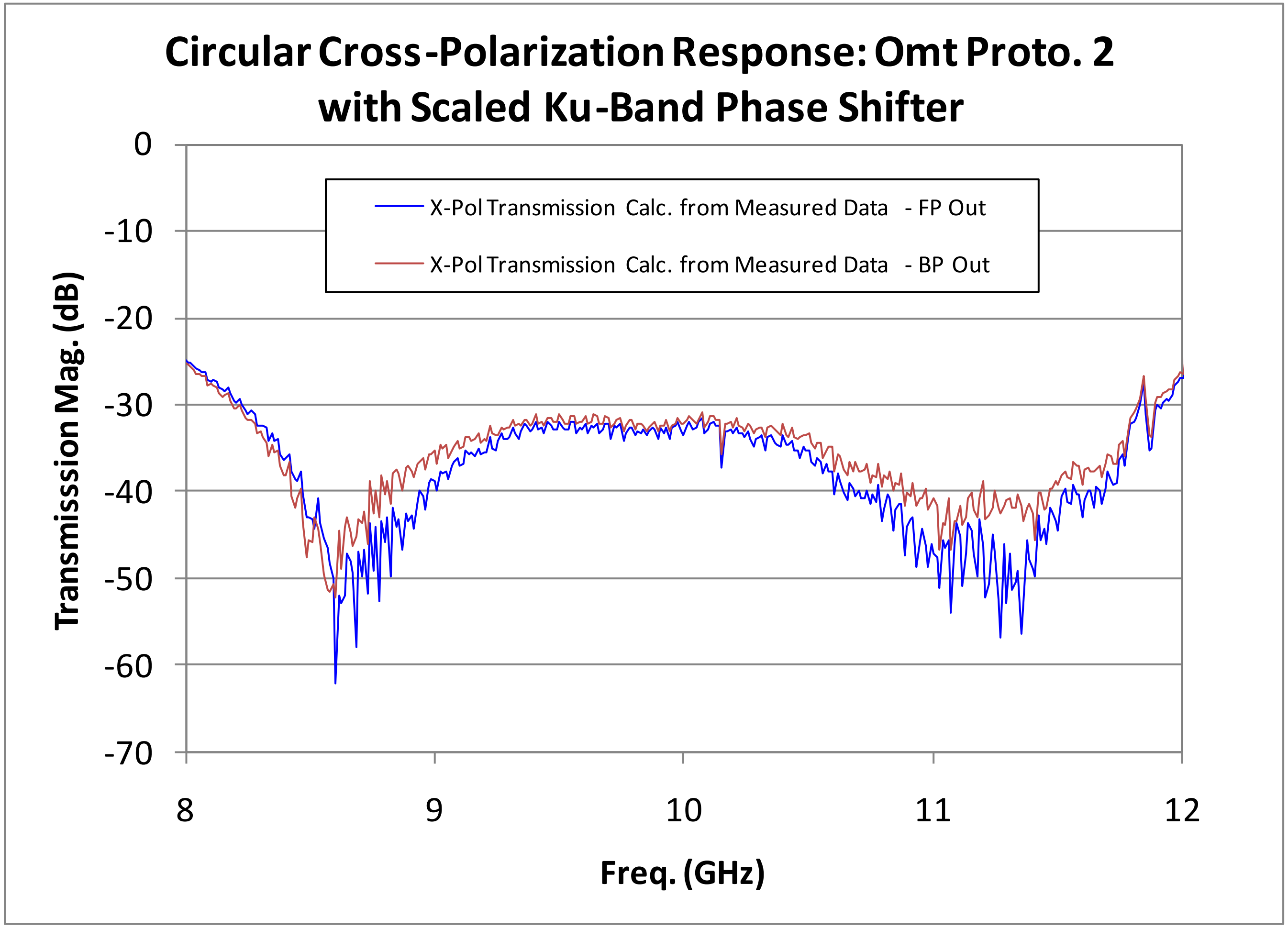
Measured Axial Ratio Performance using Scaled Ku-Band Phase Shifter Data



Circular Polarization Performance

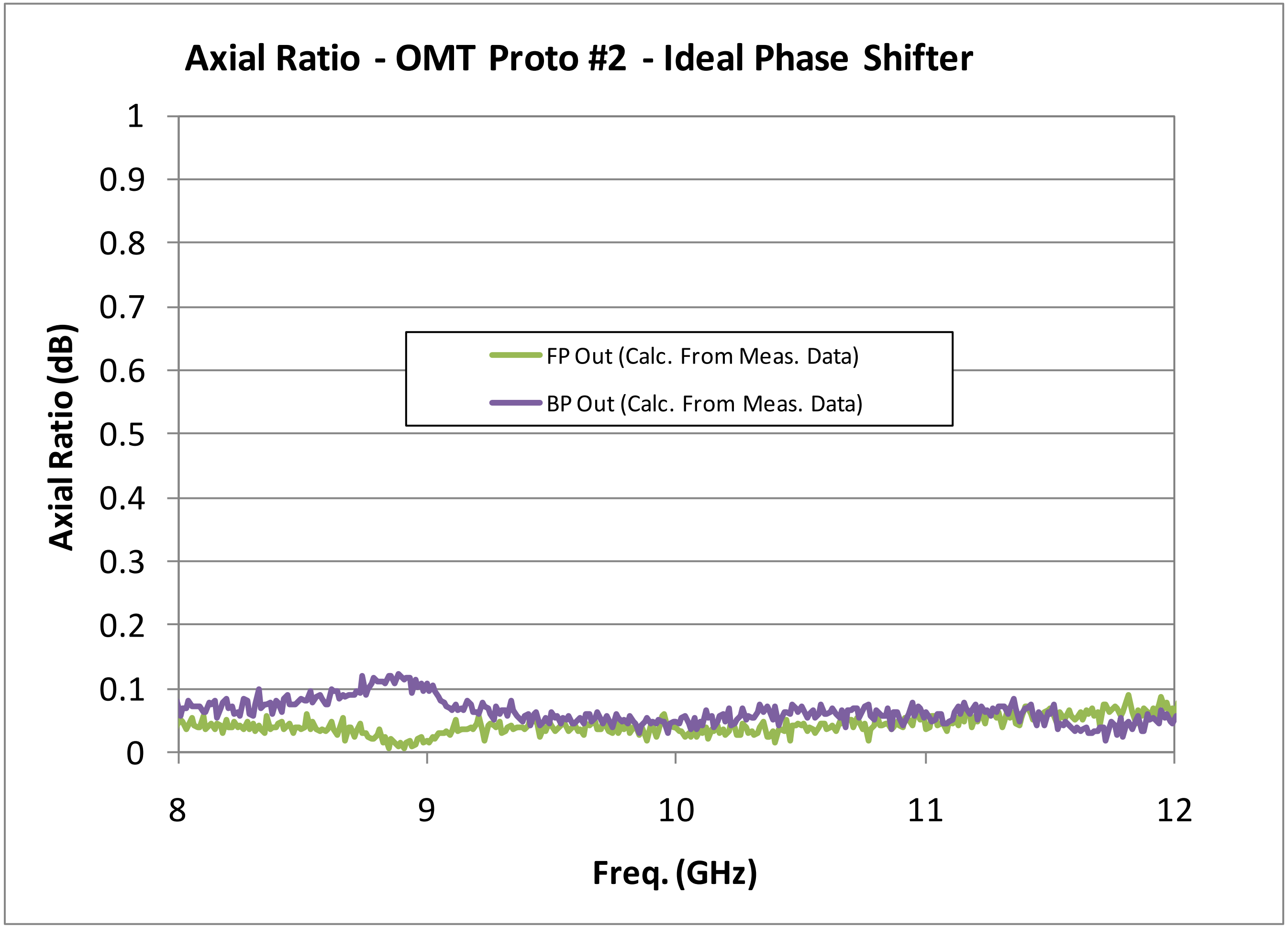


Circular Polarization Performance

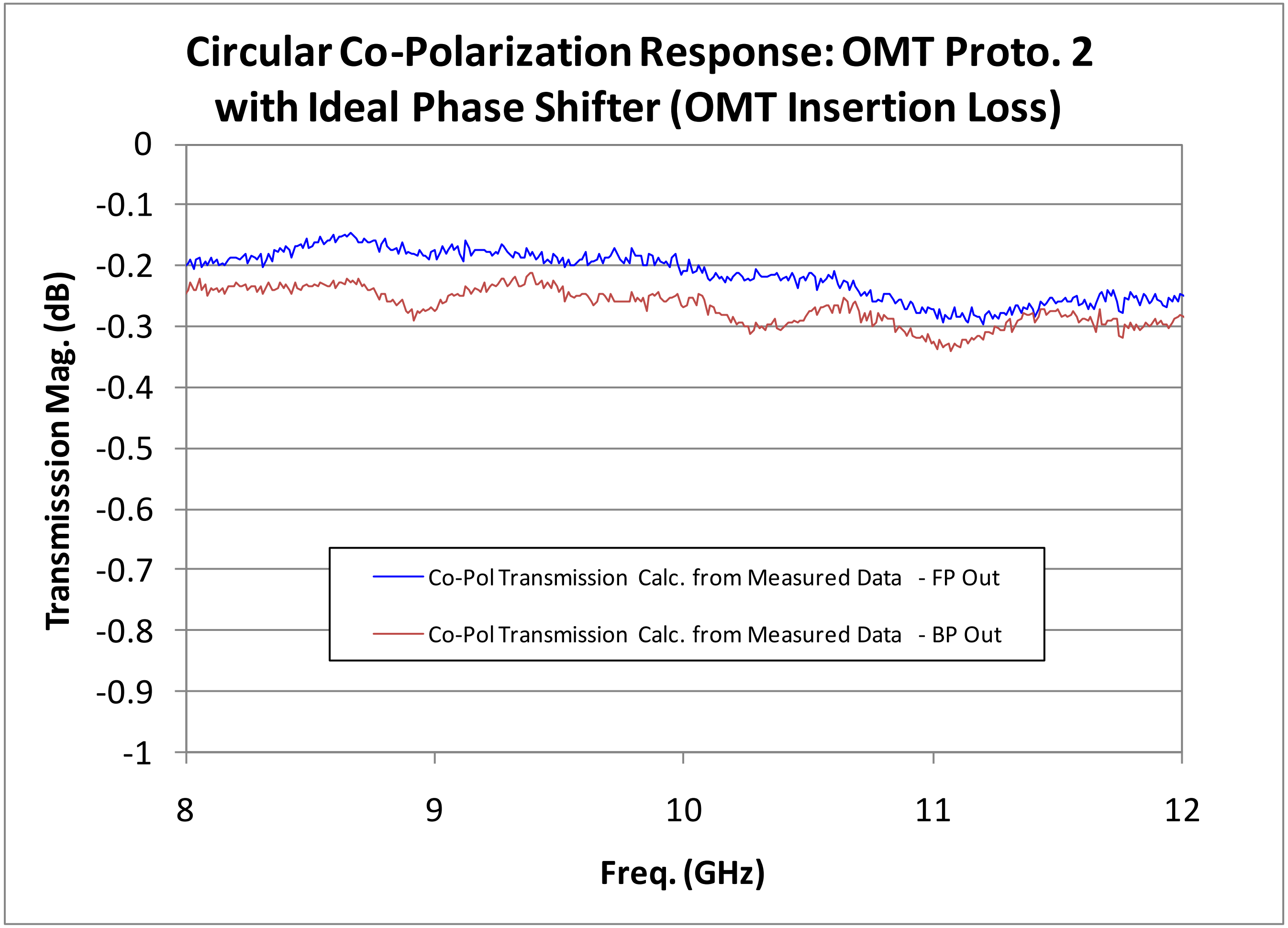


Circular Polarization Performance using Measured OMT Data and Ideal Phase Shifter

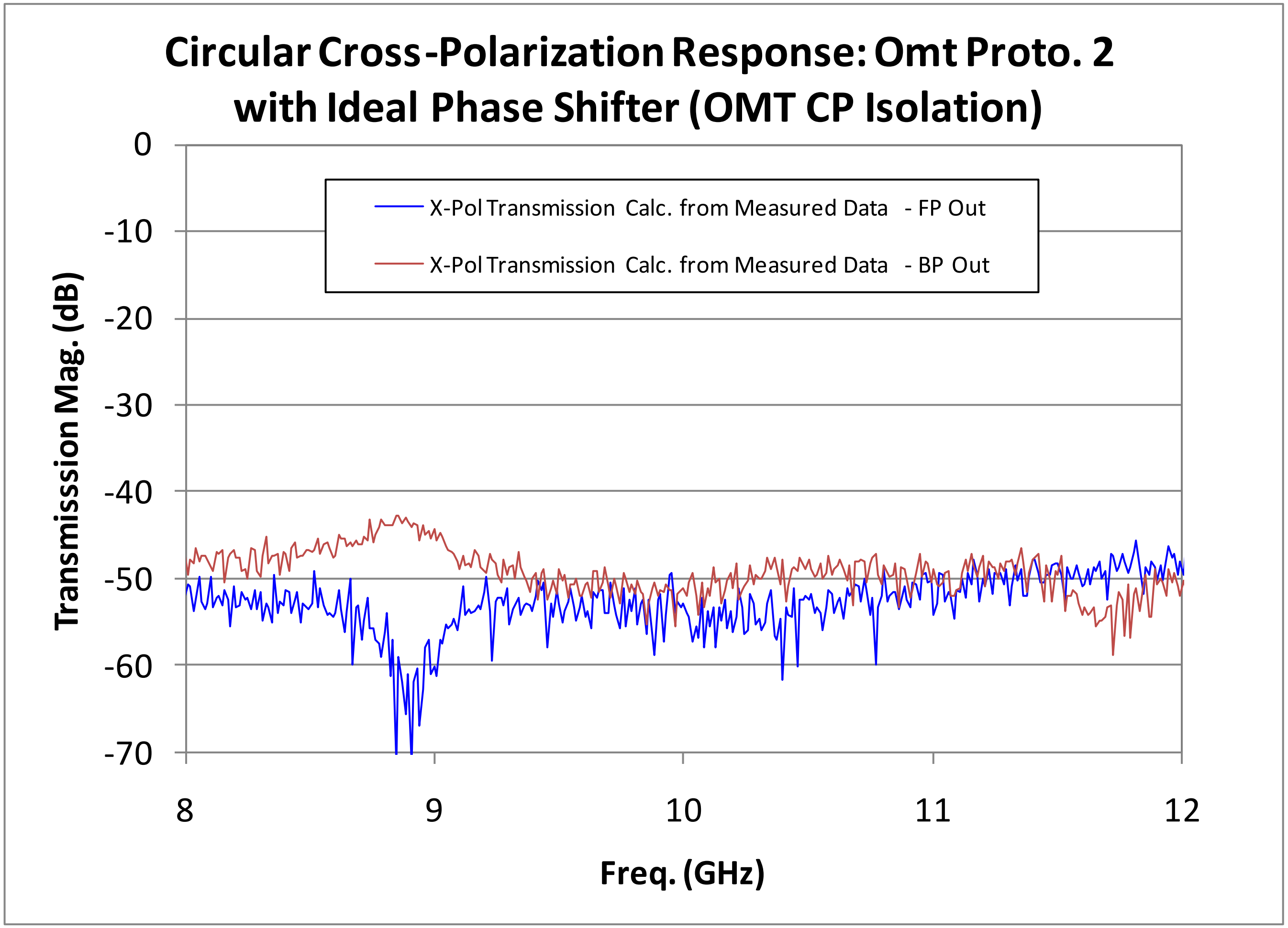
OMT Contribution to Axial Ratio



OMT CP Insertion Loss



OMT CP Isolation



Conclusions

- A novel 45 degree offset quadruple-ridge OMT design is proposed for the new EVLA wideband X-Band receivers
- Two prototypes have been fabricated and tested, and exceed specifications by a wide margin
- The compact design is amenable to cooling with a Model 22 refrigerator
- Measured results show that the novel design exhibits good axial ratio and circular polarization performance
- As with the other EVLA quadruple-ridge OMT designs, the new X-Band design is focused on excellent performance, ease of tuning and manufacturability
- The OMT electromagnetic design is ready for production