# A Novel 5 Step Septum Feed Suite

## Swedish EME-meeting May 2013
## SM6FHZ and SM6PGP

## Updated Post Conference Issue

# Outline
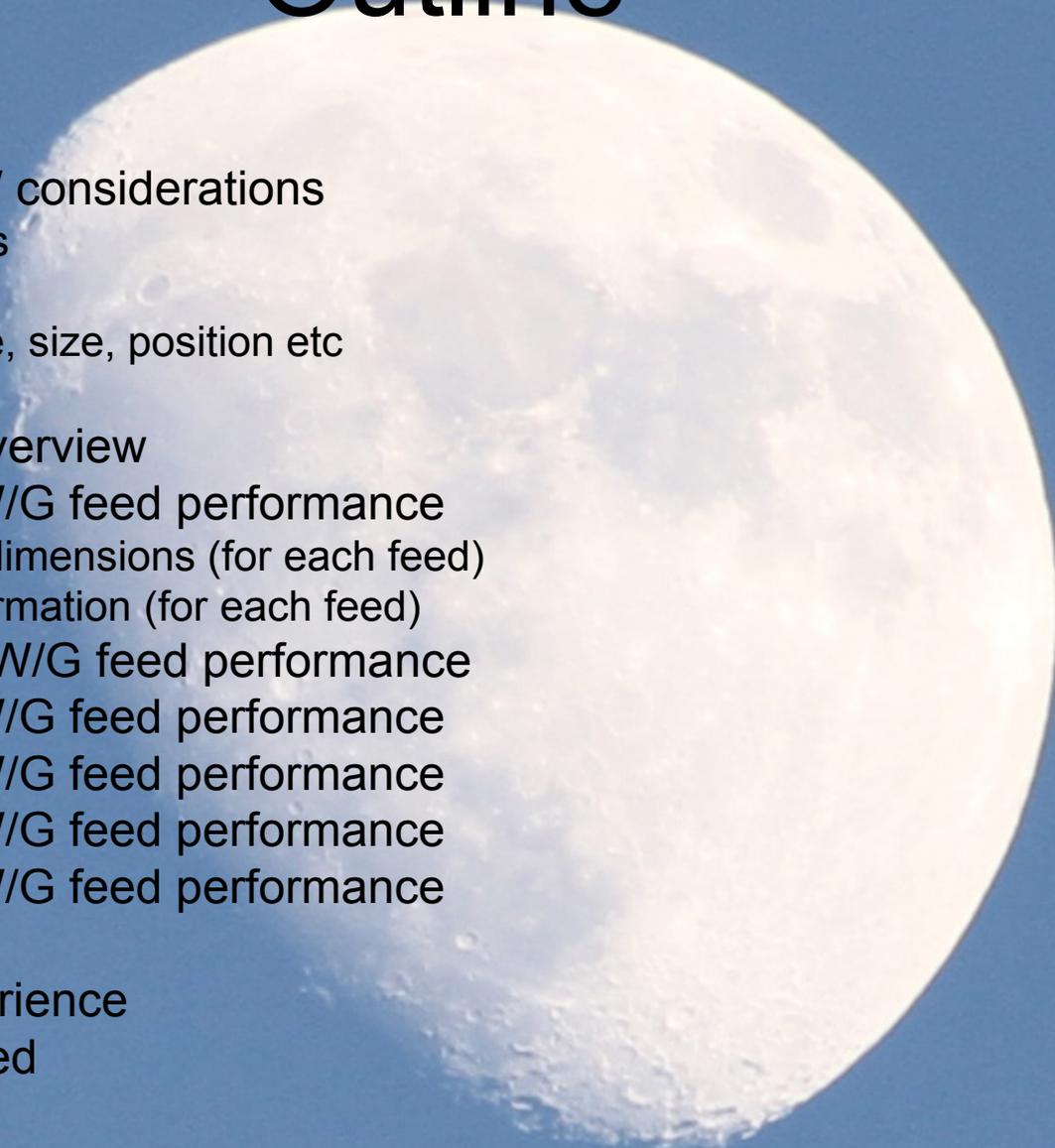
- Prerequisite
- Features
- Design criteria / considerations
  - Wave Guides
  - Septum
  - Kumar choke, size, position etc
  - Probes
- Performance overview
- 23 cm 0.71 L W/G feed performance
  - Mechanical dimensions (for each feed)
  - Detailed information (for each feed)
- 23 cm 0.795 L W/G feed performance
- 9 cm 0.748 L W/G feed performance
- 6 cm 0.749 L W/G feed performance
- 3 cm 0.692 L W/G feed performance
- 3 cm 0.795 L W/G feed performance
- Realization
- On the air experience
- Lessons Learned
- Conclusions

# Prerequisite

- I was in need for a new 23 cm feed to retrofit my 30 year old, ill built and corroded W2IMU feed. Then a need for feeds for the higher bands arose. What to do about that?

- Several existing 23 cm designs were available. I felt the performance had a potential to be improved with proper optimization using contemporary EM-simulation S/W

- Focus was put on f/D 0.32 to 0.42 (my 5.5 m dish is 0.37 f/D)

- N2UO adaptation of the W2IMU Dual Mode feed satisfies the need in the area of f/D's from ~0.42 to ~0.55

- The existing feeds for higher bands are mostly scaled versions of 23 cm feeds. I saw a opening for feeds specifically designed and optimized for the specific band to get the best possible performance

- I have learnt a lot about septums, chokes and wave guides along the way and have had a lot of fun and been frustrated as well at times

# Features

- Two 23 cm 5 step septum feeds for different f/D ranges
- 9, 6 and 3 cm feeds from standard metric plumbing copper or brass tubes
- Unprecedented top notch performance
- Focus on easy manufacturing and low tolerance sensitivity
- Suitable for f/D's ranging from 0.32 to 0.42
- The two 3 cm feeds cover both 10368 and 10450 MHz
- All comprising a Kumar choke structure

# Design criteria

- We strive for
  - Optimum amplitude feed pattern
  - Flat phase response across the full dish surface (small phase errors)
  - Low axial ratio across the full dish surface (low cross polarization)
- We can not get all of this optimized at the same time, so we have to look for the best compromise.
- The W1GHZ feed efficiency evaluation S/W "Phase_CP" has been used for this evaluation.
  - This means that these results can be compared to the results of other feeds evaluated using the same S/W.
  - Phase_CP is the latest version of Pauls evaluation S/W and takes Cross Polar Radiation as well as radiation in the diagonal cuts into consideration for the performance calculation. The earlier version did not do that. This gives a more correct picture of the performance of each feed.
  - Phase_CP can be used for both circularly and linearly polarized feeds with great success

# Wave Guide modes

- The lowest mode that propagate in a circular WG is called TE11.

E-field

H-field
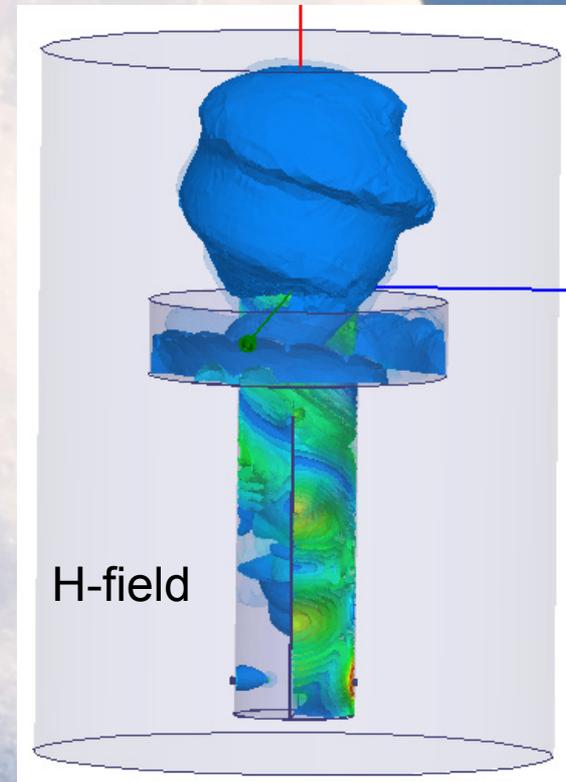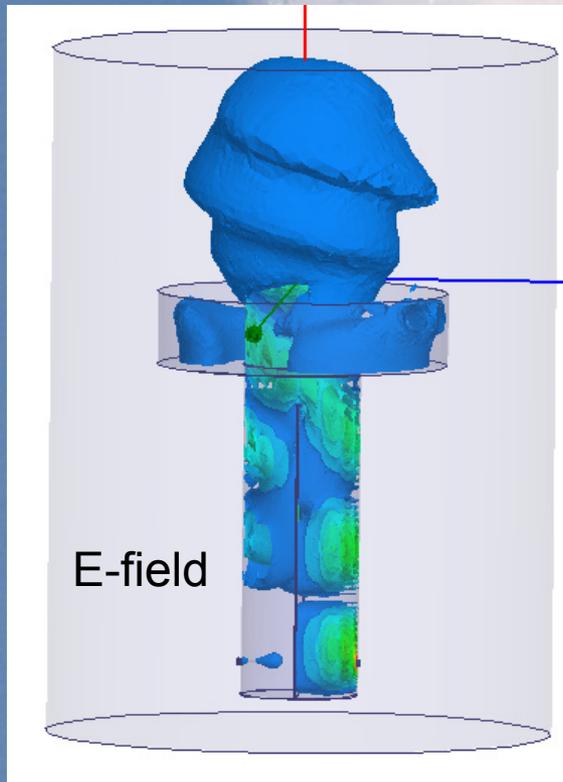
# Wave Guide size and λg (10368 MHz)/ λc for TE11
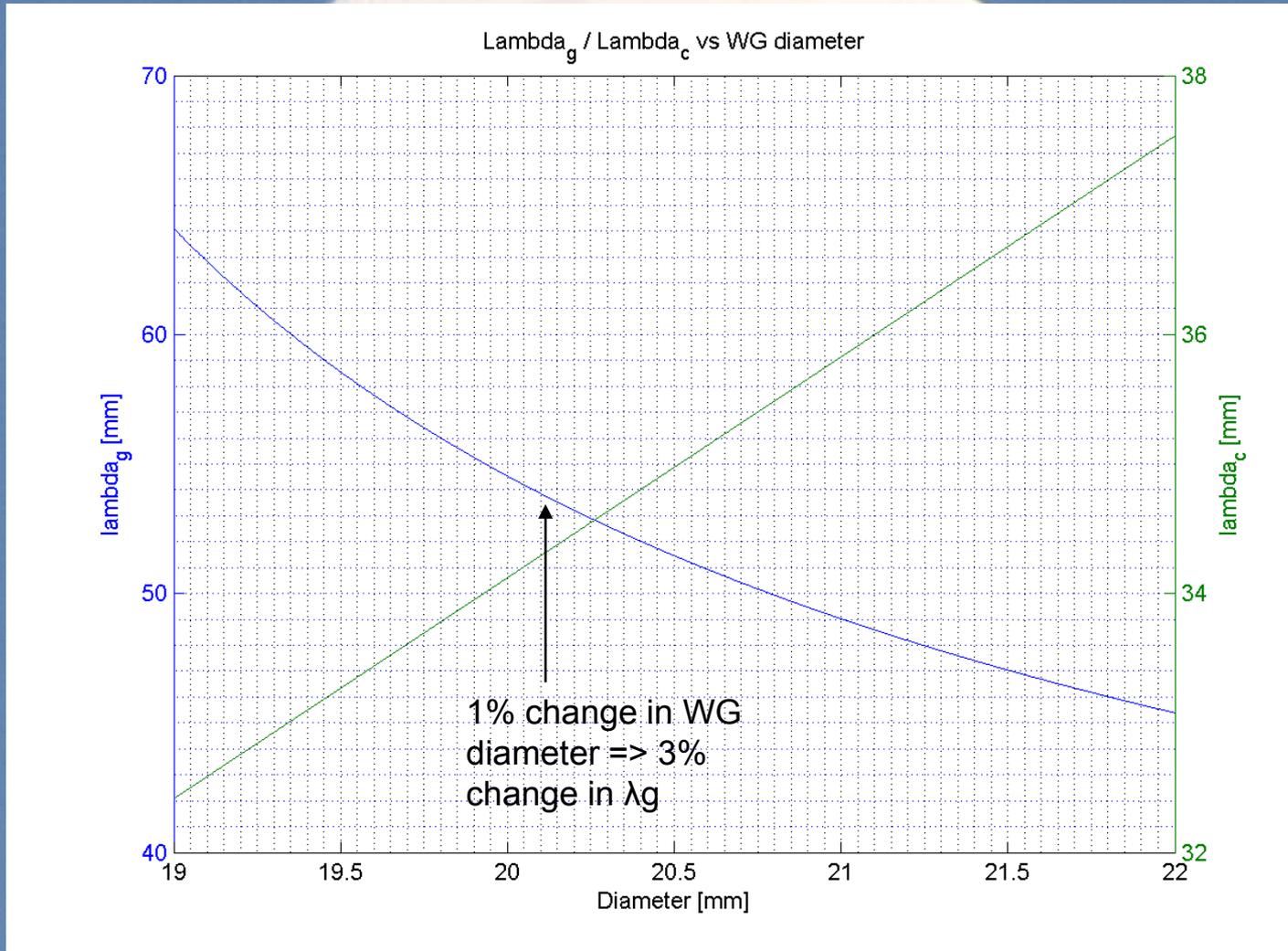
# Septum considerations

- The septum shall generate a circularly polarized wave in a way that it contains only one polarization direction in each port.
This ensures that we have

  - Good Axial Ratio

  - Low Cross Polar Radiation

- It shall also ensure good isolation between the two ports, Tx and Rx

- It shall do this over a reasonable band width

- In these designs this is accomplished by using a 5 step septum plate
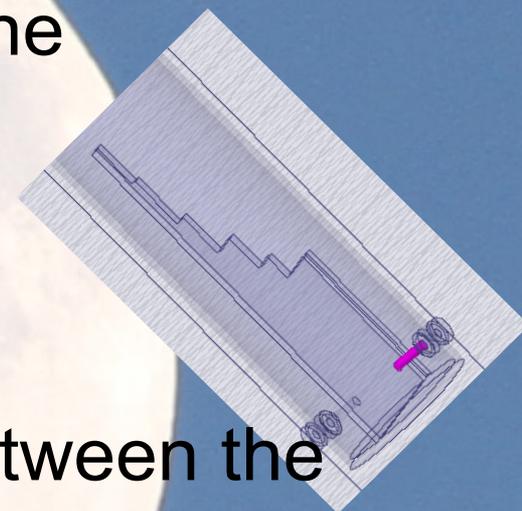
# E-field variation over a full cycle
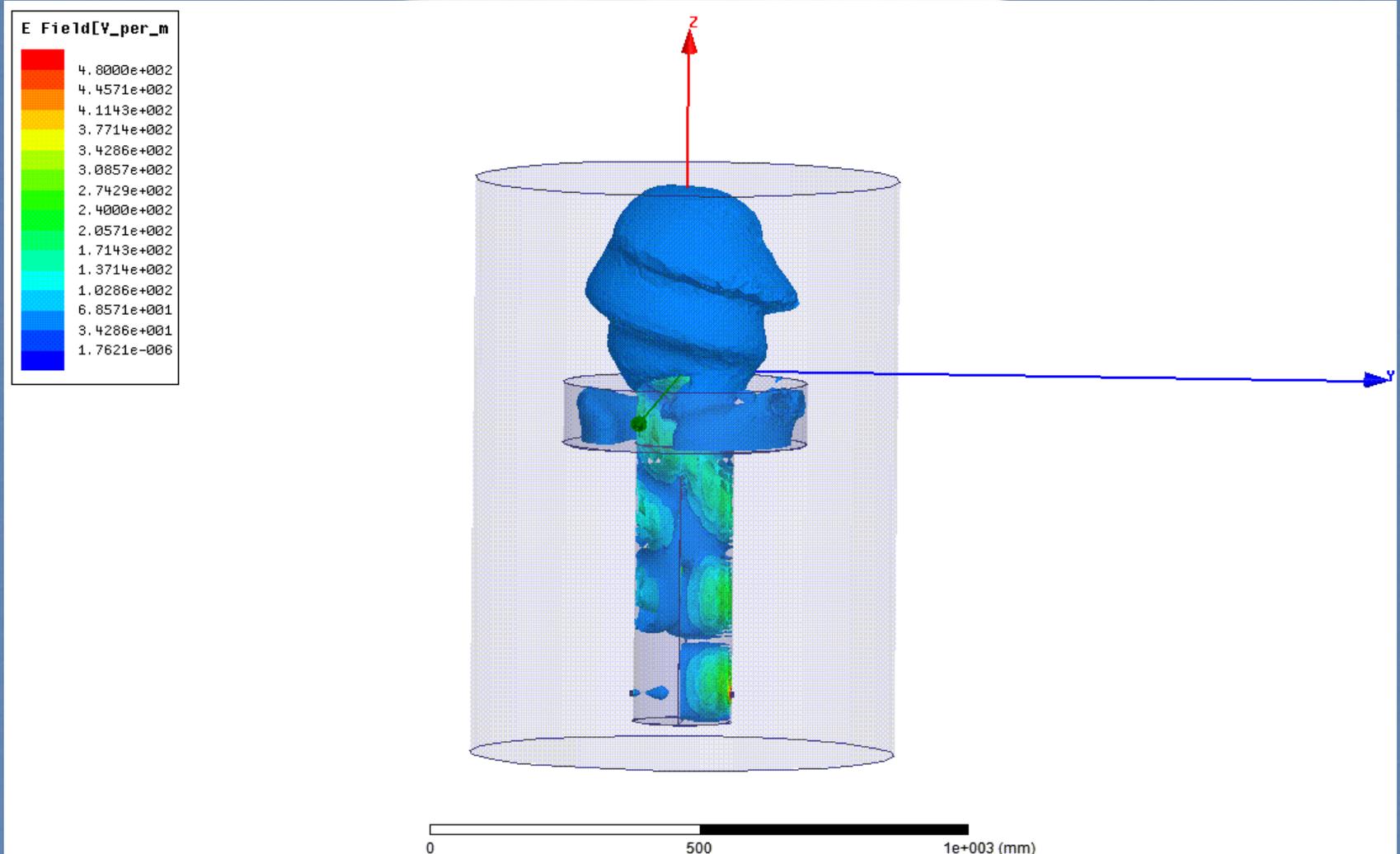
# Feed without choke

- No beam shaping in Co-pol
- High Cross-pol level in 180 deg
- Mediocre efficiency
- High noise temperature
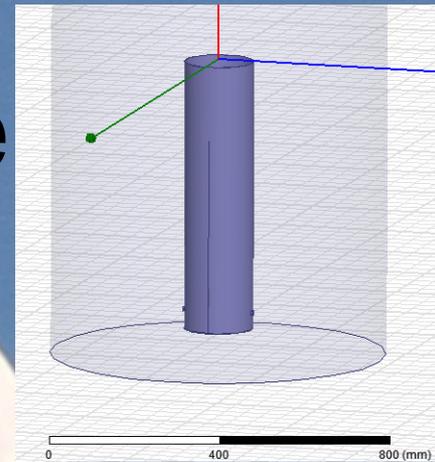
SM6FHZ 23 cm septum feed w/o choke
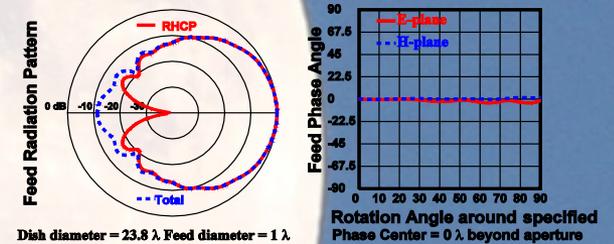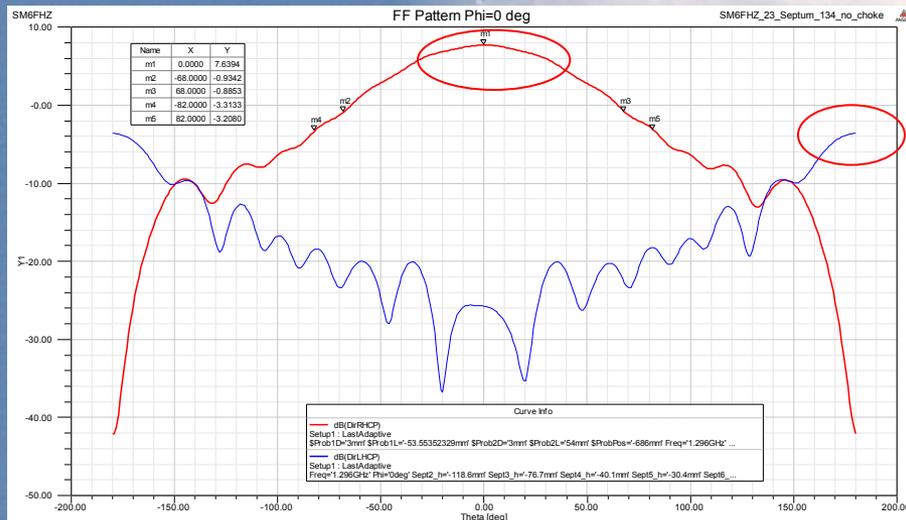
Dish diameter = 23.8 λ  Feed diameter = 1 λ

Phase Center = 0 λ beyond aperture

Feed Radiation Pattern

RHCP
Total

Feed Phase Angle
E-plane
H-plane
Rotation Angle around specified

Parabolic Dish Efficiency %

MAX Possible Efficiency with XPOL loss & Phase error
MAX Possible Efficiency with Phase error
MAX Efficiency without phase error
REAL WORLD at least 15% lower

AFTER LOSSES:
Illumination
Spillover
Feed Blockage

Parabolic Dish f/D

W1GHZ 1998-2010

FF Pattern Phi=0 deg

SM6FHZ_23_Septum_134_no_choke

| Name | X | Y |
|------|------|---------|
| m1 | 0.0000 | 7.6394 |
| m2 | -68.0000 | -0.9342 |
| m3 | 68.0000 | -0.8853 |
| m4 | -82.0000 | -3.3133 |
| m5 | 82.0000 | -3.2080 |

Curve Info
dB(DirRHCP)
Setup1 : LastAdaptive
$Prob1D='3mm' $Prob1L='-53.55352329mm' $Prob2D='3mm' $Prob2L='54mm' $ProbPos='-686mm' Freq='1.296GHz' ...
dB(DirLHCP)
Setup1 : LastAdaptive
Freq='1.296GHz' Phi='0deg' Sept2_h='-118.6mm' Sept3_h='-76.7mm' Sept4_h='-40.1mm' Sept5_h='-30.4mm' Sept6_...

# Why a Kumar choke?

- The Kumar choke is a efficient yet simple way of shaping the radiation pattern of the feed.

- It was first described by Dr. A. Kumar [ Reduce Cross-Polarization In Reflector-Type Antennas, Microwaves, March 1978 ] and has been used by VE4MA in his feed designs.

- It has some limitations and interactions with the other parts of the feed.
  - The Axial Ratio at angular offsets from bore sight is controlled by the choke
  - The Return Loss and Isolation is not affected by the choke
  - The radiation pattern can be controlled by the position and the size of the choke

- Less elaborate than the Scalar choke but comparable or superior performance

- It can be optimized using EM-simulation SW.

# Septum - choke interaction
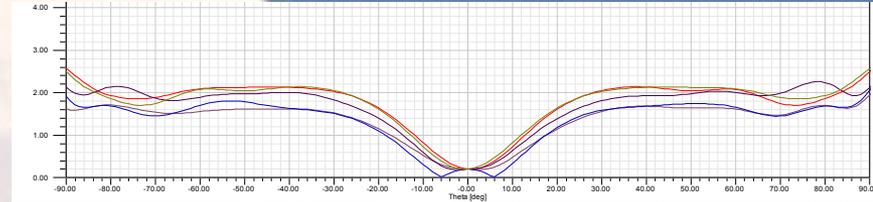
- Axial ratio optimization
  - The septum sets the Axial Ratio at bore site and the choke governs the performance at angular off-sets from bore sight
  - The choke does not change the axial ratio at bore sight very much
- A well functioning septum is essential for getting a decent axial ratio also off bore sight

# Choke impact on radiating pattern

- There is a contradiction between the wanted amplitude pattern and the phase error with respect to illumination angle

- By adjusting the choke position and dimensions you can find the best compromise

- Moving the choke with respect to the W/G mouth does not directly scale the feed pattern for other f/D's. There is a price to pay.

- The best way to strive for optimal performance at other f/D's is to change the dimension of the W/G mouth

- There are limitations on how much you can change the dimension of the W/G and maintaining the same W/G propagation mode

- W2IMU uses this in his "Dual Mode Feed" going to a higher mode as well as the first mode in the outer WG-section in an controlled way

# FF Pattern quick comparison
## Choke position relative WG-mouth



0L



-0.05L



-0.1L



-0.15L



-0.18L



-0.2L



-0.25L



-0.3L

SM6FHZ 2010-06-10
Rev B

Swedish EME meeting May 2010

14
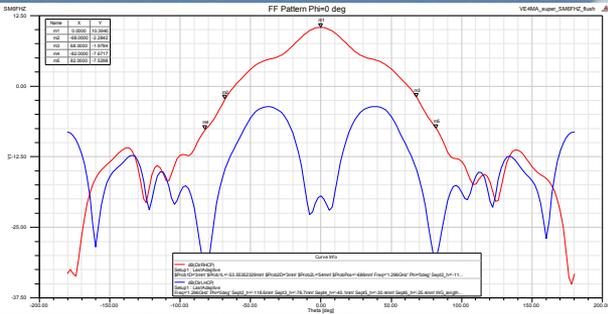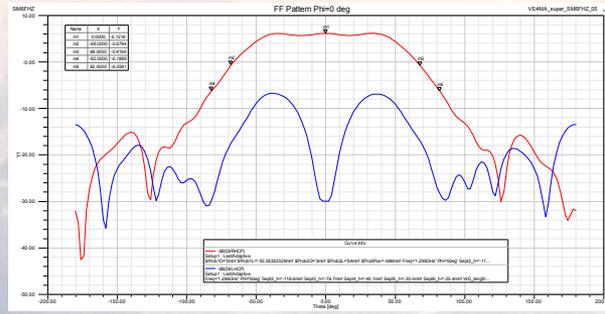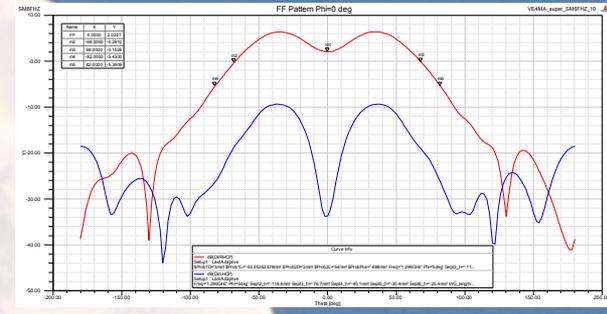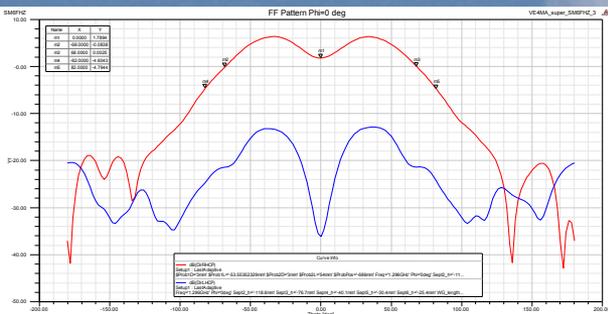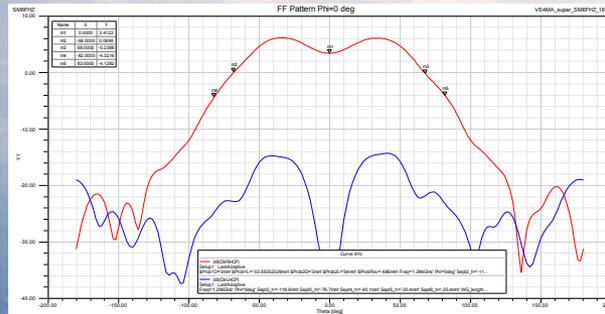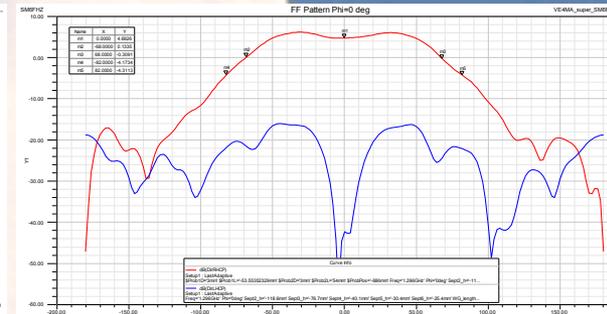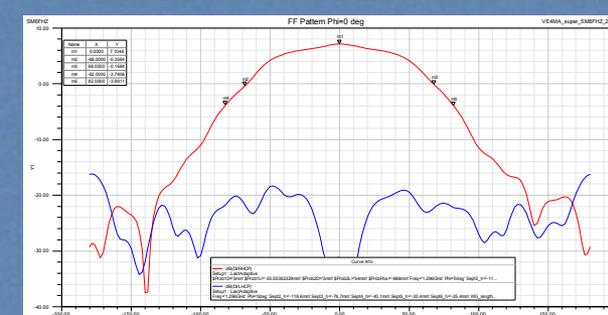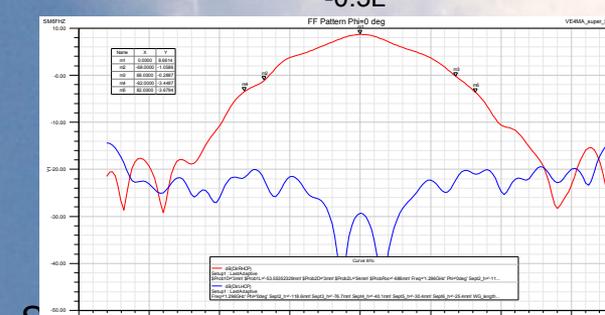
# FF Phase error quick comparison
# Choke position relative WG-mouth



0L



-0.05L



-0.1L
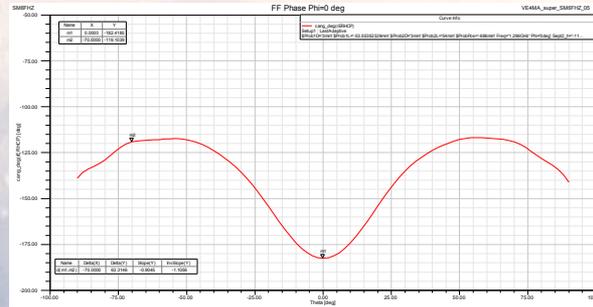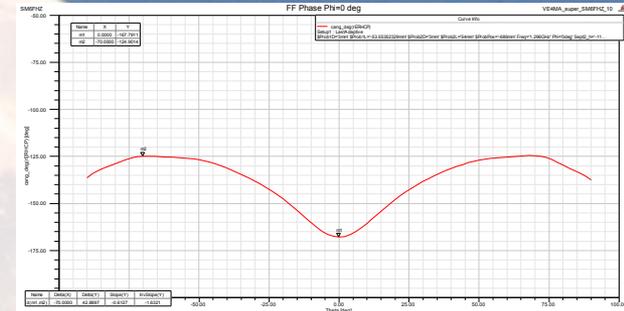


-0.15L



-0.18L



-0.2L



-0.25L



-0.30L

Rev B
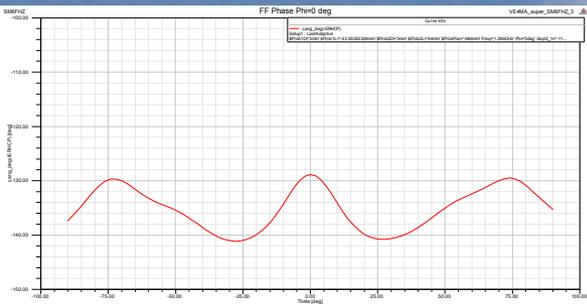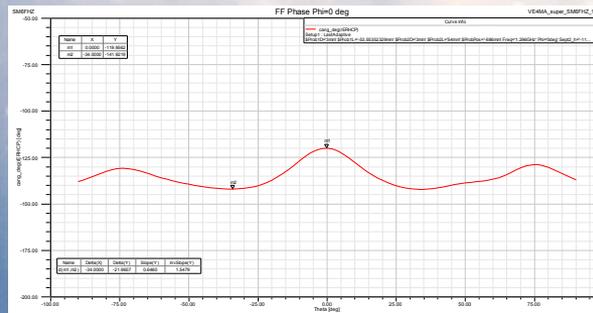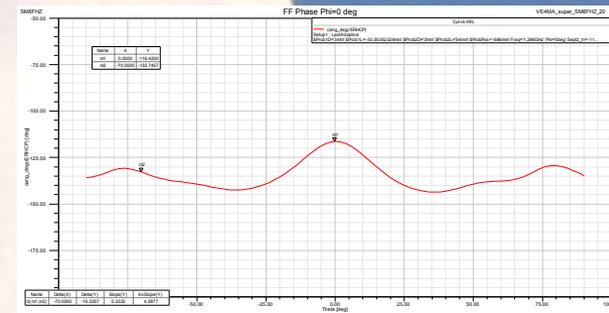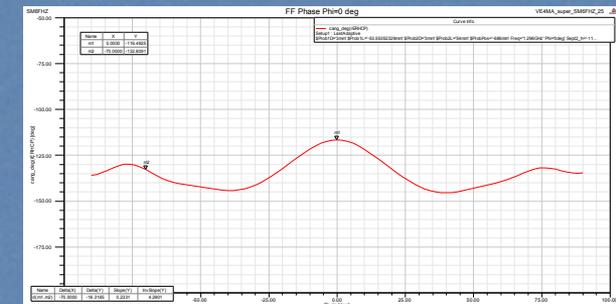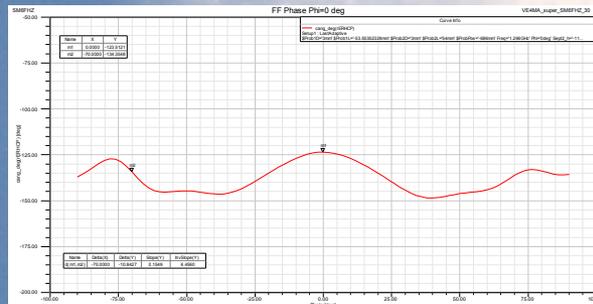
# Axial Ratio quick comparison
## Choke position relative WG-mouth



0L

-0.05L

-0.1L

-0.15L

-0.18L

-0.2L

-0.25L

-0.3L

Rev B
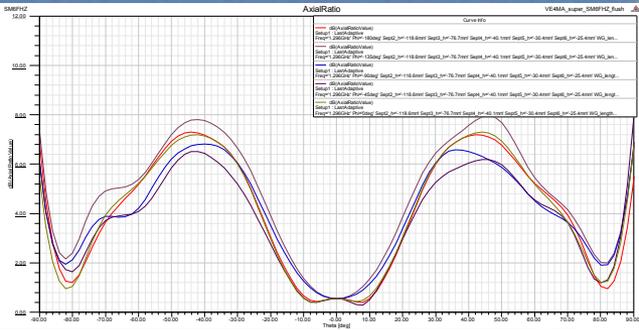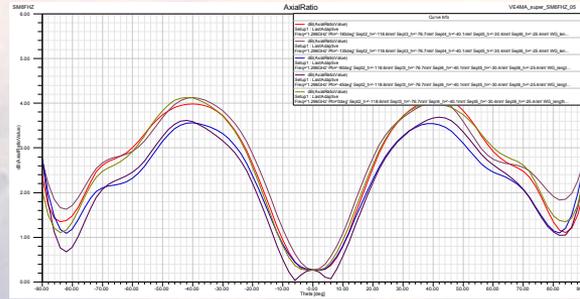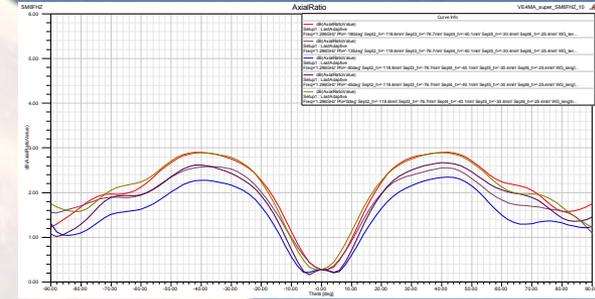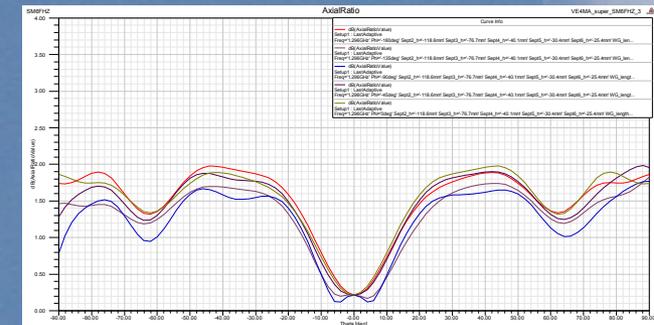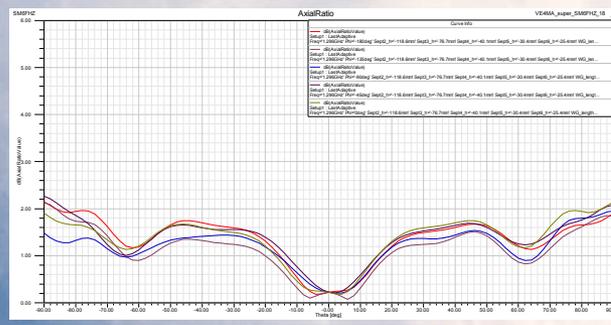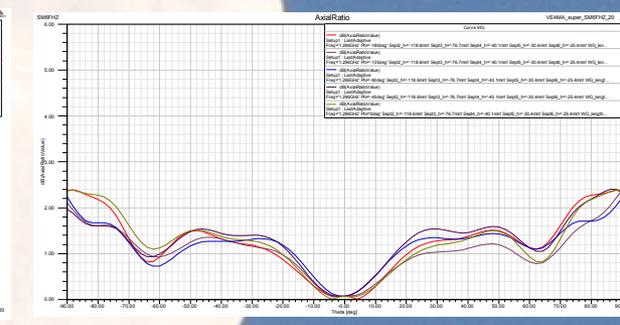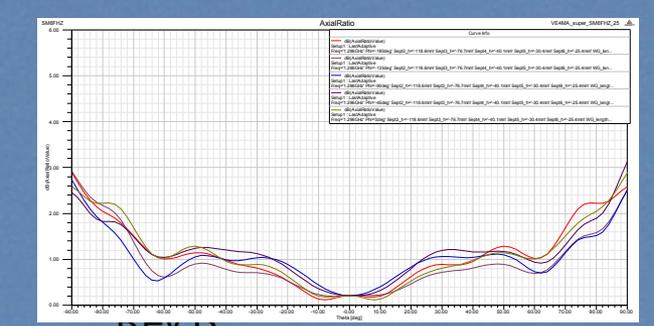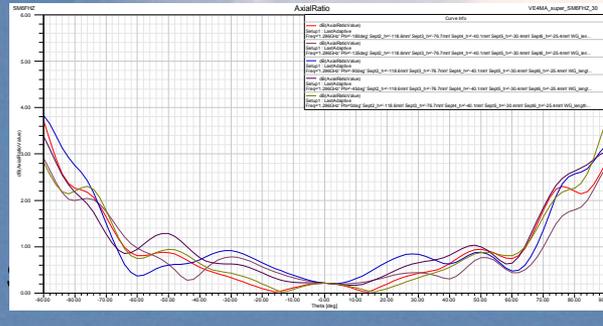
# Putting the Feed in a Dish
## Dish Reflexion

- Pointing your feed into the dish will result in a reflected wave from the dish entering the feed.

- The level of the reflexion coefficient (Γ) will be dependant on the gain of the feed (G), lambda (λ) , and the focal length of the dish (f).

$$\Gamma = \frac{G\lambda}{4\pi f}$$

# Putting the Feed in a Dish
## Dish Reflexion

- How bad can it get?
  - With a linear feed you will see the reflected wave on the Tx port but with a circular polarized feed the reflected wave will show up in the Rx port due to the phase reversal upon the reflexion in the dish surface. This affects the isolation between Tx and Rx.
  - 1296 MHz, VE4MA type feed in a 5.5m, 0.37 f/D dish will result in 29 dB RL.
  - 1296 MHz, W2IMU type feed in a 8m, 0.45 f/D dish will result in 26 dB RL.
  - 5760 MHz, VE4MA type feed in a 5.5m, 0.37 f/D dish will result in >40 dB RL.
  - 5760 MHz, VE4MA type feed in a 2m, 0.37 f/D dish will result in 33 dB RL.
  - 10368 MHz, VE4MA type feed in a 5.5m, 0.37 f/D dish will result in 47 dB RL.
  - 10368 MHz, VE4MA type feed in a 2m, 0.37 f/D dish will result in 38 dB RL.
- A spread-sheet can be found on my web page for your own further testing.
- RA3AQ proposes using a small metal coin in the centre of the feed aperture in order to fine tune the isolation in situ. This need to be done specifically for each installation but can yield excellent isolation over a narrow frequency band
- Summary.
  - This reflexion is not a major problem on the higher bands on larger dishes.
  - If the reflexion is down below the 30 dB RL region you may consider to address it.

# InDish Performance

## A quick look at all 5 feeds

# InDish Performance 23 cm (5.5 m dish)

**SM6FHZ 23 cm Septum feed 0.71L WG**

**SM6FHZ 23 cm septum feed 0.795L WG**
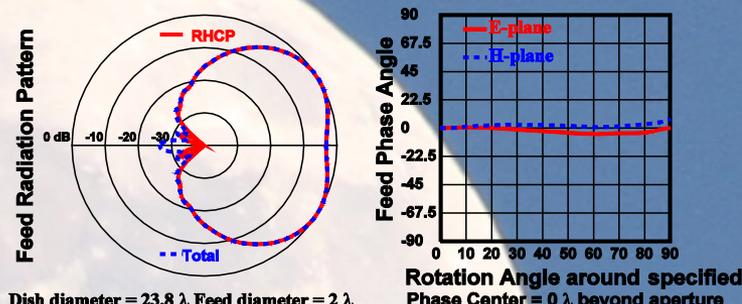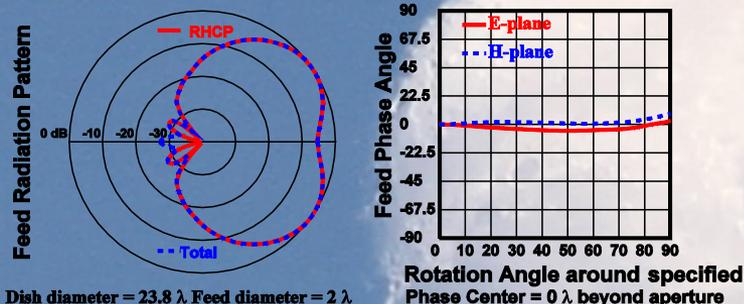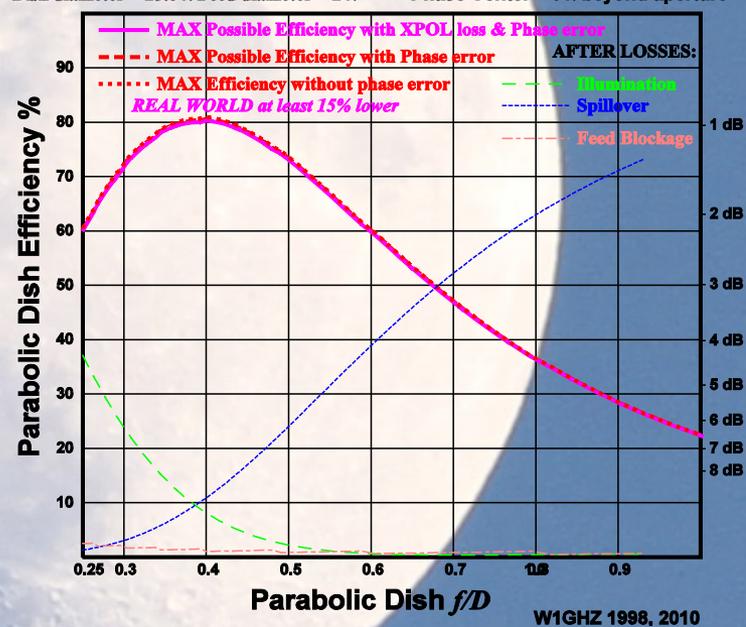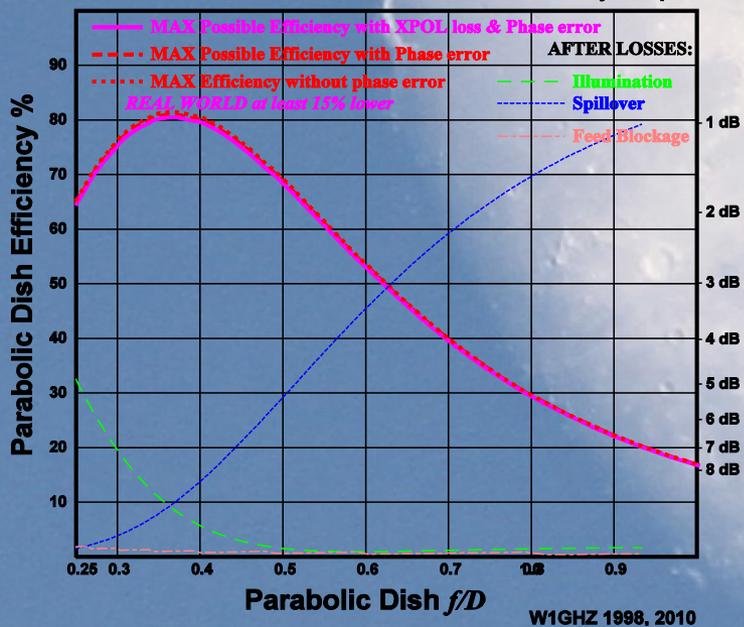


23 cm 0.71 L W/G feed performance

23 cm 0.795 L W/G feed performance

# InDish Performance 9/6 cm

**SM6FHZ 9 cm Kumar feed**

**SM6FHZ Kumar 6 cm 0.125 wl**
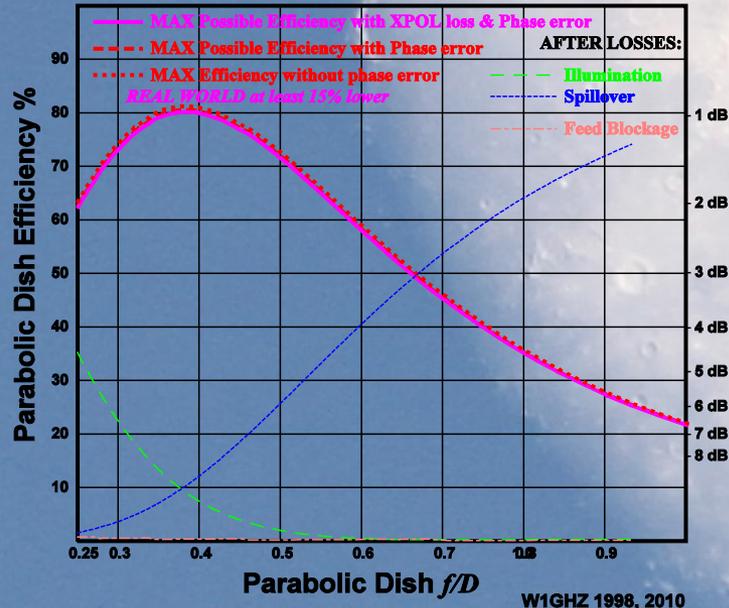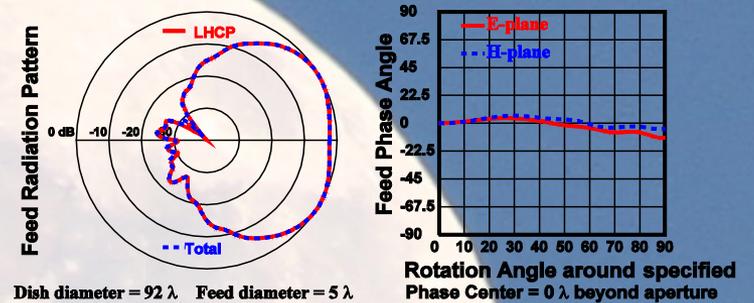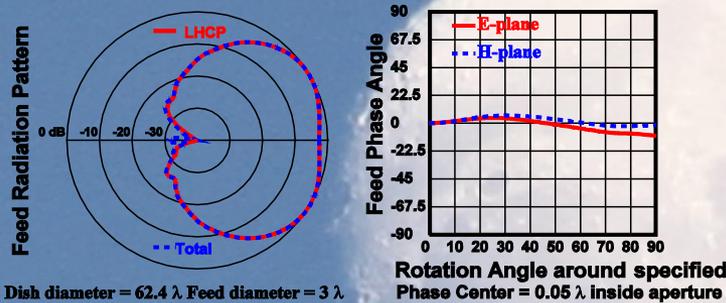


9 cm feed performance
(5.5m dish)
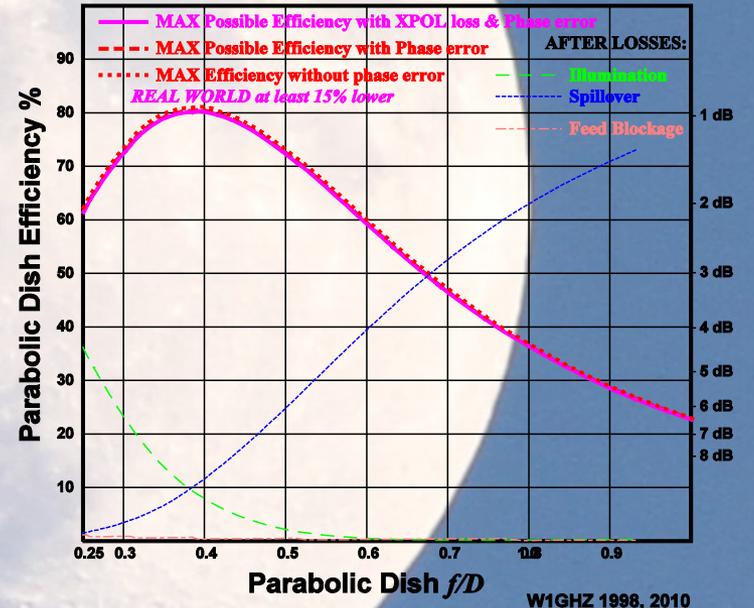
6 cm feed performance
(5.5 m dish)

# InDish Performance 3 cm (1.8 m dish)

**SM6FHZ 3 cm septum feed 0.692L WG**
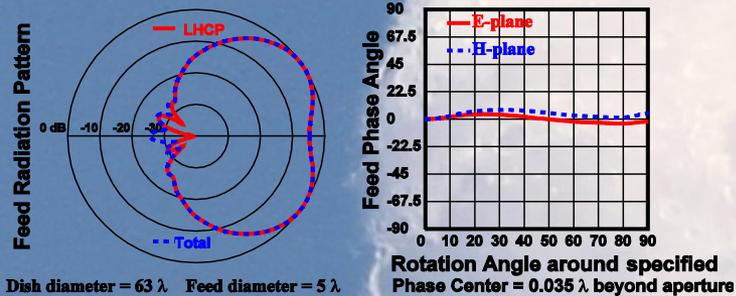
**SM6FHZ 3 cm septum feed 0.795L WG**
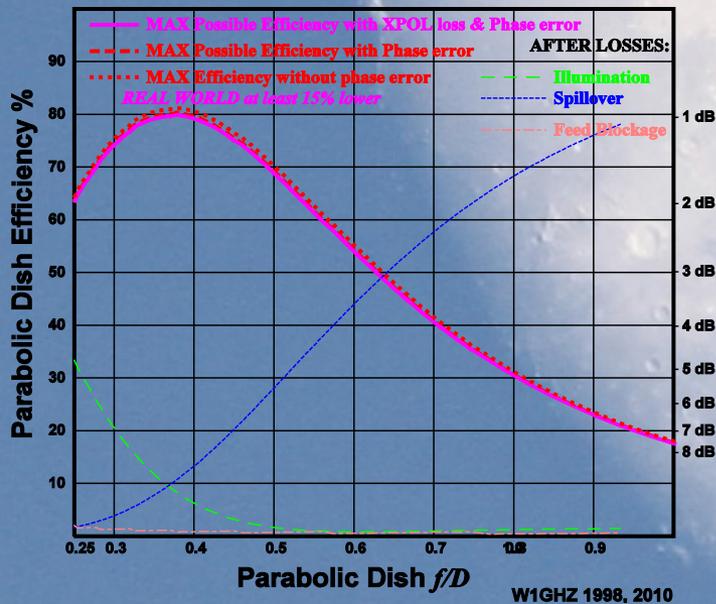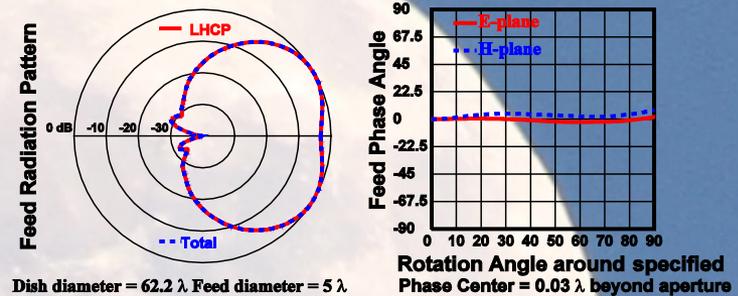


3 cm 0.692 L W/G feed performance
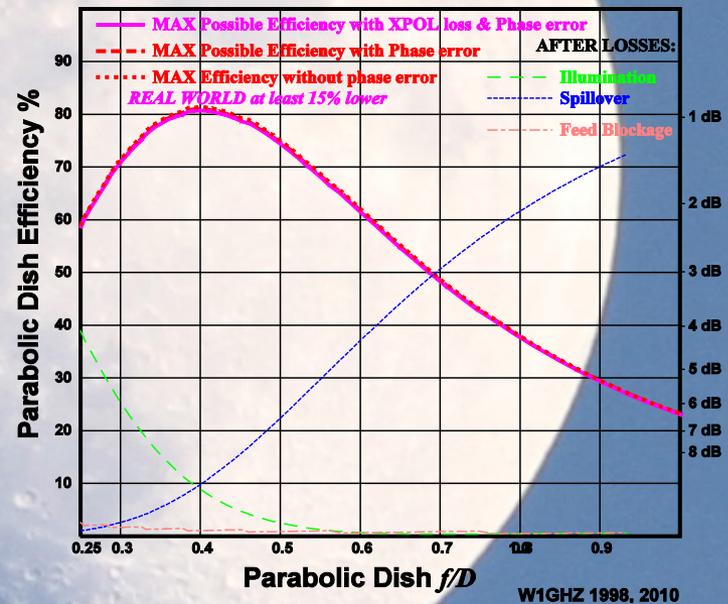
3 cm 0.795 L W/G feed performance

SM6FHZ 23 cm 5 step septum feed

0.71 lambda W/G

# Solid and transparent models from the simulation
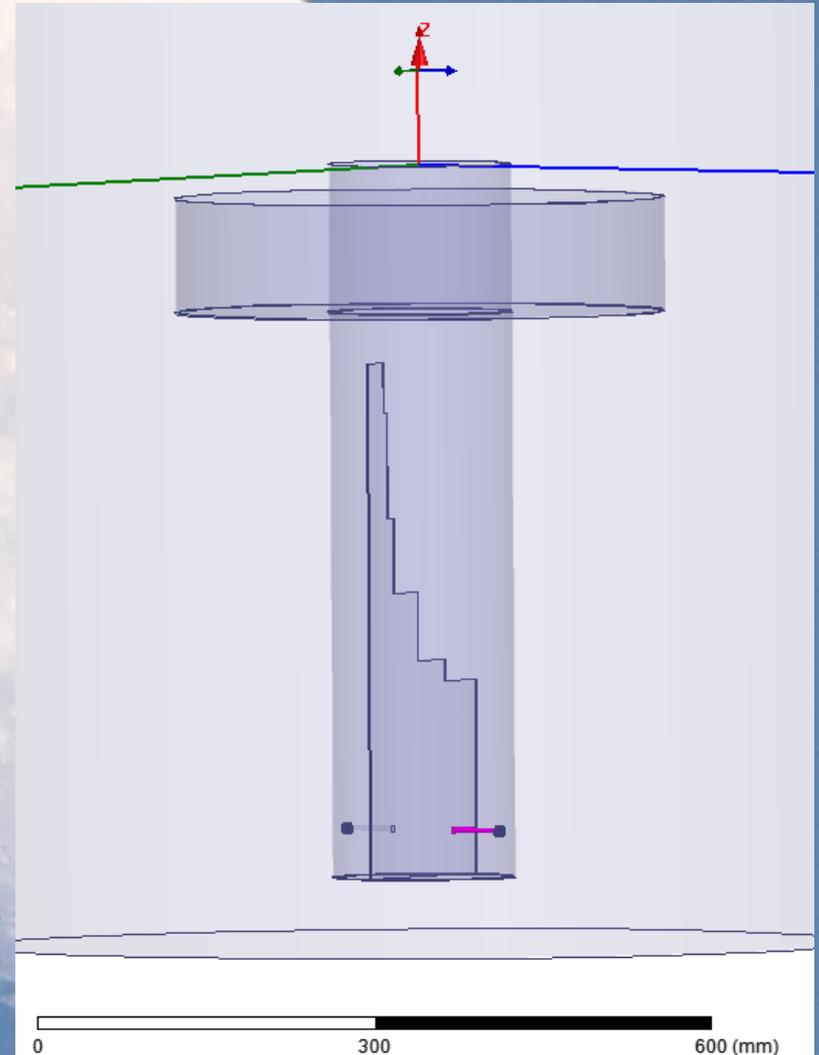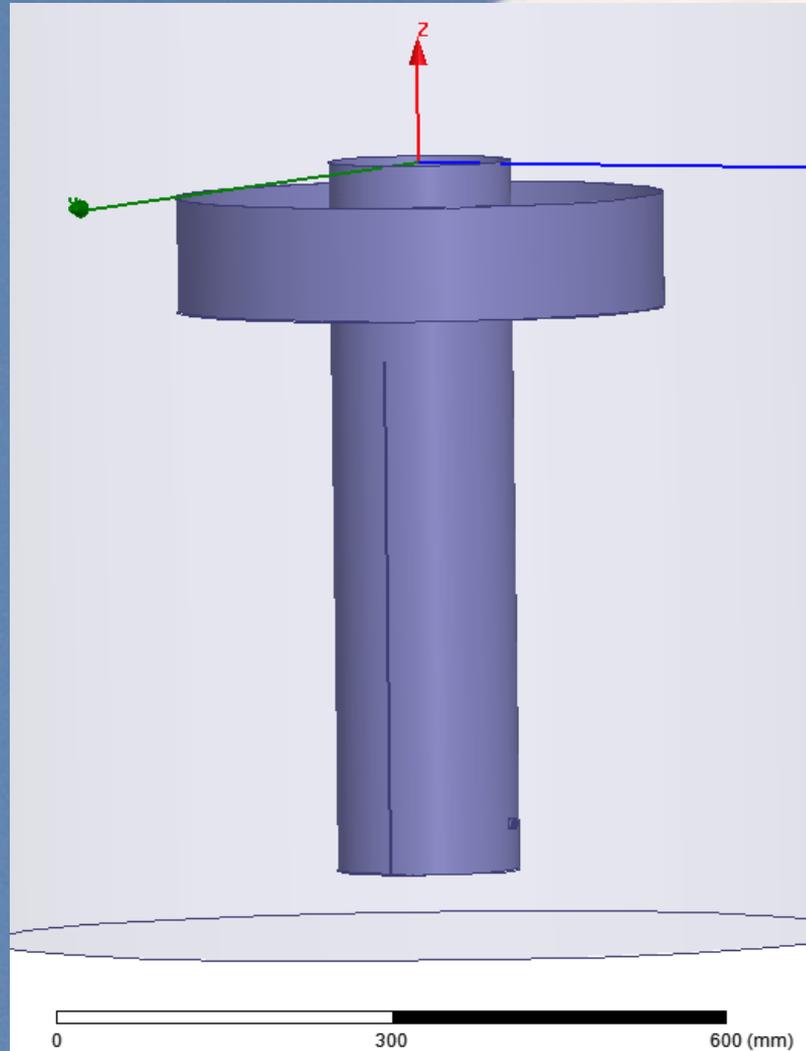
# WG and choke dimensions

Phase center -5.0

31

Circular polarization convention
for EME according to Crawford
Hill Bulletin No 1:

Tx RHCP in space
Rx LHCP in space

105.0
outer

Take polarization reversal into
account when using reflector
antennas.

Tx

LHCP

Rx

RHCP

T= 0.5 wall

T= 1.0 bottom

444.0 outer

654 outer
1.0 mm bottom
plate included

Wave guide
165/164 mm
copper tube

# Septum dimensions



Wave guide
165/164 mm
copper tube

Septum
t = 0.8 mm
copper

Bottom plate
1.0 mm
copper

45.6

24.4

96.5

29.4

68.8

39.1

62.8

75.7

20.3

117.6

177.8
Inner measure
Bottom
plate not
included

164.0

# Probe dimensions



4.0 diam.

51.3

40.7 inner

# S11, S22, S21 combined



S11, S22 and S21 combined

# 3D Total Power Far Field pattern

# Far Field Pattern 0 deg

# Far Field Phase error

# Cross Polar Ratio

# Axial Ratio

# SM6FHZ 23 cm 5 step septum feed

## 0.795 lambda W/G

# Solid and transparent models from the simulation
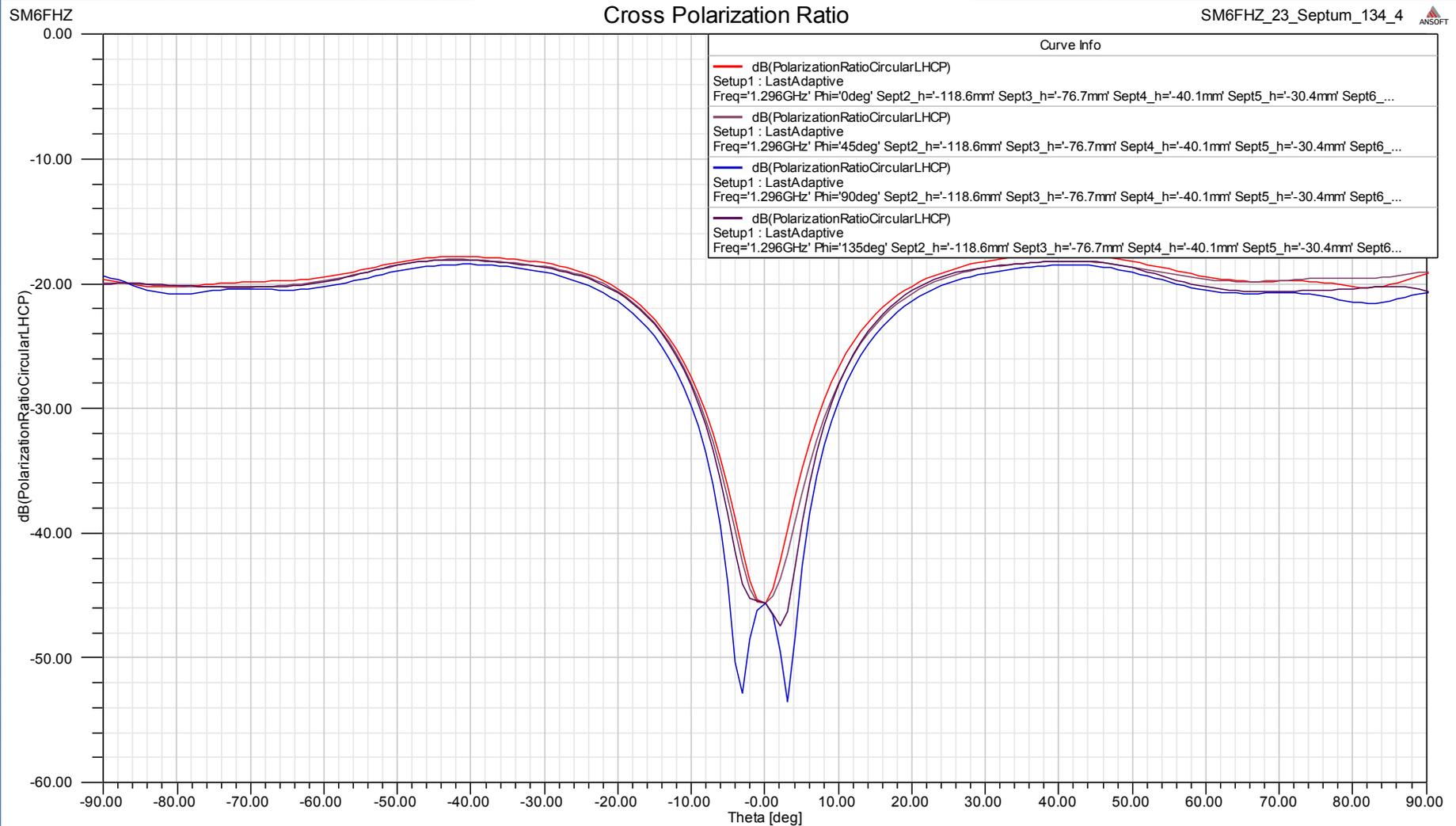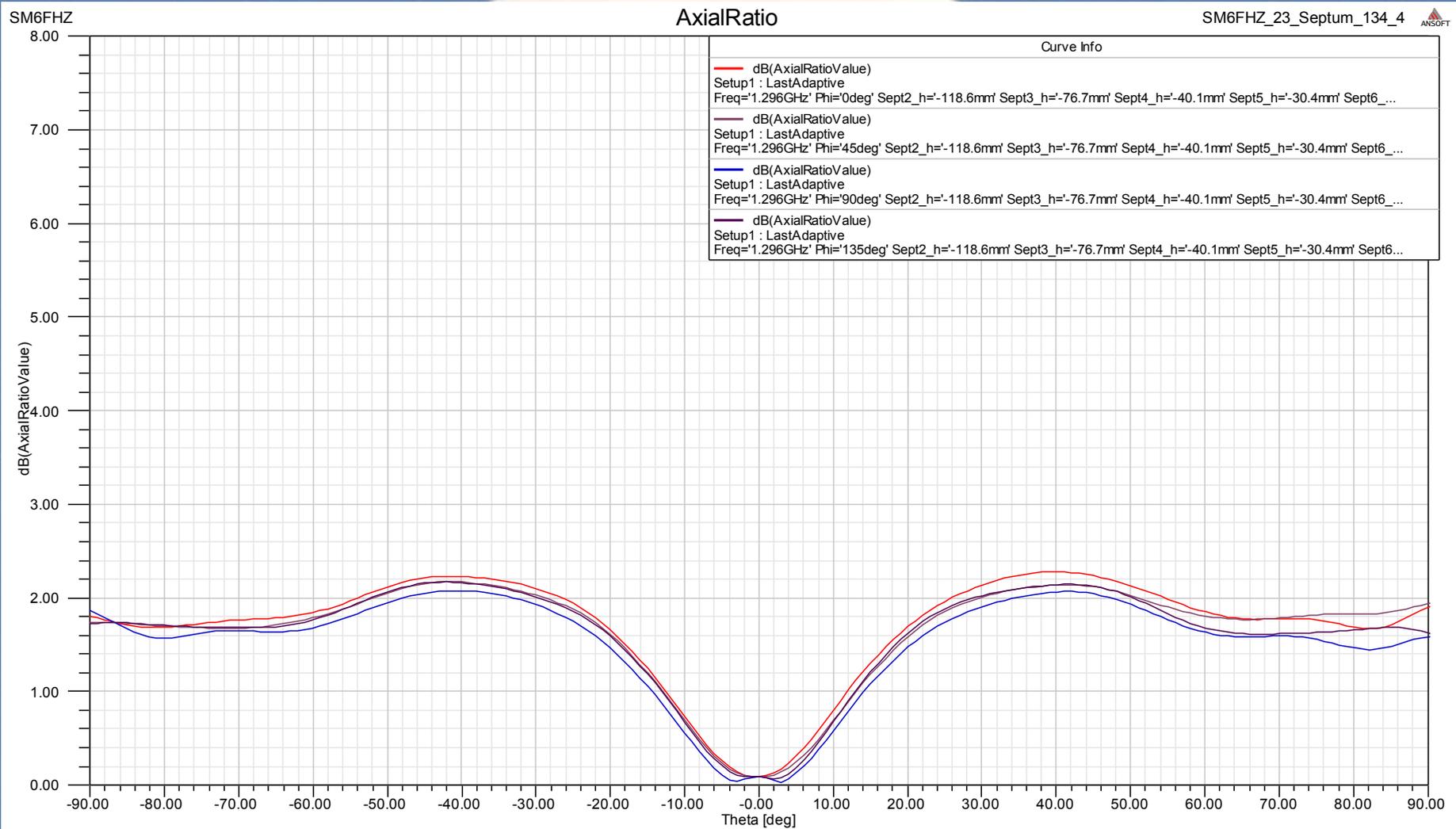
# WG and choke dimensions

Phase center 4.0

21

Circular polarization convention
for EME according to Crawford
Hill Bulletin No 1:

Tx RHCP in space
Rx LHCP in space

Take polarization reversal into
account when using reflector
antennas.

117 outer

Tx
LHCP

Rx
RHCP
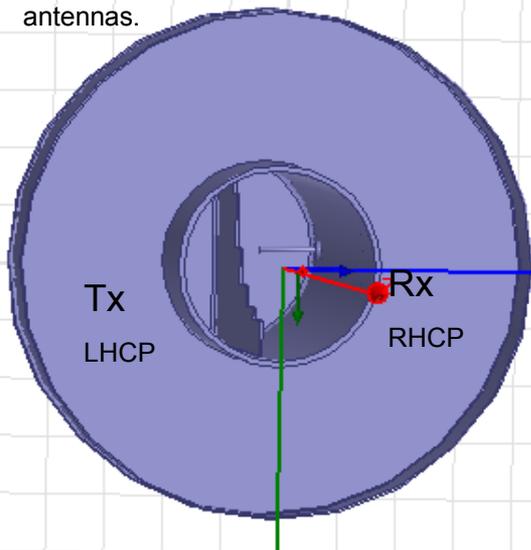
T= 0.5 wall

T= 1.0 bottom

460 outer

670 outer
1.0 mm bottom
plate included

Wave guide
186/184 mm
copper tube
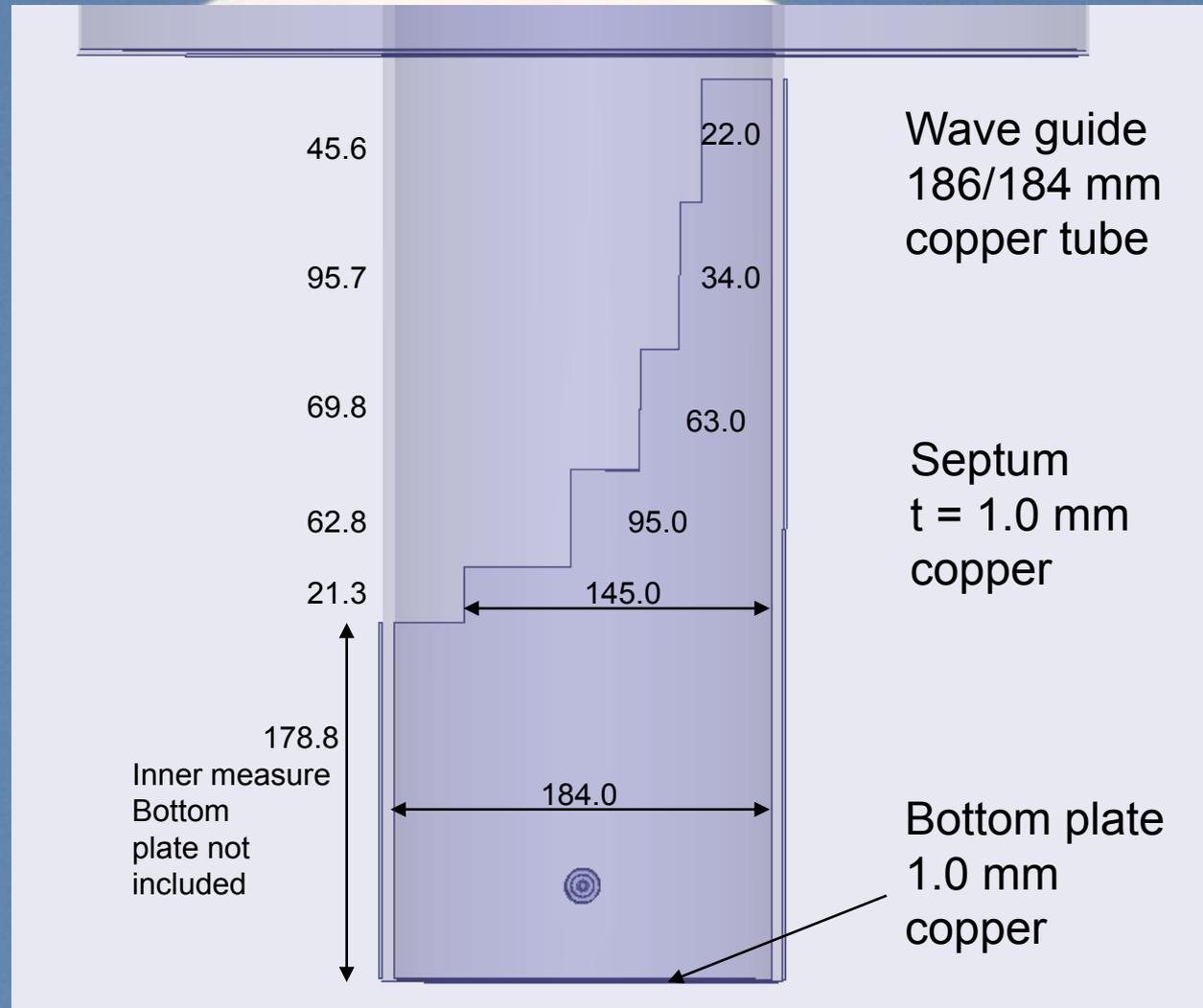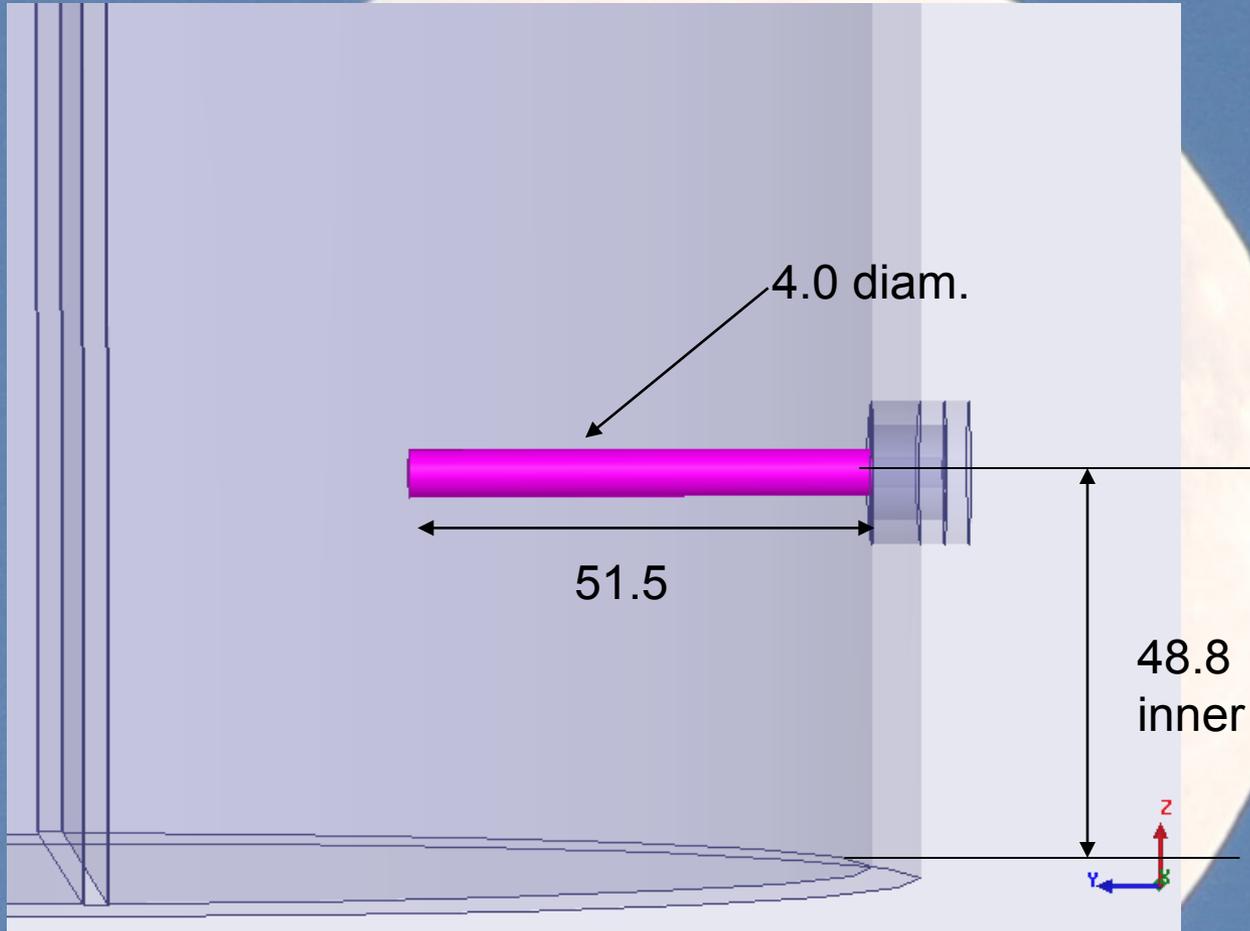
# Septum dimensions

45.6

22.0

95.7

34.0

69.8

63.0

62.8

95.0

21.3

145.0

178.8
Inner measure
Bottom
plate not
included

184.0

Wave guide
186/184 mm
copper tube

Septum
t = 1.0 mm
copper

Bottom plate
1.0 mm
copper

# Probe dimensions



4.0 diam.

51.5

48.8 inner

# S11, S22, S21 combined



S11, S22 and S21 combined
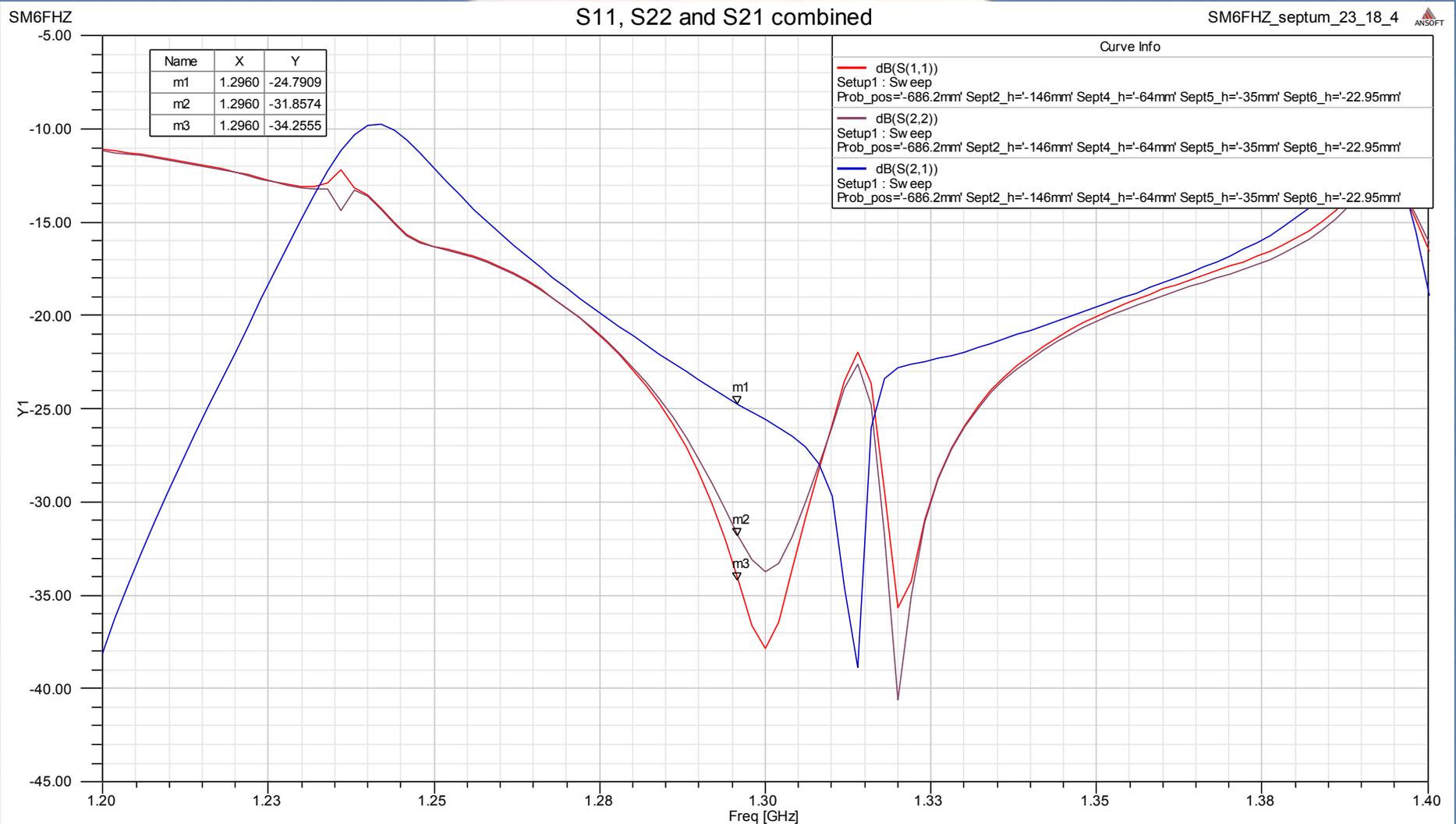
SM6FHZ

SM6FHZ_septum_23_18_4

| Name | X | Y |
|------|------|---------|
| m1 | 1.2960 | -24.7909 |
| m2 | 1.2960 | -31.8574 |
| m3 | 1.2960 | -34.2555 |

Curve Info

dB(S(1,1))
Setup1 : Sweep
Prob_pos='-686.2mm' Sept2_h='-146mm' Sept4_h='-64mm' Sept5_h='-35mm' Sept6_h='-22.95mm'

dB(S(2,2))
Setup1 : Sweep
Prob_pos='-686.2mm' Sept2_h='-146mm' Sept4_h='-64mm' Sept5_h='-35mm' Sept6_h='-22.95mm'

dB(S(2,1))
Setup1 : Sweep
Prob_pos='-686.2mm' Sept2_h='-146mm' Sept4_h='-64mm' Sept5_h='-35mm' Sept6_h='-22.95mm'

# Complex impedance Rx-port
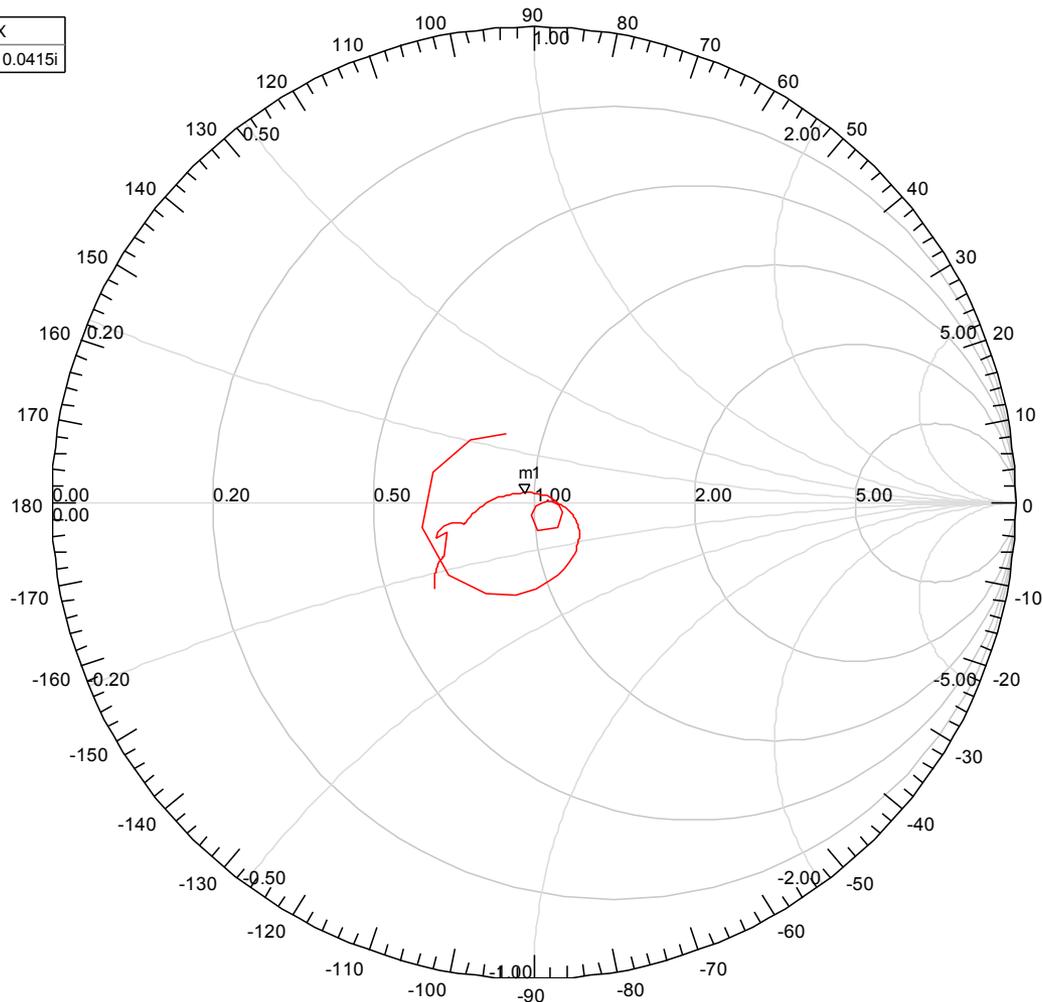
# 3D Total Power Far Field pattern
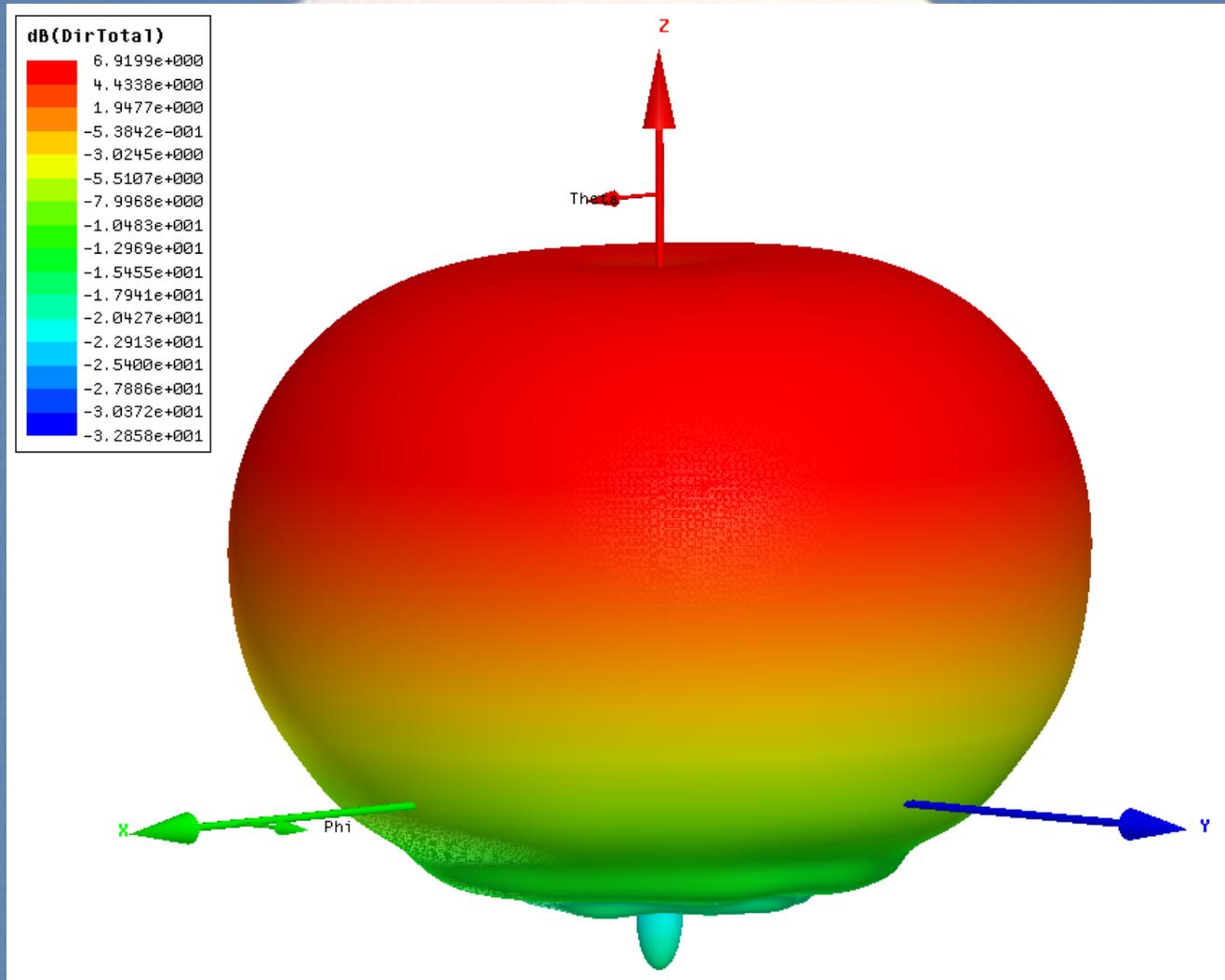
# Far Field Pattern 0 deg
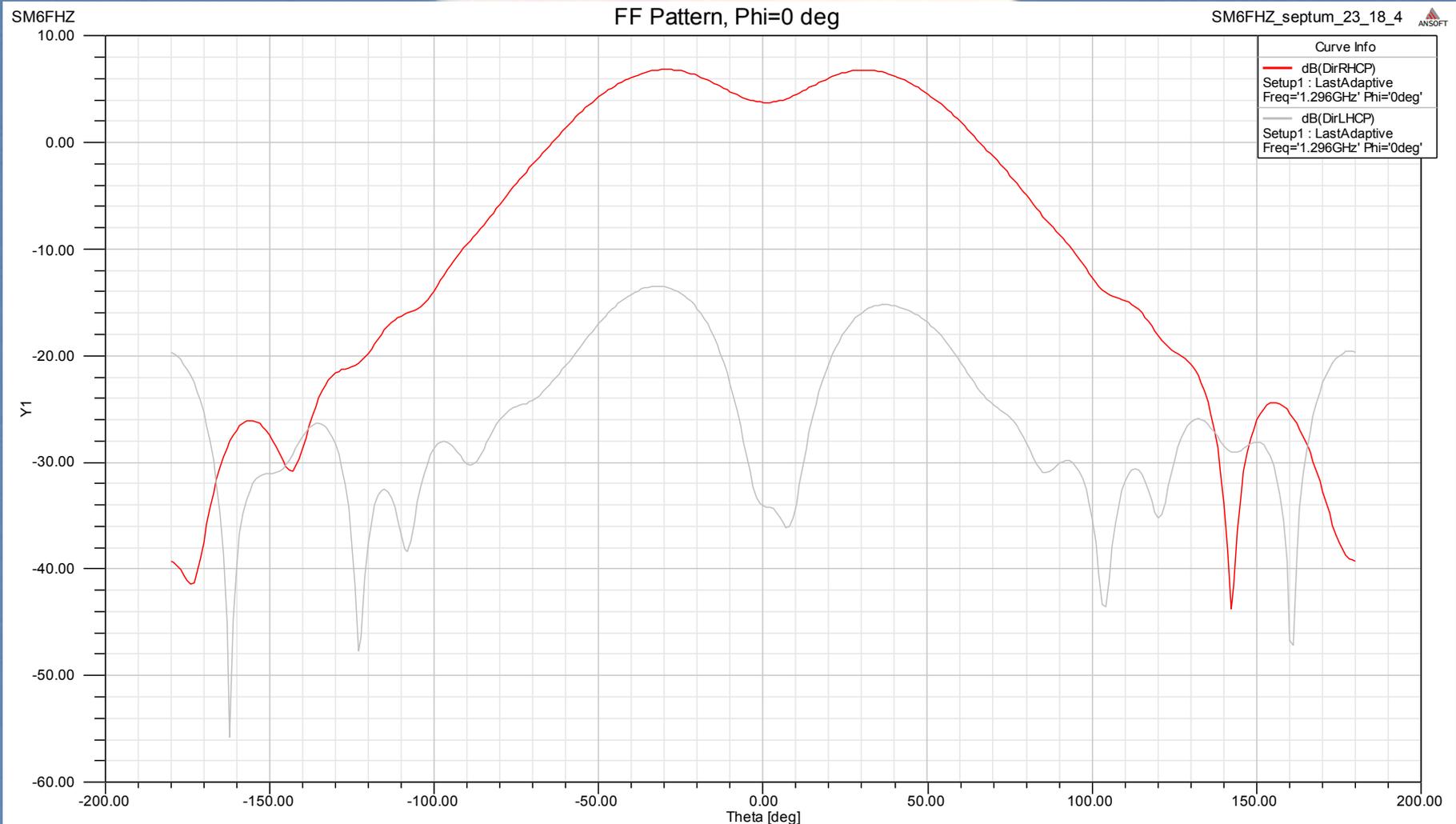
# Far Field Phase error
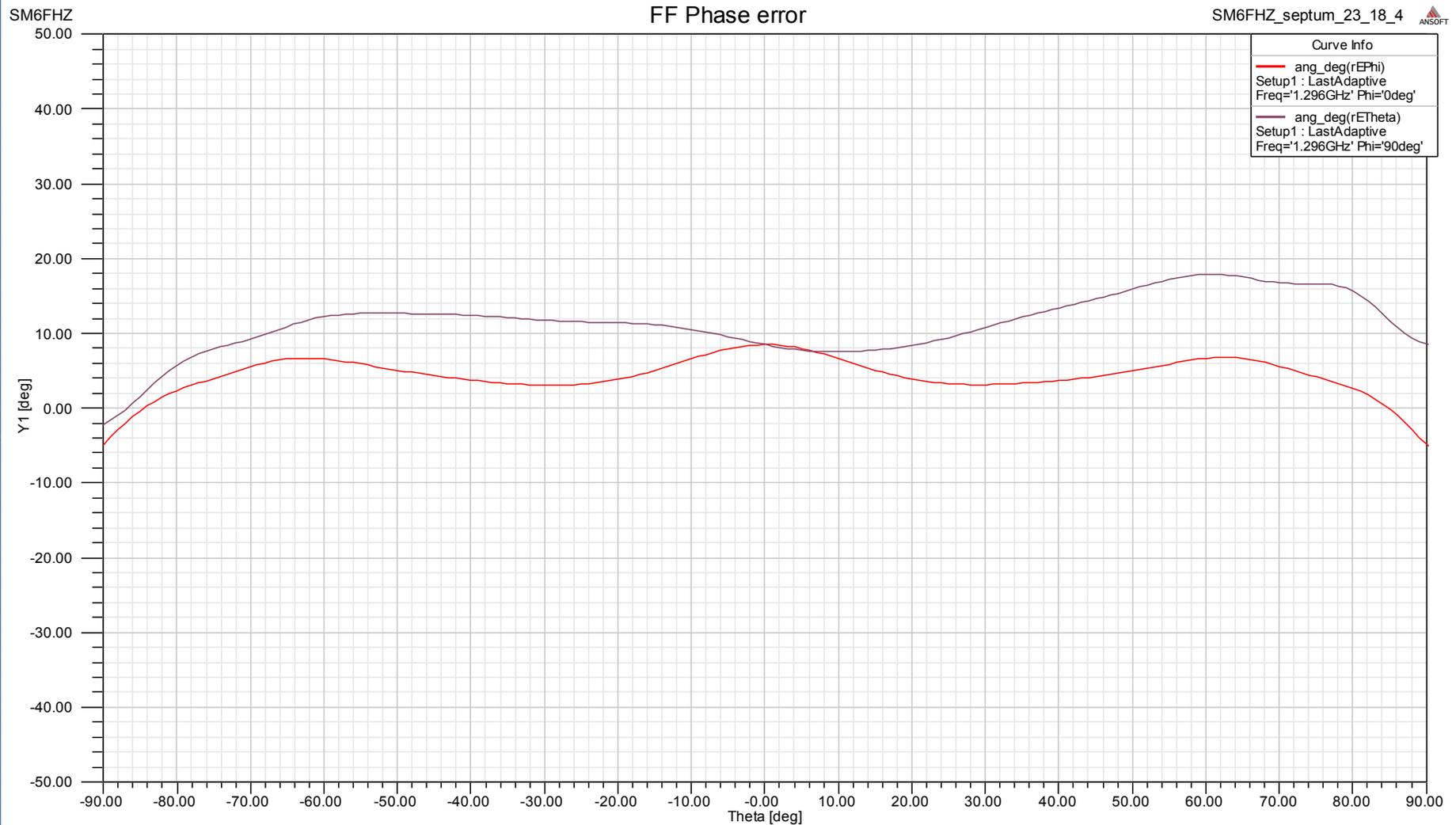
# Cross Polar Ratio
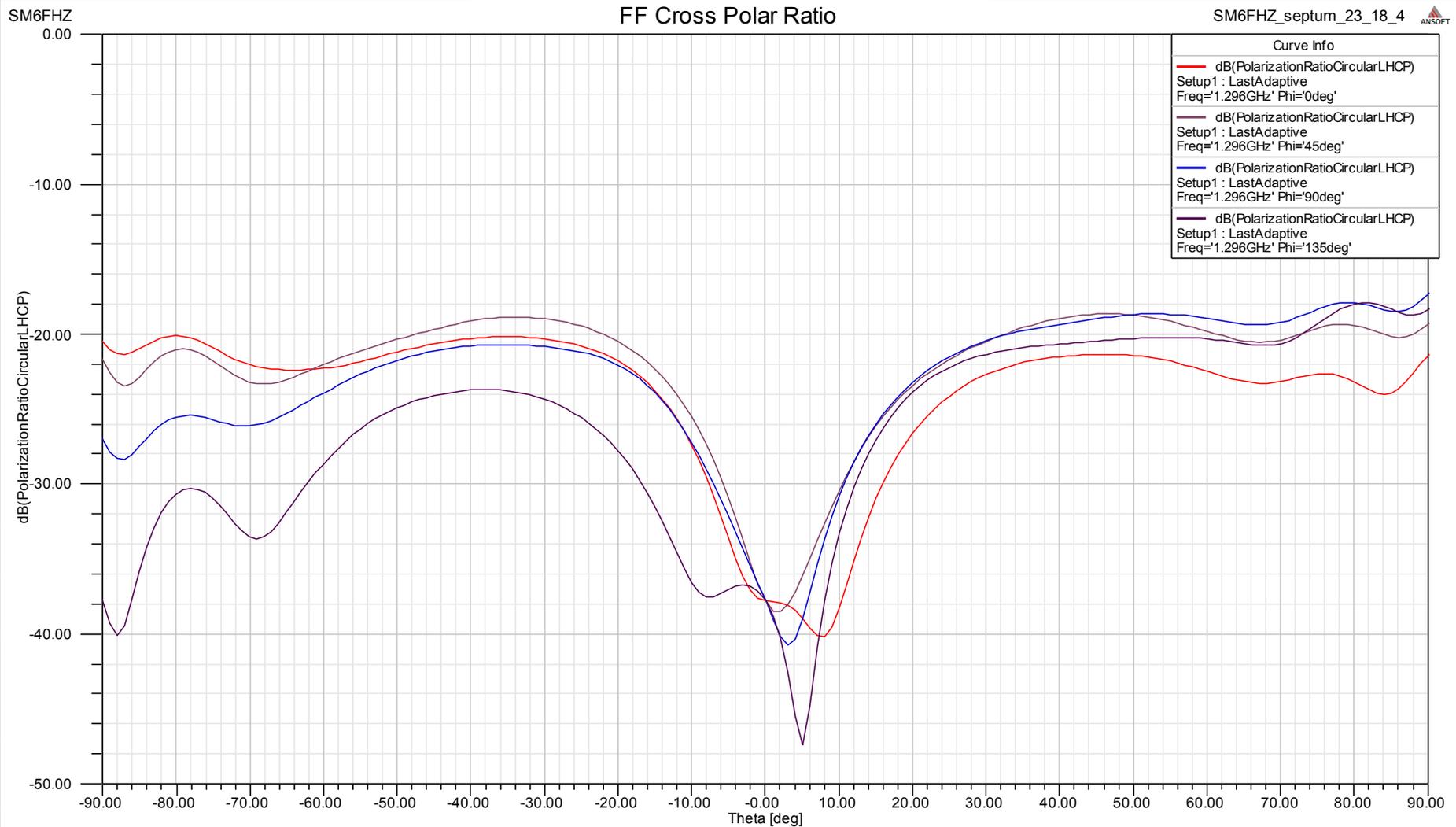
# Axial Ratio
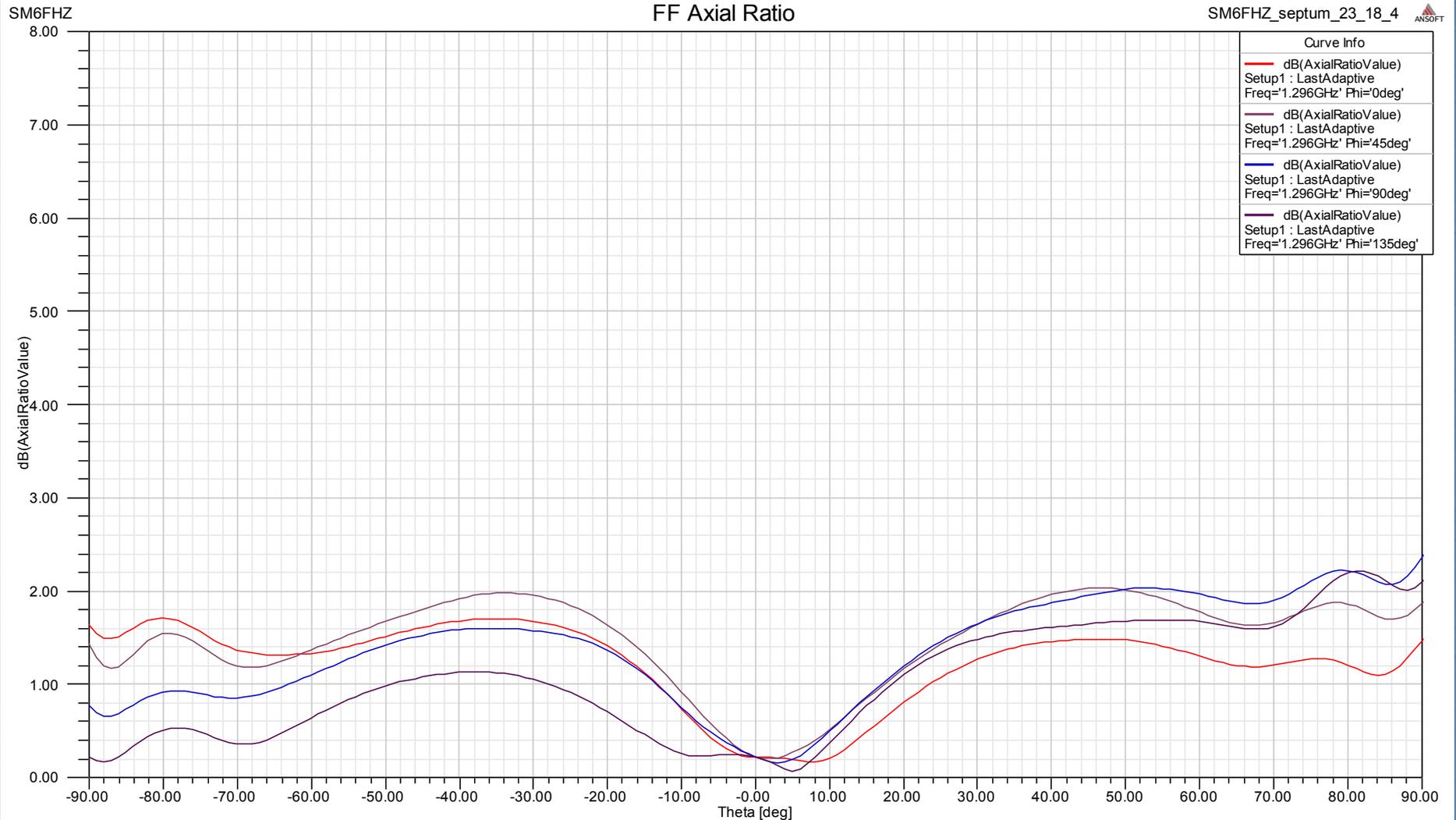
# SM6FHZ 9 cm 5 step septum feed

## 0.748 lambda W/G

# Model
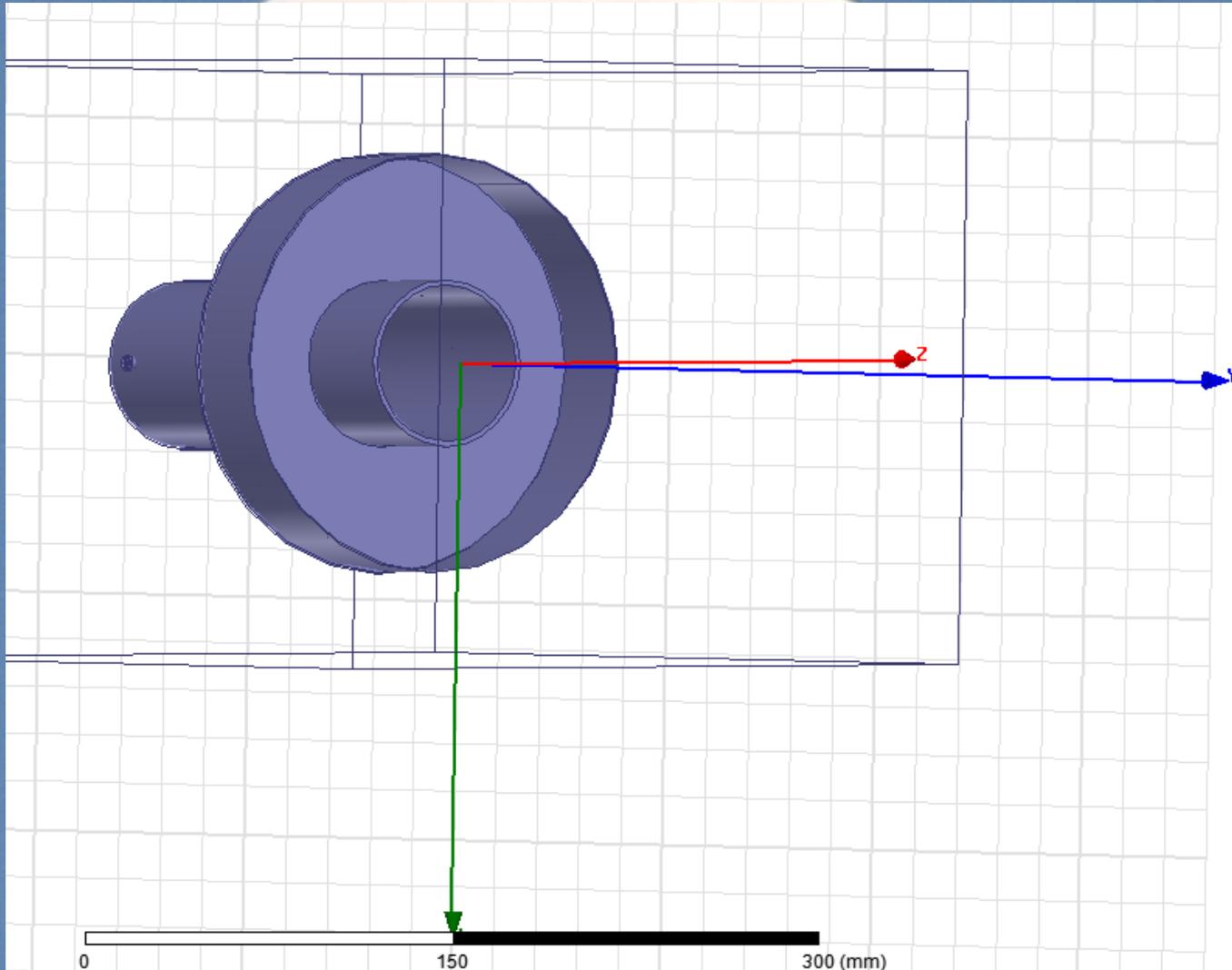
# Transparent model
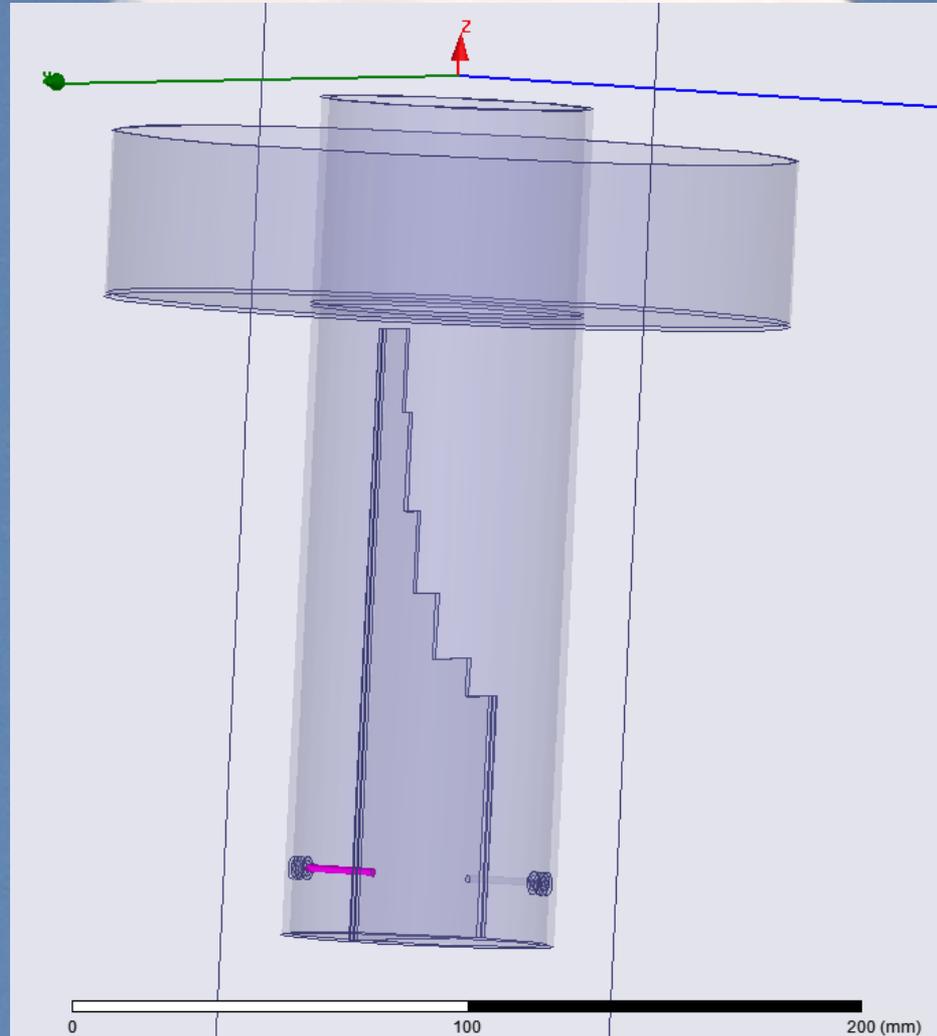
# WG and choke dimensions

Phase center 2.0

11

Circular polarization convention for EME according to Crawford Hill Bulletin No 1:

Tx RHCP in space
Rx LHCP in space

Take polarization reversal into account when using reflector antennas.

43.5
outer
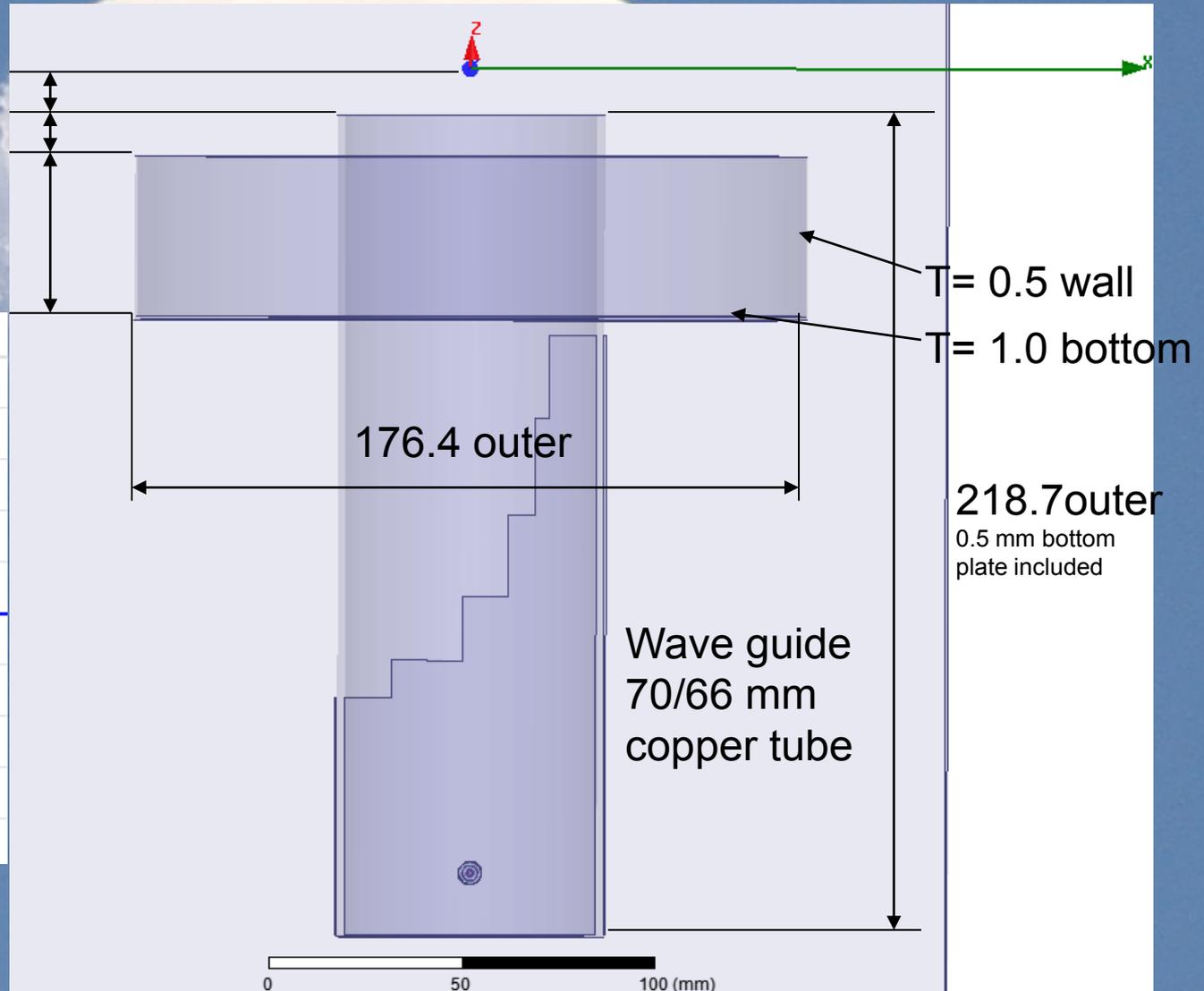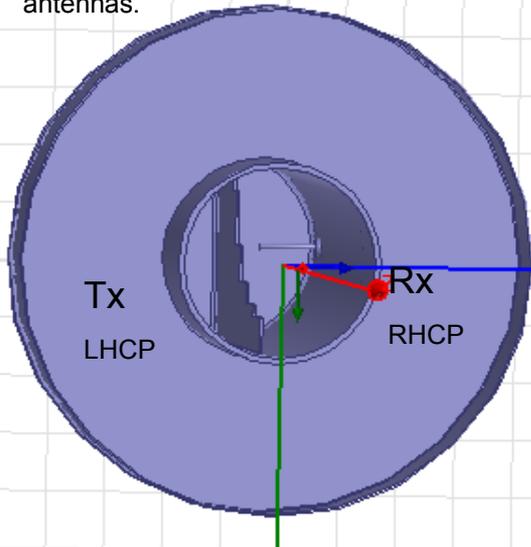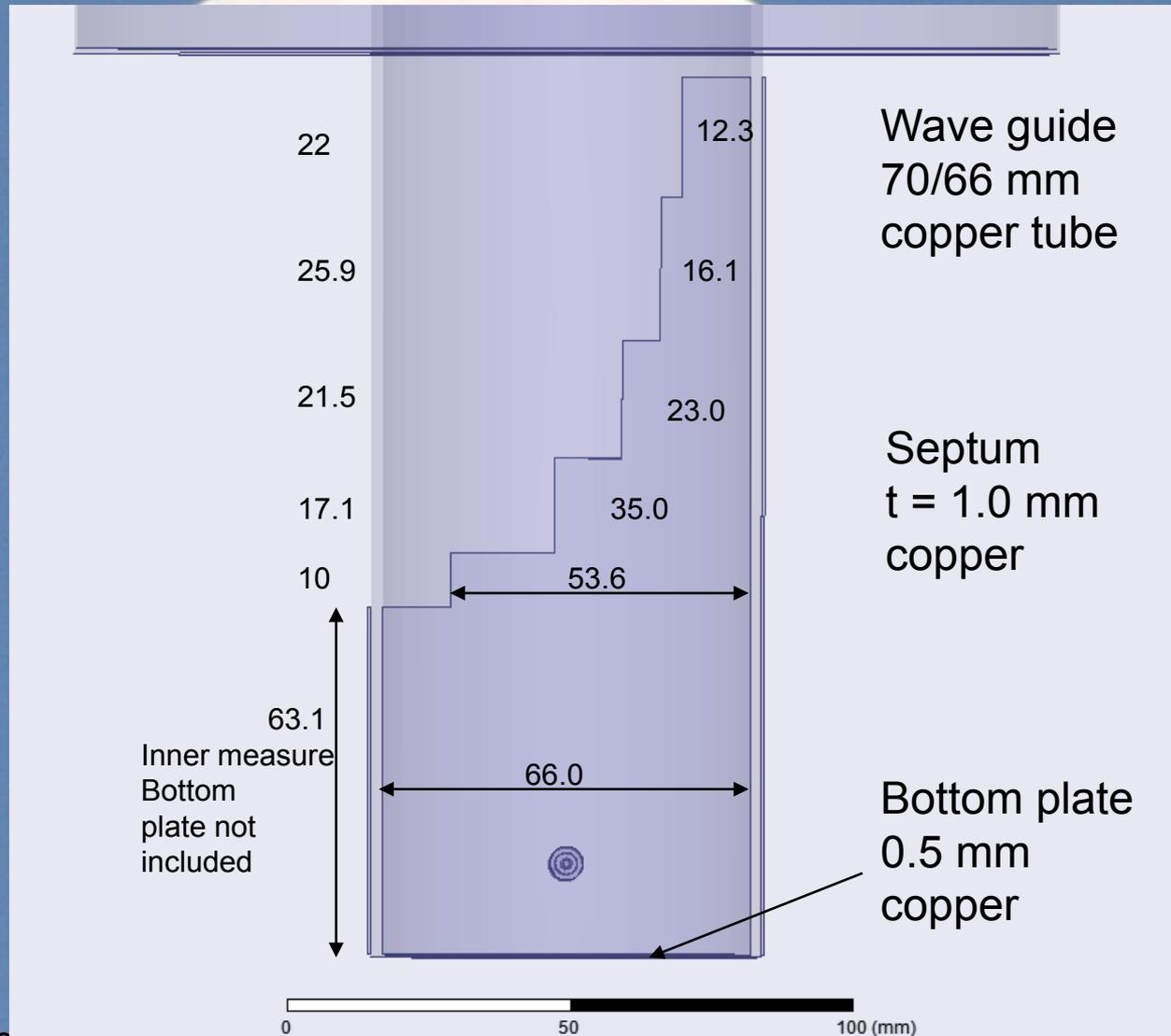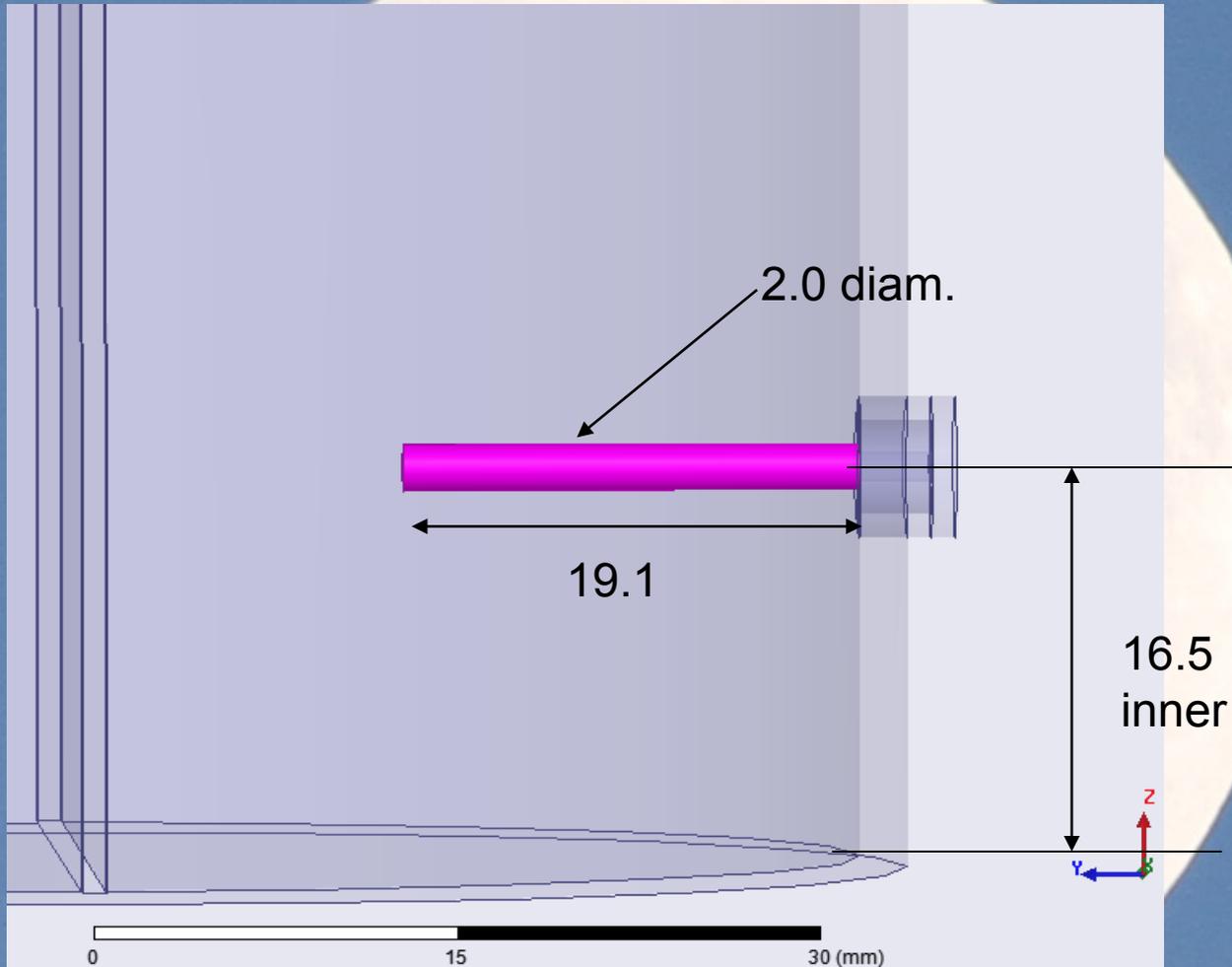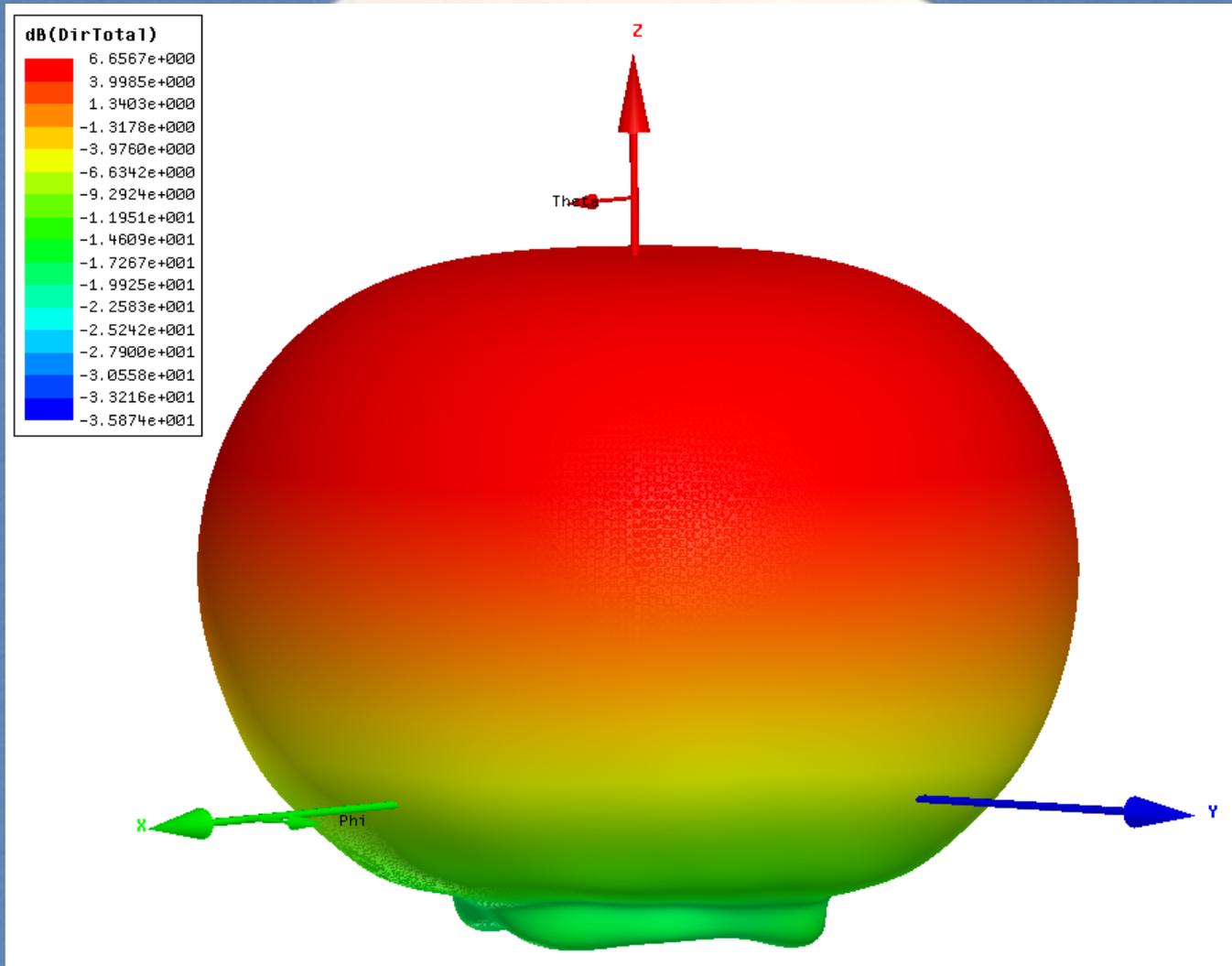
Tx

LHCP

Rx

RHCP

T= 0.5 wall

T= 1.0 bottom

176.4 outer

218.7outer
0.5 mm bottom plate included

Wave guide 70/66 mm copper tube

0        50        100 (mm)

# Septum dimensions



Wave guide
70/66 mm
copper tube

22

12.3

25.9

16.1

21.5

23.0

17.1

35.0

Septum
t = 1.0 mm
copper

10

53.6

63.1
Inner measure
Bottom
plate not
included

66.0

Bottom plate
0.5 mm
copper

0        50        100 (mm)

# Probe dimensions



2.0 diam.

19.1

16.5 inner

0          15          30 (mm)

# FF 3D Total Power pattern

# FF Directivity pattern

# S11, S22 and S21 combined
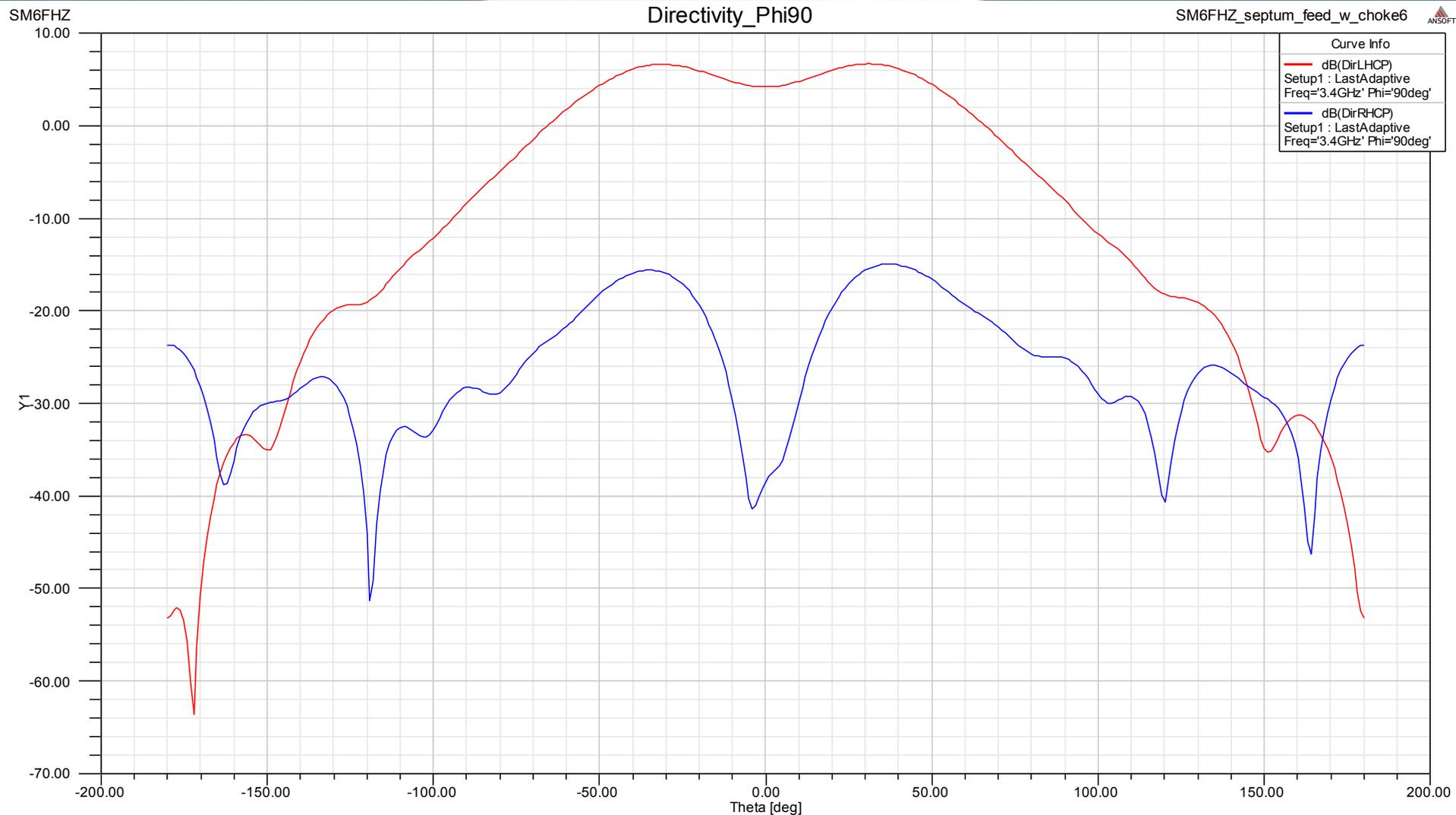


S11, S22 and S21 combined
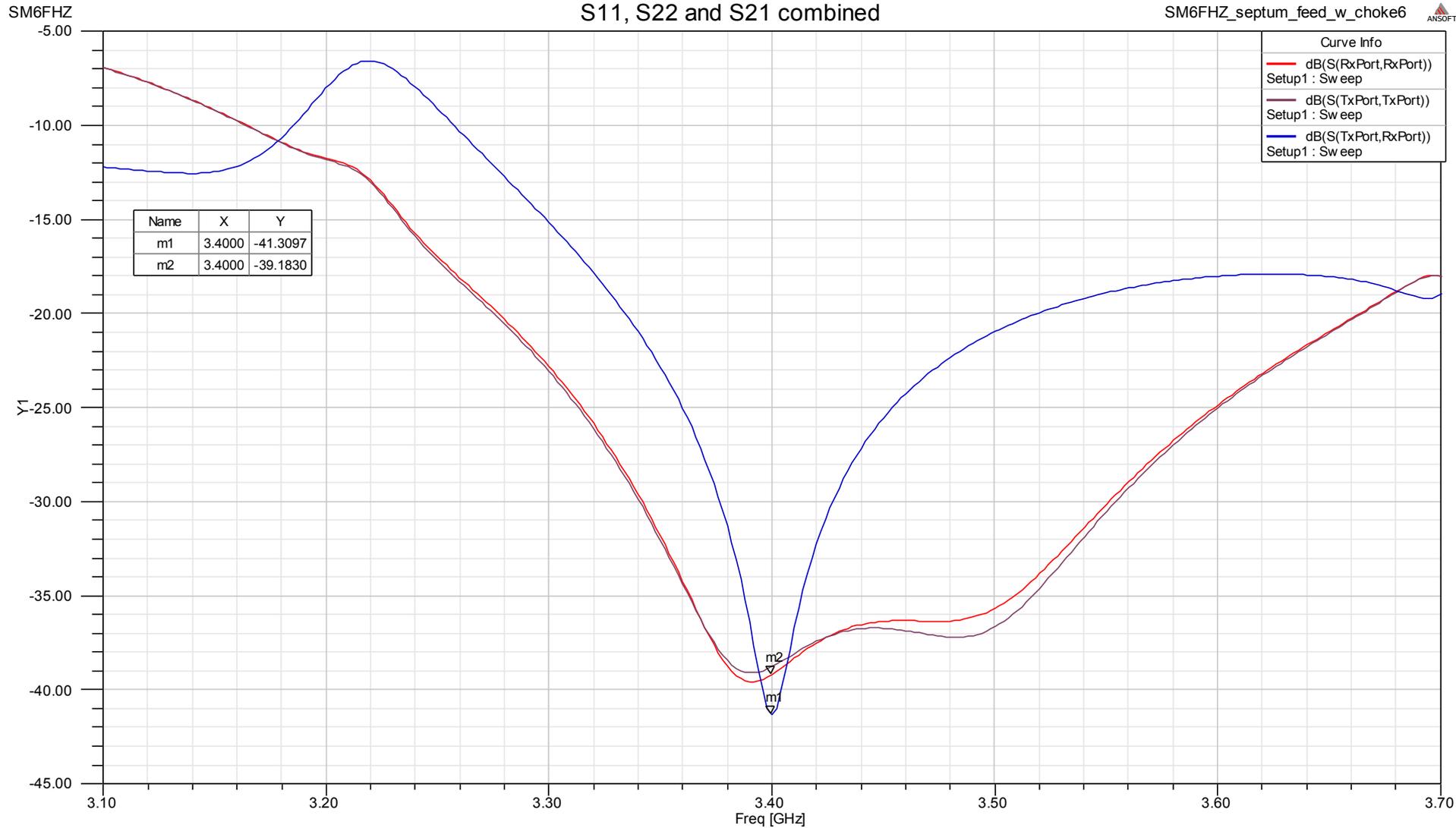
# Complex impedance Rx-port

| Name | Freq | Ang | Mag | RX |
|------|--------|----------|--------|------------------|
| m1 | 3.7000 | 16.6154 | 0.1253 | 1.2692 + 0.0924i |
| m2 | 3.4000 | -73.3845 | 0.0110 | 1.0061 - 0.0212i |
| m3 | 3.2000 | 117.7322 | 0.2570 | 0.7156 + 0.3485i |
| m4 | 3.1000 | 151.0225 | 0.4496 | 0.4012 + 0.2191i |

Rx_port_imp
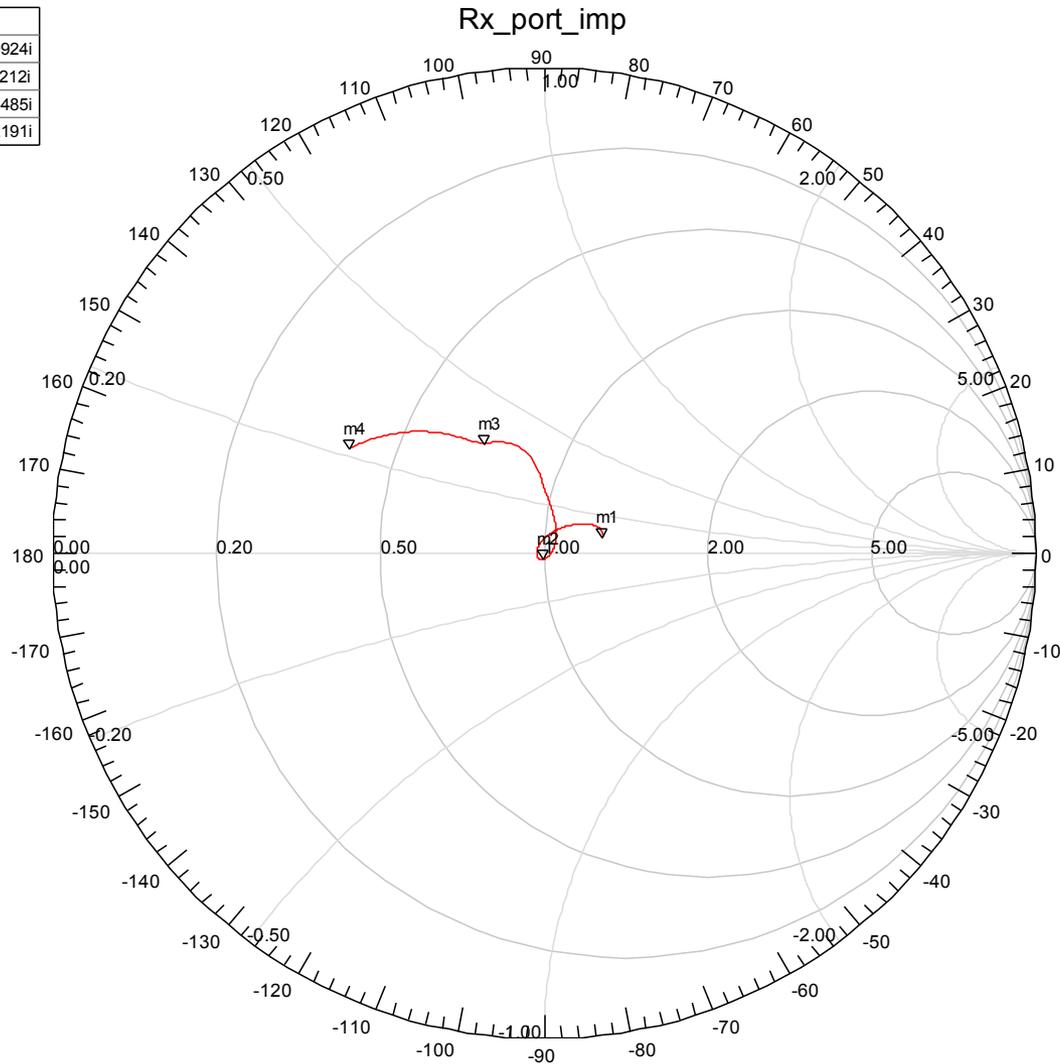
SM6FHZ_septum_feed_w_choke6

Curve Info

S(RxPort,RxPort)
Setup1 : Sweep

# FF Phase error



SM6FHZ
FF Phase Error
SM6FHZ_septum_feed_w_choke6

Curve Info
—— ang_deg(rEPhi)
Setup1 : LastAdaptive
Freq='3.4GHz' Phi='0deg'
—— ang_deg(rETheta)
Setup1 : LastAdaptive
Freq='3.4GHz' Phi='90deg'
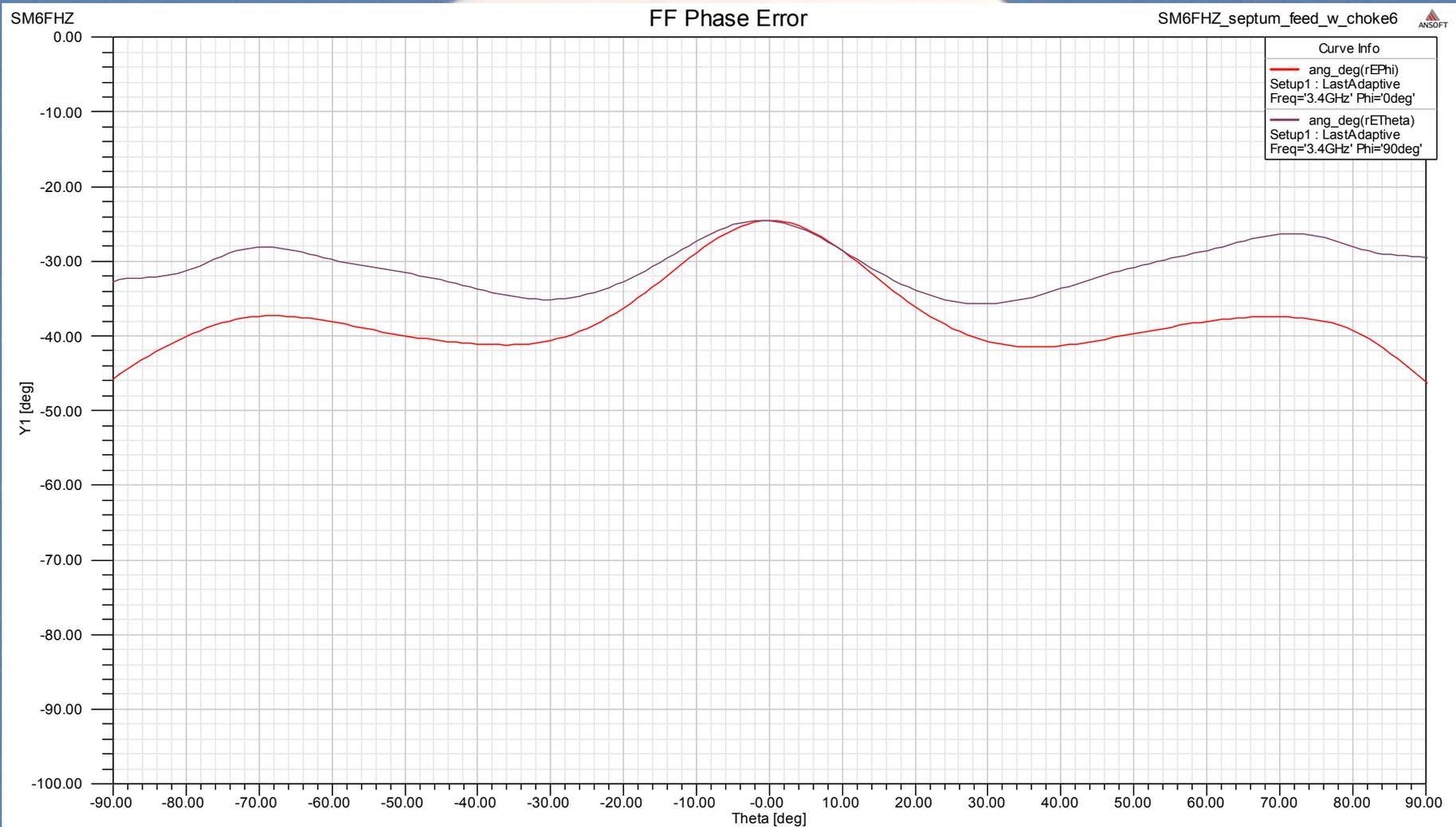
# Cross Polarization Ratio
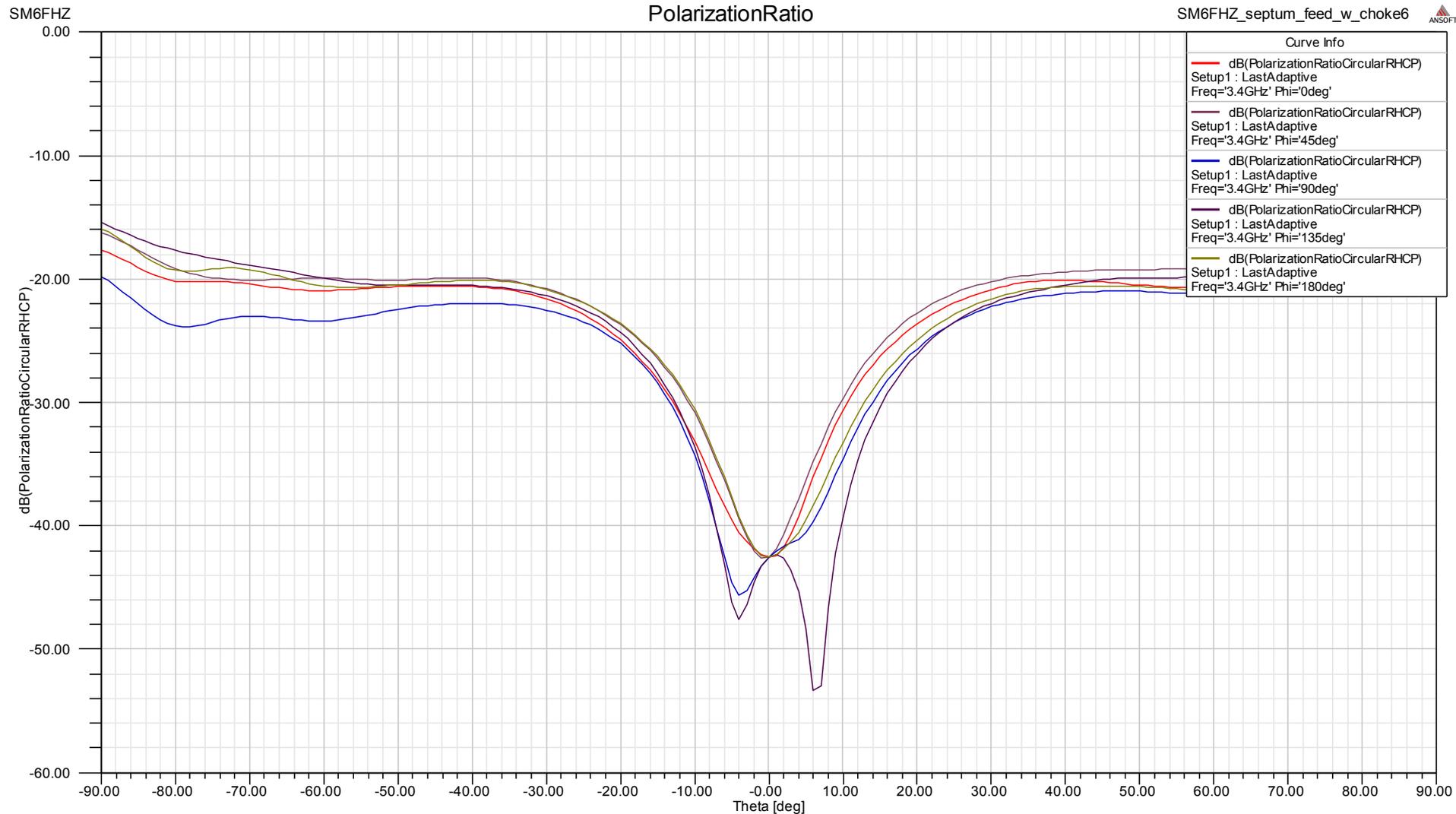
# Axial Ratio
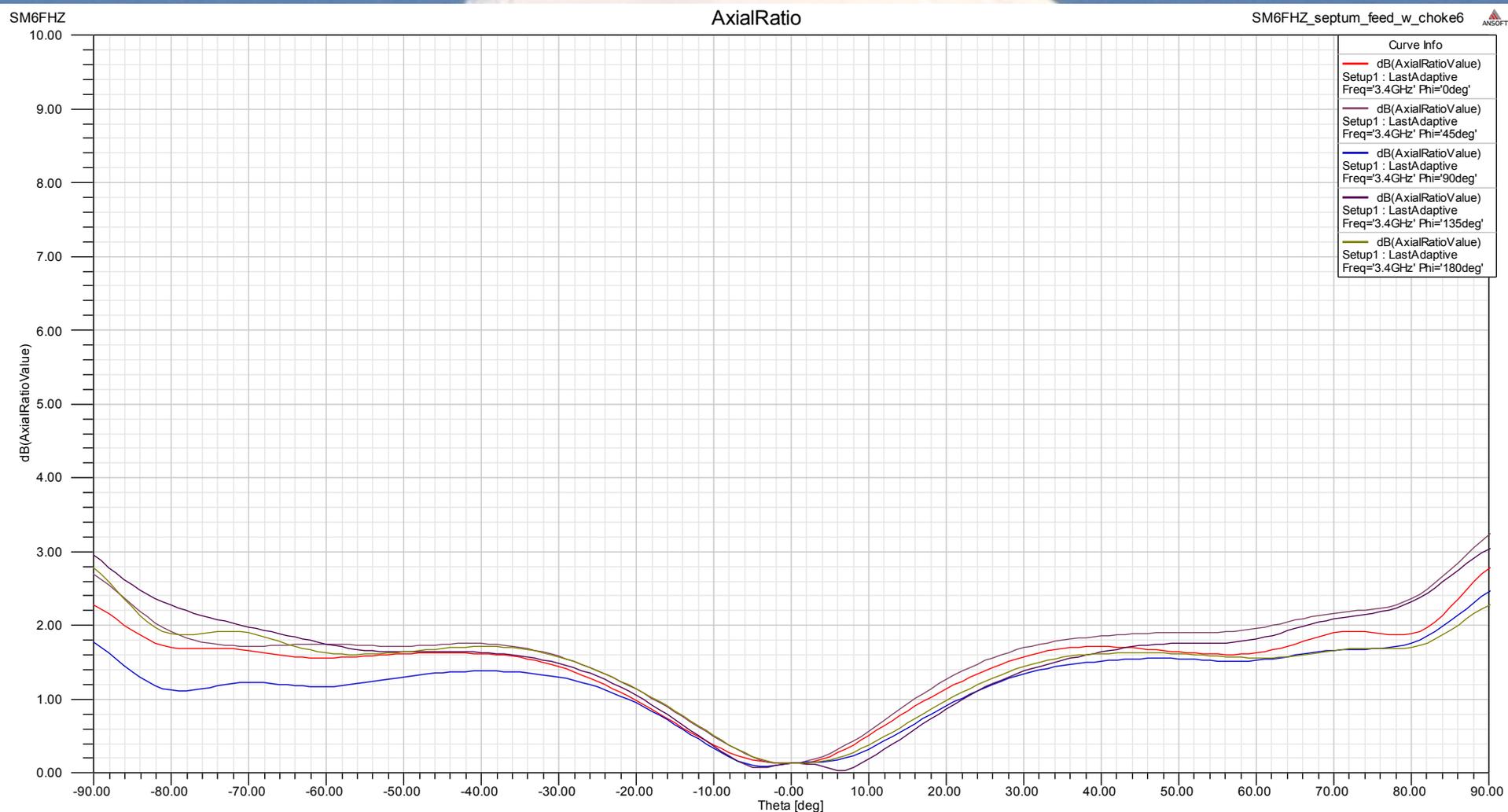
# Realization
# 9, 6 and 3 cm feeds comparison
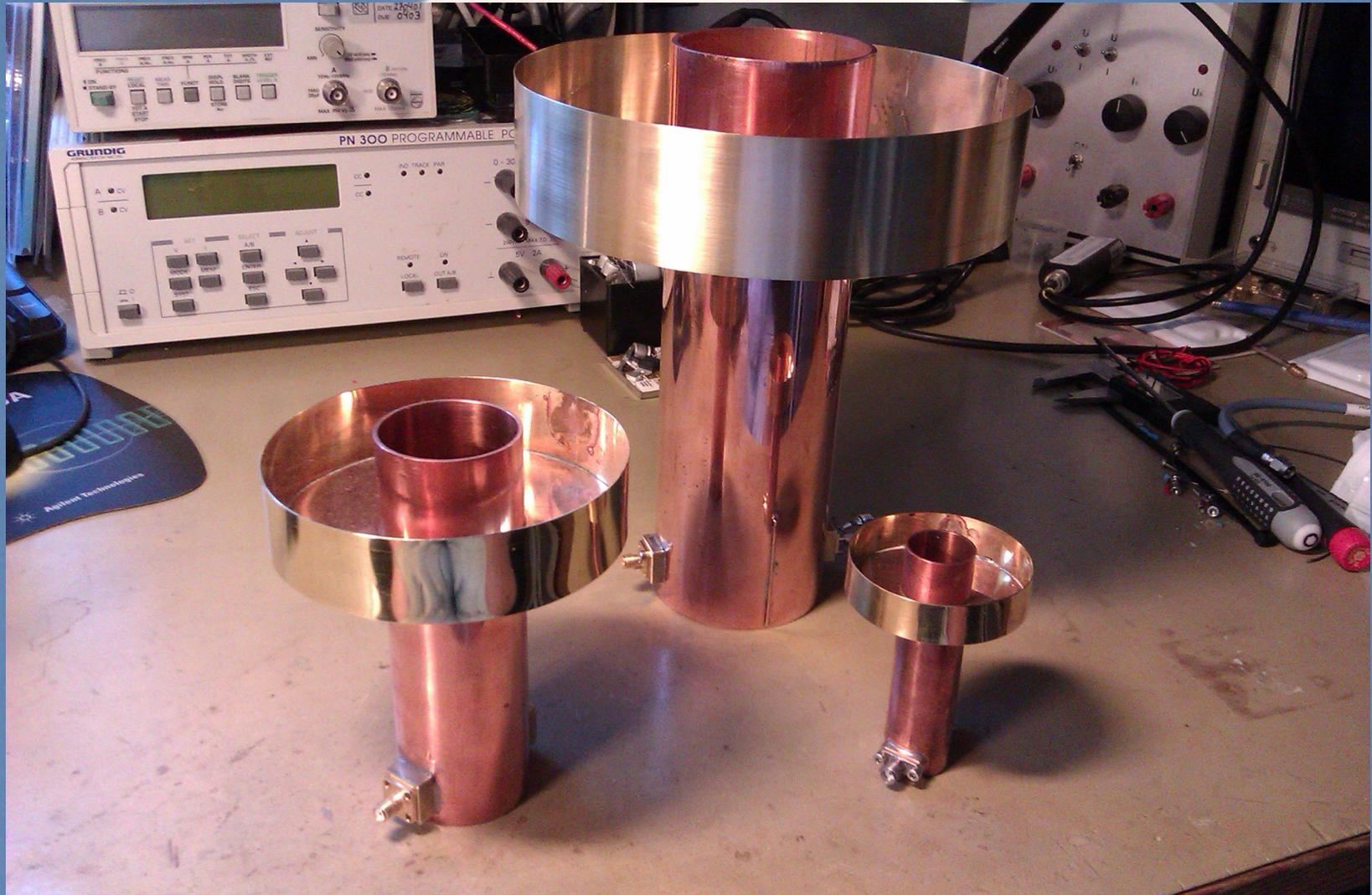
# Measured performance with partial septum soldering

# Measured performance



FHZ_9cm_after_septum_soldered_100proc
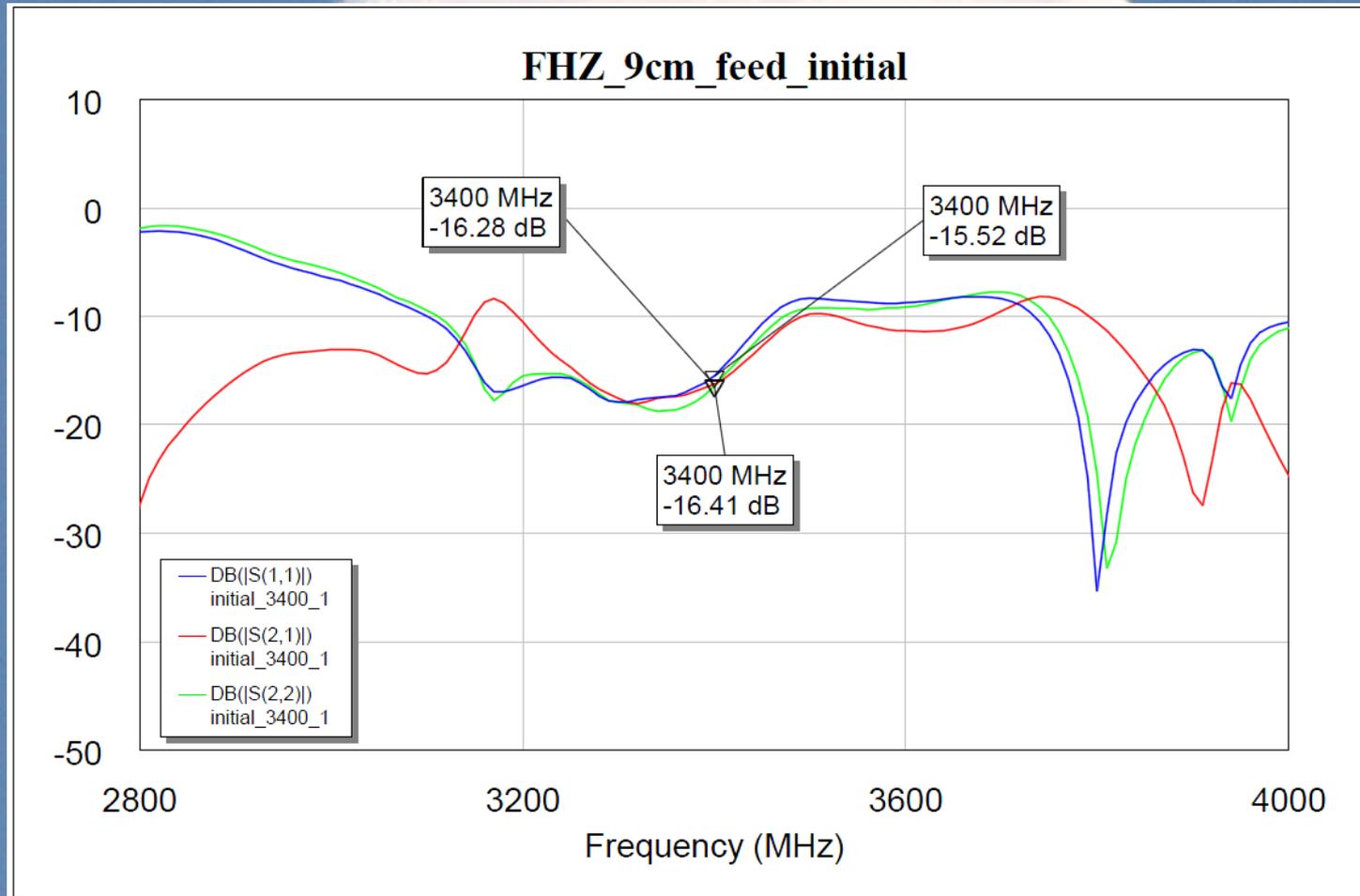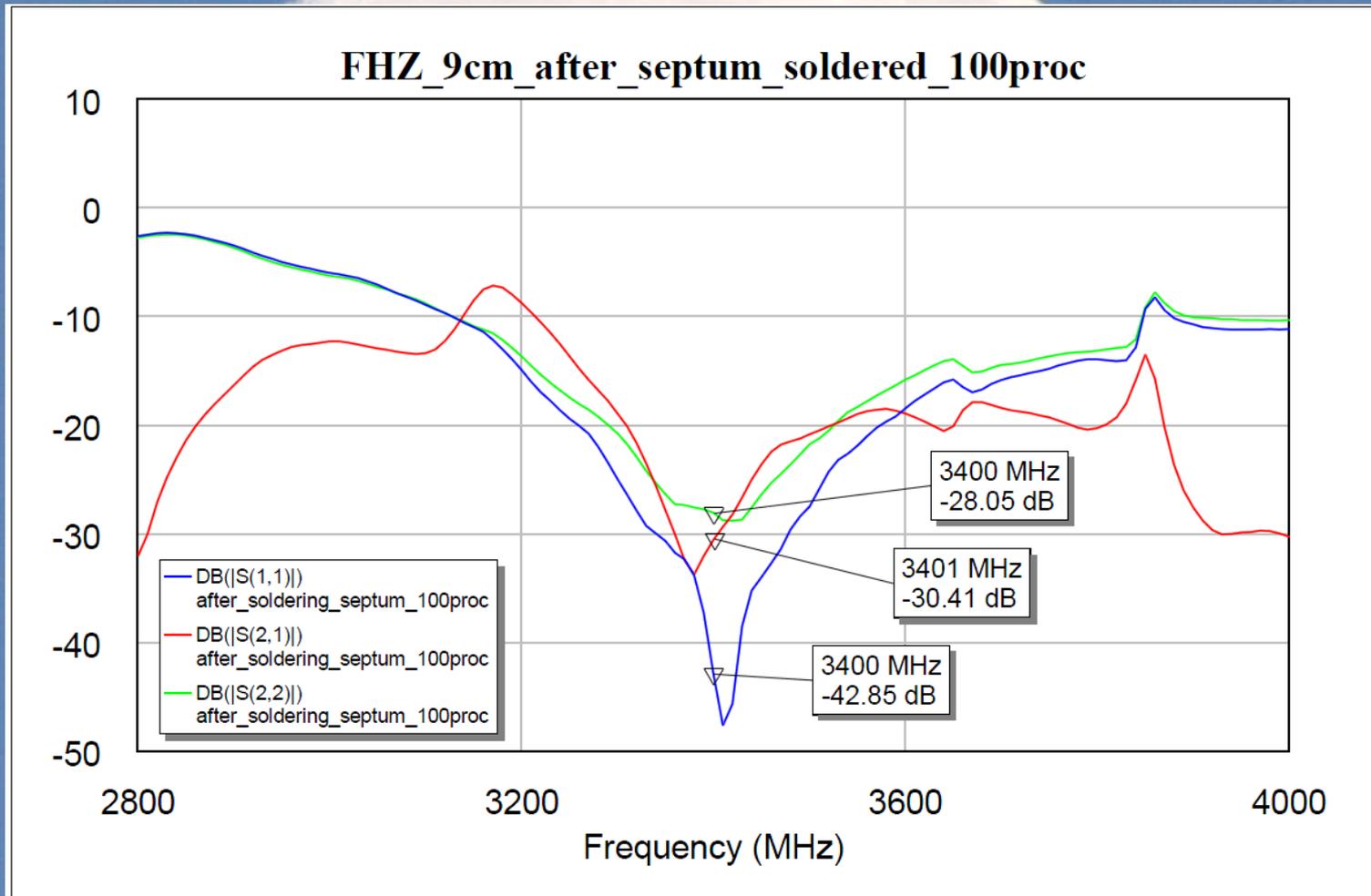
# Measured complex impedance

Reference plane about 15 mm (~0.25 WL in teflon) out from the simulated case.

SMA connector on feed included in measurement.

Measurement sweep 200 MHz wider than simulation sweep

Very good agreement between simulated and measured performance.



after_septum_soldered_100proc

—— S(1,1)
after_soldering_septum_100proc

—— S(2,2)
after_soldering_septum_100proc

Swp Max
3800MHz

3400 MHz
r 0.988292
x -0.00838929

3400 MHz
r 1.00074
x -0.0795067

Swp Min
3000MHz
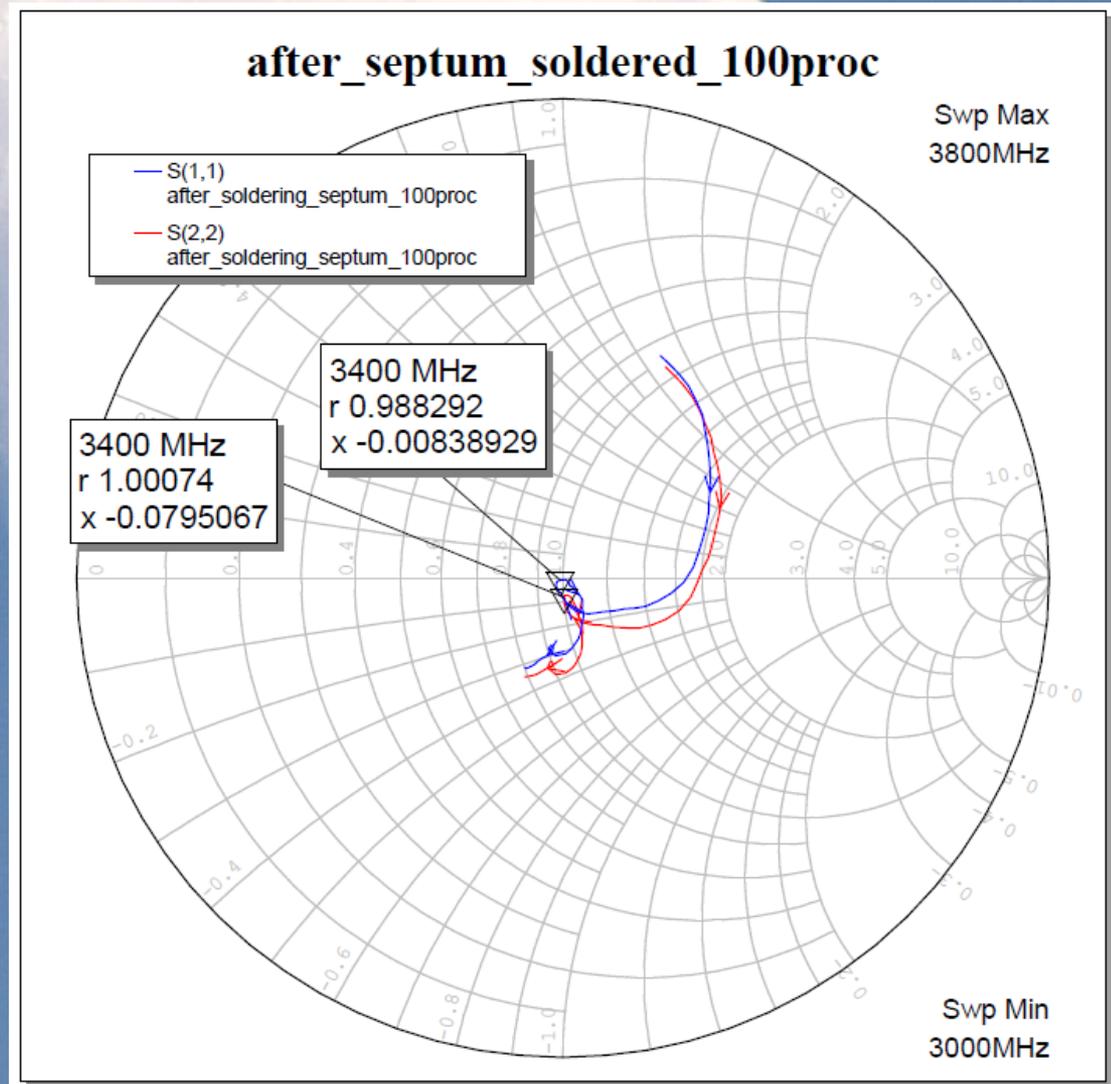
# InDish Performance, 1.8 and 2.2 m dish

**SM6FHZ 9 cm septum feed in 1.8 m dish**

**SM6FHZ 9 cm septum feed in 2.2 m dish**
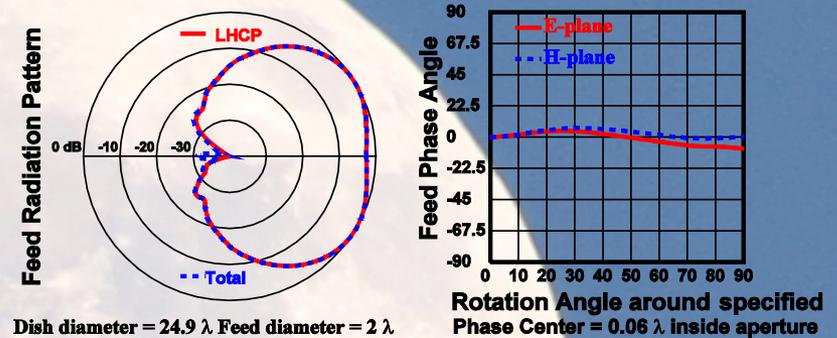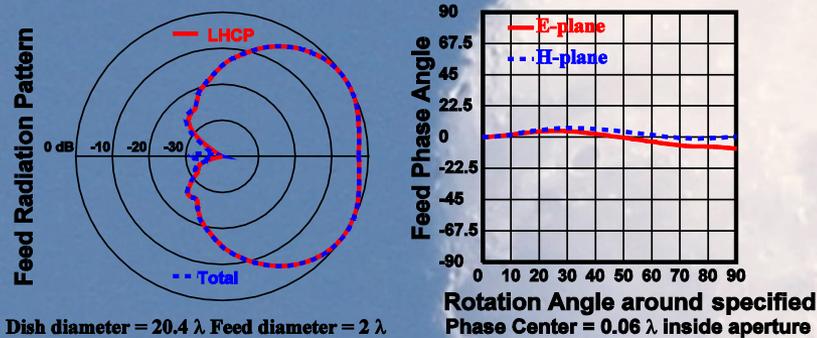


SM6FHZ 2013-06-16
Rev B

Swedish EME-meeting May 2013

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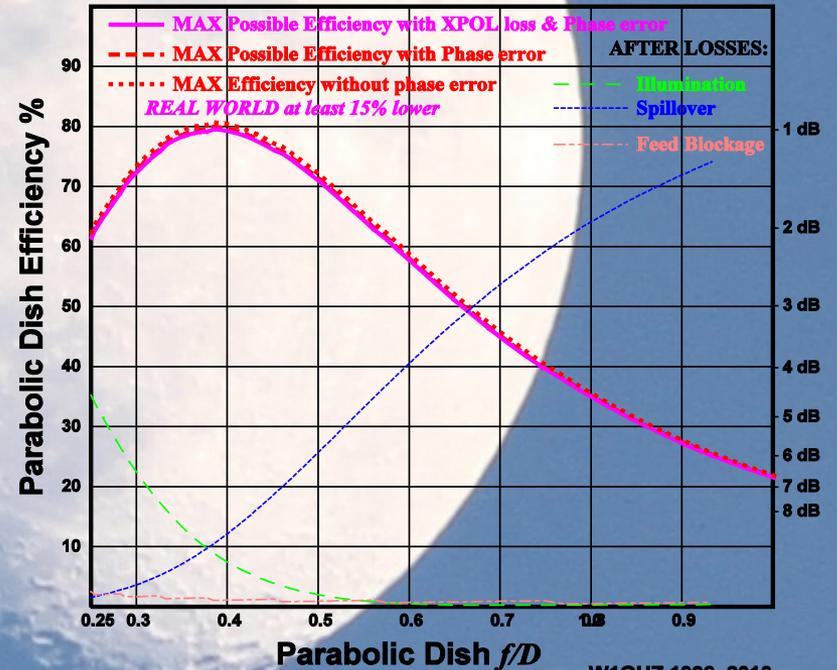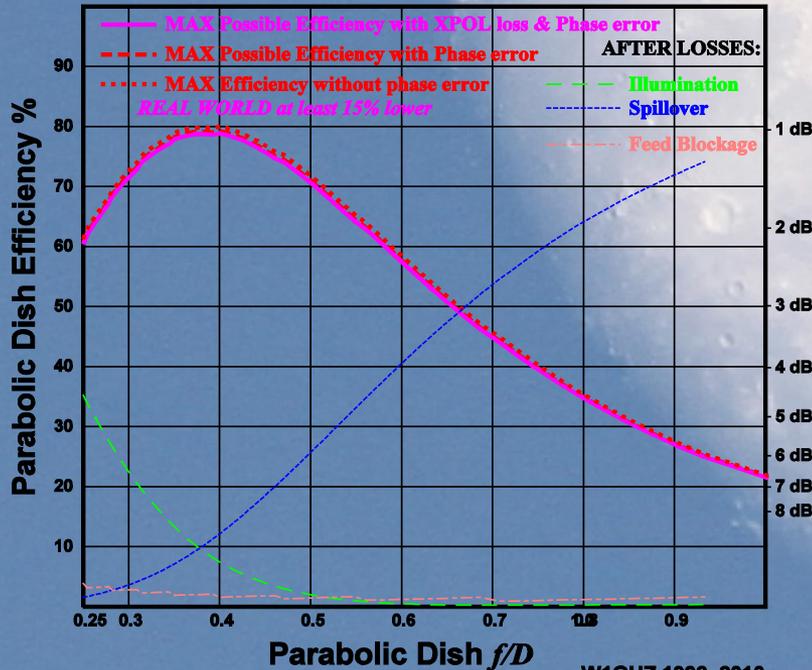
# SM6FHZ 6 cm 5 step septum feed

## 0.749 lambda W/G

# Solid and transparent models from the simulation

# WG and choke dimensions

6.0

6.5

Circular polarization convention for EME according to Crawford Hill Bulletin No 1:

Tx RHCP in space
Rx LHCP in space

Take polarization reversal into account when using reflector antennas.

26 outer

T= 0.5 wall

T= 1.0 bottom

103.4 outer

129.5 outer
0.5 mm bottom plate included

Wave guide 42/39 mm copper tube

Tx
LHCP

Rx
RHCP

0          40          80 (mm)

# Septum dimensions



Wave guide
42/39 mm
copper tube

Septum
t = 1.0 mm
copper

Bottom plate
0.5 mm
copper

13.0

15.3

12.7

10.1

5.9

7.0

9.2

13.0

21.0

32.0

39.0

37.3
Inner measure
Bottom
plate not
included

0    30    60 (mm)

# Probe dimensions

# FF 3D Total Power pattern
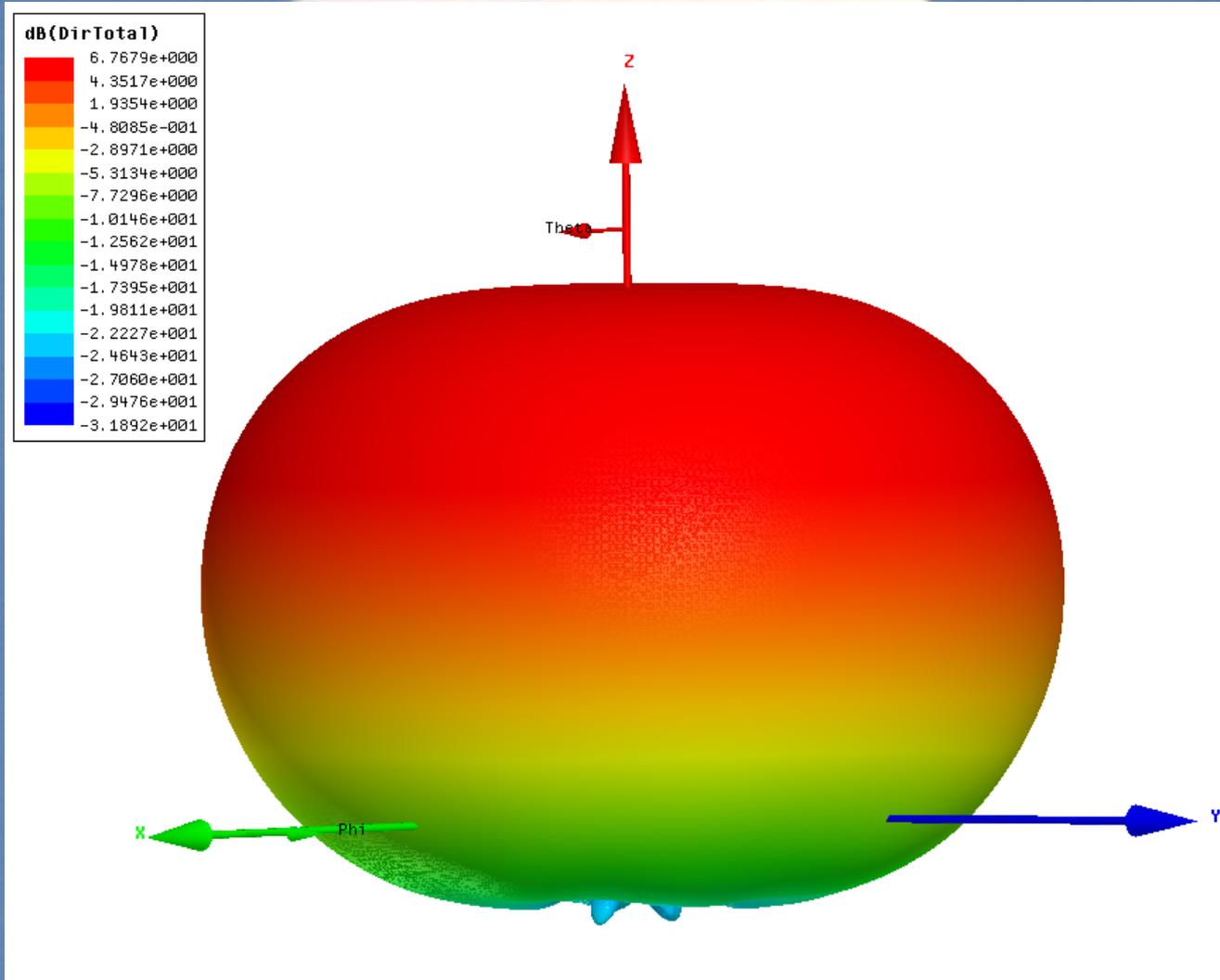
# FF Directivity pattern
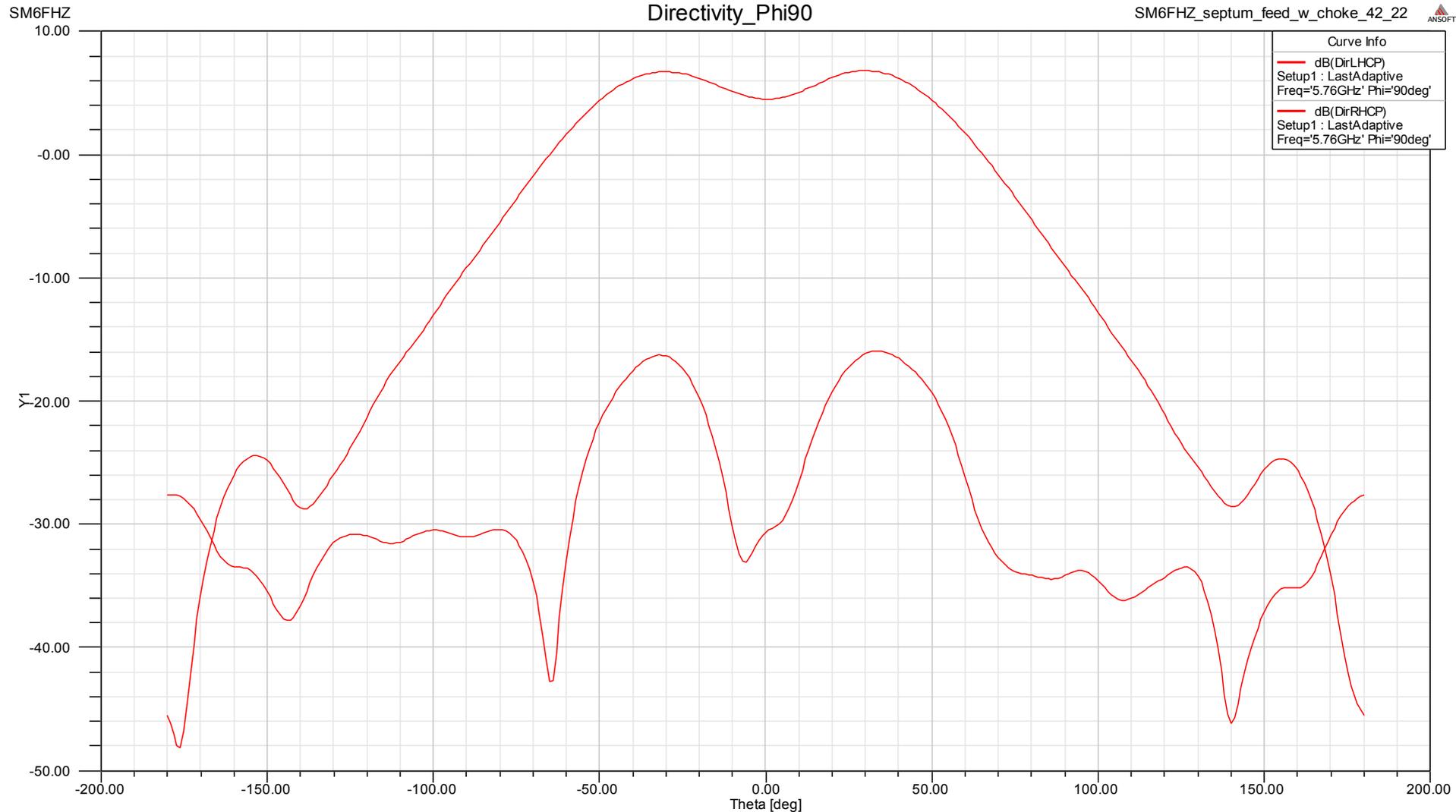
# S11, S22 and S21 combined
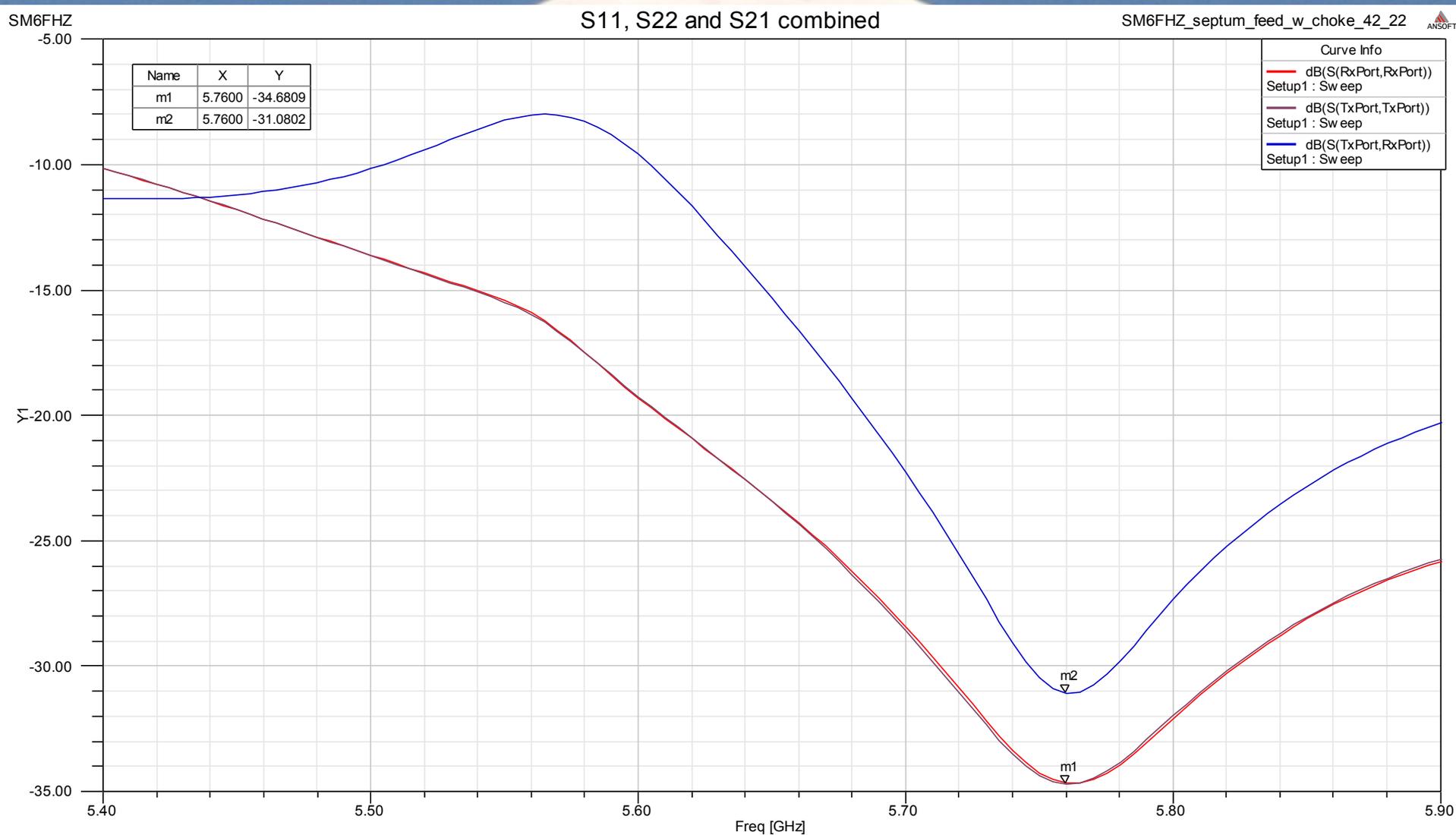
# Complex impedance Rx-port

| Name | Freq | Ang | Mag | RX |
|------|------|------|------|------|
| m1 | 5.5950 | 16.9581 | 0.1139 | 1.2414 + 0.0836i |
| m2 | 5.6900 | -15.5465 | 0.0432 | 1.0866 - 0.0252i |
| m3 | 5.7850 | -131.4701 | 0.0212 | 0.9719 - 0.0308i |
| m4 | 5.9000 | 159.2115 | 0.0512 | 0.9081 + 0.0331i |

Smith Chart 1

SM6FHZ_septum_feed_w_choke_42_22

Curve Info

S(RxPort,RxPort)
Setup1 : Sweep

# Measurements



FHZ_feed_No2_female_female_PGP
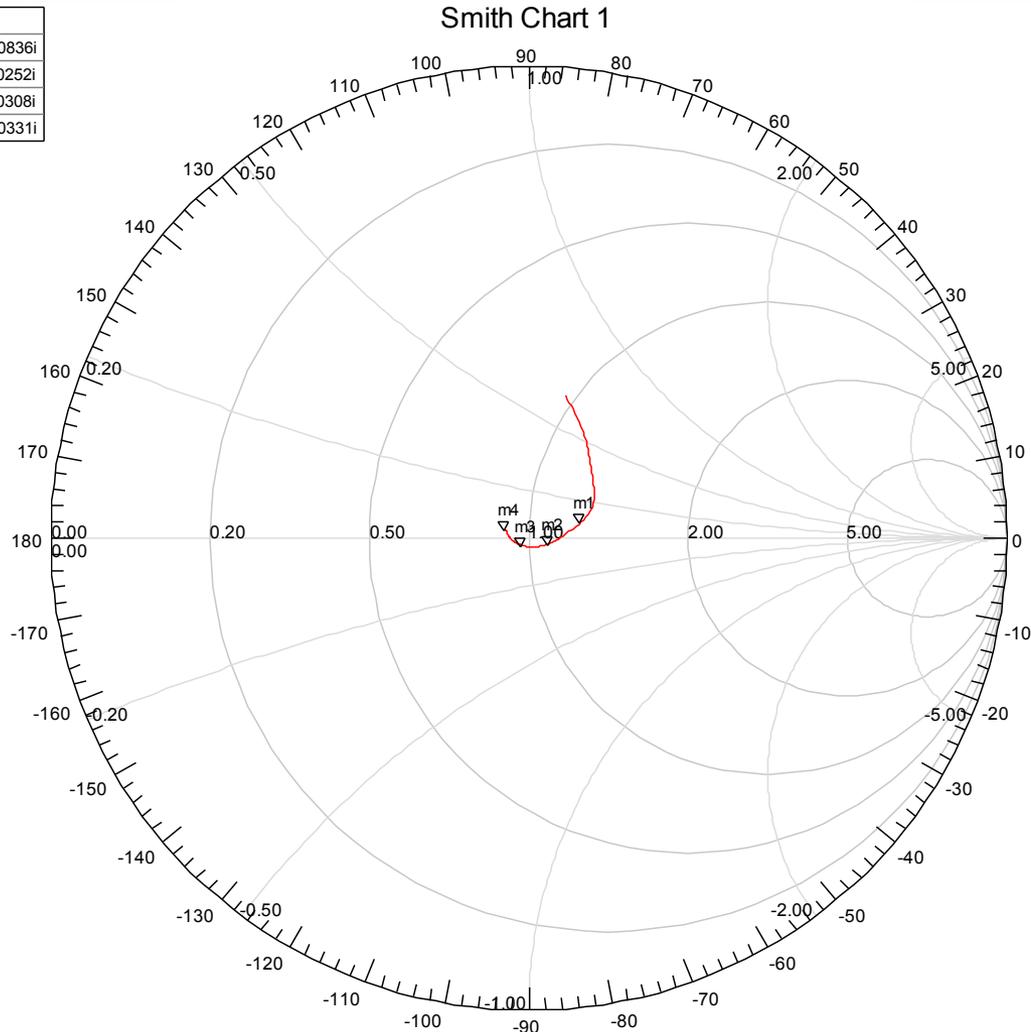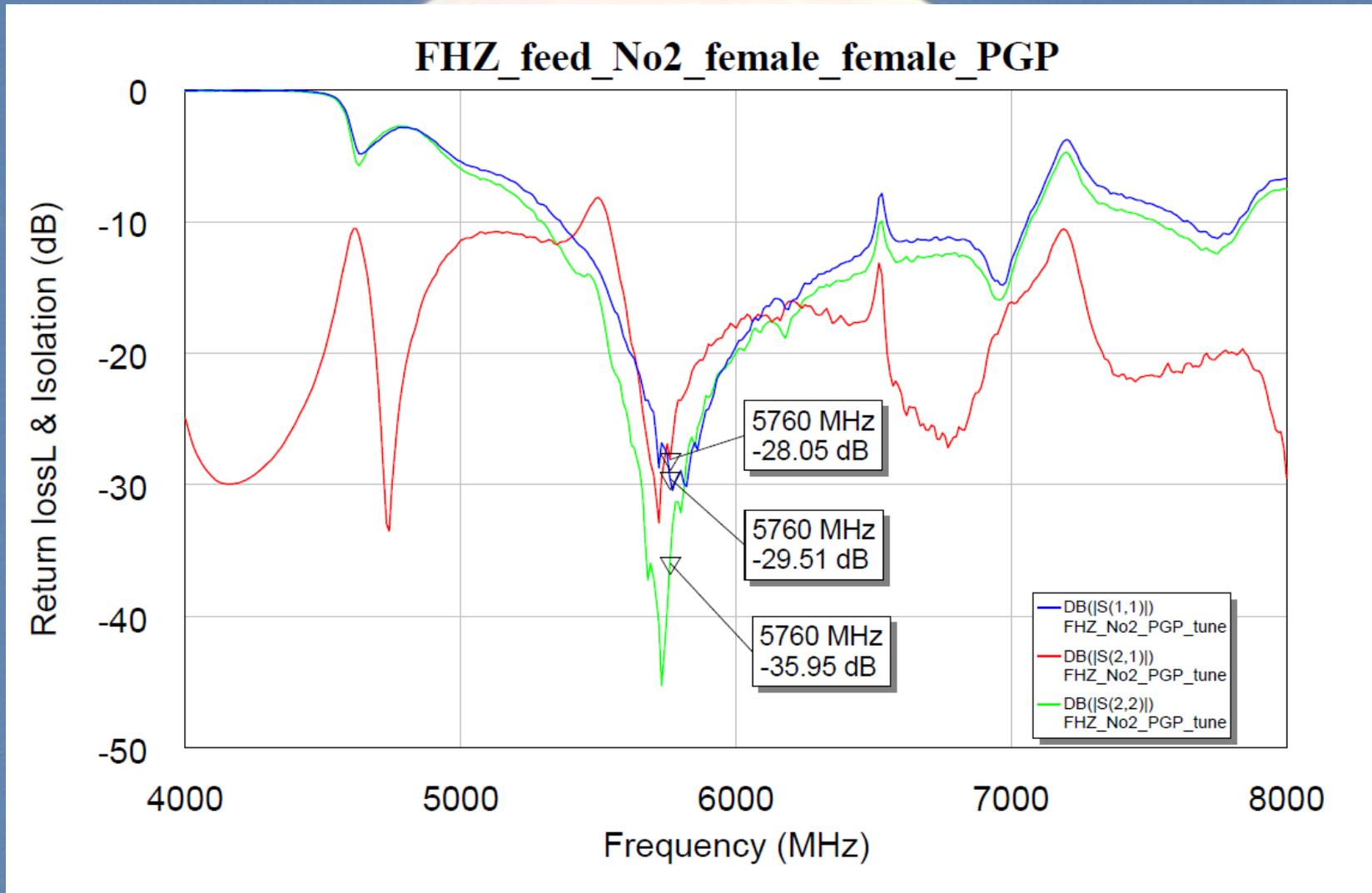
# FF Phase error
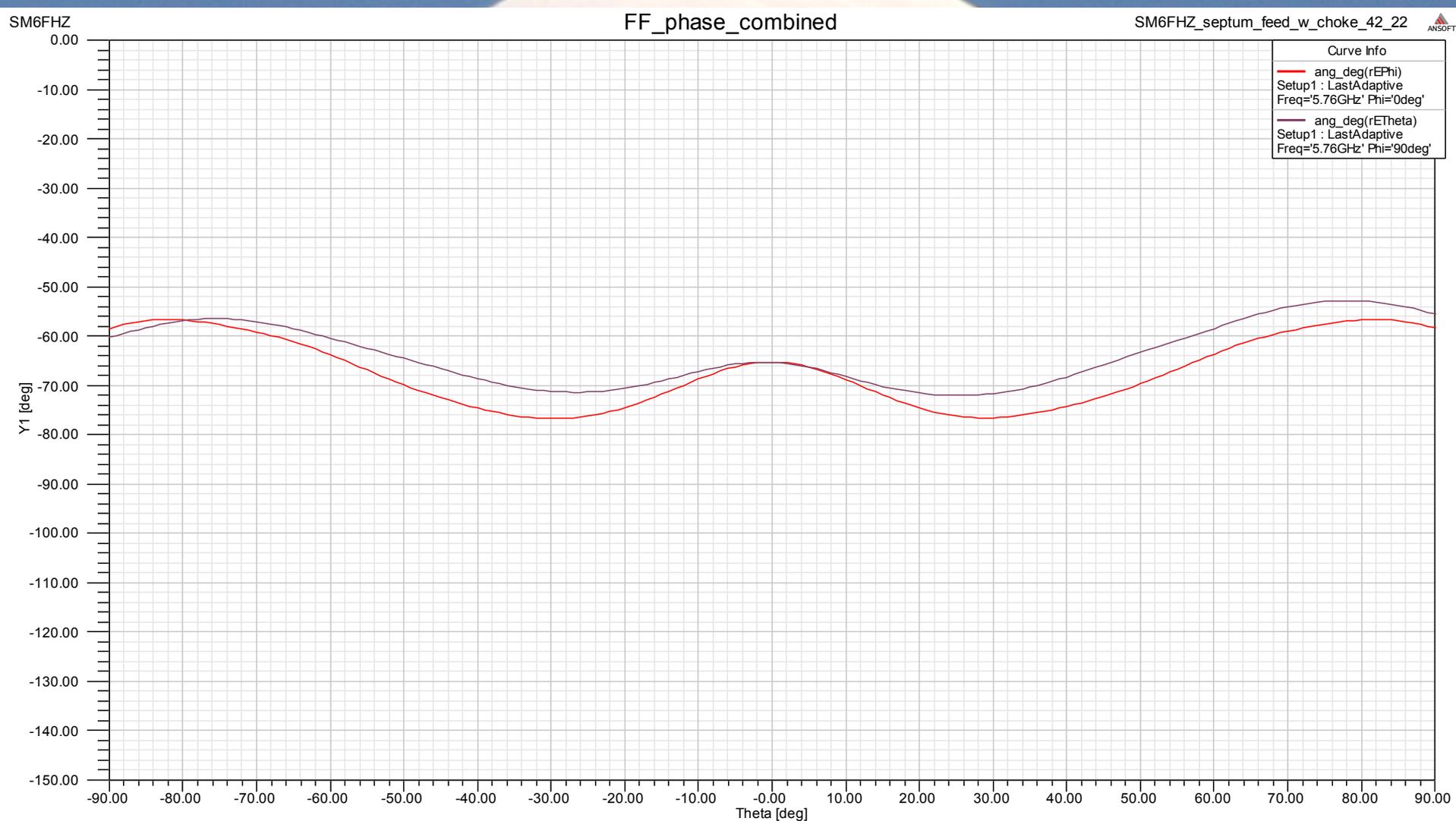
# Cross Polarization Ratio
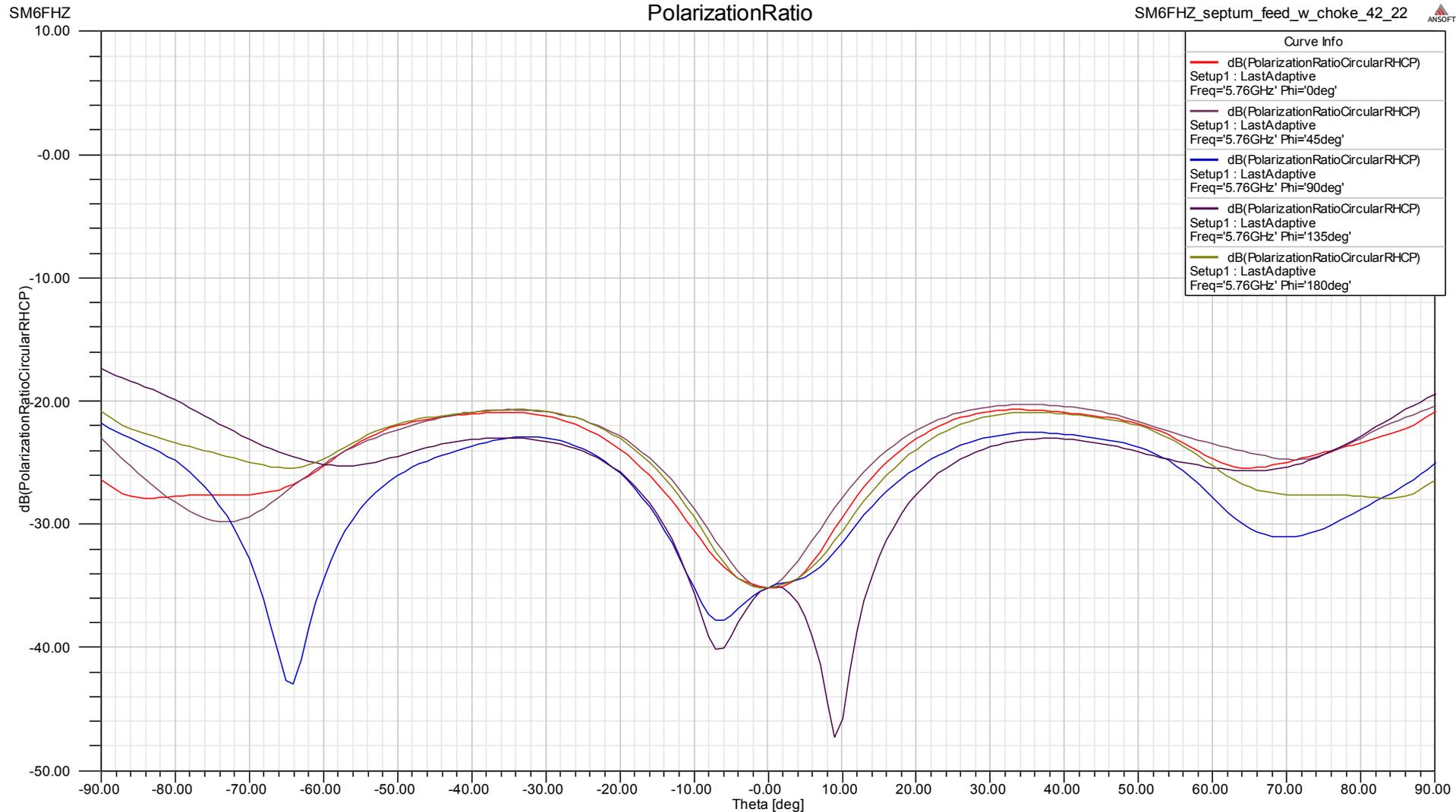
# Axial Ratio
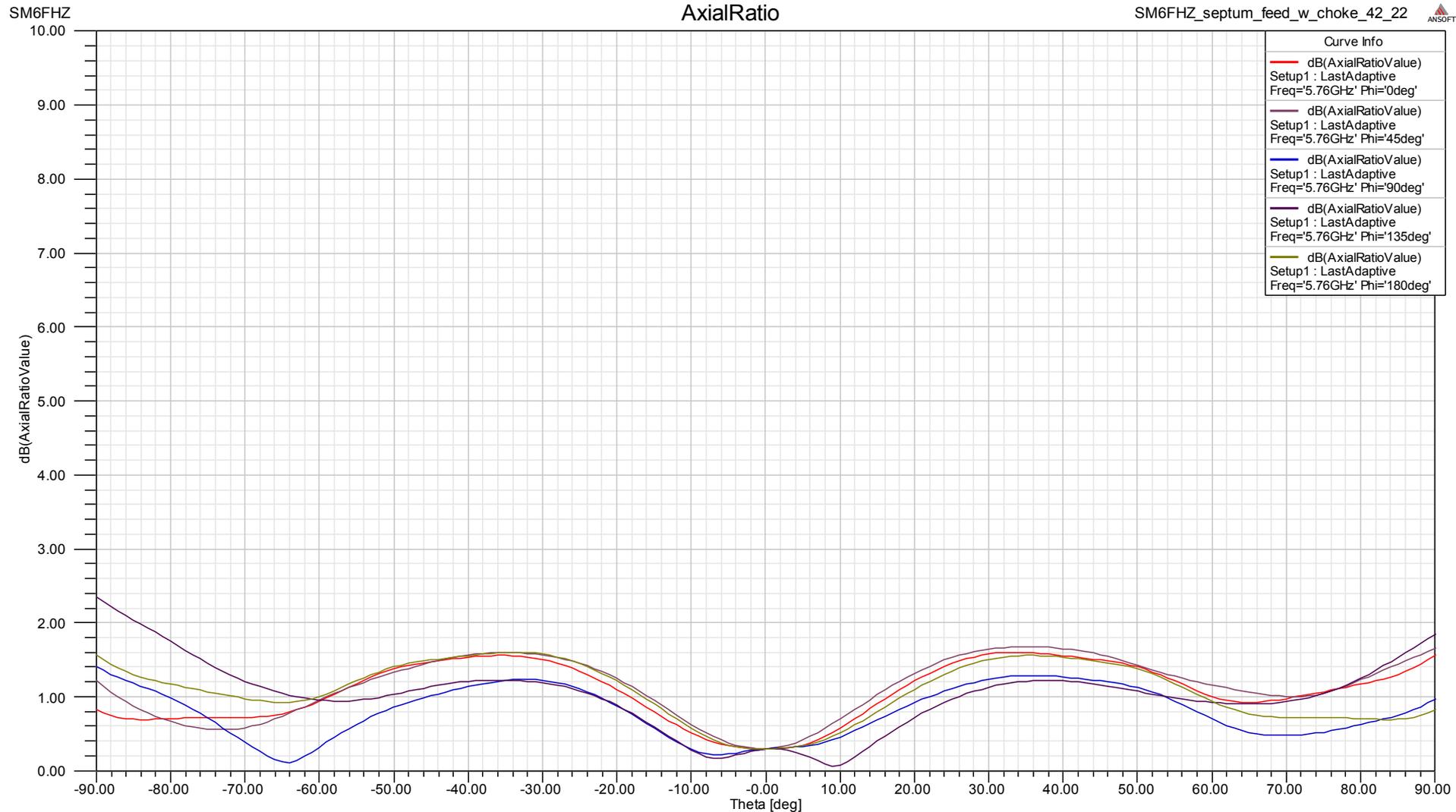
# InDish Performance

**PGP 1.8 m dish w. FHZ 6 cm Kumar feed**

**PGP 2.2 m dish w. FHZ Kumar 6 cm feed**
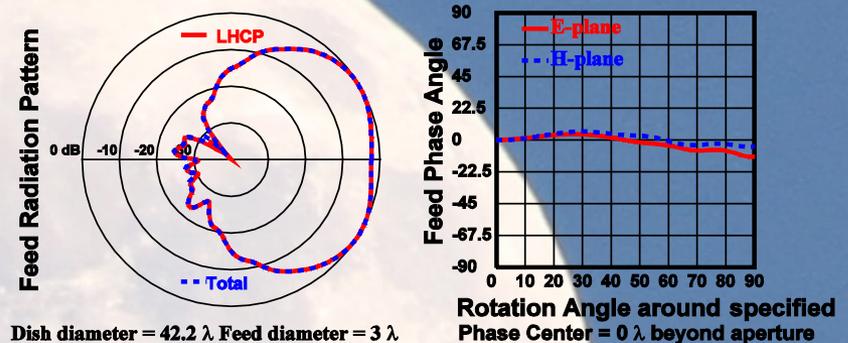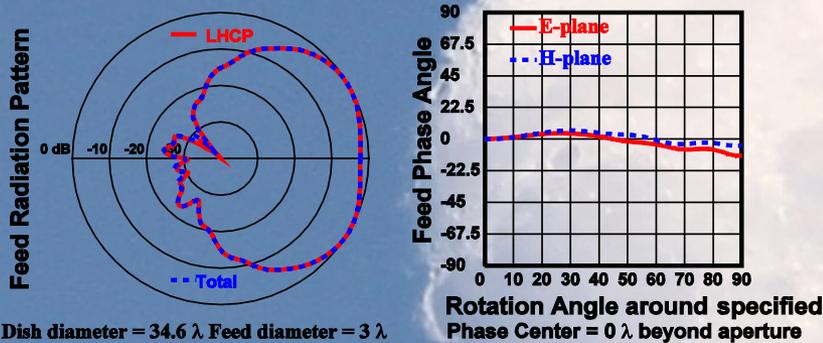


Dish diameter = 34.6 λ Feed diameter = 3 λ

Dish diameter = 42.2 λ Feed diameter = 3 λ
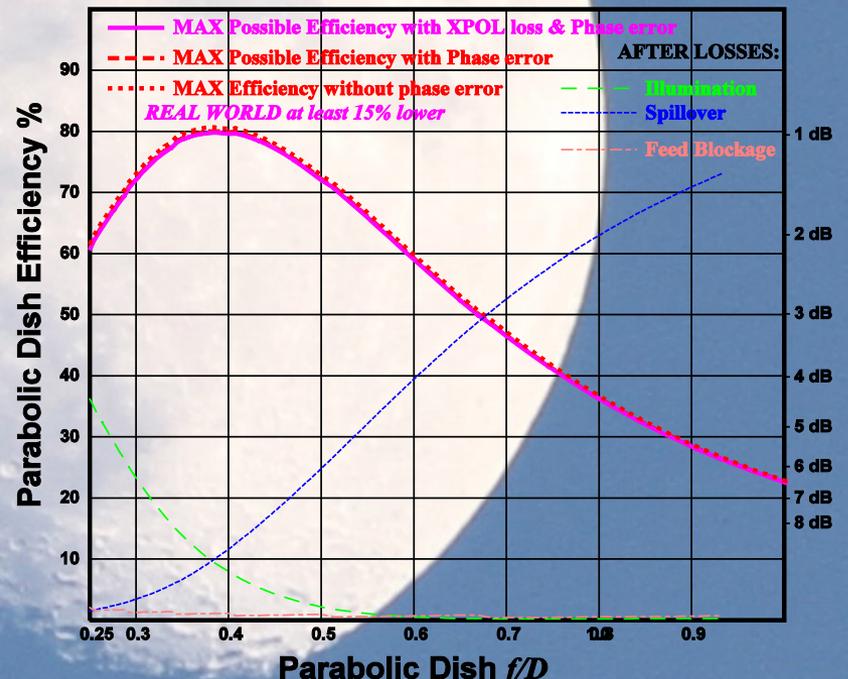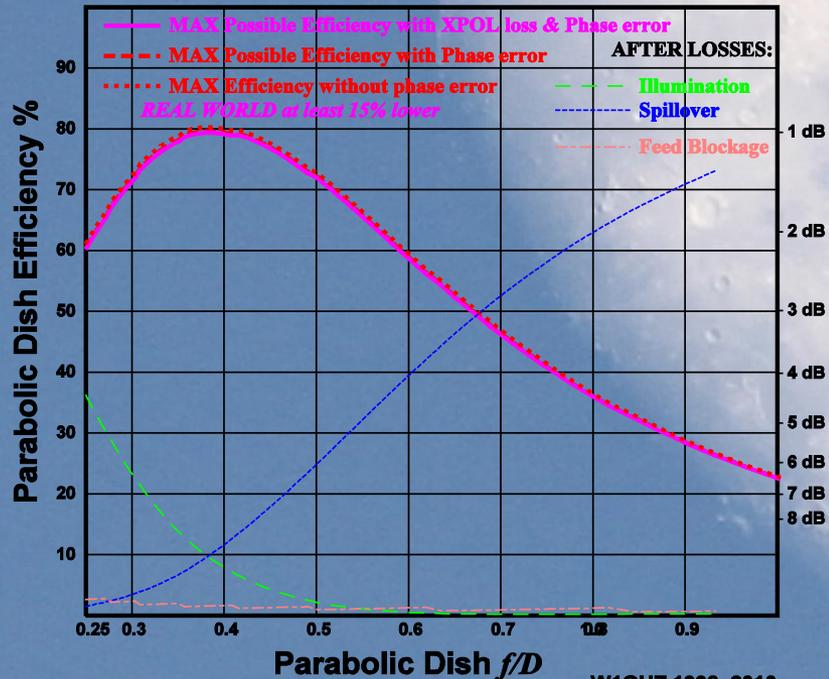
# Realization
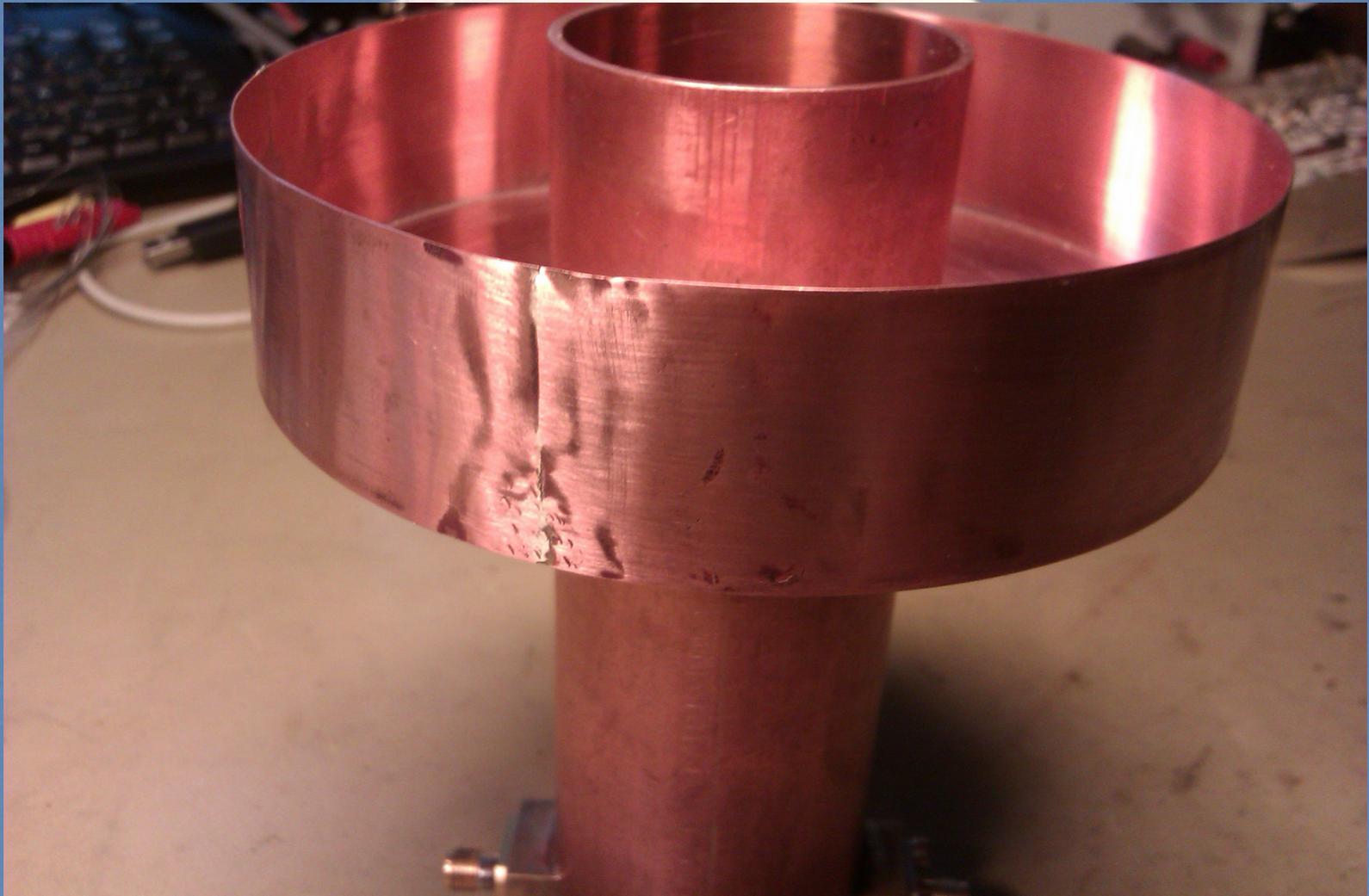
# SM6FHZ 3 cm 5 step septum feed

## 0.692 lambda W/G

# Solid and transparent models from the simulation
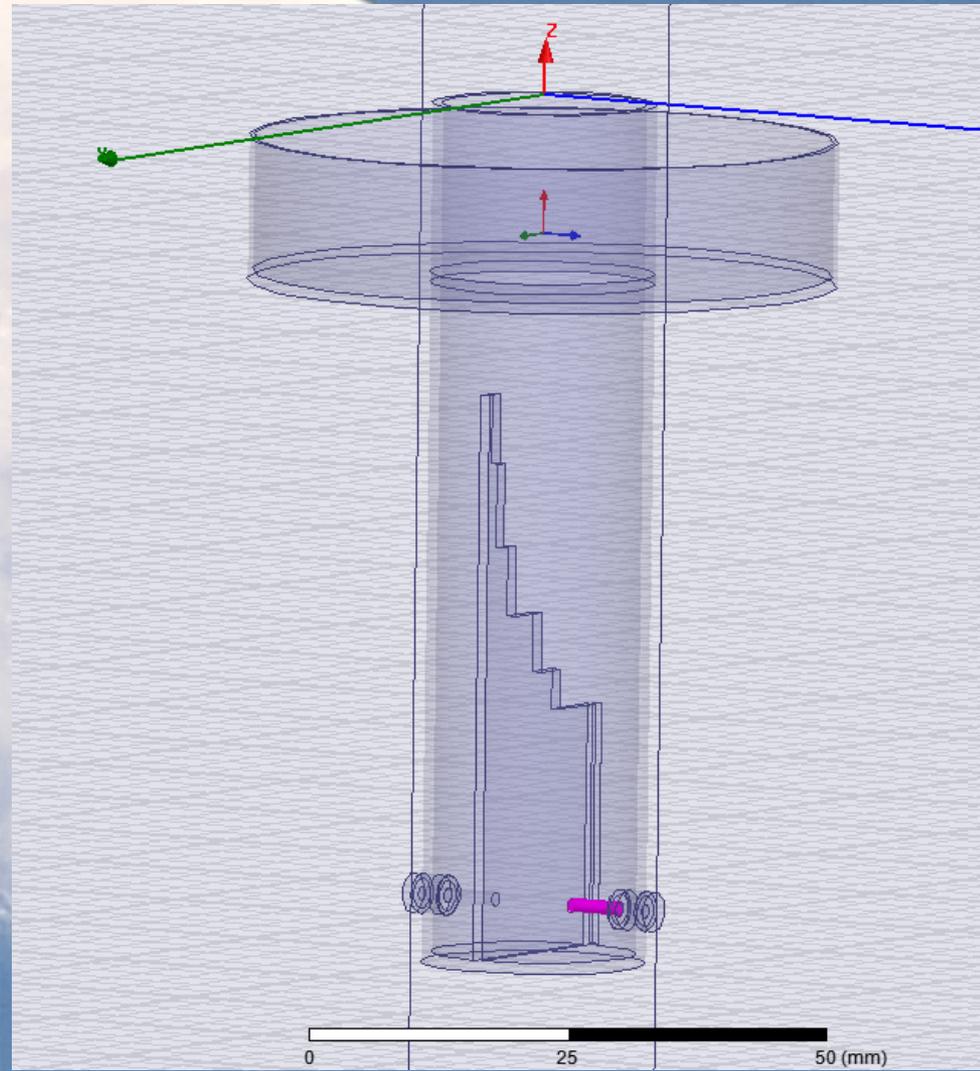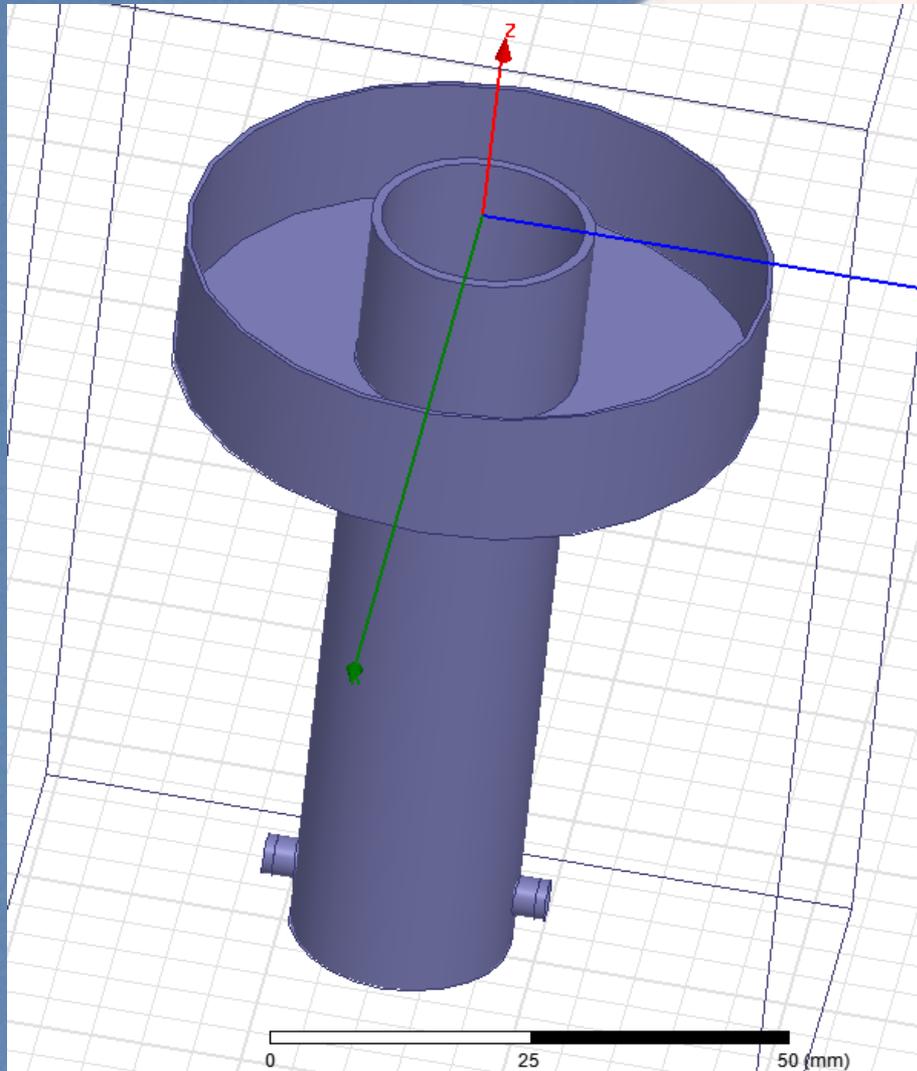
# WG and choke dimensions

Circular polarization convention for EME according to Crawford Hill Bulletin No 1:

Tx RHCP in space
Rx LHCP in space

Take polarization reversal into account when using reflector antennas.

2.0
3.5

14.4 outer

57.8 outer

T= 0.5 wall

T= 1.0 bottom

85.8 outer
1.0 mm bottom plate included

Wave guide 22/20 mm copper tube

Tx
LHCP

Rx
RHCP

# Septum dimensions



7.0

8.5

7.0

6.0

4.0

3.0

4.0

6.2

11.0

14.5

24.0
Inner measure
Bottom
plate not
included

20.0

Wave guide
22/20 mm
copper tube

Septum
t = 1.0 mm
copper

Bottom plate
1.0 mm
copper

# Probe dimensions



1.3 diam.

5.6

5.0 inner

# S11, S22, S21 combined

# 3D Total Power Far Field pattern

# Far Field Pattern 0 deg

# Far Field Phase



FF_phase_Phi90

SM6FHZ

SM6FHZ_septum_feed_w_choke4

Curve Info
— ang_deg(rETheta)
Setup1 : LastAdaptive
Freq='10.368GHz' Phi='90deg'
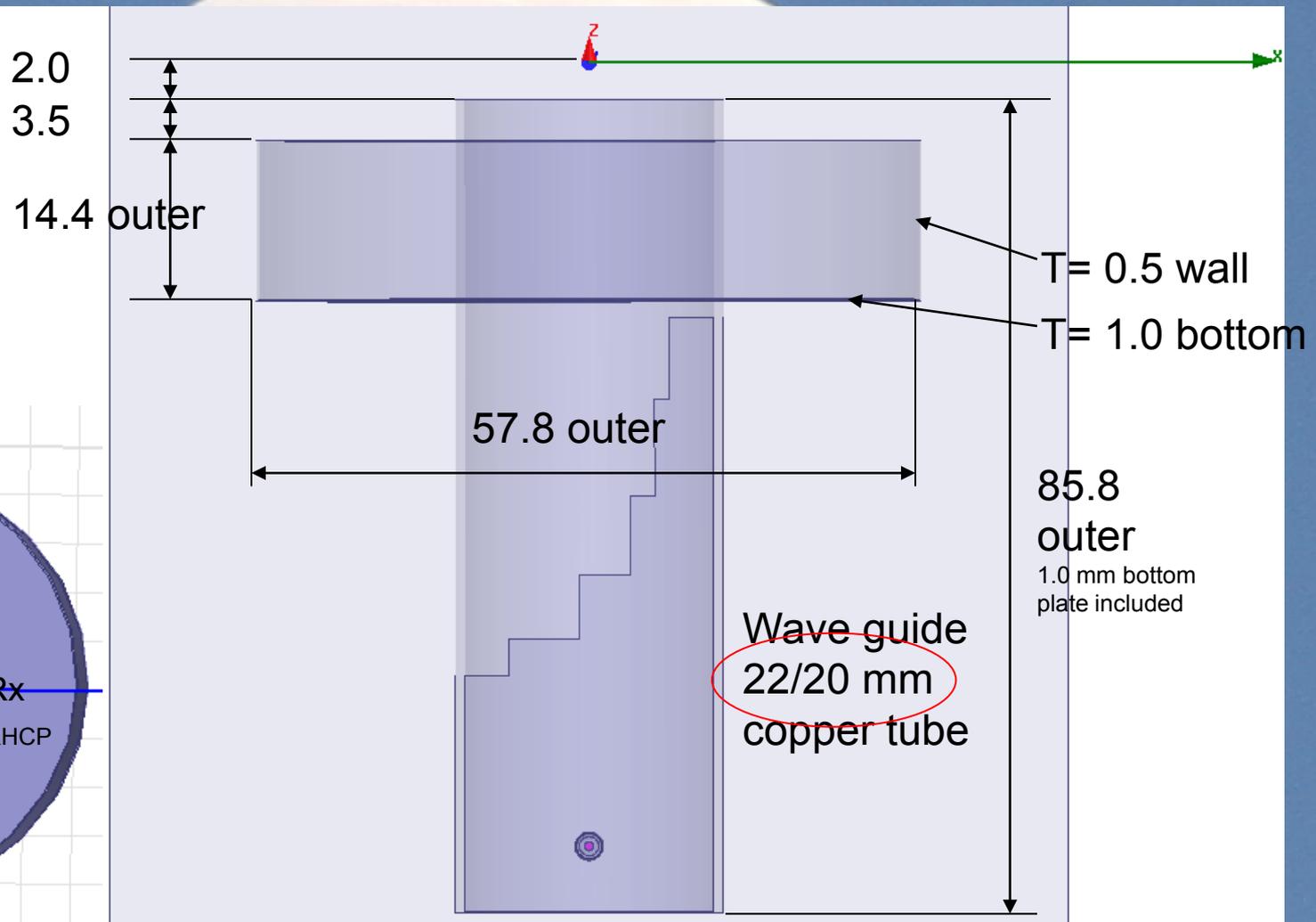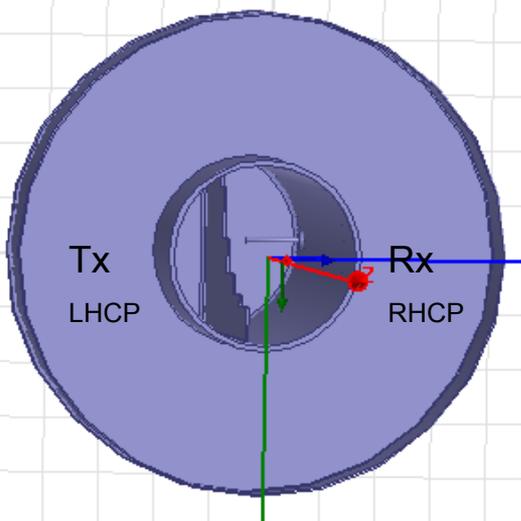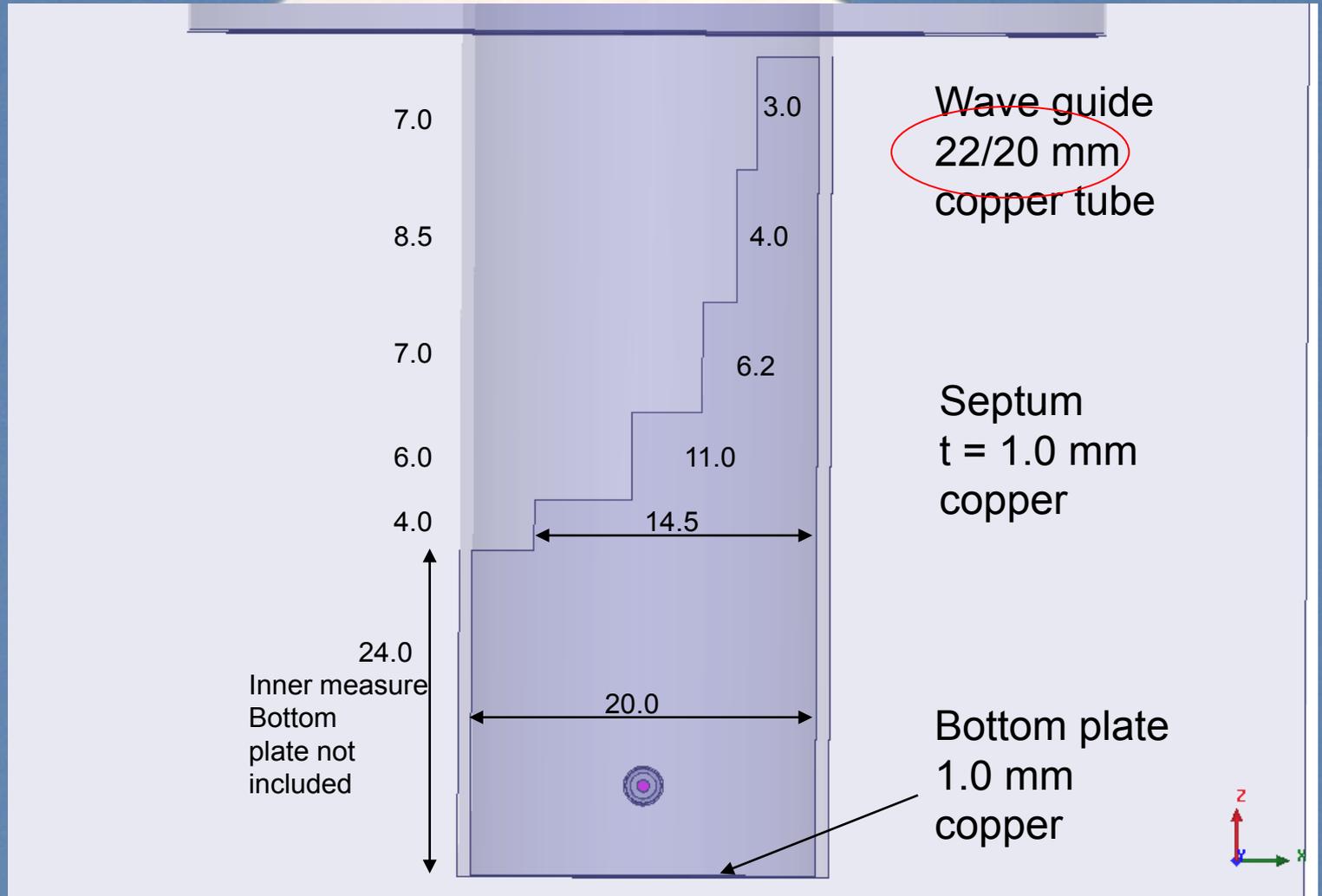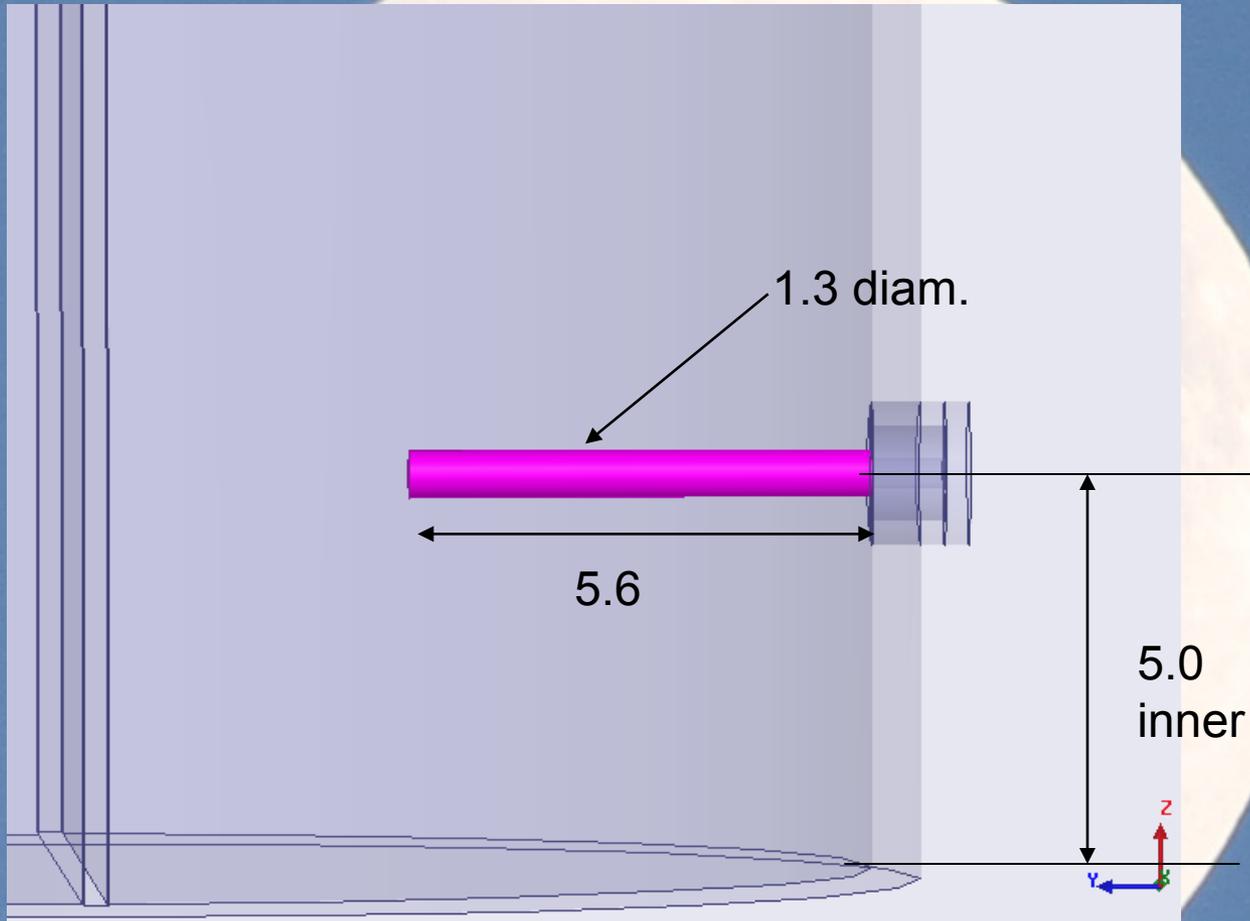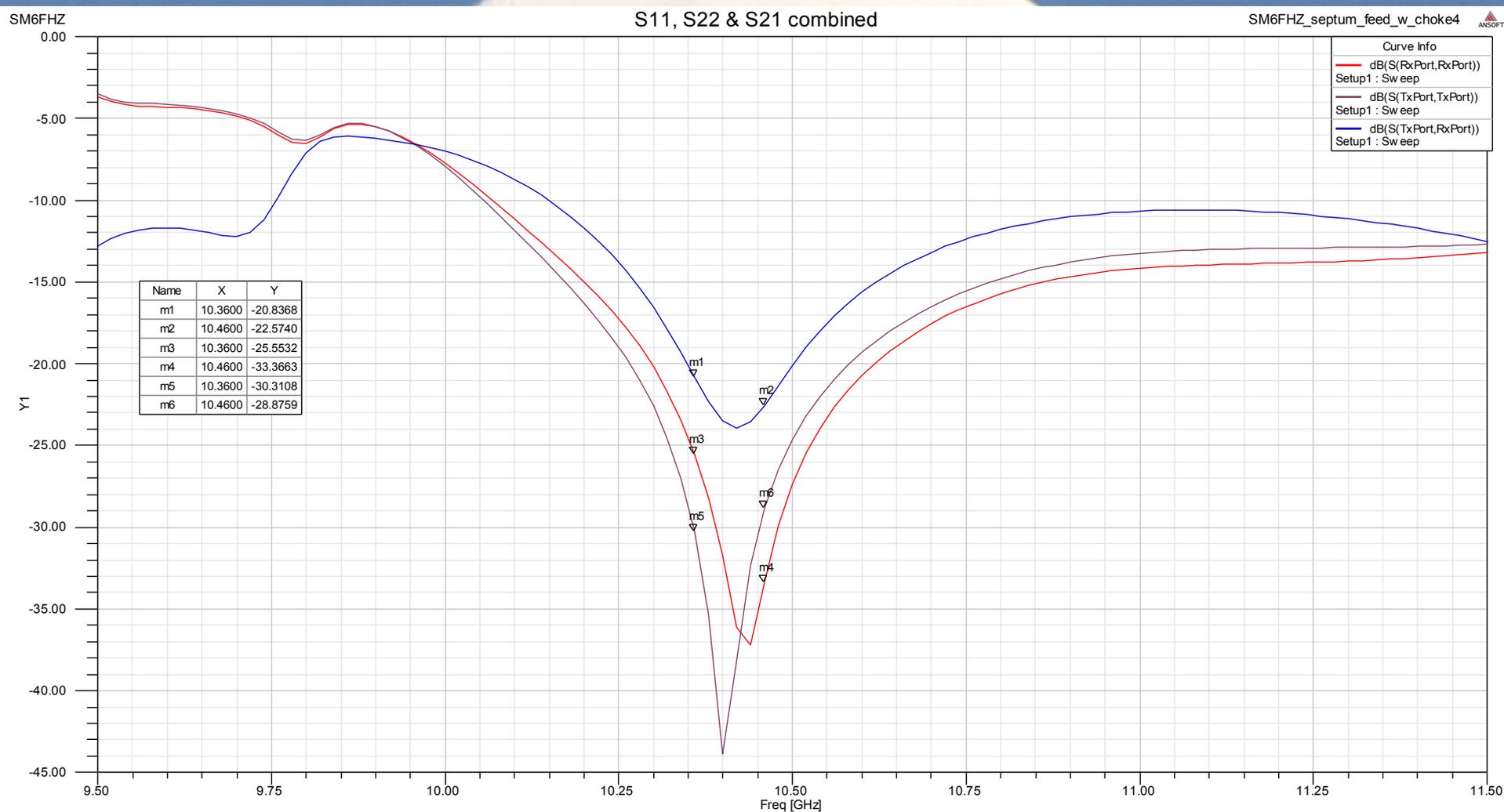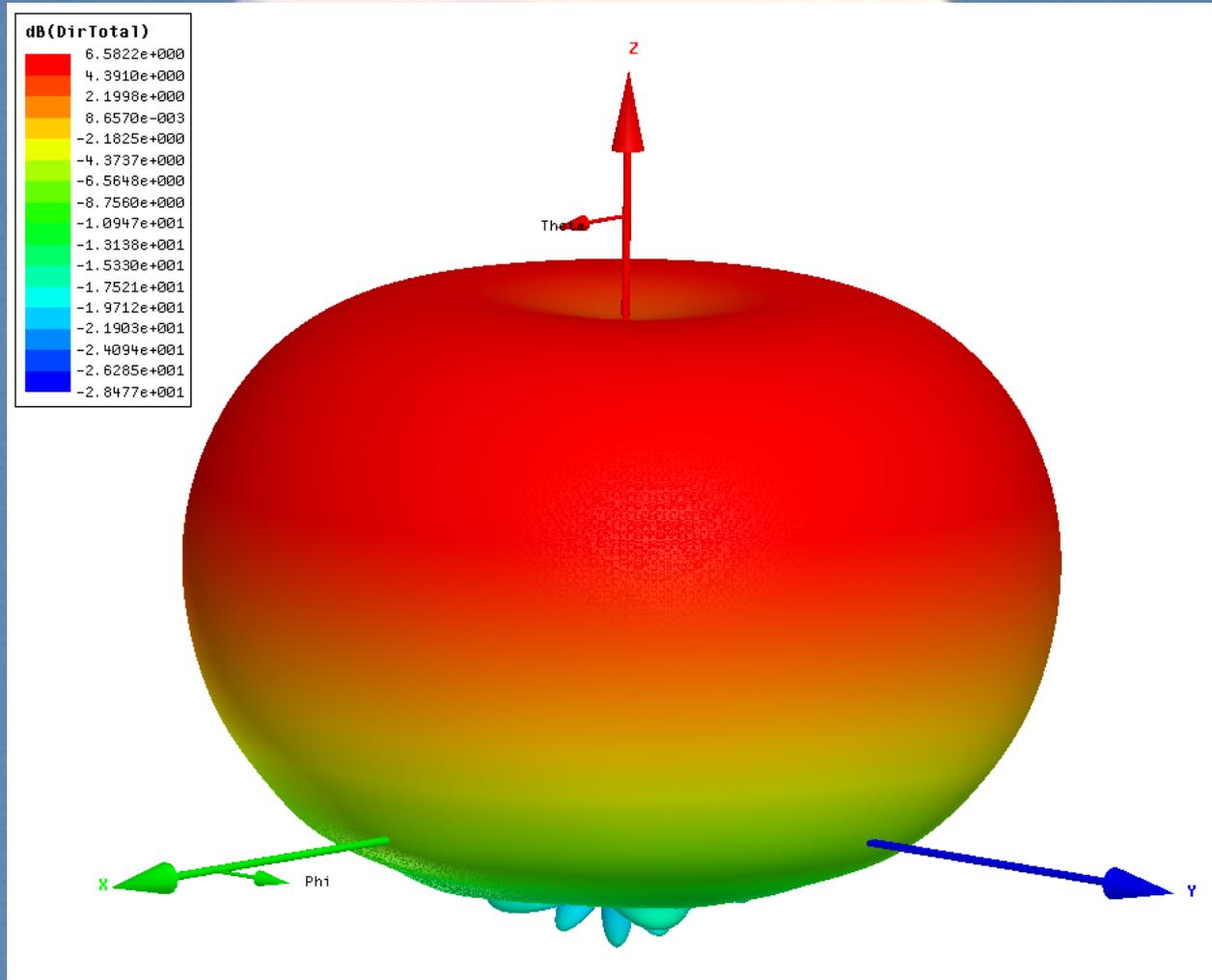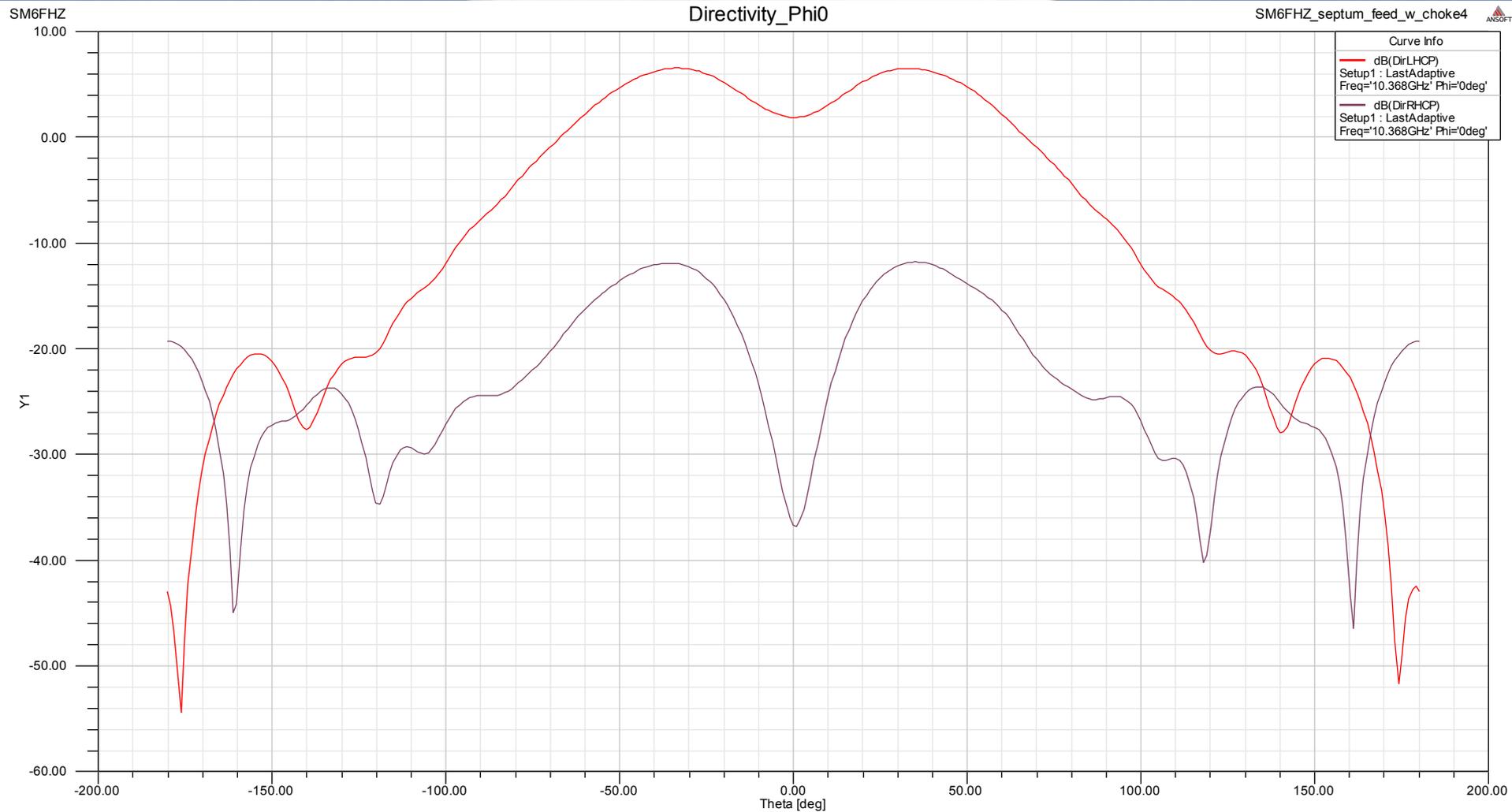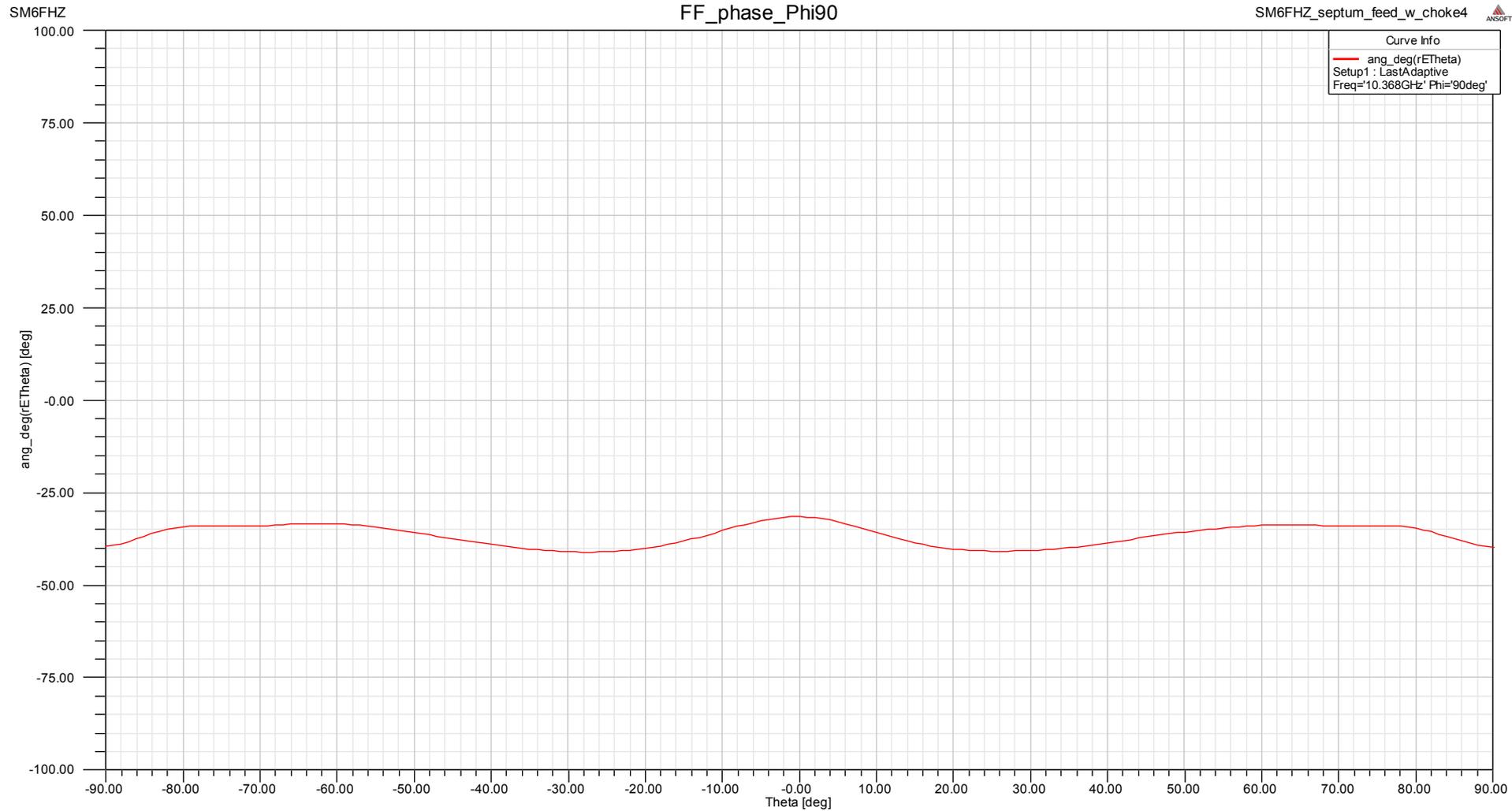
# Cross Polar Ratio
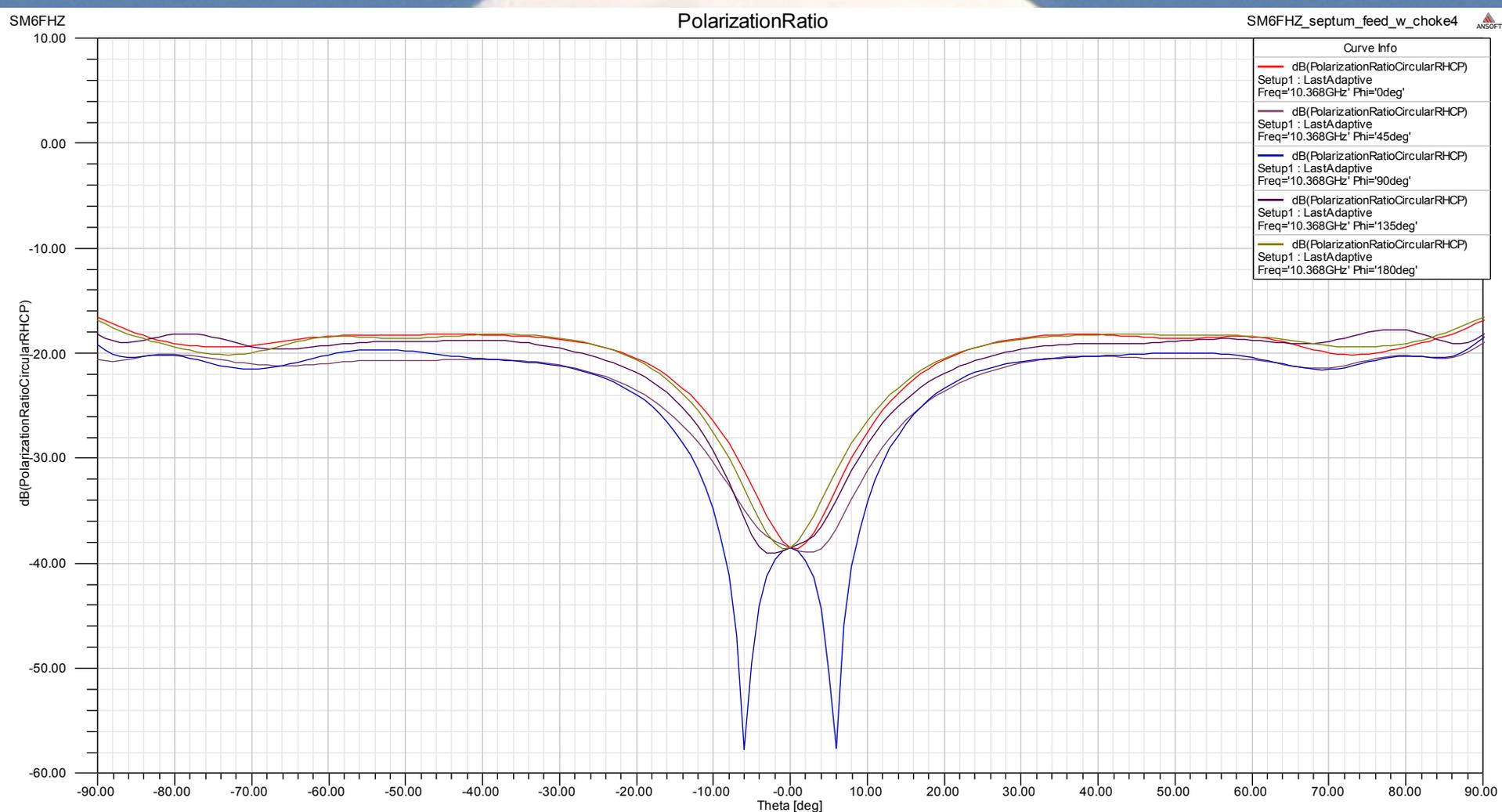
# Axial Ratio
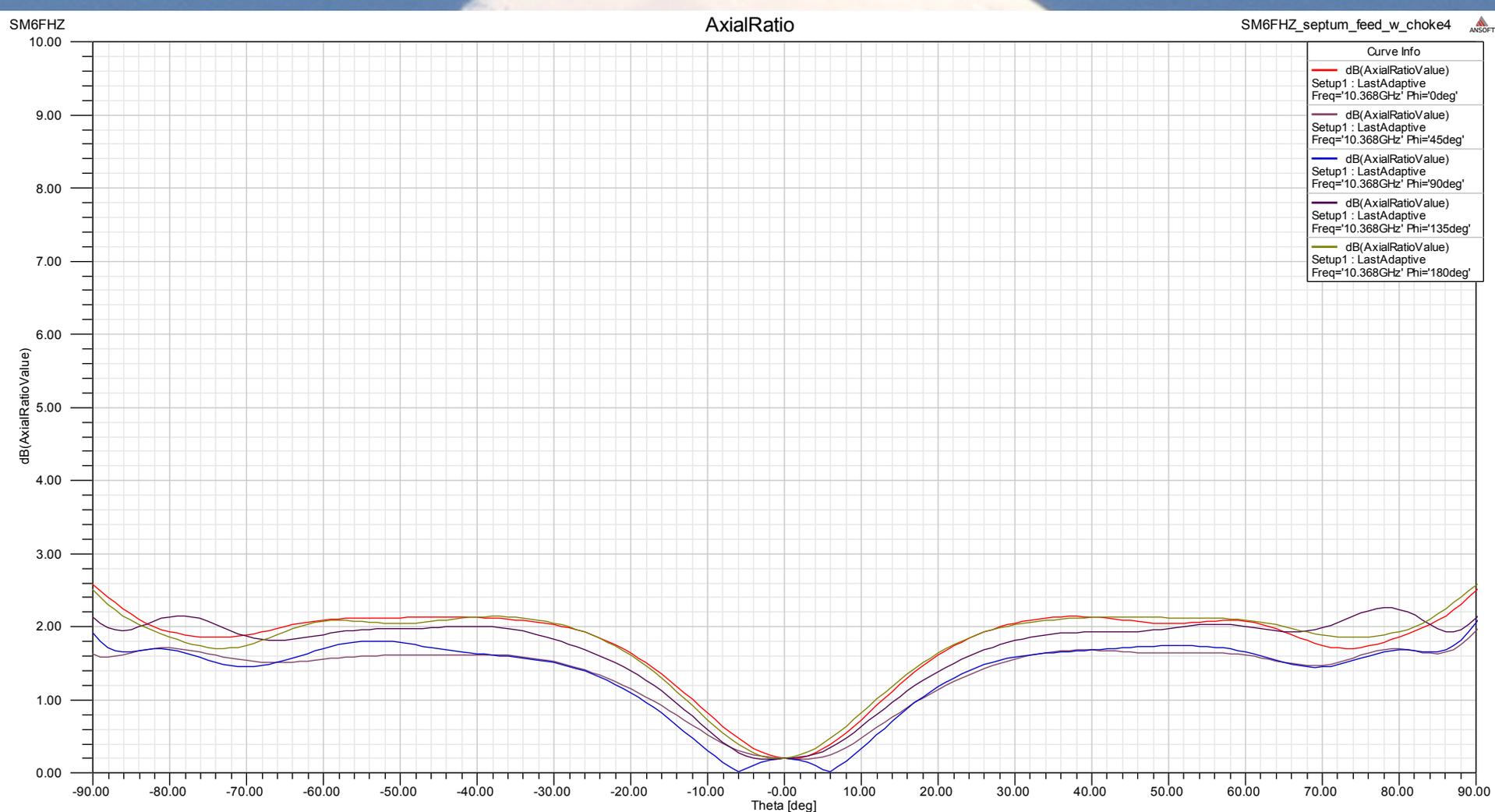
# Realization
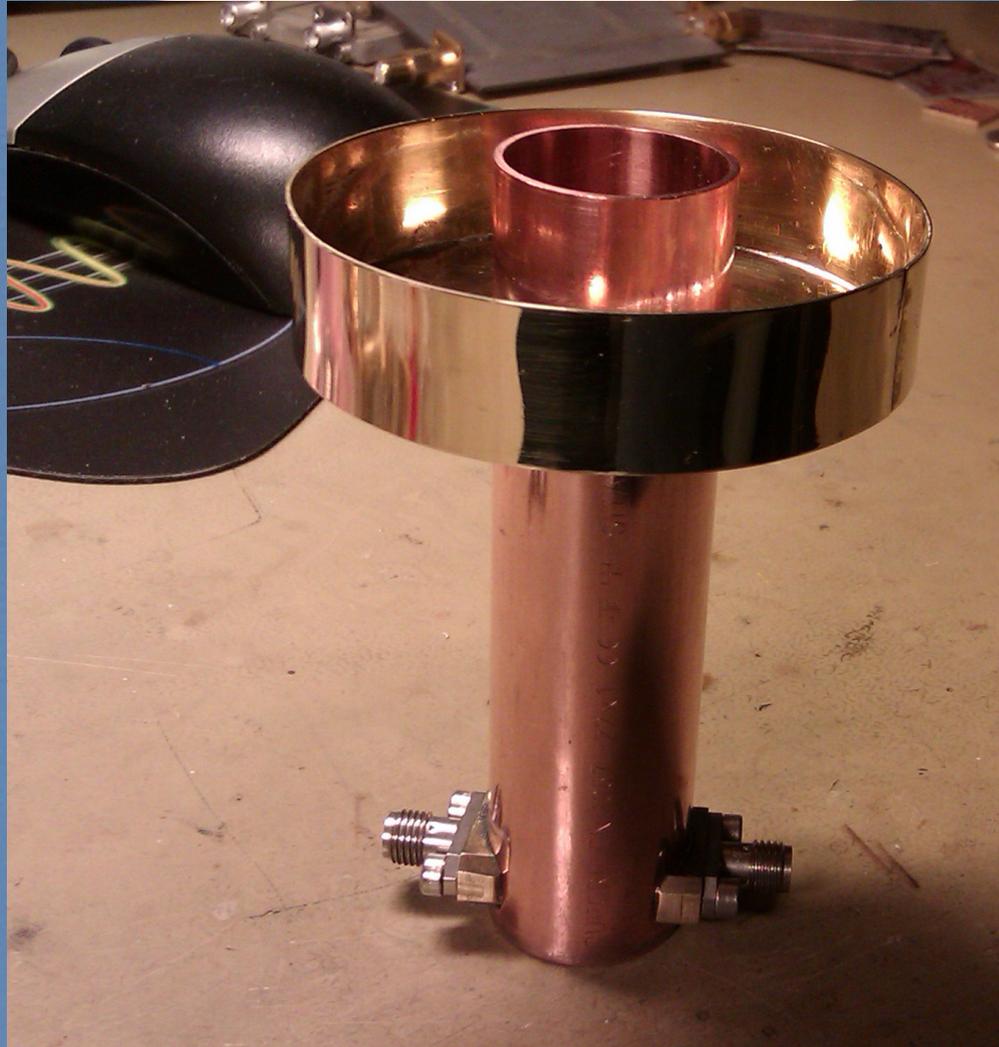
# +0.2 mm WG-diam, +1 mm septum, +1 mm WG-length

# WG and choke dimensions

2.0

3.5

14.4 outer

Circular polarization convention for EME according to Crawford Hill Bulletin No 1:

Tx RHCP in space
Rx LHCP in space

Take polarization reversal into account when using reflector antennas.

T= 0.5 wall

T= 1.0 bottom

57.8 outer

84.3 outer

1.0 mm bottom plate included

Wave guide 22/20.2 mm copper tube

Tx

LHCP

Rx

RHCP

# Septum dimensions



Wave guide
22/20.2 mm
copper tube

7.0

2.4

8.5

3.4

7.0

6.0

Septum
t = 1.0 mm
copper

6.0

10.8

4.0

13.7

24.0
Inner measure
Bottom
plate not
included

20.2

Bottom plate
1.0 mm
copper

# Probe dimensions



1.3 diam.

5.7

5.0 inner

# 20,2 mm WG-inner diam optimized

# Measurements



FHZ_Kumar_No1_20_2_probe_with_tuning
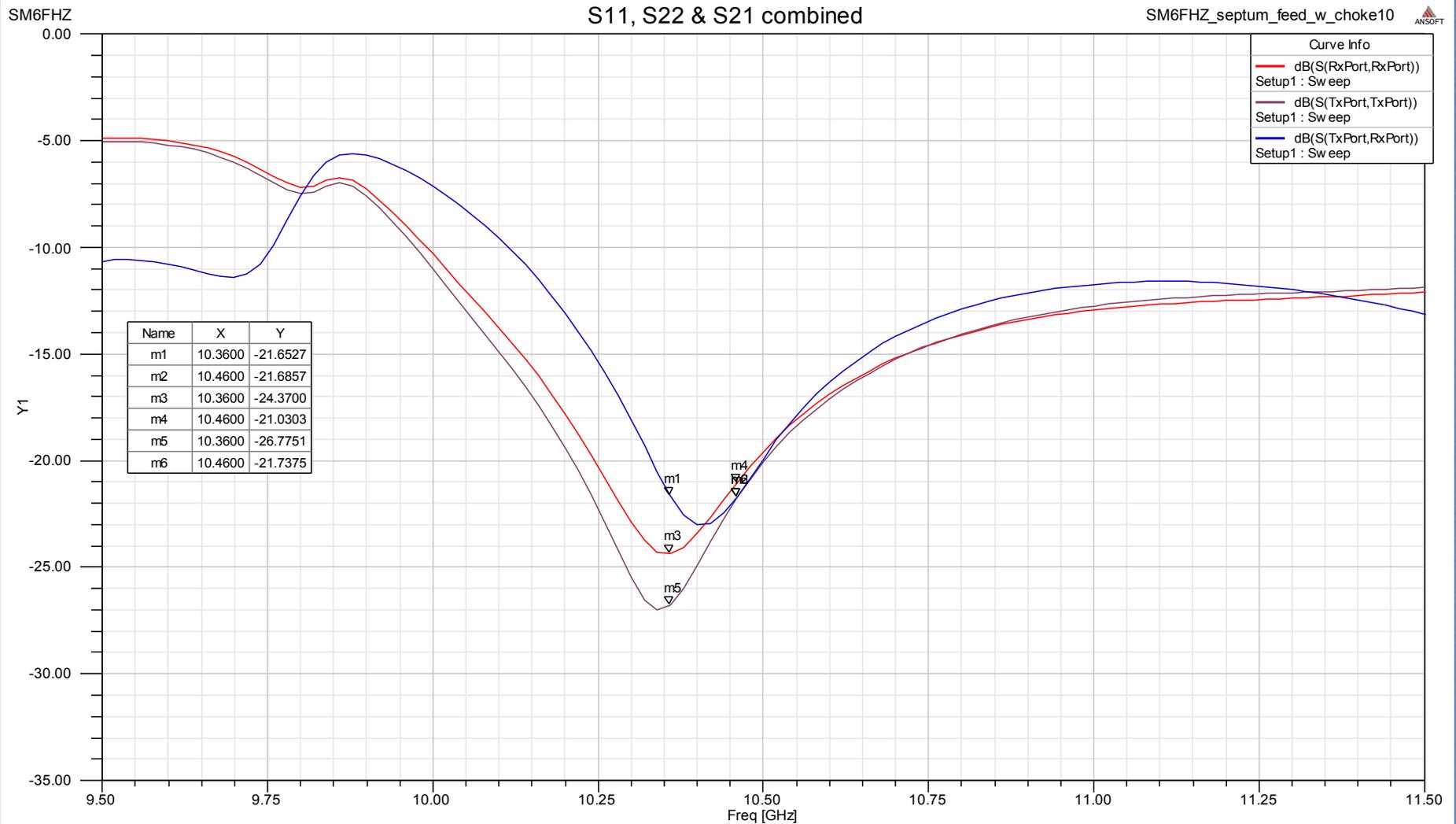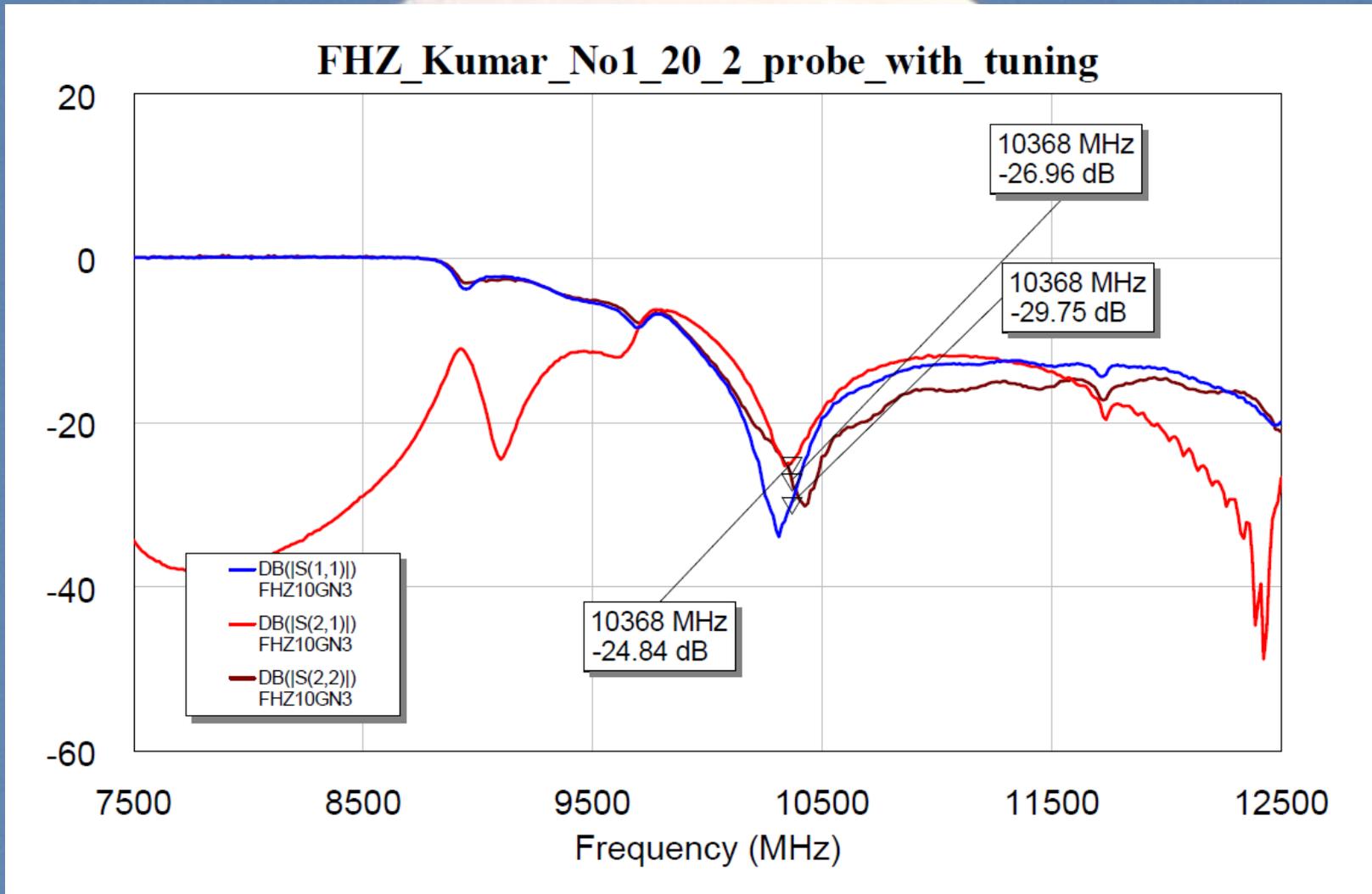
# Far Field Pattern 0 deg

# FF Phase error

# Axial Ratio

# SM6FHZ 3 cm 5 step septum feed

## 0.795 lambda W/G

# Solid and transparent models from the simulation

# WG and choke dimensions

1.5

2.5

14.9 outer

Circular polarization convention for EME according to Crawford Hill Bulletin No 1:

Tx RHCP in space
Rx LHCP in space

Take polarization reversal into account when using reflector antennas.

Tx
LHCP

Rx
RHCP

T= 0.5 wall

T= 1.0 bottom

60.0 outer

75.3 outer
1.0 mm bottom plate included

Wave guide 25/22 mm brass tube

# Septum dimensions



7.0

1.5

Wave guide
25/22 mm
brass tube

9.3

2.5

8.0

4.7

7.0

8.0

Septum
t = 1.0 mm
copper

5.0

15.0

27.0
Inner measure
Bottom
plate not
included

22.0
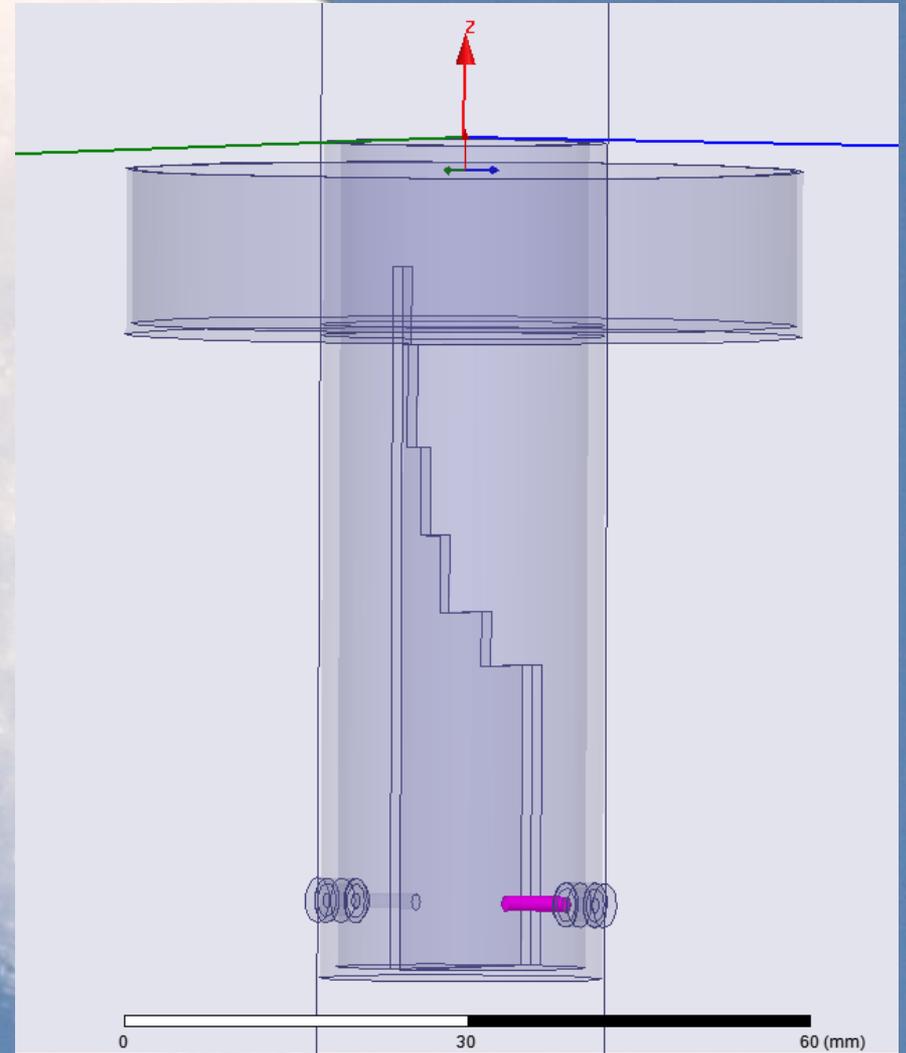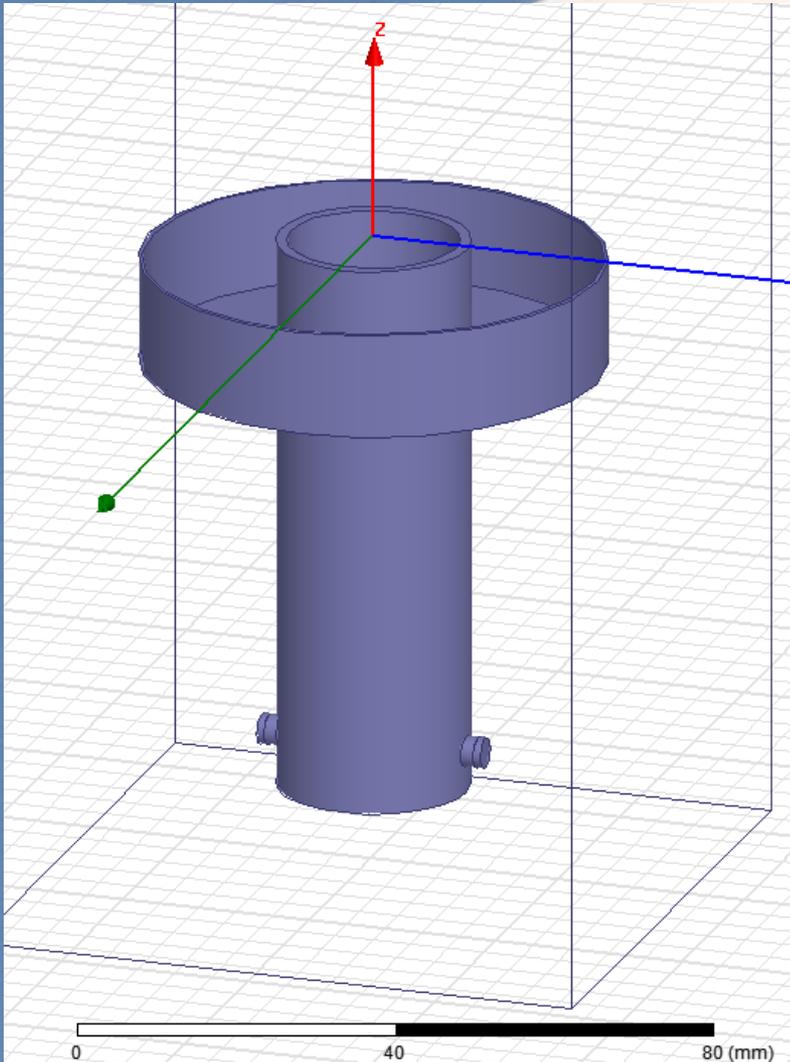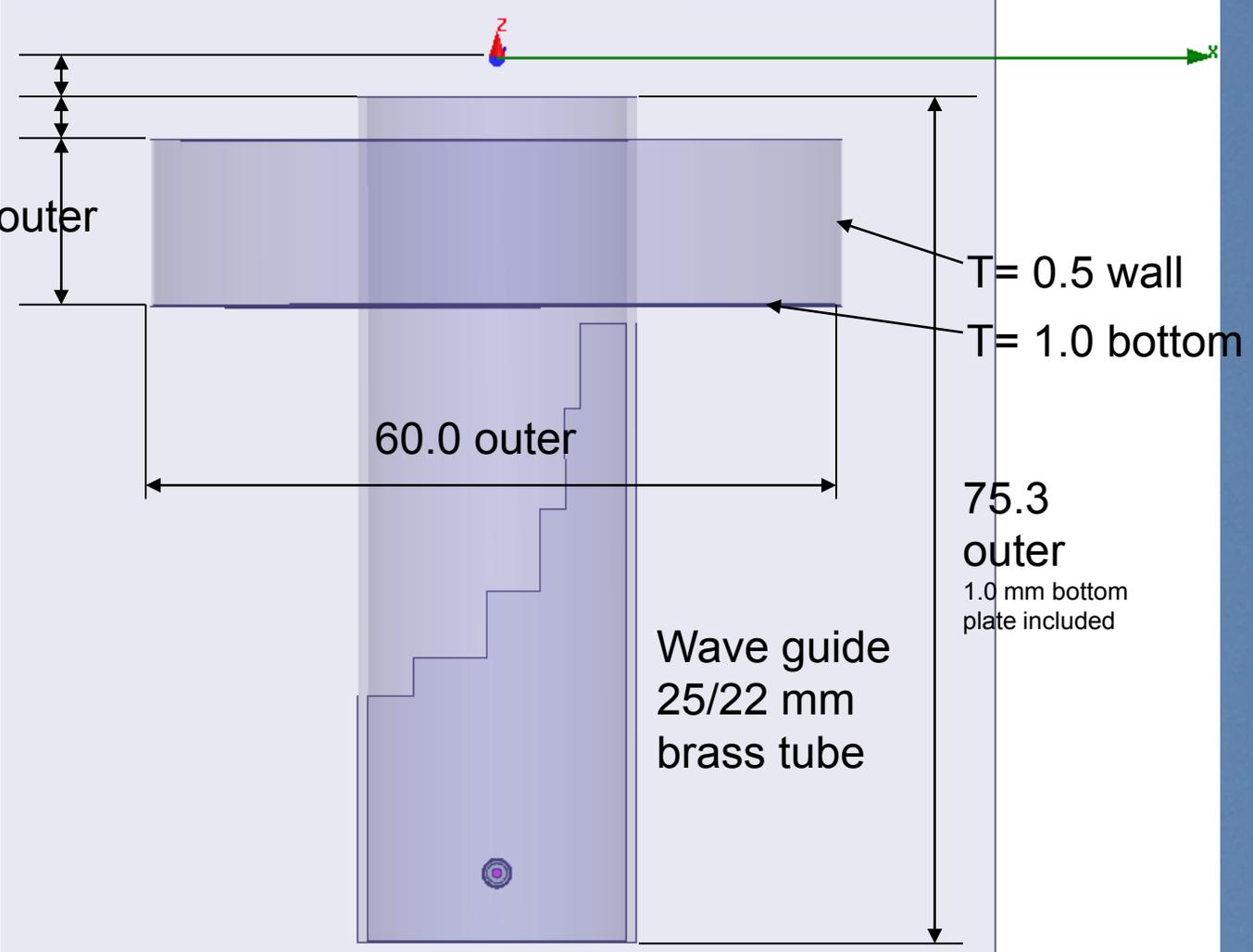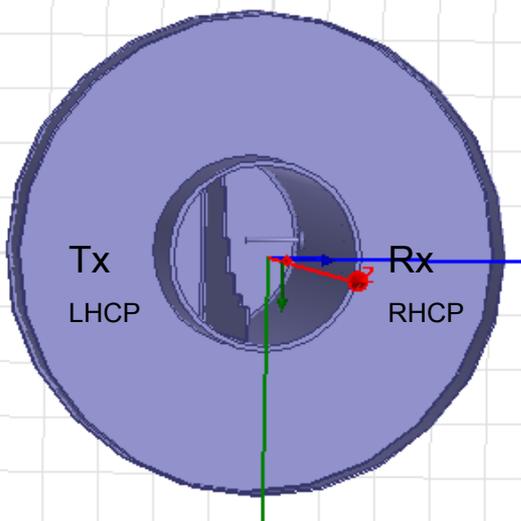
Bottom plate
1.0 mm
brass

# Probe dimensions



1.3 diam.

6.3

5.8 inner

# S11, S22, S21 combined

# 3D Total Power Far Field pattern

# Far Field Pattern 0 deg

# Far Field Phase error

# Cross Polar Ratio

# Axial Ratio

# On the air experience 6 cm
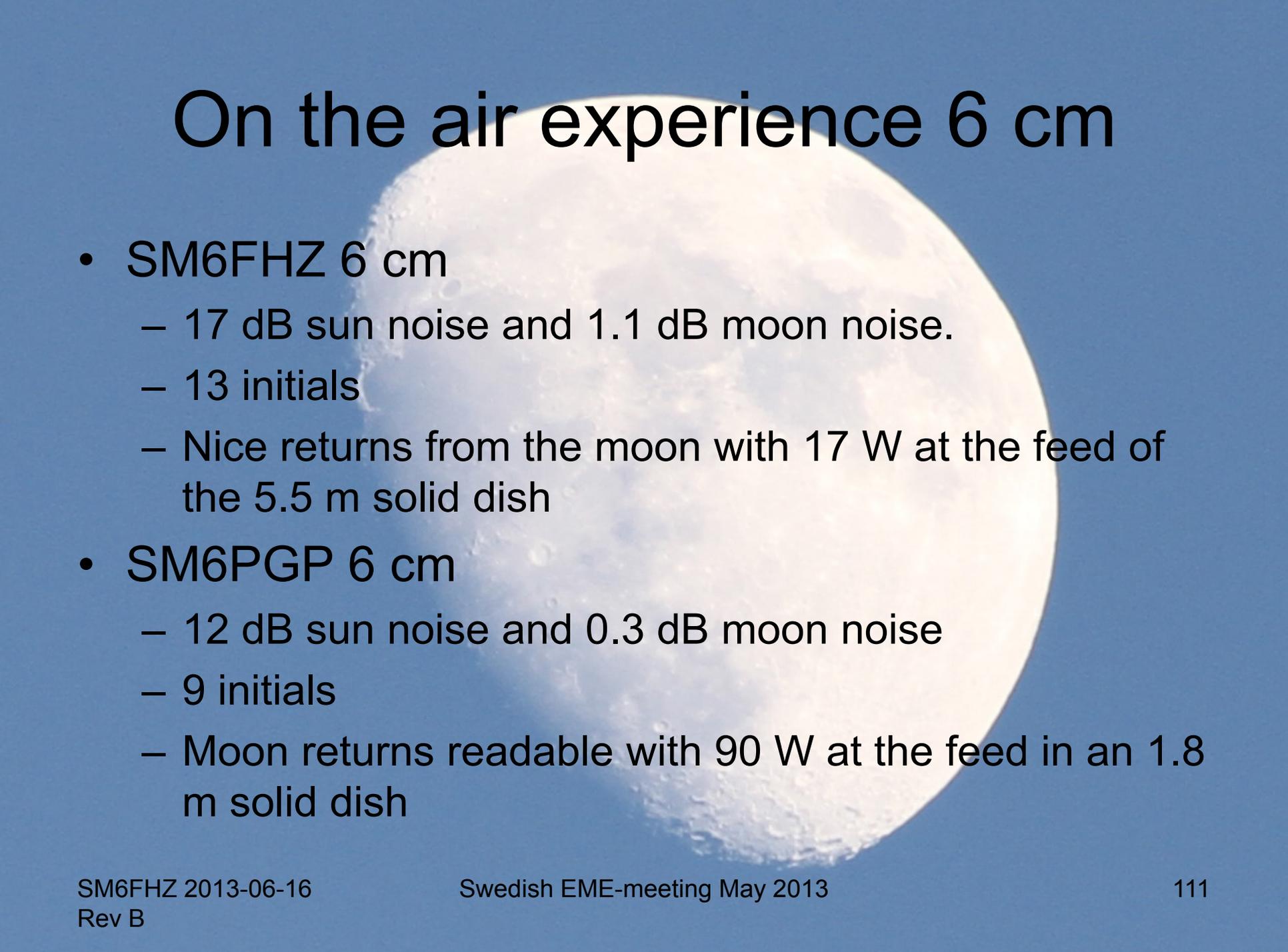
- SM6FHZ 6 cm
  - 17 dB sun noise and 1.1 dB moon noise.
  - 13 initials
  - Nice returns from the moon with 17 W at the feed of the 5.5 m solid dish
- SM6PGP 6 cm
  - 12 dB sun noise and 0.3 dB moon noise
  - 9 initials
  - Moon returns readable with 90 W at the feed in an 1.8 m solid dish

# On the air experience 3 cm

- ## SM6PGP 3 cm
  - 10 dB sun noise and 0.3 dB moon noise
  - 4 stations heard (positively identified on CW) via the moon
  - Antenna 1.8 m solid dish

# Lessons Learned

- Scaling feed dimensions from a one band design to another band is at your own risk
  - The materiel used (thickness etc) plays a important role. It is not obvious how to scale material thickness. I argue that you will not know what radiation pattern you will get if scaled.

- Soldering of the septum to 100% is crucial
  - This is true for all soldering joints in the feed

- The inner WG diameter is sensitive to tolerances
  - 0.2 mm larger diameter on 10 GHz moved the optimum isolation >100 MHz down

# Conclusion
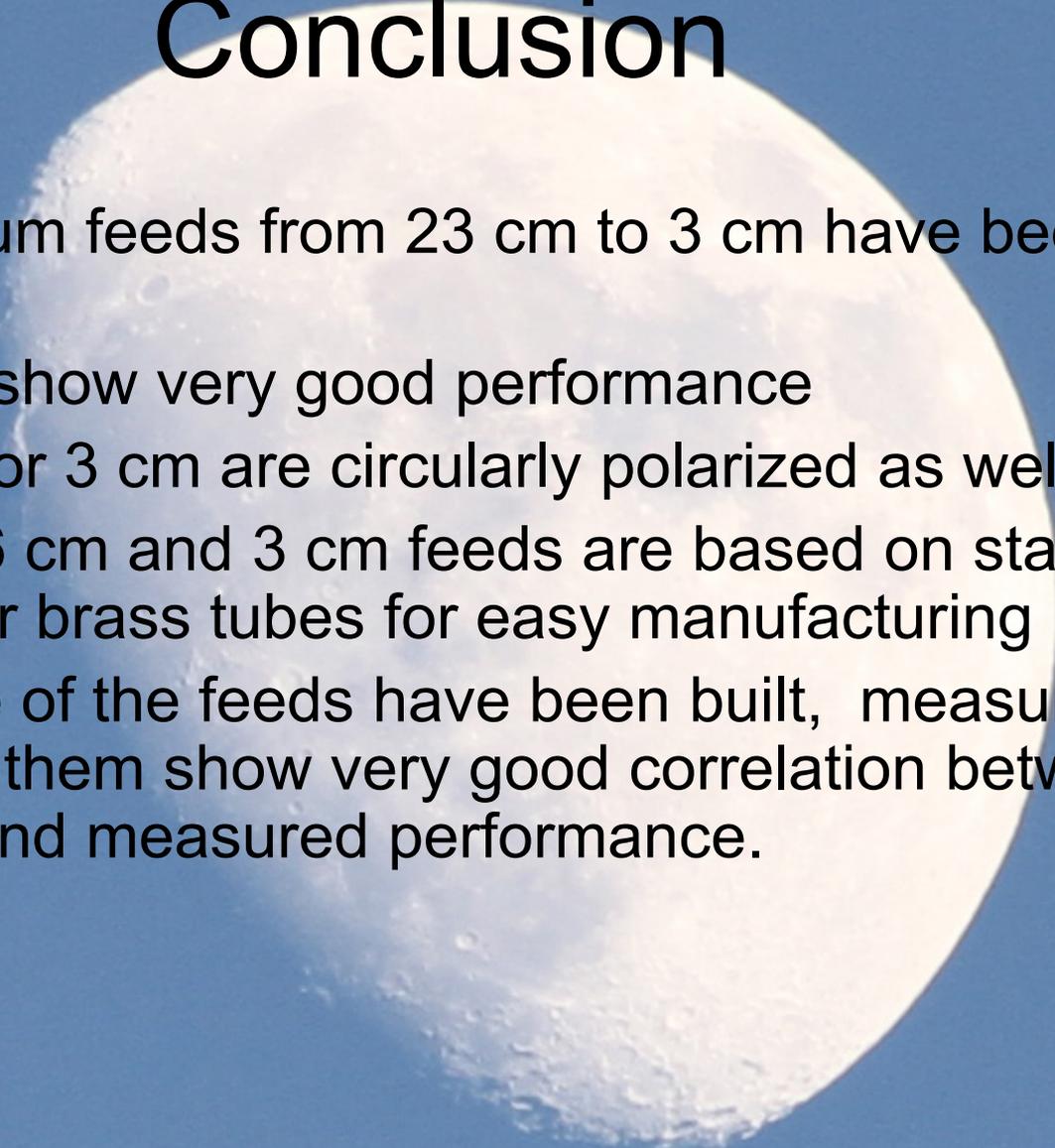
- 5 new septum feeds from 23 cm to 3 cm have been presented

- All of them show very good performance

- The feeds for 3 cm are circularly polarized as well

- The 9 cm, 6 cm and 3 cm feeds are based on standard metric Cu or brass tubes for easy manufacturing

- So far three of the feeds have been built, measured and used. All of them show very good correlation between simulated and measured performance.

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Thank you for your attention

See you all via the moon on the higher bands