Matching Dish and Feed

Optimising the dish - feed combination for EME communication

The secrets behind how to best utilizing a dish surface

SM6FHZ, EME2020, Praha

Outline

- Prerequisite and setting goals
- Feed properties and terminology
- Efficiency and G/T plots dissected
- Demonstration cases
- “How To”, step by step procedure
- Combinations to avoid
- Conclusions

Prerequisite & Goal

- Well discussed subject
  - You see on the reflectors that a lot of non scientifically supported claims are being spread, adding to the confusion for many
  - Parts will be a re-cap for some of you, but I hope all will find something new
- Hope to add some clarity to the discussion and to kill some of the myths and alternative facts flying around
- Propose a method to choose the proper feed

Your Goal?

- Optimize for Tx….Balance..Optimize for Rx
- Low Tx power → Optimize for Tx?
- Good Tx power → Optimize for Rx?
- Balance = compromise?
- You can always increase Tx-power eventually, but…..
- Removing noise that has sneaked into your Rx-system…..how do you do that?

Some “Good to Understand” terms and definitions

- Antenna area
- Directivity
- Gain
- Near Field / Far Field
- Far Field Distance
- Aperture Efficiency
- G/T (Gain over Temperature)
- Wave Guide properties

Antenna Area

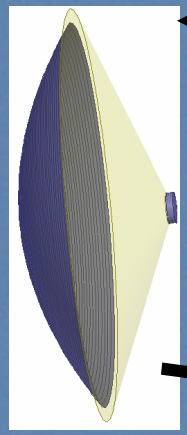
- Antenna Area = $\boldsymbol{\lambda^2 / 4\pi}$ for an isotropic radiator ($D = D_0$, unity, i.e. 0 dBi)
- Antenna Area = $\mathbf{D * \lambda^2 / 4\pi}$ for an arbitrary radiator with the directivity D (linear)
- Larger Antenna Area gives higher Directivity (= narrower Beam Widths) i.e. a larger feed is suited for a large f/D dish
- Larger Antenna Area can be accomplished by increasing size in any of the three dimensions (x, y, z)
- You **CAN NOT** fool yourself around this.

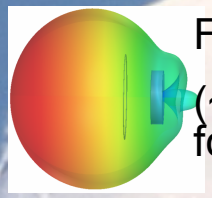
Directivity and Gain

- Need to distinguish between Directivity and Gain
- Directivity is solely dependent to Antenna Area
- Gain incorporates any losses
- **G = D * η** where η is the efficiency (0 to 1)
- We will use Directivity here and handle losses separately

Near Field and Far Field

Feed illuminating dish



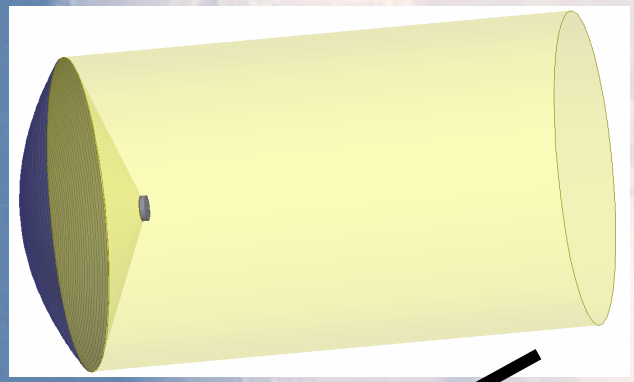


Feed Far Field

(~0.46m at 1296 MHz for a patch feed)

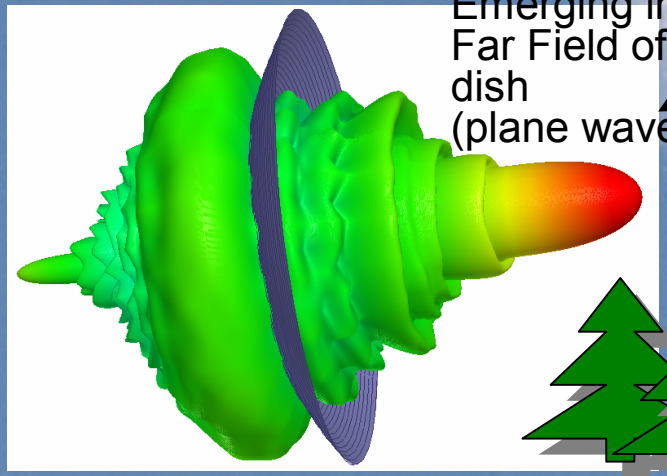
The Far Field definition used exhibits an phase error of 22.5 deg across the given aperture

$(2*D^2)/\lambda$



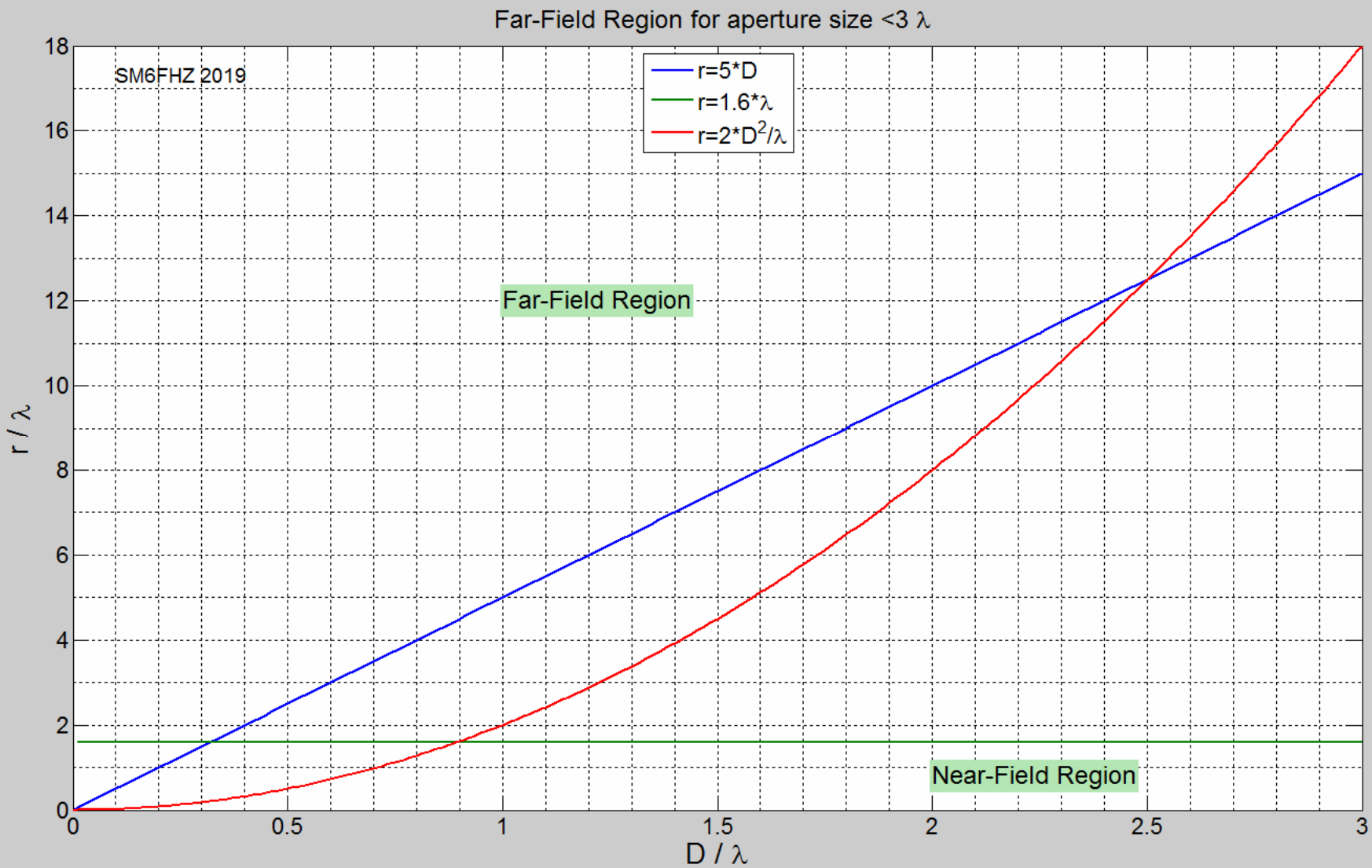
Exciting the Near Field of the dish (parallel rays)

Emerging into the Far Field of the dish (plane wave front)



(~300m at 1296 MHz for a 6m dish)

Far-field distances



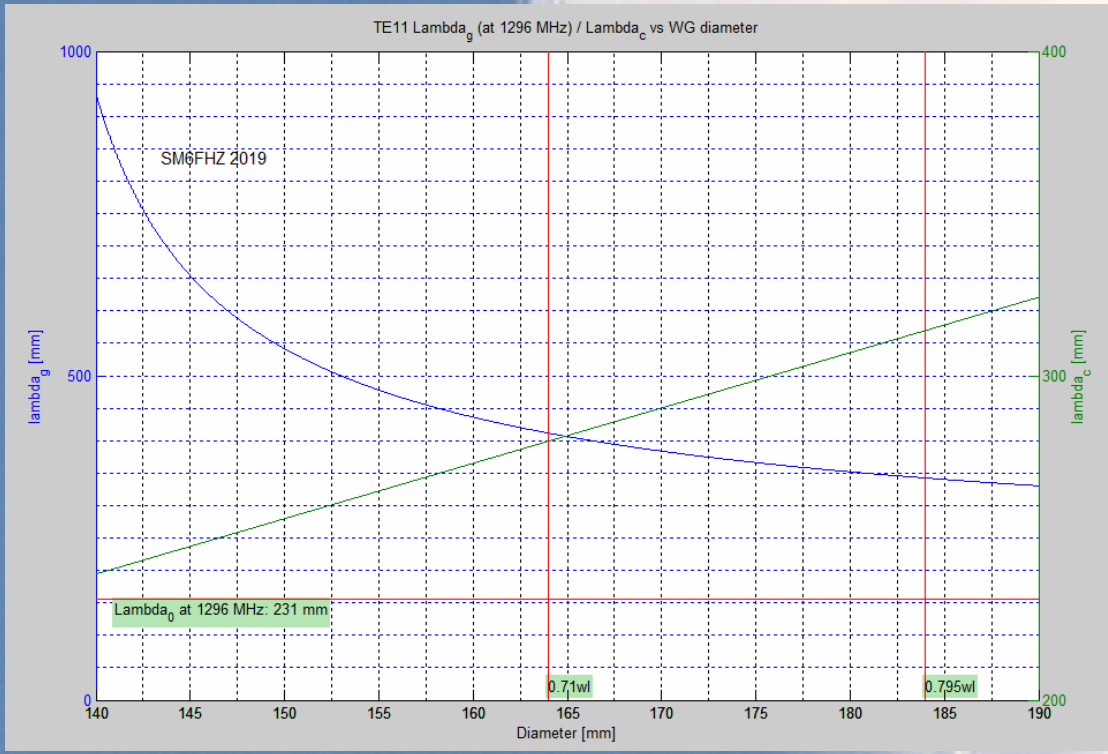
Aperture Efficiency

- The major losses are:
  - Illumination loss
  - Spill-over loss
  - Feed Blockage loss
  - Phase Error loss
  - Cross Polar loss
  - Resistive losses in the feed (Ohmic)
  - Dish surface leakage loss (not feed related)
  - Dish surface accuracy loss (not feed related)
- The process of finding a proper feed is aiming at minimizing these losses for the Dish – Feed combination in question.
- An well designed feed addresses the six first of the above losses and minimizes their impact

Wave Guide Properties

- Cut-off Wavelength (λ_c) rectangular WG TE10:
  λ_c = 2*a where a is the width of the WG
- Guide Wavelength (λ_g) rectangular WG TE10**:**
  $\lambda_g = \lambda_0$ / sqrt(ε_r - [λ_0 / λ_c]^2) where λ_0 is the free space wavelength and ε_r is the relative dielectric constant of the material inside the WG (in most cases 1 for air)
- Cut-off Wavelength (λ_c) circular WG TE11:
  λ_c = 3.412*a where a is the diameter of the WG
- Guide Wavelength (λ_g) circular WG TE11**:**
  $\lambda_g = \lambda_0$ / sqrt(ε_r - [λ_0 / λ_c]^2) where λ_0 is the free space wavelength and ε_r is the relative dielectric constant of the material inside the WG (in most cases 1 for air)

Wave Guide Properties



- You can only get a certain range of Beam Widths from a single size WG-Feed as you are limited in WG-size by Cut-off in one end and by the next mode getting excited out of control, in the other end (antenna area and directivity dependence).
- In order to illuminate a high f/D dish in a good way you need to go to a Dual Mode Feed where the higher modes are kept under control and used to shape the Radiation Pattern in the design.
- Changing any dimension on a WG-Feed will change its properties and ruin the performance of a well designed feed. It is an **Non Win** situation! Unless you have simulation capabilities and can predict the performance.
- Scaling from one band to another is not likely to turn out in a very good way.

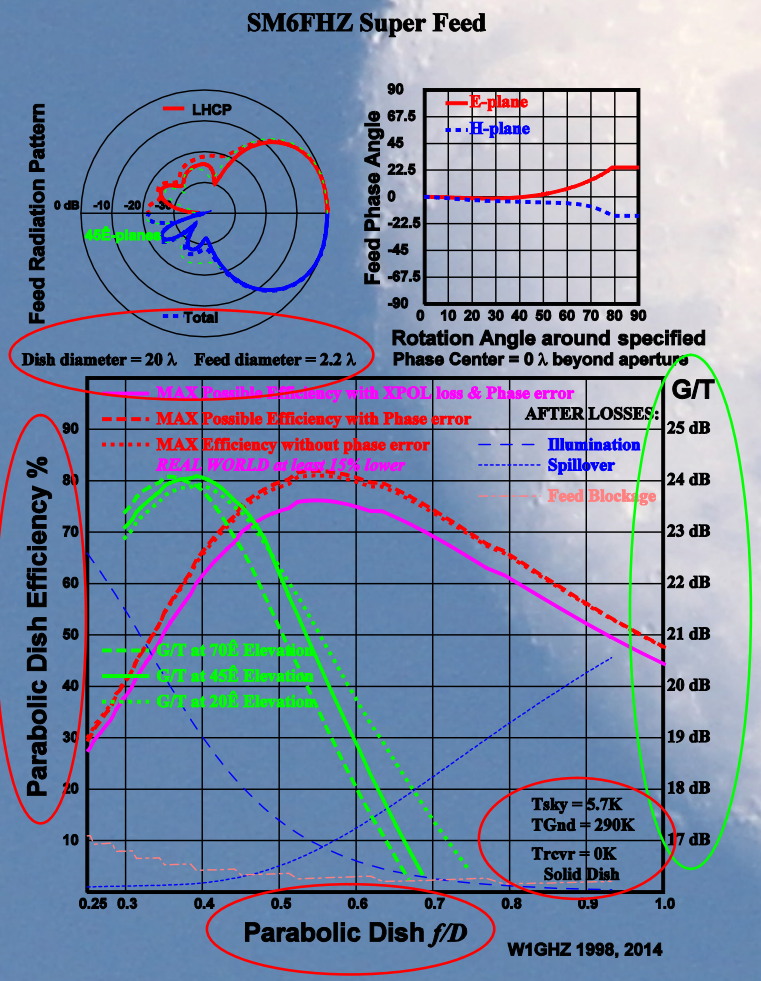
What is a GOOD feed?

- Well characterized
  - Simulated or Measured
  - You should be able to know what you will get out of the design
- Beam Width (BW)
  - Suitable for the f/D in question
  - Equal in E and H-plane out to the dish edge
- Phase error
  - Low across the full aperture, (<+/-10 degrees desirable both in E and H-plane) out to the dish edge
- Cross Polar Rejection (CPR)
  - Same property a Axial Ratio for circularly polarised feeds
  - >15 dB, 20 dB desirable, across the full dish surface
- Front-to-Back Ratio (FBR)
  - >15 dB
- Low ohmic losses (metal and dielectric)

G/T an relevant measure?

- The G/T (Gain over Temperature) figure gives a measure of the total Rx capability (=> S/N). G/T is usually shown in dB
- As the name says it shows the **ratio** between the forward **Gain and the Noise Temperature** of an antenna
- In order to be useful it need to be defined what is included in G/T
  - Antenna only
  - Antenna plus LNA
  - Antenna plus complete receiver
  - Antenna, complete receiver and environment
- W1GHZ, Paul, has made a program called Feed_GT that produces dish efficiency plots including a G/T plot
- Using Feed_GT, we will examine a few typical, and interesting, cases

The Feed_GT plot



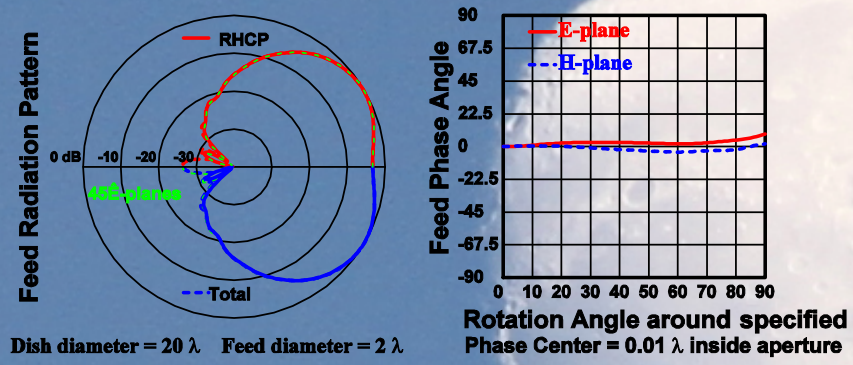
- Dish f/D on the X-axis
- Efficiency on the left Y-axis and G/T on the right Y-axis
- Dish and feed properties on top of the plot area
- Finally, but very important; Rx and noise parameters at the lower right corner of the plot area

Demonstration cases

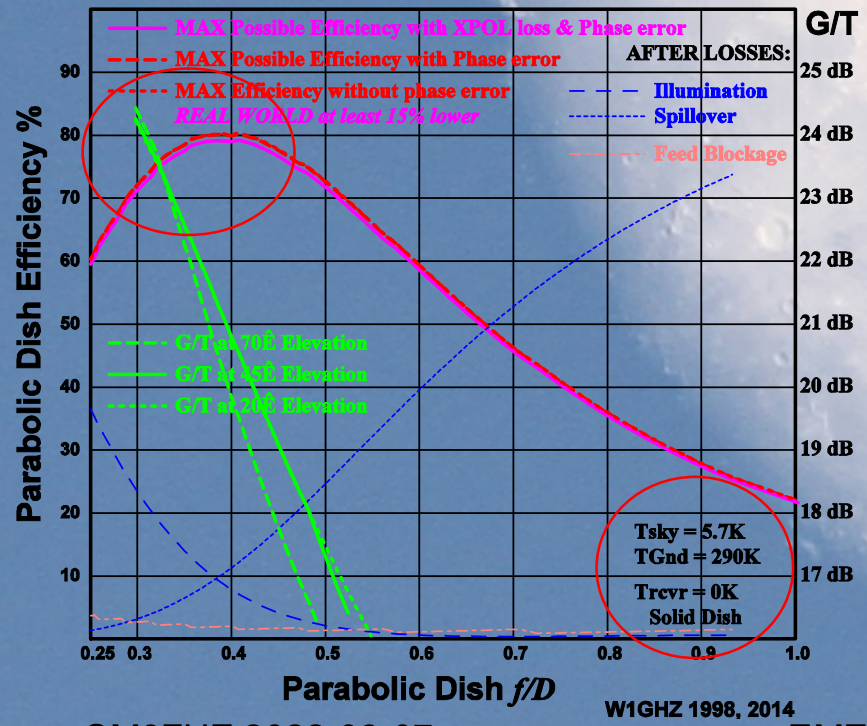
- 1296 MHz EME station
  - 20 wl dish size (~6.0m, BW ~2 deg)
  - Sky background + Moon noise
  - LNA NF
- 10 GHz EME station
  - 20 wl dish size (~60 cm = not realistic, just for comparison)
  - Sky background = Moon noise
  - LNA NF
- 10 GHz EME station
  - 87 wl dish size (~2.6m, BW ~0.79 deg, covering little more than the Moon surface)

1296 MHz EME station

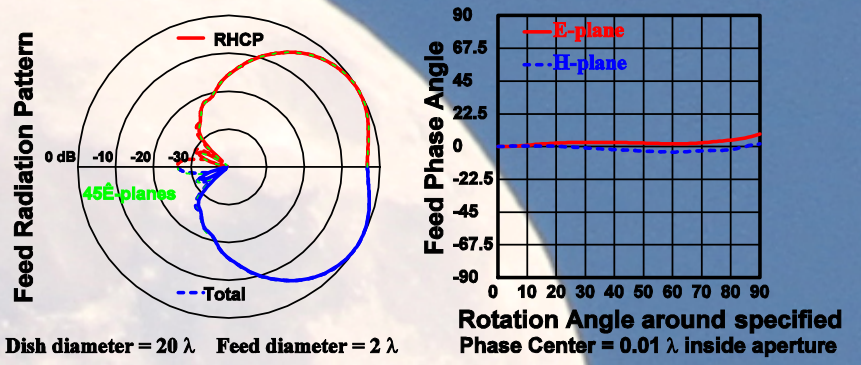
SM6FHZ Kumar Septum Feed 23cm 0.795wl V1r3



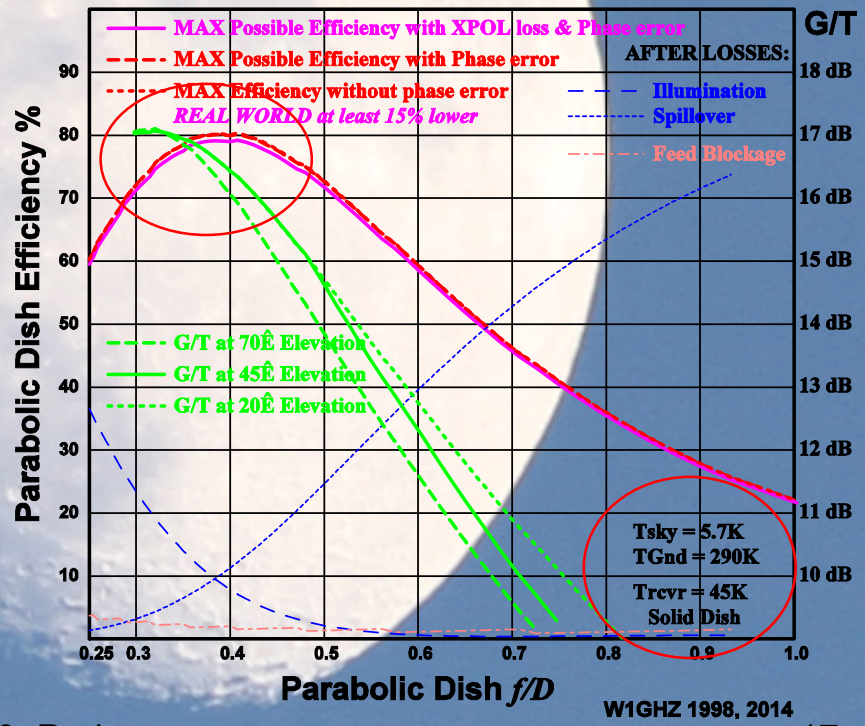
Dish diameter = 20 λ Feed diameter = 2 λ



SM6FHZ 23cm Kumar Septum feed

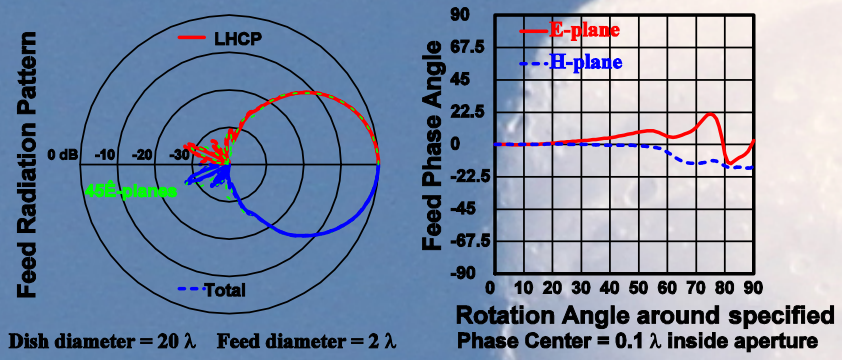


Dish diameter = 20 λ Feed diameter = 2 λ

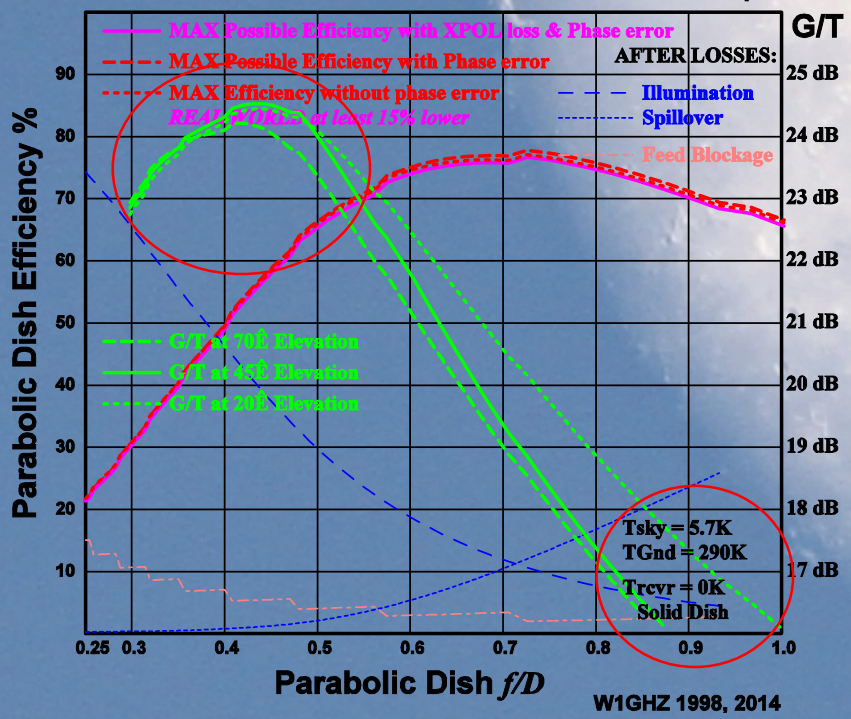


10 GHz EME station

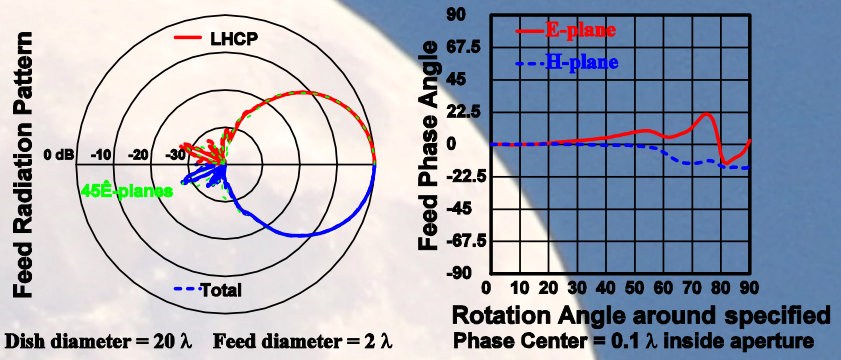
SM6FHZ 10 GHz Dual Mode 48 mm output section



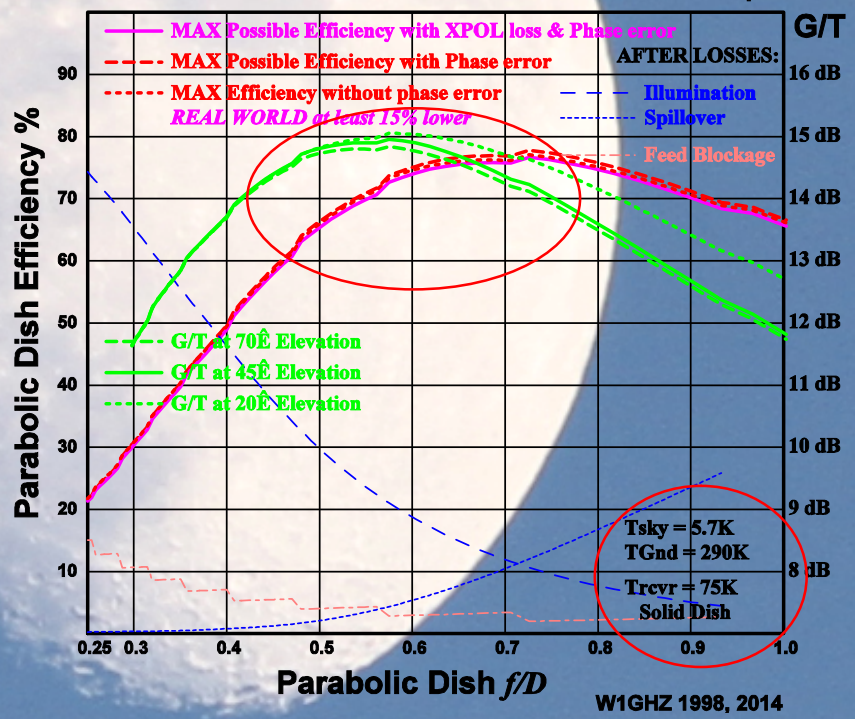
Dish diameter = 20 λ Feed diameter = 2 λ



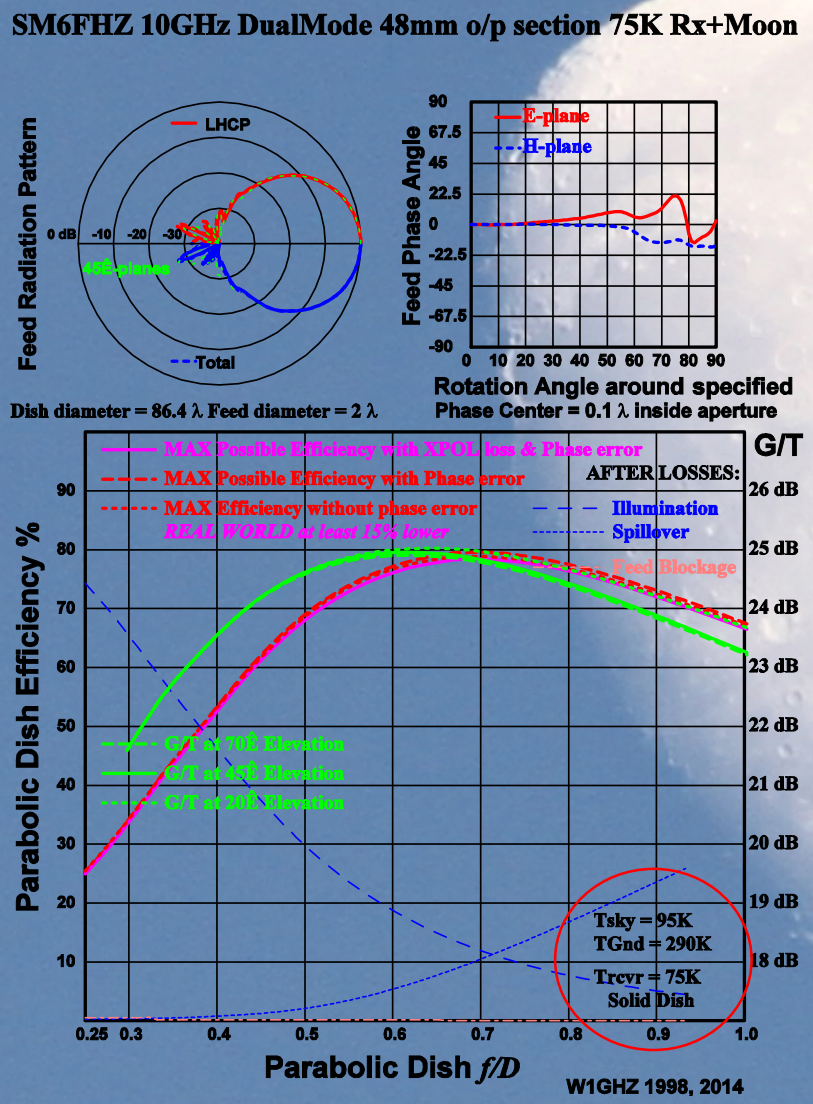
SM6FHZ 10 GHz Dual Mode 48 mm output section 75K Rx



Dish diameter = 20 λ Feed diameter = 2 λ



10 GHz EME station



- 10 GHz with 86.4 wl dish (~2.6m with an BW of ~0.79 deg)
- Tsky is an combination of sky background and Moon noise set to 95 K
- Trcvr is set to 75 K (1 dB total NF)
- As seen in the Feed_GT plot the optimum G/T with this Dual Mode feed, is at an slightly lower f/D than the maximum efficiency
- See appendix below for more Antenna Noise Temperature to G/T comparisons

Feed Choice Scheme

- In order to choose a feed for your dish, you can follow this scheme:
  - Decide what to optimise for; Tx-performance, Rx-performance or a compromise.
  - Determine your dish f/D value.
  - Look for feeds with declared performance (i.e. Feed_GT plots). If not available, ask the designer for one. If the designer can not provide one, stay away from that feed. You will not know what you are getting. Neither does the designer, obviously.
  - Do the above described analysis with respect to your performance characteristics choice.
  - Make your choice of feed and put it into your dish.
  - Optimise feed position if you do not know the focal length of your dish precisely, using CS/Sun in one ‘session’. Move feed in equal increments and plot the results to find the optimum position.
  - Check the system for key parameters like Cold Sky to Ground noise ratio (CS/G), Cold Sky to Sun noise ratio (CS/Sun) or Cold Sky to Moon noise ratio (CS/Moon) depending on what band and what size of dish you are using. Compare your numbers to VK3UM EMEcalc predictions.
- Work EME!

Hopeless cases

- Small, flat dish on low bands
  - E.G. a 2m and less TVRO dish with >0.6 f/D on 1296 MHz (9 wl dish size)
  - You risk to suffer from blocking, if using a proper feed for the f/D.
  - You risk not being in the far field of the feed, resulting in large phase errors across the aperture giving low aperture efficiency.
  - If using an incorrect feed (too wide beam), over illuminating the aperture, will result in lots of ground noise and low efficiency.
- Very deep dishes (f/D <0.3) are difficult to feed in an efficient way
  - Not many feeds will illuminate out to the dish rim.
  - In very special, low noise applications they may be an asset.

Conclusions / Takeaways

- Always use a feed that is well documented performance wise.
- Do not tamper on your own with a good feed design. That is an **Non Win** situation, unless you know what you are doing and have the possibility to simulate the resulting performance.
- There is **no "perfect match"**, you need to make a choice what to optimize for. **Set your goal!**
- The G/T figure is a powerful way to optimize your EME antenna system for Rx-performance.
- It is not more difficult to do it right from the start, but it saves you a lot of work later when trying to mend improper choices at the start. It is well spent time at the start of your microwave EME project.
- Again; You can gain dB's in choosing the proper feed for your situation. **In EME every tenth of a dB is valuable**.

Tools

- Feed_GT, W1GHZ
  - For analysing feeds in a dish
- EMEcalc, VK3UM
  - For analysing your EME system performance and aid in making the best feed choice for your situation
- Plot subtended angle vs. f/D
  - For determining at what angle the rim is in your dish and what directivity that corresponds to. See below slide
- Plot path loss increase vs. subtended angle
  - For determining the additional loss to the 10 dB down at the dish rim. See below slide

Acknowledgments

- Zdenek, OK1DFC and the EME2020 staff for arranging this conference
- Paul, W1GHZ for providing us with the Feed_GT tool
- Doug, VK3UM in memorandum for providing us with EMEcalc
- Charlie, G3WDG, Paul, W1GHZ and Dr. Mark Whale for reviewing my paper prior to publishing

Thank you very much!

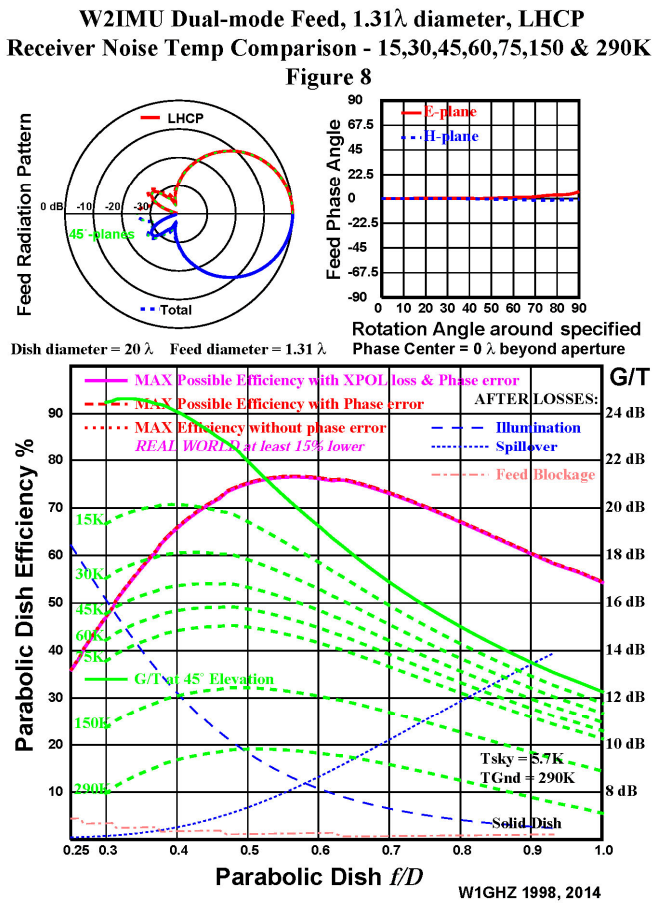
Hope to see you via EME!

Revision history

- Rev A; As presented in Praha at the EME 2020 Meeting, August 2022

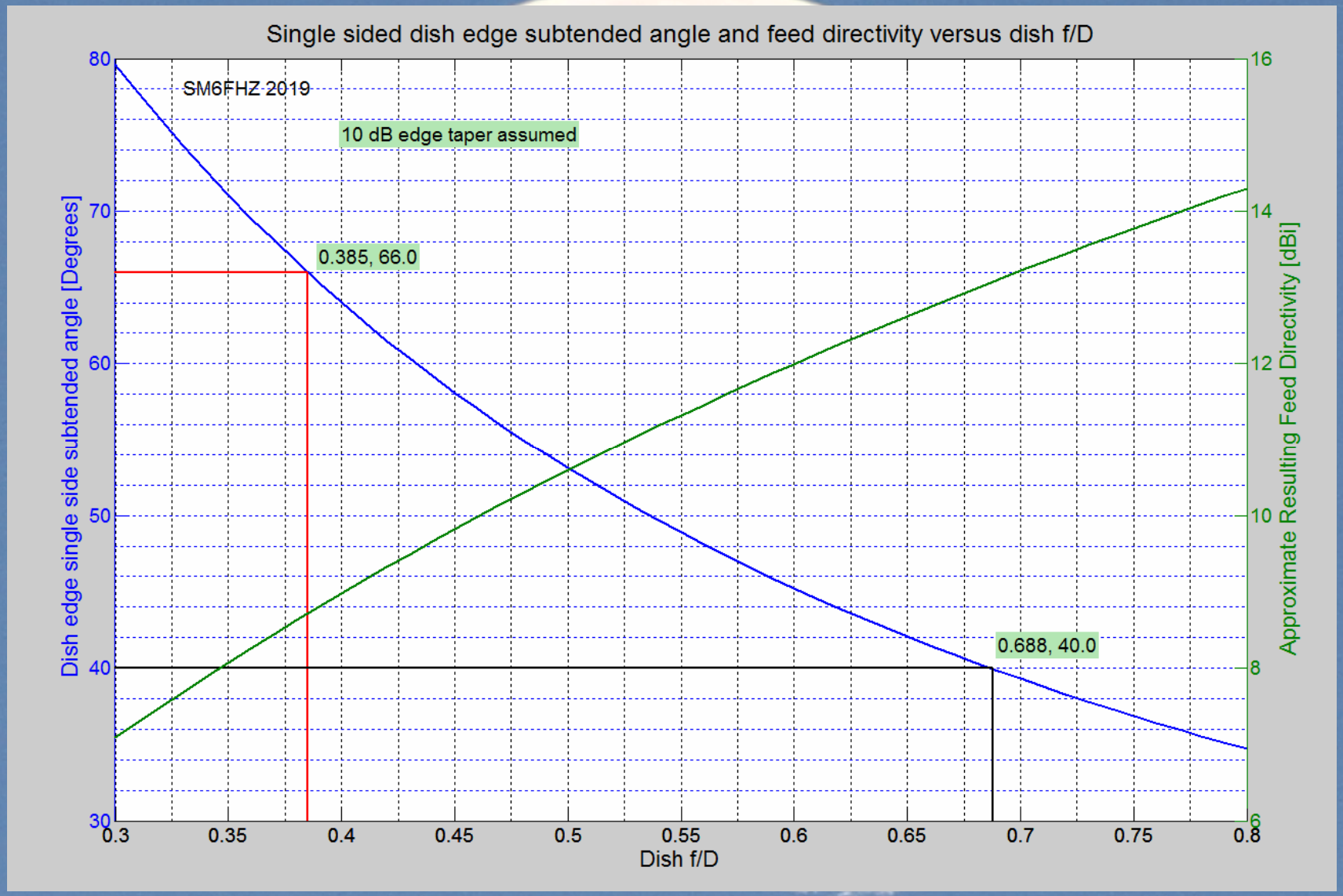
G/T as function of Rx (Antenna) Noise Temperature

Courtesy of W1GHZ



- These graphs show how G/T varies with respect to Total Antenna (Rx) Noise Temperature in K.
- As can be seen, going from 15K to 30K decreases the G/T (=Rx performance) by 2 dB! That is equivalent to going from a 3.2 m dish to a 2.5 m dish!
- Keeping the Antenna Noise Temperature down is essential, as have been shown in the above presentation material!

Feed subtended angle versus dish f/D



Additional path loss from feed to dish as function of subtended feed angle