Efficient Design and Simulation of LPDA-Fed Parabolic Reflector Antennas

Log-Periodic Dipole Array (LPDA) fed parabolic reflector antennas (dishes) are used in high-gain broadband applications, requiring constant performance over wide frequency ranges, such as satellite communication, radio astronomy, and wideband radar systems.

There has been a continuous interest in this type of antenna for almost 70 years [1-8], starting from pioneering work of DuHamel and Ore in 1958 [1]. However, even after decades of research and use, the synthesis and analysis of such antennas remain complex, requiring tuning of many parameters in a broad frequency range. By the rule, the design is based on the combination of analytical expressions, simulation and measurements.

Typically, simulation of the LPDA is done by full wave methods (such as MoM – Method of Moments), while the physical optics (PO) is used for simulation of reflector antenna. Such simulations do not account coupling between antenna and reflector. Thus, the matching of the antenna needs to be verified separately by measurements. Besides that, PO cannot be applied if the reflector is simulated with support feed struts. These difficulties can be overcame if all the parts of the antenna (LPDA+dish) are simulated by full wave method.

The standard MoM codes, which are based on meshing into triangles of 0.1 wavelength size and RWG basis functions, are quite limited in terms of the size of reflector which could be modelled. These limits can be extended for one order of magnitude by using advanced techniques of 3D EM MoM solver in WIPL-D software suit: a) automatic meshing into bilinear surfaces of maximum patch size of 2 wavelengths, b) application of higher order basis function, c) utilization of geometrical symmetry, and d) acceleration of simulation based on CPU/GPU parallelization.

It is also important for the design procedure of such antennas to have antenna models that are fully parametrized in terms of design parameters, including number of dipoles in LPDA. Creation of such model is enabled in WIPL-D Pro CAD by combining two options: a) multiple copy with scaling, and b) conversion of wire model into solid model.

The goals of the paper are:

1) demonstrate accuracy and efficiency of simulation for almost arbitrary size of the reflector,
2) propose the effective design procedure of the antenna starting from specified requests, and
3) present results for bandwidth ratio $R = 10$, and three sizes of reflector diameter, from 24.2 λ to 242 λ.

The presentation is organized in the following sections:

1) Design Requests for LPDA Fed Dish
2) Power of 3D EM Solver to Simulate Electrically Large Multiscale Structures
3) Desing Strategy for LPDA Fed Dish
4) CAD Model of LPDA
5) Design of Optimal LPDA Feed
6) Dishes Fed by Optimal LPDA
7) Gain of 70m Dish Fed by LPDA

Design Requests for LPDA Fed Dish

The 1st design request is related to start and stop operating frequency, f_{start} and f_{stop}. Typical stop-to-start frequency ratio (bandwidth ratio, $R = f_{\text{stop}}/f_{\text{start}}$) ranges from $R = 4$ to $R = 18$. Very often request is that $R = 10$, which will be used in the examples in the paper. In particular, in all examples start frequency will be set to $f_{\text{start}} = 100$ MHz.

Gain of PRA in the operating range can be estimated using simple formula

$$G[dB] = 10\log_{10}\left(\frac{4\pi}{\lambda^2}\gamma S\right) = 10\log_{10}\left[\gamma\left(\frac{D\pi}{\lambda}\right)^2\right] \qquad (1)$$

where S is the area of the reflector aperture, γ is the aperture efficiency, D is the aperture diameter, and λ is the wavelength. Rough estimate for the aperture efficiency is $y = 0.55$. Hence, gain at f_{stop} is directly related to the gain at f_{start}, $G_{\text{stop}} = G_{\text{start}} + 20\log(R)$. In that sense the 2nd design request can be related only to the gain at single frequency. In the first example in this paper the request for the gain at start frequency is set to $G_{\text{start}} = 15$ dB.

The 3rd design request is related to antenna matching. Typical request ranges from $s_{11} = -10$dB or VSWR = 2 up to VSWR = 3 in the whole operating range. In all examples in this paper the request for VSWR is set to VSWR = 2.5 ($s_{11} = -7.36$ dB).

Other possible request (front-to-back ratio, suppression of the 1st side lobe, etc.) are not considered in this paper.

Starting from the request that $G_{\text{start}} = 15$ dB and using formula (1), it is found that the diameter of the reflector should be initially set to $D = 7.25$m, which is equal to $D = 24.2$ λ at $f_{\text{stop}} = 1$ GHz. Expected gain at stop frequency is $G_{\text{stop}} = 35$ dB.

In addition, we will consider the cases where the reflector diameter is enlarged 3 times and 10 times, i.e. to $D = 21.75$m and $D = 72.5$m, which is equal to $D = 72.5$ λ and $D = 242$ λ at $f_{\text{stop}} = 1$ GHz. Expected gains at start frequencies are $G_{\text{start}} = 24.54$ dB and $G_{\text{start}} = 35$ dB, respectively, while expected gains at stop frequencies are $G_{\text{stop}} = 44.54$ dB and $G_{\text{stop}} = 55$ dB, respectively.

In order to set the design strategy, it is first necessary to understand the capabilities of 3D EM solver to simulate reflectors of these electrical sizes.

Power of 3D EM Solver to Simulate Electrically Large Multiscale Structures

WIPL-D Pro CAD is a MoM based code intended for very accurate EM simulation of general 3D EM problems. WIPL-D kernel implements MoM in the advanced way by using higher order basis functions (HOBF). Approximation of surface currents is based on polynomials where expansion can reach 8th order, for surface patches 2 lambda by 2 lambda. Mesh elements can be mixed, from lowest to highest orders.

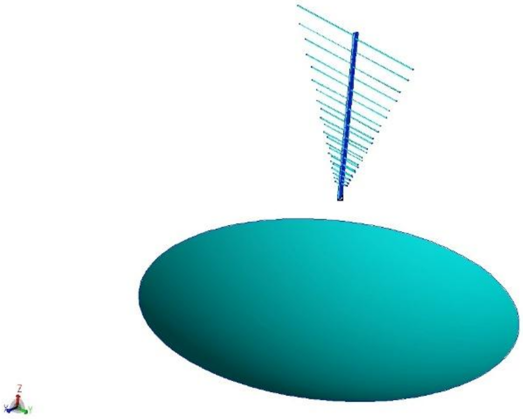


Figure 1. Reflector fed by LPDA in WIPL-D Pro CAD.

This results in order of magnitude more efficient simulation than the traditional low order MoM implementation with highly dense mesh. The mesh elements are quadrilateral rather than usual triangular mesh elements which reduces required number of unknowns two times. Additional advantages are applying symmetry and highly efficient CPU/GPU solvers.

WIPL-D Pro CAD offers fast and easy modelling of arbitrary reflectors. The default mesh assumes 1.5 lambda patches and the 3rd order of current approximation. The control of the simulation accuracy is fast and easy, by reducing mesh size on the dish to 1.4, 1.3 lambda and so on where number of unknowns slowly increase.

1.5 lambda mesh elements would require the 5th expansion order and around 50 unknowns per mesh element in general simulations. However, since they are a part of the reflector, their order can be reduced to the 3rd and they require only 18 unknowns per quad, approximately three times less.

Table 1 shows the number of unknowns and simulation time for LPDA fed dish at frequency f_{stop}=1 GHz, for three values of diameter D, where number of unknowns needed for simulation of LPDA is less than 6000 unknowns.

The hardware used was everyday inexpensive desktop configuration. CPU: Intel i9 14900K, 128 GB RAM, 2x Samsung SSD 990 PRO 4TB each. For the more demanding simulations, GPU solver was used with: GPU: Nvidia RTX 4090.

Table 1. Simulation details.

Diameter	7.25 m	21.75 m	72.5 m
Unknowns	13k	68k	600k
Simulation time	20 sec	4 min	12h

Having in mind these data, the design strategy is proposed.

Desing Strategy for LPDA Fed Dish

To propose the design strategy the following premises should be kept in mind:

1. In general case the reflector requires far away more unknowns than LPDA.
2. The full model depends on more parameters than LPDA and reflector taken separately.
3. Adding reflector to LPDA degrades the VSWR characteristic of stand-alone LPDA.
4. Initial models of LPDA, as well as of reflector should be set well as much as possible based on antenna community experience.

Having these premises in mind the following three step strategy is proposed:

1. Stand-alone LPDA is designed to satisfy the request for VSWR, and to achieve as high gain as possible in entire frequency range.
2. Reflector is added to LPDA and checked if such antenna satisfies all the requests of interest.
3. If not, the antenna parameters, the selection of which is based on previously simulated results, are varied, either manually or by an optimization routine, to improve the antenna properties towards requests of interest.

In order to design stand-alone LPDA antenna it is first necessary to create optimal CAD model, taking into account as much as possible the community experience.

CAD Model of LPDA

The basic idea of LPDA was developed in 1950s [1,2]. A set of dipoles is mounted to the metallic holder (called boom) which serves as a feeder and support. The concept is based on building extremely wide band antennas by combining larger number of narrow band dipoles. Thus, this results in linearly polarized antenna achieved by self-scaling with dipoles at discrete frequency intervals. In theory, the radiation pattern and return loss will ripple between exact scaling frequencies. This can be resolved by closely spaced scalings. In such case, the antenna is practically frequency independent.

The boom is practically a two-conductor line (square or circular cross-section). In most cases, the feeding coax is passing through one of the lines. The dipole arms are connected in criss-cross along booms.

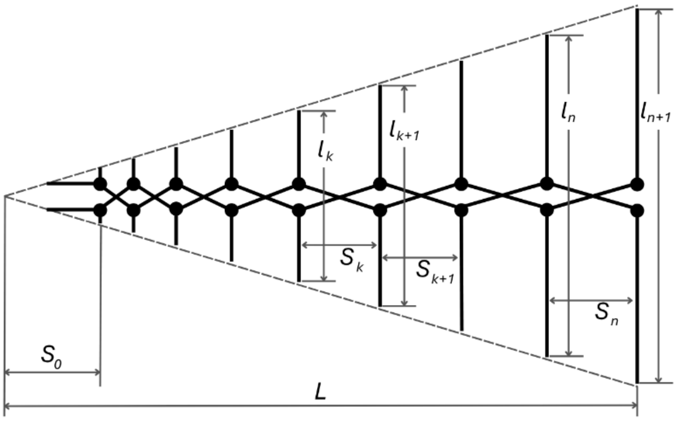


Figure 2. Sketch of LPDA concept.

Primary design parameters are: a) start and stop frequency, f_{start} and f_{stop}, b) the number of active dipoles, n, and c) the antenna total length, L.

In the WIPL-D design method, the number of dipoles is n+1. Since a common engineering problem is a ripple in the lower of part of the band, we suggest a method to improve it. A self-scaling structure is based on one radiating dipole and the two mostly coupled “neighbours”. The last element does not have a neighbour, which can be over-came by using a last one passive element. The total number of dipoles is thus n+1.

Secondary design parameters are: a) width of the boom conductors of square cross section, ***a***, b) distance between central axes of the boom conductors, ***d***, and c) radius of wires, ***r***.

The basic principle of self-scaling is that lengths and distances are in constant ratio.

$$\frac{l_{k+1}}{l_k} = \frac{s_{k+1}}{s_k} = \tau \qquad (2)$$

We start the procedure by assuming that lengths of the first and the n^{th} dipole are match for the frequency band.

$$l_1 = \frac{\lambda_{\mathrm{stop}}}{2} \quad l_n = \frac{\lambda_{\mathrm{start}}}{2} \qquad (3)$$

where λ_{start} and λ_{stop} are wavelengths at start and stop frequency, i.e. $\lambda_{\mathrm{start}}[\mathrm{m}] = 0.3 / f_{\mathrm{start}}[\mathrm{GHz}]$ and $\lambda_{\mathrm{stop}}[\mathrm{m}] = 0.3 / f_{\mathrm{start}}[\mathrm{GHz}]$. All dipoles are further shortened for the half of wire radius, $r/2$, which corresponds to effective lengths of half-wavelength dipoles. Finally, based on practical experience with tuning dipole lengths, the lengths are further modified to 48% of the wavelength.

We define the scaling constant next.

$$\tau = \sqrt[n-1]{R} \qquad R = \frac{l_n}{l_1} = \frac{\lambda_{\mathrm{start}}}{\lambda_{stop}} = \frac{f_{stop}}{f_{start}} \qquad (4)$$

The first spacing determines the position of the shortest element after start of the boom.

$$s_0 = \frac{l_1}{l_n} \cdot \frac{L}{\tau} \qquad (5)$$

The spacing in wavelengths shortward of λ/2 active element determines how dense are elements separated.

$$s_\lambda = \frac{s_0 \cdot (\tau - 1)}{\lambda_{\mathrm{stop}}} \qquad (6)$$

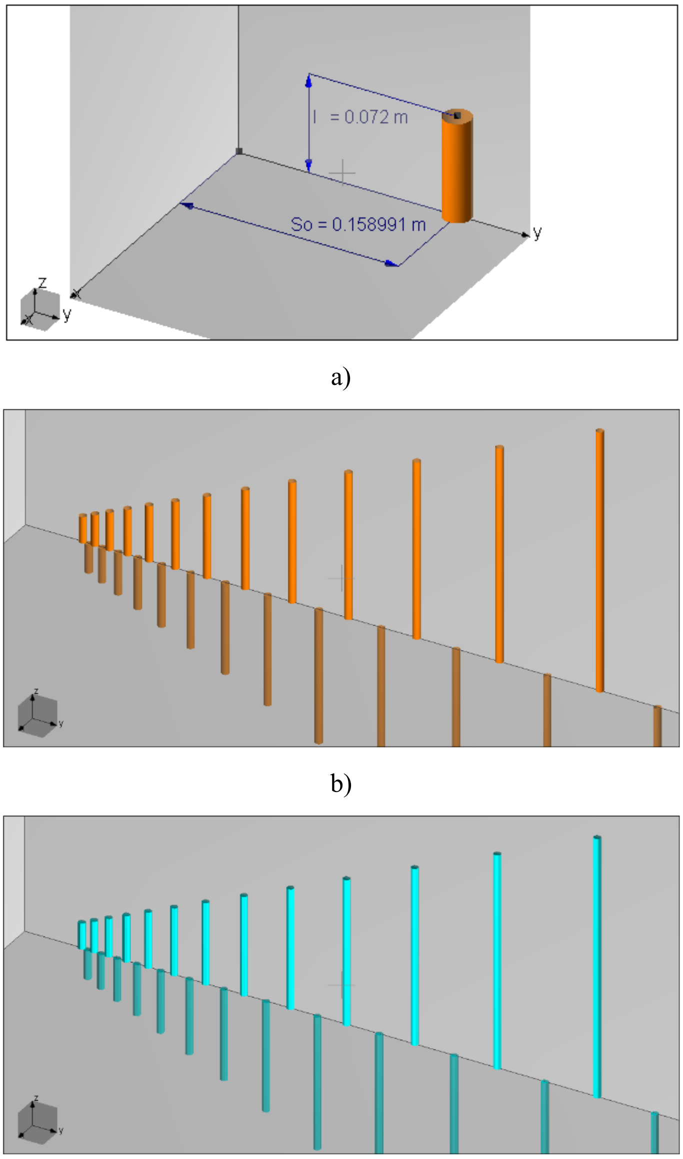
Typical values used for τ and s_λ in design of LPDAs are:

$$\tau = 1.05 \div 1.30 \quad s_\lambda = 0.05 \div 0.20 \qquad (7)$$

However, for design of LPDA used to feed reflector antennas we recommend narrowed ranges for τ and s_λ

$$\tau = 1.08 \div 1.12 \quad s_\lambda = 0.050 \div 0.055 \qquad (8)$$

The recommended values are set using primary design parameters n and L.



a)

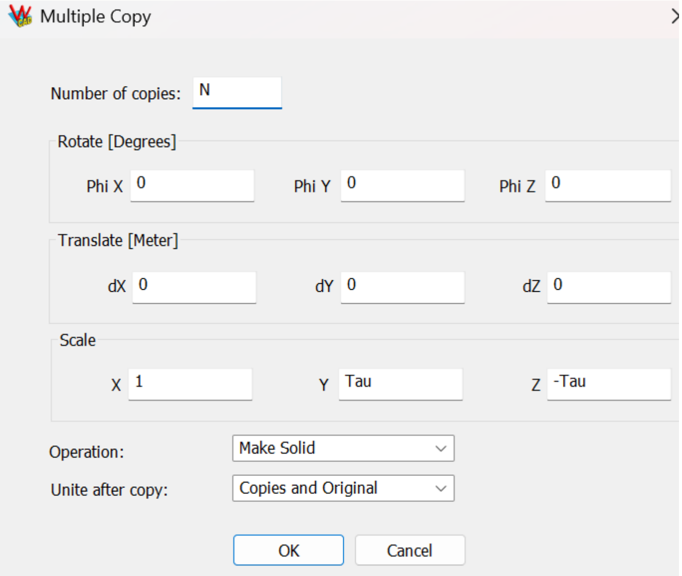
b)

c)

Figure 3. Creating LPDA dipoles parametrically.

To automatize the modelling, WIPL-D has developed a new feature converting wire bodies to solids. This allows simple modelling process: a) make a single wire of length l_1 and radius r at distance s_0 (see Fig. 3a), b) copy the wire n times and scale each copy by factor τ (see Fig. 3b), and c) automatically convert the initial wire and all their copies to solids (see Fig. 3c). Steps (b) and (c) can be done as a single command using multipole copy dialog box as shown in Fig. 4.

After adding the boom of square cross-section and voltage generator at its beginning in coordinate origin, the CAD model of LPDA is obtained as shown in Fig. 5.



Multiple Copy

Number of copies: N

Rotate [Degrees]

Phi X 0 Phi Y 0 Phi Z 0

Translate [Meter]

dX 0 dY 0 dZ 0

Scale

X 1 Y Tau Z -Tau

Operation: Make Solid

Unite after copy: Copies and Original

Figure 4. Multiple Copy dialog box.

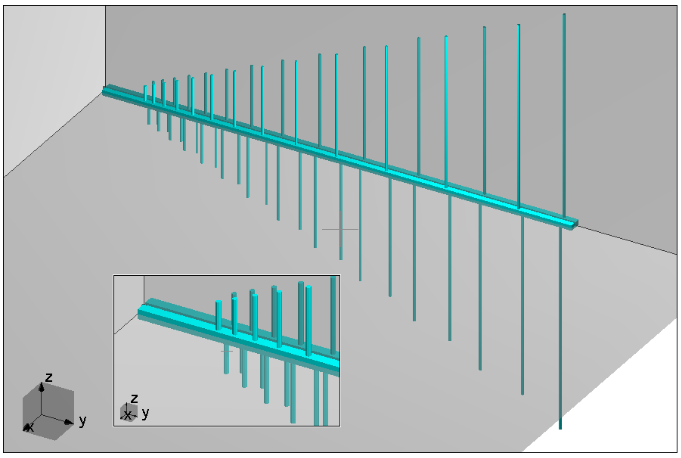


Figure 5. CAD model of LPDA.

Design of Optimal LPDA Feed

Primary parameters of LPDA (f_{start}, f_{stop}, n, L) have major impact on its properties. Having in mind that start and stop frequency are fixed, n and L are solely used in the 1st round of optimization. Secondary parameters of LPDA (a, d, r) are initially fixed to the values that can be easily realizable ($d/a>1$, $2r<a$). In this paper they are set to $a = 2\text{cm}$, $d/a = 1.3685$, and $r = 5\text{mm}$. ($d/a = 1.3685$ corresponds to characteristic impedance of $Z_c = 75\Omega$.)

Available optimization space can be determined from the following formulas for L, n, and τ:

$$L = \lambda_{\text{start}} \frac{s_\lambda \tau}{\tau - 1} \qquad (9)$$

$$n = \frac{\log_{10}(R)}{\log_{10}(\tau)} \qquad (10)$$

$$\tau = \frac{1}{1 - \lambda_{\text{start}} s_\lambda / L} \qquad (11)$$

Having in mind recommended values for τ and s_λ from (8) and applying these values to (9) and (10) the ranges for L and n are obtained as

$$L = 1.4m \div 2.2m \quad n = 20 \div 34 \qquad (12)$$

However, applying these values to (10) and (11) for various values of L from (12) it is found that for each L there are only 3 values for n. For example, for $L = 1.4$ m these values are $n = 20,21,22$. Thus in optimization process for each value of L in the above range, n can take 3 values determined by (10) and (11).

The LPDA is simulated for $L[\text{m}] = 1.45 + 0.1\,k$, $k = 0,\ldots,7$, and 3 values of n for each L. Optimal LPDA feed, is obtained for the following design parameters: $L = 1.75\text{m}$, $n = 25$.

Fig. 6 shows s_{11} of LPDA in free space vs frequency, with maximum value of s_{11} equal to s_{11} = -7.66 dB (VSWR=2.41), which satisfy the request for specified VSWR.

According to Fig. 7 gain of LPDA in free space ranges from $G_{\min} = 7$ dB to $G_{\max} = 8.5$ dB in whole frequency range, except at frequency $f = 154$ MHz, where $G = 4.164$ dB is is observed.

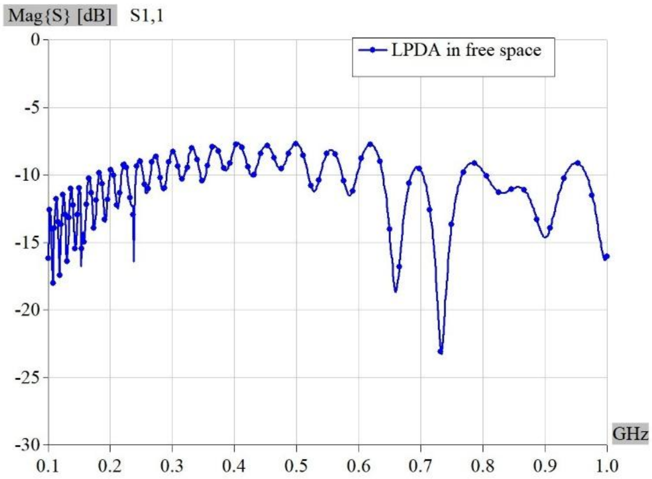


Figure 6. S_{11} of LPDA in free space vs frequency.

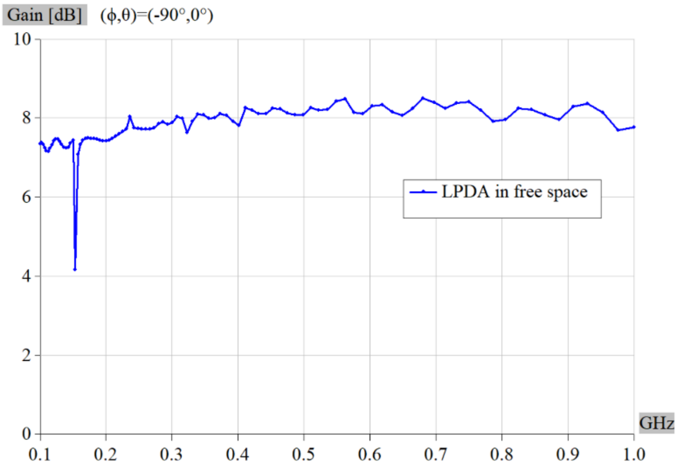


Figure 7. Gain versus frequency in main direction of LPDA in free space.

In Fig. 8 the gain in unnamed units in H-plane of LPDA in free space at drop out frequency is compared with that at frequency $f = 100$ MHz. It is seen that, although there is significant reduction of gain in main direction, the shape of the main beam is still relatively good for illumination of the main reflector.

Generally, LPDAs of such construction have a number of smaller and larger drop outs. In some of the drop outs, the radiation pattern has main beam in reverse direction, which is not acceptable. The goal of the design is to eliminate drop outs with the reverse main beam direction and minimize the level of drop outs.

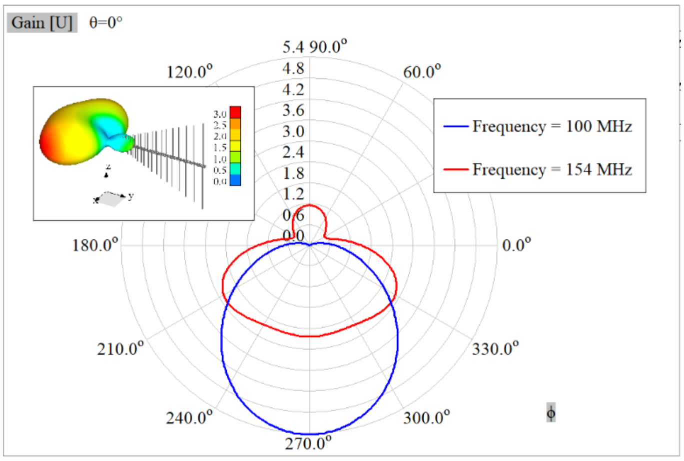


Figure 8. Gain in unnamed units in H plane of LPDA in free space at two frequencies.

Since drop outs appear in a very narrow range it is necessary to perform simulation at a relatively large number of frequency points. It is shown that minimum number of frequency points that give all information about gain and s_{11} (including detection of drop outs) is equal to $N_{\text{freq}} = 4n$-3 (n is number active elements), where these points are uniformly distributed in logarithmic scale. The m^{th} frequency (point) is calculated as

$$f_m = f_{\text{start}}\tau^{(m-1)/4} \qquad (9)$$

where $m = 1,\ldots,N_{\text{freq}}$. The results given in such frequency points are depicted in Fig. 6 by blue dots.

Dishes Fed by Optimal LPDA

Design parameters for paraboloidal reflector are: a) diameter, D, and b) focal distance F. Initial value for diameter is chosen according to (1). Having in mind that LPDAs have very wide width of the main lobe, and that the antenna should not be too close to the reflector, since the strong coupling between them would cause degradation of VSWR, the recommended values for the focal distance are in the range from $F = 0.3\ D$ to $F = 0.5$.

Optimal LPDA feed is first applied to paraboloidal reflectors of diameters $D = 7.25$m and $D = 21.75$m radii. In both cases initial focal distance is chosen so that $F/D = 0.5$. The antenna is placed in focal point with the center of its shortest element, as shown in Fig. 9.

Fig. 10 shows s_{11} versus frequency for LPDA fed dish ($D = 7.25$m). The results are compared with those of s_{11} for LPDA in free space. It is seen that s_{11} degrades significantly in the lower part of the frequency range due to coupling with the reflector.

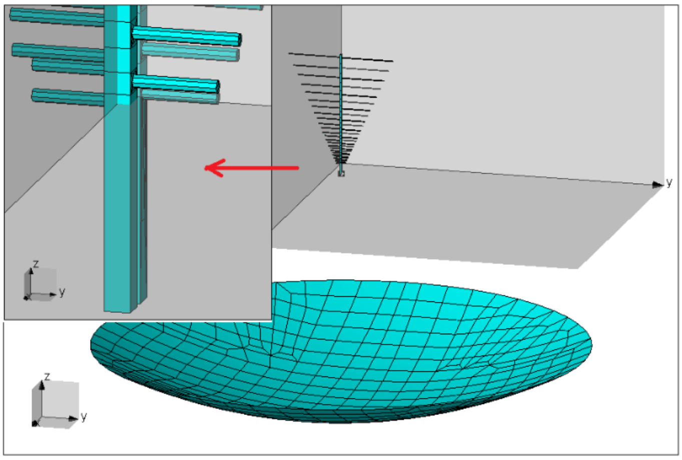


Figure 9. Meshed model of dish (D=7.25m) fed by LPDA. Inset shows placing the antenna relative to focal point.

Figure 10. S_{11} vs frequency of LPDA fed dish (D=7.25m) compared with s11 of LPDA in free space.

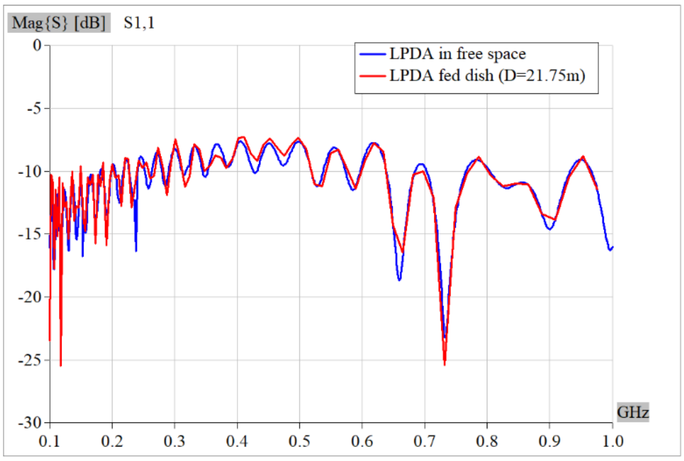


Figure 11. S_{11} vs frequency of LPDA fed dish (D=22.75m) compared with s11 of LPDA in free space.

Fig. 11 shows the same results as Fig. 10, but for dish of radius $D = 21.75$m. The results are compared with those of s_{11} for LPDA in free space. It is seen that degradation of s_{11} is negligible, which can be explained by that fact that electrical distance of the antenna from the reflector is 3 times larger, and the coupling is correspondingly weaker.

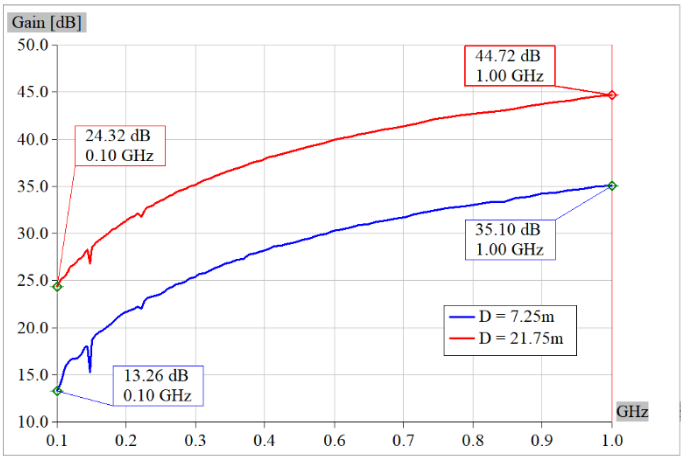


Figure 12. Gain versus frequency in main direction of LPDA fed Dishes for two diameter values.

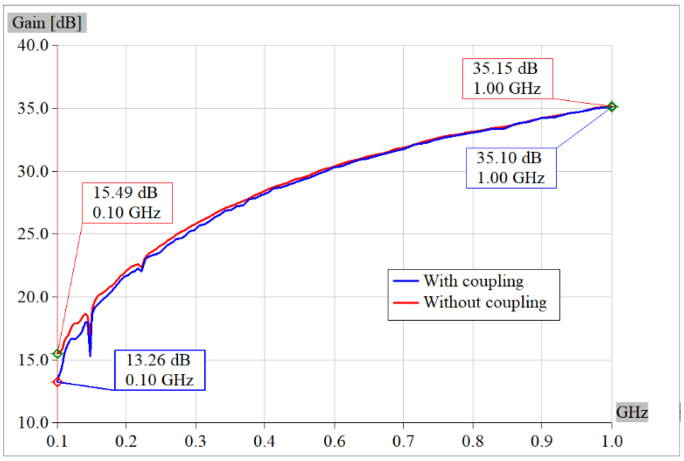


Figure 13. Gain vs frequency in main direction with and without coupling between LPDA and Dish (D=7.25m).

Fig. 12 shows gain versus frequency in main direction of LPDA fed Dishes for two diameter values. It is seen that drop outs are relatively small and that desired gains are more or less achieved in whole frequency range. The exception is the start frequency for dish of $D = 7.25$m diameter where gain is almost 2 dB bellow desired.

In order to explore if this drop out is result of mutual coupling between the antenna and the dish, the simulation is repeated by using radiation pattern of LPDA in free space to excite the dish of $D = 7.25$m diameter. (Excitation of structure by radiation pattern, either measured or evaluated, is enabled in WIPL-D 3D EM solver by using (Far) Field Generator (FG) option).

Fig. 13 shows gain vs frequency in main direction with and without coupling between the antenna and the dish of $D = 7.25$m diameter. It is seen that by excluding the coupling the gain at start frequency is increased for more than 2 dB, which confirm that drop out in gain occurred due to coupling between the antenna and reflector.

If the Field Generation simulation is repeated with the dish of $D = 21.75$m diameter, the results for gain almost coincide with those on Fig. 12. It is concluded that for this size of reflector, as well as for the larger sizes, coupling of the antenna and reflector practically neither degrade the antenna VSWR nor influence its gain.

One way to increase gain at start and nearby frequencies is to reduce focal point to diameter ratio, *F*/*D*. Fig. 14 shows the improvement in gain when this radio is reduced from *F*/*D* = 0.5 to *F*/*D* = 0.4, so that new results satisfy initial gain request. But, in this way the VSWR is further degraded with respect the results shown in Fig. 10 (not shown here). In order to improve both the gain and the VSWR it is necessary to increase both, the diameter and the radio (also not shown here).

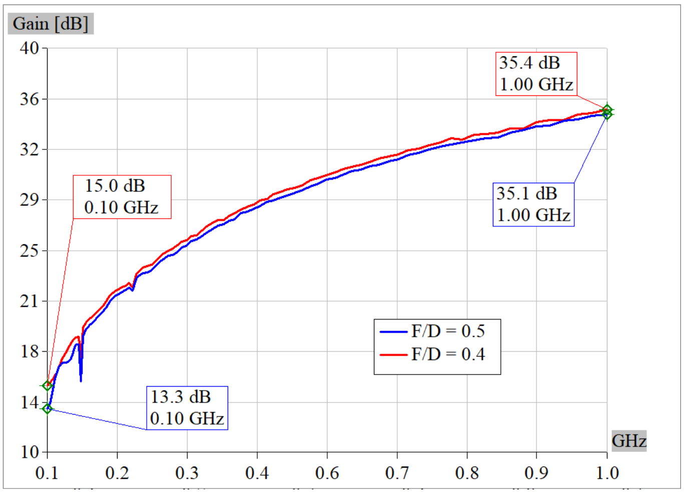


Figure 14. Gain vs frequency in main direction of LPDA fed dish (D=7.25m) for two focal distances.

Gain of 70m Dish Fed by LPDA

Evaluation of gain of 70m dish fed by LPDA, at stop frequency of $f_{stop} = 1$GHz, requires 600,000 unknowns and 12 hours at GPU augmented desktop PC. This simulation can be significantly accelerated if instead of full model of LPDA used to excite the dish, the excitation is performed by radiation pattern of LPDA, using Field Generation option. Namely, the problem poses two symmetry planes of geometry and asymmetry of excitation, which enables its decomposition into 4 problems with two symmetry planes for both, the geometry and the excitation. Thus, instead of running single problem of 600,000 unknowns, simulation is performed by running 4 problems of 150,000 unknowns, which accelerate the total simulation time more than one order of magnitude. (The process of decomposition of the problem and superposition of the results is automatized by setting the “(a)symmetry” attribute to two symmetry planes.)

Fig. 15 shows final results for gain versus frequency in main direction of LPDA fed dish for 3 sizes of reflector diameter.

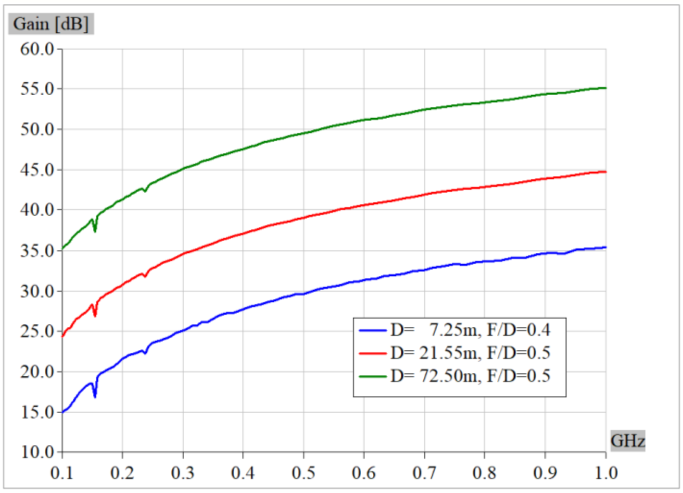


Figure 15. Gain vs frequency in main direction of LPDA fed dish for 3 sizes of reflector diameter.

References

[1] R. DuHamel and F. Ore, "Log periodic feeds for lens and reflectors," *1958 IRE International Convention Record*, New York, NY, USA, 1959, pp. 128-137.

[2] W. Imbriale, "Optimum designs of broad and narrow band parabolic reflector antennas fed with log-periodic dipole arrays," *1974 Antennas and Propagation Society International Symposium*, Atlanta, GA, USA, 1974, pp. 262-265.

[3] R. Dybdal, "Defocusing loss for a log periodic-fed reflector," in *IEEE Transactions on Antennas and Propagation*, vol. 33, no. 7, pp. 809-812, July 1985.

[4] M. Pehlıvan, K. Yeğın and Y. Aşci, "Design of 1–18 GHz parabolic reflector antenna with LPDA feed," *2016 24th Telecommunications Forum (TELFOR)*, Belgrade, Serbia, 2016, pp. 1-3.

[5] O. Sushko, S. Piltyay and F. Dubrovka, "Symmetrically Fed 1–10 GHz Log-Periodic Dipole Antenna Array Feed for Reflector Antennas," *2020 IEEE Ukrainian Microwave Week (UkrMW)*, Kharkiv, Ukraine, 2020, pp. 222-225.

[6] Yangyang Zhang et al 2022 J. Phys.: Conf. Ser. 2395 012027

[7] B. Abdelhak, G. Mohamed Anouar, A. Arab and B. Mohammed Laid, "High Gain and Wide Beam Printed LPDA with Improved Bandwidth Based on Multiple Scaling Factors," *2024 International Telecommunications Conference (ITC-Egypt)*, Cairo, Egypt, 2024, pp. 85-90.

[8] J. Park, C. Im and H. Choo, "Design of a Koch-Curved LPDA Antenna With Optimized Beamwidth to Improve the Aperture Efficiency of Reflector Antennas," in *IEEE Access*, vol. 13, pp. 106747-106758, 2025.