Circularly Polarized S-Band Square Patch Antenna With a Single Cut for S-band Small Satellites Applications

M.A.Mebrek, M.Bacha, L.Nouar, L.Hadj-Abderrahmane

***Abstract*— In this paper, the main purpose is to design an S-band patch antenna which is basically directional and circularly polarized for S-band small satellites applications. This antenna has a square shape ground and on the upper portion there is a patch which is also square but with a single truncated corner in order to get circular polarization, the connection between the patch and the ground has been established using a coaxial probe. The designed antenna can be easily integrated with a small satellite body due to the simplicity of the design. Commercially available finite element method solver based High Frequency Structural Simulator (HFSS) have been used in this analysis. The proposed antenna achieved desirable results with an axial ration of 0.17dB at center frequency of 2.2 GHz and less than 3dB for a frequency band of 31 MHz and beam width of more than 110°. The gain achieved by this antenna is around 7dBi at center frequency. The directional radiation pattern, circular polarization (CP), and high gain characteristics make the proposed antenna suitable for small satellite applications.**

Keywords—Circularly polarized; S-band; square patch; single truncated corner directional antenna; high gain; coaxial probe; small satellites.

I. INTRODUCTION

As technology has progressed, there is a trend of miniaturization of equipment's in different fields, especially in communication systems. One of the major components of the communication systems, the satellites, have undergone a significant improvement in design, weight, performance, power handling capacity and other factors over the past few years[1]. Modern small satellites allow for the achievement of many tasks and experiments in space. Nowadays, miniaturized technology makes it feasible to build small satellites. All of the subsystems constituting a small satellite must be designed to respect severe physical limitations and restrictions. The dimensions of the mini- and microsatellites generally render reflector antennas inadequate, even if they are small. In addition, the placement of mechanical elements, needed to deploy such antennas after reaching space, is a significant problem. The core of any satellite communication sub-system is the antenna; both at the ground station and onboard the satellite. The earth stations use parabolic dishes for receiving as well as transmitting signals into the space. On the other hand, helical antennas were widely used in traditional spacecraft's because of their wide beams and circular polarization. However, they have become unsuitable for mini-satellites [2]. For small satellites a patch antenna forms an attractive alternative over conventional antennas as these are compact, light-weight and require significantly less power. Both the transmitting antennas as well as the receiving antennas are circularly polarized. It eliminates the need of orientation of the antennas since a circularly polarized antenna can receive equal power in the horizontal as well as the vertical plane (ideally AR =1, or 0 dB). However, practically, antennas should have AR less than 3 dB (1.412) [3]. Conventional designs of single-feed microstrip antennas for circular polarization (CP) are usually achieved by truncating patch corners of a square patch, using nearly square or nearly circular patches, cutting a diagonal slot in the square or circular patches [4].

II. SQUARE PATCH ANTENNA

In order to simplify analysis and performance prediction, the patch is generally square [5], rectangular [6], circular [7], triangular [8], and elliptical or some other common shape. The square microstrip patch antenna is the widely used of all the types of microstrip antennas. The substrate material, dimension of antenna, feeding technique will determines the performance of microstrip antenna. Microstrip patch antenna has a ground plane on the one side of a dielectric substrate which other side has a radiating patch as shown below in Figure 1.

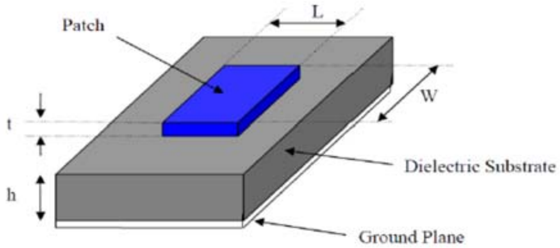

Fig. 1. Patch antenna.

A square patch is used as the main radiator. The patch is generally made of conducting material such as copper or gold and can take any possible shape. Dielectric constant of the substrate (ε_r) is typically in the range 2.2< ε_r <12. For good antenna performance, a low dielectric constant with thick dielectric substrate is desirable, as it provides better radiation, better efficiency and larger bandwidth [9]. To feed the antenna variety of methods are used. They are classified into two groups as contacting and non-contacting. The

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contacting methods are strip-line and coaxial probe, while non-contacting are aperture coupling and proximity coupling [10]. In present work coaxial probe feeding method is used as depicted in Figure2.

III. ANTENNE DIMENSIONS CALCULATION

After selecting the type of substrate which is in our case “Rogers RT/duroid 5880” with permittivity of $\varepsilon_r = 2.2$ (this substrate was chosen due to its high gain and also with using a low dielectric constant the dimensions of the antenna are reduced [9], [11]) and the resonant frequency f_R= 2.233GHz (S-band frequency for small satellites in sun synchronous orbit)), the rest of the parameters are calculated as follow [12]:

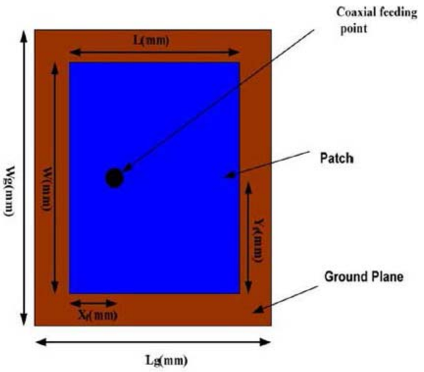

Fig. 2. Geomtery and dimensions of patch antenna.

A. Calculation of the height (h):

The height of the dielectric substrate upon which the metallic patch is mounted or placed. The height of the dielectric substrate of a microstrip antenna is calculated using the following formula:

$$h = \frac{0.3 * C}{2 * \pi * f_R * \sqrt{\varepsilon_r}} \tag{1}$$

Where:

C: Speed of light ($C = 3 * 10^{-8}\ m/s$).

f_R: Frequency of resonance in GHz,

ε_r: Permittivity of the substrate,

B. Calculation of the width (W) of the patch:

The width of the patch is calculated using the formula given as:

$$W = \frac{C}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{2}$$

In present work, the shape selected to design the antenna is the square shape. So, the dimensions of square patch length L, width W are taken to be equal.

C. Calculation of the effective dielectric constant (ε_{eff}):

The effective dielectric constant is calculated using the formula given as;

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + 12\,\frac{h}{W}\right]^{-1/2} \tag{3}$$

D. Calculation of the effective length of the patch (L_{eff}):

The effective length of the patch antenna is the sum of the actual length of the antenna and its extension or the fringe effects.

$$L_{eff} = \frac{C}{2 * f_r * \sqrt{\varepsilon_r}} \tag{4}$$

E. Calculation of the length extension (ΔL):

Length extension is the additional length at the end of the patch as a result of the fringing field along its width. It is calculated using the formula given as:

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{eff} + 0.3) * (\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258) * (\frac{W}{h} + 0.8)} \tag{5}$$

F. Calculation of the actual length (L) of the patch:

The actual length of the patch, L is the difference between the effective length and twice of the length extension of the patch. It is represented mathematically as:

$$L = L_{eff} - 2\,\Delta L \tag{6}$$

G. Calculation of the ground plane dimensions:

The ground plane dimensions are calculated for the length and the width. The ground plane length and width dimensions are more than the length and width in that order by six times thickness or height of the patch. They are calculated using the formula given as:

$$L_g = L + 6h \tag{7}$$

$$W_g = W + 6h \tag{8}$$

H. Feed point:

The feeding point position is given by the coordinates (X_f, Y_f). The feeding point coordinates are given by the following equations:

$$X_f = \frac{L}{2 * \sqrt{\varepsilon_{eff}}} \tag{9}$$

$$Y_f = \frac{W}{2} \tag{10}$$

I. Corner Trunc size:

Circular polarization can be achieved by modifying one of the patch corners or the both. Small isosceles right angle triangular patches are removed from one side corner or from the diagonally opposite corners of the square patch. The design equations for truncated length are given as [4]:

$$Q_0 = \frac{C*\sqrt{\varepsilon_r}}{4*f_r*h} \quad (11)$$

$$\frac{\Delta S}{S} = \frac{1}{2*Q_0} \quad (12)$$

$$a = L\sqrt{\frac{\Delta S}{S}} \quad (13)$$

Where:

Q_0: Unloaded quality factor,
$\frac{\Delta S}{S}$: Truncation Ratio,
a: truncated length.

For our design, we opted for the method which consists in truncating one corner [4].

IV. ANTENNA DIMENSIONS

Starting with the values we get from theoretical design (Section III), we prepared a model of antenna in Ansoft HFSS (figure 3 and figure 4). Since the theoretical design is based on closed loop formulas and the software is based on open loop formulas, the resonant frequency of the patch designed with theoretical values shifted and also the parameters used to evaluate the performance of the patch microstrip antenna as: return losses (S11), gain, directivity, beam width (BW), axial ratio (AR), voltage standing wave ratio (VSWR)…etc. were not optimized. So, we start changing the dimensions of the patch and the feeding point location. We iteratively simulate the design in a way to get the best performances possible.

Table 1.Shows the optimized dimensions selected for the design of a square microstrip patch antenna with one corner truncated.

TABLE1. Antenna Dimensions

Parameters	*Dimension (mm)*
Solution Frequency	2.233 GHz
Height of Substrate	3.41mm
Patch Dimensions	43mm
Substrate Dimensions	80mm
Feed Point “X”	10mm
Feed Point “Y”	0
Trunc Size	9mm

V. ANTENNA DESIGN

The figure below, show the square patch antenna design in 3D model. It consists of patch elements on one side of a dielectric substrate and a planar ground on the other side. It was assigned with an air box boundary and virtual radiation to create far field radiation pattern and assigned with an excitation. The antenna as shown is feeded by a coaxial probe.

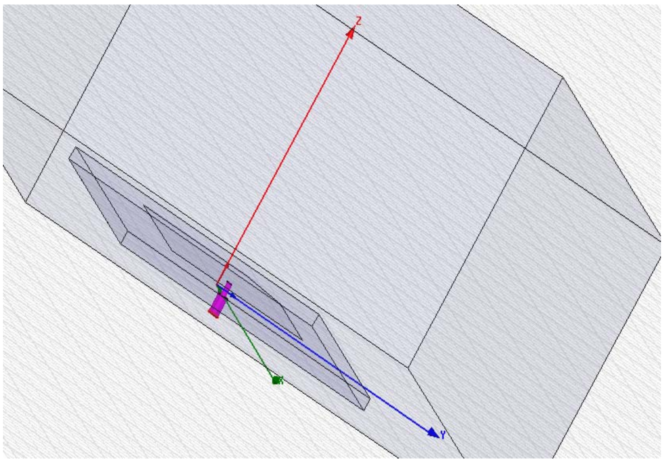

Fig. 3. Patch antenna coaxial probe feeding.

The figure below shows the full view of antenna, here the ground is taken as a square and the medium for the ground is E- plan.

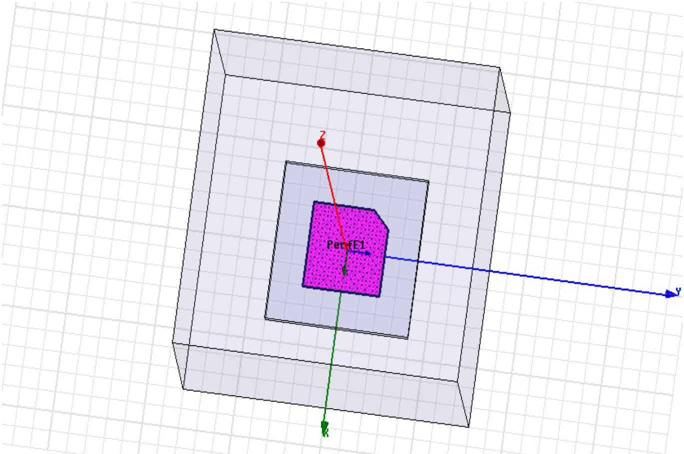

Fig. 4. View of the designed square patch antenna with the corner truncated.

VI. ANALYSIS AND RESULTS

The parameters used in literature to evaluate the performance of the are: return losses (S11), gain (G), directivity (D), beam width (BW), axial ratio (AR), voltage standing wave ratio (VSWR)…etc. are given below in Table (2):

TABLE2. Antenna Performances

Parameter	**Value**
Resonance frequency (GHz)	2,2
Return loss "S11" (dB)	-20,43
Bandwidth "BW"@-10dB (MHz)	134

Bandwidth "BW"@-15dB (MHz)	71
Bandwidth "BW"@-18dB (MHz)	32
Gain (dB)	6,97
Directivity (dB)	6,94
Axial Ratio "AR"	0,1723
3dB Axial Ratio beam width (°)	110
AR @Theta=-30° (phi=0°)	0,037
AR @Theta=-30° (phi=90°)	1,02
AR @Theta=30°(phi=0°)	0,65
AR @Theta=30°(phi=90°)	0,71
Polarization	RHCP
VSWR	1,65

The figure 5 represents the variation of Return Loses with Frequency. Plot shows a resonant frequency of 2.2 GHz with minimum of -20.43 dB return losses available at this frequency.

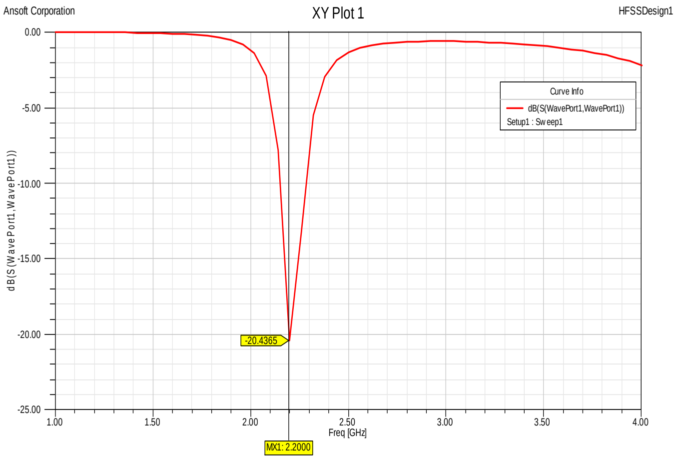

Fig. 5. Variation of return loss with frequency.

The figure 6 represents the variation of the antenna gain with Frequency. Plot shows that at the resonant frequency which is 2.2 GHz, the antenna gain is around 6.97dB. This performance of antenna is better than [13] and comparable to [9] with degraded S11 but with better AR and VSWR.

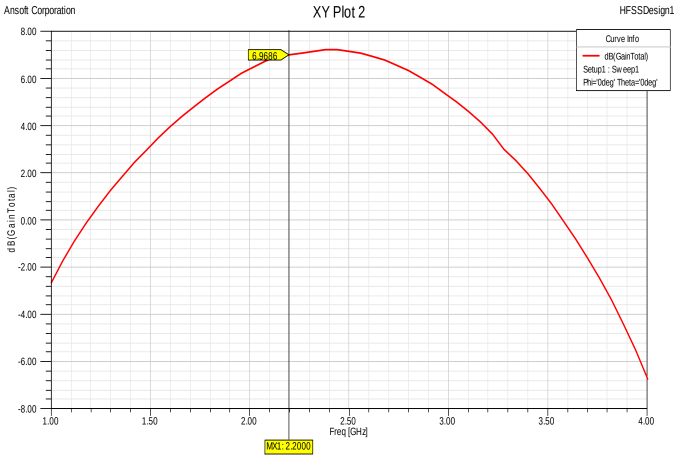

Fig. 6. Gain of the simulated antenna.

For the directivity of the antenna, figure 7 shows that the simulated antenna present a good directivity of around 6.95dB at resonance frequency.

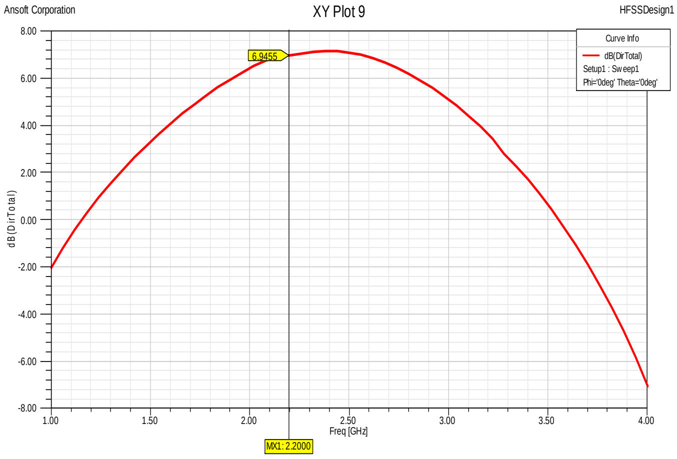

Fig. 7. Directivity of the simulated antenna.

The axial ratio is a very important parameter that helps to quantify the polarization of an antenna. The axial ratio of a wave elliptically polarized, is the relationship between major and minor axes of the ellipse, and it can take values among one and infinity [14].

For an antenna that has a purely linear polarization, the axial ratio tends to infinity because one of the components of electric field is zero. For antennas that have perfect circular polarization, the axial ratio is 1 (or 0 dB), because you have electric field components of the same magnitude, if it is an antenna with elliptical polarization, the axial ratio is greater than 1.

Axial ratio versus frequency for square patch antenna designed is shown in figure 8. The value of axial ratio is 0.1723db which is comparable to the AR obtained in [4].

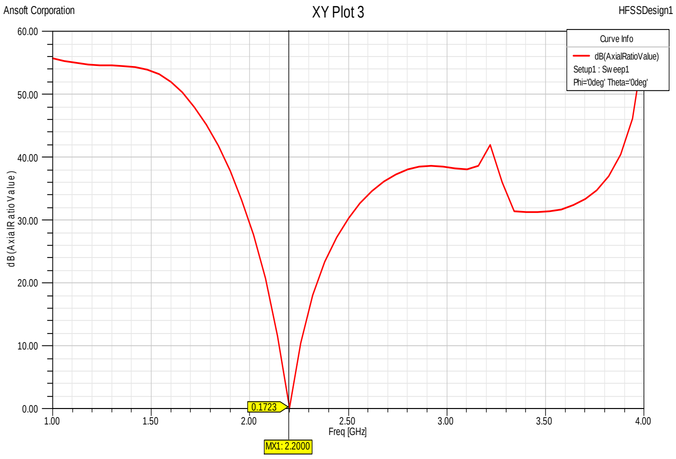

Fig. 8. Axial ratio of the simulated antenna.

Figure 9 shows the axial ratio for phi=0° and phi=90° for the range of -30°< theta <30° because the axial ratio tends to degrade away from the main beam of an antenna but for this simulated antenna the axial ratio is still under the limit of 1dB in this range.

In general the axial ratio may be indicated in a spec sheet (data sheet) for an antenna as follows: "Axial Ratio: <3 dB for +-30 degrees from main beam"[16], here we obtained better AR (<1) for the same theta range.

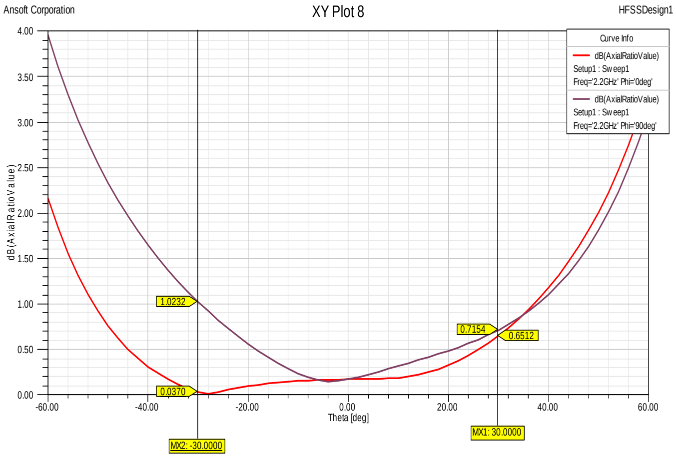

Fig. 9. Axial ratio @ Theta=30° and Theta=30°.

Figure 10 shows the polarization of the antenna. The simulated antenna has a RHCP polarization and we can see in the figure below that there is a difference of around 40dB between the RHCP gain and the LHCP gain and generally a difference of 10-15dB is sufficient to say that this is the antenna polarization [15].

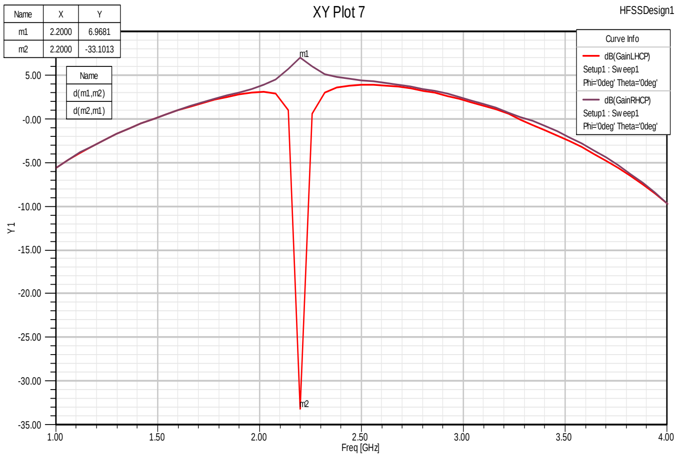

Fig. 10. RHCP & LHCP gains.

In certain references [17] [18] they are taking into account as one of the antenna performance parameters the 3dB axial ratio beam width. In the figure 11, it can be noticed that the simulated antenna present a 3dB axial ratio beam width of around 110°.

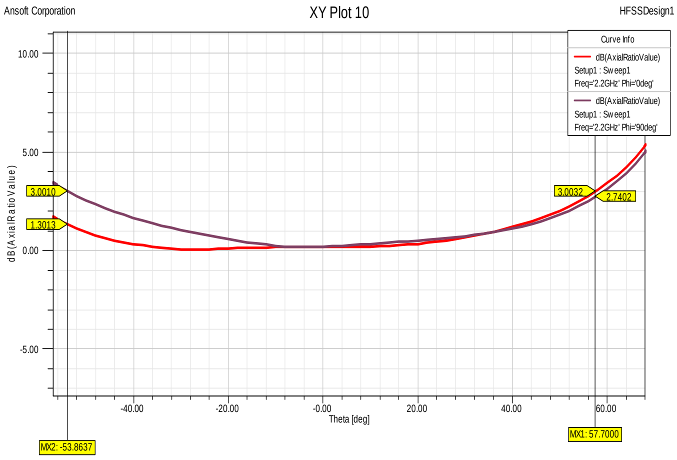

Fig. 11. 3dB Axial Ratio beam width.

Figure 12 shows the variation of VSWR with frequency. The VSWR observed to be 1.65 at resonance frequency which is less than 2dB [9] [13].

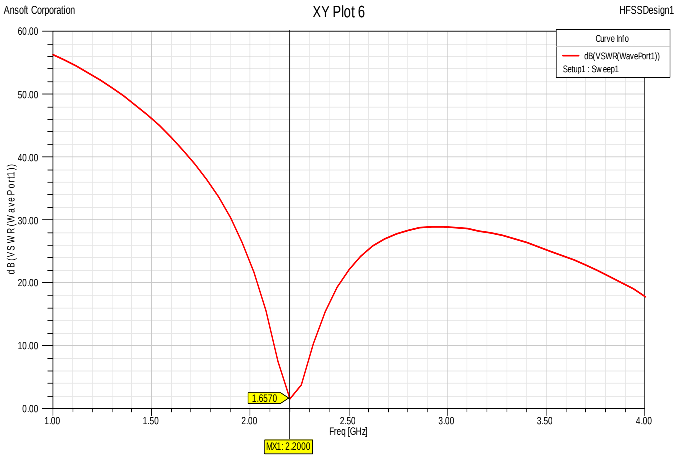

Fig. 12. VSWR with frequency.

VII. CONCLUSION

The design of square patch antenna with a single cut operating at the frequency of 2.2 GHz which is suitable for S-band small satellite applications using coaxial probe feeding technique has been completed using HFSS software.

The simulations were achieved with a good obtained performances. The simulated antenna present a gain of 6.97dB, directivity of 6.94dB and a beam width of 32MHz at S11=-18dB.

The proposed antenna consists of a single patch for single operating frequency with a good a right hand circular polarization (AR=0.17) which is suitable for the small satellite applications.

In the future, two similar works will be introduced for the same purposes. The first one will be a square patch antenna with double cut and the second one a circular patch with single cut. The both antennas shall present almost the same performances and especially the lower AR possible.

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