# Cross Polarization Uncertainty in Near-Field Probe Correction


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## ABSTRACT

The probe correction of near-field measured data can be considered as being composed of two parts. The first part is a pattern correction that corrects for the effects of the aperture size and shape of the probe and can be analyzed in terms of the far-field main component pattern of the probe. The second part is due to the non-ideal polarization properties of the probe. If the probe responded to only one vector component of the incident field in all directions, this correction would be unnecessary. But since all probes have some response to each of two orthogonal components, the polarization correction must be included. The polarization correction will be the focus of the following discussion. Previous studies have derived and tested general equations to analyze polarization uncertainty[1,2]. This paper simplifies these equations for easier application. The results of analysis and measurements for Planar, Cylindrical and Spherical near-field measurements will be summarized in a form that is general, easily applied and useful. Equations and graphs will be presented that can be used to estimate the uncertainty in the polarization correction for different AUT/Probe polarization combinations and measurement geometries. The planar case will be considered first where the concepts are derived from the probe correction theory and computer simulation and then extended to the other measurement geometries.



**Keywords**: Near-field measurements, Error Estimates, Polarization, Probe Correction


## 1.0 Polarization Parameters

Before discussing the probe correction, we will define and illustrate a polarization parameters that will be used in the following equations and compare it to traditional parameters. Axial ratio is the most widely used parameter and is defined as the ratio of the major axis to the minor axis of the polarization ellipse that is produced as the electric field vector rotates in a plane normal to the direction of propagation. The axial ratio in a given direction is not changed if the antenna is reoriented in the reference coordinate system and would be the same for the principle E-field along the X-axis, the Y-axis or any axis. The tilt angle is defined as the angle between the X-axis of the reference coordinate system and the major axis of the polarization ellipse and does change as the antenna is rotated in the reference coordinate system. The results of either near or far-field measurements are usually presented as amplitude patterns relative to the peak of the main-component and are a function of spherical angles as illustrated in Figure 1. Although not generally presented, there is also a phase pattern for each component and the

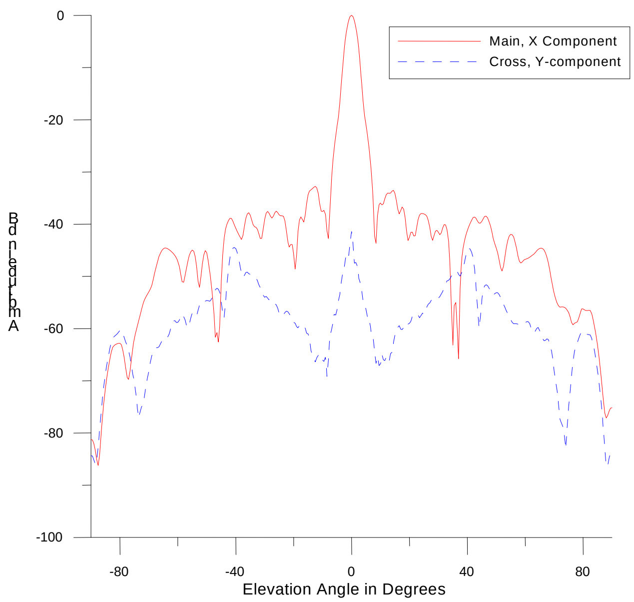


Figure 1 Main and cross component patterns.

far electric field components are complex quantities. The polarization ratios used in the probe correction equations are also complex quantities and are defined as either the ratio of horizontal to vertical or the ratio of left circular to right circular components of the electric field or the mode coefficients. In the following discussion, only the amplitudes of polarization ratios are needed and the equations can be simplified by using a modified definition of polarization ratio. Axial ratio could be used for linearly polarized antennas, but for circularly polarized antennas, a ratio of the circular components is preferred, and so the modified ratio is defined as the ratio of main to cross components amplitude and is referred to as the Main Polarization Ratio (MPR). For each Antenna Under Test (AUT), the choice of main component is determined by the main component of the AUT and is either horizontal, vertical, right or left circular. The cross component is the vector component that is orthogonal to the chosen main component. It will also be useful to use a logarithmic rather than linear scale in the final equations, and so the Main Polarization Ratio for the AUT is defined as,

$$\boldsymbol{P}(\boldsymbol{\theta},\boldsymbol{\phi}) \equiv 20*\log\left[\frac{\text{AUT Main Comp. Amp at }(\theta,\varphi)}{\text{AUT Cross Comp. Amp at }(\theta,\varphi)}\right]. \qquad (1)$$

Once the "Main" component is specified, that same component is used to define the MPR of the probes used in near-field measurements regardless of the actual polarization of the probe. For instance, if the AUT is right hand circularly polarized and the probe is linear, the ratio of right to left components is used to determine the MPR for the AUT and the probes. Two probes, or a single probe rotated by 90 degrees are used for near-field measurements. The MPR's of the two probes are denoted as shown in Equation (2)

$$\boldsymbol{\rho}'(\boldsymbol{\theta},\boldsymbol{\phi}) \equiv 20*\log\left[\frac{\text{"Main" Amp at }(\theta,\varphi)\text{ for Probe 1}}{\text{"Cross" Amp at }(\theta,\varphi)\text{ for Probe 1}}\right]$$

$$\boldsymbol{\rho}''(\boldsymbol{\theta},\boldsymbol{\phi}) \equiv 20*\log\left[\frac{\text{"Main" Amp at }(\theta,\varphi)\text{ for Probe 2}}{\text{"Cross" Amp at }(\theta,\varphi)\text{ for Probe 2}}\right]. \qquad (2)$$

### 2.0 AUT Main-Component Uncertainty Planar Measurements

Using the above definitions for MPR, it can be shown from the probe correction equations that for planar near-field measurements where the AUT main component is either X, Y linear or right, left circular and where one probe is co-polarized to the AUT and the other probe is cross polarized to the AUT, uncertainty in the main and cross component results can be estimate for all four cases with just two equations. The equations are more concise if the uncertainty is express as the ratio of the error level to the main or cross component level rather than the uncertainty in dB. For the main component uncertainty,

$$\frac{\boldsymbol{ERR-M}}{\boldsymbol{SIG-M}}[\theta,\varphi] = 20*\log\left[\frac{\text{Main error}(\theta,\varphi)}{\text{Main Amp}(\theta,\varphi)}\right]$$

$$\approx -\big(\boldsymbol{P}(\theta,\varphi)+\boldsymbol{\rho}'(\theta,\varphi)\big)$$

$$+20*\log\left|1-\frac{E'_{C\varepsilon}(\theta,\varphi)}{E'_{C}(\theta,\varphi)}\right| \qquad (3)$$

The term which is the sum of the AUT and probe MPR's is referred to as the Cross Coupling term. The second term is referred to as the Probe Polarization Calibration term. The M denotes that this expression is for the main component pattern. The cross coupling term quantifies the effect of the cross coupling between the AUT and the probe. For the main component, this is the combined effect of the AUT main to probe cross and the probe main to AUT cross. The Probe Polarization Calibration term, denoted PolCal, quantifies the reduction in the AUT main component uncertainty that results when the value of the cross polarization of the probe used in the probe correction is closer to its true value. $E'_{C}(\theta,\varphi)$ is the true value, and $E'_{C\varepsilon}(\theta,\varphi)$ the value used in the probe correction. The true value is unknown, but the ratio of the true to the used value is derived from the estimated uncertainty in the probe cross component. Figure 2 is a plot of the PolCal term and it is apparent that the error-to-signal ratio is significantly lowered even for typical probe uncertainties of 1-2 dB.

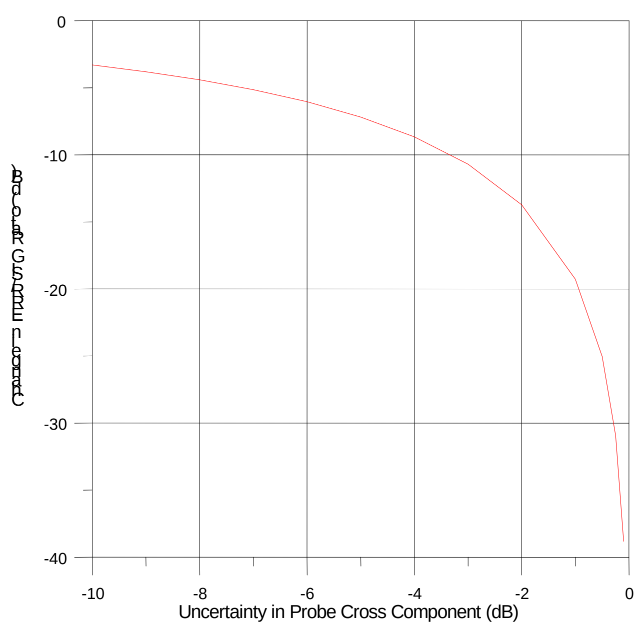


**Figure 2 Change in error to signal ratio due to probe polarization calibration.**

To estimate the uncertainty in the main component due to uncertainties in the polarization of the probe, known or estimated values for the MPR's of the AUT and the probe can be used in Equation (3) for specific cases or a set of curves can be produced by evaluating Equation (3) for typical combinations of probe and AUT polarization and typical polarization uncertainties as shown in Figure 3. It is apparent from Figure 3 that for typical probes and AUT's, the cross polarization of the probe has negligible effect on the main component pattern in any direction.

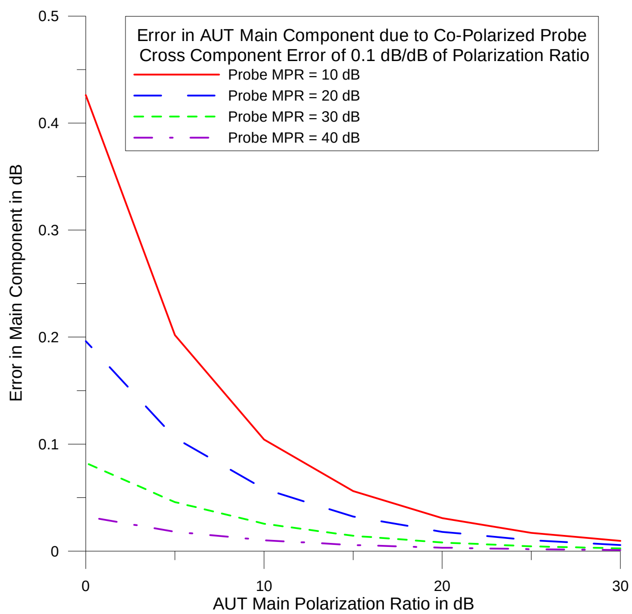


**Figure 3 Main component pattern errors due to uncertainty in probe polarization.**

## 3.0 AUT Cross Component Uncertainties, Planar Measurements

The equation for the uncertainty in the AUT cross component due to uncertainties in the polarization of the cross polarized probe is,

$$\frac{\boldsymbol{ERR-C}}{\boldsymbol{SIG-C}}[\theta,\varphi] = 20 * \log\left[\frac{\text{Cross error }(\theta,\varphi)}{\text{Cross Amp }(\theta,\varphi)}\right]$$

$$\cong \left(\boldsymbol{P}(\theta,\varphi) + \rho''(\theta,\varphi)\right)$$

$$+20 * \log\left(1 - \frac{E''_{M\varepsilon}(\theta,\varphi)}{E''_{M}(\theta,\varphi)}\right)$$

$$= \text{Cross-Coupling Term}$$

$$+ \text{Cross-Probe Polarization Calibration Term.} \quad (4)$$

The uncertainty in the AUT cross polarized pattern can be determined using Equation (4) with known or estimated polarization ratios or by using graphs that are derived from Equation (4). The Probe Polarization Calibration Term for this case is identical to the one for the main component and Figure 2 can therefore be used for these calculations. In the Cross Coupling Term, the AUT MPR, $\boldsymbol{P}(\theta,\varphi)$ is positive and the Probe MPR, $\rho''(\theta,\varphi)$ is negative and so it is the relative polarization of the AUT and probe that is the dominant factor.

Curves have also been generated for typical AUT and probe polarizations combinations and for the cases where the probe's cross polarization is assumed to be zero or to have typical calibration uncertainties. One of these is shown in Figures 4**.**

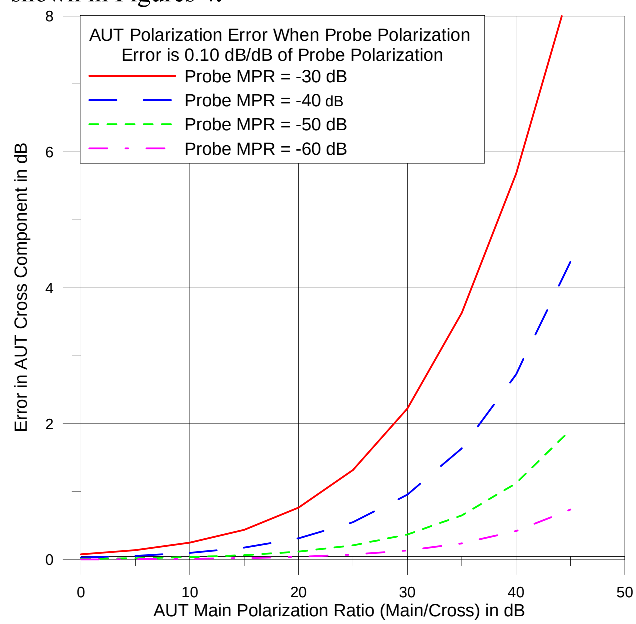


**Figure 4 AUT cross component errors for calibrated probe with uncertainty.**

The error in dB shown in Figures3 and 4 has been derived from the error to signal ratio using the relationship

$$\text{Error in dB} = \Delta_{dB} = 20 * \log\left[1 + 10^{\left(\frac{E/S}{20}\right)}\right] \quad (5)$$

## 4.0 Linear Probe Measuring a Circularly Polarized AUT, Planar Measurements

When the AUT is circularly polarized and a linear probe is used, the equations and graphs in the previous sections do not apply. The following discussion will derive equations and graphs for this case. When the AUT is circularly polarized, polarization results are usually given in terms of axial ratio. When a linearly polarized probe is used, it is rotated by 90 degrees for the second measurement or a dual polarized probe is used. In the following, the unprimed probe polarization ratio will denote both probes since they have similar polarization ratios in a given direction. The equation for this case is derived for the ratio of the axial ratio determined from the near-field measurements to the true axial ratio as shown in Equation (6).

$$\frac{\mathrm{AR}_{\mathrm{Meas}}}{\mathrm{AR}_{\mathrm{True}}} \approx 1 - \frac{2}{p_{Ac}(\theta,\varphi)}\left[1 - \frac{\rho_c(\theta,\varphi)}{\rho_{c\varepsilon}(\theta,\varphi)}\right]$$

where

$p_{Ac} =$ AUT circular pol ratio

$= \frac{\text{Main Component}}{\text{Cross Component}}$

$\rho_c =$ True Probe circular polarization ratio

$= \frac{\text{"Main Component"}}{\text{"Cross Component"}}$

$\rho_{c\varepsilon} =$ Probe circular polarization ratio used in probe correction.

(6)

The "c" subscripts in Equation (6) are used to emphasize that they are the ratio of circular rather than linear components. The circular polarization ratios for the probe

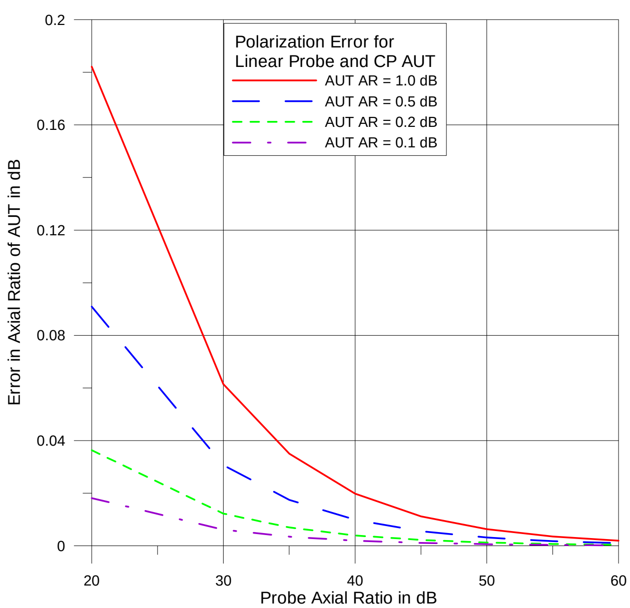


**Figure 5 Axial ratio error for linear probe and CP AUT.**

will be close to one since the probe is linearly polarized and so "Main" and "Cross" refer to AUT components. If the probe is not calibrated and assumed to be perfectly linearly polarized,

$$\rho_{c\varepsilon} \equiv 1.0 \quad (7)$$

Figure 5 shows the resulting uncertainty in the AUT axial ratio. Even smaller uncertainties result for a calibrated probe. For this case when a linear probe is used to measure a CP AUT, the primary source of uncertainty in the cross polarized results is the relative amplitude and phase between X and Y component data, not the polarization properties of the probe.

## 5.0 Spherical and Cylindrical Near-Field Measurements

All of the equations and graphs in the previous sections have been derived for the case of planar near-field measurements. Approximations have been made to emphasize the important terms, but all the results are based on the probe correction equations and are valid for typical probes. The complexity of the probe correction and far-field calculation for spherical and cylindrical measurements prevents a similar rigorous derivation for these cases. Instead, the planar results are extended to these cases from observation of probe correction effects in non-planar measurements and simulations where the probe parameters are changed and the resulting changes in the far-field patterns observed. The conclusions from these observations are:

There are two parts to the probe correction similar to the planar case. One part is due to the pattern of the probe and the other is due to the non-ideal polarization of the probe.

The magnitude of the polarization correction and the uncertainty in that correction depends on the relative polarization properties of the AUT and probe and like the planar case, there is both a cross coupling and a probe polarization calibration effect on the AUT main and cross component results. To a first approximation, the equations derived for the planar case to estimate the uncertainty due to either neglecting the probe polarization or uncertainties in the probe polarization can be used for spherical and cylindrical near-field measurements. In using these equations only a limited region of the probe's pattern is used in contrast to the planar case where the complete pattern is used. As shown explicitly in Equations (3) and (4), the polarization ratios are a function of the far-field angles. The **planar** polarization correction to the AUT far-field at given azimuth and elevation or theta and phi angles uses the probe polarization at exactly the same angles. The on-axis and principle plane cross components of the AUT and the probe may be much lower than the main component as illustrated in Figure 1, but in directions off the principle this is not generally true. In directions along the 45 degree cut for instance the "Cross" component of the AUT and/or the probe may be larger than the "Main" component as illustrated in Figure 6. This is accounted for correctly in the planar probe correction equations and the error estimates that have been derived.

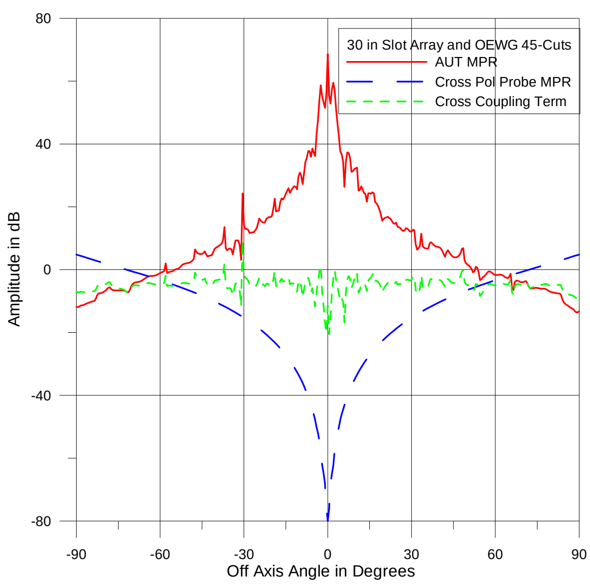


**Figure 6 AUT and Open Ended Waveguide probe polarization along 45 degree cut.**

However in spherical measurements, only a small region of the probe's pattern near its main beam axis has any influence on either the pattern or polarization terms. The size of this region will depend on the size of the AUT and the radius of the measurement sphere. The angular extent of this region is approximately the angle subtended on the measurement sphere by the projection of the AUT aperture. The pattern correction produces a small decrease in the main beam width but virtually no change in the side lobe region. The probe polarization correction is also determined by the cross component properties of the probe within this subtended angle. Due to the phase characteristics of the typical probe's cross polarized pattern that changes by 180 degrees between the four quadrants, the off-axis contributions to the cross coupling are mostly canceled out by the responses at opposite angles. The net result is that for the purpose of estimating the uncertainty in the main and cross component patterns of the AUT in every direction, **for spherical measurements**, only the on-axis polarization ratio of the probe is required. To apply the equations and curves from the planar analysis to the spherical case the polarization ratios are defined as follows.

The "main component" is determined by the far-field main component of the AUT and may be X, or Y linear. The case of a CP AUT will be considered separately. The MPR of the AUT in each direction is the ratio of the main to cross component.

The probe used for spherical measurements is always linearly polarized and rotated by 90 degrees for the two measurements or a dual port linear probe is used and assumed to be equivalent to a rotated probe. The probe measures theta and phi components and these do not usually correspond to the main and cross components of the AUT. However when the AUT is linearly polarized, and for the purpose of estimating the effects of probe polarization uncertainties, the end result of the spherical data processing including probe correction, is **as if** a co-polarized and a cross polarized probe were used. The polarization parameters of the probe for all far-field angles in Equations (3) and (4) are calculated from horizontal and vertical components, not theta and phi components. This has the largest impact for off-axis directions such as the 45 degree cut where the theta and phi components are nearly equal, but the horizontal and vertical components are not. For spherical near-field measurements, Equations (3) and (4) are modified to show the use of the on-axis probe polarization resulting in Equations (8) and (9). These are used for spherical measurements where the AUT is linear X, Y polarized. When the AUT is circularly polarized, and since the spherical probe is always linear, Equation (6) and Figure 10 are used. The on-axis polarization of the probe at (0,0) replaces the polarization at the direction (θ,φ).

For spherical near-field measurements, the error-to-signal ratio for the main component is,

$$\frac{ERR-M}{SIG-M}[\theta,\varphi] = 20*\log\left[\frac{\text{Main error}(\theta,\varphi)}{\text{Main Amp}(\theta,\varphi)}\right]$$
$$\cong -\left(P(\theta,\varphi)+\rho'(0,0)\right)$$
$$+20*\log\left|1-\frac{E'_{C\varepsilon}(0,0)}{E'_{C}(0,0)}\right|. \tag{8}$$

For spherical near-field measurements, the error-to-signal ratio for the cross component is,

$$\frac{ERR-C}{SIG-C}[\theta,\varphi] = 20*\log\left[\frac{\text{Cross error }(\theta,\varphi)}{\text{Cross Amp }(\theta,\varphi)}\right]$$

$$\cong \left(P(\theta,\varphi)+\rho''(0,0)\right)$$

$$+20*\log\left(1-\frac{E''_{M\varepsilon}(0,0)}{E''_{M}(0,0)}\right). \tag{9}$$

For cylindrical measurements, linear and CP probes can be used and they are generally co and cross polarized to the AUT as in planar measurements. Equations(3), (4) and (6) **along with** the **all the associated graphs** can be used for the corresponding cylindrical measurements. For cylindrical measurements, a region of the probe pattern that is smaller than planar and larger than spherical is used. For elevation cuts, the probe property at AZ = 0 and the given elevation angle is used similar to the planar case. For azimuth cuts, the on-axis polarization is used for the probe polarization ratio similar to the spherical case.

The above signal-to-error ratios are relative to the main or cross polarized pattern level in the given direction. The error level relative to the peak of the main component is given by,

$$\frac{Error}{Peak}(dB)) = \frac{Error}{Pattern\ Level}(dB) - \left(\frac{Pattern\ Level}{FF\ \ Peak}\right)(dB) \tag{10}$$

## 6.0 Summary

Equations have been developed to estimate the uncertainty in the main and cross component pattern results for planar, cylindrical and spherical near-field measurements. Detailed steps in the derivations have been omitted for conciseness, and are available in other reports. These equations cover the cases where the AUT is either linear or circularly polarized and measured with either linear or CP probes. Graphs have also been derived from the equations to aid in using the equations. To make these estimates, the polarization properties of the AUT and the probes are determined from pattern data or from typical results on similar antennas. The results for planar have been verified many times using measurements and simulation and are very reliable. The results for spherical have been tested for a limited number of measurement situations where the AUT is within a few wavelengths of the spherical origin. Some modification for spherical or cylindrical may be necessary for large offset distances but this has not been demonstrated by measurements. Cylindrical tests are also limited, but the results should be valid for estimating uncertainties in the majority of measurement situations.

## 7.0 REFERENCES


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