TITLE: Modeling and Validation of the Effects of a Metal Ground Plane on the RCS of an Asymmetric Trihedron

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Modeling and Validation of the Effects of a Metal Ground Plane on the RCS of an Asymmetric Trihedron

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Abstract

The T5M3 trihedron is a small and physically simple radar target that was used for modeling and experimental studies of the effects of a metal ground plane on its radar cross section (RCS). This trihedron is asymmetric and has one vertical face that is slanted backward 15 degrees from the vertical. Despite its physical simplicity as a radar target, it requires an exact solver code to accurately predict its RCS. In outdoor experimental tests, it was found to exhibit a significantly different RCS depending upon whether it is placed directly on the turntable or is isolated from the turntable. This paper presents the results of model RCS calculations via Xpatch, an approximate, physical optics-based, shooting-and-bouncing rays code, and a Method of Moments code (the fast Illinois solver code or FISC), as well as the experimental results. These calculations show the mechanisms by which the RCS of the trihedron is impacted by the metal turntable.

Introduction

This paper presents an interim report on our investigations of the interaction of a structurally simple, but electrically complex, radar target with a ground plane. This target is shown on the U.S. Army Research Laboratory (ARL) radar range turntable in Figure 1. It is an asymmetric trihedron, about 54 inches long by 24 inches high and 8 inches high, with the shorter upright side canted backward 15 degrees from vertical. The difficulties in modeling this target have been described in detail by Carter [1]. Experiments were conducted to obtain valid data. Modeling results were obtained from Xpatch* [2], an approximate, high frequency shooting-and-bouncing rays code, and from an exact integral equation (Method of Moments) [3] solver, the Fast Illinois Solver Code (FISC).*

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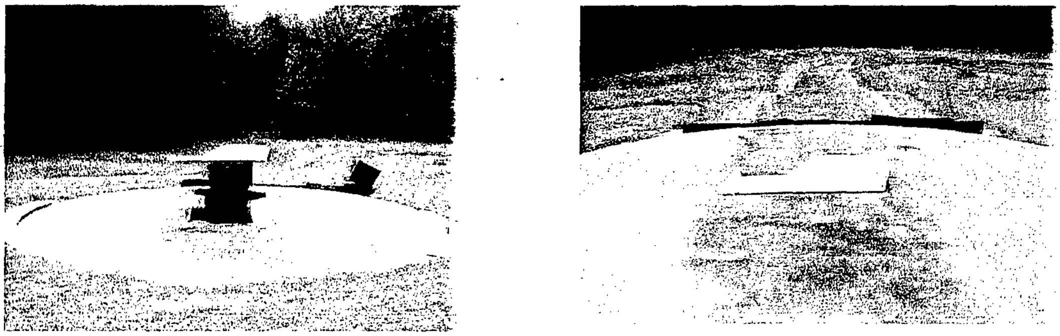


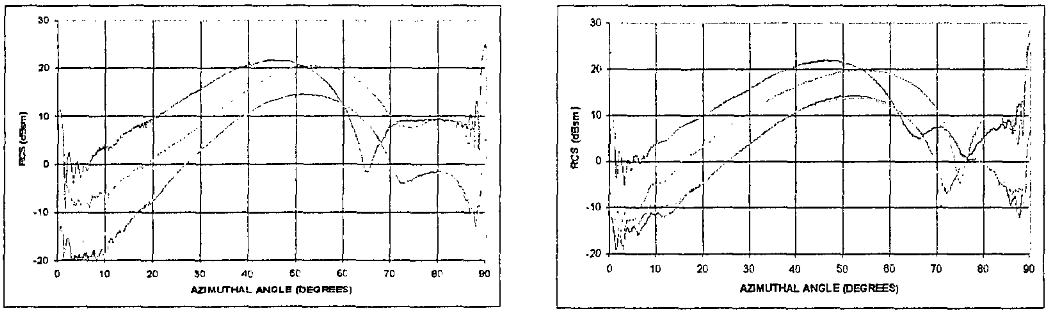
(a)

(b)

Figure 1. The trihedron shown on the turntable (a) and isolated from the turntable on a 38-inch-high wooden table surrounded by 4-inch pyramidal foam radar absorber (b). The view is looking away from the radar.

Experiments and Results

The trihedron was fabricated in the ARL machine shop from tool and fixture aluminum with a 25-microinch finish and a flatness of 0.015 inches across a 4- by 8-foot sheet. The sides were bolted together to ensure good electrical contact. All tests were conducted at the ARL outdoor radar range on a clear day in August 2001. The radar was set for a center frequency of 9 GHz and had a 1.6-GHz bandwidth. The radar was on a tower about 150 feet from the target, so the strongest scatterers on the target were in the far field. A 10-degree depression angle was used for all tests. The RCS of the empty turntable was generally well below that of the trihedron. The trihedron was tested both directly on the turntable and on a 38-inch-high wooden table covered with 4-inch pyramidal radar absorber (Figure 1). Experimental results for these two arrangements are shown in Figure 2.



(a)

(b)

Figure 2. The measured 9-GHz RCS of the trihedron isolated on the turntable (a) and on the wood table (b). Legend: blue = VV; red = VH; orange = HV; green = HH.

The major differences between the two sets of measurements areas are as follows.

1. The minimum in the VV channel (blue curve) for the isolated trihedron at an azimuthal angle of about 65 degrees becomes a double minimum for the trihedron on the turntable.

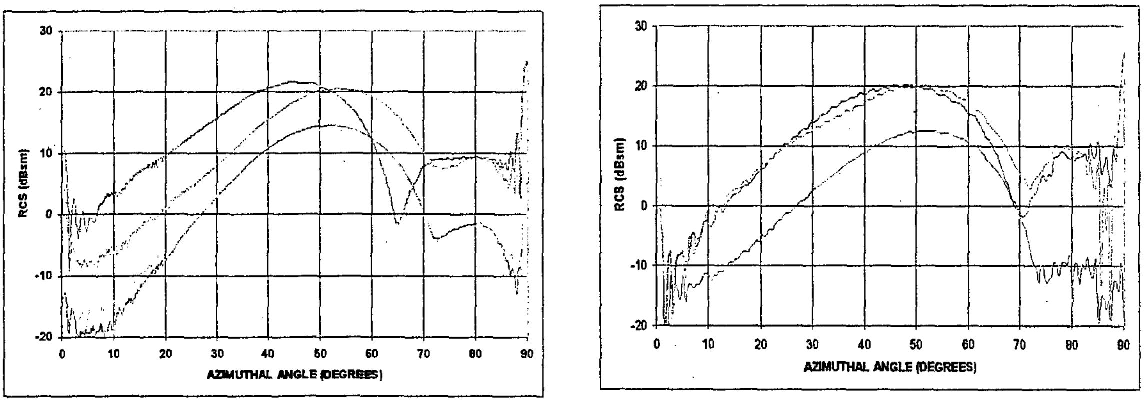
2. The minimum in the HH channel (green curve) at an azimuthal angle of about 74 degrees is about 13 dBsm deeper.

3. The minima in the cross-polarized channel RCS (VH or HV channels, red or orange curves) are a few decibels relative to square meter deeper.

The VH and HV channel RCS values should be identical and the small extent to which they are different indicates that this is good data. Additional experimental details will be presented in a forthcoming ARL Technical Report [4].

Xpatch Calculations

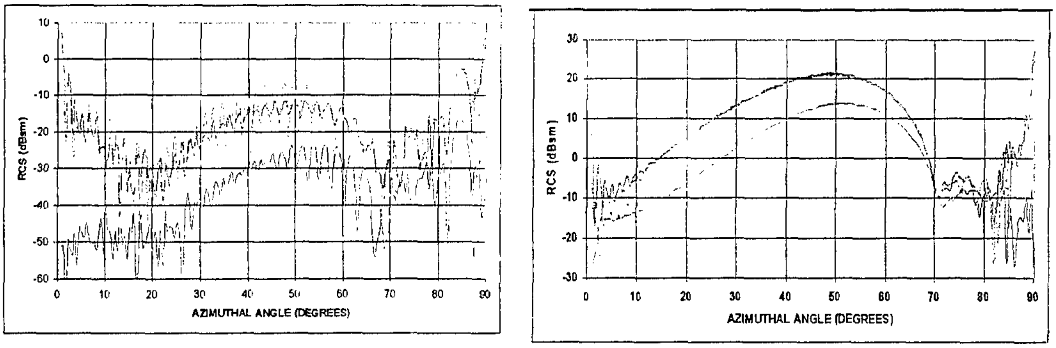
Xpatch is an approximate shooting-and-bouncing rays code that was developed for calculating the RCS of large targets at high frequencies. As an approximate code, it might be expected to miss some fine details in an RCS calculation, but it should derive the main features reasonably well and be able to predict how the RCS is changed as depression angles or frequencies are changed, or if a target is altered by adding a ground plane. The 9-GHz data and calculated Xpatch results for the isolated trihedron are shown in Figure 3.



(a) (b)

Figure 3. Xpatch calculation results (a) and experimental data (b) for the isolated trihedron. Legend: blue = VV; red = VH; orange = HV; green = HH.

The Xpatch results for the HH and VH channel RCS are in reasonable agreement with experiment, but the VV channel RCS differs significantly from the data (Xpatch calculates the VH and HV channel RCS, then averages the two [5], thus obtaining reciprocity). Additional Xpatch calculations indicate that the first bounce contribution to the RCS is small except at 0 and 90 degrees, and the large peak in all channels arises on the second bounce between the two vertical sides. These results are shown in Figure 4.

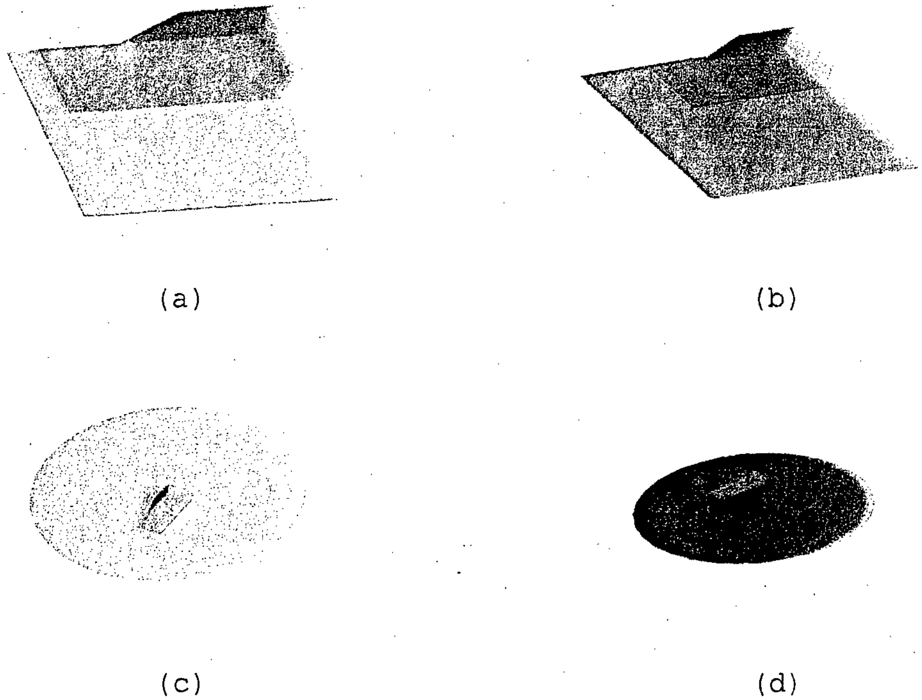


(a) (b)

Figure 4. The first bounce (a) and two bounce (b) contributions to the RCS. Legend: blue = VV; red = VH; orange = HV; green = HH.

The major differences between the data and the Xpatch results, particularly the difference between the VV and HH channel RCS, arise on the third bounce. The main reason for this is that the third bounce effects are very complicated at this depression angle, making tracking phase and amplitude of the reflected rays difficult. The geometrical arrangement is also such that a traveling wave that could not be modeled by Xpatch may be a part of the problem [6].

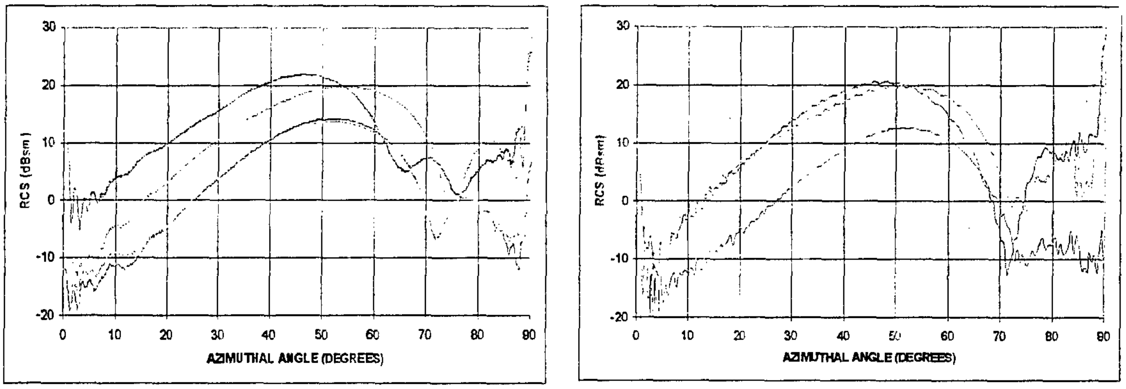
Four experimental arrangements were modeled using Xpatch. These are shown in Figure 5. The first is for the trihedron on a 62-inch square plate. If a ray is to hit one of the vertical sides of the trihedron and miss the base, altering the RCS by a direct hit, it would have to hit the turntable ground plane within 47.5 inches of the vertical seam on the trihedron. The 62-inch plate is wide enough for this with a small margin on the sides. The second ground plane arrangement is an 80-inch-wide ground plane. Any ray that can pass through the bounding box for the trihedron must hit within 71.5 inches of the seam. Such rays could alter the RCS by changing the phase of the radiation that is reflected on the third bounce. The third is a 20-foot-diameter circular plate as shown in Figure 5. In a ray tracing explanation of the effects of the ground plane on the RCS of the trihedron, this should be no different from the 80-inch plate result. If one considers the RCS as arising from induced currents that reradiate, however, the RCS results for the larger ground plane would be expected to differ from the 80-inch plate result, but the magnitude of the difference would have to be calculated. Finally, the trihedron on the wooden table surrounded by a perfect absorber was modeled as shown.


(a) (b)

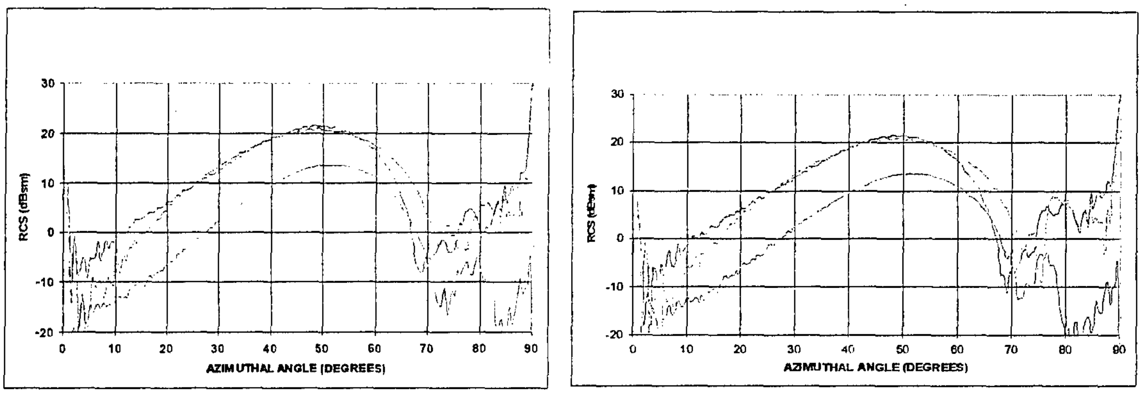
(c) (d)

Figure 5. The four experimental variations modeled via Xpatch. Legend: (a)62-inch plate; (b) 80-inch plate; (c)20-foot-diameter plate; (d) isolated on wood table.

The experimental data and the Xpatch results for the first three models are shown in Figures 6. For the 62-inch square ground plane, the Xpatch results show a much deeper VV minimum at about 70 degrees azimuth, but not a double minimum. The HH minimum is also deeper, but not as deep as for the data, and the cross-polarized channel results are a little off near the minimum. For the 80-inch square ground plane, the minimum in the VV and HH channels are broader, and there is no double minimum in the VV channel RCS. The cross-polarized channel RCS is in reasonable agreement with the data except for azimuthal angles larger than about 80 degrees. For the 20-foot-diameter ground plane, the VV minimum is at about 68 degrees and is still a broad single minimum rather than a double minimum, the HH channel results are closer to the experimental values, and the cross-polarized channel RCS is in fairly good agreement with the data except for azimuthal angles greater than about 78 degrees. In all cases, the HH and cross-polarized channel RCS are in reasonable agreement with experiment for azimuthal angles below 50 degrees, while the VV channel experimental data differs from the calculation by 10 dBsm.



(a) Experimental Data **(b) 62-inch Ground Plane**



(c) 80-inch Ground Plane **(d) 20-foot-Diameter Ground Plane**

Figure 6. The experimental data (a), Xpatch results for a 62-inch square ground plane (b), Xpatch results for an 80-inch square ground plane (c), and Xpatch results for a 20-foot-diameter ground plane (d). Legend: blue = VV; red = VH; orange = HV; green = HH.

Xpatch should obtain the same result for the isolated trihedron and for the trihedron on the wooden table if this arrangement does isolate the trihedron from the turntable. Figure 7 shows the calculated VV channel results for the isolated trihedron and for the trihedron on the wood table. The difference is small as expected. Similar results were obtained in the other channels.

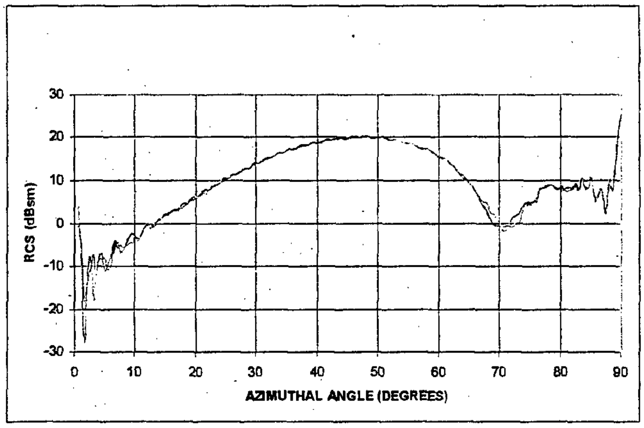


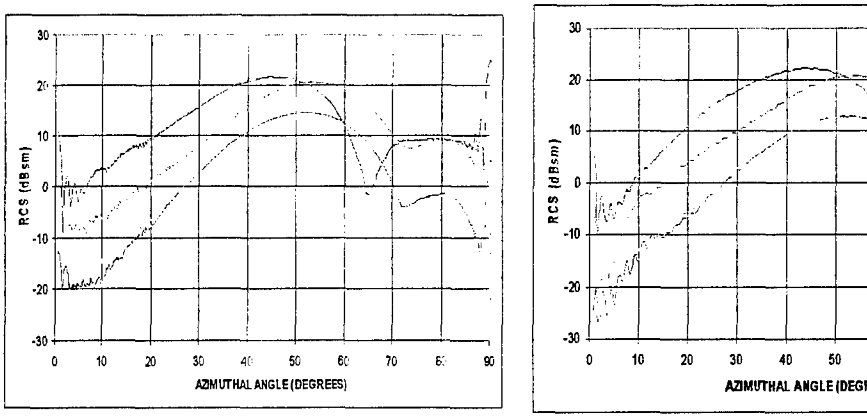
Figure 7. VV channel Xpatch results for the completely isolated trihedron (blue curve) and for the trihedron on the wood table (red curve).

FISC Results

Modeling calculations were also performed using FISC, a nominally exact code that should result in the correct answer. However, it can be set to give results of low, medium, or high accuracy as a modeler's option; it was set to medium accuracy for the calculations reported here. One other option is the use of the electric field integral equation (EFIE) or the magnetic field integral equation (MFIE) or some combination of the two (combined field integral equation or CFIE) to solve the problem. The most frequent choice, and the one appropriate for a closed electrical body such as the trihedron, is to use a CFIE composed of one-half the EFIE and one-half the MFIE; this selection was used in the calculations.

FISC uses the same facet model as Xpatch, but refines the facets so that facet sides are less than 1/10 wavelength long. It also has an option to include an infinite metal ground plane under a target. A problem will run about 2 or 3 times slower that the corresponding problem with an isolated target. The Xpatch results suggest that the entire turntable contributes to the RCS of the trihedron on the turntable, and the infinite ground plane option was selected as being a better a better model than the smaller ground planes previously described.

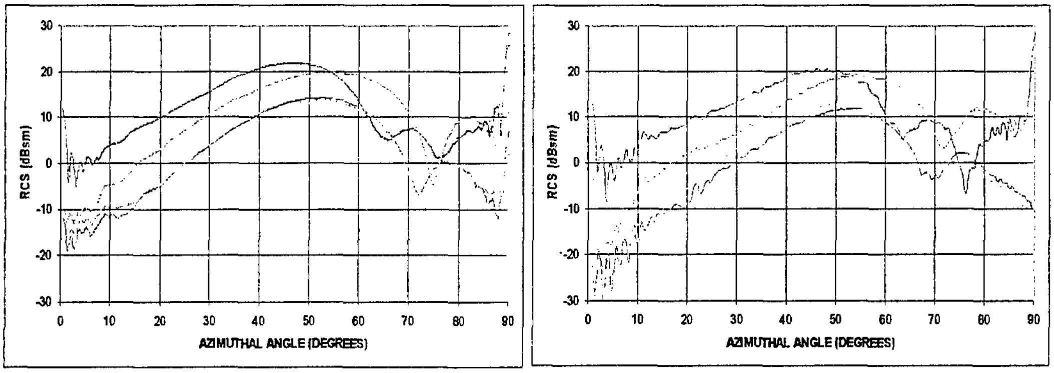
The experimental data and the FISC results for the isolated trihedron are shown in Figure 8. Unlike the Xpatch model results, The FISC results agree well with experiment in the azimuthal angle range from 50 to 85 degrees, where the Xpatch results did not agree well at all; in particular, the difference in the VV and HH channel RCS is predicted. The major differences between the FISC results and the data are in the cross-polarized channel between about 87 and 90 degrees and the HH and cross-polarized channels (and, to a lesser extent, the VV channel) from 0 to 10 degrees. The VH and HV results are generally fairly close; they should be identical.



(a) (b)

Figure 8. The experimental data (a) and the FISC calculation results (b) for the isolated trihedron. Legend: blue = VV; red = VH; orange = HV; green = HH.

The experimental data and FISC results for the trihedron on the turntable are shown in Figure 9. As for the isolated trihedron, the FISC results are in good agreement with the data for all azimuthal angles except for the 0 to 10 and 87 to 90 degrees ranges. The double minimum in the VV channel and the deepening of the minimum in the HH channel are reasonably well predicted. The difference between the VH and HV results is a little greater than for the isolated trihedron.



(a) (b)

Figure 9. The experimental data (a) and FISC calculation results (b) for the trihedron on the turntable. Legend: blue = VV; red = VH; orange = HV; green = HH.

Conclusions

Xpatch predicts a definite interaction between the ground plane and the trihedron, but misses fine, but important, details, probably because of the approximations it uses. It does predict that the trihedron on the wood table is fairly well isolated from the ground plane. The calculations are also fast, requiring 10 to 120 minutes of computation time depending on the size of the problem. FISC with medium accuracy does a much better job of predicting the results and gets many details, such as the double minimum in the VV channel and the differences in the VV and HH channels. Still, it does not get all details correct; the results for azimuthal angles between 0 and 10 degrees and 87 and 90 degrees differ from the data by as much as 10 dBsm. The high accuracy option in FISC should give a more accurate prediction, but will take even longer than the 1000 plus hour computation time with the medium accuracy option.

Future Plans

Additional measurements of the trihedron both isolated and on the ground plane at frequencies of 10, 35, and 94 GHz and depression angles of 10, 15, 20, and 30 degrees are planned. Additional modeling studies using Xpatch, FISC, or a finite difference time domain code will also be pursued. Other codes that should provide accurate results for this problem are under development and will be tried when they become available. It will be particularly interesting to know how well Xpatch can model these results at other depression angles and higher frequencies.

Acknowledgments

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