Performance Comparison between Trapezoidal and Triangular Serrated Compact Antenna Test Ranges with Smooth Transition at the Corners

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Abstract --- This paper presented a theoretical and numerical assessment trapezoidal and triangular serrated Compact Antenna Test Range (CATR) The CATR provides uniform illumination within the Fresnel region to the test antenna. The performance comparison between trapezoidal and triangular serrated edge compact range reflector with Smooth Transition at the Corners (STC) are investigated. Application of serrated edge has been shown to be a good method to control diffraction at the edges of the reflectors. In this paper the Fresnel fields of trapezoidal and triangular serrated CATRs with STC are analyzed by the Physical Optics (PO) techniques. It is observed that trapezoidal serrated CATR gives ripples free and enhanced quiet zone width than triangular serrated CATR.

Indexing Terms--- Fresnel Region, Quiet Zone, Physical Optics, Ripples, Serration

INTRODUCTION

Parabolic reflectors are commonly used in compact ranges to generate the desired plane wave to illuminate the object under test in RCS and antenna pattern measurement. The stray signals emanating from reflector edges interfere with this desired plane wave and, consequently, corrupt the fields in the test zone. The performance of the quiet zone will be degraded for traditional CATR without an edge treatment of the reflector antenna. Usually, the ripples in both the phase and magnitude of the field intensity inside the quiet zone are caused by stray signals, which come from edge diffraction, reflector surface errors, feed spillover, and multiple bounces from the RF anechoic chamber. The diffracted field is spread in all directions interfering with the major reflected field in constructive and destructive patterns. The result is the appearance of maxima and minima of the field amplitude across the plane wave front in the quiet zone. Diffraction from edges causes deviation of the phase of the plane wave, too. There are two popular ways to reduce diffraction from reflector edges: serrated-edge reflectors and rolled-edge reflectors. Rolled-edge modifications at the edge of the reflector are introduced to direct the diffracted field mainly to the side and the back of the reflector. Serrated edges of reflectors produce multiple low-amplitude diffractions, which are randomized in amplitude, phase and polarization. That is why the probability of their cancellation in any point of the quiet zone is high. If this is done properly, the edge diffracted fields will not contribute to the stray signal errors in the quiet zone. This means that corner diffracted fields from tips and valleys of the serrations will be the dominant terms. Since corner diffracted fields are much weaker than edge diffracted fields, this approach can be used to design the serrations.

METHOD OF ANALYSIS

The field over an arbitrary plane (z = constant) in the Fresnel region is given by [4]

$$E_x(x,y,z) = -\frac{jk}{2\pi z} e^{-jkz} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E_{ax}(x',y') e^{jk\left\{(x'-x)^2+(y'-y)^2\right\}/2z} dx'dy'$$

A square aperture reflector of 45λ×45λ is equipped with trapezoidal and triangular serrations as shown in Figure 1 and Figure.2. A recourse is taken to decompose the aperture area S into three parts S_1, S_2 and S_3 such that $S=S_1+S_2-S_3$ as shown in Figure 3 and Figure.4. The boundary functions $g^+(y')$ and $g^-(y')$ are expressed as a Fourier series of trapezoidal serrations with STC and $h^+(x')$ and $h^-(x')$ are described as the Fourier series of triangular serrations with STC. A quasi-analytical expression can be derived for the Fresnel zone field of a serrated edge reflector can be written as

$$E_x(x,y,z) = \frac{-jE_0}{2} e^{-jkz}\left(I_1+I_2+I_3\right)$$

where

$$I_1 = \frac{k}{\pi z}\int_{-h=\frac{-b_0}{2}}^{h=\frac{b_0}{2}} e^{jk(y'-y)^2/2z} dy' \int_{g^-(y')}^{g^+(y')} e^{jk(x'-x)^2/2z} dx'$$

$$= \frac{k}{\pi z}\left[F(t_+)-F(t_-)\right]\left[F(s'_+)-F(s'_-)\right]$$

$$I_2 = \frac{k}{\pi z}\int_{-w=\frac{-a_0}{2}}^{w=\frac{a_0}{2}} e^{jk(x'-x)^2/2z} dx' \int_{h^-(x')}^{h^+(x')} e^{jk(y'-y)^2/2z} dy'$$

$$= \frac{k}{\pi z}\left[F(s_+)-F(s_-)\right]\left[F(t'_+)-F(t'_-)\right]$$

$$I_3 = \frac{k}{\pi z}\int_{-w=\frac{-a_0}{2}}^{w=\frac{a_0}{2}} e^{jk(x'-x)^2/2z} dx' \int_{-h=\frac{-b_0}{2}}^{h=\frac{b_0}{2}} e^{jk(y'-y)^2/2z} dy'$$

$$= \frac{k}{\pi z}\left[F(s_+)-F(s_-)\right]\left[F(t_+)-F(t_-)\right]$$

and

$$t_\pm = \sqrt{\frac{k}{\pi z}}(\pm h - y),\ s'_+ = \sqrt{\frac{k}{\pi z}}\left(-g^-(y')-x\right)$$

and $s'_- = \sqrt{\frac{k}{\pi z}}\left(-g^+(y')-x\right)$

$$s_\pm = \sqrt{\frac{k}{\pi z}}(\pm w - x),\ t'_+ = \sqrt{\frac{k}{\pi z}}\left(-h^-(x')-y\right)$$

and $t'_- = \sqrt{\frac{k}{\pi z}}\left(-h^+(x')-y\right)$

$$F(s) = \int_0^s e^{-j\pi r^2/2} dr$$

= the complex form of the Fresnel integral

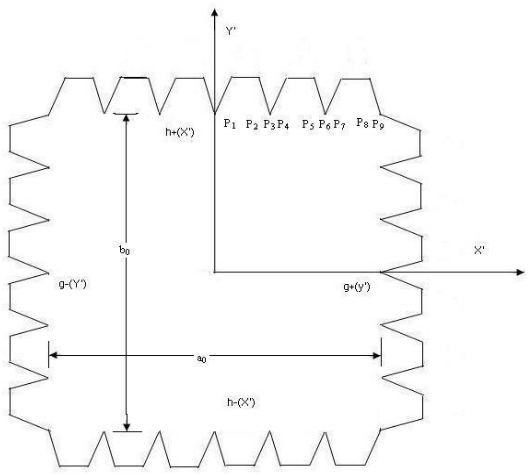

Figure 1. Square aperture reflector with trapezoidal serrations

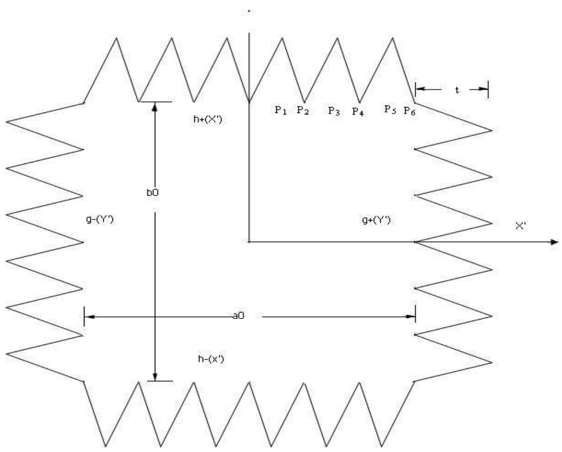

Figure 2. Square aperture reflector with triangular serrations

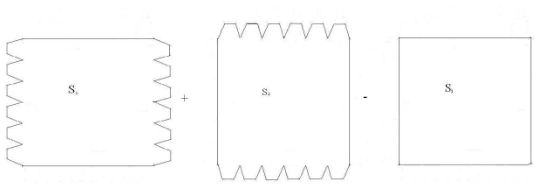

Figure 3: Decomposition of aperture S into three parts S_1, S_2, and S_3

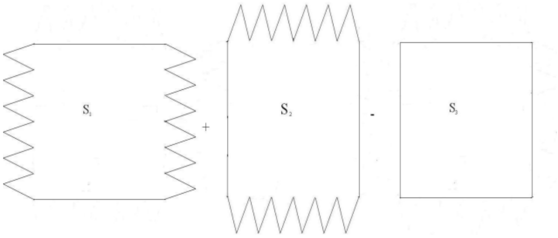

Figure 4: Decomposition of aperture S into three parts S_1, S_2, and S_3

Fourier series of Trapezoidal Serrations

$$g^{+}(y')=\frac{a_0}{2}+\frac{1}{p_9}\{p_1t+2t(p_2-p_1)+t(p_3-p_2)+t(p_4-p_3)$$
$$+2t(p_5-p_4)+t(p_6-p_5)+t(p_7-p_6)$$
$$+2(p_8-p_7)+2(p_8-p_7)\}+\sum_{n=1}^{\infty}a_n\cos(qy')$$

where

$$a_n=\frac{2t}{qp_9}\left\{\frac{1}{p_1}\left[p_1\sin q_1+\frac{1}{q}\cos q_1-\frac{1}{q}\right]\right.$$
$$+\frac{1}{q}(\sin q_2-\sin q_1)\quad-\frac{(p_3\sin q_3-p_2\sin q_2)}{(p_3-p_2)}$$
$$-\frac{1}{(p_3-p_2)}\left[\frac{1}{q}(\cos q_3-\cos q_2)\right]$$
$$+\frac{p_3}{(p_3-p_2)}(\sin q_3-\sin q_2)$$
$$+\frac{(p_4\sin q_4-p_3\sin q_3)}{(p_4-p_3)}$$
$$+\frac{1}{(p_4-p_3)}\left[\frac{1}{q}(\cos q_4-\cos q_3)\right]$$
$$-\frac{p_3(\sin q_4-\sin q_3)}{(p_4-p_3)}$$
$$+\frac{(p_7\sin q_7-p_6\sin q_6)}{(p_7-p_6)}-\frac{(p_6\sin q_6-p_5\sin q_5)}{(p_6-p_5)}$$
$$+(\sin q_5-\sin q_4)\quad+\frac{p_6((\sin q_6-\sin q_5))}{(p_6-p_5)}$$
$$-\frac{(p_6\sin q_6-p_5\sin q_5)}{(p_6-p_5)}$$
$$-\frac{p_6(\sin q_7-\sin q_6)}{(p_7-p_6)}$$
$$-\frac{1}{(p_6-p_5)}\left[\frac{1}{q}(\cos q_6-\cos q_5)\right]$$
$$+\frac{1}{(p_7-p_6)}\left[\frac{1}{q}(\cos q_7-\cos q_6)\right]$$
$$-\frac{(p_9\sin q_9-p_8\sin q_8)}{(p_9-p_8)}+\frac{(\sin q_9-\sin q_8)}{(p_9-p_8)p_9}$$
$$\left.-\frac{1}{(p_9-p_8)}\left[\frac{1}{q}(\cos q_9-\cos q_8)\right]\right]\right\}$$

$$q=\frac{n\pi}{p_9},\ q_i=qp_i$$

Fourier series of Triangular Serrations

$$g^{+}(y')=\frac{a_0}{2}+\frac{1}{p_6}\{p_1t-t(p_2-p_1)+t(p_3-p_2)$$
$$-t(p_4-p_3)+t(p_5-p_4)-t(p_6-p_5)\}$$
$$+\sum_{n=1}^{\infty}a_n\cos(qy')$$

where

$$a_n=\frac{2t}{p_1p_6}\left[\frac{p_1}{q}\sin q_1+\left(\frac{1}{q}\right)^2\cos q_1-\left(\frac{1}{q}\right)^2\right]$$
$$+\frac{-2t}{p_6(p_2-p_1)}\left\{\left(\frac{1}{q}\right)^2(\cos q_2-\cos q_1)-\frac{1}{q}(p_1\sin q_1+p_2\sin q_1)\right\}$$
$$+\frac{2t}{p_6(p_3-p_2)}\left\{\left(\frac{1}{q}\right)^2(\cos q_3-\cos q_2)-\frac{1}{q}(p_2\sin q_3+p_3\sin q_3)\right\}$$
$$+\frac{-2t}{p_6(p_4-p_3)}\left\{\left(\frac{1}{q}\right)^2(\cos q_4-\cos q_3)-\frac{1}{q}(p_3\sin q_3+p_4\sin q_3)\right\}$$
$$+\frac{2t}{p_6(p_5-p_4)}\left\{\left(\frac{1}{q}\right)^2(\cos q_5-\cos q_4)-\frac{1}{q}(p_4\sin q_5+p_5\sin q_5)\right\}$$
$$+\frac{-2t}{p_6(p_6-p_5)}\left\{\left(\frac{1}{q}\right)^2(\cos q_6-\cos q_5)-\frac{1}{q}(p_5\sin q_5+p_6\sin q_5)\right\}$$

$$q = \frac{n\pi}{p_6}, \quad q_i = qp_i$$

RESULTS AND DISCUSSION

A square aperture of dimension $45\lambda \times 45\lambda$ is equipped with trapezoidal and triangular serrations are shown in Figure.1 and Figure.2 respectively. Fresnel field calculations are made at the distance of 64λ along the z-axis. The variation of relative power in dB with transverse in wavelength is furnished in Figure.5 and Figure 6. From Figure.5 and Figure.6, it is observed that by proper selection of width and height factors (Table 1, 2, and 3), lesser ripple and enhanced quiet zone width are observed in trapezoidal serrations than triangular serrations. It is concluded that, trapezoidal type of serrated CATR gives better performance that triangular type of serrated CATR.

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TABLE.1. WIDTH MODULATION FACTORS FOR TRAPEZOIDAL SERRATIONS

CASE	P	P_1/P	P_2/P	P_3/P	P_4/P	P_5/P	P_6/P	P_7/P	P_8/P	P_9/P
1	$(a_0/2)/25$	2.222	5.555	7.777	10	13.333	16.666	18.888	22.222	25
2	$(a_0/2)/22.5$	2	5	7	9	12	15	17	20	22.5
3	$(a_0/2)/20$	1.777	4.444	6.222	8	10.666	13.333	15.111	17.777	20

TABLE.2. WIDTH MODULATION FACTORS FOR TRIANGULAR SERRATIONS

CASE	P	P_1/P	P_2/P	P_3/P	P_4/P	P_5/P	P_6/P
1	$(a_0/2)/25$	4.166	8.333	12.5	16.666	20.833	25
2	$(a_0/2)/22.5$	3.75	7.5	11.25	15	18.75	22.5
3	$(a_0/2)/20$	3.333	6.666	10	12.333	16.666	20

TABLE.3. HEIGHT MODULATION FACTOR FOR TRAPEZOIDAL AND TRIANGULAR SERRATIONS

t
1 λ

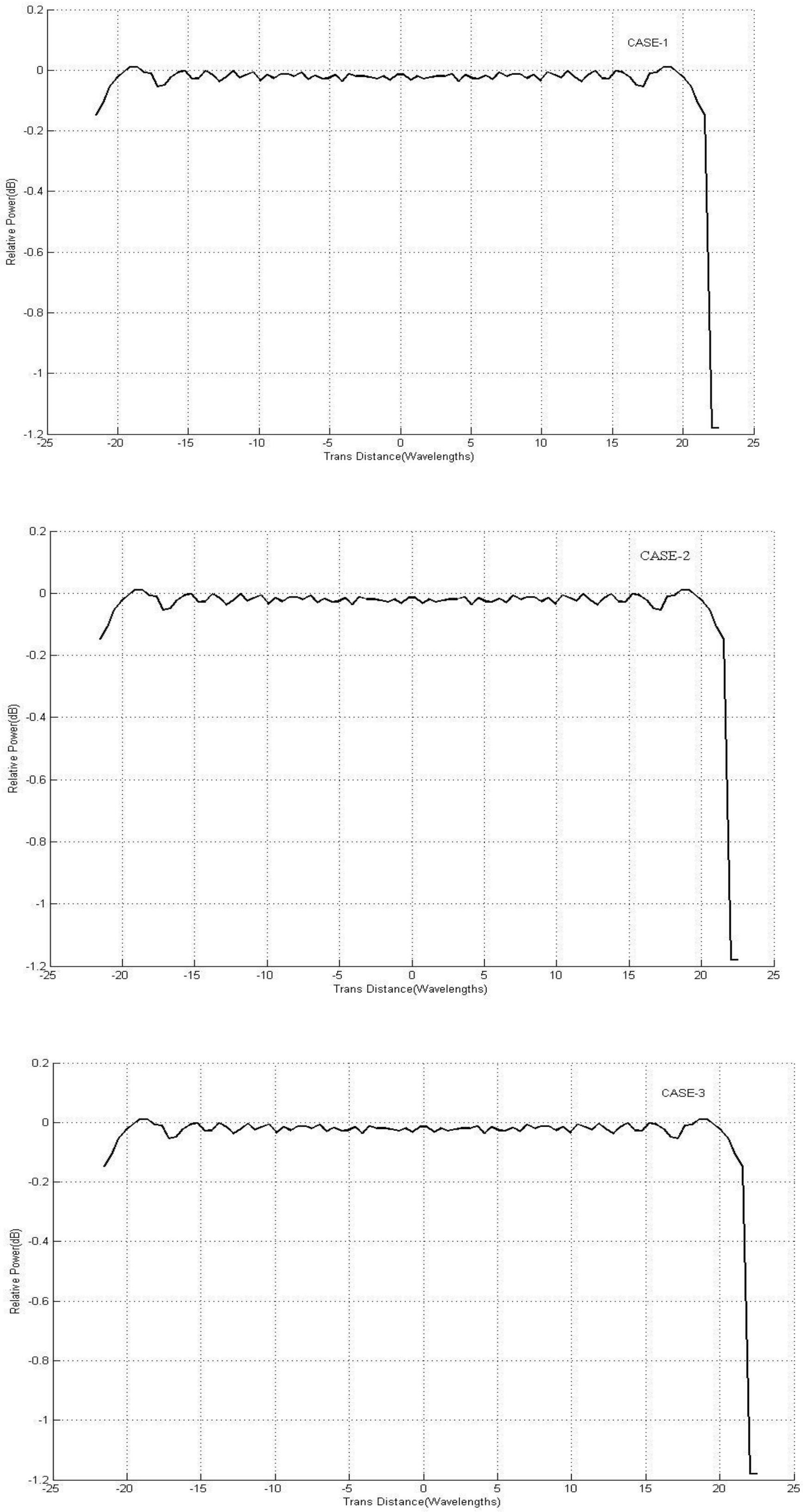

Figure 5: Fresnel zone field of $45\lambda \times 45\lambda$ trapezoidal serrated reflector for cases1, 2&3

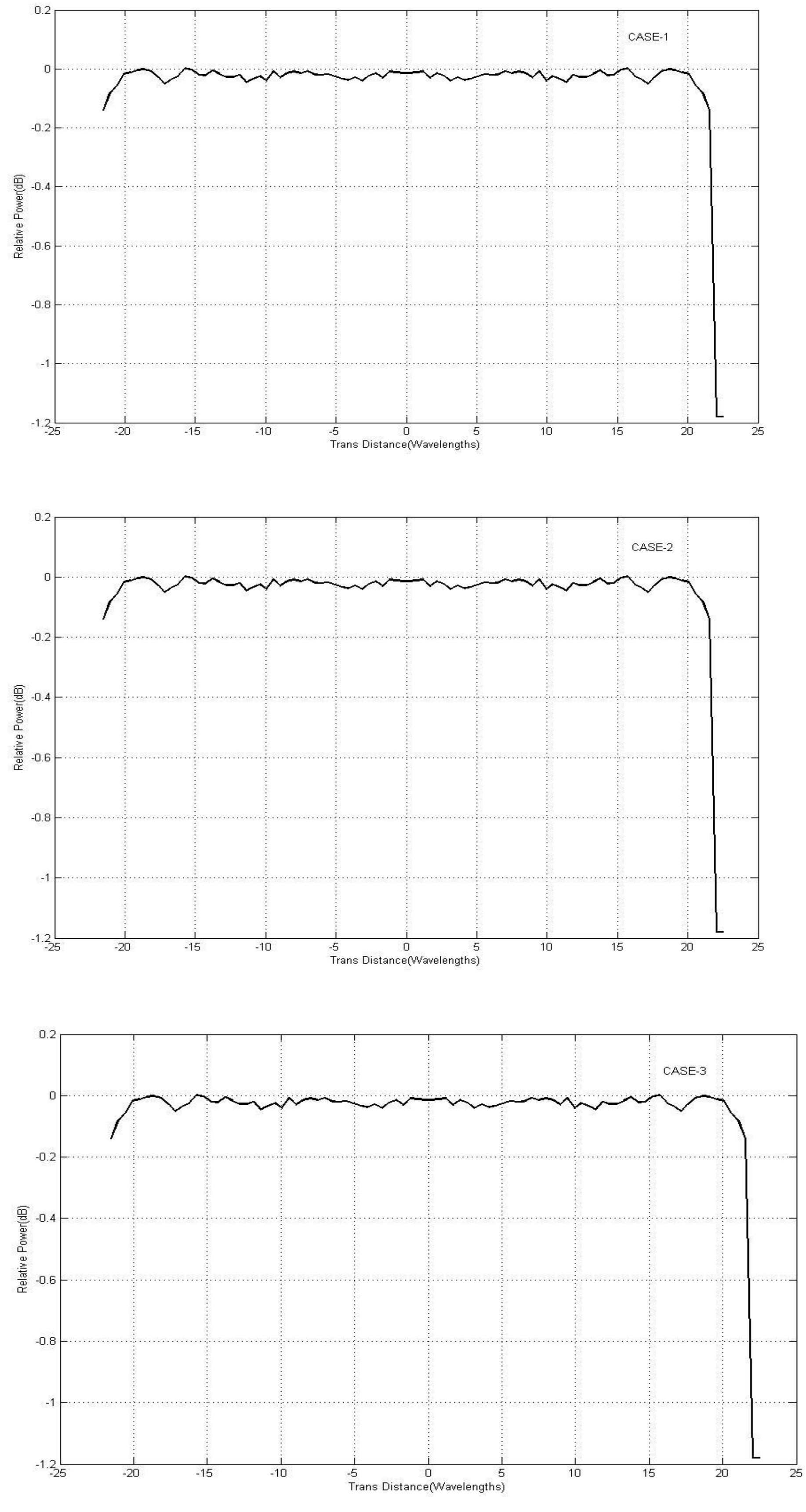

Figure 6: Fresnel zone field of $45\lambda \times 45\lambda$ triangular serrated reflector for cases 1, 2 &3

CONCLUSIONS

A PO technique has been developed in this paper to properly design serrated edge reflectors using diffraction theory. It is based on the fact that the serrated edges must be designed to keep the edge diffracted fields outside the quiet zone. The design of the reflector with serrations is the crux of the CATR. A method to reduce the ripple in the quiet zone is to serrate the rim of the reflector. Triangular serrations are often employed. The computed results reveal that serrations of the trapezoidal gives the least ripples in the quiet zone.

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