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VIABILITY OF SUPER HYBRID MODULATED SERRATIONS FOR IMPROVED PERFORMANCE OF CATRS

Koushik Ghattamaneni[1], Mallepudi Sriram Pavan Kumar[1], T. Venkata Rama Krishna[2],
[1]Student, Electronics and Communication Engineering. VFSTR (Vignan University), India,
powerupram@gmail.com
[2]Professor, Electronics and Communication Engineering. VFSTR (Vignan University), India

ABSTRACT

This paper presented a theoretical and numerical investigation of the Compact Antenna Test Range (CATR) equipped with Super Hybrid Modulated Serrations. The investigation was based on diffraction theory and precisely, the Fresnel diffraction formulation. The use of CATR is to provide uniform illumination within the Fresnel region which is to test antenna. This paper contains usage of serrated edges has been shown to be a beneficiary to control diffraction at the edges of the reflectors. In order to get into the positive effect of serrated edges a less rigorous analysis technique known as Physical Optics (PO) is frequently used. Ripple free and enhanced quiet zone width are observed for specific values of width and height modulation factors. The performance of super serrated reflector is evaluated in order to observe the effects of edge diffraction on the test zone fields

Key words: Fresnel Region, Physical Optics, Quiet Zone, Ripples, Serration.

1. INTRODUCTION

The compact range has become a popular alternative to the conventional far field range for real-time measurement of an antenna radiation patterns or target scattering profile. In a typical compact range configuration, an electromagnetic ray collimator such as a parabolic reflector is used to transform a diverging wave into a plane wave in order to create a far field test environment in the near field of the reflector. Compact range performance is usually specified as the extent and uniformity of the plane wave which illuminates the test item. While the extent of the plane wave is limited, of course, by the size of the ray collimating reflector, the uniformity is limited by diffraction effects. Serrated edge treatment has been employed as a mean of mitigating the effects of edge diffraction associated with compact range reflectors. The purpose of the present work is to develop and apply an analytical tool with the intention of developing an improved serrated edge design. In this note a physical optics analysis is applied to the serrated reflector. Hence PO is a powerful analysis technique from the point of view of numerical efficiency in the case of objects for which specular reflection direction is important, in such problems as radiation pattern of a reflector antenna. In order to evaluate the PO integrals in an efficient manner, several Adaptive Quadrature formulas are employed [1]. It is observed that in the near in angular region, PO accurately predicts the radiated field.

The total electric field intensity of the wave front inside the quiet zone can expressed as

$$\vec{E}_{total} = \vec{E}_A + \vec{E}_B + \vec{E}_C + \vec{E}_D \qquad (1)$$

For a CATR measurement system, there are several ways to reduce the ripples of both phase and magnitude inside the quit zone. This can be done using the following method:

- A: Reduction of the edge diffraction fields by using serrated edges, rolled edges, or R-card along the edges of the reflector;
- B: Reduction of the spillover field from the feed into quiet zone by use of a high performance RF fences;
- C: Employing a CATR reflector with a small surface error;
- D: Reduction of the stray signals from the environment getting into the quit zone by using both a large chamber and high performance microwave absorbers.

Edge diffraction problem creates ripples in the quiet zone. This factor creates the major problems with compare to the remaining factors. In this paper serrated edge treatment is considered to reduce the ripples [2-7].

2. METHODOLOGY

The analysis of the Fresnel field of a square aperture with super hybrid serrations using the method of physical optics (PO). In this paper four different shapes of serrations are used in four sides. This analysis is so general that it can be applied to any serration geometry. This paper presents a gist of the analysis of super hybrid geometry shown in Figure 1. The Fresnel diffraction formula which gives the x-polarized field over an arbitrary plane (z = constant) in the Fresnel region is [4-9]

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

It will be a laborious task to find an analytical expression in a closed form for the Fresnel diffraction pattern of an aperture with these serrated edges. Hence, recourse is taken to decompose the aperture area S into three parts S_1, S_2 and S_3, such that $S=S_1+S_2-S_3$ (Figure 2). A quasi-analytical expression can now be derived for the Fresnel field [2-3]. The super hybrid modulated serrations described by the boundary functions $h^+(x')$ and $g^+(y')$ are expressed as Fourier series of width modulated exponential with rate of rise 'a_i'. The serrated edges are described by the functions $h^+(x'), h^-(x')$, and $g^+(y')$ and $g^-(y')$ and $E_{ax}(x', y') = E_0$ for $(x', y') \in S$. Now, equation (2) can be rearranged as

$$E_x(x,y,z) = \frac{-jE_0}{2} e^{-ikz}\left(I_1 + I_2 - I_3\right) \qquad (3)$$

where

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

$$= \frac{k}{\pi z}\left[F(t_+) - F(t_-)\right]\left[F(s_+') - F(s_-')\right] \qquad (3.a)$$

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

$$= \frac{k}{\pi z}\left[F(s_+) - F(s_-)\right]\left[F(t_+') - F(t_-')\right] \qquad (3.b)$$

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

$$= \frac{k}{\pi z}\left[F(s_+) - F(s_-)\right]\left[F(t_+) - F(t_-)\right] \qquad (3.c)$$

And

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

$$s_-' = \sqrt{\frac{k}{\pi z}}\left(-g^+(y') - x\right), s_\pm = \sqrt{\frac{k}{\pi z}}(\pm w - x),$$

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

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

= the complex form of the Fresnel integral

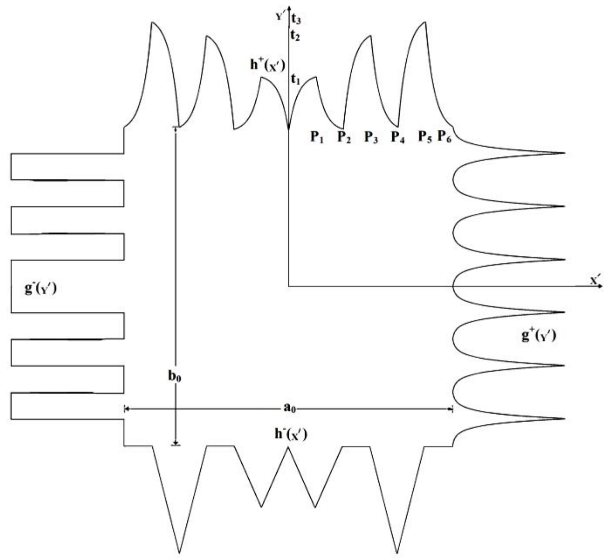


Figure 1: Super Hybrid Serrated CATR

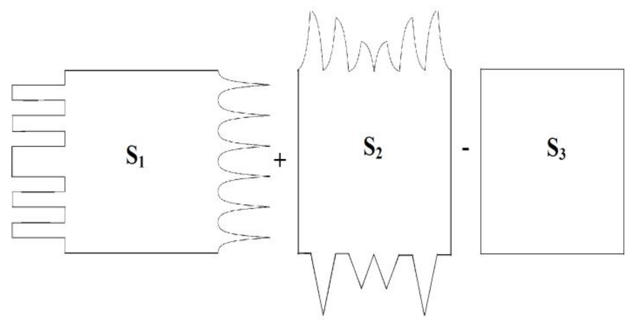


Figure 2: Decomposition of Serrated Aperture

2.1 Fourier series of Width & Height Modulated Exponential Serrations

The serrations described by the boundary functions $h^+(x')$ are expressed as a Fourier series of width and height modulated Exponential function. The Fourier series expansion of $h^+(x')$ is given by

$$h^+(x') = \frac{a_0}{2} + \frac{2t_1}{p_6 a_1}\left[(1+p_1 a_1)e^{-a_1 p_1} - 1 + p_1 a_1\right] + \frac{2t_1}{p_6}\left[1 - e^{-a_2(p_2-p_1)}\right] + \frac{2t_2}{p_6 a_4}\left[1 - e^{-a_4(p_4-p_3)}\right] + \frac{2t_2}{p_6 a_3}\left[a_3(p_3-p_2)\left(1+e^{-a_3(p_3-p_2)}\right) + \left(e^{-a_3(p_3-p_2)} - 1\right)\right] + \frac{2t_3}{p_6 a_5}\left[a_5(p_5-p_4)\left(1+e^{-a_5(p_5-p_4)}\right) + \left(e^{-a_5(p_5-p_4)} - 1\right)\right] + \frac{2t_3}{p_6 a_6}\left[1 - e^{-a_6(p_6-p_5)}\right] + \sum_{n=1}^{\infty} a_n \cos(qx')$$

where

$$a_n=\frac{2t_1}{p_6}\Big[q\sin(q_1)\left(1+e^{-a_1p_1}\right)-b_1\left\{\left(-a_1\cos(q_1)+q\sin(q_1)+a_1\right)e^{-a_1p_1}\right\}\Big]$$
$$+\frac{2t_1b_2e^{a_2p_1}}{p_6}\left[e^{-a_2p_2}\left(-a_2\cos(q_2)+q\sin(q_2)\right)-e^{-a_2p_1}\left(-a_2\cos(q_1)+q\sin(q_1)\right)\right]$$
$$+\frac{2t_2}{p_6}\Bigg[q\left(\sin(q_3)-\sin(q_2)\right)\left(1+e^{-a_3(p_3-p_2)}\right)$$
$$-b_3e^{a_3p_2}\left\{e^{-a_3p_3}\left(-a_3\cos(q_3)+q\sin(q_3)\right)\right.$$
$$\left.-e^{-a_3p_2}\left(-a_3\cos(q_2)+q\sin(q_2)\right)\right\}\Bigg]$$
$$+\frac{2t_2b_4e^{a_4p_3}}{p_6}\Big[e^{-a_4p_4}\left(-a_4\cos(q_4)+q\sin(q_4)\right)$$
$$-e^{-a_4p_3}\left(-a_4\cos(q_3)+q\sin(q_3)\right)\Big]$$
$$+\frac{2t_3}{p_6}\Bigg[q\left(\sin(q_5)-\sin(q_4)\right)\left(1+e^{-a_5(p_5-p_4)}\right)$$
$$-b_5e^{a_5p_4}\left\{e^{-a_5p_5}\left(-a_5\cos(q_5)+q\sin(q_5)\right)\right.$$
$$\left.-e^{-a_5p_4}\left(-a_5\cos(q_4)+q\sin(q_4)\right)\right\}\Bigg]$$
$$+\frac{2t_3b_6e^{a_6p_5}}{p_6}\Big[e^{-a_6p_6}\left(-a_6\cos(q_6)+q\sin(q_6)\right)$$
$$-e^{-a_6p_5}\left(-a_6\cos(q_5)+q\sin(q_5)\right)\Big]$$

2.2 Fourier series of width modulated Triangular On-Off Serrations

The serrations described by the boundary functions $h^-(x')$ are expressed as a Fourier series of width modulated Triangular On-Off function. The Fourier series expansion of $h^-(x')$ is given by

$$h^+(x')=\frac{a_0}{2}+\frac{1}{p_6}\Big[t_1p_1-t_1(p_2-p_1)$$
$$+t_2(p_4-p_3)-(p_5-p_4)t_2\Big]+\sum_{n=1}^{\infty}a_n\cos(qx')$$

where

$$a_n=\frac{2t_1}{p_1p_6}\left[\frac{p_1}{q}\sin q_1+\left(\frac{1}{q}\right)^2\cos q_1-\left(\frac{1}{q}\right)^2\right]$$
$$\frac{2t_1}{p_6(p_2-p_1)}\left\{\left(\frac{1}{q}\right)^2(\cos q_2-\cos q_1)-\frac{1}{q}(p_1\sin q_1+p_2\sin q_1)\right\}$$
$$+\frac{2t_2}{p_6(p_4-p_3)}\left\{\left(\frac{1}{q}\right)^2(\cos q_4-\cos q_3)-\frac{1}{q}(p_3\sin q_4+p_4\sin q_4)\right\}$$
$$\frac{2t_2}{p_6(p_5-p_4)}\left\{\left(\frac{1}{q}\right)^2(\cos q_5-\cos q_4)-\frac{1}{q}(p_5\sin q_4+p_5\sin q_4)\right\}$$

2.3 Fourier series of width & height modulated Concave Serrations

The serrations described by the boundary functions $g^+(y')$ are expressed as a Fourier series of width and height modulated Concave function. The Fourier series expansion of $g^+(y')$ is given by

$$g^+(y')=\frac{a_0}{2}+\frac{2t_1}{p_6}\left[\frac{1}{a_1}\left(1-e^{-a_1p_1}\right)+\frac{1}{a_2}\left(1-e^{-a_2(p_2-p_1)}\right)+\frac{1}{a_3}\left(1-e^{a_3(p_2-p_3)}\right)\right.$$
$$\left.+\frac{1}{a_4}\left(1-e^{-a_4(p_4-p_3)}\right)+\frac{1}{a_5}\left(1-e^{a_5(p_4-p_5)}\right)+\frac{1}{a_6}\left(1-e^{-a_6(p_6-p_5)}\right)\right]+\sum_{n=1}^{\infty}a_n\cos(qy')$$

where

$$a_n=\frac{2t_1}{p_6}\Big[b_1\left\{a_1\cos(q_1)+q\sin(q_1)-a_1e^{-a_1p_1}\right\}+b_2\left\{e^{a_2(p_1-p_2)}\left(-a_2\cos(q_2)+q\sin(q_2)\right)\right.$$
$$\left.+a_2\cos(q_1)-q\sin(q_1)\right\}+b_3\left\{a_3\cos(q_3)+q\sin(q_3)-e^{a_3(p_2-p_3)}\left(a_3\cos(q_2)+q\sin(q_2)\right)\right\}$$
$$+b_4\left\{e^{a_4(p_3-p_4)}\left(-a_4\cos(q_4)+q\sin(q_4)\right)+a_4\cos(q_3)-q\sin(q_3)\right\}+b_5\left\{a_5\cos(q_5)\right.$$
$$\left.+q\sin(q_5)-e^{a_5(p_4-p_5)}\left(a_5\cos(q_4)+q\sin(q_4)\right)\right\}+b_6\left\{e^{a_6(p_5-p_6)}\left(-a_6\cos(q_6)+q\sin(q_6)\right)\right.$$
$$\left.+a_6\cos(q_5)+q\sin(q_5)\right\}\Big]$$

2.4 Fourier series of width modulated Rectangular On-Off Serrations

The serrations described by the boundary functions $g^-(y')$ are expressed as a Fourier series of width modulated Rectangular On-Off function. The Fourier series expansion of $g^-(y')$ is given by

$$g^-(y')=\frac{a_0}{2}+\frac{2t_1}{p_6}\left[p_1-(p_3-p_2)+(p_5-p_4)\right]+\sum_{n=1}^{\infty}a_n\cos(qy')$$

where

$$a_n=\frac{2t_1q}{p_6}\left[\sin(q_1)+\sin(q_3)-\sin(q_2)+\sin(q_5)-\sin(q_4)\right]$$

where

$$q=\frac{n\pi}{p_6};q^i=qp_i;b_i=\frac{1}{a_i^2+q^2}$$

3. SIMULATION RESULTS

The technique presented here is best suited to the analysis of serrated reflectors commonly employed in compact range systems for reduced edge diffraction. A square reflector of aperture dimensions 45λ×45λ is considered to be equipped with super hybrid modulated serrations. The field is computed as a function of transverse distance in wavelengths at a distance of z=64λ from the reflector aperture plane. The Fresnel integral were simulated using Matlab7.0.1. The Fresnel field is computed for the different values of width and height modulation factors indicated in Tables 1 & 2. The relative power in dB vs. transverse distance in wavelengths with the space constant a_i=0.6 for exponential and concave serrations is presented for different cases in Figures 3 to5.

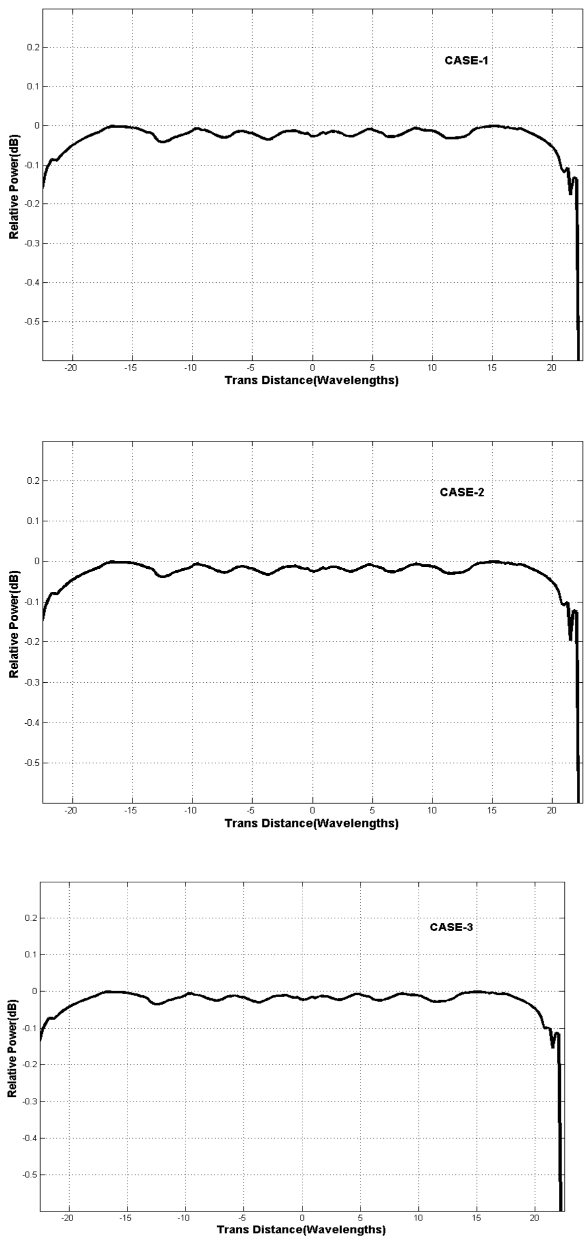
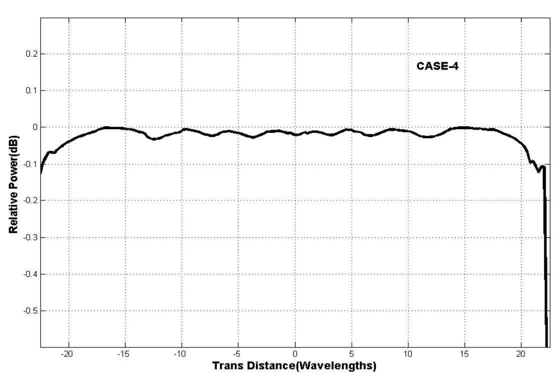


Figure 3: Fresnel zone field for 45λ×45λ super hybrid modulated serrated CATR for cases 1, 2, 3.



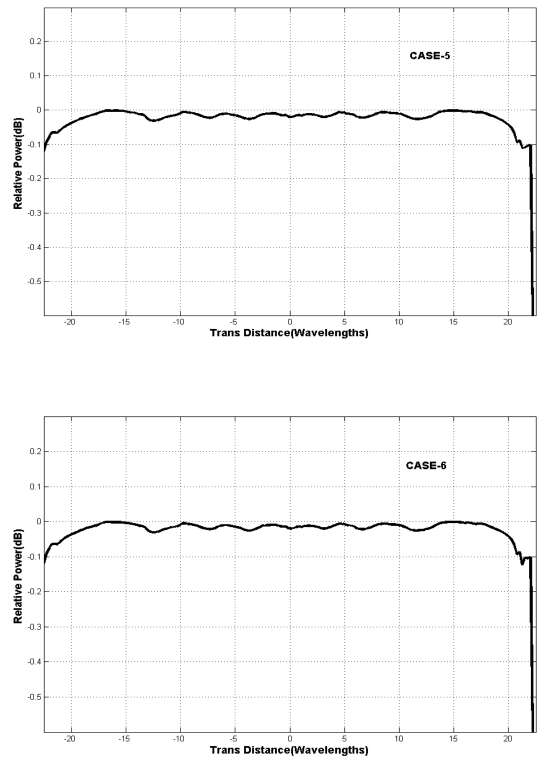
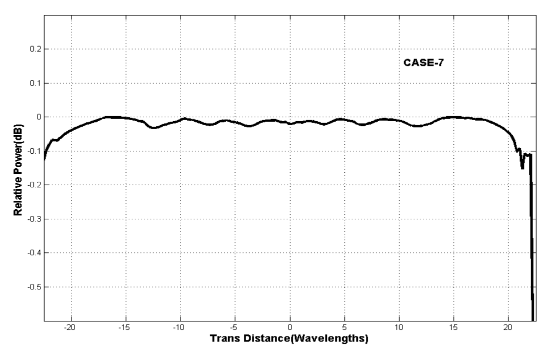
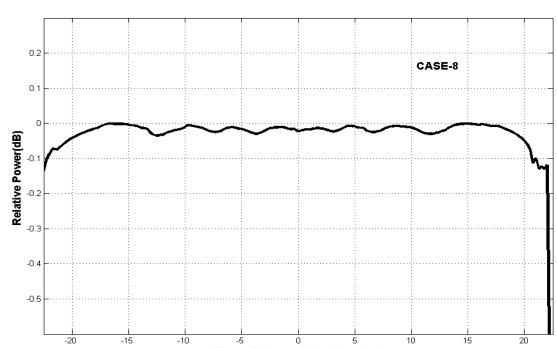


Figure 4: Fresnel zone field for 45λ×45λ super hybrid modulated serrated CATR for cases 4, 5, 6.





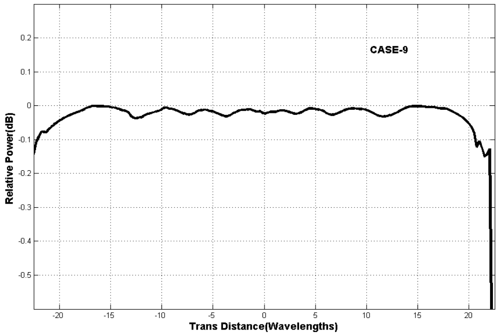


Figure 5: Fresnel zone field for 45λ×45λ super hybrid modulated serrated CATR for cases 7, 8, 9

Table.1: Width modulation factors for super hybrid modulated serrations

CASE	P	P_1/P	P_2/P	P_3/P	P_4/P	P_5/P	P_6/P
1	$(a_0/2)/45$	6	8	20	24	40	45
2	$(a_0/2)/40$	5.3	7.1	17.7	21.3	35.5	40
3	$(a_0/2)/35$	4.6	6.2	15.5	18.6	31.1	35
4	$(a_0/2)/30$	4	5.3	13.3	16	26.6	30
5	$(a_0/2)/27$	3.6	4.8	12	14.4	24	27
6	$(a_0/2)/25$	3.3	4.4	11.1	13.3	22.2	25
7	$(a_0/2)/22.5$	3	4	10	12	20	22.5
8	$(a_0/2)/20$	2.6	3.5	8.8	10.6	17.7	20
9	$(a_0/2)/18$	2.4	3.2	8	9.6	16	18

Table.2: Height modulation factor for super hybrid modulated serrations

T	t_1/t	t_2/t	t_3/t
1λ	0.5	0.75	1

4. CONCLUSION

This paper presented a performance evaluation of the super hybrid modulated serrated edge reflector with rectangular aperture for different values of width and height modulation factors. The quiet zone field of a 45λ×45λ is assessed for different cases as illustrated in Tables 1 & 2. From the graphs, it is observed that less ripple and enhanced quiet zone width are observed in this super hybrid serrated CATR than identical serrated CATRs. Cases 3, 5 & 6 give very superior performance than the remaining cases. It is concluded that, super hybrid modulated CATRs gives better performance.

5. ACKNOWLEDGEMENT

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