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Analysis Of Obstruction Shadowing In Bullington Double Knife Edge Diffraction Loss Computation

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***Abstract*— In this paper, relevant mathematical models and conditions for determination of obstruction shadowing in the Bullington double knife edge diffraction loss computation is presented. The paper introduced the concept of effective single knife edge equivalent clearance height, hse which is always greater or equal to the clearance height of each of the knife edge obstructions in the signal path. Sample numerical Bullington double knife edge diffraction obstructions are used to demonstrate the application of the mathematical models and conditions presented in this paper. The numerical example is for a 20 Km wireless communication link with dual knife edge obstructions h1 =30m and h2 =16 m where h1 is located at 2 km from the transmitter and (d2t) the distance of h2 from the transmitter is varied from 19 Km to 2 Km. The results show that obstruction 1 just overshadows obstruction 2 at d2t =11 Km . At this point, the distance (d12) between the h1 and h2 is 9 Km. For all d2t >11 Km, the obstruction 2 remained overshadowed by obstruction 1. When overshadowing occurs, the single knife edge equivalent clearance height, hs determined using the classical Bullington double knife edge obstructions model is less than the effective single knife edge equivalent clearance height, hse obtained. The corrected effective single knife edge equivalent clearance height ensures that the correct value of diffraction loss is obtained when dual knife edge diffraction loss is computed using the Bullington double knife edge diffraction loss model.**

***Keywords*— Obstruction Shadowing, Bullington Method, Double Knife Edge Obstruction, Diffraction Loss, Percentage Clearance.**

I. INTRODUCTION

Obstructions located along wireless signal path can cause diffraction especially at high frequencies where the wavelengths are very small and comparable to the physical size of the obstructions [1,2,3,4,5]. Such obstructions cause the spreading of the signals around the object which eventually leads to diffraction loss [6,7,8,9]. The method used to compute diffraction loss depends on the nature of the obstruction and also on the number of obstructions located along the signal path. Isolated hills or trees can be modeled as single knife edge diffraction obstruction [10,11,12]. In this case, the clearance height of the single knife edge obstruction and its distance from the transmitter can be used to determine the diffraction parameter and hence the diffraction loss [13,14,15,16].

However, when two knife edge obstructions are identified, then the popular Bullington double knife edge diffraction loss method can be used to determine the single knife edge equivalent clearance height along with its distance from the transmitter [16,17,18,19]. These derived parameter values are then used to determine the effective diffraction parameter and hence the effective diffraction loss caused by the two knife edge obstruction.

The single knife edge equivalent clearance height of Bullington double knife edge obstructions can be determined using geometric construction. However, analytical expressions that can be used to automate the computation are presented in this paper. Furthermore, the analytical expressions are further examined in this paper to determine the shadowing effects that can occur when the two knife edge obstructions are close enough to one another. The analysis in those paper seeks to determine the distance, (d12) between any given two knife edge obstruction (h1 and h2) at which the taller obstructions shadows the other obstruction and hence eliminates its effect on the effective diffraction loss in the link. In this case, the Bullington double knife edge obstructions reduce to a single knife edge obstruction. The relevant mathematical expression and computation procedure are presented in this paper along with sample numerical computations that demonstrated how the ideas can be applied.

II. BULLINGTON DOUBLE KNIFE EDGE DIFFRACTION LOSS

Bullington double knife edge diffraction loss [16,17,18,19] can be explained using the dual knife edge obstructions in Figure 1. In Figure 1, there are two knife edge obstructions with line-of-sight (LOS) clearance heights $h_1$and h_2, where h_1 is at a distance of $d_{1t}$from the transmitter and a distance of $d_{1r}$from the reciever. Likewise, $h_2$is at a distance of d_{2t} from the transmitter , T and a distance of $d_{2r}$from the receive, R. The height of the single knife edge equivalent obstruction for the obstructions h_1 and h_2 is denoted as h_s and its distance from the transmitter , T is denoted as d_{st}, where [16,17,18,19];

$$d_{st} = \left(\frac{(h_2)d_{1t}}{[(h_2)d_{1t}]+[(h_1)d_{2r}]}\right)d \qquad (1)$$

$$h_s = \frac{(h_1)(h_2)d}{[(h_2)d_{1t}]+[(h_1)d_{2r}]} \qquad (2)$$

$$d_{sr} = d - d_{st} \qquad (3)$$

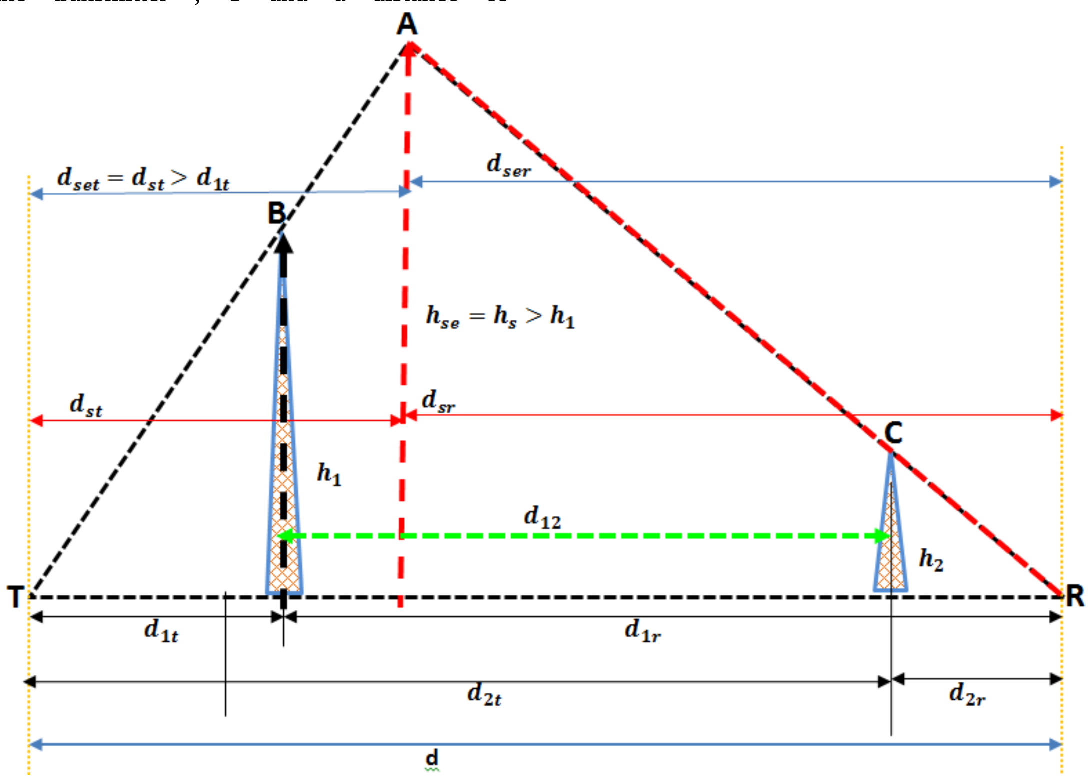

Figure 1 The dual knife edge obstructions

In the classical Bullington double knife edge computation, at any point in time, the single knife edge equivalent height, $h_s$is expected to be greater than any of $h_1$and h_2, that is; $h_s \geq h_1$ and $h_s \geq h_2$. Let d_{12}be the distance between the obstruction 1 and obstruction 2, hence;

$$d = d_{1t} + d_{12} \quad + d_{2r} \qquad (3)$$

$$d_{2r} = d - d_{1t} - d_{12} \qquad (4)$$

$$d_{1t} = d - d_{2r} - d_{12} \qquad (5)$$

If the two obstructions are close, there is a value of d_{12} at which the single knife edge equivalent height will tend to be less or equall to any of $h_1$or h_2 or both. In that case, one obstruction has shaded and hence eliminated the effect of the other obstruction, as shown in Figure 2. However, as stated earlier, the single knife edge equivalent height is greater than any of $h_1$and h_2. Hence, the concept of effective single knife edge equivalent height, h_{se} is introduced in this paper for the Bullington double knife edge computation. In this case, while by the classical Bullington double knife edge single knife edge equivalent height of Eq 2, h_s can be less that $h_1$or h_2, but the effective single knife edge equivalent height,h_{se} inroduced in this paper will always be greater or equall to the maxmum of $h_1$and h_2 . Specifically, if $h_2 > h_1$, when $d_{12} = \left[\left(\frac{h_2}{h_1}\right) - 1\right] d_{1t}$ then $h_s = h_2$. However, when $d_{12} > \left[\left(\frac{h_2}{h_1}\right) - 1\right] d_{1t}$ then $h_s < h_2$. So, the effective formular for computing the effective single knife edge bequivalent hieght , h_{se} is given as

$$h_{se} = maximum\ \left(h_1,\ h_2,\ \frac{(h_1)(h_2)d}{[(h_2)d_{1t}]+[(h_1)d_{2r}]}\right) = maximum\ (h_1,\ h_2,\ h_s) \qquad (6)$$

The distance of h_{se} from the transmiter is denoted as d_{set} and the distance of h_{se} from the receiver is denoted as d_{ser} where ;

$$d_{set} = \begin{Bmatrix} d_{st}\ \ if\ maximum\ (h_1,\ h_2,\ h_s) = h_s \\ d_{1t}\ \ if\ maximum\ (h_1,\ h_2,\ h_s) = h_1 \\ d_{2t}\ \ if\ maximum\ (h_1,\ h_2,\ h_s) = h_2 \end{Bmatrix} \qquad (7)$$

$$d_{ser} = d - d_{set} \qquad (8)$$

Esentially, the value of h_{se}depends on the values of h_1 ,h_2, d_{1t}andd_{12}. The situation where $h_{se} \geq h_s$occurs when one obstruction shadows the other obstruction. This can happen when the two obstructions are sufficiently close to one another. So, for any given $h_1$and h_2 , the distnce apart, d_{12}at which one obstruction shadows the other obstruction can be determined. Now, if $h_1 > h_2$ then, h_s can be expressed in terms of $d_{2r}$and d_{12} as follows;

$$h_s = \frac{(h_1)d}{d - d_{2r} - d_{12} + \left[\left(\frac{h_1}{h_2}\right)d_{2r}\right]} = \frac{(h_1)d}{d + \left[\left(\frac{h_1}{h_2}\right) - 1\right]d_{2r} - d_{12}} \qquad (9)$$

In this case, the $h_{se} \geq h_s$ will occur when ;

$$d \leq d + \left[\left(\frac{h_1}{h_2}\right) - 1\right] d_{2r} - d_{12} \qquad (10)$$

This gives;

$$d_{12} \leq \left[\left(\frac{h_1}{h_2}\right) - 1\right] d_{2r} \qquad (11)$$

Figure 2 shows the case when $d_{12} = \left[\left(\frac{h_1}{h_2}\right) - 1\right] d_{2r}$, hence $h_{se} = h_s$. On the other hand, Figure 3 shows the case when $d_{12} < \left[\left(\frac{h_1}{h_2}\right) - 1\right] d_{2r}$; hence $h_{se} \geq h_s$.

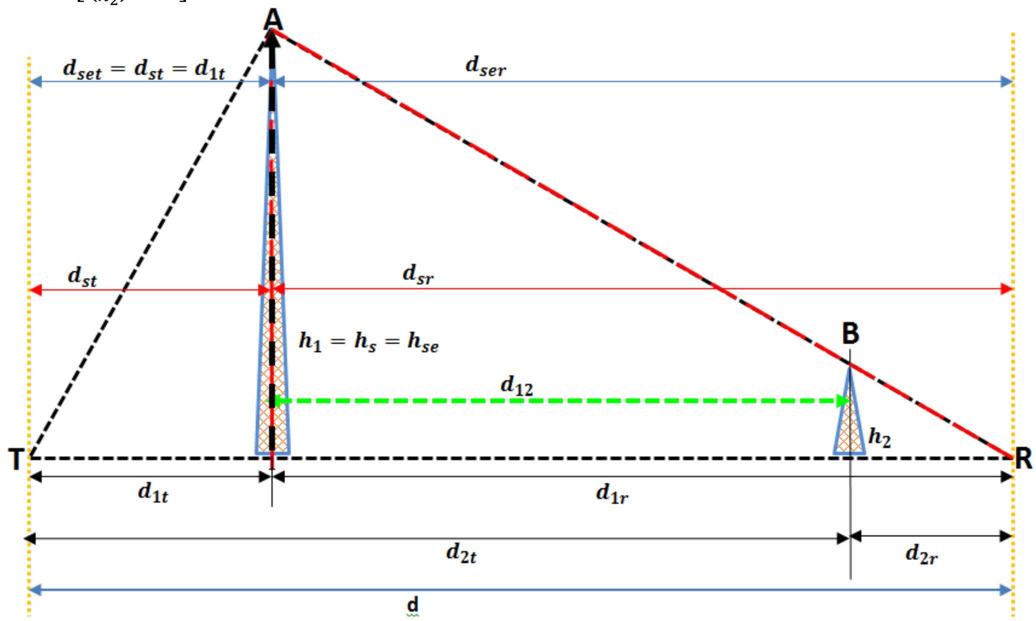

Figure 2 Obstruction $h_1$just shadows and hence eleiminates the effect of obstruction h_2; $h_{se} = h_s$

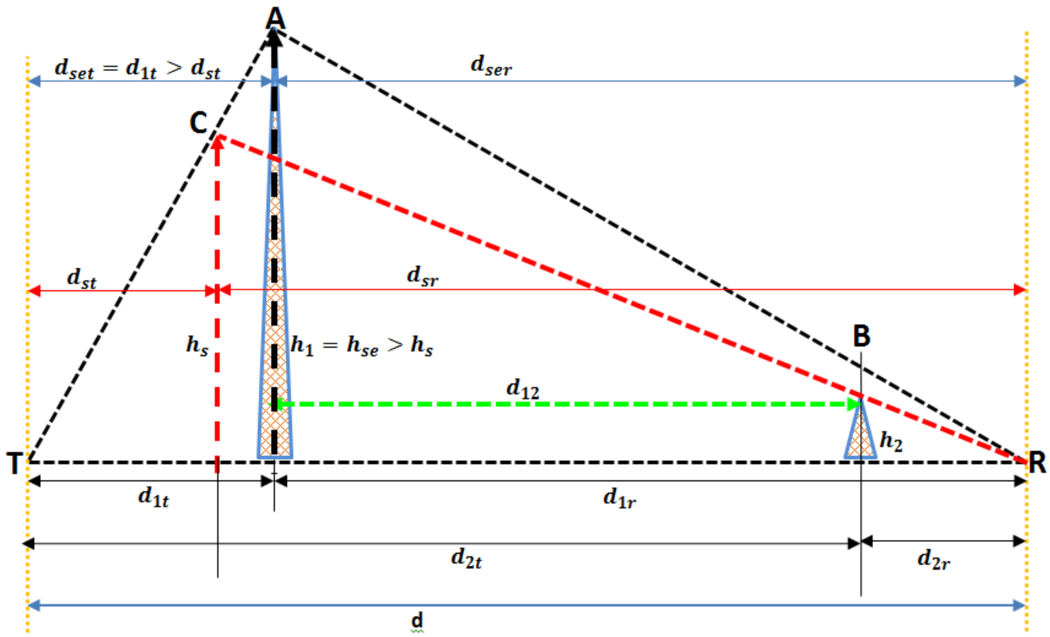

Figure 3 Obstruction $h_1$excessively shadows and hence eleiminates the effect of obstruction h_2; $h_{se} \geq h_s$

From Eq 11 it can be seen that if $h_1 = 1.5h_2$ and $d_{2r} > 5\ m$, then, $d_{12} = (1.5 - 1)5 = 2.5$ m. That means, when the two obstructions are 2.5 m apart, obstruction h_1 will overshadow obstruction h_2. However, if $h_2 = h_1$, then d_{12} must be zero before one obstruction can overshadow the other one. This can be explained from Eq 9 which when $h_2 = h_1$ it gives;

$$h_s = \frac{(h_1)d}{d + \left[\left(\frac{h_1}{h_1}\right) - 1\right] d_{1t} - d_{12}} = \frac{(h_1)d}{d - d_{12}} \qquad (12)$$

Similarly , if $h_2 > h_1$ then, h_s can be expressed in terms of $d_{1t}$and d_{12} as follows;

$$h_s = \frac{(h_2)d}{\left[\left(\frac{h_2}{h_1}\right) d_{1t}\right] + d - d_{1t} - d_{12}} = \frac{(h_2)d}{d + \left[\left(\frac{h_2}{h_1}\right) - 1\right] d_{1t} - d_{12}} \qquad (13)$$

In this case, the h_{smin} will occur when ;

$$d = d + \left[\left(\frac{h_2}{h_1}\right) - 1\right] d_{1t} - d_{12} \qquad (14)$$

This gives;

$$d_{12} = \left[\left(\frac{h_2}{h_1}\right) - 1\right] d_{1t} \qquad (15)$$

Once the effective obstruction height, h_{se} is determined, the knife edge diffration loss can be computed using the expression,

$$G(dB) = 6.9 + 20\text{Log}\left[\left(\sqrt{(V-0.1)^2+1}\right) + V - 0.1\right] \quad (16)$$

Where V is the diffraction parameter, and it is given as follows;

$$V \quad = h_{se}\left(\sqrt{\frac{2((d_{set})+(d_{ser}))}{ʎ(d_{set})(d_{ser})}}\right) \quad (17)$$

The wavelength λ is given as;

$$ʎ = \frac{c}{f} \quad (18)$$

where f is frequency in Hz and, c is = $3\text{x}10^3 m/s$).

III. SIMULATION, RESULTS AND DISCUSSION

The simulation is based on the mathematical expressions presented in Eq 1 to 18. First, a dual knife edge obstructions with d =20 Km, d1t = 2 Km, d1r = 18 Km, h1 = 30 m, h2 = 15 m is simulated with varying d2t from d2t =19 Km to d2t =2 Km and the results are presented in Table 1 and Figure 4. The results show that obstruction 1 just overshadows obstruction 2 at d2t =11 Km and d12 = 9 Km. For all d2t >11 Km, the obstruction 2 remained overshadowed by obstruction 1. Table 1 and Figure 4 show that at d12 = [h1/h2-1]d2r the overshadowing effect starts , which confirms the condition stated in Eq 11.

The results for the diffraction parameter, V and the knife edge diffraction loss, G(dB) in Table 2 and Figure 4 show that the both V and G(dB) decreases as d2t decreases. This is because both hs and hse decreases with d2t. When overshadowing take place at d2t =11, Vhe =Vhse and G(dB)hs =G(dB)hse. However, as d2t continue to decrease below 11 Km, the Vhs and G(dB)hs continue to decrease but the Vhse and G(dB)hse remain constant at their values at d2t =11.

This paper has been able to provide relevant mathematical models and conditions for analyzing the overshadowing effect that can occur in dual single knife edge diffraction loss.

Table 1 The results of the simulation with the following data: d =20 Km, d1t = 2 Km, d1r = 18 Km, h1 = 30 m, h2 = 15 m and with varying d2t from d2t =19 Km to d2t =2 Km

d1t (Km)	d2t (Km)	dst (Km)	dset (Km)	d12 (Km)	[h1/h2-1]d2r (Km)	hs (m)	hse (m)	Clearance heights	Distance from the transmitter	Staus
2	19	10.0	10.0	17	1	150.0	150.0	hes= hs> h1	dest =dst>d1t	no shadowing
2	18	6.7	6.7	16	2	100.0	100.0	hes= hs> h1	dest =dst>d1t	no shadowing
2	17	5.0	5.0	15	3	75.0	75.0	hes= hs> h1	dest =dst>d1t	no shadowing
2	16	4.0	4.0	14	4	60.0	60.0	hes= hs> h1	dest =dst>d1t	no shadowing
2	15	3.3	3.3	13	5	50.0	50.0	hes= hs> h1	dest =dst>d1t	no shadowing
2	14	2.9	2.9	12	6	42.9	42.9	hes= hs> h1	dest =dst>d1t	no shadowing
2	13	2.5	2.5	11	7	37.5	37.5	hes= hs> h1	dest =dst>d1t	no shadowing
2	12	2.2	2.2	10	8	33.3	33.3	hes= hs> h1	dest =dst>d1t	no shadowing
2	11	2.0	2.0	9	9	30.0	30.0	hes= hs = h1	dest =dst=d1t	h2 is shadowed by h12
2	10	1.8	2.0	8	10	27.3	30.0	hes = h1>hs	dest =d1t>dst	h2 is shadowed by h12
2	9	1.7	2.0	7	11	25.0	30.0	hes = h1>hs	dest =d1t>dst	h2 is shadowed by h12
2	8	1.5	2.0	6	12	23.1	30.0	hes = h1>hs	dest =d1t>dst	h2 is shadowed by h12
2	7	1.4	2.0	5	13	21.4	30.0	hes = h1>hs	dest =d1t>dst	h2 is shadowed by h12
2	6	1.3	2.0	4	14	20.0	30.0	hes = h1>hs	dest =d1t>dst	h2 is shadowed by h12
2	5	1.3	2.0	3	15	18.8	30.0	hes = h1>hs	dest =d1t>dst	h2 is shadowed by h12
2	4	1.2	2.0	2	16	17.6	30.0	hes = h1>hs	dest =d1t>dst	h2 is shadowed by h12
2	3	1.1	2.0	1	17	16.7	30.0	hes = h1>hs	dest =d1t>dst	h2 is shadowed by h12
2	2	1.1	2.0	0	18	15.8	30.0	hes = h1>hs	dest =d1t>dst	h2 is shadowed by h12

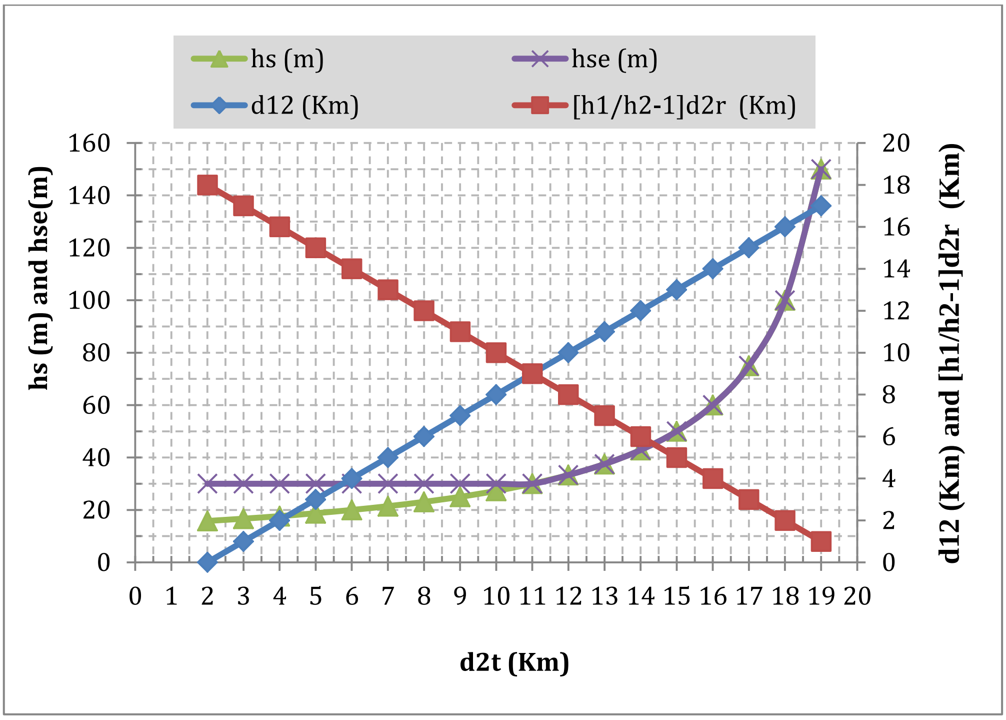

Figure 4 Clearance heights versus distance of obstruction 1 from the transmitter

Table 2 The diffraction parameter and the knife edge diffraction loss for the simulation in Table 1

dt2	Vhs	G(dB) hs	V hse	G(dB) hse
19	13.4	35.4	13.4	35.4
18	9.5	32.4	9.5	32.4
17	7.7	30.6	7.7	30.6
16	6.7	29.4	6.7	29.4
15	6	28.4	6	28.4
14	5.5	27.6	5.5	27.6
13	5.1	26.9	5.1	26.9
12	4.7	26.4	4.7	26.4
11	4.5	25.8	4.5	25.8
10	4.2	25.4	4.5	25.8
9	4	25	4.5	25.8
8	3.9	24.6	4.5	25.8
7	3.7	24.3	4.5	25.8
6	3.6	23.9	4.5	25.8
5	3.5	23.6	4.5	25.8
4	3.4	23.4	4.5	25.8
3	3.3	23.1	4.5	25.8
2	3.2	22.9	4.5	25.8

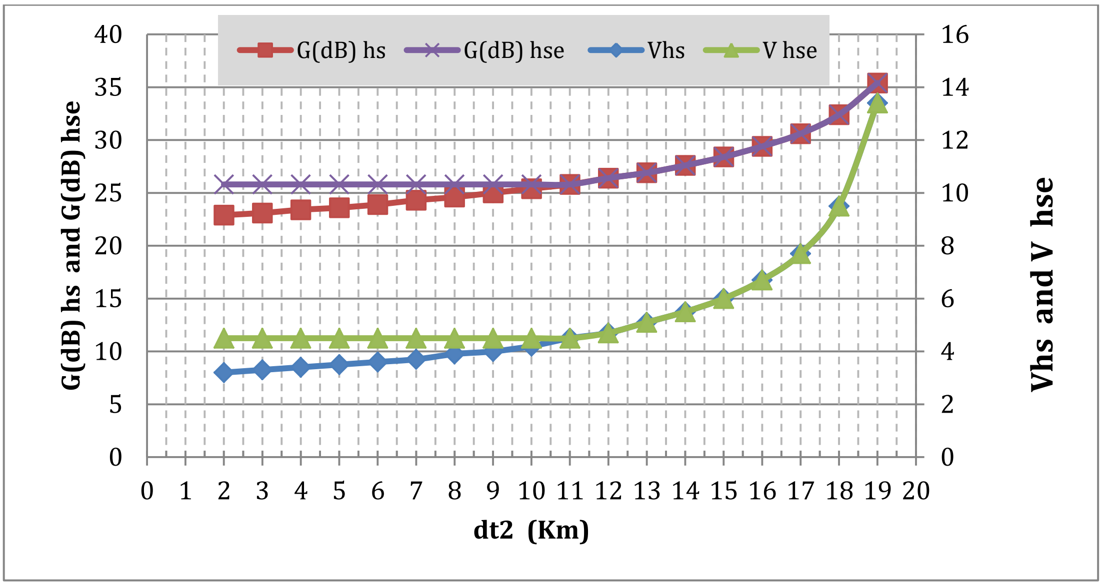

Figure 5 The diffraction parameter and the knife edge diffraction loss versus dt2 for the simulation in Table 1

IV. CONCLUSION

The Bullington double knife edge diffraction obstruction is presented and the shadowing effect that can occur when the obstructions are sufficiently close to each other is studied. Relevant mathematical expressions and conditions for overshadowing to occur are derived. Sample numerical Bullington double knife edge diffraction obstructions are used to demonstrate the application of the mathematical models and conditions presented in this paper. The ideas presented in this paper is useful for automated computation of Bullington double knife edge diffraction loss as it provides the requisite analytical models and conditions that can be used to automate the determination of overshadowing effect and the account for it in the Bullington double knife edge diffraction loss computations.

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