EXCESS LOSS MEASUREMENT ON ISOLATED SINGLE TREE CANOPIES AT MICROWAVE FREQUENCIES

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ABSTRACT

Experimental investigations have been carried out on five (5) different isolated tree species in order to measure the propagation loss on each tree when a CW (at 3.2-3.9 and 4.9-5.9 GHz) is propagated through them. The tree species are cedar (Cedrus Deodara), silver maple (Acer Saccharinum), horse chestnut (Aesculus Hippocastanum), common whitebeam (Sorbus aria) and common hazel (Corylus Avellana). In all of these experiments, canopy geometry was adopted and all the trees were in in-leaf state. Results of the investigations have revealed that the presence of isolated single trees along a radio path can affect signal propagation leading to loss in signal strength (attenuation). For example, propagation loss of about 30 dB in excess of free space was measured on one of the trees. This is quite enormous and can reduce communication coverage range.

Keywords: Propagation loss, experimental investigation, free space, excess loss.

INTRODUCTION

The natural occurrence of trees along radio path in outdoor propagation is inevitable especially in rural and semi-urban areas. Their presence either as a single tree or group of trees has significant effects on radio waves especially at microwave frequency. In addition, trees may also grow over time in an area initially free of obstruction thereby leading to shadowing effect. Trees may block the line of sight (LOS) path, and also scatter the radiated wave, forcing it to follow different paths (multipath) to the receiver. Removing all trees obstructing radio propagation is an impractical solution, but a pragmatic approach aimed at characterising their effects is desirable. So, understanding the features of the physical environment in which radio waves propagate is critical to proper modelling of a reliable communication channel. In order to realise this, the effects of trees must be taken into consideration at RF planning stage for outdoor propagation.

This, has in the recent past, attracted a number of theoretical studies and measurement campaigns aimed at estimating the effects of trees on radio wave propagation. Summary of these are as presented in our earlier paper Adegoke et.al (2015).

MEASUREMENT DETAILS

Experimental investigation was carried out on five different isolated tree species; cedar (*Cedrus Deodara),* silver maple (*Acer Saccharinum*), horse chestnut (*Aesculus Hippocastanum*), common whitebeam (*Sorbus aria*) and common hazel (*Corylus Avellana*). The objective of this investigation is to determine the propagation loss on each of the trees when a CW (at 3.2-3.9 and 4.9-5.9 GHz) is propagated through them. The experimental site is Leicester, in the United Kingdom. As expected, the trees are of different geometries and their basic dimensions are as listed in Table 1.0. The link geometry is as shown in Figure 1.0.

S/N	Tree Names	Height (m)	Trunk Diameter (cm)	Canopy Diameter (m)	Leaf shape	Leaf Size
1	Cedar (*Cedrus Deodara*)	13	(i)	6	Needles	(ii)
2	Horse chestnut (*Aesculus Hippocastanum*)	6.4	35	5.5	Palmate	30 X 10cm
3	Silver maple (*Acer Saccharinum*)	12	40	6	Lobed	8 X 8cm
4	Common whitebeam (*Sorbus aria*)	14	65	9	Pinnate	14 X 7cm
5	Common hazel (*Corylus Avellana*)	10	30	5.2	Pinnate	10 X 6cm

Table 1.0 Parameter table for the isolated trees

(i) No accessibility since trunk was covered by branches and leaves.
(ii) Needle size, too small to measure.

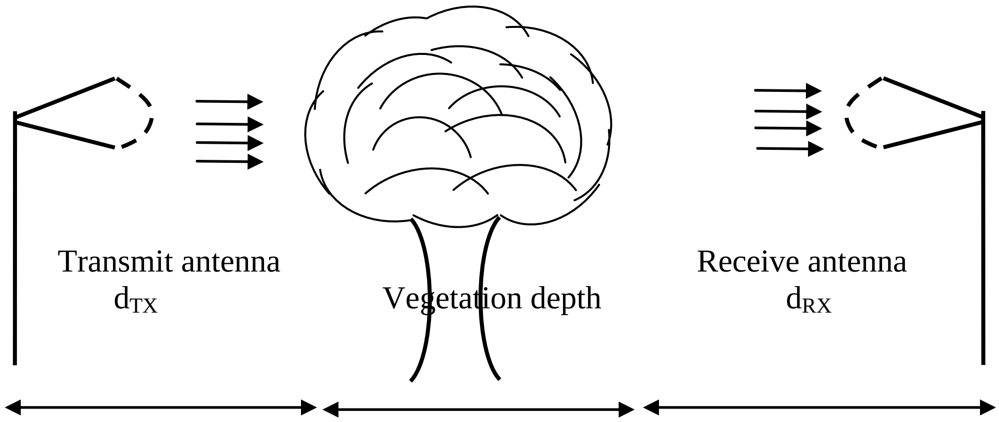

Figure 1.0 Link configuration for isolated tree measurement

In the measurement setup, the separation distance between transmit and receive antenna was maintained at 15 m while alignment of both transmit and receive antenna was established in each case. Both antenna heights were maintained at 2.8 m (canopy level) for all the trees except “common whitebeam” where the antennas were adjusted to 4.5 m height to match up with canopy level. The antenna orientation adopted throughout the experimentation is vertical polarisation. The environmental conditions during the measurement were nearly the same for all the trees. Although, occasional wind was noticed in some instances, its effect on RSS is about ±3 dBm. There were no spurious reflections by either pedestrian or cyclists since none of the trees fall within pathways or cyclist lane. In order to determine the excess loss due to only trees, a separate measurement was initially conducted in a grassy open field so as to calculate the free space loss. Results are as shown in Figure 2.0. Then using extraction process, Figure 2.0 was normally subtracted from the results of measurement taken in the presence of trees.

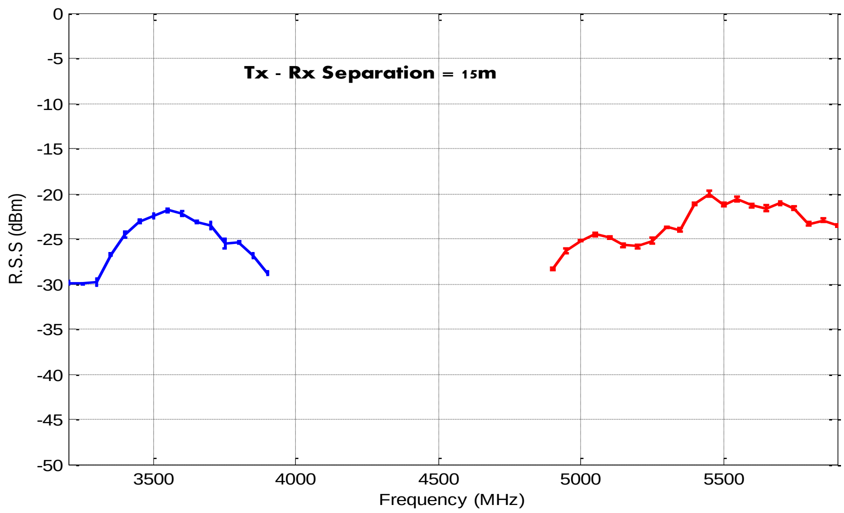

Figure 2.0 Free space R.S.S versus frequency for a fixed distance at 3.5 and 5.4 GHz bands.

RESULTS, ANALYSIS AND DISCUSSION

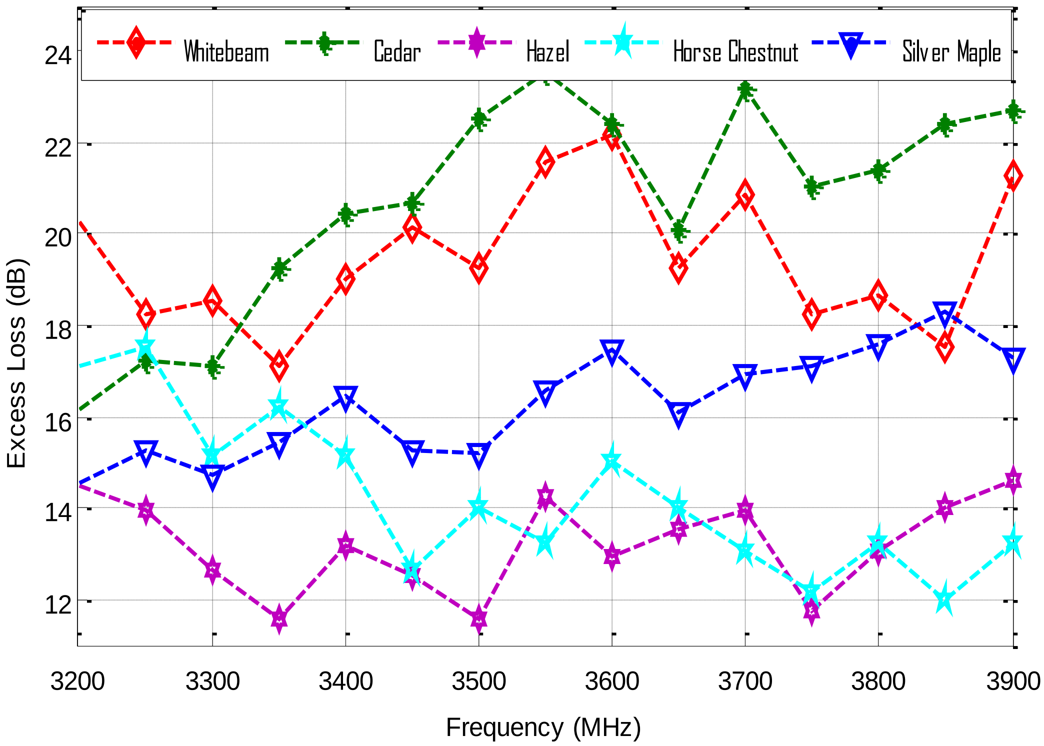

Figure 3a. Excess Loss across different trees at 3.2 – 3.9 GHz

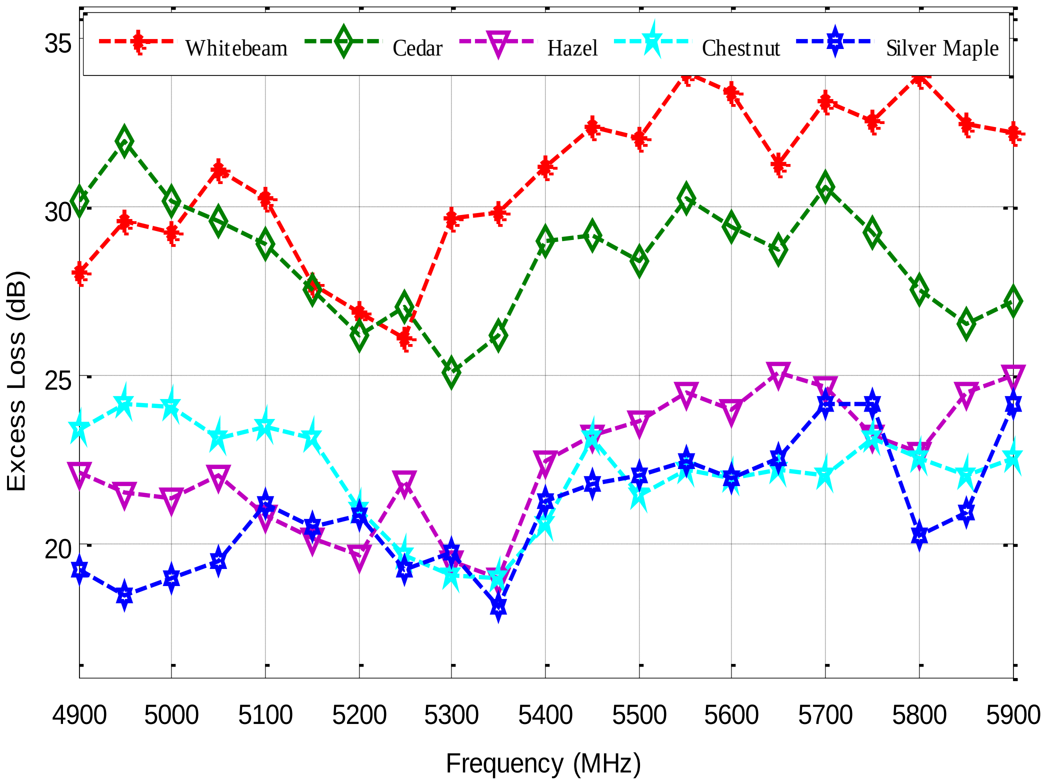

Figure 3b. Excess Loss across different trees at 4.9 – 5.9 GHz

	Mean attenuation values (dB)		Canopy thickness (m)
	3.2 - 3.9 GHz	**4.9 - 5.9 GHz**	
Common whitebeam	**20 ± 2.1**	**30 ± 2.3**	**9**
Cedar	**21± 1.8**	**29 ± 1.6**	**6.5**
Silver maple	**16 ± 1.2**	**21 ± 1.4**	**6**
Horse chestnut	**14 ± 1.8**	**22 ± 2.0**	**5.5**
Common hazel	**13 ± 1.4**	**22 ± 1.7**	**5.2**

Table 2.0. Measured mean excess loss and their standard deviation values.

Figure 3 (a & b) shows attenuation of transmitted signals by various trees. Variation in the measured attenuation by an individual tree with frequency is also seen. The key components under investigation here are frequency and canopy thickness. Common whitebeam tree gave the highest attenuation values of 20 dB and 30 dB respectively at 3.5 GHz and 5.4 GHz bands. In the parameter table (Table 1.0), this tree has the highest canopy thickness of 9 m. This is the possible reason for recording such a high loss across it coupled with its leaf size of 14 x 7 cm. With this thickness, signals will have to travel more in the lossy canopy elements causing absorption and more depolarisation. With a canopy depth of 6.5 m, the cedar tree measures 21 dB and 29 dB at 3.5 GHz and 5.4 GHz bands respectively. Also, a large density of foliage is seen in the canopy of this tree (cedar) which is an additional contributing factor to the excess loss. This coniferous tree has a tightly-packed needle-shaped leaves resulting in a small gap fraction. This (gap fraction) is the portion of tree canopies that is unobstructed by tree elements e.g leaves, twigs and branches. Hence, high obscuration and shadowing causing full blockage to the line of sight (LOS) path. The canopy thickness of remaining trees is nearly the same (5-6 m) and all gave attenuation values within same range. Due to the measurement geometry adopted in this experimentation, received power at the observation point is the direct component which has been strongly attenuated by the canopy elements. So, the main propagation mode here is by direct component with less scattering. Another prominent feature on the plot (Figure 3a & b) is that as the frequency transit from 3.5 GHz to 5.4 GHz bands, increase in excess loss is recorded. This can possibly be explained using the size of signal's wavelength at 5.4 GHz band which is smaller than at 3.5 GHz band and would suffer more depolarisation and scattering when propagated through tree's canopy. Thus, a reason for recording higher losses at 5.4 GHz band.

Similar observations were reported by Joshi et al. (2008) where an experimental investigation was carried out on seven tropical trees at millimetre frequency (35 GHz). Each of the trees presents different attenuation values. Points of maximum and minimum losses were observed in their results. In all, the ficus tree offered the highest propagation loss of 28.4 dB which is due to its high canopy thickness and densely distributed branches. An empirical relationship predicting the insertion loss (for single trees) is given by this author as

$$L = 0.4f^{0.18}d^{0.59} \qquad 1.0$$

Where L is the propagation loss in decibels, f is the frequency in MHz and d is the vegetation depth in metres.

This prediction model is however, considered inappropriate for estimating excess loss in single trees due to a slower dependence of excess loss on the canopy thickness. Investigation in our research work reveals that increasing the canopy thickness of a single tree would result in a corresponding loss increase of the same or higher factor. This is further dependent on the density of the canopy elements. Also, limit points do exist for canopy thickness in single trees. For example, applying Equation 1.0 to a depth of 50 m would give inaccurate result, since a depth of 50 m falls into the category of short woodland which has a different structural arrangement from single isolated trees. The limit point for isolated tree canopy thickness has been considered in our work in the formulation of loss prediction model involving isolated trees.

Kajiwara (2000) measured mean attenuation values of 18 dB and 6.3 dB on foliated plane trees and gingko trees at centimetre wavelength (29.5 GHz). The plane tree has leaf dimension of 20 x 23 cm that almost make the tree opaque to radiated wave. Thus, a possible reason for high propagation loss. The gingko tree has a smaller leaf dimension (6 x 4 cm) with high visibility through the canopy. The author went further by adding more branches to increase canopy thickness. This resulted in higher attenuation as the canopy thickness increased. This, therefore corroborates the justification made above for recording high propagation loss on Whitebeam tree due to higher canopy thickness. Similar trends of depth and frequency dependent loss were reported in Durgin et al. (1998) and Karlsson et al. (2001). Dalley et al. (1999) measured losses between 16.2 dB and 25.3 dB on an isolated horse chestnut tree at cm wavelength (3.5 and 26.5 GHz respectively) taking a 90% confidence limit. An additional 2 dB excess loss was measured when the observation point was shifted from 5 m to 25 m away from the tree

CONCLUSION

Results from this investigation indicate that the presence of isolated trees along a radio path can affect signal propagation leading to reduction in signal strength (attenuation). As seen in

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our measurement data, propagation loss in isolated trees can be as high as 30 dB. For transmission that follows canopy geometry, this loss is dependent on canopy thickness and frequency. In addition, density of foliage within the canopy is also found to be a contributing factor as canopies of same thickness were seen to measure different loss values.

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