VEGETATION ATTENUATION AND ITS DEPENDENCE ON FOLIAGE DENSITY

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ABSTRACT

The dependence of vegetation attenuation on foliage density has been investigated. Measurements were conducted on isolated single trees with varying degrees of foliation at SHF frequencies. These trees are Silver Maple (*Acer Saccharinum*), Horse chestnut (*Aesculus Hippocastanum*), Double white hawthorn (*Crataegus oxycantha 'Plena'*) and Dawn redwood (*Metasequoia glyptostroboides*). The measurement geometry adopted is such that the antenna boresight is always pointing towards the canopy for greater illumination. Result of this investigation revealed that as the experimental trees grow more leaves, canopy gap fraction becomes smaller, causing high radiation interception and leading to high signal attenuation. The result is a clear evidence of the significance of foliage in the estimation of vegetation attenuation.

Keywords: Attenuation, foliage density, isolated tree, obscuration, radiation interception.

INTRODUCTION

The presence of vegetation along radio propagation path can cause significant attenuation of radio waves and result in much reduction of the communication coverage range of the radio equipment Li et al. [1]. This attenuation is as a result of scattering, absorption, reflection and diffraction suffered by the waves. A quantitative knowledge of excess propagation loss suffered by radio wave due to presence of foliage is essential for planning a communication link in any vegetated channel. This has stimulated a lot of experimental work by researchers in the field [2-6]. Generally, the foliage induced excess loss will be a function of the propagating frequency and vegetation depth as in the relation

$$L\,(dB) = x\, f^{y}\, d_f^{z} \qquad (1.0)$$

Where x, y and z are variables in which their values can be obtained through measurements. y and z indicate the frequency and distance dependences of vegetation-induced excess loss in the parametric equation. All existing empirical loss prediction models are in agreement with Equation 1 above. However, our recent findings Adegoke [7] revealed that the degree of vegetation foliation is another key factor that will determine the amount of excess vegetation loss.

In an effort to substantiate this, Kajiwara [8] measured propagation losses on two foliated isolated trees (Plane and Gingko) at 29.5 GHz. He recorded 18 dB and 6.3 dB respectively on the trees. The author went further to populate canopy elements by adding more branches to the trees, aimed at increasing leaf density and canopy thickness. His observation revealed increase in measured attenuation. Savage et al. [6] carried out series of measurement campaigns on selected vegetation at 1.3, 2.0 and 11.6 GHz. Their results show that leaf density, leaf state and measurement geometry are other important factors influencing signal attenuation in vegetation. In a similar manner, Rogers et al. [9] carried out a study in UK on the effects of millimetre wavelengths radiowave propagating through vegetation. Reports of their study showed that vegetation attenuation is dependent on certain number of factors e.g leaf state, leaf density, vegetation type e.t.c. Ndzi et al. [10] carried out a study on the effects of vegetation on wideband signals. The paper highlighted the important issues needed to be considered when estimating vegetation attenuation. The dependence on frequency, depth, geometry and density was highlighted. Also, difficulties in quantifying some of these contributing factors were highlighted which invariably introduced a complexity in the development of prediction models. The paper noted that, most, if not all of the existing models do not take explicitly into consideration, vegetation density parameter. Benzair [11] had equally carried out experimental investigations on vegetation at 1-4 GHz to determine the attenuation with respect to trees in-leaf and out-of-leaf. He conducted the experiment during spring/autumn when the tree is with dense foliage. Also, in autumn/winter when the tree had lost all its foliage. In his result, he observed that vegetation attenuation is a function of many parameters among which are, foliage density, tree type, height e.t.c.

In this paper, we have investigated the dependence of excess vegetation loss on foliage density, apart from propagating frequency and depth of penetration.

Site Description and Measurement Details

The detail of experimental site and measurement equipment descriptions are as described in Adegoke et al. [12, 13]. Experimental investigations were carried out on four deciduous trees aimed at quantifying excess attenuation by degrees of canopy foliation. The trees description is as described in Table 1.0. The measurement geometry adopted is such that the antenna boresight is always pointing towards the canopy for greater illumination. In each case, a separation distance of 15 m was maintained between transmit and receive antenna with a constant power of 20 dBm being generated from the transmitter.

In realising the objective of this work, efforts were made to monitor the process of leaf growth on the trees under investigation. The first experiment was conducted on silver maple tree (at 3.2-3.9 and 4.9-5.9 GHz) in May 2013, when the leaves were just protruding from twigs. A repeat experiment was carried out on same tree nearly four weeks later (June 2013) when the leaves had developed. The same procedure was followed for all other trees. In each case, the degree of foliation varies; a factor that is dependent on the rate of leaf growth in individual tree. During the measurements, the transmitter was configured to a ‘step sweep’ mode so as to sweep across the selected frequency bands at a step size of 50 MHz with a dwell time of 70 seconds on each frequency. Figure 1.0 shows two states of foliation in one of the trees under investigation (dawn redwood) and the corresponding measurement geometry.

S/N	Tree Names	Height (m)	Trunk Diameter (cm)	Canopy Diameter (m)	Leaf shape	Leaf Size
1	Horse chestnut (*Aesculus Hippocastanum*)	6.4	35	5.5	Palmate	30 X 10cm
2	Silver maple (*Acer Saccharinum*)	12	40	6	Lobed	8 X 8cm
3	Double white hawthorn (*Crataegus oxycantha 'Plena'*)	5.8	31	5.4	Pinnate	6 X 3cm
4	Dawn redwood (*Metasequoia glyptostroboides*)	9	(i)	3.8	Linear	4 X 1cm

Table 1.0 Parameter table for the isolated trees

(i) No accessibility since trunk was covered by branches and leaves.

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(a) (b)

Figure 1.0 Dawn redwood tree (*Metasequoia glyptostroboides*) (a) Out-of- Leaf state (b) In-Leaf state

Results, Analysis and Discussion

(i) Silver maple tree

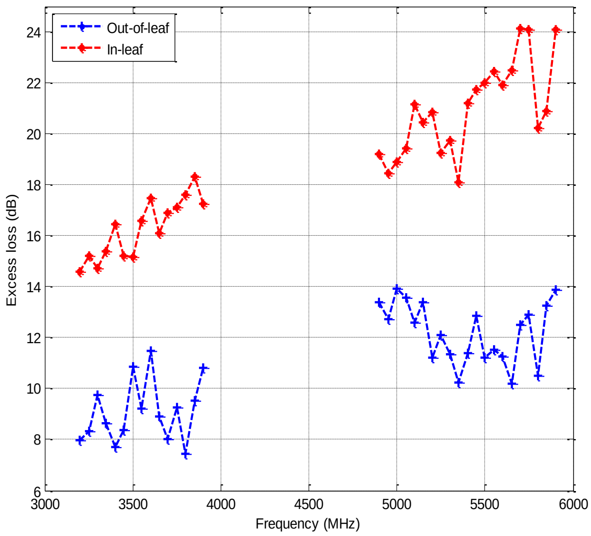

Figure 2.0 Excess loss on silver maple tree at two foliation states at 3.2-3.9 GHz and 4.9-5.9 GHz

(ii) Horse Chestnut tree

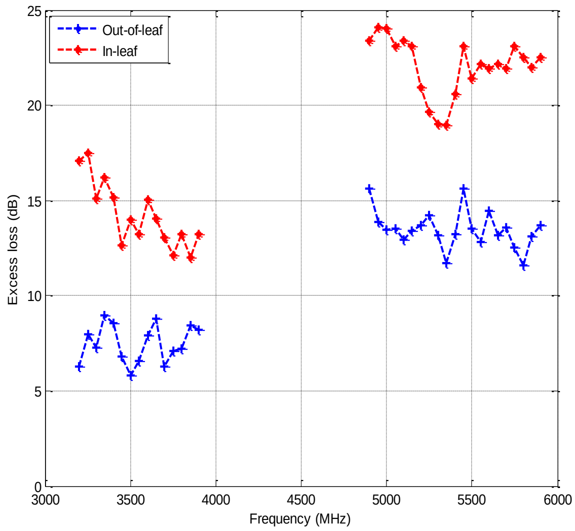

Figure 3.0 Excess loss on Horse chestnut tree at two foliation states at 3.2-3.9 GHz and 4.9-5.9 GHz

(iii) Double white hawthorn tree

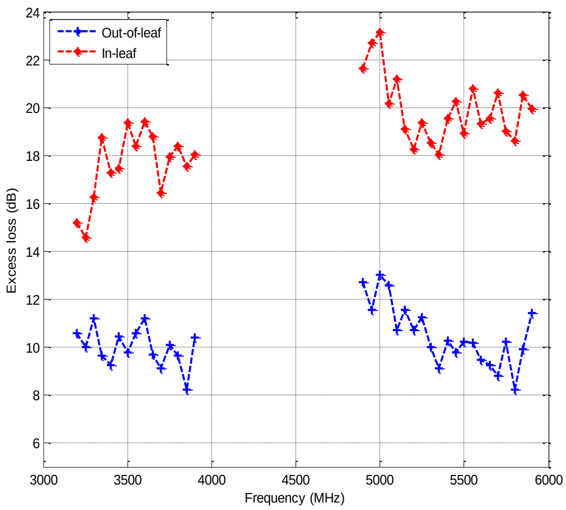

Figure 4.0 Excess loss on hawthorn tree at two foliation states at 3.2-3.9 GHz and 4.9-5.9 GHz

(iv) Dawn redwood tree.

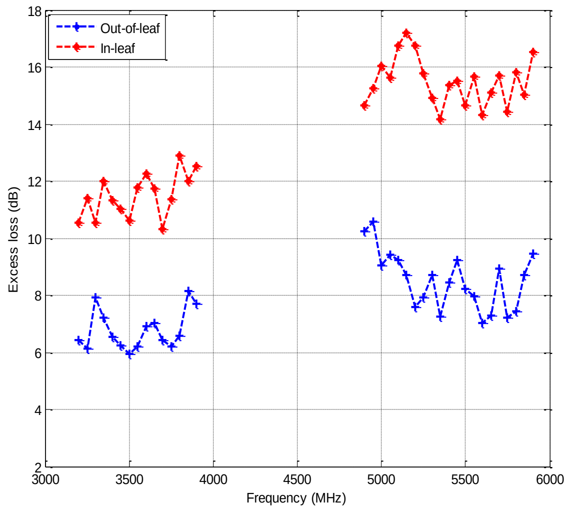

Figure 5.0 Excess loss on Dawn redwood tree at two foliation states at 3.2-3.9 GHz and 4.9-5.9 GHz

	Silver maple tree		**Horse chestnut tree**		**Double white hawthorn tree**		**Dawn redwood tree**	
	3.5 GHz	5.4 GHz	3.5 GHz	5.4 GHz	3.5 GHz	5.4 GHz	3.5 GHz	5.4 GHz
Winter data (dB)	9 ± 1.1	12 ± 0.9	7 ± 1.1	13 ± 1.3	9 ± 0.7	11 ± 0.9	6 ± 1.4	9 ± 1.7
Summer data (dB)	16 ±1.2	21 ±1.4	14 ± 1.8	22 ± 2.0	17 ± 1.3	20 ± 1.1	12 ± 2.0	16 ± 1.6
Loss difference (dB)	7	9	7	9	8	9	6	7

Table 2.0 Mean excess loss values in winter and summer periods on the experimental trees at 3.5 GHz and 5.4 GHz bands and their standard deviation.

As shown in Figures 2.0 to 5.0, high propagation loss was recorded in summer period (in all the trees) compared with winter data. This is likely due to the presence of leaves on the trees during summer. At this state (in-leaf), canopy gap fraction becomes small causing high radiation interception and possibly, high signal absorption. The absorption here is largely due to moisture level of the leaves Caldeirinha [14] and Schubert et al. [15]. This claim is also supported by Benzair [11] where tree components (leaves, twigs and branches) are said to contain considerable amount of water during spring/summer and will have additional effect on propagating radio waves. But there are no available experimental data sufficient to quantify this effect. In in-leaf state, radiated signal is being shadowed due to high obscuration by the canopy elements. Thus, as the tree defoliates, the gap fraction becomes larger and for signals at centimetre (cm) wavelength, propagation becomes easier with less radiation interception and absorption.

From Table 2.0, between 6 dB and 9 dB loss difference is seen to have been measured on individual trees at these two different stages of foliation. From the experimental trees and except for redwood tree, little traces of leaves were spotted on the canopies of the remaining trees at initial measurement period. The 9 dB measured on redwood tree (Figure 5.0 at 5.4 GHz band) at no-leaf state is caused by the tree branches and twigs only. An additional 7 dB loss was recorded on same tree, three weeks after the initial measurement (no-leaf) when it has grown leaves. This 7 dB extra loss is therefore likely due to the presence of the leaves on the tree canopy. Consequently, one can say that if this tree is monitored over time as it develops more leaves; there is a high tendency that extra loss would be added as revealed in the experimental data for other trees. The average loss difference in each band together with the standard deviation in the band recorded in silver maple, horse chestnut and hawthorn trees (Table 2.0) falls within same range. Though, the canopy thickness of these trees is nearly the same, this should not be considered generic as trees of same canopy thickness may give different attenuation values. Other factors that come into play here is the density of these leaves on the canopy and portion of the canopy that is illuminated by the antenna beamwidth. Some of the empirical loss prediction models in the literature FITU-R [2] and COST 235 [4] have shown through their parametric equations that there is an additional excess loss in in-leaf over out-of-leaf state as in

$$L\,(dB) = 0.39\, f^{0.39}\, d_f^{0.25} \qquad in - leaf \qquad (2)$$

$$L\,(dB) = 0.37\, f^{0.18}\, d_f^{0.59} \qquad out - of - leaf \qquad (3)$$

$$L\,(dB) = 15.6\, f^{-0.009}\, d_f^{0.26} \qquad in - leaf \qquad (4)$$

$$L\,(dB) = 26.6\, f^{-0.2}\, d_f^{0.5} \qquad out - of - leaf \qquad (5)$$

Using the FITU-R (2 & 3) parametric equations and at a frequency of 5.4 GHz, a comparison is made between the two states of foliation with the illustrated plot in Figure 6.0.

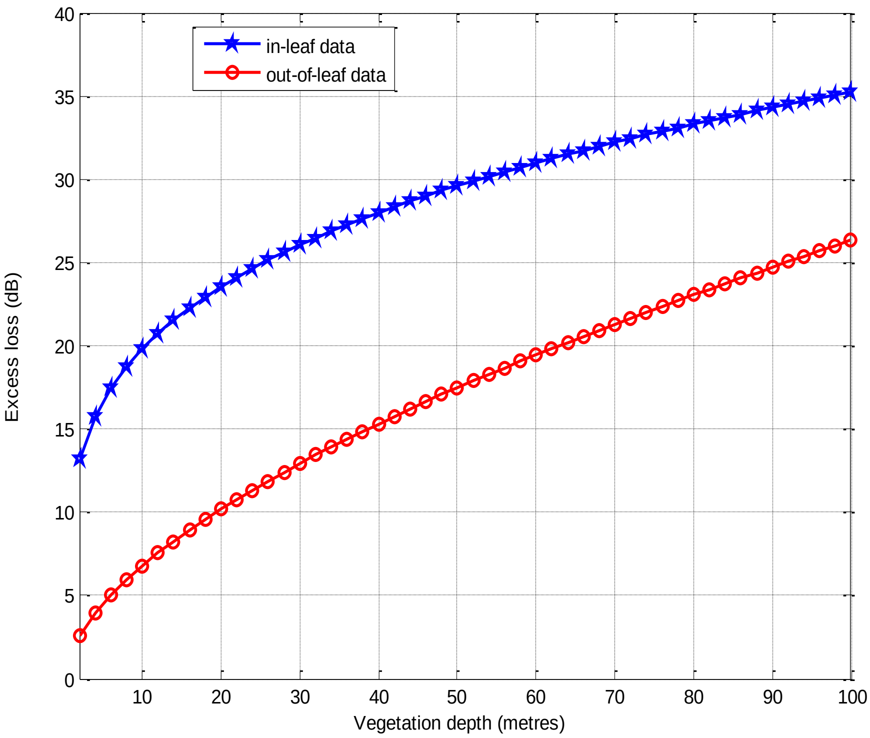

Figure 6.0 Plot comparing in-leaf and out-of-leaf prediction loss for FITU-R model at 5.4 GHz

From the plot, an approximate loss difference of 12 dB is observed between propagation in in-leaf and out-of-leaf case. The in-leaf case experiences more losses due to the presence of more absorbing and scattering elements Al-Nuaimi et al. [4].
So, in the design of link budget in vegetation, consideration must be given to this seasonal effect on vegetation for effective radio communication. In line with this, an average seasonal loss on vegetation was given in Benzair, [11] as

$$L_{full\ leaf} = L_{No\ leaf}\ x\ 1.5\ x\ f^{0.4} \qquad (6)$$

Where f in GHz and L in dB.
The interpretation of the above is that for 1 GHz, about half of the total excess loss (in foliated tree) is due to the presence of leaves while the remaining loss is caused by branches and twigs. In the frequency range of the current experiment, our investigation reveals various degrees of leaves contribution to excess loss which are comparable to Benzair's submission.

CONCLUSION

In this paper, the dependence of excess vegetation attenuation on foliage density has been investigated. Results of investigation on isolated single trees revealed that as trees grow leaves, the value of excess attenuation measured across them increases. Between in-leaf and out-of leaf states, a significant amount of propagation loss difference was observed which is due to leaves. The investigation further revealed that in full leaf state, a greater portion of the total attenuation is contributed by the leaves. Apparently, it can be concluded that leaves have significant effects on radio waves especially at microwave frequencies.

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