Attenuation of Radiofrequency Waves due to Vegetation in Colombia

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***Abstract*—We present in this paper the preliminary empirical model of the attenuation produced by nine vegetation types with diverse heights and climate conditions in Colombia. Measurements were performed in co and cross-polarization. Five frequency bands with the following central frequencies were considered: 150 MHz, 360 MHz, 580 MHz, 850 MHz, and 3600 MHz. As expected, a comparison between measurements and calculations with the Fitted International Telecommunication Union (FITU) attenuation model shows a strong dependence of the attenuation with the type of vegetation and its spatial distribution. FITU model shows a good agreement with measurements in coniferous forest and citrus plantation. On the other hand, the model presents more than 10 dBs of underestimation for some native species in the propagation losses for the highest measured frequency bands, while, for balsa, the model presents more than 10 dBs of overestimation. Based on these results, an adaptation of the existing attenuation model for propagation through vegetation, in special the FITU model, is proposed for Colombian conditions.**

Keywords—Propagation through vegetation, Measurements, Propagation model, FITU.

I. Introduction

Propagation modeling is an essential tool for wireless network design and radiofrequency (RF) interference studies. The attenuation of radio waves propagated through vegetation has been estimated using different approaches including empirical and semi-empirical propagation models. However, the practical application of the semi-empirical models is limited by their complexity and parameters-value availability. Something similar happens with empirical models that are simpler mathematically but, as the former, are fitted from specific cases. In fact, RF wave attenuation strongly depends on the vegetation type since the attenuation is produced by absorption and multiple reflections and diffractions given in trunks, branches, and leaves. Since few studies have been conducted in tropical regions [1], most of models have not been fitted to the attenuation produced by vegetation species in tropical countries.

In this paper, experimental results of the radio wave attenuation produced by representative vegetation in Colombia are presented. In addition, a comparison between measurements and calculations with the Fitted International Telecommunication Union (FITU) attenuation model [1] is used to formulate an adaptation of this model according to the behavior shown by Colombian vegetation species.

II. Model of Vegetation Attenuation

Different models of propagation loss in forest environments have been proposed depending on the frequency range and the available experimental data [2, 3]. One of the most used models to estimate the losses in excess due to vegetation is the Fitted International Telecommunication Union (FITU) model [1]. This model defines the losses in excess as a function of the frequency and the vegetation depth. The losses for a forest with and without leaves are estimated, respectively, as

$$L = 0.37\, f^{0.18} d^{0.59} \tag{1}$$

and

$$L = 0.39 f^{0.39} d^{0.25}, \tag{2}$$

where L are the losses in dB, f is the frequency in MHz, and d is the depth in meters.

In a general form, the FITU model can be written as

$$L = A f^{B} d^{C}, \tag{3}$$

where A, B, and C are empirical constants. It is notable from (1) and (2) that the constant A presents a value close to 0.38 in both cases, meanwhile the constants B and C show a higher variability comparing the case with and without leaves.

III. Experimental Estimation of Vegetation Losses

The attenuation in excess due to nine vegetation types with diverse heights and climate conditions in Colombia was measured in the UHF range. Measurements were performed at the following frequencies: 150 MHz, 360 MHz, 580 MHz, 850 MHz, and 3600 MHz. In each frequency, the channel vacancy was first verified and the average total link losses was measured as shown in Fig. 1. 20 samples in two 500-kHz bands around each frequency were measured to calculate the average. To obtain the vegetation losses, the measurement in each site was replicated with the link without the vegetation obstruction. Therefore, the vegetation losses were calculated as the difference between the basic transmission losses with

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obstruction due to the vegetation and the basic transmission losses of the link with line of sight.

Nine types of vegetation located in three sites were considered. In each site, species with three heights were characterized as described in Table 1. Sites were selected to provide variability in climatic conditions in Colombia, as shown in Fig. 2. Specifically, Libertad is located in Meta, has an elevation of 365 m, an average temperature of 27°C, and 76% of humidity. Palmira is located in Valle del Cauca, has an elevation of 1001 m, an average temperature of 29 °C, and62% of humidity. Neusa, on the other hand, is located in Cundinamarca, has an elevation of 2978 m, an average temperature of 10 °C, and80% of humidity.

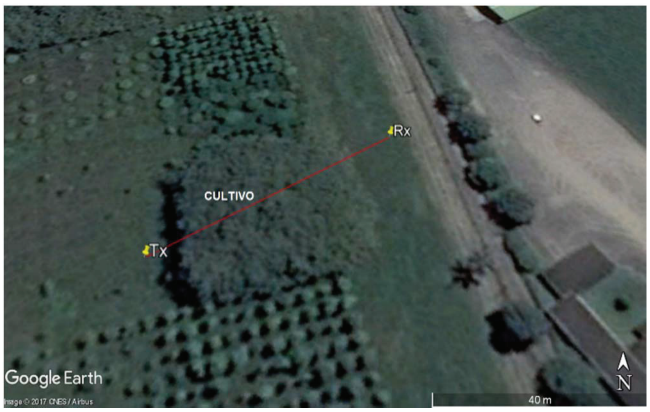
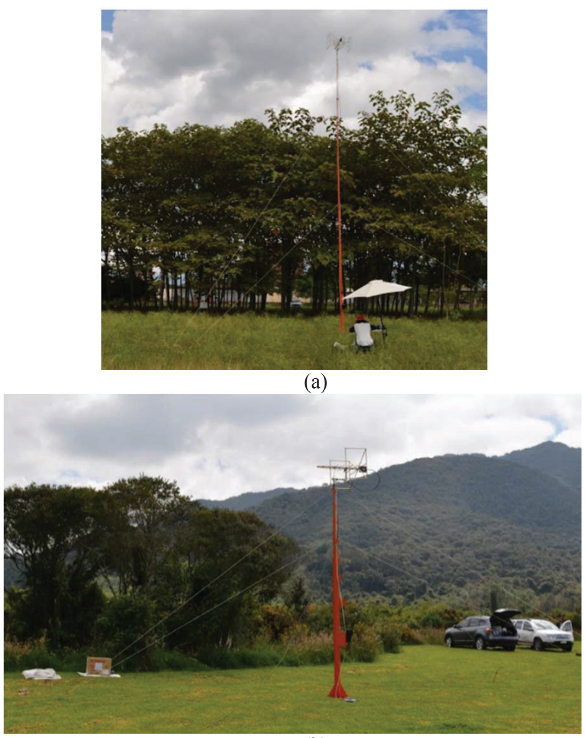


Figure 1. Aerial view of vegetation measured in Palmira, Valle del Cauca, Colombia.



(a)

(b)

Figure 2. Measurements performed in different locations: (a) balsa in Palmira, Valle del Cauca, Colombia and (b) native forest in Neusa, Cundinamarca, Colombia.

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IV. EXPERIMENTAL RESULTS

Figures 3 to 11 present the losses in excess estimated for each vegetation species. For comparison, the FITU model prediction, trace labeled as FITU-R (in-leaf), is plotted in each case. The results show that the measured losses follow a similar dependence with the frequency as the proposed by the FITU model in most cases. However, there are some cases, for example in Figs. 4 to 7, where the model presents a considerable difference with the experimental results. For this reason, a fitted model, labeled as the FITU-R (fitting) in Figs. 3 to 11, was developed by adjusting the constants B and C in (3). As expected, the figures show a better agreement between the experimental results and the adapted FITU model than the original FITU model for most of the cases. Particularly, the only case, in which the original FITU model shows a better performance, is in the balsa forests. This is probably due to the high variation in the losses values experimentally estimated.

Table 1 shows the variables of the adjusted FITU model in (3) obtained for each characterized vegetation. The fitted was performed by maintaining A as a constant. It can be seen that variables B and C are close to the values provided by the original FITU model; that is B between 0.18 and 0.39 and C between 0.25 and 0.59.

TABLE I. CONSTANTS FITTED FOR THE ADJUSTEED FITU MODEL FOR EACH MEASUREMENTS SITE.

Species	Site	Height (m)	Distance (m)	A	B	C
Cytrics	Libertad	4	19.8	0.39	0.5108	0.0539
Young Rubber	Libertad	8	41.6	0.39	0.1937	0.7866
Native Forest	Libertad	15	27.7	0.39	0.3114	0.5847
Mahogany	Palmira	4	16.4	0.39	0.2883	0.4642
Balsa	Palmira	8	20.3	0.39	0.2312	0.1240
Balsa	Palmira	15	23.6	0.39	0.0284	1.0411
Native Vegetation	Neusa	4	90	0.39	0.4638	-0.019
Native Vegetation	Neusa	8	96	0.39	0.2540	0.4024
Coniferous Forest	Neusa	15	125	0.39	0.5254	0.1276

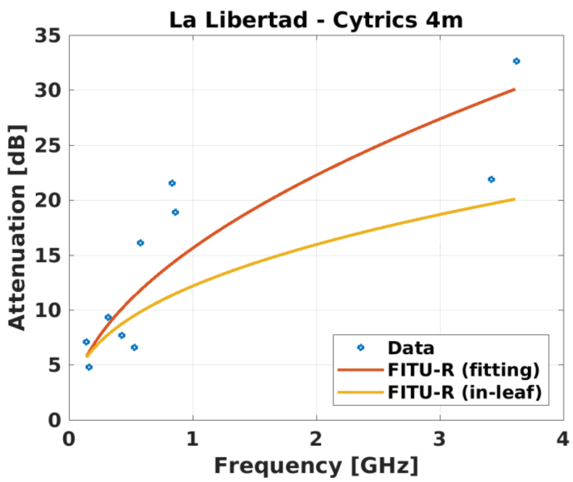

Figure 3. Losses in excess due to vegetationexperimentally estimated and calculated using the FITU and the adjusted FITU models for a cytrics plantation in La Libertad, Meta, Colombia.

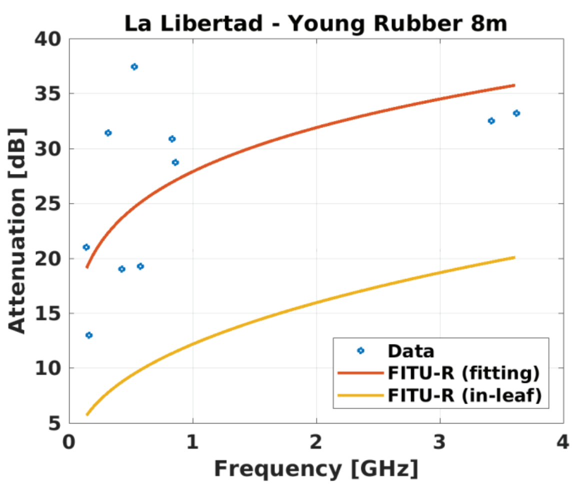

Figure 4. Losses in excess due to vegetation experimentally estimated and calculated using the FITU and the adjusted FITU models for a young rubber plantation in La Libertad, Colombia.

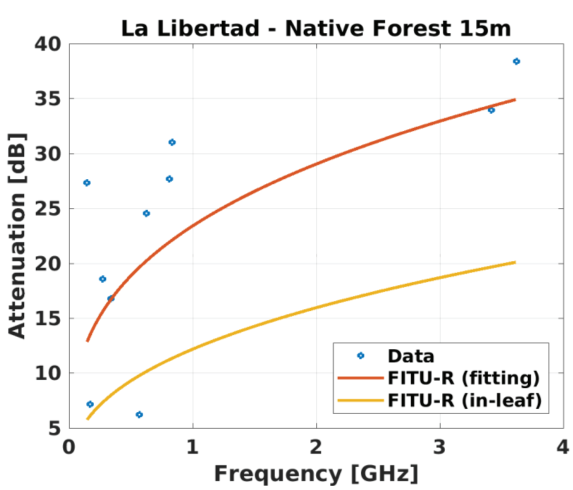

Figure 5. Losses in excess due to vegetation experimentally estimated and calculated using the FITU and the adjusted FITU models for a native forest in La Libertad, Colombia.

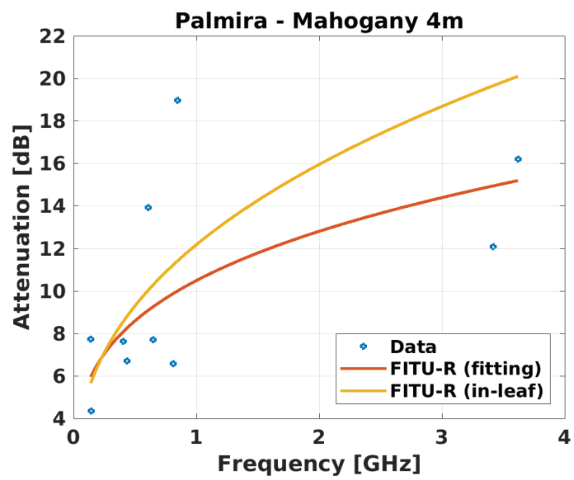

Figure 6. Losses in excess due to vegetation experimentally estimated and calculated using the FITU and the adjusted FITU models for a mahogany plantation in Palmira,Colombia.

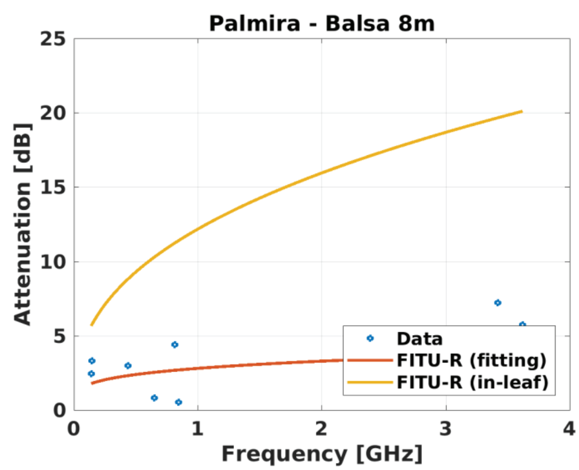

Figure 7. Losses in excess due to vegetation experimentally estimated and calculated using the FITU and the adjusted FITU models for a balsa forest inPalmira,Colombia.

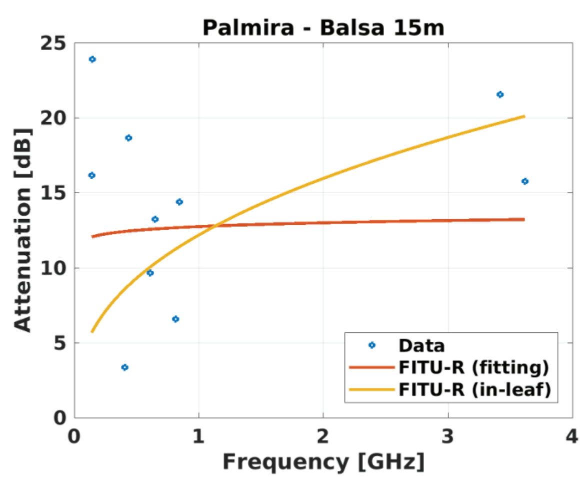

Figure 8. Losses in excess due to vegetation experimentally estimated and calculated using the FITU and the adjusted FITU models for a 15-m balsa forest inPalmira,Colombia.

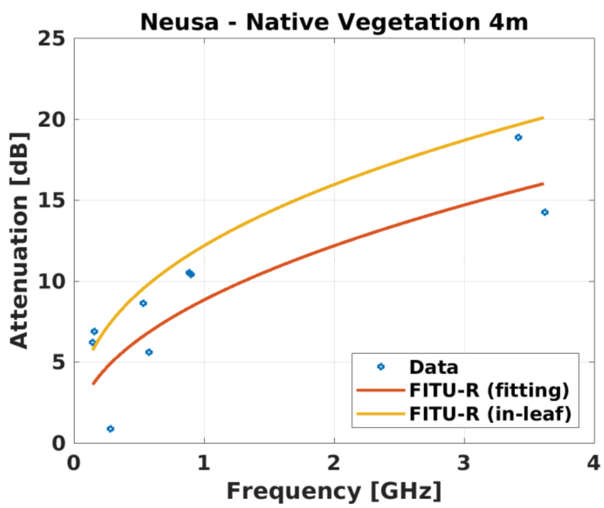

Figure 9. Losses in excess due to vegetation experimentally estimated and calculated using the FITU and the adjusted FITU models for 4-m native vegetation inNeusa, Cundinamarca,Colombia.

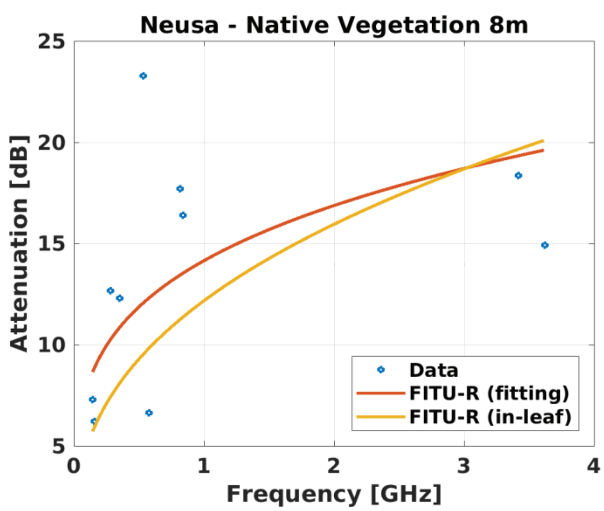

Figure 10. Losses in excess due to vegetation experimentally estimated and calculated using the FITU and the adjusted FITU models for 8-m native vegetation inNeusa, Cundinamarca, Colombia.

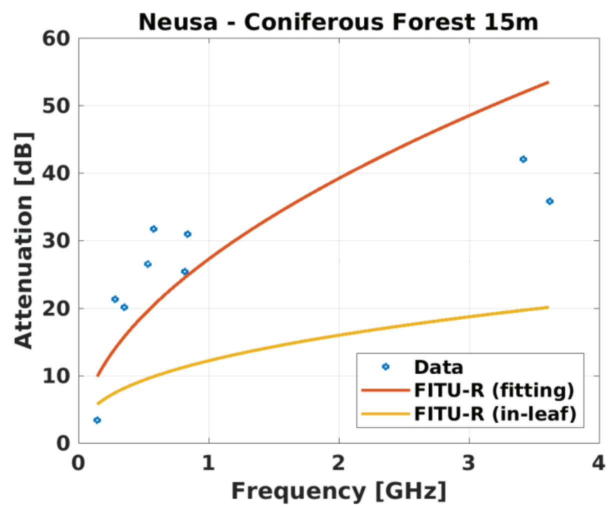

Figure 11. Losses in excess due to vegetation experimentally estimated and calculated using the FITU and the adjusted FITU models for 15-m coniferous forest inNeusa, Cundinamarca, Colombia.

V. CONCLUSION

Experimental characterization and models of vegetation propagation losses in tropical species in the UHF are presented in this paper. Results are compared with the FITU model and show that model presents more than 10 dBs of underestimation for some native species in the propagation losses for the highest measured frequency bands, while, for balsa, the model presents more than 10 dBs of overestimation. An adapated version of the FITU model is proposed for each characterized species and a better agreement is obtained. These results constitute an adaptation of the FITU model for Colombian conditions.

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