Numerical Analysis of Brillouin Precursor Formation Through Wet Loamy Soil-filled Waveguide

Muhammad Dawood, Kaixing Li
Klipsch School of Electrical and Computer Engineering
New Mexico State University
Las Cruces, New Mexico, USA
dawood@nmsu.edu

Ana Vazquez Alejos
Dept. of Teoria de la Señal y Comunicaciones
University of Vigo
Vigo, Spain
analejos@uvigo.es

***Abstract*—In this paper Brillouin Precursor formation through wet loamy soil-filled waveguide operating in dominant TE_{10} mode is discussed. Simulations are performed for precursor formations in TE mode and TEM modes and results are compared.**

I. INTRODUCTION

It is well established theoretically [1] and demonstrated experimentally [2-5] that Brillouin precursors arise when an ultrawideband (UWB) electromagnetic (EM) wave propagates through a dispersive media. Further, Brillouin precursor (BP) attenuates algebraically as compared to the exponential decay experienced by the carrier. This property of the precursor field can be exploited to design remote sensing systems, such as ground-penetrating radar, for imaging through dispersive medium.

In this paper, we investigate the behavior of BP through a rectangular waveguide operating in its dominant TE_{10} mode. The waveguide is filled with wet loamy soil comprised of 75% local soil and 25% tap water by volume. Precursors in TEM and TE_{10} modes are compared.

II. THEORITICAL FORMULATION

We consider wet loamy soil consisting of 25% tap water and 75% soil by volume as per [2]. The relative real and imaginary parts of soil permittivity, ε_r' and ε_r'' are estimated both experimentally and according to the mixing model as shown in Fig. 7 of [2]. These are then used to estimate the attenuation constant α (Nep/m) and the phase constant β (rad/m) through the waveguide operating in its dominant TE_{10} mode as given in (1) and (2) below. In (1-2) constant "*c*" denotes the speed of light and f_c is the waveguide cutoff frequency in Hz.

$$\alpha \cong \alpha_d = \frac{\omega \varepsilon_r''}{2c\sqrt{\varepsilon_r'\left[1-\left(\frac{f_c}{f}\right)^2\right]}} \quad \text{(Nep/m)} \tag{1}$$

$$\beta = \frac{\omega}{c}\sqrt{\varepsilon_r'\left[1-\left(\frac{f_c}{f}\right)^2\right]} \quad \text{(Rad/m)} \tag{2}$$

The dimensions for the rectangular waveguide are: a=16.52 cm, b=8.29 cm, z=37.50 cm. Thus, the cutoff frequency for soil-filled and air-filled waveguide are about 200MHz, 0.9 GHz, respectively.

The attenuation constant α (Nep/m) and the phase constant β (rad/m) for TEM mode through soil are calculated as follows:

$$\gamma = \alpha + j\beta = j\frac{\omega}{c}\sqrt{\varepsilon_r' - j\varepsilon_r''} \tag{3}$$

It has been established experimentally [2-5] that precursors can be formed when a band-limited sine-modulated pulse is decomposed into its orthogonal frequency components such that if only a limited set of 2M+1 frequency components are considered around its carrier frequency f_0, the time-domain transmitted signal $\tilde{x}(t)$ can be re-constructed with significant accuracy. Assuming the amplitude of the kth frequency component $A_k(z) = |X_k| e^{-\alpha_k z}$ at a distance *z*, the reconstructed signal can be represented as:

$$\tilde{x}(z,t) \approx \frac{1}{2M+1}\sum_{k=-M}^{M} A_k(z)\cos\left(2\pi f_k t - \beta_k z + \phi_k\right) \tag{4}$$

Where α_k and β_k are estimated components at k[th] frequency as per (1-3).

III. NUMERICAL SIMULATIONS

Depicted in Fig. 1 and Fig. 2 are the numerical results for the model in (1-3), indicating values for TEM mode through soil, TE mode through soil-filled and air-filled waveguide. We chose the operating frequency for soil and air, respectively, 250MHz - 3GHz, and 1GHz-3GHz. As can be seen in these figures, air has a very small value for attenuation constant and phase constant compared to soil. The propagation constants pertaining to TE and TEM modes are close.

978-1-5090-4412-2/17/$31.00 ©2017 IEEE

Figures 3 and 4 depict Brillouin precursor formation at two different depths through the wet soil for both TEM and TE modes. Since the attenuation constant and phase constant for TE and TEM mode are close to each other, the precursors are almost of identical amplitude as indicated in Figure 5.

Conclusions

This paper investigates the effect on the Brillouin precursor formation through wet loamy soil-filled waveguide operating in TE_{10} mode. Numerical calculations indicate that precursors do emerge through soil-filled waveguide. Experimental results will be presented at the symposium.

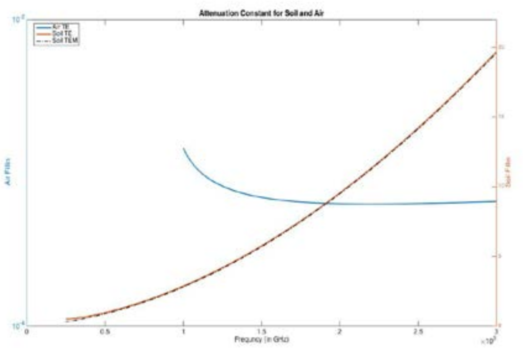

Fig. 1: Attenuation constant for TE_{10} mode's soil and air.

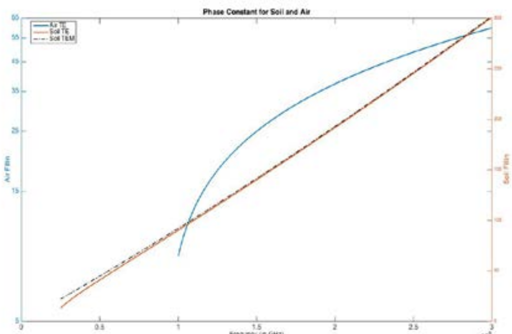

Fig.2: Phase constant in TE_{10} through air and soil-filled waveguide, as well as in TEM mode through wet loamy soil.

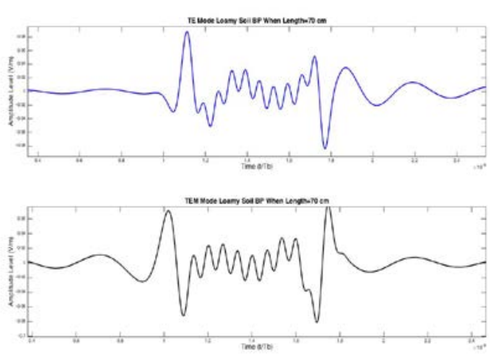

Fig.3: Brillouin Precursor in TEM and TE_{10} mode through wet loamy soil-filled waveguide at a depth of 50 cm, center frequency 1.5 GHz.

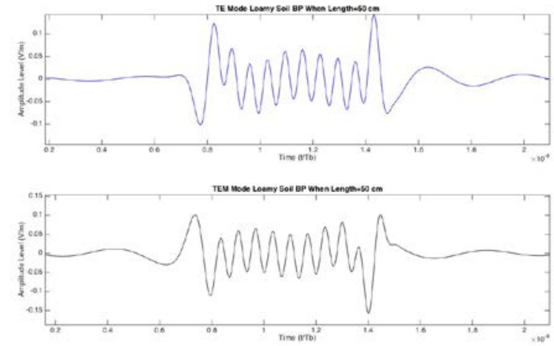

Fig.4: Brillouin Precursor in TEM mode and in TE_{10} mode through wet loamy soil-filled waveguide at a depth of 70 cm, center frequency 1.5 GHz.

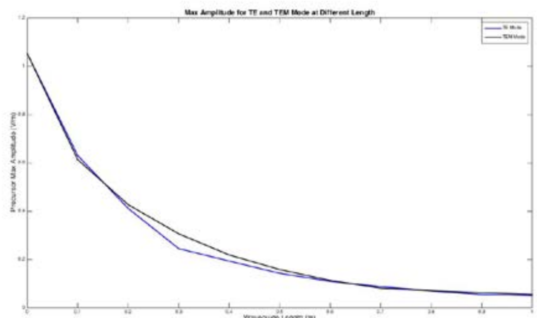

Fig.5: Maximum amplitude of Brillouin Precursor in TEM and TE_{10} modes through wet loamy soil-filled waveguide at a center frequency of 1.5 GHz.

REFERENCES

[1] K. E. Oughstun, "Dynamical evolution of the Brillouin precursor in Rocard-Powles-Debye model dielectrics," IEEE Trans. Ant. & Prop., vol. 53, pp. 1582–1590, 2005.

[2] Habeeb Mohammed, Muhammad Dawood, Ana Vázquez Alejos, "Experimental detection and characterization of Brillouin precursor through loamy soil at microwave frequencies", *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 50, n. 2, pp. 436-445, February 2012.

[3] Muhammad Dawood, Habeeb Mohammed, Ana Vázquez Alejos, "Experimental Detection of Brillouin Precursors Through Tap Water at Microwave Frequencies", *IET Electronics Letters* vol. 46, nº 25, pp. 1645 – 1647, December 9th 2010.

[4] Ana Vázquez Alejos, Muhammad Dawood, Luis Medina, "Experimental dynamical evolution of the Brillouin precursor for broadband wireless communication through vegetation", Progress In Electromagnetics Research vol. 111, pp. 291-309, 2011.

[5] Ana Vázquez Alejos, Muhammad Dawood, Habeeb U.R. Mohammed, "Analysis of Brillouin precursor propagation through foliage for digital sequences of pulses", *IEEE Geoscience and Remote Sensing Letters*, vol. 8, issue 1, pp. 59-63, January 2011..