Novel Surface Wave Exciters for Power Line Fault Detection and Communications

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***Abstract*— A novel conformal surface wave (CSW) exciter is introduced which can excite electromagnetic (EM) surface waves along unshielded power line cables non-intrusively. The CSW exciter is small, cost effective and can be easily placed on a power cable compared to conventional monopole type launchers or horn type launchers. Besides cable fault detection, the potential applications of the proposed exciter include broadband power line (BPL) communication and high frequency power transmission.**

Keywords- Surface wave, CSW exciter, unshielded cable.

I. INTRODUCTION

Recently, there has been a growing interest on surface wave propagation for application in power line communication [1], structural health monitoring [2], and terahertz applications [3]. A surface wave is a wave that travels along the boundary between two different media, such as air and an insulating material. Surface wave propagation along a conductor surface is an interesting phenomenon observed and theoretically investigated by Sommerfeld [4] and Zenneck [5]. The governing equations which are the basis of the electromagnetic surface wave theory were developed by Maxwell. Georg Goubau [6] demonstrated the propagation of surface waves along the interface of a wire and a thin dielectric layer of coating. His work showed that if the phase velocity of the wave was lower in the interface than its velocity in free space then in that case most of the fields could be concentrated around the conductor dielectric interface. Goubau proposed that effective surface wave propagation would result if a conductor is coated with a layer of dielectric. Similarly if a conductor contains surface that is not very smooth and hence result in lower wave phase velocity then that may also result in surface wave propagation. Goubau developed surface wave launchers of the shape of horns.

More recently, Elmore [1] studied the potential for surface wave propagation on overhead un-insulated power lines for possible power line communication application. By using conical shaped slotted launchers mounted on overhead lines, he was able to achieve a broadband response around 2 GHz.

The excitation and propagation of surface waves have potential applications in broadband power line communication, high frequency power transfer and power line fault detection. For communications and fault detection, it is necessary to induce pulses along power lines which would contain broadband signals. Typically these pulses are few nanoseconds wide which make the frequency range to be in the vicinity of two hundred MHz or so.

Previous launchers were studied and developed for microwave and high frequency application at around 2 GHz. For fault detection type application we need launchers that can operate at around 250 MHz. The launchers proposed in the literature although broadband are extremely large for conformal low profile applications.

This work presents a new class of surface wave launchers that are designed to operate against insulated power line conductors, such as PVC and PUR cables. The experimental results presented in this paper show effective surface wave propagation by using monopole type launchers. First, a conventional wire monopole on a ground plane is considered followed by a wide monopole on a ground plane. Finally a conformal monopole launcher is introduced which consists of a wrapped around ground plane.

II. CONCEPT AND DESIGN OF THE PROPOSED SURFACE WAVE EXCITER

We investigated the excitation and propagation of surface waves along an unenergized unshielded XLPE power cable. The cable had a conductor radius of 0.6 cm. The insulation thickness and permittivity were 0.2 cm and 2.2, respectively. In [7], it was shown that for such a cable 50%-99% of the excited power can be transmitted as surface waves within the 63 MHz to 411 MHz frequency band.

The design of the surface wave exciter was started from a simplified geometry. For Case 1, a simple 300 mm long vertical aluminum wire monopole was built on a 415 mm by 260 mm aluminum ground plane as shown in Fig 1. This length corresponds to a quarter wave monopole operating at 250 MHz. Since the ground plane is only a fraction of the wavelength at 250 MHz, its size affects the performance of the surface wave launcher [7].

Two identical monopoles were placed 214 cm apart on a cable as shown in Fig. 1.

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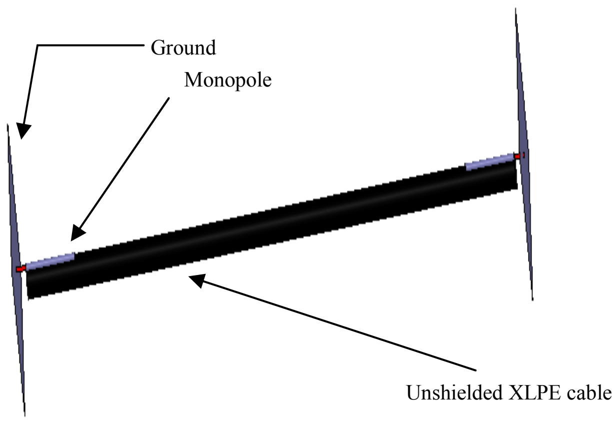

Figure 1. Wire monopoles on an unshielded XLPE cable.

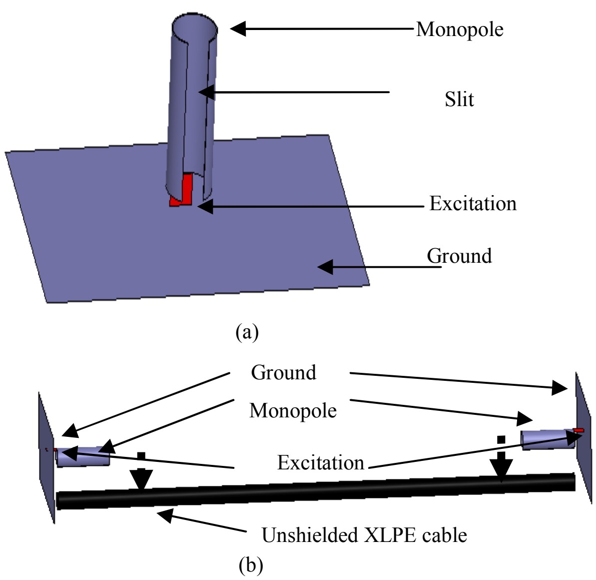

Figure 2. (a) Construction of the vertical wide monopole (b) Signal injection into cable using monopoles, dotted down arrow means monopoles are actually placed on that location of the cable.

For Case 2, two wide monopoles were used (see Fig. 2). From classical antenna theory it is well known that a fat or wide dipole or monopole provides wider operating bandwidth. For example, a bow-tie dipole is more wideband than a wire dipole. Similarly a dipole made of a fat conductor is wideband than a dipole made of a thin conductor. The same concept was applied to build a monopole for the surface wave propagation experiments. On a conceptual level a wide monopole would allow the currents to flow more smoothly on its surfaces because of its increased surface area resulting in less frequency sensitivity; hence the surface wave transmission from one end of the cable to the other can be improved. The conductor for the wide monopole was flexible and had a slit in order to make it agreeable to the cable.

For Case 3, a conformal monopole launcher was designed and developed. Due to its vertical construction and size, the monopole shown in Fig. 2 may not be suitable for locations where space is limited. To overcome this limitation the conformal geometry shown in Fig. 3 was investigated. This

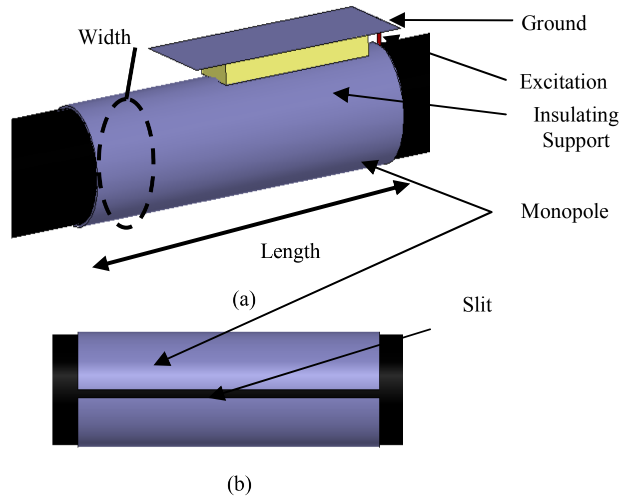

Figure 3. Proposed conformal surface wave exciter- (a) 3-D view (b) bottom view.

monopole was made from a flexible copper conductor and wrapped around the power cable. The ground plane was also made from copper conductor but it had a very thin paper insulation layer on one side. Note that the ground plane is parallel to the monopole. This structure resembles an Inverted L Antenna (ILA). An ILA is a monopole antenna with a small radiation resistance, narrow bandwidth, and modified radiation patterns compared to a wire monopole antenna [8]. Without additional matching an ILA is not an efficient far field antenna [9]. However, far field performance is not our concern as we are interested in an effective surface wave launcher. The parallel arrangement of the ground plane does not solve the space issue since a large ground plane could not be accommodated in a space restricted location. Reducing the area of the ground plane does not solve this issue either since a very small ground plane severely affects the impedance and hence results in narrow bandwidth [10]. A new approach is to fold the ground plane several times. Indeed, the folded ground plane will occupy much less space, but effectively it would have the same area as that of the unfolded ground plane. This arrangement makes the monopole structure conformal in nature. This is why we call it a conformal surface wave exciter or CSW exciter rather than a monopole antenna.

III. RESULTS

The measured return losses of the wire monopole (shown in Fig. 1) in air and on the cable are shown in Fig. 4. The antenna in air has a resonant frequency of 250 MHz. The same antenna when placed on an XLPE cable (214 cm long and 6 mm diameter) shows a broadband return loss characteristic.

The transmission performance between the wire monopoles in the presence and absence of the power cable is shown in Fig. 5. For the experiment, two ports of a network analyzer (Agilent E5071C) were connected to two monopoles in order to measure the transmission of signals between the monopoles. From Fig. 5, we found that when the monopoles were in the air without

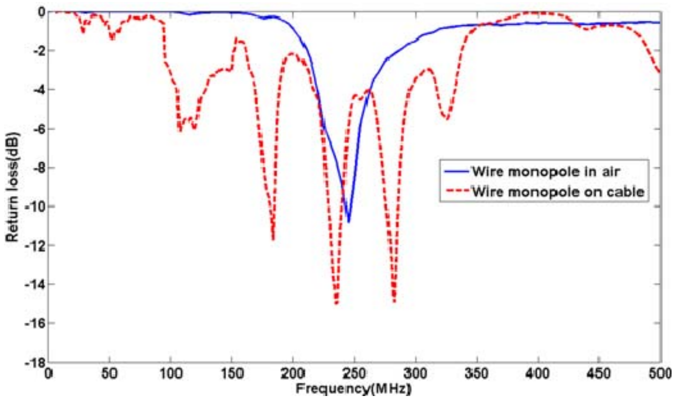

Figure 4. Return loss performance of the vertical wire monopole.

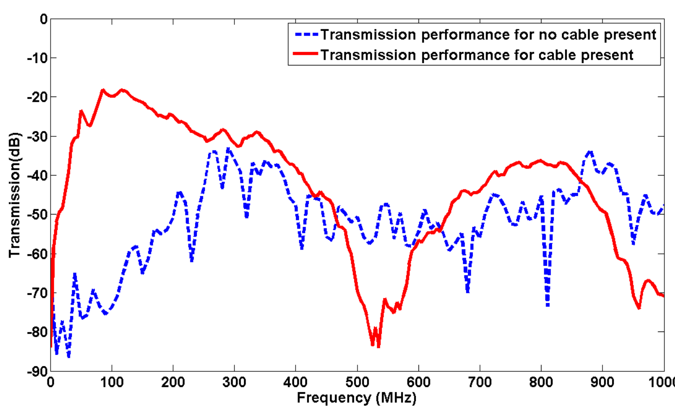

Figure 5. Comparison of transmission performance between monopoles with and without the cable.

the cable, the transmission was always smaller than -30 dB. Especially in the lower frequency region, i.e. up to 250 MHz, the transmission is even less than -40 dB. We also observe that there is a significant improvement of transmission when the cable is present. Especially from 90 MHz to 135 MHz the transmission improves by at least 20 dB. This broadband response is due to the broadband reflection performance of the monopole on cable as we observe from Fig. 4. The transmission performance between two wide monopoles (shown in Fig. 2) is compared with the transmission between two wire monopole in Fig. 6. It is observed that the wide monopole has 280 MHz (95 MHz to 375 MHz) transmission bandwidth which is much wider than the 45 MHZ bandwidth of the wire monopole. The wide monopole antenna has broad impedance bandwidth than the thin wire monopole.

Finally, the transmission performance of the CSW exciter shown in Fig. 3 was investigated by placing them next to the same power cable. As shown in Fig. 7, we see that over 90 MHz to 500 MHz, the vertical wide monopole has better (lower) return loss on most frequencies compared to the return loss of the CSW exciter. From Fig. 8, it is evident that the transmission bandwidth found with the CSW exciter is narrower (105 MHz) than the bandwidth (280 MHz) found for the vertical wide monopole. This happens because the parallel configuration of the ground plane for the latter contributes more reactance to the antenna impedance. This causes more

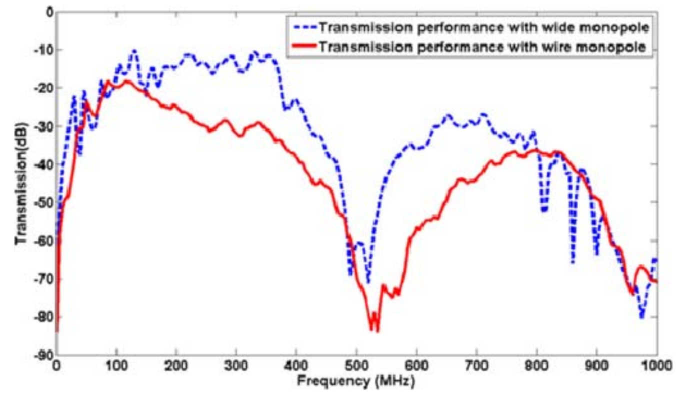

Figure 6. Transmission comparison between the vertical wide monopole and the wire monopole.

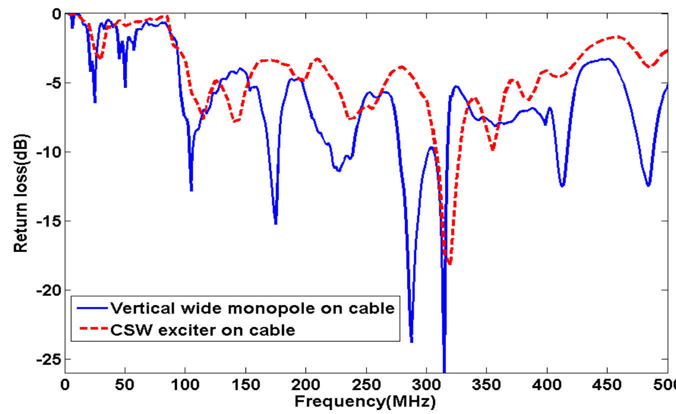

Figure 7. Return loss comparison between the vertical wide monopole and the CSW exciter.

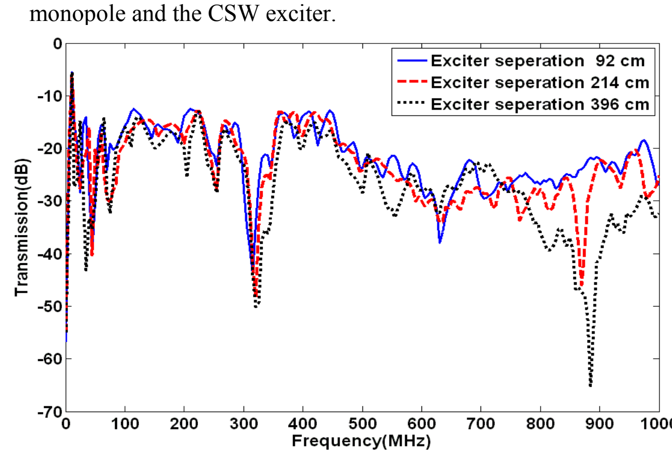

Figure 8. Transmission response of the proposed CSW exciter.

reflections and hence the bandwidth becomes narrower. The CSW exciter had a reduced sized ground plane (300 mm x 150 mm) compared to the ground plane of 415 mm x 260 mm for the vertical wide monopole. Also the CSW is basically an ILA while the wide monopole is a wideband antenna.

IV. Conclusion

The concept of surface wave propagation is studied by developing several surface wave launchers of the monopole configuration. The objective here is to attain wideband surface wave propagation on a power cable which has the potentials for power line fault diagnostics and power line communication. Although a wide monopole results in a much wider transmission bandwidth a new CSW exciter is introduced, which will be more amenable for power line applications.

References

[1] G. E. Elmore, "System and apparatus for transmitting a surface wave over a single conductor," US patent 7567154B2, July 2009.

[2] T. Tang and A. T. Yeung "Full-Scale Field Testing of Surface Waves – TDR Technique in Integrity Evaluation of Large-Diameter Bored Piles", Proc. TDR 2006, Purdue University, West Lafayette, USA, Sept. 2006.

[3] T. Akalin, A. Treizebré, and B. Bocquet, "Single-wire transmission lines at terahertz frequencies," IEEE Trans. Microw. Theory Tech., vol. 54, no. 6, pp. 2762-2767, June 2006.

[4] A. Sommerfeld, "Transmission of electrodynamic waves along a cylindrical conductor," Annalen der Physik und Chemie, vol. 67, pp. 233–290, 1899

[5] J. Zenneck, "On the propagation of plane electromagnetic waves along a planar conductor surface and its relationship to wireless telegraphy," Annalen der Physik, series 4, vol. 23, pp. 848–866, 1907.

[6] G. Goubau, "Surface waves and their application to transmission lines," J. Applied Physics, vol. 21, pp. 1119–1128, 1950.

[7] R. H. Bhuiyan, "Proximity coupled non-intrusive wireless sensors for monitoring and diagnostics," PhD Dissertation, Dept. Elec. Eng., Univ. S. Carolina, Nov. 2010.

[8] K. Fujimoto, Mobile Antenna Systems Handbook, 3rd ed., Artech House, 2008.

[9] C. A. Balanis, Modern Antenna Handbook, John Wiley and Sons, 2008

[10] M. J. Ammann and M. John, "Optimum design of the printed strip monopole," IEEE Antennas Propag. Mag., vol. 47, no.6, pp. 59-61, Dec. 2005.