A Study on Transverse Magnetic Wave Propagation Characteristics of Dielectric Wrapped Wire

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Abstract. The transverse magnetic wave propagation characteristics of the dielectric wrapped wires are studied. The transverse magnetic wave transmission model of a dielectric wrapped wire is revised based on the variable separation method. The spatial relationship between electromagnetic wave emission and reflection is obtained. An experiment is developed using the new actuator and coupler. The results show that the surface wave guide formed by a single wire wrapped in a low loss medium can be used as a high speed data transmission channel.

Keywords: Power line communication; electromagnetic wave transmission; surface wave.

1. Introduction
At present, power line communication technology has been studied well, and the scenarios of power line carriers in the power grid have gradually evolved from high-voltage lines to medium- and low-voltage power lines. The power line data communication on the medium-voltage side is slow due to the complex network structure and large attenuation. Low-speed data transmission and limited high-rate testing are still far from practical applications. Surface electromagnetic waves have a transmission effect and can serve as a carrier for transmitting information. Surface electromagnetic waves have become one of the research hotspots.

In recent years, the rigorous solution of the electromagnetic field excited by vertical and horizontal electric dipoles on the surface of a smooth large ball was obtained by Houzonmis and Magnetis. In June 2001, the Home-Plug 1.0 standard released by HPA set the transmission rate to 14 Mbps. Therefore, the transmission performance of power line communication has no need to be verified, and the transmission rate has been recognized by international organizations and industry alliances. Surface wave-based power line communication UWB communication transmission verification mechanism is still in the theoretical research stage, but in general, due to the formation and transmission mechanism of surface waves, it is required to work in the 30-300 GHz frequency band. The mechanism is complicated and the research threshold is high. There are not many researches on the propagation characteristics of this frequency band, and the corresponding surface wave communication mechanism testing methods are insufficient. The development and development of equipment and systems are slow. According to the characteristics of electromagnetic waves, as the frequency increases, the surface wave phenomenon becomes more and more significant, and the surface wave becomes the main component in the conduction system.
In this paper, the electromagnetic surface wave transmission mechanism based on power line network is studied. The formation conditions of surface waves on the power line are studied. The rectangular epitaxial horn coupling device is used to realize the epitaxial expansion of the field mode to realize the surface of power line conductors and wrapping materials of different sizes. The wave pattern is matched so that the electromagnetic field energy is injected into the conductor as much as possible; the square guiding cavity and the medium guiding block are designed, and the main mode electromagnetic energy guiding the electromagnetic wave is concentrated on the surface of the power line conductor and the dielectric layer, and propagates laterally along the conductor. Aiming at the technical preview, the surface wave is used as a breakthrough to provide a verification method and device for the feasibility of ultra-wideband transmission of power-line dielectric wrapped wires, which lays a theoretical foundation for the application of UHF and EHF in power line networks. Verification scheme.

2. Transverse Magnetic Wave Transmission Model of Dielectric Wrapped Wires

In this paper, based on the actual surface wave waveguide transmission, a transverse magnetic wave transmission model of a dielectric wrapped wire is established, including two parts, a simplified model of the dielectric wrapped wire and a simplified model transmission characteristic analysis of the dielectric wrapped wire. The simplified model design of the dielectric wrapped wire is shown in the Fig. 1:

![Figure 1. Simplified analysis model for dielectric wrapped wires.](image)

The transmission length of the wrapped wire of the medium is not fixed. In order to solve the transmission characteristics, combined with the shape distribution of the general medium wrapped wire, the coordinate system is selected by using the cylindrical coordinates. The wire is infinitely long in the z direction and the cross section remains unchanged. The wire and the medium are both circular. The wire radius is b, the medium radius is a, the dielectric constant is $\varepsilon_1, \mu_1$, and the air dielectric constant is $\varepsilon_2, \mu_2$.

2.1. Electromagnetic Field Analysis of Dielectric Wrapped Wire Transmission

Transverse magnetic wave (TM) is the transmission model in TM mode, but the transmission model in TE mode is similar to TM mode. TM mode and TE mode are needed to synthesize the transmission characteristics. Therefore, TM mode and TE mode are analyzed in transmission characteristics analysis.

$$\psi^{m1} = AB_n^{m1}(k_{\rho_1}\rho)\cos(n\phi)e^{-jk_1z}; \quad (1) \quad \text{TM mode}$$

$$\psi^{e1} = BB_n^{e1}(k_{\rho_1}\rho)\sin(n\phi)e^{-jk_1z}; \quad (2) \quad \text{TE mode}$$

The above formula is the basic solution of the medium, and the basic solution of air is:

$$\psi^{m2} = CB_n^{m2}(k_{\rho_2}\rho)\cos(n\phi)e^{-jk_2z}; \quad (1) \quad \text{TM mode}$$
$$\psi^2 = DB^2_z(k_{\rho z}^2 \rho)\sin(n\phi)e^{-jk_{\rho z}^2z}$$}

(2) TE mode

among them, $k_{\rho z}^2 + k_{\phi}^2 = k_1^2 = \omega^2\varepsilon_1\mu_1$, $k_{\rho z}^2 + k_{\phi}^2 = k_2^2 = \omega^2\varepsilon_2\mu_2$

According to the superposition theorem of electromagnetic field, the solution of electromagnetic field can be superposed by the solution of the electric field strength of the single source and the solution of the magnetic induction of the individual source. Therefore, according to the expression equation of wave vector propagation, for TM mode, $\vec{A} = \hat{e}_z\psi$ is substituted into the complex frequency. The Maxwell equations of the domain, and simplified:

$$E_{\rho} = \frac{j\omega\varepsilon}{\mu}\frac{\partial^2\psi}{\partial \rho^2 \partial z^2}, \quad H_{\rho} = \frac{\partial \psi}{\partial \rho \partial \phi}$$

$$E_{\phi} = \frac{j\omega\varepsilon}{\mu}\frac{\partial^2\psi}{\partial \phi^2 \partial z^2}, \quad H_{\phi} = -\frac{\partial \psi}{\partial \rho}$$

$$E_z = \frac{j\omega\varepsilon}{\mu}\left(\frac{\partial^2\psi}{\partial z^2} + k^2\right)\psi, \quad H_z = 0$$

(3)

2.2. Electromagnetic field transmission characteristics of synthetic medium and air

The electromagnetic fields of the medium and air are the synthesis of the respective TM mode and TE mode:

$$\vec{E}_{medium} = \hat{e}_\rho E_{\rho}(\psi^{e}, \psi^{m}) + \hat{e}_\phi E_{\phi}(\psi^{e}, \psi^{m}) + \hat{e}_z E_{z}(\psi^{e}, \psi^{m})$$

(4)

$$\vec{H}_{medium} = \hat{e}_\rho H_{\rho}(\psi^{e}, \psi^{m}) + \hat{e}_\phi H_{\phi}(\psi^{e}, \psi^{m}) + \hat{e}_z H_{z}(\psi^{e}, \psi^{m})$$

(5)

Under the boundary condition, that is, the boundary of $\rho = a$, since neither side of the boundary is a conductive medium, there is no surface current or magnetic current, then there are $H_{z1} = H_{z2}$, $E_{z1} = E_{z2}$, $H_{\phi1} = H_{\phi2}$, $E_{\phi1} = E_{\phi2}$, and substitution can be simplified. The electromagnetic field expression is:

$$\begin{vmatrix}
\varepsilon_1 k_{\rho z}^2 F_1 & 0 & \varepsilon_1 k_{\rho z}^2 F_3 & 0 \\
0 & \mu_k k_{\phi}^2 F_2 & 0 & \mu_k k_{\phi}^2 F_4 \\
k_{\phi} F_1' & k_n F_2 & k_{\rho z} F_3' & k_n F_4' \\
k_{\phi} F_1' & k_n F_2 & k_{\rho z} F_3' & k_n F_4'
\end{vmatrix} = 0$$

(6)

Among them, $F_1 = B_n^{m1}(k_{\rho}(a))$, $F_2 = B_n^{m2}(k_{\phi}(a))$, $F_3 = B_n^{m2}(k_{\rho z}(a))$, $F_4 = B_n^{m2}(k_{\phi}(a))$.

For medium-wrapped conductors, in the air region outside the medium, the field above the medium frequency should be exponentially decaying, while the field below the medium frequency is an outward-propagating wave.

$$F_3 = F_4 = K_n(jk_{\rho z}a) = \frac{\pi}{2}(-j)^{n+1} H_n^{(2)}(k_{\rho z}a)$$

(7)

On the boundary of $\rho = b$, one side is the ideal conductor, and the other side is $\varepsilon_1, \mu_1$, which should satisfy the boundary condition: $E_z = 0, E_\phi = 0$. 


$$F_1 = J_n(k_{\rho}a)N_n(k_{\rho}b) - N_n(k_{\rho}a)J_n(k_{\rho}b)$$  \hfill (8)\\
$$F_2 = J_n(k_{\rho}a)N'_n(k_{\rho}b) - N_n(k_{\rho}a)J'_n(k_{\rho}b)$$  \hfill (9)

When $n=0$, it is TM mode, and the corresponding cutoff frequency is 0, that is, the TM0 mode can transmit without attenuation at all frequencies. The electromagnetic field expression in TM0 mode is a transverse magnetic wave transmission model of a dielectric wrapped wire.

3. Transverse Magnetic Wave Device for Exciting a Dielectric Wrapped Wire

The methods used for wired communication include transmission lines and waveguides. The transmission line is composed of two wires, and the waveguide has a rectangular waveguide, a circular waveguide, a coaxial wire, and the like. A system in which a metal wire located in a medium is used as a transmission mode is a surface electromagnetic wave waveguide. The waveguide system consists of a transmitter, a rectangular waveguide, a surface wave excitation coupling device, a dielectric wrapped wire transmission medium, and a receiver, as shown in the following figure.

![Figure 2. Basic surface diagram of electromagnetic surface wave transmission.](image)

(1) The signal output from the transmitter cannot pass through the rectangular waveguide and cannot directly connect the dielectric to the wire to transmit the medium. The surface wave excitation coupling device efficiently guides electromagnetic waves in the rectangular waveguide onto the dielectric wrapped wire transmission medium, exciting a tightly bound electromagnetic surface wave mode that can be transmitted with low power consumption.

(2) The surface electromagnetic waves on the dielectric-coated wire transmission medium cannot be directly converted to a rectangular waveguide and finally processed by the receiver. The surface wave excitation coupling device efficiently guides the surface wave mode on the dielectric-wrapped wire transmission medium into the rectangular waveguide, exciting the transmission mode of the rectangular waveguide capable of low-loss transmission.

4. Transverse Magnetic Wave Transmission Verification Experiment of Dielectric Wrapped Wires

In this paper, a transverse magnetic wave transmission verification method for dielectric wrapped wires is designed. A method for transmission verification based on surface wave-based power line transmission is designed. From the two dimensions of qualitative (transmission feasibility) and quantitative (transmission performance evaluation), the verification is based on The surface wave of the dielectric wrapped wire electromagnetic wave transmission feasibility.

4.1. Transmission Reliability Test

Arbitrarily select a certain length of dielectric wrapped wire, including but not limited to high voltage, medium and low voltage power lines, etc. One end of the wire is connected to the signal source through the test cable and the connector and the excitation device, and the local oscillator signal source and the baseband signal source are set and applied. Signals and other transmission signals are fed; the other end of the wires is connected to the signal analyzer through the receiving device and the test cable and the connector, and the spectrum and the received signal are recorded. After repeated measurement for a
certain number of times, the spectrum and the signal analyzer receive the spectrum and receive a signal record to determine if the dielectric wrapped wire produces a surface wave and the signal is transmitted along the wire.

![Figure 3.](image)

**Figure 3.** Feasibility verification of transverse magnetic wave transmission of dielectric wrapped wires. The segment of the wire that generates the surface wave is wrapped, the transmission signal is confirmed to be transmitted along the wire, and the transmission performance evaluation is performed. The vector network analyzer is used to measure various parameters of the wave waveguide along the surface of the wire.

4.2. **Transmission Performance Evaluation**

One end of the wire is connected to the vector network analyzer through the test cable and the connector and the excitation/receiving device, and the other end of the wire is also connected to the vector network analyzer through the test cable and the connector and the excitation/receiving device, and the two ends are excited and received. The complementary setting, that is, the excitation at one end and the reception at the other end, through the comparative analysis of the excitation signal and the received signal, the transmission parameters such as the communication rate of the surface wave are measured, and the feasibility of the surface waveguide transmission rate above Gbps is further discussed.

5. **Summary**

In this paper, feasibility verification is taken as part of transmission verification. From the qualitative and quantitative dimensions, a transverse magnetic wave transmission verification method for dielectric wrapped wires is designed to verify the feasibility of electromagnetic wave transmission of dielectric wrapped wires based on surface waves. The possibility of wave field existence proves the performance of surface wave transmission rate, and considers the discontinuity of surface wave transmission, etc., and introduces external signal feeding, which provides a complete technical solution for technical verification based on surface wave transmission.

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