EXCITATION AND USE OF GUIDED SURFACE WAVE MODES ON LOSSY MEDIA

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This Patent Cooperation Treaty Application claims priority to, and the benefit of, co-pending U.S. Patent Application Number 14/483,089 entitled "Excitation and Use of Guided Surface Wave Modes on Lossy Media" filed on September 10, 2014, which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] For over a century, signals transmitted by radio waves involved radiation fields launched using conventional antenna structures. In contrast to radio science, electrical power distribution systems in the last century involved the transmission of energy guided along electrical conductors. This understanding of the distinction between radio frequency (RF) and power transmission has existed since the early 1900's.

SUMMARY OF INVENTION

[0002a] According to a first aspect of the present invention, there is provided a guided surface waveguide probe, comprising:

a charge terminal elevated over a lossy conducting medium; and

a coupling circuit configured to couple an excitation source to the charge terminal, the coupling circuit configured to provide a voltage to the charge terminal that establishes an electric field having a wave tilt (W) that intersects the lossy conducting medium at a tangent of a complex Brewster angle ($\psi_{i,B}$) at a Hankel crossover distance (Rx) from the guided surface waveguide probe.

[0002b] According to a second aspect of the present invention, there is provided a system, comprising:

a guided surface waveguide probe, including:

a charge terminal elevated over a lossy conducting medium; and

a coupling circuit configured to provide a voltage to the charge terminal that establishes an electric field having a wave tilt (W) that intersects the lossy

conducting medium at a tangent of a complex Brewster angle (ψ_0) at a Hankel crossover distance (R_x) from the guided surface waveguide probe; and

an excitation source coupled to the charge terminal via the coupling circuit.

[0002c] According to a third aspect of the present invention, there is provided a method, comprising:

positioning a charge terminal at a defined height over a lossy conducting medium;

positioning a compensation terminal below the charge terminal and over the lossy conducting medium, the compensation terminal separated from the charge terminal by a defined distance; and

exciting the charge terminal and the compensation terminal with excitation voltages having a complex phase difference, where the excitation voltages establish an electric field having a wave tilt (W) that corresponds to a wave illuminating the lossy conducting medium at a complex Brewster angle ($\psi_{i,B}$) at a Hankel crossover distance (R_x) from the charge terminal and the compensation terminal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Many aspects of the present disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

[0004] FIG. 1 is a chart that depicts field strength as a function of distance for a guided electromagnetic field and a radiated electromagnetic field.

[0005] FIG. 2 is a drawing that illustrates a propagation interface with two regions employed for transmission of a guided surface wave according to various embodiments of the present disclosure.

[0006] FIGS. 3A and 3B are drawings that illustrate a complex angle of insertion of an electric field synthesized by guided surface waveguide probes according to the various embodiments of the present disclosure.

CLAIMS

Therefore, the following is claimed:

1. A guided surface waveguide probe, comprising:

a charge terminal elevated over a lossy conducting medium; and

a coupling circuit configured to couple an excitation source to the charge terminal, the coupling circuit configured to provide a voltage to the charge terminal that establishes an electric field having a wave tilt (W) that intersects the lossy conducting medium at a tangent of a complex Brewster angle ($\psi_{i,B}$) at a Hankel crossover distance (R_x) from the guided surface waveguide probe.

2. The guided surface waveguide probe of claim 1, wherein the coupling circuit comprises a coil coupled between the excitation source and the charge terminal.

3. The guided surface waveguide probe of claim 2, wherein the coil is a helical coil.

4. The guided surface waveguide probe of claim 2, wherein the excitation source is coupled to the coil via a tap connection.

5. The guided surface waveguide probe of claim 4, wherein the tap connection is at an impedance matching point on the coil.

6. The guided surface waveguide probe of claim 4, wherein an impedance matching network is coupled between the excitation source and the tap connection on the coil.

7. The guided surface waveguide probe of claim 2, wherein the excitation source is magnetically coupled to the coil.

8. The guided surface waveguide probe of claim 2, wherein the charge terminal is coupled to the coil via a tap connection.

9. The guided surface waveguide probe of claim 1, wherein the charge terminal is positioned at a physical height (h_p) corresponding to a magnitude of an effective height of the guided surface waveguide probe, where the effective height is given by $h_{eff}=R_x \tan \psi_{i,B}=h_p e^{j\Phi}$, with $\psi_{i,B}=(\pi/2)-\theta_{i,B}$ and Φ is a phase of the effective height.

10. The guided surface waveguide probe of claim 9, wherein the phase Φ is approximately equal to an angle W of the wave tilt of illumination that corresponds to the complex Brewster angle.

11. The guided surface waveguide probe of claim 1, wherein the charge terminal has an effective spherical diameter, and the charge terminal is positioned at a height that is at least four times the effective spherical diameter.

12. The guided surface waveguide probe of claim 11, wherein the charge terminal is a spherical terminal with the effective spherical diameter equal to a diameter of the spherical terminal.

13. The guided surface waveguide probe of claim 11, wherein the height of the charge terminal is greater than a physical height (h_p) corresponding to a magnitude of an effective height of the guided surface waveguide probe, where the effective height is given by $h_{eff}=R_x \tan \psi_{i,B}=h_p e^{j\Phi}$, with $\psi_{i,B}=(\pi/2)-\theta_{i,B}$ and Φ is a phase of the effective height.

14. The guided surface waveguide probe of claim 13, further comprising a compensation terminal positioned below the charge terminal, the compensation terminal coupled to the coupling circuit.

15. The guided surface waveguide probe of claim 14, wherein the compensation terminal is positioned below the charge terminal at a distance equal to the physical height (h_p).

16. The guided surface waveguide probe of claim 15, wherein Φ is a complex phase difference between the compensation terminal and the charge terminal.

17. The guided surface waveguide probe of claim 1, wherein the lossy conducting medium is a terrestrial medium.

18. A system, comprising:

a guided surface waveguide probe, including:

a charge terminal elevated over a lossy conducting medium; and

a coupling circuit configured to provide a voltage to the charge terminal that establishes an electric field having a wave tilt (W) that intersects the lossy conducting medium at a tangent of a complex Brewster angle (ψ_0) at a Hankel crossover distance (R_x) from the guided surface waveguide probe; and

an excitation source coupled to the charge terminal via the coupling circuit.

19. The system of claim 18, further comprising a probe control system configured to adjust the guided surface waveguide probe based at least in part upon characteristics of the lossy conducting medium.

20. The system of claim 19, wherein the lossy conducting medium is a terrestrial medium.

21. The system of claim 19, wherein the coupling circuit comprises a coil coupled between the excitation source and the charge terminal, the charge terminal coupled to the coil via a variable tap.

22. The system of claim 21, wherein the coil is a helical coil.

23. The system of claim 21, wherein the probe control system adjusts a position of the variable tap in response to a change in the characteristics of the lossy conducting medium.

24. The system of claim 23, wherein the adjustment of the position of the variable tap adjusts the wave tilt of the electric field to correspond to a wave illumination that intersects the lossy conducting medium at the complex Brewster angle ($\psi_{i,B}$) at the Hankel crossover distance (R_x).

25. The system of claim 22, wherein the guided surface waveguide probe further comprises a compensation terminal positioned below the charge terminal, the compensation terminal coupled to the coupling circuit.

26. The system of claim 25, wherein the compensation terminal is positioned below the charge terminal at a distance equal to a physical height (h_p) corresponding to a magnitude of an effective height of the guided surface waveguide probe, where the effective height is given by $h_{eff}=R_x \tan \psi_{i,B}=h_p e^{j\Phi}$, with $\psi=(\pi/2)-\theta_{i,B}$ and wherein Φ is a complex phase difference between the compensation terminal and the charge terminal.

27. The system of claim 25, wherein the probe control system adjusts a position of the compensation terminal in response to a change in the characteristics of the lossy conducting medium.

28. A method, comprising:

positioning a charge terminal at a defined height over a lossy conducting medium;

positioning a compensation terminal below the charge terminal and over the lossy conducting medium, the compensation terminal separated from the charge terminal by a defined distance; and

exciting the charge terminal and the compensation terminal with excitation voltages having a complex phase difference, where the excitation voltages establish an electric field having a wave tilt (W) that corresponds to a wave illuminating the lossy conducting medium at a complex Brewster angle ($\psi_{i,B}$) at a Hankel crossover distance (R_x) from the charge terminal and the compensation terminal.

29. The method of claim 28, wherein the charge terminal has an effective spherical diameter, and the charge terminal is positioned at the defined height is at least four times the effective spherical diameter.

30. The method of claim 28, wherein the defined distance is equal to a physical height (h_p) corresponding to a magnitude of an effective height of the charge terminal, where the effective height is given by $h_{eff}=R_x \tan \psi_{i,B}=h_p e^{j\Phi}$, with $\psi=(\pi/2)-\theta_{i,B}$ and wherein Φ is the complex phase difference between the compensation terminal and the charge terminal.

31. The method of claim 28, wherein the charge terminal and the compensation terminal are coupled to an excitation source via a coil, the charge terminal coupled to the coil by a variable tap.

32. The method of claim 31, further comprising adjusting a position of the variable tap to establish the electric field with the wave tilt intersecting the lossy conducting medium at the complex Brewster angle ($\psi_{i,B}$) at the Hankel crossover distance (R_x).