BACKGROUND

[0003] 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

[0004] Embodiments of the present disclosure are related to adaptation of polyphase waveguide probes.

[0004a] According to a first aspect of the present invention, there is provided a method, comprising: exciting a first charge terminal and a second charge terminal of a polyphase waveguide probe with excitation voltages to synthesize a plurality of fields that substantially match a guided surface-waveguide mode of the lossy conducting medium to transmit energy along a surface of the lossy conducting medium via a radial surface current, the first charge terminal positioned at a defined height over the lossy conducting medium and the second charge terminal positioned below the first charge terminal by a defined distance; detecting a change in operating conditions associated with the polyphase waveguide probe comprising detecting a change in an electric field strength associated with the radial surface current or detecting a change in conductivity of the lossy conducting medium; and in response to the detected change, adjusting the polyphase probe to improve the matching of the guided surface waveguide mode.

[0004b] According to a second aspect of the present invention, there is provided a system, comprising: a polyphase waveguide probe configured to create a plurality of resultant fields that are substantially mode-matched to a Zenneck surface wave mode on a surface of a lossy conducting medium, the polyphase waveguide probe configured to impose a plurality of voltage magnitudes and a plurality of phases on a plurality of charge terminals; and a probe control system configured to adjust the polyphase waveguide probe based at least in part upon characteristics of the lossy

conducting medium, wherein the probe control system is configured to adjust the plurality of voltage magnitudes and the plurality of phases on the plurality of charge terminals to improve the mode-matching of the Zenneck surface wave mode in response to a detected change in the characteristics of the lossy conducting medium.

[0005] There is disclosed a method comprises exciting a first charge terminal and a second charge terminal of a polyphase waveguide probe with excitation voltages to synthesize a plurality of fields that substantially match a guided surface-waveguide mode of the lossy conducting medium to transmit energy along a surface of the lossy conducting medium via a radial surface current, detecting a change in operating conditions associated with the polyphase waveguide probe and, in response to the detected change, adjusting the polyphase probe to improve the matching of the guided surface waveguide mode. The first charge terminal can be positioned at a defined height over the lossy conducting medium and the second charge terminal positioned below the first charge terminal by a defined distance. Detecting the change in operating conditions associated with the polyphase waveguide probe can comprise detecting a change in an electric field strength associated with the radial surface current.

[0006] The change in the electric field strength can be detected by a field meter located beyond a defined radial distance from the polyphase waveguide probe. The defined radial distance can be associated with a transition between a close-in radial surface current and a far-out radial surface current of the polyphase waveguide probe. Detecting the change in operating conditions associated with the polyphase waveguide probe can comprise detecting a change in conductivity of the lossy conducting medium. The change in the conductivity can be detected by a ground parameter meter located at a defined radial distance from the polyphase waveguide probe. The defined radial distance

can be associated with a transition between a close-in radial surface current and a far-out radial surface current of the polyphase waveguide probe. The lossy conducting medium can be a terrestrial medium. The resultant fields can be substantially mode-matched to a Zenneck surface wave mode on a surface of the terrestrial medium.

[0007] Adjusting the polyphase probe can comprise adjusting a height of the first charge terminal and/or a height of the second charge terminal above the lossy conducting medium. The defined distance between the first and second charge terminals can remain the same. The first charge terminal and the second charge terminal can be coupled to an excitation source via a coil. The first charge terminal can be coupled to the coil via a variable tap and adjusting the polyphase probe can comprise adjusting a position of the variable tap on the coil, and/or the second charge terminal can be coupled to the coil via a variable tap and adjusting the polyphase probe can comprise adjusting a position of the variable tap on the coil. Adjusting the polyphase probe can comprise adjusting a size of the first charge terminal or a size of the second charge terminal.

[0008] A radial surface current density of the guided surface-waveguide mode can be substantially expressed by

$$J_{\rho}(\rho,\phi,0) = \frac{I_o \gamma}{4} H_1^{(2)}(-j\gamma\rho),$$

where γ is a surface wave radial propagation constant given by $\gamma = j\sqrt{k_o^2 + u_2^2}$ and u_2 is a vertical propagation constant given by $u_2 = \frac{-jk_o}{\sqrt{1 + (\varepsilon_r - jx)}}$, where $x \equiv \frac{\sigma}{\omega\varepsilon_o}$, σ is a conductivity of the terrestrial medium, ω is equal to $2\pi f$, where f is a frequency of excitation of the polyphase waveguide probe, ε_o is a permittivity of free space, ε_r is a relative permittivity of the terrestrial medium, and a free-space wave number $\mathrm{k_o}$ is equal to $\frac{2\pi}{\lambda_o}$, where λ_o is a free-space wavelength of the polyphase waveguide probe, j is equal to $\sqrt{-1}$, ρ is a radial coordinate, z is a vertical coordinate normal to the terrestrial medium, φ is an azimuthal coordinate, I_o is a net polyphase probe current, and $\mathrm{H_1^{(2)}}(-j\gamma\rho)$ is a Hankel function of a second kind and a first order with a complex argument $-j\gamma\rho$, for an $e^{+j\omega t}$ time variation, where t is time.

[0009] There is disclosed a system, comprises a polyphase waveguide probe configured to create a plurality of resultant fields that are substantially mode-matched to a Zenneck surface wave mode on a surface of a lossy conducting medium, and a probe control system configured to adjust the polyphase waveguide probe based at least in part upon characteristics of the lossy conducting medium. The probe control system can be configured to adjust the polyphase waveguide probe to improve the mode-matching of the Zenneck surface wave mode in response to a detected change in the characteristics of the lossy conducting medium.

[0010] The polyphase waveguide probe can comprise a probe coupling circuit coupled to a plurality of charge terminals, the probe coupling circuit configured to impose a plurality of voltage magnitudes and a plurality of phases on the plurality of charge terminals. The probe control system can be configured to adjust the plurality of voltage magnitudes and the plurality of phases on the plurality of charge terminals to improve the mode-matching of the Zenneck surface wave mode. The plurality of charge terminals can be coupled to a coil of the probe coupling circuit via at least one variable tap. Adjusting the plurality of voltage magnitudes and the plurality of phases on the plurality of charge terminals can comprise adjusting a position of the at least one variable tap. The probe control system can be configured to adjust the position of the at least one variable tap via a tap controller. The probe control system can be configured to adjust a height of at least one charge terminal of the plurality of charge terminals above the lossy conducting medium to improve the mode-matching of the Zenneck surface wave mode. The probe control system can be configured to reposition the at least one charge terminal via a charge terminal positioning system.

[0011] A radial surface current density of the Zenneck surface wave mode can be substantially expressed by

$$J_{\rho}(\rho,\phi,0) = \frac{I_o \gamma}{4} H_1^{(2)}(-j\gamma\rho),$$

where γ is a surface wave radial propagation constant given by $\gamma = j\sqrt{k_o^2 + u_2^2}$ and u_2 is a vertical propagation constant given by $u_2 = \frac{-jk_o}{\sqrt{1 + (\varepsilon_r - jx)}}$, where

CLAIMS

1. A method, comprising:

exciting a first charge terminal and a second charge terminal of a polyphase waveguide probe with excitation voltages to synthesize a plurality of fields that substantially match a guided surface-waveguide mode of the lossy conducting medium to transmit energy along a surface of the lossy conducting medium via a radial surface current, the first charge terminal positioned at a defined height over the lossy conducting medium and the second charge terminal positioned below the first charge terminal by a defined distance;

detecting a change in operating conditions associated with the polyphase waveguide probe comprising detecting a change in an electric field strength associated with the radial surface current or detecting a change in conductivity of the lossy conducting medium; and

in response to the detected change, adjusting the polyphase probe to improve the matching of the guided surface waveguide mode.

2. The method of claim 1, wherein the change in the electric field strength is detected by a field meter located beyond a defined radial distance from the polyphase waveguide probe, the defined radial distance associated with a transition between a close-in radial surface current and a far-out radial surface current of the polyphase waveguide probe.

3. The method of claim 1, wherein the change in the conductivity is detected by a ground parameter meter located at a defined radial distance from the polyphase waveguide probe, the defined radial distance associated with a transition between a close-in radial surface current and a far-out radial surface current of the polyphase waveguide probe.

4. The method of claim 1, wherein the lossy conducting medium is a terrestrial medium.

5. The method of claim 4, wherein the resultant fields are substantially mode-matched to a Zenneck surface wave mode on a surface of a terrestrial medium.

6. The method of claim 1, wherein adjusting the polyphase probe comprises adjusting a height of the first charge terminal or a height of the second charge terminal above the lossy conducting medium.

7. The method of claim 6, wherein adjusting the polyphase probe comprises adjusting the height of the first charge terminal and the height of the second charge terminal above the lossy conducting medium.

8. The method of claim 7, wherein the defined distance between the first and second charge terminals remains the same.

9. The method of claim 1, wherein the first charge terminal and the second charge terminal are coupled to an excitation source via a coil.

10. The method of claim 9, wherein the first charge terminal is coupled to the coil via a variable tap and adjusting the polyphase probe comprises adjusting a position of the variable tap on the coil.

11. The method of claim 10, wherein the second charge terminal is coupled to the coil via a second variable tap and adjusting the polyphase probe further comprises adjusting a position of the second variable tap on the coil.

12. The method of claim 9, wherein the second charge terminal is coupled to the coil via a variable tap and adjusting the polyphase probe comprises adjusting a position of the variable tap on the coil.

13. The method of claim 1, wherein adjusting the polyphase probe comprises adjusting a size of the first charge terminal or a size of the second charge terminal.

14. The method of claim 1, wherein a radial surface current density of the guided surface-waveguide mode is substantially expressed by

$$J_{\rho}(\rho,\phi,0) = \frac{I_o \gamma}{4} H_1^{(2)}(-j\gamma\rho),$$

where γ is a surface wave radial propagation constant given by $\gamma = j\sqrt{k_o^2 + u_2^2}$ and u_2 is a vertical propagation constant given by

$$u_2 = \frac{-jk_o}{\sqrt{1 + (\varepsilon_r - jx)}}, \text{ where } x \equiv \frac{\sigma}{\omega\varepsilon_o},$$

σ is a conductivity of the terrestrial medium, ω is equal to $2\pi f$, where f is a frequency of excitation of the polyphase waveguide probe, ε_o is a permittivity of free space, ε_r is a relative permittivity of the terrestrial medium, and a free-space wave number k_o is equal to

$$\frac{2\pi}{\lambda_o},$$

where λ_o is a free-space wavelength of the polyphase waveguide probe, j is equal to $\sqrt{-1}$, ρ is a radial coordinate, z is a vertical coordinate normal to the terrestrial medium, φ is an azimuthal coordinate, I_o is a net polyphase probe current, and $H_1^{(2)}(-j\gamma\rho)$ is a Hankel function of a second kind and a first order with a complex argument $-j\gamma\rho$, for an $e^{+j\omega t}$ time variation, where t is time.

15. A system, comprising:

a polyphase waveguide probe configured to create a plurality of resultant fields that are substantially mode-matched to a Zenneck surface wave mode on a surface of a lossy conducting medium, the polyphase waveguide probe configured to impose a plurality of voltage magnitudes and a plurality of phases on a plurality of charge terminals; and

a probe control system configured to adjust the polyphase waveguide probe based at least in part upon characteristics of the lossy conducting medium, wherein the probe control system is configured to adjust the plurality of voltage magnitudes and the plurality of phases on the plurality of charge terminals to improve the mode-matching of the Zenneck surface wave mode in response to a detected change in the characteristics of the lossy conducting medium.

16. The system of claim 15, wherein a radial surface current density of the Zenneck surface wave mode is substantially expressed by

$$J_{\rho}(\rho,\phi,0) = \frac{I_o \gamma}{4} H_1^{(2)}(-j\gamma\rho),$$

where γ is a surface wave radial propagation constant given by $\gamma = j\sqrt{k_o^2 + u_2^2}$ and u_2 is a vertical propagation constant given by $u_2 = \frac{-j k_o}{\sqrt{1 + (\varepsilon_r - j x)}}$, where $x = \frac{\sigma}{\omega \varepsilon_o}$, σ is a conductivity of the lossy conducting medium, ω is equal to $2\pi f$, where f is a frequency of excitation of the polyphase waveguide probe, ε_o is a permittivity of free space, ε_r is a relative permittivity of the lossy conducting medium, and a free-space wave number k_o is equal to $\frac{2\pi}{\lambda_o}$, where λ_o is a free-space wavelength of the polyphase waveguide probe, j is equal to $\sqrt{-1}$, ρ is a radial coordinate, z is a vertical coordinate normal to the terrestrial medium, φ is an azimuthal coordinate, I_o is a net polyphase probe current, and $H_1^{(2)}(-j\gamma\rho)$ is a Hankel function of a second kind and first order with complex argument $-j\gamma\rho$, for an $e^{+j\omega t}$ time variation, where t is time.

17. The system of claim 15, wherein the polyphase waveguide probe comprises a probe coupling circuit coupled to the plurality of charge terminals, the probe coupling circuit configured to impose the plurality of voltage magnitudes and the plurality of phases on the plurality of charge terminals.

18. The system of claim 15, wherein the plurality of charge terminals are coupled to a coil of the probe coupling circuit via at least one variable tap.

19. The system of claim 18, wherein adjusting the plurality of voltage magnitudes and the plurality of phases on the plurality of charge terminals comprises adjusting a position of the at least one variable tap.

20. The system of claim 19, wherein the probe control system is configured to adjust the position of the at least one variable tap via a tap controller.

21. The system of claim 15, wherein the probe control system is configured to adjust a height of at least one charge terminal of the plurality of charge terminals above the lossy conducting medium to improve the mode-matching of the Zenneck surface wave mode.

22. The system of claim 21, wherein the probe control system is configured to reposition the at least one charge terminal via a charge terminal positioning system.