[0002d] ~~According to a fourth aspect of the present invention, there is provided~~ There is also disclosed an apparatus, comprising: a receive circuit operable to receive energy transmitted from a polyphase waveguide probe in a form of a Zenneck surface wave along a surface of a lossy conducting medium when the receive circuit is positioned above the lossy conducting medium.

[0002e] According to a ~~fifth~~ fourth aspect of the present invention, there is provided a power transmission system, comprising: a polyphase waveguide probe formed of a plurality of charge terminals positioned relative to a lossy conducting medium; an excitation source coupled to the plurality of charge terminals, wherein the excitation source is operable to excite the plurality of charge terminals, the excitation of the plurality of charge terminals generating a plurality of electromagnetic fields which are substantially mode-matched to a Zenneck surface wave mode on a surface of the lossy conducting medium; and a receive circuit operable to receive electrical energy from the polyphase waveguide probe via a guided surface wave along the surface of the lossy conducting medium.

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 a 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] FIG. 3 is a drawing that illustrates a polyphase waveguide probe disposed with respect to a propagation interface of FIG. 2 according to an embodiment of the present disclosure.

[0007] FIG. 4 is a drawing that provides one example illustration of a phase shift in a ground current that facilitates the launching of a guided surface-waveguide mode on a lossy conducting medium in the propagation interface of FIG. 3 according to an embodiment of the present disclosure.

8. The apparatus of any one of claims 3-7, 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 $u_2 = \frac{-jk_o}{\sqrt{1 + (\varepsilon_r - jx)}}$, 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 lossy conducting 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.

9. The apparatus of any one of claims 3-8, wherein the Zenneck surface wave mode is substantially expressed as

$$H_\phi = \frac{-\gamma I_o}{4} e^{-u_2 z} H_1^{(2)}(-j\gamma\rho),$$

$$E_\rho = \frac{-\gamma I_o}{4}\left(\frac{u_2}{j\omega\varepsilon_o}\right) e^{-u_2 z} H_1^{(2)}(-j\gamma\rho), \text{ and}$$

$$E_z = \frac{-\gamma I_o}{4}\left(\frac{-\gamma}{\omega\varepsilon_o}\right) e^{-u_2 z} H_0^{(2)}(-j\gamma\rho)$$

where H_ϕ is an azimuthal magnetic field strength, E_ρ is a radial electric field strength, E_z is a vertical electric field strength, 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 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

conducting lossy 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 lossy conducting medium, φ is an azimuthal coordinate, I_o is a net polyphase probe current, $H_1^{(2)}(-j\gamma\rho)$ is a Hankel function of a second kind and first order with complex argument $-j\gamma\rho$, and $H_0^{(2)}(-j\gamma\rho)$ is a Hankel function of a second kind and zero order with complex argument $-j\gamma\rho$ for an $e^{+j\omega t}$ time variation, where t is time.

10. The apparatus of any one of claim 3-7 or 8-9, wherein the excitation source is configured to apply a plurality of voltage magnitudes and a plurality of phases on the plurality of charge terminals.

11. The apparatus of claim 10, wherein the polyphase waveguide probe further comprises a coil coupled between the charge terminals.

12. A method, comprising:

positioning a receive circuit above a surface of a terrestrial medium; and

receiving, via the receive circuit, energy transmitted from a polyphase waveguide probe in a form of a Zenneck surface wave along the surface of the terrestrial medium.

13. The method of claim 12, wherein an electrical load coupled to the receive circuit loads an excitation source coupled to the polyphase waveguide probe that produces the Zenneck surface wave.

14. The method of claim 12, wherein the energy comprises electrical power, and the method further comprises applying the electrical power to an electrical load coupled to the receive circuit, where the electrical power is used as a power source for the electrical load.

15. The method of any one of claims ~~12~~-13 or 14, further comprising impedance-matching ~~an~~ the electrical load to the receive circuit.

16. The method of any one of claims 13-15, further comprising establishing a maximum power transfer from the receive circuit to the electrical load.

~~17. An apparatus, comprising:~~

~~a receive circuit operable to receive energy transmitted from a polyphase waveguide probe in a form of a Zenneck surface wave along a surface of a lossy conducting medium when the receive circuit is positioned above the lossy conducting medium.~~

~~18. The apparatus of claim 17, wherein the lossy conducting medium is or includes a terrestrial medium.~~

~~19. The apparatus of any one of claims 17 or 18, wherein an electrical load coupled to the receive circuit loads an excitation source coupled to the polyphase waveguide probe that generates the Zenneck surface wave.~~

~~20. The apparatus of any one of claims 17-19, wherein the receive circuit further comprises one of a magnetic coil, a linear probe, or a tuned resonator.~~

~~21~~17. A power transmission system, comprising:

a polyphase waveguide probe formed of a plurality of charge terminals positioned relative to a lossy conducting medium;

an excitation source coupled to the plurality of charge terminals, wherein the excitation source is operable to excite the plurality of charge terminals, the excitation of the plurality of charge terminals generating a plurality of electromagnetic fields which are substantially mode-matched to a Zenneck surface wave mode on a surface of the lossy conducting medium; and

a receive circuit operable to receive electrical energy from the polyphase waveguide probe via a guided surface wave along the surface of the lossy conducting medium.

~~22~~18. The power transmission system of claim ~~24~~17, wherein an electrical load coupled to the receive circuit loads the polyphase waveguide probe.

~~23~~19. The power transmission system of claim 17~~21~~, wherein an electrical load is coupled to the receive circuit and the electrical energy is used as a power source for the electrical load.

~~24~~20. The power transmission system of any one of claims ~~22~~ 18 or ~~23~~19, wherein a maximum power transfer is established from the receive circuit to the electrical load.