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# Antennas for Transmitting Fast Transients Through an Air/Earth Interface

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## Abstract

This paper summarizes various kinds of antennas utilizing fast transient electromagnetic fields for scattering from buried targets. The emphasis here is on the influence of the earth/air interface on antenna location and orientation. One class of such antennas is in contact with the earth surface, giving efficient coupling to the soil, but at the price of longer times to set up and move the antennas. The second class consists of antennas above and spaced away from the ground surface. Both classes make use of Brewster-angle concepts in varying degrees in matching the fields into the ground.

## 1. Introduction

In identifying buried targets, one approach consists of transmitting a fast transient electromagnetic (EM) wave into the earth to scatter from the target and be received by the same or a different antenna for processing to find the aspect-independent complex resonant frequencies appearing in the singularity-expansion-method (SEM) representation of the target scattering [10, 11, 12]. Typical important frequencies in the transient wave are in the hundreds of MHz, perhaps extending above or below this depending on target dimensions and the permittivity of the target (if dielectric) and surrounding medium. The conductivity of the soil is quite important, limiting the depth of targets to which the technique can be applied due to the attenuation of such EM waves.

For this purpose one needs appropriate antennas for transmission and reception. Such antennas can be located in principle at various locations in the earth or above the earth surface. For convenience in setting up and moving the antennas it is preferable that they be on or above the earth surface. There is of course, a limitation of how deep the targets can be buried due to the ground conductivity and the associated attenuation of the electromagnetic wave. In any event one can look at antennas appropriate to this class of ground penetrating radars to consider their relative advantages and disadvantages.

Figure 1.1 indicates various possible antenna locations (whether for transmission, reception, or both). Each has its distinct characteristics as an electromagnetic boundary-value problem, involving not only the antenna geometry, but also the earth surface and soil characteristics. The case of a buried antenna is not considered here. Moving up, one can have an antenna in contact with or just above the earth surface. Which of these is appropriate in a given circumstance depends on the properties of the earth surface and the desired rapidity of measurement (setting up, taking down, and moving the antenna). Finally, one can have an antenna above the earth surface which can be very mobile, but which has less efficient coupling to the target.

These antennas can be of various kinds. For the high frequencies of interest, for which the antennas can be significantly directive, it is convenient to think of these in terms of an antenna aperture which can be many wavelengths across for at least some of the frequencies of interest in the transient wave. As indicated in fig. 1.2, this aperture might be at (or near) and parallel to the earth surface, or above the earth surface with a more general orientation. By appropriate orientation of the antenna aperture and/or the field distribution on the aperture the wave can be given a desired direction of incidence above and/or below the earth surface.

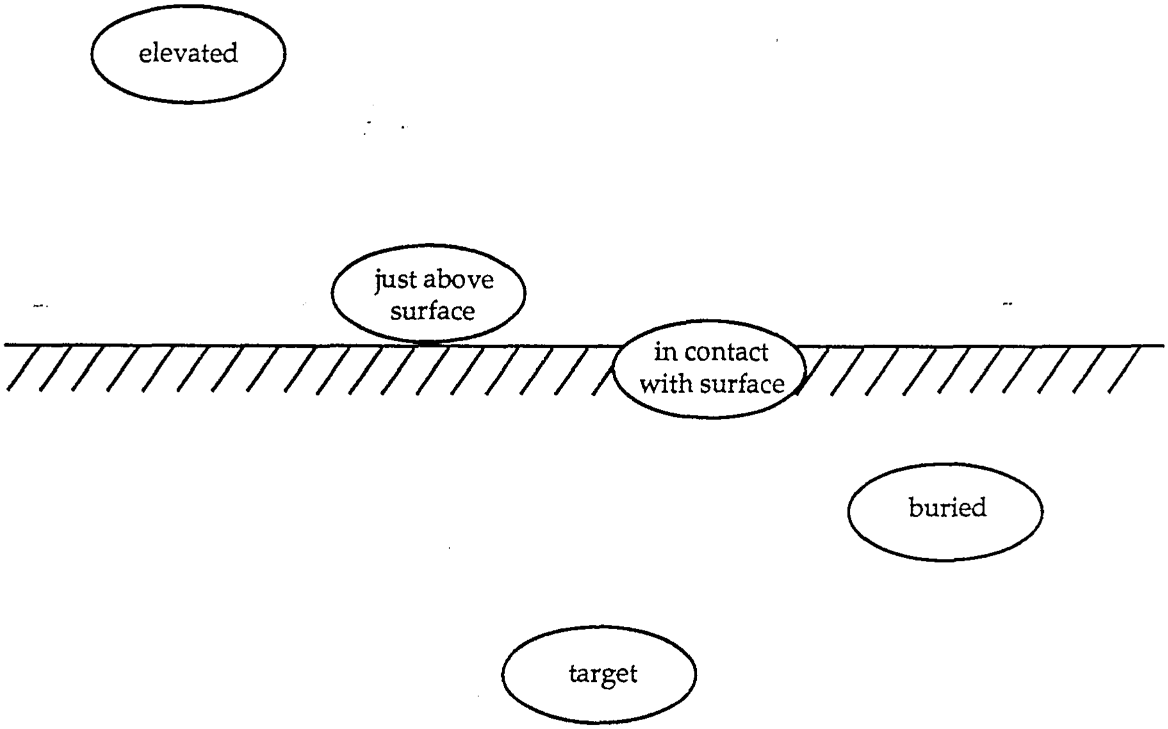


Fig. 1.1 Antenna Locations

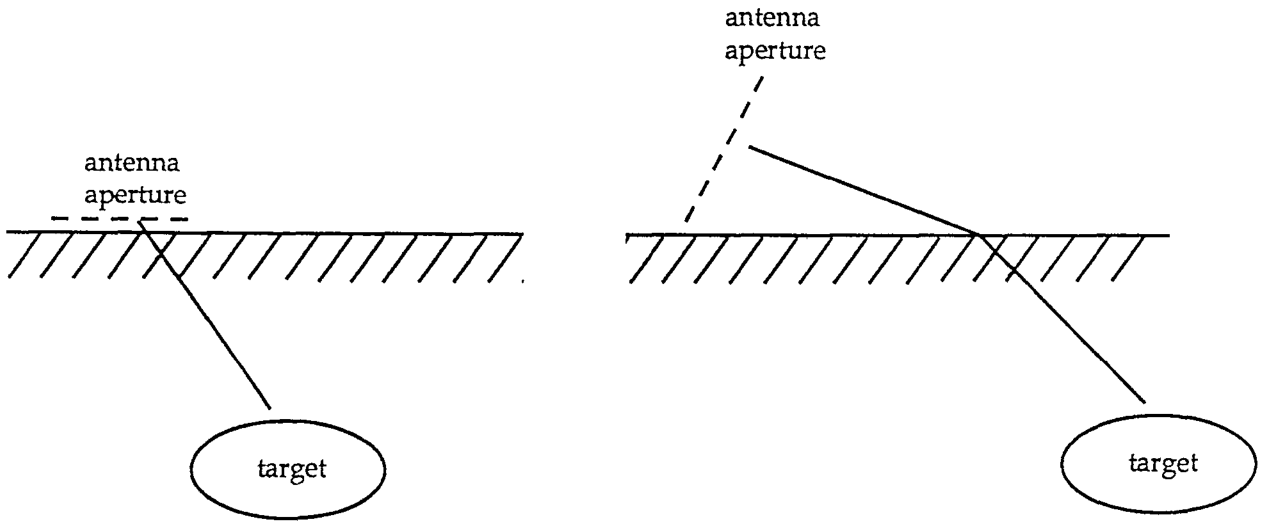


Fig. 1.2 Antenna Apertures At or Above the Earth Surface

## 2. Antennas at Earth Surface

For antennas at the earth surface with many wavelengths across the aperture at the ground surface, there is the basic problem of matching waves into the ground. Fig. 2.1A shows one way to accomplish this by utilizing the approximate Brewster angle (for vertical polarization) for the air (or other dielectric above the earth surface) and the soil [1]. In this case, there is a TEM wave launched on a flat-plate conical transmission line with a small angle of divergence such that for at least the centrally located rays the wave is transmitted through the interface of the two dielectrics at the Brewster angle [7] given by

$$\begin{aligned} \tan(\psi_{iB}) &= \left[\frac{\varepsilon_2}{\varepsilon_1}\right]^{\frac{1}{2}} = \cot(\psi_{tB}) \\ \psi_{iB} + \psi_{tB} &= \frac{\pi}{2} \end{aligned} \qquad (2.1)$$

Note that the soil conductivity $\sigma_2$ limits the application of the Brewster-angle concept to radian frequencies $\omega >> \sigma_2/\varepsilon_2$. This can be complicated by surface irregularities, soil inhomogeneities and frequency dependence of $\varepsilon_2$ and $\sigma_2$. There is also the question of the contact of the conductors to the soil surface. Ideally these penetrate into the ground in the same direction as the rays (i.e., $\simeq \psi_{tB}$).

By introducing highly conducting sheets to make an anisotropic lens region with variable $\varepsilon_1$, one can also match the wave into the soil with vertical (or other) direction of propagation in the soil. In [3, 13] such a lens is discussed with a two-dimensional shape, independent of one transverse coordinate (the coordinate normal to the page in fig. 2.1B).

Another approach is that used for the DISCUS elements [2, 4, 5, 6]. Each element is designed to maintain an approximately constant characteristic impedance (transmission-line sense) from the source via a parallel-plate lateral transmission line (fig. 2.1C). This takes the form of a flange on the two sloping plates which in turn connect to the ground. In part, the wave between these plates is also incident on the ground at near the Brewster angle. Note that the soil permittivity $\varepsilon_2$ lowers the transmission-line impedance below the ground surface. (Note the conducting connections into the ground.) This low impedance is achieved above this ground surface by the sloping plates (oriented near the Brewster angle) forming two approximate "transmission lines" above the ground surface with impedance proportional to the small height (near the flange) of these plates above the ground.

Taking an array of such elements as in fig. 2.1D one can create a rather large antenna aperture at the earth surface if this surface is sufficiently flat or at least smooth. By triggering the sources in a plane-wave sequence various propagation directions in the soil are possible. In this case the individual elements need to be sufficiently small in terms of wavelengths.

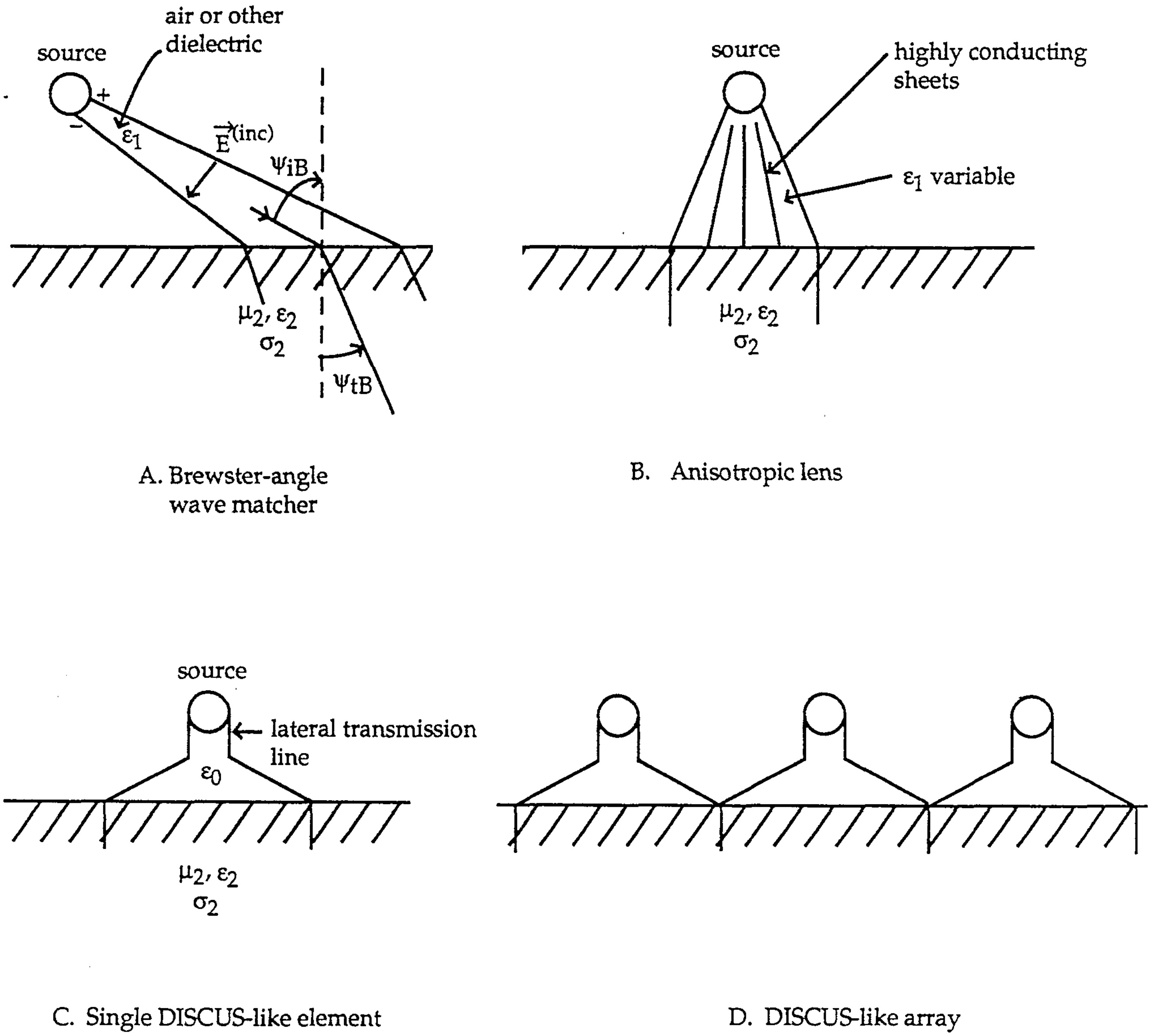


Fig. 2.1 Antennas at the Earth Surface for Transmitting and/or Receiving Subsurface Waves

The various antennas in fig. 2.1 can be used in transmission and reception. One can use the same antenna for both, or use separate antennas for each function. In the latter case the relatively large signal from the transmitter is reduced at the receiver so that the scattered signal can be better measured. One can also position and orient the two antennas (cross polarization) to minimize the direct coupling.

Note that the various antennas in fig. 2 are all ideally in electrical contact with the earth surface. This restricts the use of such antennas in the sense that they are not as quickly moved as those not in contact with the earth. In this latter case other kinds of antennas are more appropriate.

3. Above-Ground Antennas

Now consider antennas above the earth surface at a sufficient distance (and orientation) that the presence of the soil does not significantly affect the antenna performance. The actual antenna(s) could have several possible designs. As indicated in fig. 3.1 this could be a reflector IRA (impulse radiating antenna) [9, 14, 15]. Comparing to fig. 1.2 this is a type of aperture with respect to the ground surface so as to have its main beam incident (with vertical polarization) at the Brewster angle $\psi_{iB}$ as in (2.1). Such an antenna can be mounted on some portable platform (e.g., the back of a pickup truck). The beam of such an antenna is mechanically steered by rotating the antenna. One can also use an array IRA, in which case the beam is electronically steered, making the antenna more complex due to the large number of small elements making up the array [8].

As indicated in fig. 3.1, by using vertical polarization and orienting the transmitting antenna so that its main beam meets the earth surface at the Brewster angle $\psi_{iB}$, not only is the transmitted wave into the soil (at angle $\psi_{tB}$) maximized, but also the scattered (reflected) wave from the earth surface (at angle $\psi_{iB}$) is minimized. A receiver positioned beyond the target from the transmitter (as in fig. 3.1) then sees the small scattered wave from the ground surface. By adjusting antennas to minimize this surface scattering, one obtains a measurement of $\psi_{iB}$ and thereby the permittivity $\varepsilon_2$ of the soil via (2.1). In this position one can also receive (at a later time) the scattered wave from the target. Note that this target-scattered wave propagates up through the soil at angle $\psi_{tB}$, exiting at $\psi_{iB}$ on its way to the receiving antenna. If the two antennas are identical and at the same elevation with symmetrical (rotation and/or reflection) orientation, then the half-way point between the two antennas lies above the target.

The receiving antenna can also be moved to other points on a circle centered on the target while maintaining the same orientation with respect to the target as indicated in fig. 3.2. By moving the receiver away from the position directly opposite the transmitter one avoids the ideally small ground-surface-scattered wave in the receiver. One can position the antennas at various places around the target to take advantage of the aspect dependence of the pole residues [10], thereby maximizing the signal associated with the aspect-independent natural frequencies. Utilizing the Brewster angle for transmission through the earth surface, the polarization is constrained to be vertical. If one uses horizontal polarization as well so as to obtain more aspect information, the target-scattered signal will be reduced by scattering of the waves at the earth surface (both on entering and leaving the soil).

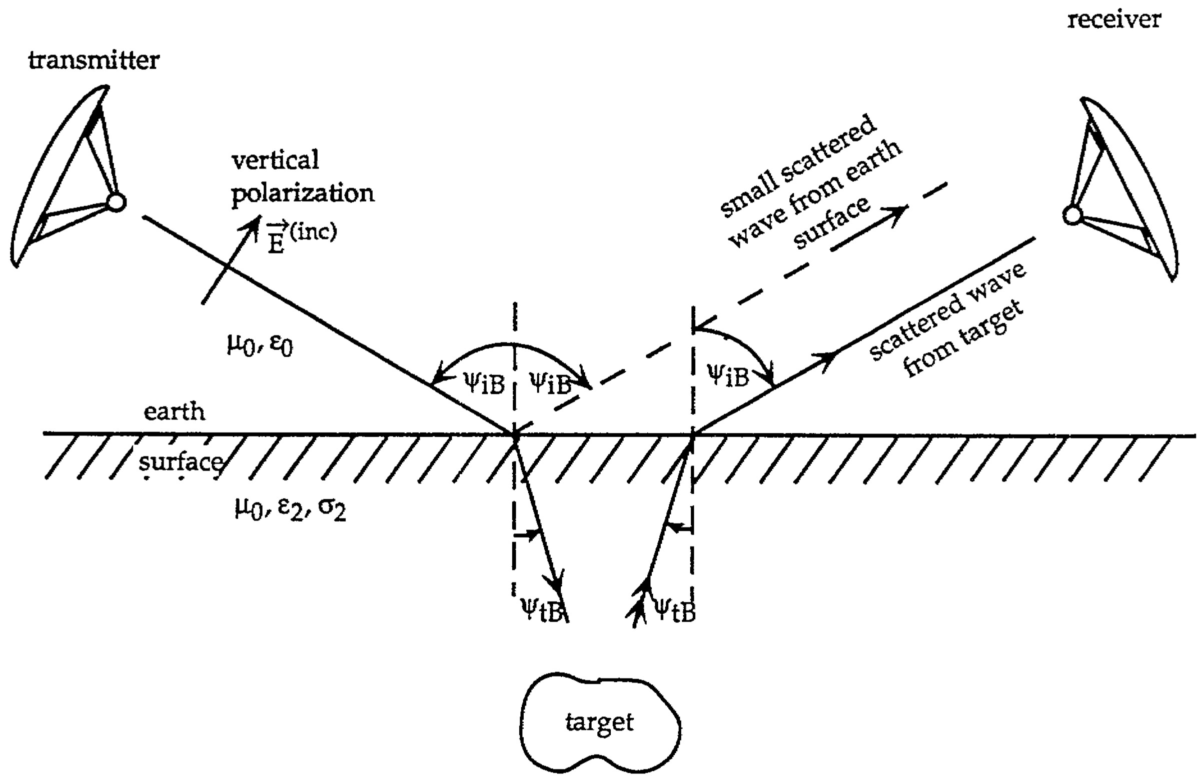


Fig. 3.1 Reflector IRA Oriented at Brewster Angle to Earth Surface: Side View.

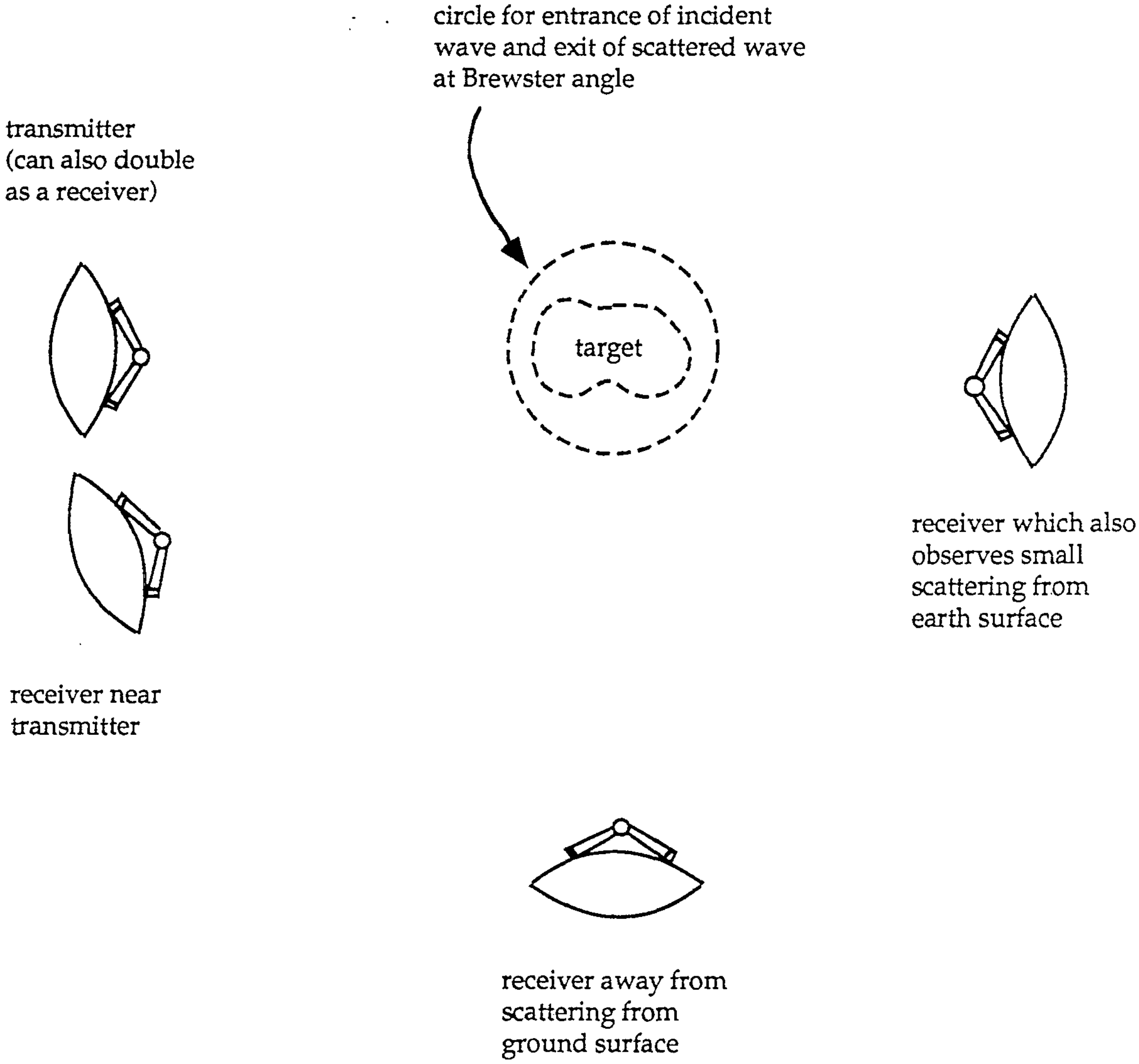


Fig. 3.2 Transmitting and Receiving Antennas Oriented at Brewster Angle: Top View.

## 4. Concluding Remarks

The two kinds of antennas, those at and above the ground surface, have advantages and disadvantages for identifying subsurface targets. A significant factor is the time one is willing to spend investigating a particular target, since setting up and taking down the antennas can be quite different in the two cases. The smoothness and accessibility of a particular patch of ground surface also affects the decision concerning use of a ground-contacting antenna.

One may use one antenna for both transmission and reception for convenience. Using two antennas to separate these roles and provide greater signal-to-noise ratio, one has two antennas to choose. These need not be the same, but may be so for convenience. One antenna may be in contact with the earth surface while a second is moved around above the earth surface.

References


1. C. E. Baum, The Brewster Angle Wave Matcher, Sensor and Simulation Note 37, March 1967.

2. C. E. Baum, EMP Simulators for Various Types of Nuclear EMP Environments: An Interim Categorization, Sensor and Simulation Note 240, January 1978, and IEEE Trans. Antennas and Propagation, 1978, pp. 35-53, and IEEE Trans. EMC, 1978, pp. 35-53.

3. A. P. Stone and C. E. Baum, An Anisotropic Lens for Transitioning Plane Waves Between Media of Different Permittivities, Sensor and Simulation Note 291, April 1986, and IEEE Trans. Antennas and Propagation, 1988, pp. 1571-1579.

4. Y.- G. Chen, S. Lloyd, R. Crumley, C. E. Baum, and D. V. Giri, Design Procedures for Arrays Which Approximate a Distributed Source at the Air-Earth Interface, Sensor and Simulation Note 292, May 1986.

5. T. M. Flanagan, C. E. Mallon, R. Denson, and R. Leadon, A Wide-Bandwidth Electric-Field Sensor for Lossy Media, Sensor and Simulation Note 297, January 1987.

6. Y.- G. Chen, S. Lloyd, R. Crumley, C. E. Baum, Low Voltage Experiments Concerning a Section of a Pulser Array Near the Air-Earth Interface, Sensor and Simulation Note 322, February 1990.

7. C. E. Baum, Wedge Dielectric Lenses for TEM Waves Between Parallel Plates, Sensor and Simulation Note 332, September 1991.

8. C. E. Baum, Timed Arrays for Radiating Impulse-Like Transient Fields, Sensor and Simulation Note 361, July 1993.

9. D. V. Giri and C. E. Baum, Reflector IRA Design and Boresight Temporal Waveforms, Sensor and Simulation Note 365, February 1994.

10. C. E. Baum, The SEM Representation of Scattering From Perfectly Conducting Targets in Simple Lossy Media, Interaction Note 492, April 1993.

11. C. E. Baum, Concerning the Identification of Buried Dielectric Targets, Interaction Note 504, July 1994.

12. L. J. Peters, Jr., and J. D. Young, Applications of Subsurface Transient Radar, pp. 296-351, in E. K. Miller (ed.) *Time-Domain Measurements in Electromagnetics*, Van Nostrand Reinhold, 1986.

13. C. E. Baum and A. P. Stone, *Transient Lens Synthesis: Differential Geometry in Electromagnetic Theory*, Hemisphere Publishing Corp. (Taylor and Francis), 1991.

14. C. E. Baum and E. G. Farr, Impulse Radiating Antennas, in H. Bertoni et. al. (eds.), pp. 139-147, in H. Bertoni et. al. (eds.), *Ultra-Wideband, Short-Pulse Electromagnetics*, Plenum Press, 1993.

15. E. G. Farr, C. E. Baum, and C. J. Buchenauer, Impulse Radiating Antennas, Part II, in H. Bertoni et. al. (eds.), *Ultra-Wideband, Short-Pulse Electromagnetics II*, Plenum Press (in publication).