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Some Considerations Concerning a Horizontally Polarized Transmission-Line Simulator

Capt Carl E. Baum
Air Force Weapons Laboratory

Abstract

Large cylindrical transmission lines are used to simulate free-space electromagnetic plane waves over limited volumes. One possible design of such a transmission line has both the simulator axis and the electric field in its center parallel to the ground; the simulator is raised somewhat above the ground. In this note we discuss some of the problems related to the design of such a simulator. This discussion is qualitative and points out some possible design features which could be used to try to reduce some of the mechanical difficulties in constructing such a simulator while still trying to maintain a good electromagnetic performance.

I. Introduction

A free-space electromagnetic plane wave can be simulated by using the TEM mode of wave propagation on cylindrical transmission lines provided one is only concerned about the wave over some cross-section dimensions which are smaller than the cross-section dimensions of the transmission line by some appropriate factor. Conical transmission lines can also be used for this purpose provided the radius of curvature of the spherical wave at the position of interest is sufficiently large. Various types of cylindrical transmission lines can be used for producing an approximately uniform plane wave over a restricted region of space.[1,2] Conical transmission lines can be used to launch and terminate high-frequency waves on cylindrical transmission lines.[3] Various simulators have been built using these concepts.

One aspect of the design of such simulators concerns the orientation of the simulator with respect to things which can perturb the electromagnetic fields, such as the local terrain. The examples of large simulators of this type, such as ALECS I and ARES I, avoid this problem by using large conducting sheets (or mesh or wire arrays) next to the ground and thereby isolating the main portion of the electromagnetic wave from any significant influence of the local soil. In such cases the electric field near the center of the transmission line is approximately vertically polarized, at least for parallel plate geometries (and other similar geometries) as have been used in the past. We call such examples vertically polarized transmission lines. Figure 1A illustrates a side view of such a simulator where the conducting sheet next to the ground is flat from end to end; this design is used in ALECS I. Figure 1B shows a case where the conducting sheet next to the ground is sloped near each end by shaping the ground (or finding an approximation to such a shape already existing in the terrain); this design is used in ARES I.

An alternative approach to such a transmission-line simulator is to position it at some other orientation with respect to the terrain such that one of the conducting plates is not used to isolate the electromagnetic wave from the ground. Specifically,

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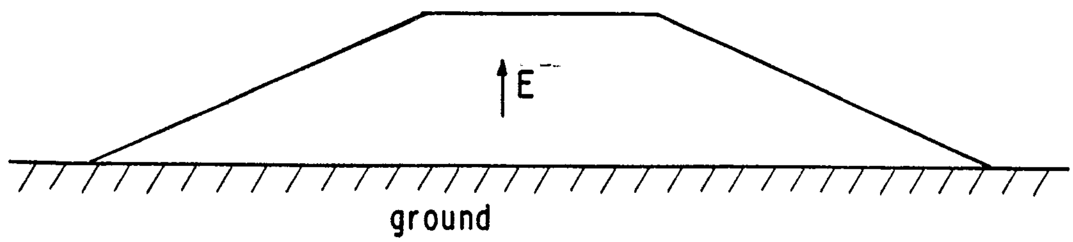
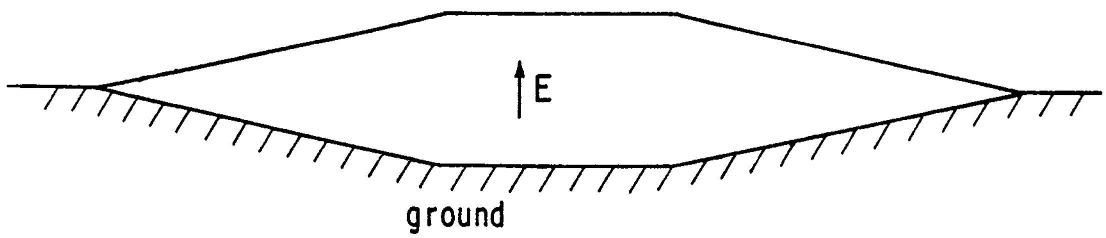
1. Lt Carl E. Baum, Sensor and Simulation Note 21, Impedances and Field Distributions for Parallel Plate Transmission Line Simulators, June 1966.

2. Lt Carl E. Baum, Sensor and Simulation Note 27, Impedances and Field Distributions for Symmetrical Two Wire and Four Wire Transmission Line Simulators, October 1966.

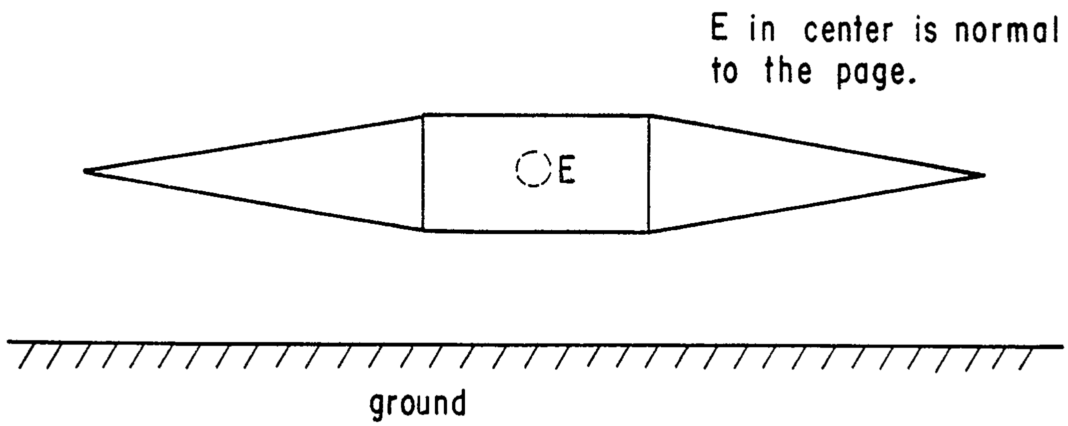
3. Capt Carl E. Baum, Sensor and Simulation Note 31, The Conical Transmission Line as a Wave Launcher and Terminator for a Cylindrical Transmission Line, January 1967.



A. VERTICALLY POLARIZED WITH FLAT GROUND PLANE



B. VERTICALLY POLARIZED WITH GROUND PLANE SLOPED AT ENDS



C. HORIZONTALLY POLARIZED AND SUPPORTED ABOVE GROUND

FIGURE 1. TRANSMISSION - LINE GEOMETRIES

consider cases in which the transmission line is rotated about its axis such that the electric field near the center of the transmission line is approximately horizontally polarized. We call such examples horizontally polarized transmission lines. The perturbation due to the ground can be minimized in this case by supporting the transmission line sufficiently high above the ground. An example of a horizontally polarized transmission line is shown in figure 1C.

One problem associated with horizontally polarized transmission lines is then how to support them above the ground. For a transmission line with cross-section dimensions of a few meters or less the mechanical problems of supporting it above the ground (or floor) at heights comparable to or a little larger than the cross-section dimensions are rather minor. However, for large transmission lines for simulating fields over large systems (missiles, aircraft, etc.) the cross-section dimensions can get rather large. For example ARES I has a conductor spacing of 40 meters for its cylindrical transmission line. In addition, supporting the system to be tested at such heights further increases the construction difficulty. If one also has to support a large high voltage pulser (or pulsers) the difficulty is further compounded. These mechanical problems together with the additional electromagnetic problems associated with a horizontally polarized transmission line made it an unattractive alternative for ARES I, particularly since primary interest in ARES I has centered on use with missiles which can be oriented vertically. However, at the time we designed the basic features of ARES I, the possible uses of a large horizontally polarized transmission line appeared to warrant further investigation. At that time we considered many of the concepts which we now discuss in this note. Although the basic concept then is not new, it still has possibilities.

Of course there may be various reasons for building a large horizontally polarized transmission-line simulator in spite of some increased construction difficulties. In particular these reasons may relate to the type of system to be tested. If one is concerned about missiles it is often convenient to position them vertically with the incident electric field parallel to the missile axis. In such a case a vertically polarized transmission line like ARES I is appropriate. On the other hand suppose that one is concerned about testing a large aircraft (while it is not flying). Then one would like to be able to have the incident electric field parallel to the body or the wings, the largest dimensions of the aircraft. In addition one would like to be able to position a large aircraft in the simulator in its normal upright attitude with respect to the ground, if only for mechanical simplicity. This would imply the use of a horizontally polarized transmission line for such tests.

Thus for some types of system tests a large horizontally polarized transmission line may be desirable from a system point of view. However, as discussed above, a vertical polarization is usually desirable for large transmission lines from a simulator point of view. One is then led to consider possible compromises in the design of a horizontally polarized transmission line. For example, instead of placing the simulator and system to be tested high above the ground one might try to quantitatively determine the influence of the ground on the simulator performance with a view to minimizing the height of the simulator and system above the ground. Furthermore one might look at the effects of various ground contours on simulator performance. The simulator could be high above the ground in certain places and close to the ground in others. There are various approaches to a compromise design in which the mechanical difficulties are minimized while trying to maintain some reasonably good electromagnetic performance.

In this note we discuss, from a qualitative viewpoint, some of the design features which might be included in a large horizontally polarized transmission-line simulator. We hope that this note will give the reader some feel for some of the design options. First we look at some of the design options for a horizontally polarized transmission line without considering the ground effects. Second we look at some designs aimed at minimizing ground effects while having the system to be tested and portions of the transmission line not too high off the ground. Third we consider some design features related to the pulsers used to drive such a transmission line.

The reader should note that the concepts employed are qualitative but can be used to compare various design approaches, at least to some limited degree. Many details need an accurate quantitative treatment from theoretical and/or experimental viewpoints. After such a treatment one should be able to quantitatively understand the influence of the various simulator design parameters such as height above the ground at positions along the length of the simulator.

II. Simulator Geometry Excluding Effects of the Ground

Now briefly consider some of the general design features of a horizontally polarized transmission-line simulator. Some of the possible design options are shown in a top view in figure 2. The simulator geometry is considered in three parts: the input transition (and/or wave launcher), the cylindrical transmission line, and the termination.

The input transition might consist of single or multiple conical transmission lines which transport the wave from one or more launch points and launch the wave over the cross section of the cylindrical transmission line. Based on the cross-section dimensions of the cylindrical transmission line, and the desired planarity of the wave entering the cylindrical transmission line, one can choose a length for the single or multiple conical transitions.[3] There are various possible designs for an input transition, two of which are indicated in figure 2. One might use a

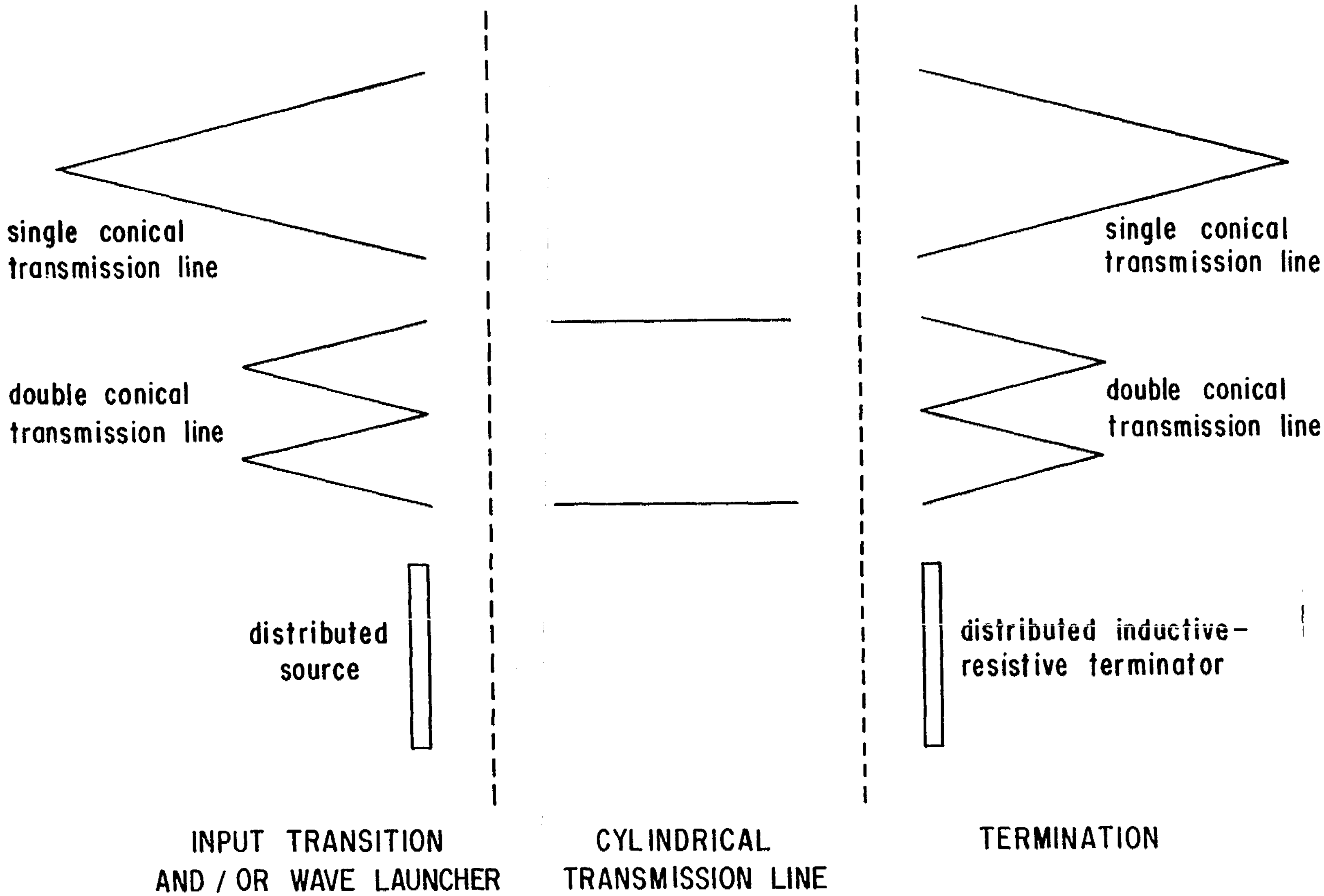


FIGURE 2. SOME OPTIONAL GEOMETRIES FOR PARTS OF A HORIZONTALLY POLARIZED TRANSMISSION-LINE SIMULATOR: TOP VIEW

single conical transmission line to transport the wave from a single launch point and match it into the cylindrical transmission line. With appropriate symmetry in the structure the single conical transmission line can support a wave which has the two sides of the line differential (at equal but opposite potentials) with respect to the ground. Call this a differential mode of wave propagation. Exciting such a wave also influences the pulser design (which we discuss later).

An alternate design for the input transition consists of a double conical transmission line (shown as one of the options in figure 2). This would be driven simultaneously from the two conical apexes. The two conical lines connect together along a line on a vertical plane which also contains the lengthwise axis of the simulator. This vertical plane is also a plane of symmetry of the simulator. The outermost conductors of the pair of conical lines join to the conductors of the cylindrical transmission line. The length of the input transition section required to achieve a certain planarity of the wave entering the cylindrical line is reduced by using a double conical line instead of a single one. Further, since we are considering a cylindrical line which has a vertical symmetry plane containing the simulator axis we can use special conical transmission lines which have the inside conducting sheets or grids of the two conical lines much larger than the outside sheets or conductor arrays. As discussed in reference 3 this is a special case which allows good matching of the field distribution between a multiple conical line and a cylindrical line.

In considering these various possibilities for conical transmission lines one will have to carefully consider the problem of matching the wave into the cylindrical transmission line. For example, there are distortions introduced into the wave at the bends where the conical line(s) join the cylindrical line.[4] A similar distortion is introduced where two conical lines join to form a multiple conical transition. These distortions can appear at the system to be tested. They can be minimized by appropriate choices for the location of the system and the design of the conical transmission line(s).

Another possible design for the wave launcher (also indicated in figure 2) consists of replacing the conical transmission lines by a large distributed source. This distributed source would consist of an entire array of pulse generators located on a plane perpendicular to the simulator axis and fired simultaneously to launch a plane wave onto the cylindrical transmission line. This source plane would be located at the input to the cylindrical

4. Capt Carl E. Baum, Sensor and Simulation Note 47, The Diffraction of an Electromagnetic Plane Wave at a Bend in a Perfectly Conducting Planar Sheet, August 1967.

transmission line. The sources would be distributed over the source plane in a manner to match the desired TEM mode on the cylindrical transmission line. Such a distributed source would be a large complex structure.

The center section of the simulator is just a cylindrical transmission line connecting to the input transition on one end and the termination on the other end. The system to be tested would be located near the front of the cylindrical transmission line, i.e. near where the input transition meets the cylindrical line. The system might even partly extend into the input transition. The spacing of the two plates (or conductor arrays) which form the cylindrical transmission line needs to be large enough that the electromagnetic interaction of the system and simulator conductors does not significantly perturb the system response. For large systems (like large aircraft) the spacing for the cylindrical line can get quite large. For some desired electric field level the voltage on the transmission line is proportional to the spacing. For large electric fields the voltage required of the pulser(s) can then be rather large.

In figure 2 the cylindrical transmission line is shown as having its conductors approximately located on two vertical planes parallel to the simulator axis. These conductors could also be on curved cylindrical surfaces consisting of straight lines parallel to the cylinder axis. Curved surfaces might be used to minimize voltage breakdown problems and/or to shape the field distribution in some particular way. Of course, the input transition (or distributed source) and the termination will have to match to such curved surfaces.

As another alternative the length of the cylindrical transmission line can be reduced to zero. The input transition then connects directly to the termination. The system test location is then in part of the input transition and/or part of the termination section.

There are several possibilities for the termination which connects to the output of the cylindrical transmission line. As shown in figure 2 one might use a single or double conical transmission line, similar to the input transition; resistive loads would be connected at the conical apexes. A third possibility is to use a distributed inductive-resistive terminator.[5] This type of terminator has the advantage of being very short compared to a conical transmission line. However, the distributed inductive-resistive terminator may be somewhat more complex a structure than the conical transmission line(s).

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5. Capt Carl E. Baum, Sensor and Simulation Note 53, Admittance Sheets for Terminating High-Frequency Transmission Lines, April 1968.

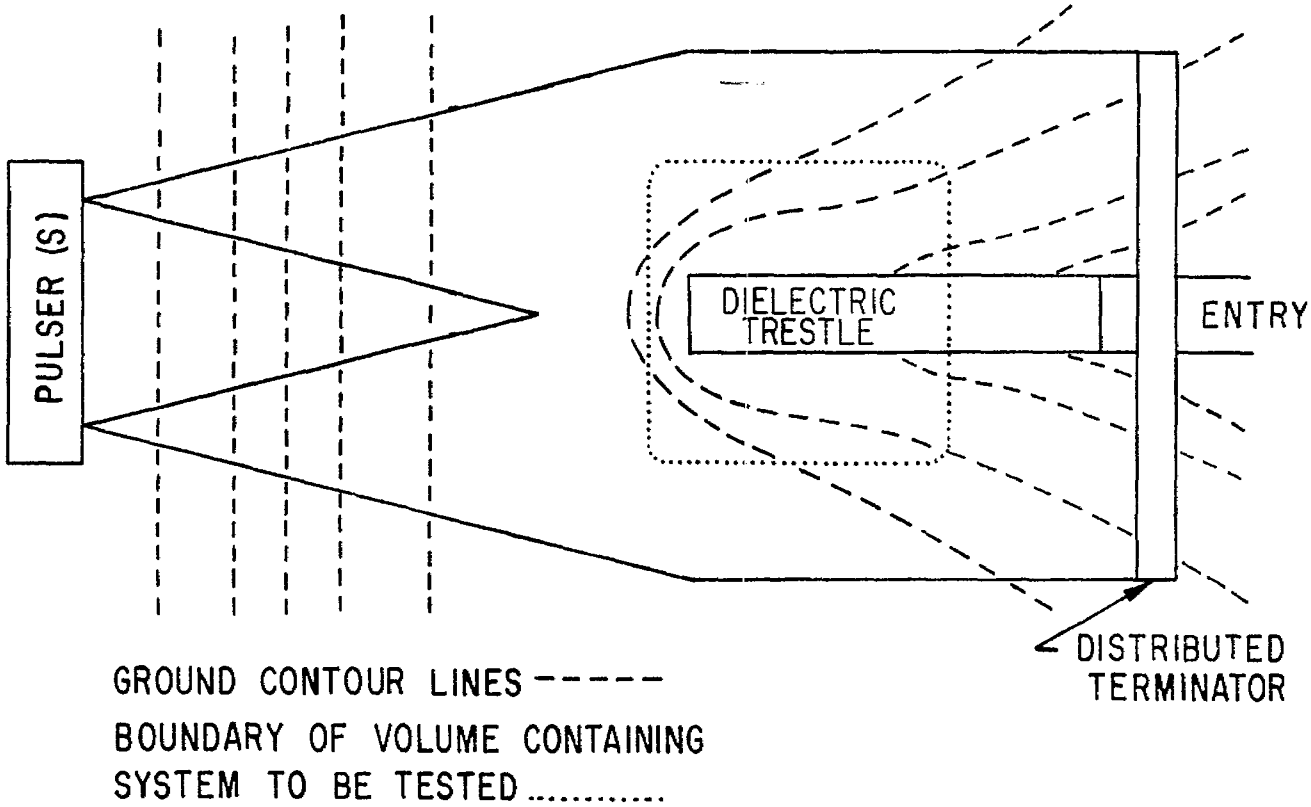
For purposes of the illustrations accompanying our following discussion we assume a double conical input transition, followed by a cylindrical transmission line with conductors approximately located on two vertical planes parallel to the simulator axis. This is assumed to be followed by a distributed inductive-resistive terminator which is schematically indicated as a rectangular parallelepiped connected to the cylindrical transmission line.

III. Simulator Geometry Including Effects of the Ground

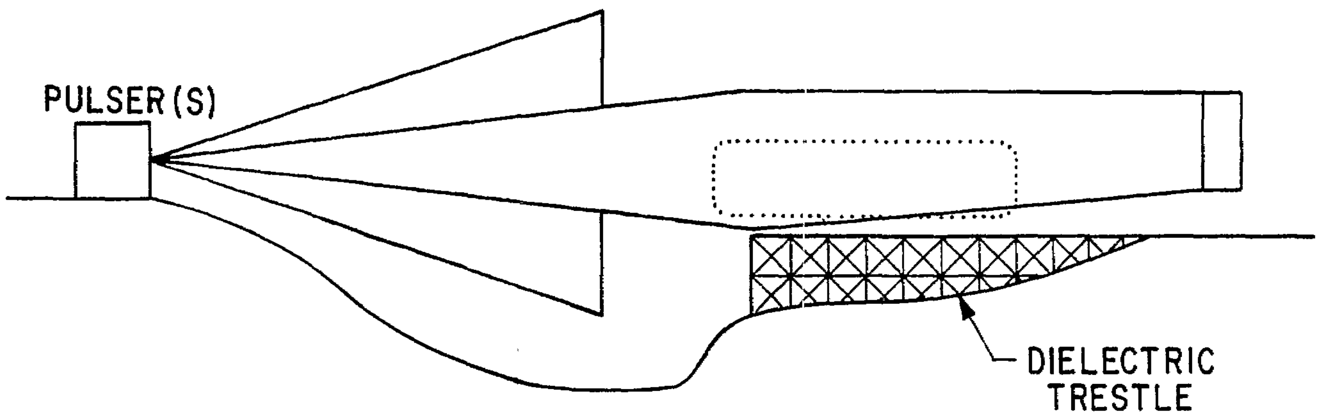
In figure 3 we show top and side views of a horizontally polarized transmission line above the ground. Also shown is some possible contouring of the ground pointed toward improving simulator performance while reducing the mechanical difficulties of supporting particularly the high voltage pulser(s) and the system to be tested.

As a first item of interest consider reducing the attenuation of the electromagnetic wave between the pulser(s) and the system to be tested. One way to do this is to increase the height of the input transition (or at least the portions of it with the most significant fields) above the ground beneath it. In this approach one is simply trying to minimize the interaction of the wave with the ground. On the other hand the pulser(s) and system to be tested might not be so high above the ground in order to minimize the problem of supporting these items. This would imply that the ground be contoured as a valley with the pulser(s) on one side and the system on the other as shown in figure 3. The system would enter the simulator through the back end by temporarily moving away the distributed terminator, perhaps by constructing the terminator as a two-piece gate which opens at its center.

Another item of interest is the electromagnetic coupling between the system and the ground. The incident electromagnetic wave induces currents on the system under test; these currents may exhibit resonant behavior in many cases. If the system is too close to the ground there will be electromagnetic coupling between these currents and the ground, a conducting dielectric. This coupling can change the currents induced on the system. Assuming we are trying to simulate a situation in which the system is far removed from the ground (e.g. in flight) then we need to have the system supported above the ground. However, the system may be rather large and heavy. Thus one might try to compromise between low electromagnetic coupling of the system to the ground and mechanical ease of supporting the system. As shown in figure 3 one might support the system with a dielectric trestle (nonconducting). This trestle might be designed to be the continuation of a roadway entering the simulator from the rear. The system might be moved out onto the trestle from the roadway. The top of the trestle might be level but the ground under the trestle could



A. TOP VIEW INCLUDING CONTOUR LINES



B. SIDE VIEW

FIGURE 3. CONTOURED GROUND INCLUDED WITH TRANSMISSION LINE

be sloped to obtain the required height of the system above the ground. The ground could also be sloped away from the sides of the trestle as shown in figure 3. Parts of the system (such as aircraft wings) may extend much wider than the trestle width. With appropriate ground contours only part of the system might be relatively close to the ground.

A further electromagnetic problem relates to the incident wave. Depending on the simulator geometry the incident wave may reflect off the ground and appear as another pulse (perhaps distorted) at the system. This problem can perhaps be minimized by appropriate ground contours. For example by sloping the ground away to the sides on both sides of the trestle (as in figure 3) the reflected wave can be partly scattered toward the sides of the simulator. Similarly ground contouring near the end of the trellis can be used to scatter part of the reflected fields away from the system. Also by appropriate ground contouring one can try to insure that the reflections from the ground reaching the system are dispersed in time. The reflections from the ground are also dependent on the permittivity and conductivity of the ground.[6] One might try to minimize the ground reflections by finding a site with minimum ground permittivity and minimum ground conductivity.

As the wave propagates along the cylindrical transmission line toward the terminator, the interaction of the wave with the ground becomes more significant if the ground is contoured as shown in figure 3. One of the effects of this interaction could be viewed as a change in the characteristic impedance of the transmission line. Perhaps one can partly compensate for this effect by changing the shape of the transmission-line conductors to try to alter the impedance in a direction roughly opposite to the change introduced by the presence of the ground. However, the influence of the ground may be to make the impedance (as a function of frequency) a complex number. This might limit the effectiveness of changing the geometry of the transmission-line conductors as a function of frequency. Another possible compensation technique might be the insertion of passive loading elements (inductors, capacitors, resistors) into the transmission-line conductors in an attempt to control the impedance of the transmission line and minimize reflections.

As one can see there are many possible approaches to the problem of minimizing the adverse electromagnetic effects associated with the ground while also trying to minimize the mechanical difficulties associated with supporting the pulser(s) and system to be tested. There are also mechanical difficulties involved in

6. Capt Carl E. Baum, EMP Theoretical Note 25, The Reflection of Pulsed Waves from the Surface of a Conducting Dielectric, February 1967.

supporting the transmission-line conductors and the distributed terminator. These can be supported by towers, guys, etc. and are not shown in figure 3. Certain portions of the towers (along the conductor arrays forming the simulator) can be considered as parts of the conductor array and can thus be metallic. The remaining portions should generally be made of insulating dielectric. An exception to this can be made in cases where the additional metal is placed in a region of no electric field. As an example one might have a metal tower along a straight vertical line where the two innermost conductor arrays of the two conical transmission lines meet. This particular tower lies in a symmetry plane of the simulator which also contains the lengthwise simulator axis. On this symmetry plane there is ideally no vertical component of the electric field. In this case, then, extending the metal tower to the ground should introduce little electromagnetic perturbation.

IV. Some Pulser Considerations

As discussed in section II the appropriate type of wave to be launched on this kind of simulator is a differential one; i.e. one for which the two sides of the cylindrical transmission line have equal but opposite potentials (+V and -V) with respect to the ground. In a more refined sense one could think of an electromagnetic field distribution which has the corresponding appropriate symmetry with respect to the vertical plane of symmetry of the simulator (which also contains the lengthwise simulator axis). This differential electromagnetic pulse implies an appropriate differential pulser or group of pulsers.

As an example, consider the simulator configuration in figure 3. We have +V and -V as the potentials put on the outermost conductors of the two conical transmission lines. The innermost conductors of the two conical lines join together and should be driven at the same potential; by symmetry the potential of these inner conductors should be zero (with respect to the ground). One way to drive such a simulator is to use two single-ended pulsers fired simultaneously, each driving one of the conical transmission lines. The case (or electrical "ground") of each pulser would be connected to the inner conductors of its associated conical line; one pulser would put +V on the outer conductors of its conical line while the other pulser would put out -V. The two pulsers should be electrically the same except for opposite polarities.

An alternate way to drive such a simulator (of the type in figure 3) is to connect the apexes of the conical transmission lines to some central point with two transmission lines. At this central point there would be a single differential pulser appropriately connected to the two transmission lines.

The essential feature is that the pulser(s) must be designed and connected to the simulator in such a manner that the desired electromagnetic wave is produced. For the type of simulator under discussion it is desirable to have the pulser system differential, at least in the type of wave that it ultimately launches into the simulator. This implies that the pulser configuration be itself differential or that something be done to the wave to make it differential, at least on a transient basis.

V. Summary

From a qualitative viewpoint there are many things that can be done to improve the design of a horizontally polarized transmission-line simulator. By appropriate contouring of the ground beneath the simulator one can try to reduce the adverse electromagnetic effects associated with the ground proximity and to reduce the mechanical problems associated with supporting the pulser(s) and the system to be tested. Various features of the ground contouring can be based on compromises between electromagnetic and mechanical considerations. The electromagnetic distortion due to the ground proximity is influenced by the conductivity and permittivity of the ground. Depending on the specific type of distortion (attenuation, reflection, etc.) the distortion may be minimized by an optimum choice of the permittivity and conductivity of the ground. Site selection may then be influenced both by the surface contour of the land and by the electromagnetic parameters of the ground.

Note that the present discussion has been a qualitative one, considering some of the possible design options and indicating some of the things which can be considered in optimizing the design. There are many detailed problems to be considered. The various design problems associated with the horizontally polarized transmission-line simulator need to be quantified. Then one could design such a simulator to have a particular performance and have some appreciation of the quantitative difficulties involved in achieving that performance.