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The Conical Transmission Line as a Wave Launcher and Terminator for a Cylindrical Transmission Line

Capt Carl E. Baum
Air Force Weapons Laboratory

Abstract

A conical transmission line can be used to launch and terminate a wave on a cylindrical transmission line. Better results are obtained for a relatively long conical line than for the shorter line. A multiple conical transmission line assembly can be used in some cases to improve on the characteristics of a single conical line.

I. Introduction

A cylindrical transmission line is often used to simulate a free-space plane electromagnetic wave because of the TEM wave which is the principal propagation mode on the structure. There are various types of cylindrical transmission lines which also have the property that the field distribution is nearly uniform over a significant part of their cross sections, thus making a good approximation to a free-space plane wave.[1,2] This TEM mode ideally exists for all frequencies, but for frequencies such that the radian wavelength is of the order of, or less than, the cross section dimensions of the transmission line other modes can also exist. In many cases, we would like to be able to launch fast rising pulses on such structures, with a rise time significantly shorter than the transit time across the cross section. So the problem is how to launch such a wave (either a fast pulse or a high frequency sine wave) on such a transmission line without launching other modes as well. Similarly, we would like to be able to terminate such a wave on the cylindrical transmission line without introducing other disturbances.

One approach to this problem, which is used in the ALECS-I simulator at Kirtland AFB, is to match the cylindrical transmission line with two transmission lines (one on each end) which have the same cross section shape as the cylindrical transmission line but which gradually and uniformly taper to much smaller cross section sizes.[3] At these smaller cross section dimensions it is easier to launch and terminate the wave. Actually these uniformly tapered transmission lines are conical transmission lines. We define a conical transmission line as two or more separate conductors (assumed perfect conductors) which can be generated (geometrically) by lines which all pass through one point (the apex). In a simple medium a TEM mode exists in spherical coordinates (centered about the apex) with fields in the angular directions only. The idea is then to match the field distribution on the conical transmission line to that on the cylindrical transmission line, thus achieving a smooth transition. This technique can be used with various types of cylindrical transmission lines and is illustrated in figure 1 for parallel plate types of cylindrical transmission lines.

Still, the conical transmission line is not a perfect solution. The wavefront on the conical line is spherical as compared to the planar wavefront desired on the cylindrical transmission line. Thus, in launching the wave on the cylindrical transmission line there is some time dispersion across the cross section of the cylindrical transmission line. Conveniently, this time dispersion can be reduced for a given cross section (of the cylindrical transmission line)by lengthening the conical transition.

A further possible improvement in the wave launching structure is to use multiple conical transmission lines, matched to the field distribution on the cylindrical transmission line. In this case each conical transmission line launches a part of the wave, covering some fraction of the cross section of the cylindrical transmission line. All the conical lines have the same transit time and are driven simultaneously from separate sources or from one or more sources connected through additional transmission lines to the inputs of the conical lines. Such

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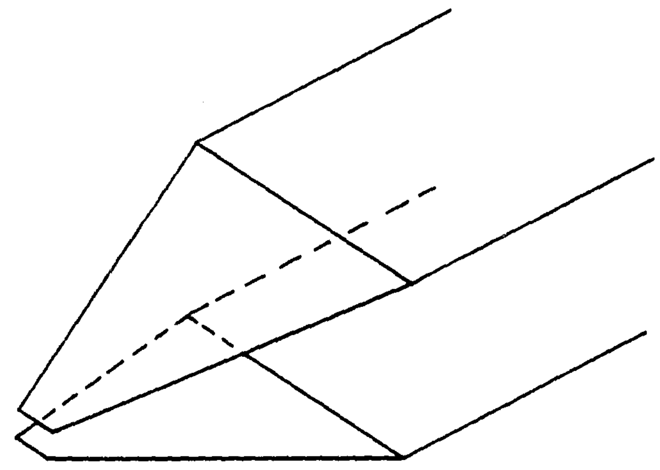
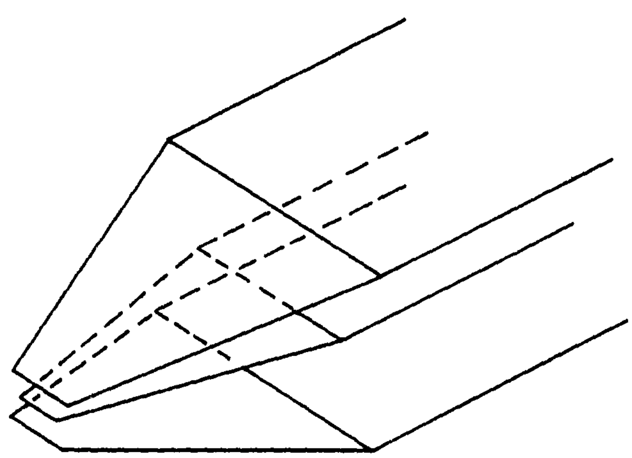
1. Lt Carl E. Baum, Sensor and Simulation Note XXI, Impedances and Field Distributions for Parallel Plate Transmission Line Simulators, June 1966.
2. Lt Carl E. Baum, Sensor and Simulation Note XXVII, Impedances and Field Distributions for Symmetrical Two Wire and Four Wire Transmission Line Simulators, October 1966.
3. Ralph E. Partridge, Sensor and Simulation Note I, EMP Testing Facility, Feb. 1964.



A. TWO PLATE



B. THREE PLATE

FIGURE 1. EXAMPLES OF MATCHED CONICAL AND CYLINDRICAL TRANSMISSION LINES.

multiple conical transmission lines might also be used to terminate TEM waves on the cylindrical transmission line, with each conical line terminated in its characteristic impedance. The multiple conical transmission lines can further reduce the time dispersion in launching and terminating plane waves on cylindrical transmission lines.

II. The Conical Transmission Line

Consider the coordinate systems in figure 2. The origin of the spherical coordinates $(\rho,\ \theta,\phi)$ is taken as the apex of a conical transmission line. The z axis is taken as an axis of symmetry, where appropriate. The conical transmission line then has two or more conductors, the surfaces of which are described as functions of θ and ϕ, but not of ρ. As developed by Smythe[4] the TEM solution has potential functions for the fields of the form

$$w(\theta,\phi) = u(\theta,\phi) + jv(\theta,\phi) = f_1\left(2e^{j\phi}\tan\left(\frac{\theta}{2}\right)\right) \tag{1}$$

Multiplying by $e^{\pm jk\rho}$ where the propagation constant k is of the form

$$k = \sqrt{-j\omega\mu(\sigma+j\omega\varepsilon)} \tag{2}$$

(where typically, but not necessarily, we take $\sigma = 0$ and $k = \omega/c$ where c is the speed of light in vacuum) then gives waves propagating in the $\pm\ \rho$ direction with the field strengths varying as $1/\rho$ and surfaces of constant ρ (spheres) as surfaces of constant phase.

From the form of the TEM solution of equation 1, an equivalent cylindrical transmission line can be developed as in Smythe. If we make a coordinate transformation of the form

$$x' = 2z_o\cos\phi\tan\left(\frac{\theta}{2}\right) \tag{3}$$

and

$$y' = 2z_o\sin\phi\tan\left(\frac{\theta}{2}\right) \tag{4}$$

(where z_o is a constant to be used later) then the complex potential function of equation 1 becomes

$$w(\theta,\phi) = f_1\left(\frac{x'+jy'}{z_o}\right) = f_2(x'+jy') \tag{5}$$

In this form the potential functions on the equivalent cylindrical transmission line can be found by the well-known procedure of conformal transformation. If cylindrical coordinates (r,ϕ) are used instead of cartesian coordinates for the equivalent cylindrical transmission line, the transformation is of the form

$$r = 2z_o\tan\left(\frac{\theta}{2}\right) \tag{6}$$

$$\phi = \phi \tag{7}$$

Note that the ϕ coordinate is the same in both the spherical and cylindrical systems while the θ coordinate maps only to the r coordinate. To complete the transformation to the equivalent cylindrical line we can also map ρ to z' as

4. W. R. Smythe, Static and Dynamic Electricity, 2nd ed., 1950, p. 479.

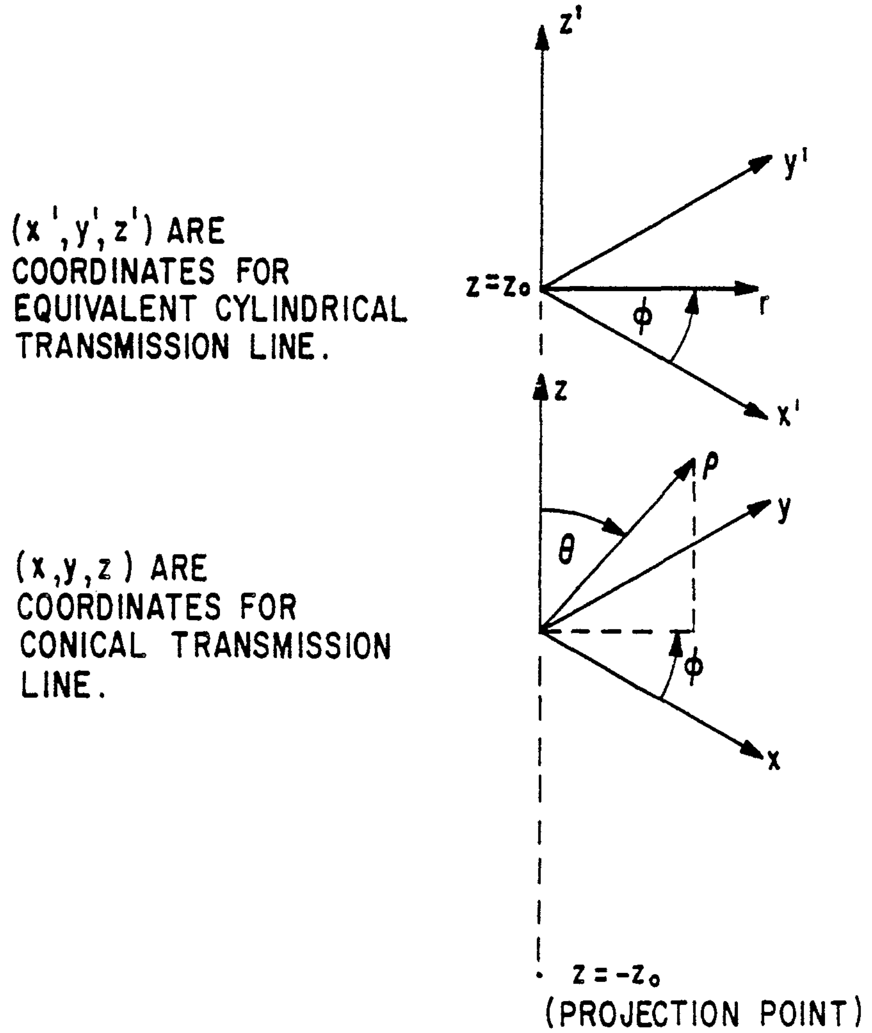


FIGURE 2. COORDINATE SYSTEMS FOR CONICAL TRANSMISSION LINE.

$$\rho = z' \tag{8}$$

so that propagation on the equivalent line is in the $\pm z'$ direction in the TEM mode.

This fact of an equivalent cylindrical transmission line can be used to solve for both the impedance and field distribution of the conical transmission line. Mapping to the cylindrical line we can try to solve this problem; or, we may use a cylindrical line which is well known for its impedance and field and potential distributions, and transform it back to an equivalent conical transmission line for which, then, the impedance and field distribution are also known. Note that the choice of the direction of the z axis from the conical apex is arbitrary, meaning there is more than one equivalent cylindrical transmission line for each conical transmission line and vice versa. As an example, consider the transmission line formed by two circular cones described by constant $\theta = \theta_1$ and $\theta = \theta_2$ $(0 < \theta_1 < \theta_2 < \pi)$. This transforms to an equivalent coax with radii

$$r_1 = 2z_o \tan\left(\frac{\theta_1}{2}\right) \tag{9}$$

and

$$r_2 = 2z_o \tan\left(\frac{\theta_2}{2}\right) \tag{10}$$

which then gives the well-known result for the impedance, Z_c, of

$$Z_c = \frac{Z}{2\pi} \ln\left(\frac{r_2}{r_1}\right) = \frac{Z}{2\pi} \ln \left[\frac{\tan\left(\frac{\theta_2}{2}\right)}{\tan\left(\frac{\theta_1}{2}\right)}\right] \quad . \tag{11}$$

where the wave impedance is given by

$$Z = \left(\frac{j\omega\mu}{\sigma + j\omega\varepsilon}\right)^{1/2} \tag{12}$$

Referring again to the coordinate sketch in figure 2, there is a geometrical procedure for obtaining the equivalent cylindrical transmission line. Consider the intersection of the conical line with a sphere of radius z_o. The (x', y') or (r,ϕ) plane is a projection plane which is perpendicular to the z axis (intersecting at $z = +z_o$) and tangent to the sphere. Then consider a projection point at $z = -z_o$. Construct a line through the projection point and a point of interest on the sphere. The intersection of this line with the projection plane is the mapped point on the plane from the sphere. Continuing this for all points of interest on the sphere maps the conical line (and the potential functions) to the equivalent cylindrical line. This geometrical procedure is consistent with the mathematical transformation of equations (6) and (7). Note that the angle of the projection line with respect to the z axis is $\theta/2$ and the normal distance from the projection point to the projection plane is $2z_o$. Conveniently, for small θ, the $\rho = z_o$ sphere and the projection plane are approximately the same surface, and the geometric distortion in the transformation is small.

III. Matching Conical and Cylindrical Transmission Lines

With the transformations just discussed it is possible to calculate the impedance and field distribution of conical transmission lines. Now consider using conical transmission lines to launch plane waves on cylindrical transmission lines. If the wave on the conical line is to propagate onto the cylindrical line without reflection, a first requirement is that the two lines have the same characteristic impedance. This concept, however, only applies to transmission lines with wavelengths much larger than appropriate cross section dimensions but of the order of or less than the length of the transmission lines. Then for conical lines with lengths much greater than cross section dimensions the impedances should approximately match to launch waves onto the cylindrical transmission line, at least for wavelengths somewhat larger than the cross section dimensions. For such frequencies and lower it would also seem desirable to maintain a gradual transition to the cylindrical transmission line with the two lines having approximately the same shape cross sections to maintain the field distribution of the cylindrical line near the juncture of the two lines. This may not typically apply for positions far from this juncture compared to the appropriate cross section dimensions.

For frequencies, with corresponding wavelengths shorter than the cross section dimensions, however, simple transmission line concepts may not always apply. For example, matching the characteristic impedances may not be sufficient. Specifically, the spherical wavefront on the conical line does not exactly match the planar wavefront on the cylindrical line. Over the cross section of the cylindrical line (at the juncture), and external to the transmission line for distances to which significant fields extend, there is then a certain time dispersion in matching the spherical wave into a plane wave. In other words, on the cylindrical line a cross section is not exactly a plane of constant phase. For wavelengths comparable to this dispersion distance or times comparable to this dispersion time the wave does not necessarily propagate down the cylindrical line as a plane wave. This transit time dispersion over cross section dimensions of interest is than an indication of the rise time characteristics of the wave on the cylindrical line, say to a step function signal at the input to the conical line. We say "indication" because the actual rise characteristics and frequency response characteristics may be somewhat more complex. However, to minimize the rise time one can try to minimize this transit time dispersion. Note that for this analysis we assume $\sigma = 0$ so that there is no attenuation of the wave from this parameter.

To match the two transmission lines let us first make the two impedances the same. Second, the cross sections of the two lines should be approximately the same so that the field distribution in the TEM mode on each is approximately the same and the wave on one smoothly transitions into the other. One way to achieve these points is to make the conical transmission line such that its cylindrical equivalent and the actual cylindrical transmission line are one and the same. Then consider the cylindrical line as parallel to the z axis, and in some cases the z axis can be the axis of symmetry of the cylindrical line. Then consider the coordinate systems for the joined, equivalent, conical and cylindrical transmission lines at a constant ϕ (since ϕ is not varied by the transformation) as in figure 3. On the z axis the transition point is taken at $z = z_o$, consistent with the previous transformations.

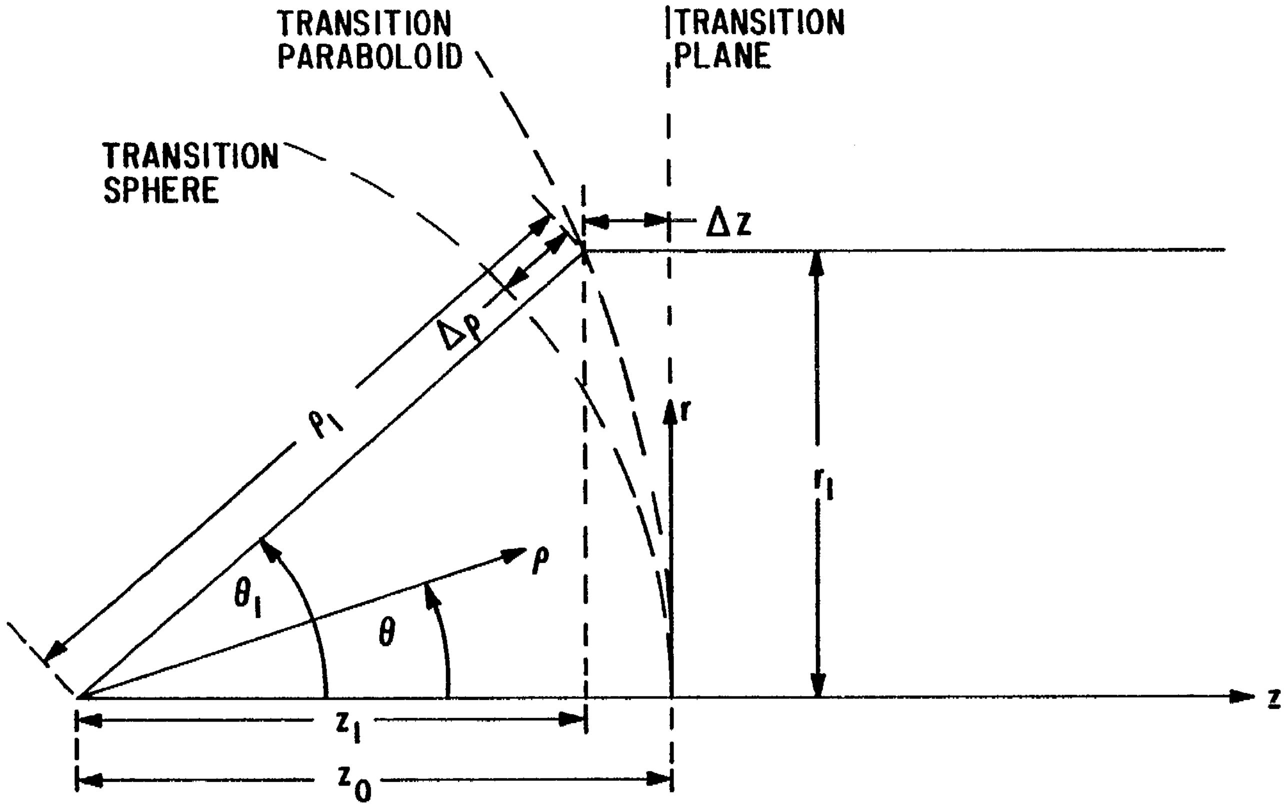


FIGURE 3. COORDINATE SYSTEMS FOR JOINED TRANSMISSION LINES

Consider the field distributions in the TEM modes on the two equivalent transmission lines. Ignoring transit time considerations one can find a surface on which these field distributions match. Designate this surface by (ρ_1, ϕ, θ_1) and (r_1, ϕ, z_1). The transformation, equation (6), gives

$$r_1 = 2z_o \tan\left(\frac{\theta_1}{2}\right) \tag{13}$$

From the geometry there are also the relations

$$r_1 = \rho_1 \sin(\theta_1) \tag{14}$$

and

$$r_1 = z_1 \tan(\theta_1) \tag{15}$$

Some useful trigonometric relationships are

$$\tan\left(\frac{\theta_1}{2}\right) = \frac{\sin(\theta_1)}{1+\cos(\theta_1)} \tag{16}$$

and

$$\tan(\theta_1) = \frac{2\tan\left(\frac{\theta_1}{2}\right)}{1-\tan^2\left(\frac{\theta_1}{2}\right)} \tag{17}$$

Combining equations (13), (14), and (16) gives

$$\frac{\rho_1}{z_o} = \frac{2}{1+\cos(\theta_1)} \tag{18}$$

and combining equations (13), (15), and (17) gives

$$\frac{r_1}{z_1} = \frac{\frac{r_1}{z_o}}{1 - \left(\frac{r_1}{2z_o}\right)^2} \tag{19}$$

for the surface on which these field distributions are equal. Rewriting equation (19) as

$$\left(\frac{r_1}{2z_o}\right)^2 = 1 - \frac{z_1}{z_o} \tag{20}$$

note that this surface is a paraboloid. We choose to call it the transition paraboloid.

Call the spherical surface, $\rho = z_o$, the transition sphere and the plane, $z = z_o$, the transition plane. These are surfaces of constant phase, in the TEM modes, on the conical and cylindrical lines, respectively, and these surfaces are tangent at one point (on the z axis), where they are also tangent to the transition paraboloid. The distance between the spherical and planar surfaces, divided by the propagation speed, gives the transit time dispersion in matching the waves on the two transmission lines as a function of θ or r. For convenience relate this dispersion distance to the transition paraboloid which we take as the surface dividing the two transmission lines. Then on the conical line the dispersion distance is

$$\Delta\rho = \rho_1 - z_o = z_o \frac{1-\cos(\theta_1)}{1+\cos(\theta_1)} = z_o \tan^2\left(\frac{\theta_1}{2}\right) \tag{21}$$

On the cylindrical line the dispersion distance is

$$\Delta z = z_o - z_1 = z_o \left(\frac{r_1}{2z_o}\right)^2 = z_o \tan^2\left(\frac{\theta_1}{2}\right) \tag{22}$$

This definition of dispersion distance, then gives

$$\Delta\rho = \Delta z \tag{23}$$

and the total dispersion distance is

$$d_1 = \Delta\rho + \Delta z = \frac{r_1^2}{2z_o} = 2z_o \tan^2\left(\frac{\theta_1}{2}\right) \tag{24}$$

For small θ_1 this is approximately

$$d_1 \simeq z_o \frac{\theta_1^2}{2} \tag{25}$$

If θ_1 represents the maximum θ of interest, or r_1 represents the maximum r of interest for significant fields on the respective transmission lines (calling these quantities then θ_3 and r_3), the maximum dispersion distance is then

$$d_3 = \frac{r_3^2}{2z_o} = 2z_o \tan^2\left(\frac{\theta_3}{2}\right) \tag{26}$$

This maximum dispersion distance can then be reduced by decreasing the cross section dimensions of the cylindrical transmission line and/or increasing the length of the conical transmission line.

Another way to look at the matched conical and cylindrical transmission lines is to consider some of the approximate rise characteristics of a wave as a function of position down the cylindrical line. Consider a step function wave on the conical line which has unity amplitude (electric or magnetic field) on the z axis at $\rho = z_o$. The field on the z axis, at distances far from the transition paraboloid compared to the cross section dimensions, and for times much longer than transit times for the cross section and other dimensions of interest, settles down to unity amplitude on the cylindrical line and to amplitude z_o/ρ on the conical line. This is due to the equivalence of the transmission lines, mapping the potential between the two, and the lack of distortion in this mapping in the limit of small θ (i.e., $\rho_1 d\theta_1 = dr_1$ at $(\rho_1,\theta_1) = (z_o,0)$). For small θ_3 (i.e., a gradual conical transition), this long time field strength will also be nearly unity on the z axis near the transition paraboloid.

As this step function wave propagates down the conical-cylindrical structure the initial rise on the z axis has an amplitude of z_o/ρ. This initial rise is in the form of a spherical wave, with a distribution characteristic of the conical line. Referring to figure 4 one can see that the first signal to reach an observer on the z axis must come by the shortest path from the input of the conical transmission line . Actually, the first disturbance introduced into the spherical wave, to convert it into an approximate plane wave, occurs at the ρ_1 on the conical structure corresponding to the smallest r on the cylindrical structure. For the smallest dimensions refer to the conductors on the respective transmission lines. Call the distance from the z axis to the closest conductor on the cylindrical line, r_2, together with the corresponding coordinates, z_2, ρ_2, and θ_2, for the position on the transition paraboloid. The first disturbance (or reflection) in the spherical wave occurs at this point.

We assume for this analysis that there are no disturbances for $z>z_o$ on the cylindrical line to send reflections back to the observation point, at least for times of interest. At the observation point on the z axis the initial step rise to a value, z_o/z, lasts for at least the extra time it takes the first reflection to arrive. As illustrated in figure 4, for $z_2 \le z \le 2z_2$, the reflection occurs at (r_2,z_2) and the corresponding time lag is

$$t_o = \frac{1}{c}\left\{\left[z_2^2+r_2^2\right]^{1/2} + \left[(z-z_2)^2 + r_2^2\right]^{1/2} - z\right\} \tag{27}$$

For $r_2 \ll z_2$ this reduces to

$$t_o \simeq \frac{1}{c}\left\{z_2 + \frac{r_2^2}{2z_2} + \left[(z-z_2)^2+r_2^2\right]^{1/2} - z\right\} \tag{28}$$

Note that c is the velocity of propagation of the wave, typically the speed of light in vacuum. For $2z_2 \le z$ the first reflection to arrive at the observer comes again from the conductor on the cylindrical line closest to the z axis, and from a point halfway between $z = 0$ and the observer, this path being the shortest reflection path to the observer. The time lag on the reflection is now

$$t_o = \frac{1}{c}\left\{2\left[\left(\frac{z}{2}\right)^2+r_2^2\right]^{1/2} - z\right\} = \frac{1}{c}\left\{\left[z^2+4r_2^2\right]^{1/2} - z\right\} \tag{29}$$

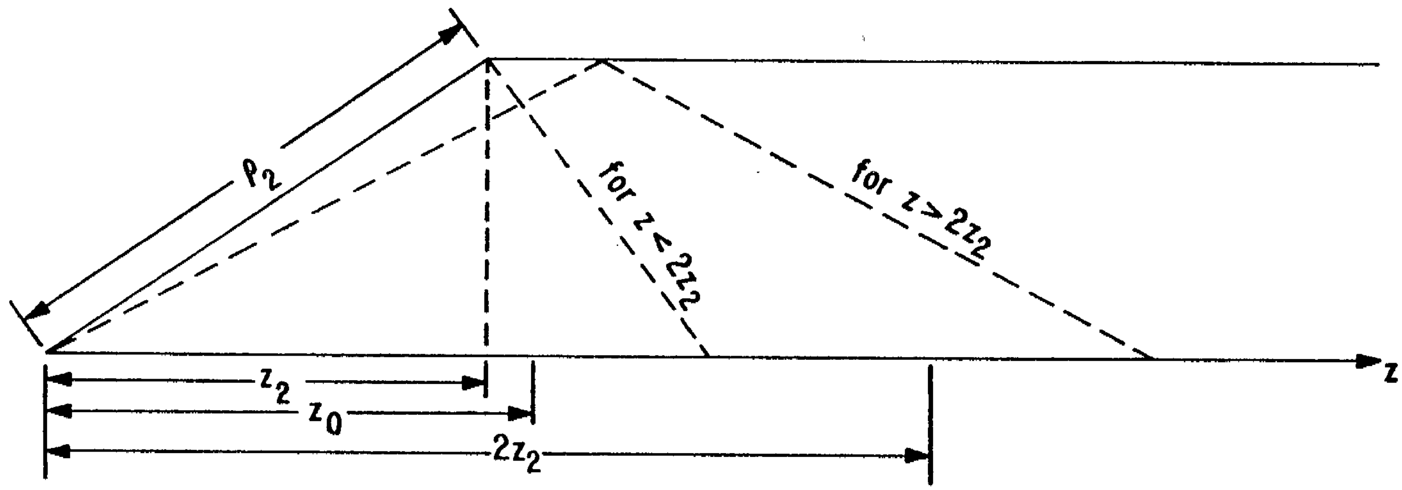


FIGURE 4. FIRST REFLECTION PROPAGATION PATHS FOR AN OBSERVER ON THE z AXIS

For $2r_2 << z$ this reduces to

$$t_o \approx \frac{2}{c} \frac{r_2^2}{z} \tag{30}$$

Thus, as the observer moves to larger z not only does the amplitude of the step rise decrease as z^{-1}, but also the time to the first reflection decreases in a similar manner.

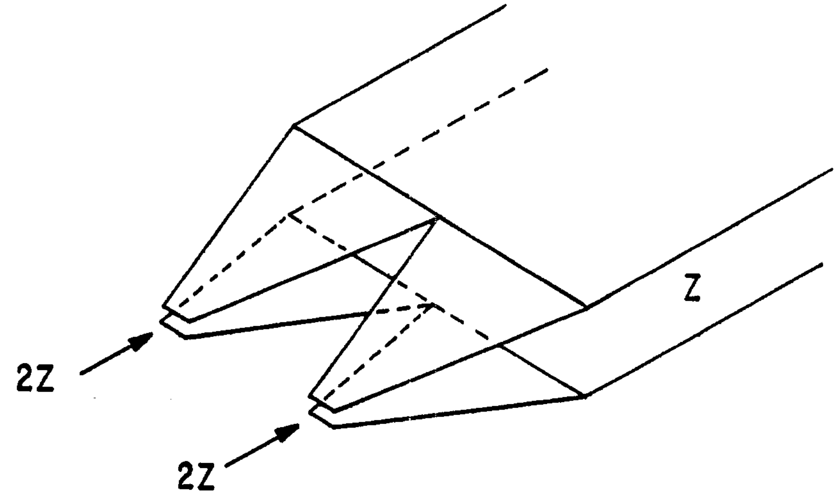
What happens for times at and subsequent to the first reflection arrival is difficult to say. This may depend on several factors, including the cross section shape of the cylindrical line, the length of the conical line, and the observation point. For large z_o/r_3, the case of a gradual transition, the transition characteristics are optimized. To get a picture of just what happens for some of the more complicated details, and their practical significance, one might measure the response of a particular conical-cylindrical transmission line system, including, for very large such systems, an electrical scale model of the same.

IV. Multiple Conical Transmission Lines

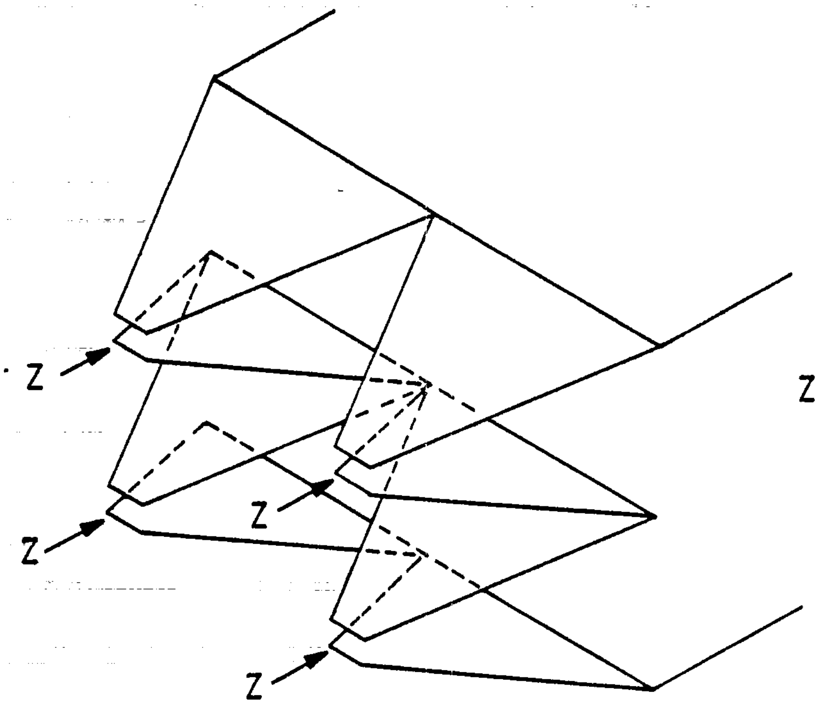
In discussing the optimization of the conical transmission line as a wave launcher on a cylindrical transmission line we calculated a maximum dispersion distance in equation (26) as an indication of the quality of the match. To optimize the transition r_3 may be decreased and/or z_o may be increased. For a given cylindrical transmission line r_3 can be minimized by centrally locating the z axis on the cross section. If z_o is also limited for some reason, then we have a certain minimum value of d_3.

However, there is another technique which may improve the situation, namely the use of several conical transmission lines as the wave launching assembly. This is illustrated in figure 5 with two examples. The basic idea is to divide a cross section of the given cylindrical transmission line into a number of separate areas. Each area is then fed by a separate conical transmission line. For convenience assume all the conical lines to be of equal length (but this is not necessary). Then simultaneously drive the inputs to all the conical lines with the same signal (but possibly different amplitudes) so that the waves on all the conical lines arrive at the input cross section of the cylindrical line at the same time. The conical lines should be arranged and driven such that together the waves on the conical lines match the TEM field distribution on the cylindrical line. For a given length of conical transition, z_o, one can then reduce d_3 by using a multiple conical transition assembly to reduce the r_3 associated with the individual conical lines. Alternatively one might choose a certain d_3 and by reducing r_3 allow a reduction in z_o.

In figure 5A we have the case of a wide symmetrical two plate transmission line of impedance, Z, driven by two conical lines, each of impedance, 2Z, in a parallel arrangement. Figure 5B gives another case in which a symmetrical two plate transmission line of impedance, Z, is driven by four conical transmission lines, each of impedance Z, in a series-parallel arrangement. The conical lines can be driven by separate sources or from a single source. Figure 6 schematically shows some signal feed

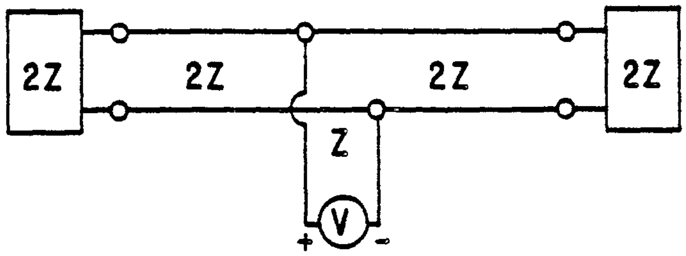


A. WIDE TWO PLATE TRANMISSION LINE

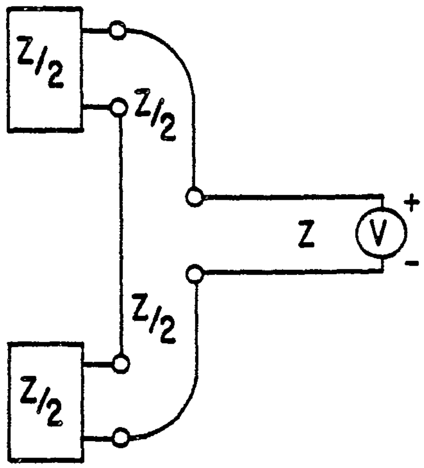


B. WIDE AND HIGH TWO PLATE TRANSMISSION LINE

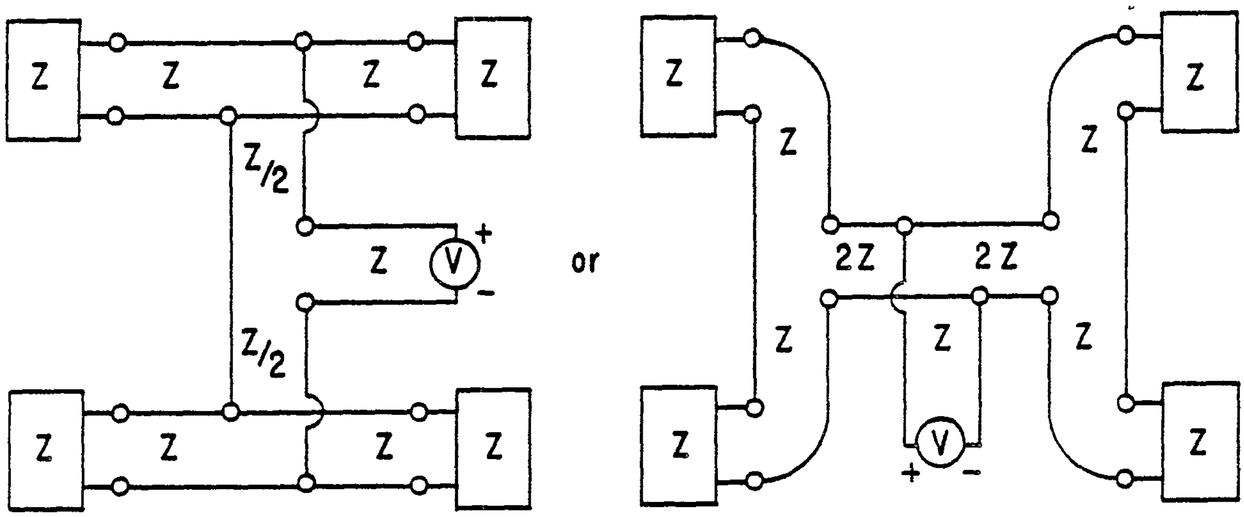
FIGURE 5. MULTIPLE CONICAL TRANSITIONS



A. PARALLEL (FOR TWO FEED POINTS)



B. SERIES (FOR TWO FEED POINTS)



C. SERIES PARALLEL (FOR FOUR FEED POINTS)

FIGURE 6. SINGLE SIGNAL FEED TRANSMISSION LINE NETWORKS FOR MULTIPLE CONICAL FEED POINTS

systems for driving multiple conical transition assemblies from a single source. These feed systems have impedances for pulse matching, without reflection, from the source to the conical inputs (indicated schematically as loads), with equal transit times from the source to each of the conical inputs. One must also take care that the hookup to the conical lines has the proper sequence with proper polarities. The waves reaching the cylindrical line from the conical lines must have the right polarities and the network should also pass low frequencies onto the cylindrical line. The parallel network of figure 6A would be appropriate for the multiple conical transition of figure 5A. The series-parallel networks of figure 6C would be appropriate for the multiple conical transition of figure 5B.

The multiple conical transition assembly can also be used to terminate waves on a cylindrical line either with resistors for each conical line, or using the networks of figure 6, with a single resistor. The use of several conical lines then allows for some flexibility in arrangement of sources and terminations. If the impedance of the cylindrical transmission line is not that desired as a load for the signal source more than one source might be used, arranged to better match the impedances. With different multiple conical arrangements the conical lines can have impedances higher or lower than that of the cylindrical line.

There are limitations in this technique. Consider a multiple conical transition assembly which is used to terminate a wave on a cylindrical line. Let there be separate resistors terminating each conical line. Use enough conical lines such that the cross section dimensions of each conical line are much less than those of the cylindrical line. Similarly, let the lengths of the conical lines be much less than the cross section dimensions of the cylindrical line. Then the terminating resistors approximate a resistive sheet which for low frequencies terminates the cylindrical line but for high frequencies (wavelengths smaller than the cross section dimensions of the cylindrical line) does not terminate it. With the proper distribution of the conical lines, and thus the resistors, the resistive sheet has a surface resistance equal to the wave impedance (377 Ω for free space). The wave reflects off such a sheet with a reflection coefficient (for the electric field) of -1/3. Of course, the presence of the very small conical lines provides complications to this picture, particularly for wavelengths of the order of the various conical transmission line dimensions.

In a multiple conical transition assembly one might typically use two plate conical lines. The output of the conical lines are arranged so that the conductors are along equipotentials for the TEM mode on the cylindrical line. Thus, the outputs of the conical lines do not necessarily form a regular rectangular array, but some sort of distorted array corresponding to the equipotentials on the cylindrical line.[5] Even if the conical lines are so distributed there is another problem. For conical two plate transmission lines with gradual tapers the field distribution is approximately that of a cylindrical two plate transmission line. Except for cases of plate width much greater than plate spacing, a significant fraction of the electromagnetic energy is not between the plates, but outside. Thus,

5. See reference 1 for these equipotentials for symmetrical two and three plate transmission lines.

although we can cover a certain part of the cross section of a cylindrical line with a two plate conical line of the appropriate impedance, the field distributions do not quite match. This introduces reflections at the juncture of the conical lines with the cylindrical line, limiting the multiple conical transition technique.

There are some special cases which avoid this last problem. Consider a cylindrical transmission line with the appropriate symmetry such that one of the equipotentials is a plane extending through the cross section. Examples of this are the symmetrical two plate and two and four wire transmission lines.[6] Then one divides these cylindrical lines along this plane of symmetry, driving each side with a separate conical transmission line. Each conical line has one conducting plate (or approximation to a conducting plate) for one of its conductors. This plate ends at the intersection of the symmetry plane with the input cross section of the cylindrical line. This is illustrated in figure 7 for the cases of the symmetrical two plate line and the symmetrical four wire line.

Another way to look at these cases is to first symmetrically match a conical line to the cylindrical line. Then add two conducting sheets (sandwiched initially as one) along the flat, center equipotential, extending from the conical input to the input cross section of the cylindrical line and sidewards to a distance to intersect most of the normal electric field. Separate the two sheets at the conical input end to produce two separate conical lines. The field distribution on each of these conical lines then does approximately match the field distribution needed on the appropriate half of the cylindrical line. One can feed this type of structure with two sources, each of half the cylindrical line impedance, or with one source using a network as in figure 6B. Likewise one can use such a structure to terminate a wave on such a cylindrical line.

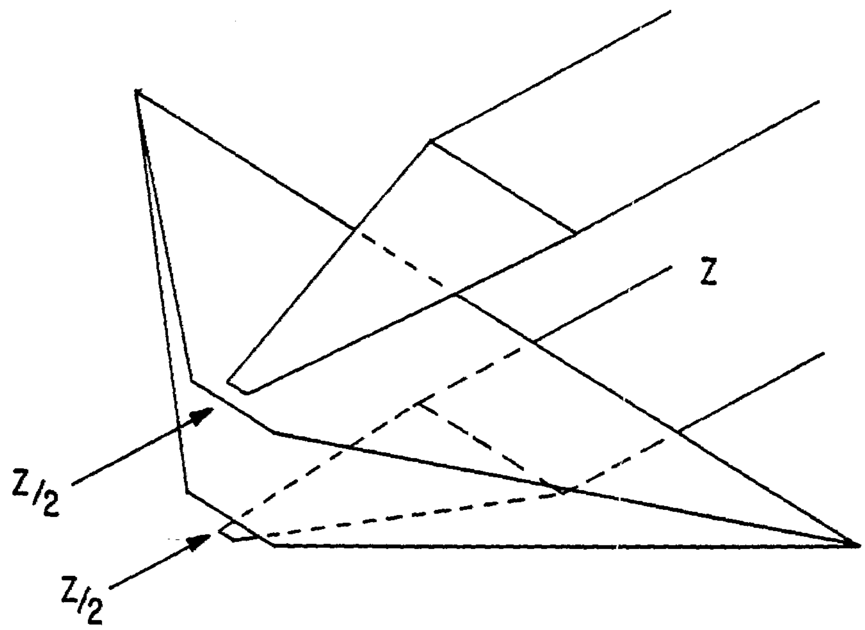
V. Summary

A conical transmission line can be used to launch a plane wave on a cylindrical transmission line. To optimize the plane wave on the cylindrical line the conical line can have approximately the same cross section shape as the cylindrical line and the length of the conical line can be much greater than the cross section dimensions of the cylindrical line. This gives a smooth transition.

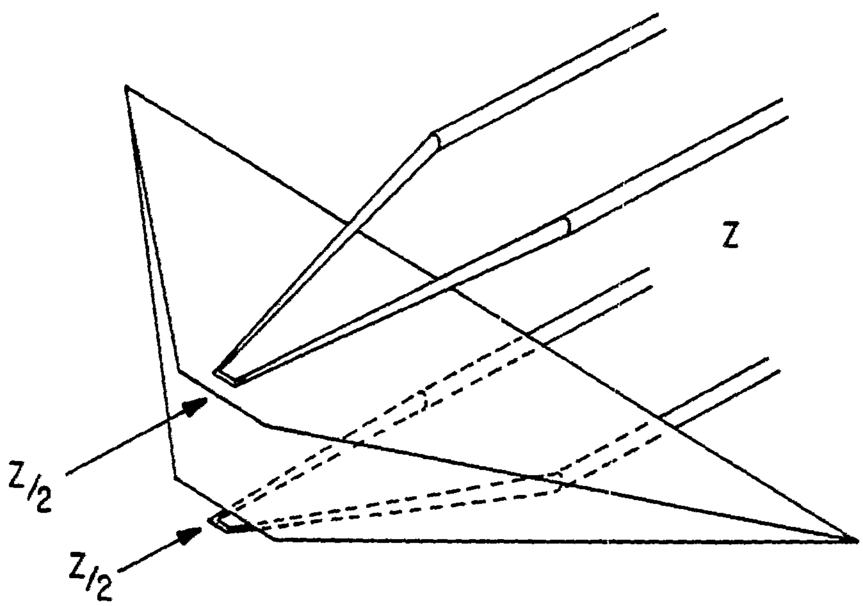
One may improve the transition assembly by the use of multiple conical transmission lines. In some cases, however, this technique may introduce new problems, while in others it may prove advantageous.

In many cases, it may be desirable to measure the response characteristics of a given transition assembly. For contemplated very large structures these measurements can be made on an electrical scale model.

6. Described in references 1 and 2.



A. SYMMETRICAL TWO PLATE TRANSMISSION LINE WITH TWO FEED POINTS.



B. SYMMETRICAL FOUR WIRE TRANSMISSION LINE WITH TWO FEED POINTS.

FIGURE 7. SPECIAL CASES FOR MULTIPLE CONICAL TRANSITIONS