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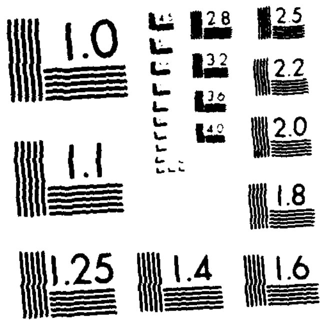

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April 1983

THE TRANSVERSE CURRENT ON A STRIP DIPOLE ANTENNA

Syracuse University/University of Lowell

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The magnitude and distribution of the current flow transverse to the axis of a small strip dipole antenna is evaluated numerically by means of the moment method. This current is found to be small compared to the axial current and to be a sensitive function of the dipole width.

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THE TRANSVERSE CURRENT ON A STRIP DIPOLE ANTENNA

A.D. Wunsch

RADC Postdoctoral Fellow

Abstract

The magnitude and distribution of the current flow transverse to the axis of a small strip dipole antenna is evaluated numerically by means of the moment method. This current is found to be small compared to the axial current and to be a sensitive function of the dipole width.

THE TRANSVERSE CURRENT ON A STRIP DIPOLE ANTENNA

All analyses of the current on thin wire dipole antennas presuppose that this current is directed parallel to the antenna axis. This assumption is made irrespective of the shape of the cross-section of the wire. If the wire antenna has a circular cross-section and is fed in a symmetric manner, no approximation is made in assuming a purely axial current. For antennas having a non-circular cross-section, a component of current transverse to the antenna axis can exist. The strip dipole, which is now increasingly used in arrays of microwave antennas, can possess such a transverse component; we have investigated its magnitude and distribution when the antenna is electrically small.

The antenna, of width 2b and length 2h, driven at its center by a delta function generator of potential V, is shown in Figure 1. We seek both surface current density components $K_x(x,z)$ and $K_z(x,z)$. The antenna current creates a magnetic vector potential $\vec{A}(x,y,z) = A_z \hat{a}_z = A_x \hat{a}_x$ from which we can derive the components of the electric field generated by the antenna. Thus:

$$E_z(x,y,z) = \frac{-j\omega}{\beta^2}\left[\frac{\partial^2 A_z}{\partial z^2} + \frac{\partial^2 A_x}{\partial x \partial z} + \beta^2 A_z\right] \tag{1}$$

$$E_x(x,y,z) = \frac{-j\omega}{\beta^2}\left[\frac{\partial^2 A_x}{\partial x^2} + \frac{\partial^2 A_z}{\partial x \partial z} + \beta^2 A_x\right] \tag{2}$$

Here:

$$A_z(x,y,z) = \frac{\mu_0}{4\pi} \int_{-h}^{h} \int_{-b}^{b} K_z(x',z')\, G(R)\, dx'\, dz' \tag{3}$$

$$A_x(x,y,z) = \frac{\mu_0}{4\pi} \int_{-h}^{h} \int_{-b}^{b} K_x(x',z')\, G(R)\, dx'\, dz' \tag{4}$$

where $G(R) = e^{-j\beta R}/R$, $\beta = \omega\sqrt{\mu_0\varepsilon_0}$, ω is the radian frequency in use and

$$R = \sqrt{(x-x')^2 + y^2 + (z-z')^2} \tag{5}$$

is the distance between a source point $x',0,z'$, on the antenna and a general observation point at x,y,z.

On the antenna, E_x and E_z must fulfill these boundary conditions:

$$\left.\begin{aligned} E_z(x,0,z) &= -V\,\delta(z), && (6)\\ E_x(x,0,z) &= 0 && (7)\end{aligned}\right\} -b<x<b,\ -h<z<h$$

Equation (6) is a result of the assumed delta function driving generator while (7) follows if we assume a perfectly conducting metal strip.

Using (1) and (2) to find E_x and E_z in the rectangle occupied by the antenna, using (6) and (7) on the left in (1) and (2), and using

(3) and (4) to describe A_x and A_z in (1) and (2) we arrive at a coupled pair of integral equations valid for $-h<z<h$, $-b<x<b$, $y=0$:

$$-V\delta(z) = \frac{-j\omega}{\beta^2}\frac{\mu_o}{4\pi}\left[\frac{\partial^2}{\partial z^2}\int_{-h}^{h}\int_{-b}^{b} K_z(x',z')G(R)dx'dz' + \frac{\partial}{\partial z}\frac{\partial}{\partial x}\int_{-h}^{h}\int_{-b}^{b} K_x(x',z')G(R)dx'dz' + \beta^2\int_{-h}^{h}\int_{-b}^{b} K_z(x',z')G(R)dx'dz'\right] \quad (8)$$

$$0 = \frac{-j\omega}{\beta^2}\frac{\mu_o}{4\pi}\left[\frac{\partial^2}{\partial x^2}\int_{-h}^{h}\int_{-b}^{b} K_x(x',z')G(R)dx'dz' + \frac{\partial}{\partial z}\frac{\partial}{\partial x}\int_{-h}^{h}\int_{-b}^{b} K_z(x',z')G(R)dx'dz' + \beta^2\int_{-h}^{h}\int_{-b}^{b} K_x(x',z')G(R)dx'dz'\right] \quad (9)$$

Note than R in (8) and (9) is now $\sqrt{(x-x')^2 + (z-z')^2}$.
The preceding equations are coupled versions of Pocklington's integral equation.

To solve (8) and (9) by an iterative procedure we first assume that the longitudinal surface current density K_z is considerably stronger than the transverse surface current density K_x. We neglect K_x in (8) and then solve this equation to obtain a first approximation to $K_z(x,z)$. With this K_z, (9) is now solved for $K_x(x,z)$. An improved $K_z(x,z)$ can now be obtained if we again solve (8) for K_z using the recently derived $K_x(x,z)$. In theory the procedure can be continued indefinitely.

The solution of (8) with $K_x=0$ is a standard problem in antenna theory: the problem of obtaining the axial current on a dipole antenna on which there is no transverse current. There is a large literature on this subject and much numerical data which we can use.

To simplify this still rather complicated problem we have restricted ourselves to the electrically short, electrically narrow, strip dipole, i.e.: $Kh \ll 1$, $Kb \ll 1$. The antenna is assumed sufficiently small to render valid a quasi-stationary (low frequency) solution for K_x and K_z. In this approach ω is small enough so that we can take $e^{-j\beta R} = 1$ where it appears in $G(R)$ in (8) and (9). We also set $\beta^2 = 0$ where it appears within the brackets on the right sides of (8) and (9).

With these approximations and with $K_x = 0$ we solve (8) to obtain a first approximation to $K_z(x,z)$. Here we are aided by the writings of King[1][2] on the electrically short cylindrical dipole and on the equivalent radius of dipoles with non-cylindrical cross-section. From reference (1) we find that in the quasi-stationary limit the distribution of current varies with z as $(1-(|z|/h))$. For the strip dipole K_z is also a function of the transverse coordinate x (see Fig. 1). This variation of K_z can be determined from reference (2) to be $1/(\sqrt{1-(x^2/b^2)})$. Thus, on the strip dipole

$$K_z(x,z) = \frac{K_o\ (1-(|z|/h))}{\sqrt{1-(x^2/b^2)}} \qquad (10)$$

This result is limited to rather narrow antennas, i.e., $b \ll h$. Note that K_o is the axial surface current density at x=0, z=0+, i.e., at the center of the antenna. Observe that the surface current density

$\to\infty$ as the edge of the antenna is approached ($x \to b$). This behavior conforms to well known edge conditions[3].

Substituting (10) into (9) we now seek a solution for $K_x(x,z)$. Here we employ the moment method[4]. The unknown transverse current density K_x is represented in (9) by a "complete domain expansion", i.e., a series expansion is used which represents K_x over the entire antenna. Such expansions have been used by Richmond[5] to find the current excited on a wire by an incident plane wave. He has employed, with success, Fourier, Maclaurin, Legendre polynomial, and other series. The double series we will use for $K_x(x,z)$ is:

$$K_x(x',z') = \left\{ \begin{array}{ll} \sum_{n=1}^{N} \sum_{m=1}^{N} A_{n,m} \sin\left(\frac{n\pi x'}{b}\right) P_{m-1}\left(\frac{2z'}{h} - 1\right) & 0<z'<h \\ \sum_{n=1}^{N} \sum_{m=1}^{N} -A_{n,m} \sin\left(\frac{n\pi x'}{b}\right) P_{m-1}\left(\frac{2|z'|}{h} - 1\right) & -h<z'<0 \end{array} \right\} -b<x'<b \qquad (11)$$

where P_{m-1} is the Legendre polynomial of order m-1.

Using the physical symmetries of this problem we can show that K_x is an odd function of both x and z. These symmetries are accounted for in the form assumed for K_x in (11). The requirement that K_x vanish at the edges of the antenna is also satisfied by this expansion.

A polynomial representation of the z variation of $K_x(x,z)$ is advantageous since it allows the z' integration of K_x in (9) to be done analytically when K_x is represented by (11). Only the integrations on x' in (9) must be done numerically; these require a modest amount of computer time.

We have chosen both 9 and 16 term series in (11) (i.e., N=3 and N=4). By enforcing $E_x=0$, i.e., (9), at a uniform grid of N^2 points on the antenna we can obtain N^2 equations in the N^2 unknowns $a_{n,m}$. Because of the symmetry present in (11) these grid points can be confined entirely to ¼ of the antenna, say $0<x<b$, $0<z<h$. The simultaneous equations are easily solved on a computer. The coefficients $a_{n,m}$ are then substituted into (11) from which the transverse surface current density is then constructed.

Our results are shown in Figures 2 and 3 where we h plotted $K_x(x,z)/K_0$, i.e., the transverse current density normali to the axial surface current density at the center of the anten Ve can make several conclusions: Over most of the antenna the results for the 9 and 16 term series are not very different; this should assure us that we are using series with a sufficiently large number of terms. The transverse component of the surface current density is generally much smaller than the axial component, e.g., for b/h = .1 the ratio K_x/K_0 is of the order of .001, for b/h = .2 it is of the order of .01. We see that K_x/K_0 is a sensitive function of the normalized antenna width b/h, increasing rapidly as b/h increases.

Studying K_x as it changes with the axial variable z we notice that it is strongest at the ends of the antenna and near the generator. From symmetry, we can argue that $K_x(z=0+)=0=K_x(z=0-)$. Thus, starting at z=0+, K_x rises steeply with increasing z and achieves a peak near the generator. We have not plotted K_x in the immediate vicinity of the generator since the polynomial series employed is not capable of representing this rapidly changing behavior. Moreover, the formula for the axial component of current density (11) used in this analysis is itself of questionable validity so near to the generator because of the infinite susceptance theoretically "seen" by the delta function driving source. In a physically realizable situation this portion of the antenna, say $0 \leq z \leq .05h$ would be absent anyway, having been replaced by a feed structure.

Starting at x=0, and examining the variation of K_x with x, we see that the transverse current density increases at first almost linearly with x and reaches a peak somewhere between .65b and .7b. From this peak the current declines rapidly to zero at the edge of the antenna. This qualitative behavior is more or less independent of the axial location z and insensitive to the ratio b/h.

In an interesting paper, Denlinger(6) has analyzed the behavior of the current density on an infinite microstrip line located above a substrate. His graphical picture of the transverse current density on the strip is qualitatively very similar to ours and displays a peak at x=.7b.

If we choose to make another iteration in our solution of (8) and (9) and thereby improve our representations of K_x and K_z we must substitute our most recently obtained series representation of K_x into (8) and again solve this equation for K_z. The difference between this new K_z and the one given by (10) is the same order of magnitude as K_x. Since K_x is so vastly smaller than K_z this next iteration was deemed unnecessary.

One interesting numerical result which we have found is the 180 degree phase shift existing between K_x and K_z. Thus K_z, the dominant component of the surface current density, is maximum near the edges of the antenna ($x=\pm b$) and causes a transverse flow of current directed inward toward the z axis.

The transverse current has negligible effect on the radiation pattern of the antenna for two reasons: (a) K_x is small compared to K_z and (b) the symmetry condition $K_x(x,z)=-K_x(x,z)$ guarantees that the radiation field contributed by the transverse currents on the two halves $-b<x\leq 0$ and $0\leq x<b$ will cancel. For strip dipoles belonging to arrays this symmetry can be lost and there would be a greater tendency for the transverse current to contribute to the radiation field of the array.

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LEGEND TO ILLUSTRATIONS

Figure 1	Strip Dipole
Figure 2	Normalized Transverse Surface Current Density K_x/K_o at x=.65b
Figure 3	Normalized Transverse Surface Current Density K_x/K_o at Various Values of z/h for b/h=.1

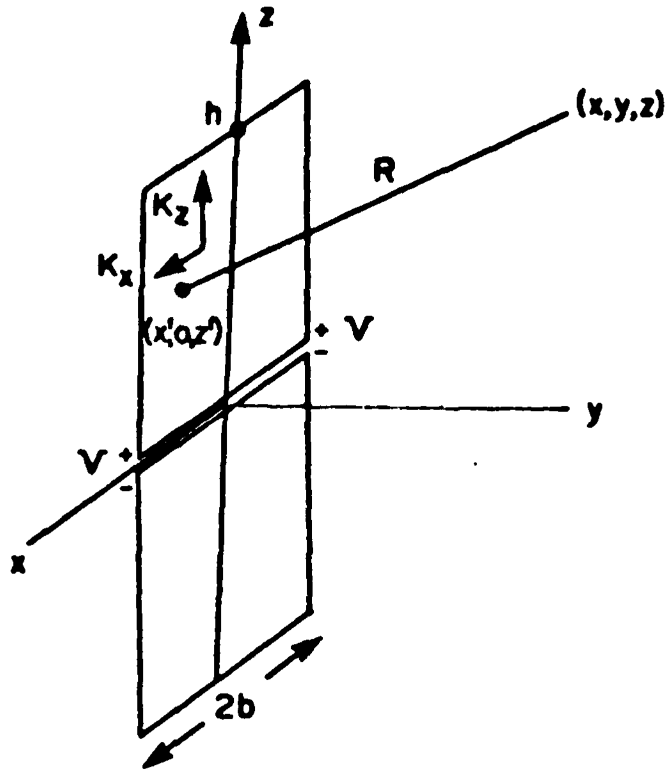
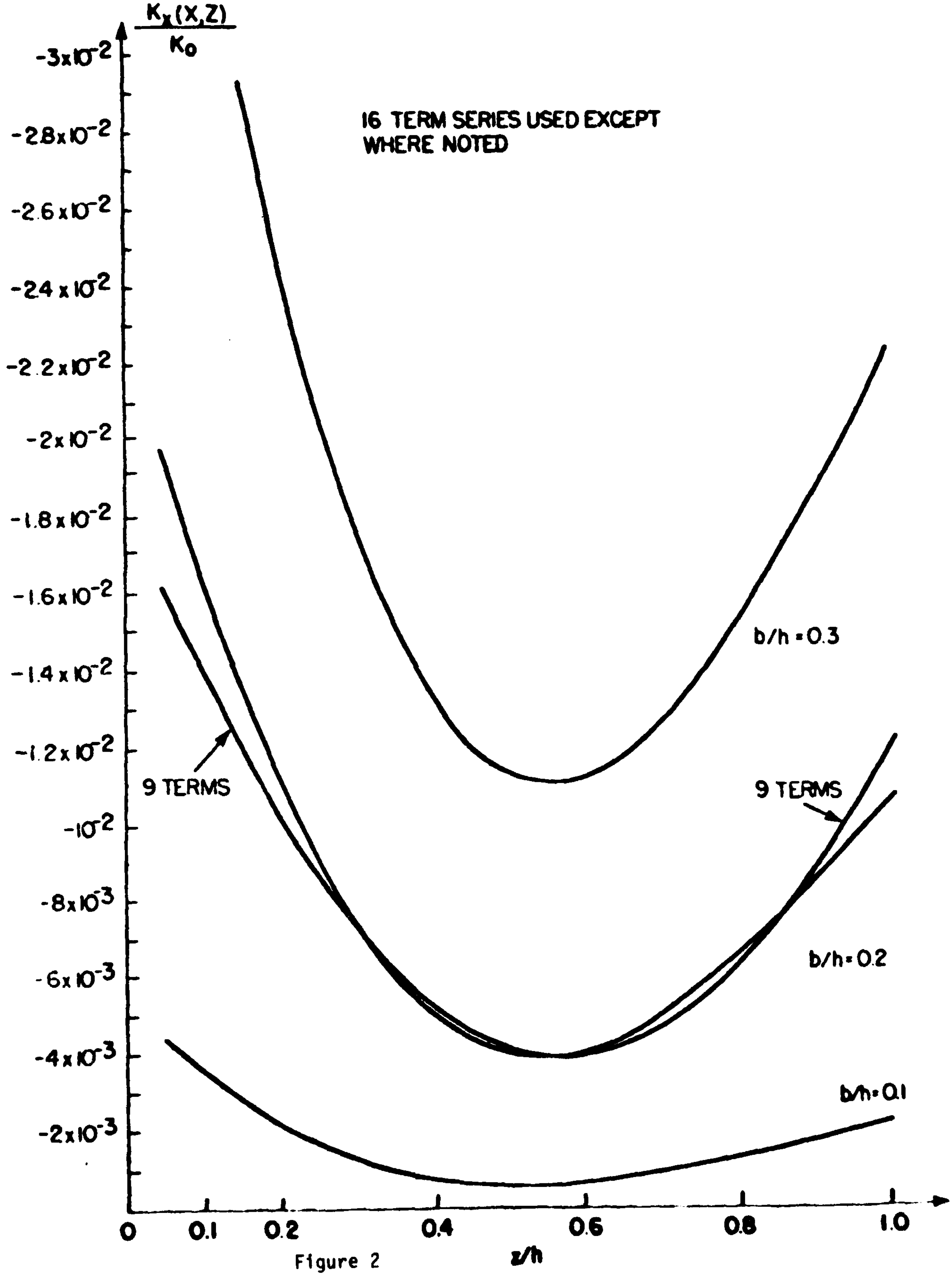


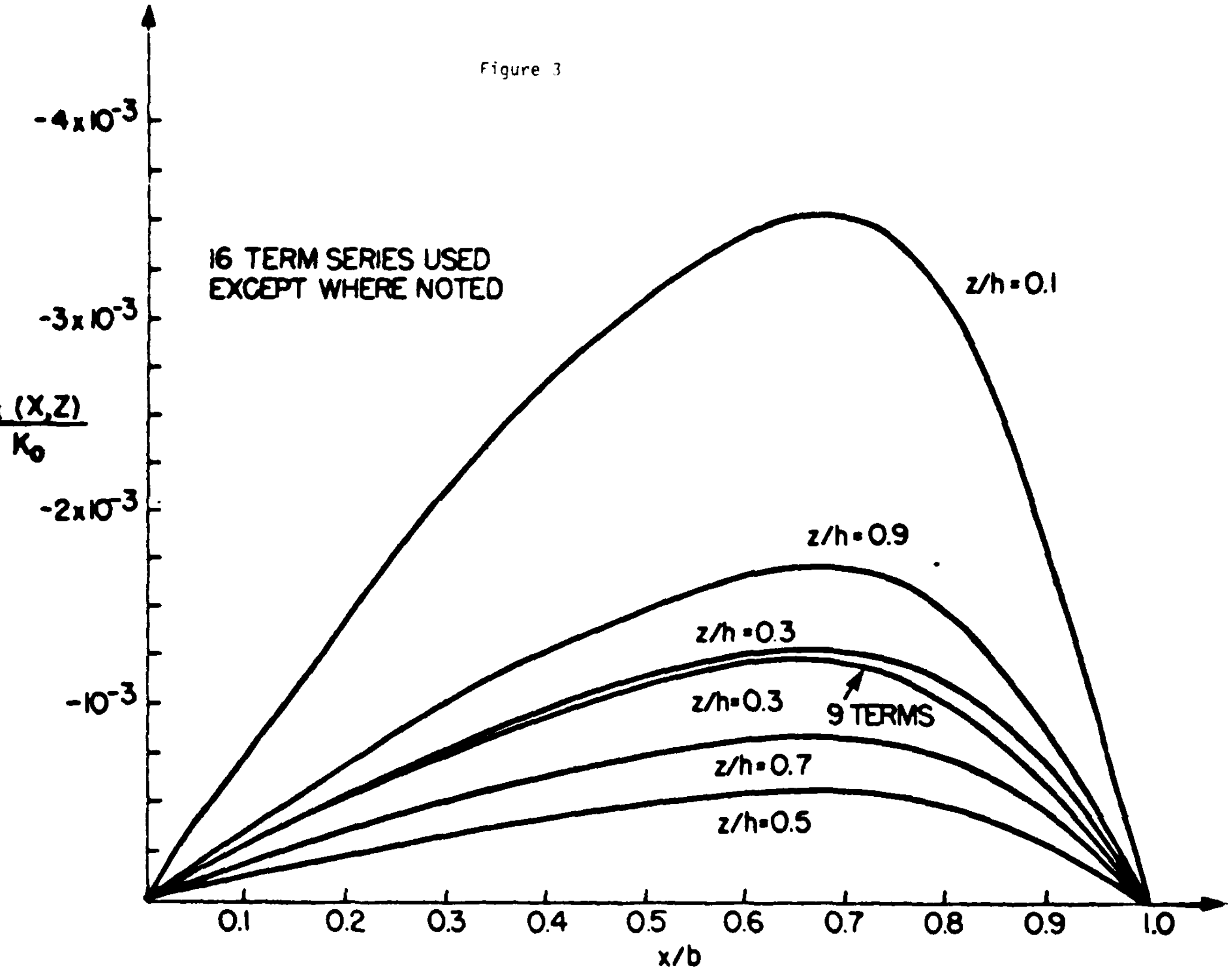
Figure 1



$\frac{K_x(X,Z)}{K_0}$
-3×10^{-2}
-2.8×10^{-2}
-2.6×10^{-2}
-2.4×10^{-2}
-2.2×10^{-2}
-2×10^{-2}
-1.8×10^{-2}
-1.6×10^{-2}
-1.4×10^{-2}
-1.2×10^{-2}
-10^{-2}
-8×10^{-3}
-6×10^{-3}
-4×10^{-3}
-2×10^{-3}
16 TERM SERIES USED EXCEPT WHERE NOTED
b/h = 0.3
9 TERMS
9 TERMS
b/h = 0.2
b/h = 0.1
0
0.1
0.2
0.4
0.6
0.8
1.0
z/h

Figure 2

Figure 3


16 TERM SERIES USED
EXCEPT WHERE NOTED
$\frac{K_x(X,Z)}{K_0}$
-4×10^{-3}
-3×10^{-3}
-2×10^{-3}
-10^{-3}
z/h = 0.1
z/h = 0.9
z/h = 0.3
z/h = 0.3
9 TERMS
z/h = 0.7
z/h = 0.5
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
x/b

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