ABSTRACT

A certain rhombic illuminator used to test the hardness of aircraft systems is studied with regard to its low frequency behavior. The upper frequency limit on the validity of the two-wire transmission line model for the rhombic illuminator is determined using a simple numerical model. The magnitudes of the transverse field components determined using the numerical model are found to differ significantly from those of the two-wire line model at frequencies as low as 2 MHz.

INTRODUCTION

The Hardness Surveillance Illuminator (HSI) is a full-scale antenna system used to qualify, verify and maintain electromagnetic pulse (EMP) hardened aircraft systems. The HSI facility at Kirtland AFB offers the capability of low-level CW testing of aircraft. The basic geometry of the HSI rhombic antenna is shown in Figure 1. The region in Figure 1 designated as the “working volume” represents the location of the aircraft under test. The HSI rhombic antenna system may be driven in either a common-mode (push-push) configuration or a differential mode (push-pull) configuration with respect to the ground plane. The common-mode configuration generates electric fields with dominant vertical components (principal components).

TRANSMISSION LINE MODEL OF THE HSI

At low frequencies, the HSI antenna may be modelled by a two-wire transmission line over a perfectly conducting ground plane as shown in Figure 2. The transverse electromagnetic fields over any cross-section of the HSI working volume may be approximated by the fields of the corresponding two-wire line TEM mode. The TEM fields of the two-wire line under common-mode or differential-mode excitation are obtained by considering the static field of equivalent line charges over a perfectly conducting ground plane. For a given set of working volume dimensions, the
values of the wire separation and wire height above
ground may be optimized with regard to field uniformity
in the interest of brevity, only common-mode
excitation results are presented here. The maximum
cross-sectional dimensions (at the apex of the antenna,
y=125m) determined for maximum field uniformity
under common-mode excitation are 2a=32m and b=26m.
The cross-sectional dimensions of the working volume
shown in Figure 1 are given by 2a'=45m (width) and
b'=15m (height).

The principal and nonprincipal transverse electric
fields (E, and E, respectively) for common-mode
excitation of the two-wire line are given by

\[ E_1 = \frac{q}{2\pi \varepsilon_0} \left[ \frac{(x-b)}{(x-a)^2 + (z-b)^2} + \frac{(z-b)}{(x+a)^2 + (z-b)^2} \right] \]

and

\[ E_2 = \frac{q}{2\pi \varepsilon_0} \left[ \frac{(x+a)}{(x-a)^2 + (z-b)^2} + \frac{(z-a)}{(x-a)^2 + (z+b)^2} \right] \]

where q is the line charge density, \( \varepsilon_0 \) is the permittivity of vacuum, 2a is the distance between
the wire centers and b is the height of the wires above
the ground plane. The value of the line charge density is
related to the potential difference between each of the
wires and ground (V) and the characteristic impedance
of the common-mode two-wire line (Z_cm) as given by

\[ Z_{cm} = \frac{\eta_b}{4\pi} \left\{ \ln \left[ 1 + \frac{1 + (rb)\eta_b}{1 - (rb)\eta_b} \right] \right. \]

\[ \left. + \frac{1}{2} \ln \left[ 1 + \frac{b/a}{2} \right] \right\} \]

where \( \eta_b \) is the intrinsic impedance of vacuum and r is the radius of the wires.
The TEM transmission line model of the HSI is a
low frequency approximation since higher order modes
are not included in the transmission line model.
In order to investigate the effects of these approximations on the accuracy of the transmission line
model, a thin-wire model of the HSI is considered.

NUMERICAL ELECTROMAGNETICS
CODE MODEL OF THE HSI

The Numerical Electromagnetics Code allows for
the actual geometry of the rhombic antenna to be
included in the formulation of the solution. The HSI
facility is modeled as a rhombic antenna driven in the
common-mode configuration over a perfectly conducting
ground plane as illustrated in Figure 3. The four wires
of the rhombic antenna are denoted as wire #1 and
wire #3 in the launch (source) region which are
connected with wire #2 and wire #4, respectively, in the
termination region. The number of segments used to
model each of the four wires of the HSI is based
on the frequency of operation. The segments on the launching
region wires (#1 and #3) are
numbered from the ground
plane to the apex of the antenna. That is, the first segment on each wire is connected to the ground plane
while the last segment is connected to the termination
wire at the apex. The segments on the termination
region wires (#2 and #4) are numbered from the apex
to the ground plane. The two common-mode voltage
sources (applied electric-field sources), \( V_{1} \) and \( V_{2} \), are
placed on the first segment of wire #1 and wire #3,
respectively. Both voltage sources are one volt with a
phase of zero degrees. The terminations are lumped
resistive loads of 630 \( \Omega \) which together in parallel yield
the average characteristic impedance of the transmission
line (315 \( \Omega \)).

COMPARISON OF RESULTS FOR
THE TWO HSI MODELS

The principal and nonprincipal transverse electric
fields over any transverse cross-section \(-\pi/2 \leq \alpha',
0 \leq \phi \leq \pi/2\) of the HSI working volume are symmetric about
the y-z plane given common-mode excitation. Therefore,
a complete characterization of the transverse fields is obtained by plotting the respective fields over only one-half of the cross-section\((0\leq x\leq a')\) and \([0\leq z\leq b']\) as shown in Figure 4. The transverse cross-section located at the center of the working volume is located at \(y=125m\). The dimensions of the RI at \(y=125m\) are \(2a=25.48m\) (wire separation) and \(b=20.70m\) (wire height above ground plane). The transverse electric field components of a similarly spaced two-wire transmission line over a ground plane are shown in Figures 5 and 6. The corresponding transverse fields of the 2 MHz NEC HSI model are shown in Figures 7 and 8. The general distribution of the principal and non-principal field components for the two HSI models are quite similar in shape. However, the magnitude of the 2 MHz NEC model fields are significantly larger than the corresponding transmission line values. The principal electric field component of both HSI models contains a broad peak along the upper edge of the working volume \(z=b'\) which corresponds to points directly below the transmission line conductor. The principal electric field is relatively uniform over the remainder of the working volume. The nonprincipal electric field component is zero-valued along the lower edge of the working volume (the field component is tangent to the perfectly conducting ground plane) and increases in magnitude as the observation point is moved away from the ground plane. The nonprincipal electric field contains a null along the upper edge of the working volume which corresponds to the point where the horizontal components due to both wires and their images cancel one another. The \(x\)-coordinate of this null lies between the transmission line center point \(x=0\) and the coordinate of the transmission line conductor \(x=a(y)\).

The magnitudes of the principal electric field at the four corners of the working volume cross-section (See Figure 4) are compared to the corresponding transmission line model values in Figures 9a through Figure 9d. The uniformity in the shape of the plots in Figure 9 reveals that the magnitude of the principal field varies with frequency but the field distribution remains essentially unchanged over the frequency range of interest. A similar plot of the nonprincipal electric field component at \((a',b')\) is shown in Figure 10. As shown in Figures 9 and 10, both the principal and nonprincipal field component magnitudes vary by as much as 40 percent from the predicted value of the transmission line model.

Figure 4. Surface in the Working Volume Over Which the Transverse Field Components are Plotted.

Figure 5. Magnitude of the Principal Electric Field Over the Working Volume Cross-Section (See Figure 4) Using the Transmission Line Model.

Figure 6. Magnitude of the Nonprincipal Electric Field Over the Working Volume Cross-Section (See Figure 4) Using the Transmission Line Model.
Figure 7. Magnitude of the Principal Electric Field Over the Working Volume Cross-Section (See Figure 4) Using the NEC Model at 2 MHz.

Figure 8. Magnitude of the Nonprincipal Electric Field Over the Working Volume Cross-Section (See Figure 4) Using the NEC Model at 2 MHz.

Figure 9. Variation in $|E_z|$ from 100 kHz to 4 MHz at (a.) (0,0), (b.) ($a',0$), (c.) (0,$b'$) and (d.) ($a',b'$). [The dashed lines represent the value of $|E_z|$ predicted by the transmission line model.]
REFERENCES


ACKNOWLEDGEMENT

This research was sponsored by the United States Air Force, Air Force Systems Command, Weapons Laboratory, Kirtland Air Force Base, New Mexico 87117-6008 through its contract with United International Engineering, Inc. of Albuquerque, New Mexico, Contract F29601-88-C-0001, Subtask 03-05/00.