NOTE 1

EMP TESTING FACILITY

by

R.E. Partridge
Los Alamos Scientific Laboratory

25 February 1964

SSN #1

EMP TESTING FACILITY

There is a continuing need for a very flexible facility for investigating the response of sensors and systems to radio-frequency electromagnetic radiation. Specific objectives for constructing such a facility are to:

a) Obtain experimental verification of theoretical behavior of configurations of conductors in EM fields,

b) Calibrate proposed sensors and verify the response of sensors which were used in the past with inadequate testing facilities,

c) Study mutual interference between closely-spaced sensors,

d) Study the effects of non-ideal geometries, such as airframes or rocket bodies on sensor behavior,

e) Study and verify the response of sensors in a nuclear radiation environment,

f) Investigate EM signal propagation in a nuclear radiation environment, and

g) Study the response of electronic subsystems to a combined EM and nuclear radiation environment.

The proposed facility, as originally envisioned by John Malik, consists essentially of a parallel-plate transmission line, wherein the basic TEM propagation mode is indistinguishable from free-space propagation. Tapered sections form transitions from the relatively small dimensions of conventional coaxial cable or pulse generators up to a room-sized working volume, and back down to a termination or coaxial cable. Below the lower plate of the working volume is a screened room in which is located the instrumentation. A roadway or catwalk leads in from the side to permit bringing in equipment and positioning a portable flash x-ray unit. A second room or space adjacent to the screened room would permit obtaining high dose rates from the flash unit in small volumes.

The dimensions of such a structure are determined by the size of objects to be irradiated and the frequency response desired. Since the vertical electric field is essentially short-circuited by the vertical dimensions of most configurations of conductors, the vertical dimension of the working volume must be sufficiently large that the corrections to compensate for a non-infinite geometry become reasonable. A reasonable compromise between the errors involved and practical dimensions to construct seems to be a vertical dimension of about five times the largest object to be inserted in the working volume. This introduces a 20 percent field change and hence corrections of 50 percent accuracy reduce the field uncertainty to 10 percent and corrections of 5 percent accuracy reduce it to

1 percent. If the largest object to be tested is one meter high, the corresponding structure height of five meters (ten meters based on considerations to follow) is reasonable from a construction standpoint. Such a structure would cease to operate in the fundamental TEM mode approximately at a frequency where this spacing becomes one electrical radian, or 9.55 Mc/s. Probably the structure finally proposed below could be used appreciably above this frequency.

The transverse dimensions of the working volume are determined by related conditions. The static field generated by a conducting object in the impressed field is equal to the impressed field at the object and falls off as the cube of the distance in the immediate neighborhood. Thus the field perturbation is reduced to under 1 percent at a distance of five times the height of the object if it has inappreciable horizontal dimensions, and is somewhat worse otherwise. Similarly, reciprocity considerations dictate that the object must not be closer than five heights from any fringe areas where the impressed field is non-uniform. Thus if two objects are to be side-by-side in the transverse plane, the width of the unfringing portion of the working volume must be at least fifteen times the object height. (Note that this basis of calculation intrinsically defines the fringing field as differing by a factor of two from the nominal field. Other calculations, such as basic sensor sensitivity, require much more stringent conditions.) Since the field strength below the edge of a flat upper plate differs by approximately a factor of two from that of the uniform portion, the upper plate width is essentially set at fifteen times the object height and three times the upper plate height.

The field fringing in the longitudinal direction is determined by the taper of the matching sections at the ends of the working volume, and hence is considerably less than that at the sides. Since it would be highly desirable to be able to space at least three sensors along the propagation direction, a working length of fifteen object heights seems to be a good compromise.

Although many sensors can be scaled down in size, and hence could be tested in a smaller facility, there are a few basic limitations which make a structure of this size seem necessary:

a) Many sensors are essentially capacitive probes. It is difficult to make accurate capacitance and voltage measurements if the probe is scaled to a very small size.

b) Airframe or rocket models must be investigated with free space both above and below, and the measurements either telemetered out or recorded inside. The model must be large enough to accommodate the telemetry or recording equipment and item (a) above in turn applies to measurements on sensors mounted on the model.

c) Scaling of behavior in a nuclear radiation environment is considerably more difficult than ordinary scaling.

d) There will undoubtedly be some pragmatic testing of electronic subsystems which cannot be scaled down.

Several modifications of the basic parallel-plate transmission line have been investigated in an attempt to find a geometry with minimum fringing in order to minimize the size of structure required to obtain the requisite working volume. A number of typical field structures are included as Figures 1 to 8. It may be seen from these that none is significantly better than the basic configuration (Figure 1) or the three-plate quasi-shielded configuration (Figure 2). Guard wires and plates have been investigated and do afford some improvement. However, the guard voltage must propagate without reflections on the guard system just as does the main signal on its structure, and the difficulties of maintaining characteristic impedance in the construction and excitation of the guard system appear to be more formidable than simply building a slightly wider parallel-plate main structure.

An important factor to be considered is radiation to and from the structure. As the frequency components of pulses (or the frequency of sinusoidal signals) approaches the upper limit described earlier, the structure begins to operate less like a transmission line and more like a vertical rhombic antenna. At lower frequencies the structure simply looks like a short dipole, and produces a static field. However, the rapid falloff with distance of a static field is of no avail if the applied voltage is made very large, as it certainly will be upon occasion. Even if the above mentioned two factors were not problems, the following probably would be. Above its intended operating frequencies the structure will be just as good a receiving antenna as it is a transmitting antenna. Hence incoming VHF and UHF radiation can block the input circuits of measuring instrumentation or at least require filtering which would greatly increase the instrumental difficulties. These considerations and another to be mentioned later lead one to desire a quasi-coaxial structure. However, the sides of such a structure would be subjected to a very considerable wind load. Leaving off the sides of such a structure leads to a nearly optimum design, since this almost eliminates the wind loading, while still retaining most of the shielding effect. The rhombic antenna radiation mode simply does not exist, except in higher-order modes. The external static field is reduced to that of a quadrupole. Reciprocity indicates that the receiving properties are similarly affected. The field structure of hal:

of the resulting three-plate line was shown in Figure 2. This design has the additional advantage that sides can always be incorporated in the future (with some aerodynamic loading considerations) if the shielding is ever found to be inadequate. The upper plate should be wider than the central plate. A typical set of possible dimensions is shown in Figure 9. The vertical taper of the transition sections is taken to be 1:10 for the central plate and 1:5 for the upper ground plate.

When a field plot of curvilinear squares is employed, the characteristic impedance of such a structure is $120\pi \frac{h}{w}$, where h/w is the ratio of the number of squares along the field lines to the number across. Thus from Figure 10 we see that the impedance is approximately $\frac{1}{4}\left(120\pi \frac{20}{38.6}\right) = 48.8$ ohm. (Fortuitously close to standard coaxial cable impedances.) Note that Figure 10 is a modification of Figure 2, based on the 1:3 height:width ratio for the working volume.

There undoubtedly will be a desire to use this facility for larger objects from time to time. The working volume can be made larger, at the expense of worse external radiation problems and a poorer impedance match, by making the center plate over the working volume removable and by driving the upper plate instead of the center plate. The center plate floats electrically at half the potential of the upper plate. This is sketched in Figure 11. The characteristic impedance of this configuration is approximately 89 ohms.

There will be some sensors and systems to be tested at higher frequencies and with shorter pulses. These would require a smaller structure. It is proposed that a smaller version (perhaps one meter high) be built in addition to the larger structure. This permits us to kill two birds with one stone, since the smaller structure can be built first and used as a model to search for "bugs" in the design before the larger structure is built. For instance, pulses can be transmitted through the smaller structure and the plates can be bent and moved until there are no remaining reflections to indicate mismatches. The resulting configuration is then scaled up to form the larger structure.

Techniques for driving the system from a coaxial cable, from a high-voltage pulser, and for resonating to obtain high-voltage sinusoidal fields are sketched in Figure 12. Note that in the third case the termination is to be disconnected from the far end.

There are a number of practical details which can contribute to the usefulness and ease of working with this facility:

a) The roof of the screened instrumentation room (the lower plate of the working volume) can have a set of fitted beams and plates which permit installir test objects at virtually any location, and yet form a roof strong enough to support personnel.

b) A hydraulic ram or elevator (perhaps one of those used for filling station grease racks) can be installed in the floor of the screened room for lifting personnel to a convenient working height and for lifting racks of equipment. Another might be provided for the flash x-ray unit.

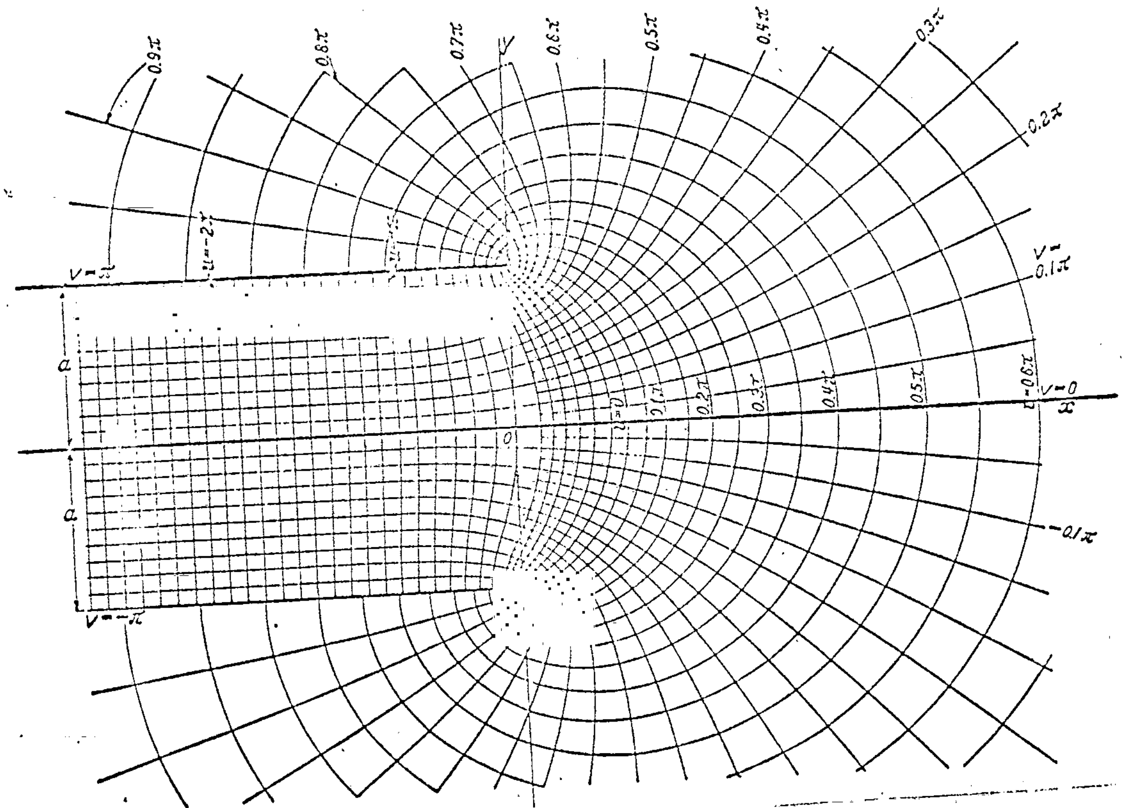
c) A rain and sun cover of canvas or plastic could be installed above or below the top plate for working in inclement weather. Alternatively, the upper plate over the working area could be made of aluminum sheet or roofing instead of mesh.

d) Electric power outlets and conduits leading to the screened room should be installed around the working area.

e) Floodlights should be installed on the support structure to illuminate the working volume. If there is concern that the conduits to these lights would perturb the field, the conduits could be run up along the upper plate, with provision for unplugging the leads when the upper plate is used as the driven element.

f) Precision measurements will require power which is isolated electricall and is regulated both in voltage and in frequency. This is most readily obtained from an MG set which in turn is driven from the commercial power lines. If it is not possible to incorporate the MG set in the initial construction, at least space should be provided and lines roughed in for later installation of such a set.

Ralph E. Partridge
25 February 1964

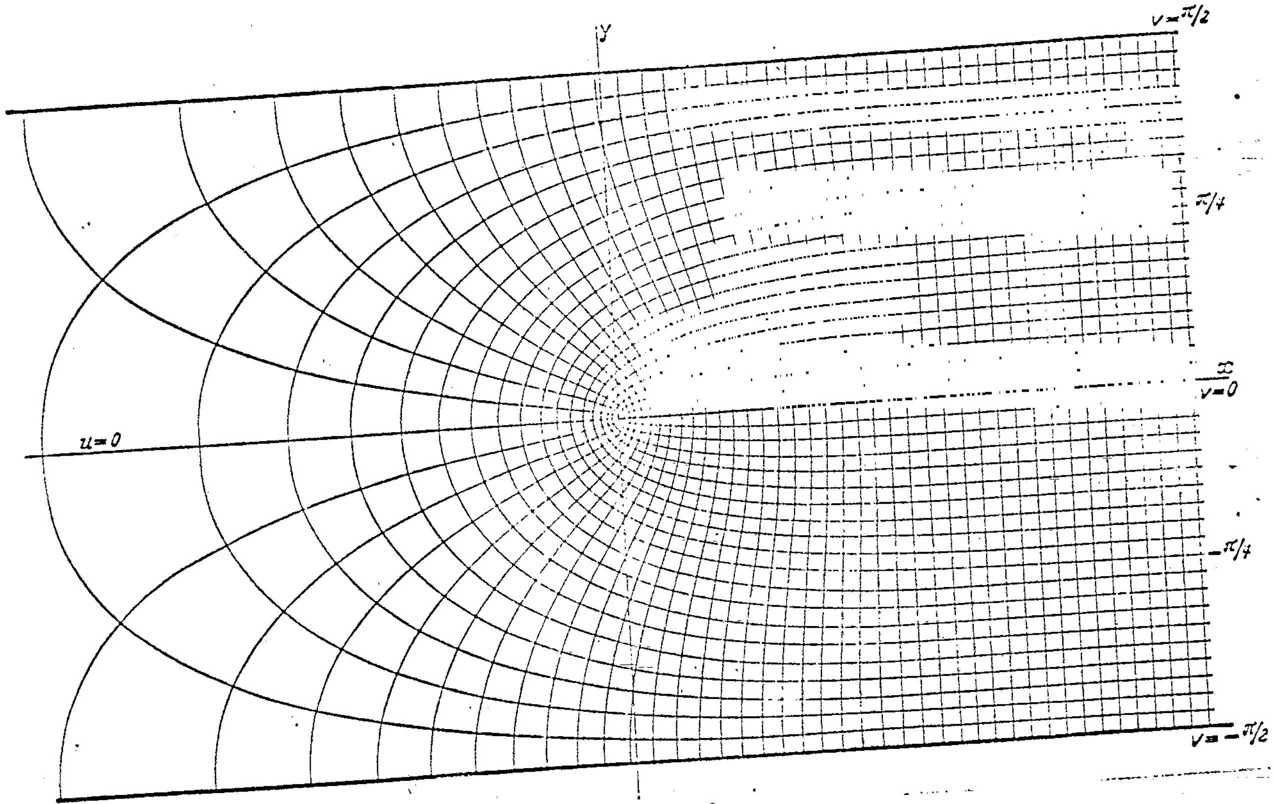


Maxwell curves, $z = \frac{a}{\pi}(w + 1 + e^{w})$

FIGURE 1

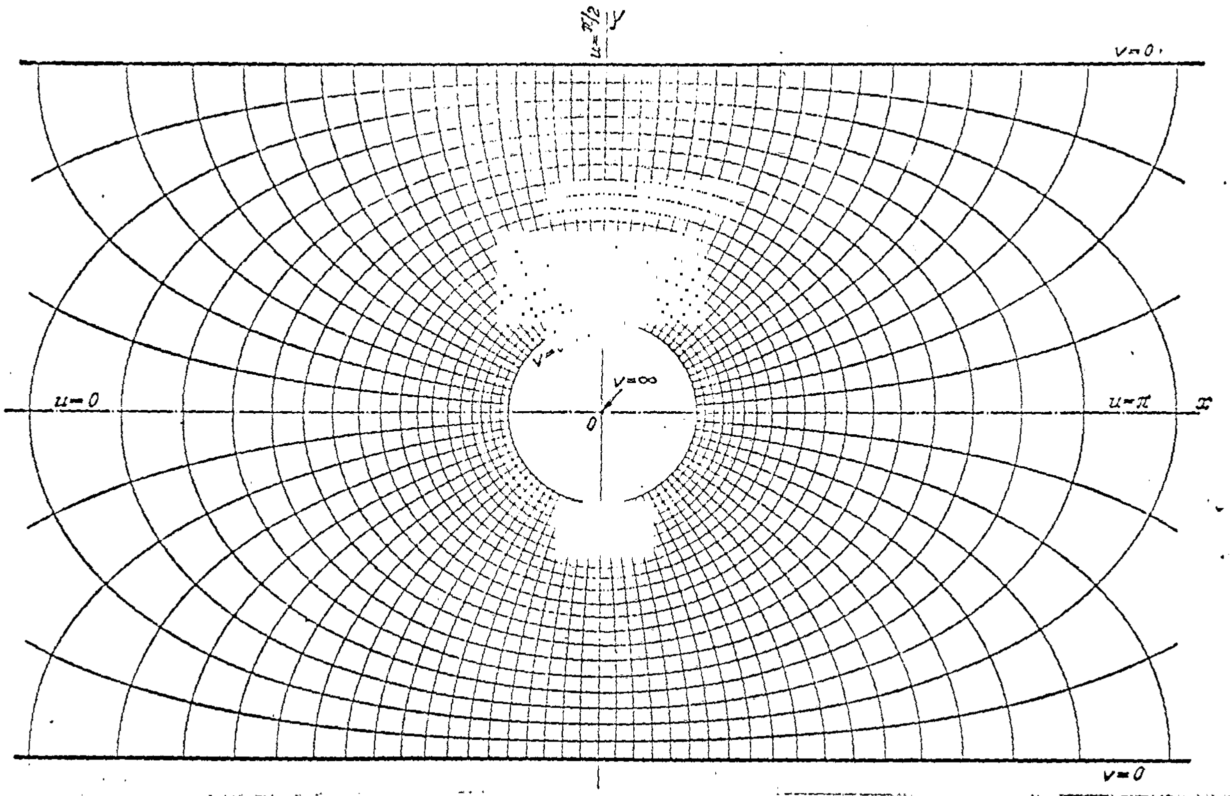
$$Z_0 = \frac{V}{I} = \frac{E \cdot h}{H \cdot w}$$

$$\frac{E}{H} = 120\pi$$



ln cosh curves, $z = \frac{2a}{\pi} \ln \cosh w$

FIGURE 2



ln tan curves, $z = \frac{2a}{\pi} \ln \tan w - ia$

FIGURE 3