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A TEM-HORN ANTENNA WITH DIELECTRIC LENS FOR FAST IMPULSE RESPONSE

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MASTER

INTRODUCTION

We recently designed and built a TEM-horn antenna with a dielectric aperture lens in order to achieve faster transient pulse response. TEM (*t*ransverse *e*lectro*m*agnetic) horns are commonly used for wideband time-domain work because they offer minimum dispersion as a traveling-wave endfire structure (which can be made fairly nonresonant). However, even carefully designed TEM horns have an inherent pulse-smearing geometrical effect due to spherical wavefront propagation within the structure. A dielectric planar-convex aperture lens is used to accomplish this plane-wave to spherical-wave conversion, by collimating the wavefront between the plates in order to improve the impulse response.

The antenna consists of a conventional TEM-horn configuration (two flat, long triangularly-shaped conducting plates with a constant separation angle), and an additional solid Teflon™ lens placed at the aperture end of the plates. A 91-cm-long antenna was designed and built. Two different schemes were employed for the plate configuration: the first version utilizes single-sided etched copper traces on low-loss printed-wiring boards, and the other version utilizes solid copper plates. In both configurations, expanded polystyrene is employed as a solid structural supporting material between the plates, and the dielectric planar-convex lens is located at the aperture end of the plates.

The *printed-board configuration* is designed with stepped resistive loading at the aperture end of the traces in order to minimize ringing antenna currents, and a custom transition from the parallel-plate antenna structure to coaxial feedpoint. The *solid-plate configuration* was then developed because the impulse response of the printed-board topology wasn't good enough. The resulting step-equivalent risetime (10-90%) of the solid-plate version is 20 ps, the fastest TEM-horn we have designed and built to date. This paper describes our antenna design for both plate configurations, and measurements of the

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resulting performance for two nominally identical antennas. This type of antenna offers very good short-pulse operation, and is highly recommended for wideband time-domain antenna work.

PRINTED-BOARD ANTENNA CONFIGURATION

The printed-board configuration was the first design effort for our next-generation of time-domain antennas, with two primary features: 1) incorporate a planar-convex dielectric lens to collimate the internal spherical-wave behavior of a TEM horn, resulting in much faster transient response (for either transmit or receive operation), and 2) incorporate resistive loading on the conducting plates of the TEM horn in order to reduce the undesired ringing of antenna currents between the feedpoint and the aperture.

Figure 1 shows one of two identically-built TEM horn antennas which utilizes the printed-board construction. Most of the body consists of solid expanded polystyrene, with a dielectic constant very close to free-space (for minimal perturbation of the electromagnetic fields in the antenna structure). The lens is seen positioned between the aperture end of the two printed-wiring boards, with single-sided copper traces on the outside surfaces of the two boards. The aperture plate (and lens) width is 30.5 cm, and the plate separation (lens height) is 12.7 cm. The length of the flat-plate conductors is 80.0 cm from the focal point to the center of the aperture end of each conductor. The resulting plate-separation angle is 9°, and the plate-width angle is 22°. Because the primary goal was to minimize the duration of the time-domain impulse response, the plate-separation angle is shallow compared to typical TEM-horn designs of 15-20°. The surge impedance along the antenna was allowed to increase from the feedpoint level of 50 Ω up to about 95 Ω at the aperture, in order to increase the main-beam transmit gain and/or receive sensitivity with a given aperture width.

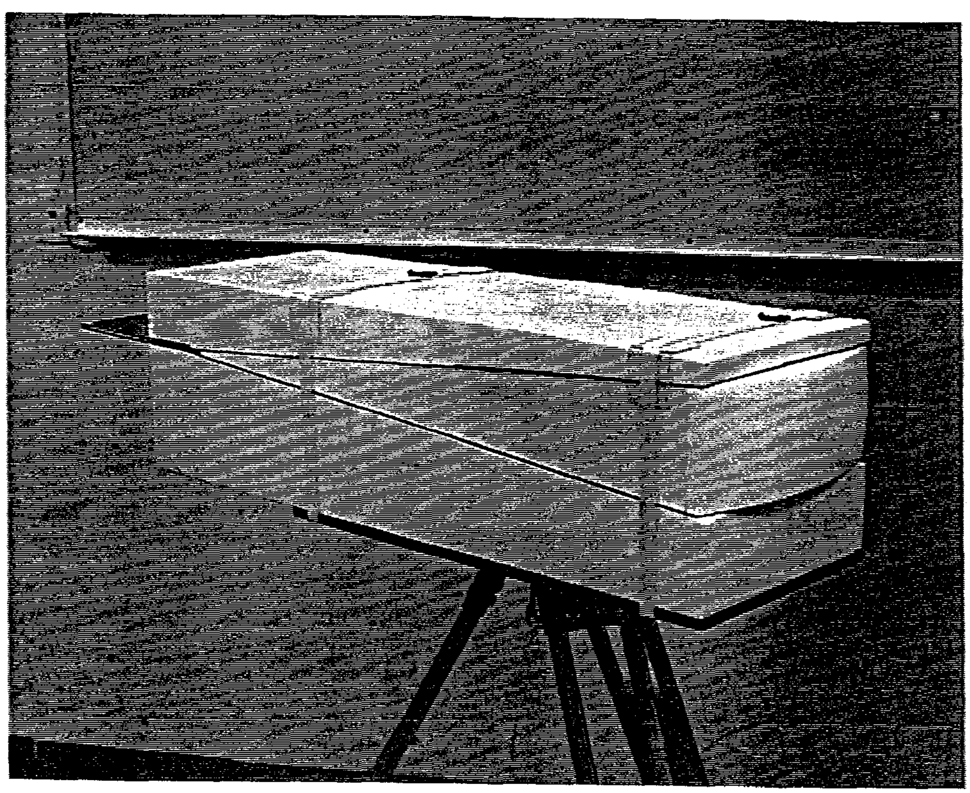

Figure 1. Printed-board configuration of TEM-horn antenna with dielectric lens.

Figure 2 shows the top and bottom printed-wiring boards (of the two antennas - one is turned upside-down). These boards are Rogers RT/Duroid 5880 material, with the lowest dielectric constant and loss commercially available. At the aperture end (or right side) of the boards, there are six rectangular sections of resistive loading, consisting of nichrome thin-film material. Their surface resistivity increases in a stepped exponential fashion, to approximate a continuously-increasing loss to the antenna plate currents.

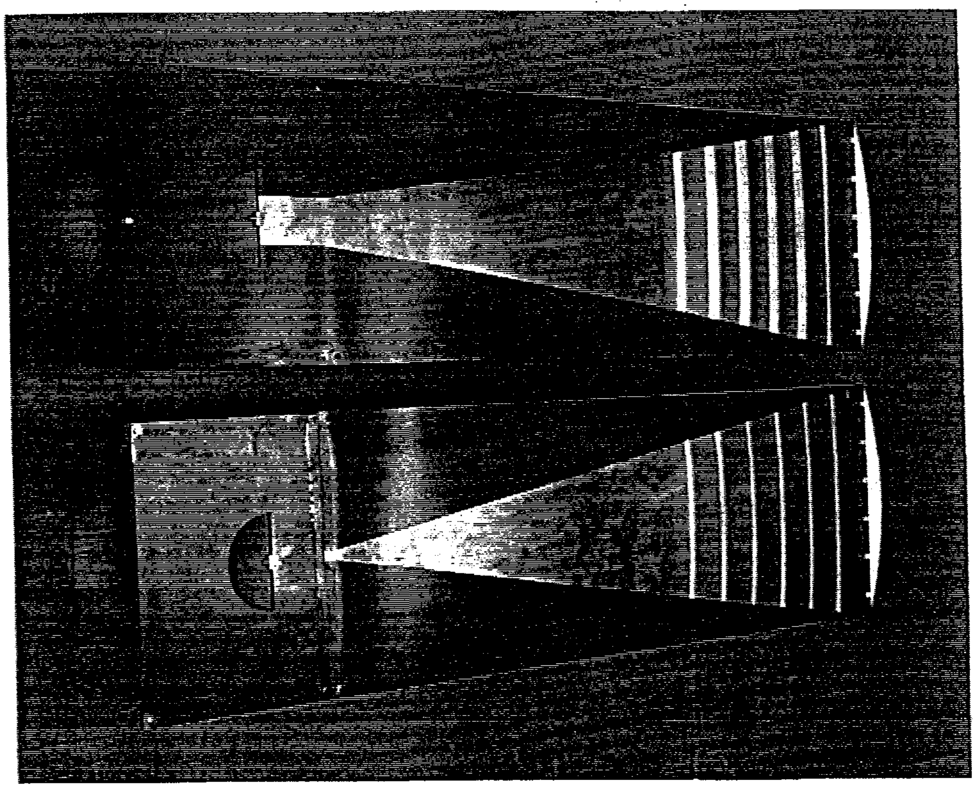

Figure 2. Top surface (lower antenna shown) and bottom surface of printed-board configuration of TEM-horn antenna.

At the feedpoint region, the bottom antenna has a small butterfly-shaped copper trace which is an integral portion of the custom transmission-line transition from the endfire-coax input (SMA female) to the balanced parallel-plate cross-section of the antenna proper. This transition was carefully designed and is a unique succession of endfire coax, balanced stripline, unbalanced microstrip, and finally balanced parallel-plate topology for most of the antenna flared region. It was expressly designed to provide a smooth transition from the coaxial port to balanced antenna currents on the antenna plates, with minimal variation in surge impedance through the feed transition region.

The Teflon™ (polytetrafluoroethylene) lens was designed with straight-forward geometrical equal-path ray tracing, with a planar inner face and a convex aperture or outer face. Then a 3D spherical curve-fit was performed so that the resulting planar-spherical lens could be easily made on a CNC machine.

After two nominally identical printed-board antennas were assembled, the time-domain radiation performance was measured in a boresight transmit-receive configuration, with step generator and 20-GHz sampling oscilloscope. Compared to our older TEM horns, this new antenna offered several times better gain or sensitivity, but the step-equivalent risetime was much too slow (on the order of 100 ps). The increased main-beam gain is directly due to the increased plate separation or aperture height, which increases the aperture area of the antenna. The poor time-domain response is surmised to be due to pulse smearing of the currents in the antenna conductors due to the direct presence of the printed-wiring board dielectric substrate. This has the effect of slowing the propagation velocity of the antenna current on the substrate side (inner surface) of the copper traces. On the other hand, the current on the outer/air side of the copper traces propagates at the speed of light, and the resulting combination of these two current components suffers pulse spreading due to different overall propagation times along the antenna conducting plates.

SOLID-PLATE ANTENNA CONFIGURATION

After we found out that the transient response of the printed-board configuration was too slow, a simpler version was designed and retrofitted into the same polystyrene antenna body. This second configuration consists of solid metal plates in place of the single-sided printed-wiring boards, in the attempt to remove the board substrate and its' pulse-spreading effect. Figure 3 shows both TEM horns, after retrofitting with the metal-plate configuration for the antenna conductors.

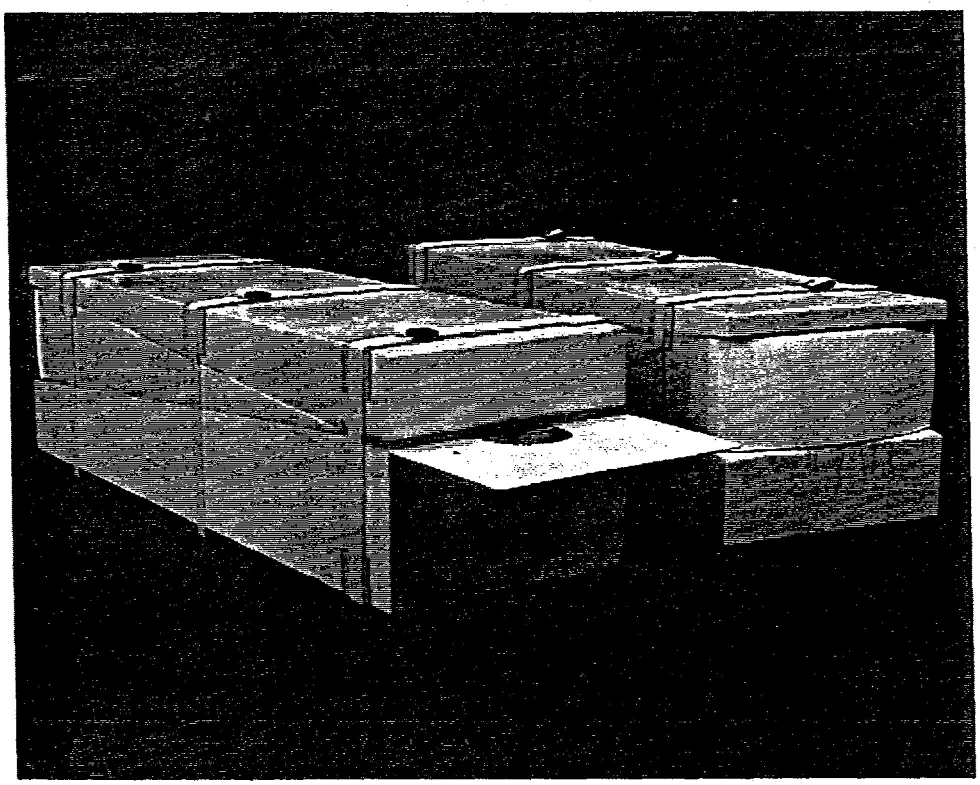

Figure 3. Solid-plate configuration of TEM-horn antennas.

Figure 4 shows the top and bottom conductors of the solid-plate configuration, with a very clean geometry. The triangular conductors are full length, with no resistive loading; the lenses are the same ones used for the printed-board configuration. Figure 5 then shows a close-up view of the feedpoint region. This consists of a simple, but carefully constructed transition from transverse-fed coaxial line to unbalanced parallel-plate which smoothly transforms to the balanced parallel-plate antenna structure. In past antenna design efforts, a variety of coax-to-parallel-plate transitions have been constructed and evaluated. This transverse-fed topology has worked the best for short-duration time-domain operation at low voltage levels. Attempts were made to build both antennas with identical feedpoint characteristics, and step time-domain reflectometry was used to empirically adjust the feedpoint conductor spacing in order to have the same surge impedance variation in each antenna.

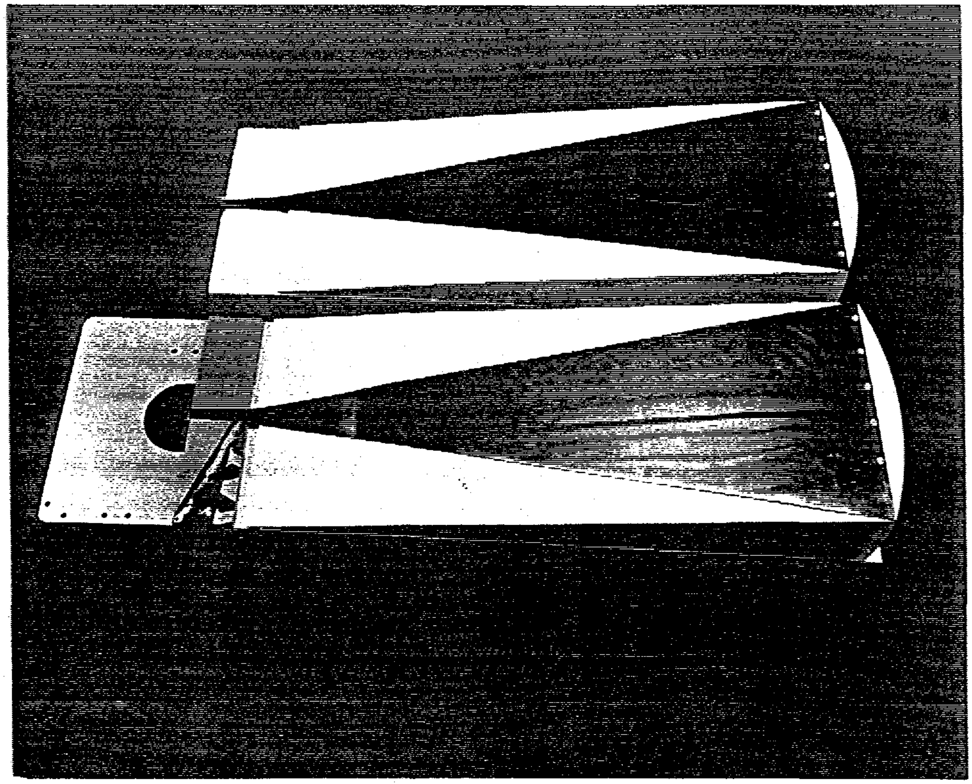

Figure 4. Top and bottom conductors of solid-plate antenna configuration.

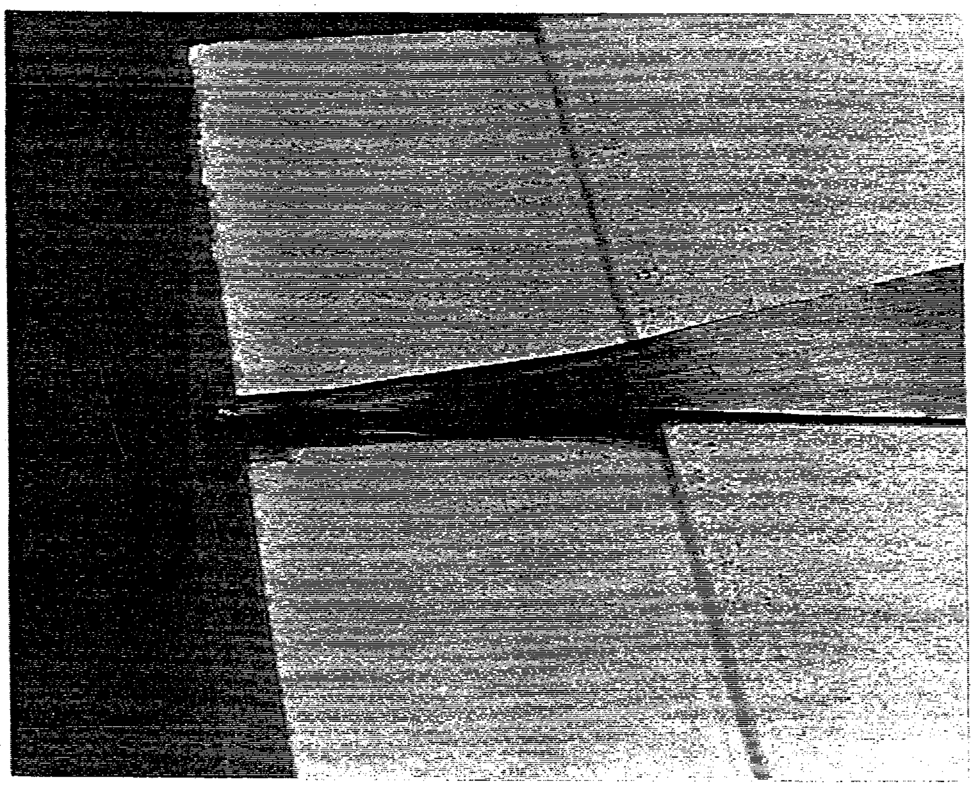

Figure 5. Close-up view of feedpoint region of solid-plate antenna configuration.

After this pair of TEM-horn antennas was assembled, they were extensively used for time-domain electromagnetic measurements. After about seven months of use, we re-measured the boresight/main-beam time-domain performance of the antenna pair in a transmit-receive configuration. Figure 6 shows the indoor antenna setup, with both TEM horns boresight aligned for main-beam response. The transmitting apparatus is at the rear of the photo, aimed at the receiving equipment, which is nearest to the camera. The aperture separation was 2.00 m, and the transmitting antenna was excited with a very fast step waveform. The receiving system consisted of a 20-GHz sampling oscilloscope. The measurement system step response had a 10-90% transition duration (risetime) of 29 ps.

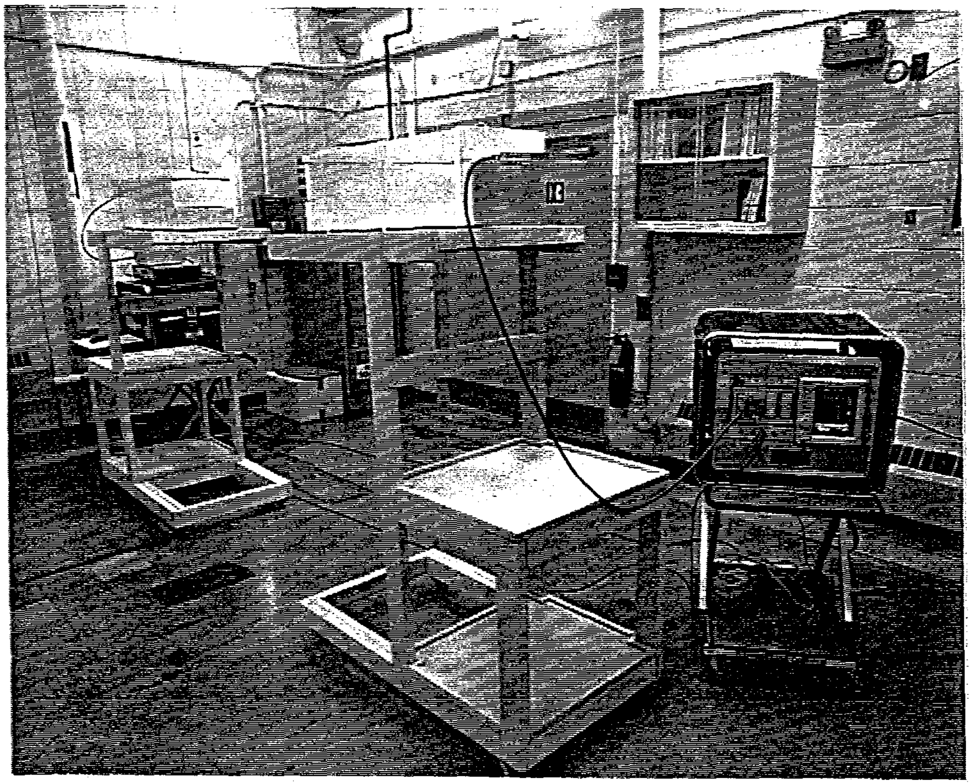

Figure 6. Experimental setup to measure boresight time-domain response of solid-plate antennas.

Figure 7 shows the two measured waveforms for this characterization. The step waveform is that of the measurement system, without the antennas. The impulse waveform is the received waveform with the double-antenna configuration; this clearly shows the derivative transmitting response of a TEM-horn antenna (the receive antenna has a replica response - the time-integral of the transmitting response). The time alignment of the two waveforms is arbitrary, as there is a 2-m propagation delay between the antennas.

Figure 8 shows the same system step waveform and a time-integration of the antenna response waveform. Using simple quadrature analysis of the transition duration (10-90% risetime), based on the assumption of Gaussian system components, the degradation or slowing of the transition duration can be unfolded from the response risetime. The observed or measured risetime, $t_r(mmt)$, is the squared sum of the each antenna's 'step-equivalent' risetime, $t_r(ant)$, and the risetime of the measurement system, $t_r(sys)$:

$$t_r^2(mmt) = 2\,t_r^2(ant) + t_r^2(sys).$$

This assumes that the two antennas are very similar in radiation performance, which has been verified. Solving for the antenna step-equivalent transition duration,

$$t_r(ant) = \sqrt{\tfrac{1}{2}\left[t_r^2(mmt) - t_r^2(sys)\right]}$$
$$= \sqrt{\tfrac{1}{2}\left[(40.7ps)^2 - (28.9ps)^2\right]}$$
$$= 20.3ps.$$

This is the fastest transient response of any time-domain antenna which we have designed and built in our department.

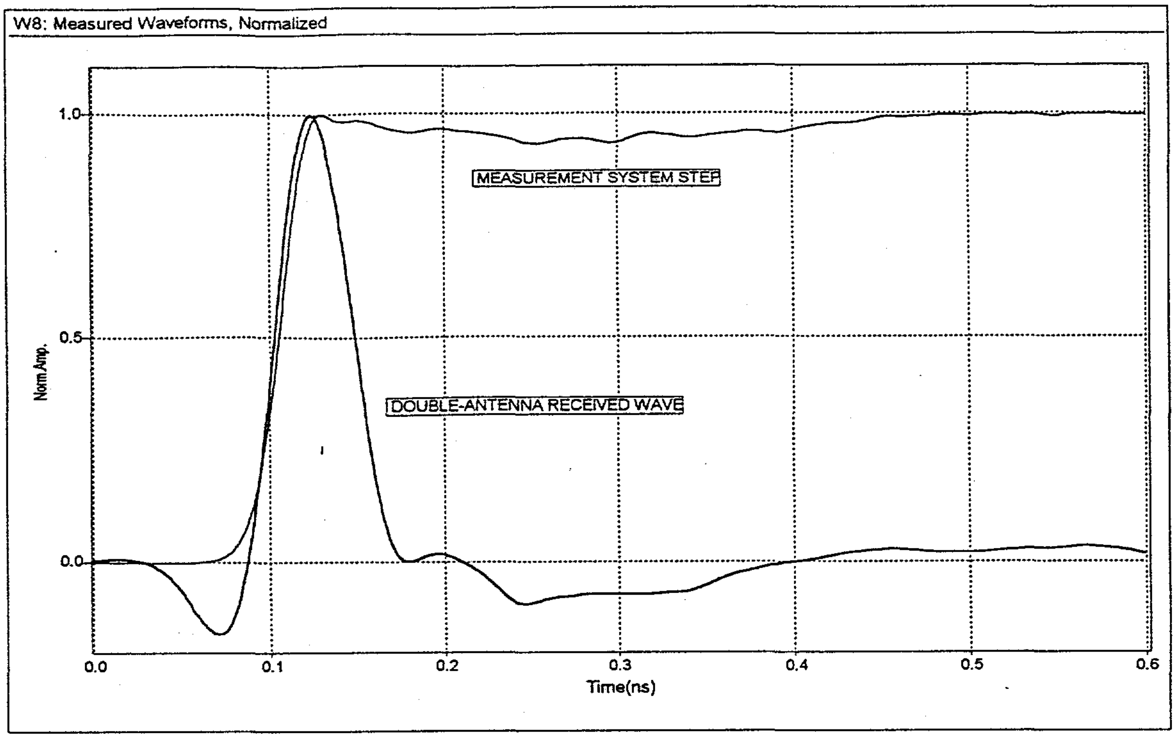

Figure 7. Boresight time-domain response of solid-plate antennas.

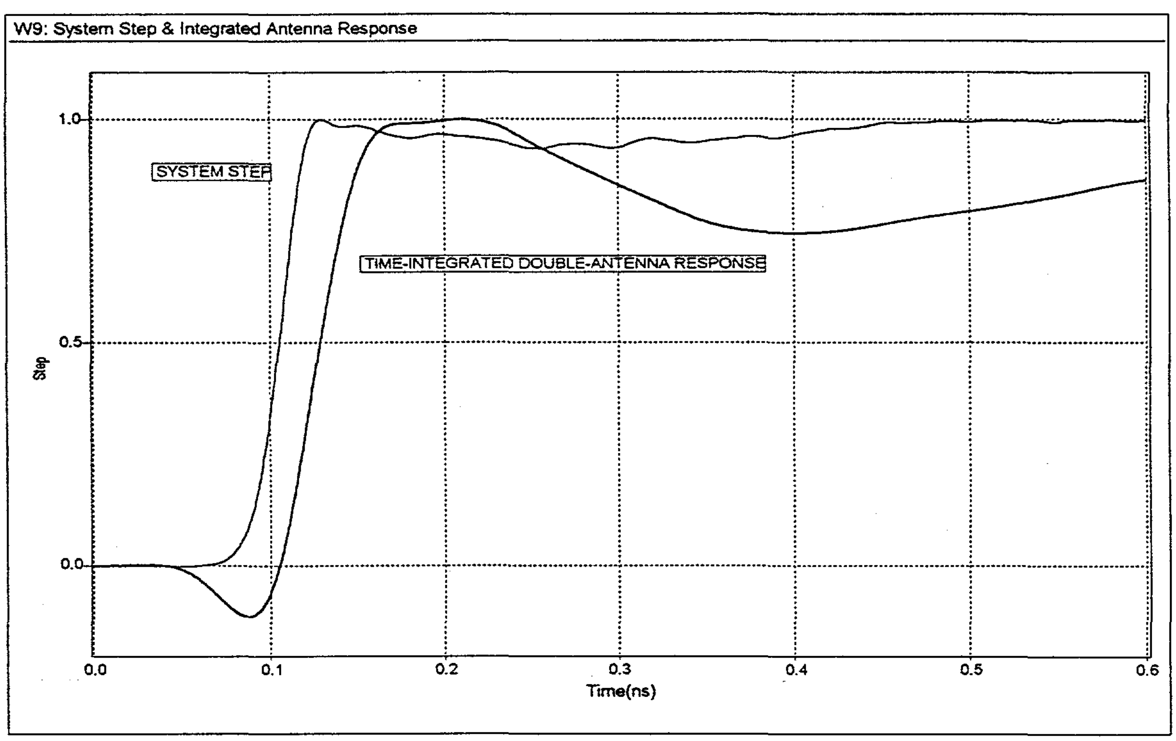

Figure 8. Time-Integrated 'Step-Equivalent' boresight time-domain response of solid-plate antennas.

SUMMARY

We designed and constructed a pair of TEM-horn antennas specifically for very fast time-domain boresight response. Two physical topologies were made: a printed-board configuration, and a solid-plate configuration. The printed-board configuration has much slower transient response, which we think is due to pulse-smearing of the antenna currents in the dielectric substrate of the printed-wiring boards. The solid-plate version has a 20-ps transition-duration response in the main-beam endfire (boresight) direction, which is the fastest (or highest bandwidth) we have seen to date. And, since the antenna has a round-trip antenna-current propagation time of 6 ns, it offers clean radiated electromagnetic-field measurement capability with a clear time of several ns. The printed-board version has resistive loading at the aperture end of the conductors, which should offer better low-frequency performance (time has not permitted studying this issue however). The dielectric lens certainly does improve the transient performance of the TEM horn, and was simple to design. In the future, we plan to study possible enhancements to either configuration version.