TRANSIENT SCATTERING MEASUREMENTS

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There is considerable interest in accurate measurement of the transient scattering characteristics of complicated structures. This interest stems from the use of transient data in target discrimination schemes using the E/S pulse method and the future use of ultra-wide band radar in target detection and identification.

To achieve accurate transient measurements, the measurement system impulse response must be deconvolved from the raw measurements. For direct time domain measurements the deconvolution of the system response is difficult due to the limited dynamic range, stability, and power output of most measurement systems. One way around some of these difficulties is to perform the measurements in the frequency domain using an automated frequency-stepping vector network analyzer. The measurements are performed over a wide band of frequencies and the transient response is synthesized via the Inverse Fourier Transform. The resulting transient response is equivalent to the direct time domain measurement provided the system and target are linear and time invariant. Modern network analyzers however provide much greater dynamic range, power, and stability than most current time domain systems and allow for improved results when applying the deconvolution procedure.

This paper will discuss the calibration procedure used to remove clutter and the system impulse response from raw measurements. The effectiveness of frequency domain measurements in synthesizing transient target responses will be demonstrated using both a sphere and a thin wire as calibration standards. Theoretical results and direct time domain measurements corrected using a similar procedure will be presented to substantiate the synthesized transient responses for simple structures as well as several complicated targets.

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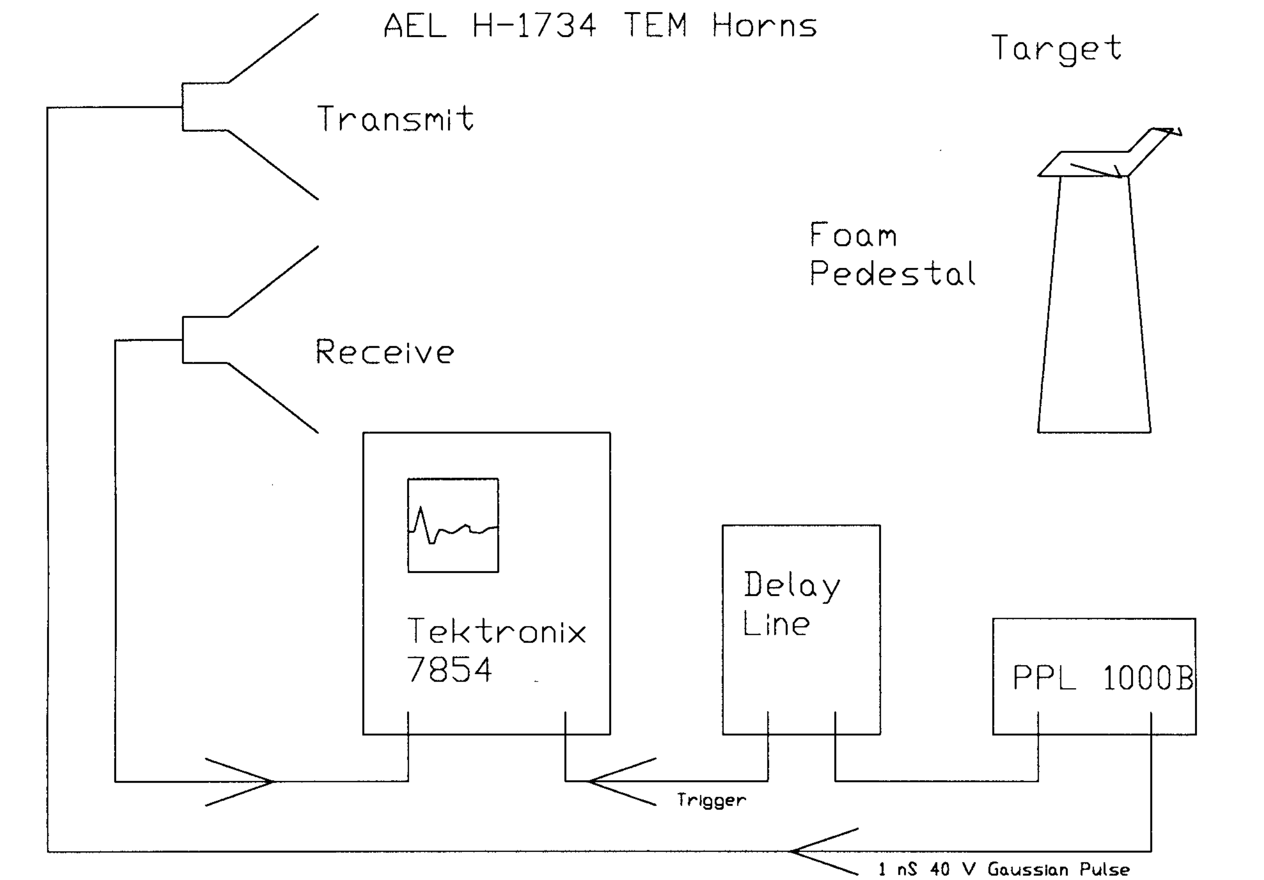
Overview

- Free-field transient scattering measurement configuration
- Block diagram representation of measurement system
- Calibration procedure
- Results

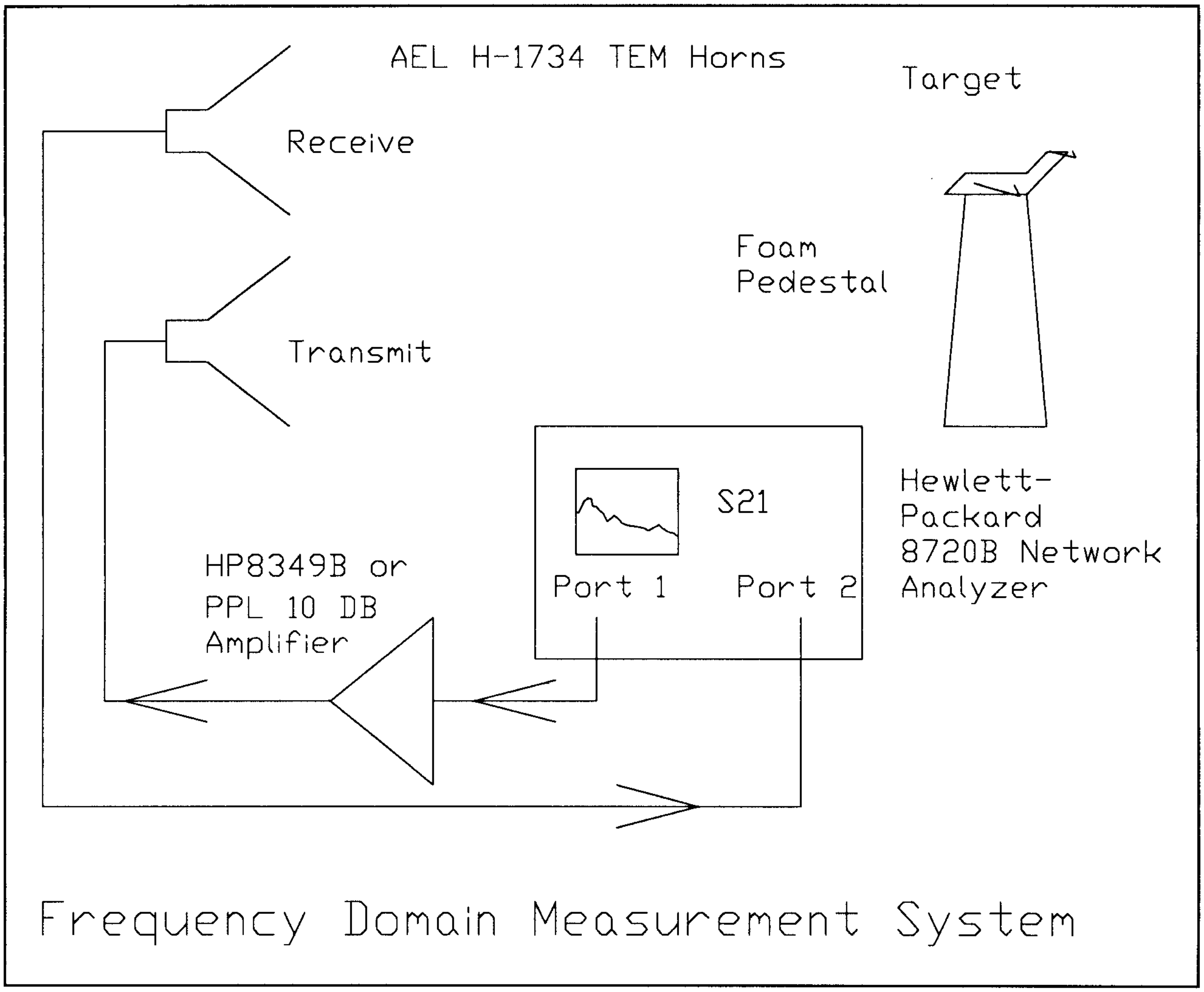
Goals

- Accurate transient measurements
- Enhanced late time information
  - Improved SEM mode extraction
  - Improved E/S-Pulse discrimination
- Early time information
  - Improved detection schemes
  - Additional discrimination information

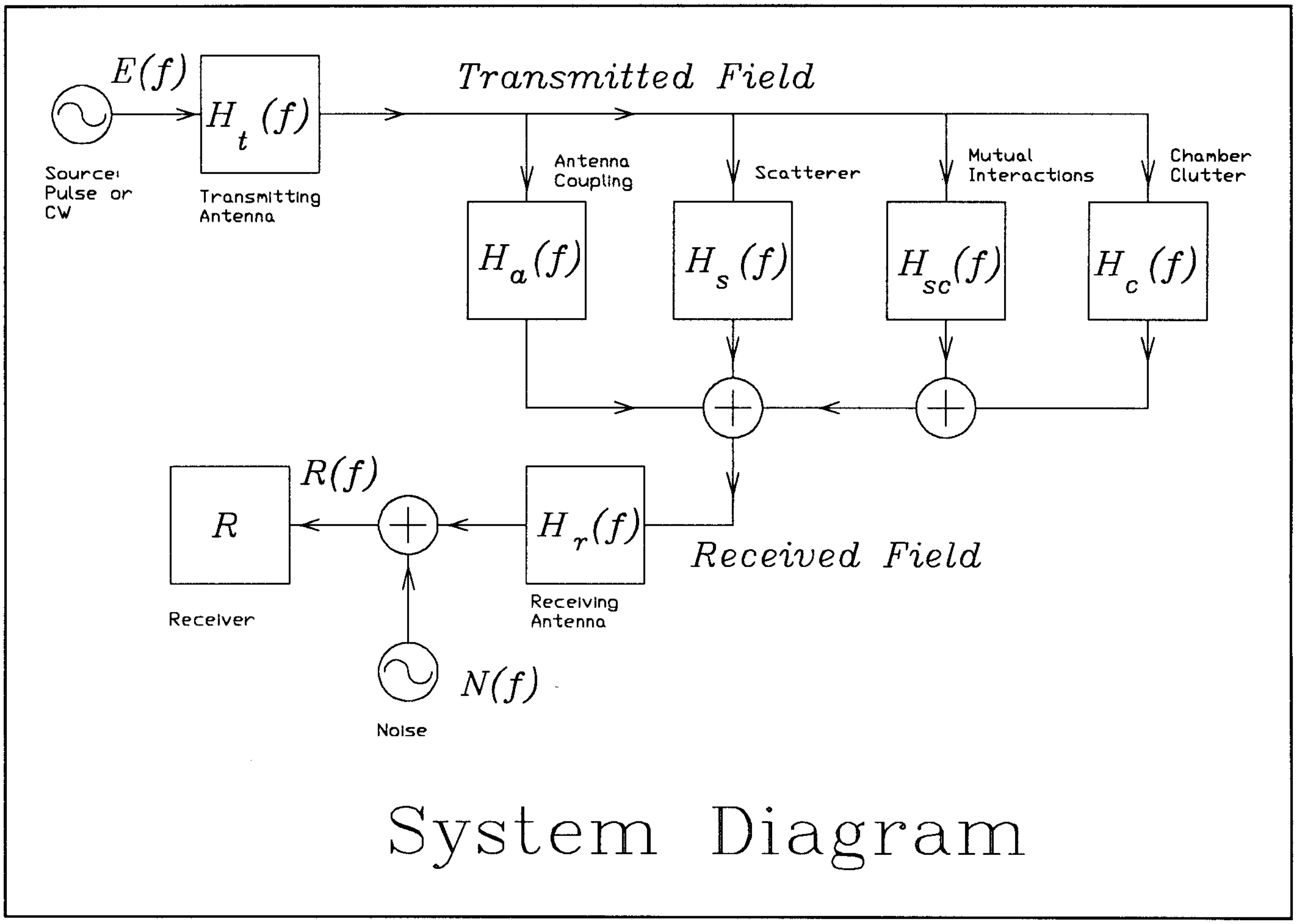


Time Domain Measurement System

- Extraneous reflections are easily removed
- Limited Dynamic Range (30 dB)
- Stability of oscilloscope & pulse generator is limited
- Pulse shape is not adjustable
- Distortion of transmit-receive system limits effectiveness of narrow pulses



- Extremely wide dynamic range (100 dB)
- Wide frequency sweep (130 MHz - 20 GHz); Hence, very short duration synthesized pulses
- Targets must be linear and time invariant
- Requires knowledge of the response of a known calibration target



Calibration Proceedure

- Measure empty chamber or ground plane (background measurement)

$$R^b(f) = S(f)\{H_a(f) + H_c(f)\} + N^b(f)$$

where $S(f)$ is system transfer function defined as,

$$S(f) = H_r(f)\, H_t(f)\, E(f)$$

- Measure known calibration target

$$R^{c+b}(f) = S(f)\{H_a(f) + H_c(f) + H_s^c(f) + H_{sc}^c(f)\} + N^{c+b}(f)$$

where,

$H_s^c(f)$ = calibrator transfer function (known!)

$H_{sc}^c(f)$ = calibrator to chamber transfer function; causal in time domain

- Measure desired target

$$R^{t+b}(f) = S(f)\ \{H_a(f) + H_c(f) + H_s^t(f) + H_{sc}^t\} + N^{t+b}(f)$$

where,

$H_s^t(f)$ = target transfer function

$H_{sc}^t(f)$ = target to chamber transfer function; causal in time domain

- Subtract background measurement from cal target and desired target measurements

$$R^c(f) = R^{c+b}(f) - R^b(f)$$
$$R^t(f) = R^{t+b}(f) - R^b(f)$$

So,

$$R^c(f) = S(f)\{H_s^c(f) + H_{sc}^c(f)\} + N^c(f)$$
$$R^t(f) = S(f)\{H_s^t(f) + H_{sc}^t(f)\} + N^t(f)$$

where,

$$N^c(f) = N^{c+b}(f) - N^b(f)$$
$$N^t(f) = N^{t+b}(f) - N^b(f)$$

Problem : Interaction terms preclude proper evaluation of ***S(f)*** and target transfer function

Option 1. Assume interaction terms are small and neglect noise.

$$R^c(f) = S(f) H_s^c(f)$$
$$R^t(f) = S(f) H_s^t(f)$$

- Solve for ***S(f)***

$$S(f) = \frac{R^c(f)}{H_s^c(f)}$$

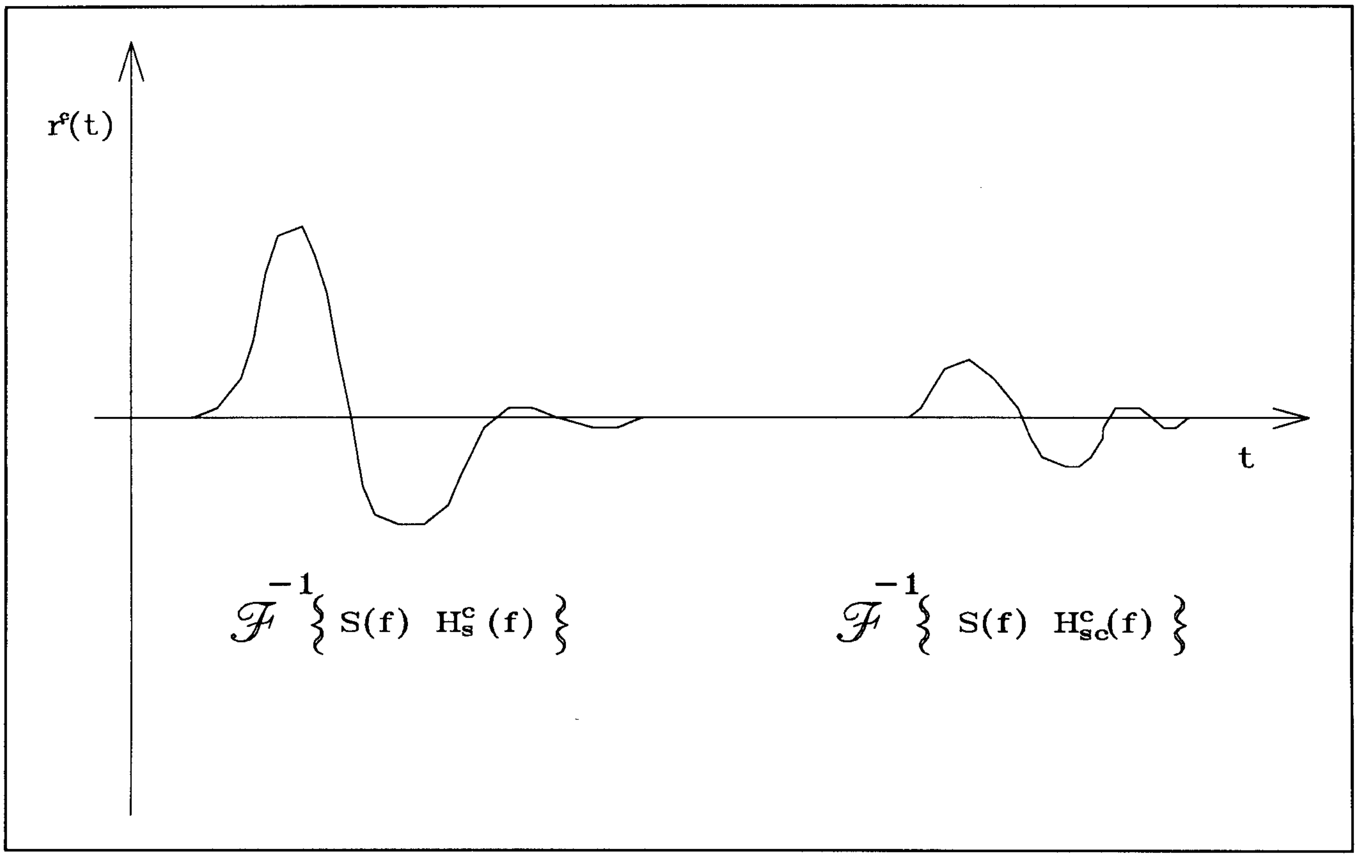
- Compute target transfer function.

$$H_s^t(f) = \frac{R^t(f)}{S(f)}$$

Option 2. Transform $\boldsymbol{R^c(f)}$ to time domain and use windowing to eliminate causal interaction term. Neglect noise terms.

- Define time response of $\boldsymbol{R^c(f)}$ measurement

$$r^c(t) = \mathscr{F}^{-1}\{R^c(f)\}$$



- Multiply $r^c(t)$ by window function $w(t)$ to exclude interaction

$$r^{cw}(t) = r^c(t)\,w(t)$$

- If $\mathcal{F}^{-1}\{S(f)\,H_s^c(f)\}$ is time limited and not truncated by $w(t)$ then,

$$R^{cw}(f) = S(f)H_s^c(f)$$

- Solve for $S(f)$

$$S(f) = \frac{R^{cw}(f)}{H_s^c(f)}$$

Thus,

$$H_s^t(f) + H_{sc}^t(f) = \frac{R^t(f)}{S(f)}$$

- Apply Inverse Fourier Transform.

$$h_s^t(t) + h_{sc}^t(t) = \mathscr{F}^{-1}\{\frac{R^t(f)}{S(f)}\}$$

- Target impulse response is approximately time limited.
- Interaction term is causal and delayed, Therefore, target impulse response unaffected

Results

- Theoretical Models for Canonical Results

  - Thin Wires - frequency domain moment-method
piece-wise sinusoidal basis functions
Galerkin method
thin-wire approximation

  - Spheres - Mie series

- Typical Experimental Configurations

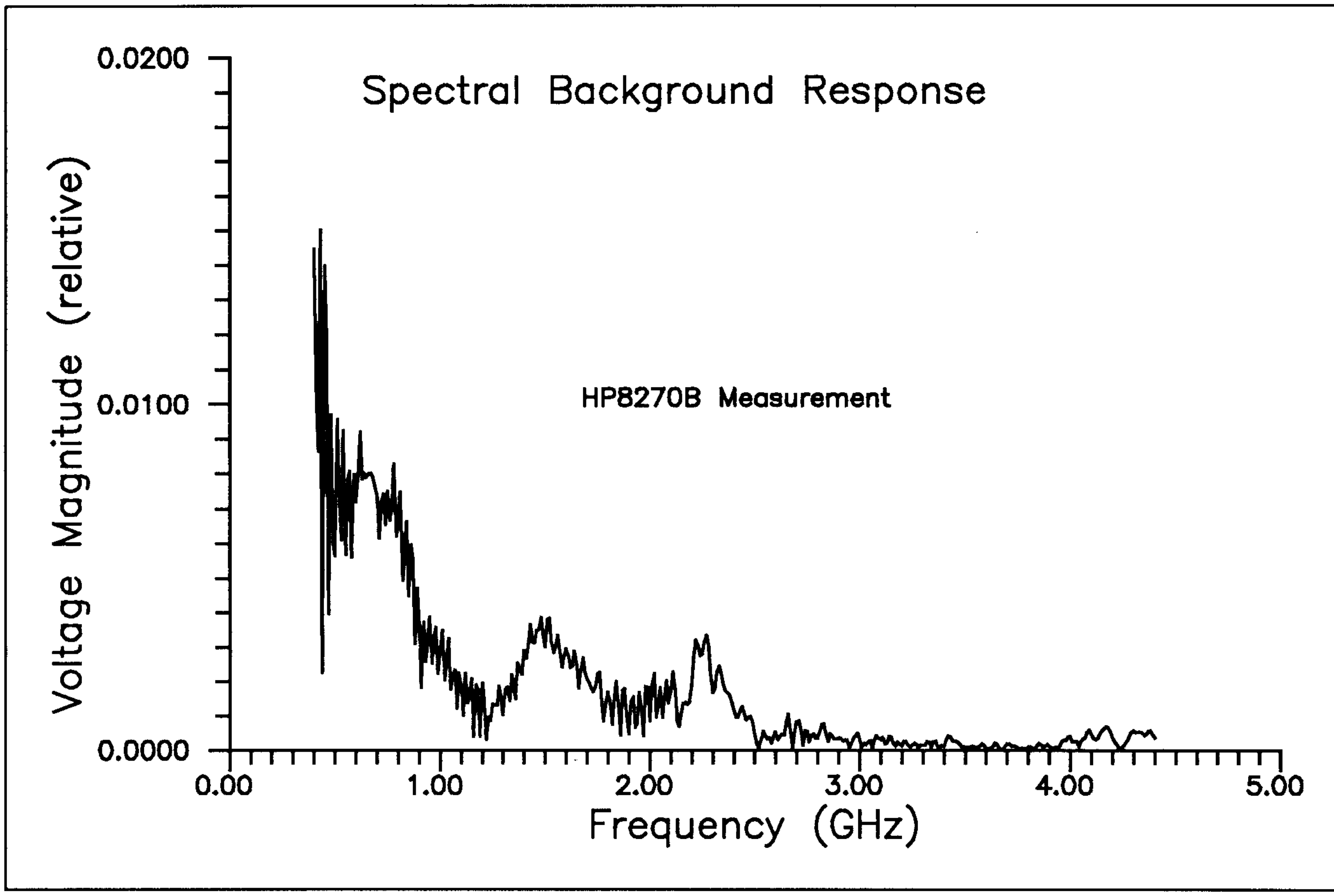
Low Band - (PPL Amplifier)

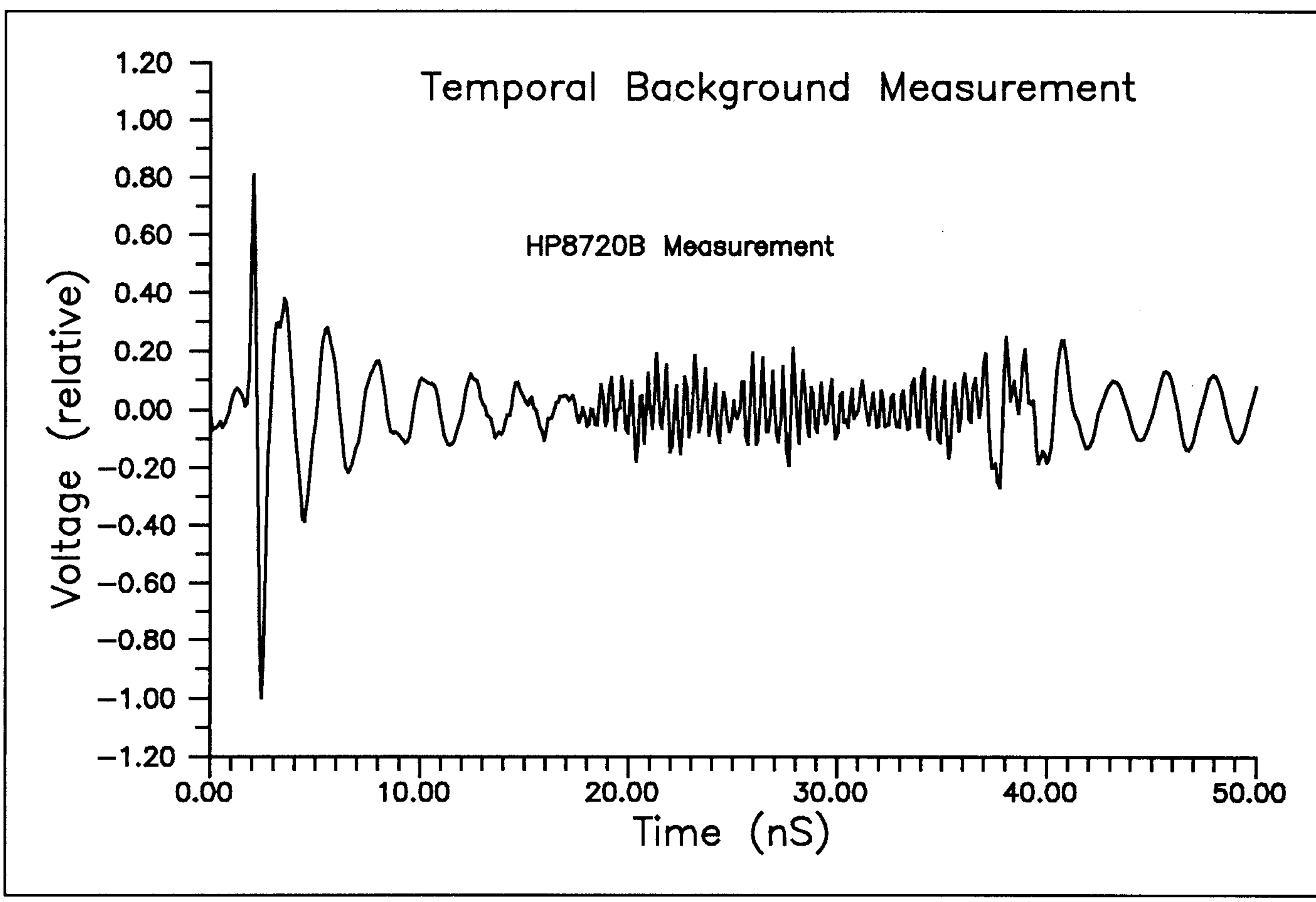
Sweep Range	: 0.4-4.4 GHz
Number of Points	: 401
IF Bandwidth	: 30 Hz
Averaging Factor	: 10
Output Power	: -10 dBm ($\approx$ 0 dBm with amp)
Window Function	: Double Gaussian

High Band - (HP8439B Amplifier)

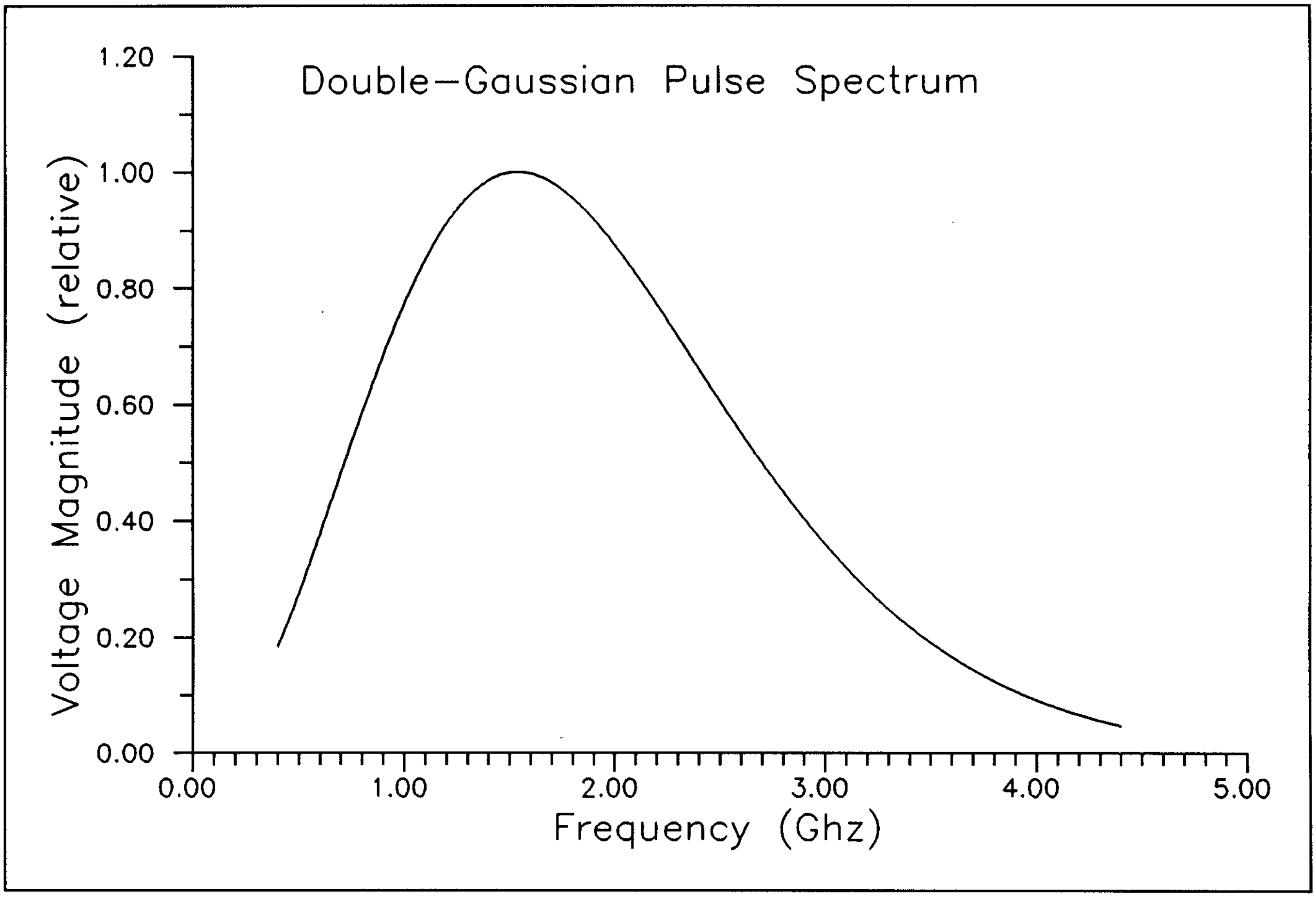
Sweep Range	: 1.0 - 9.0 GHz
Number of Points	: 801
IF Bandwidth	: 30 Hz
Averaging Factor	: 10
Output Power	: -10 dBm ($\approx$ +15 dBm with amp)
Window Function	: 1/10 cosine taper (1.0 - 7.0 GHz)

SYSTEM CHARACTERISTICS

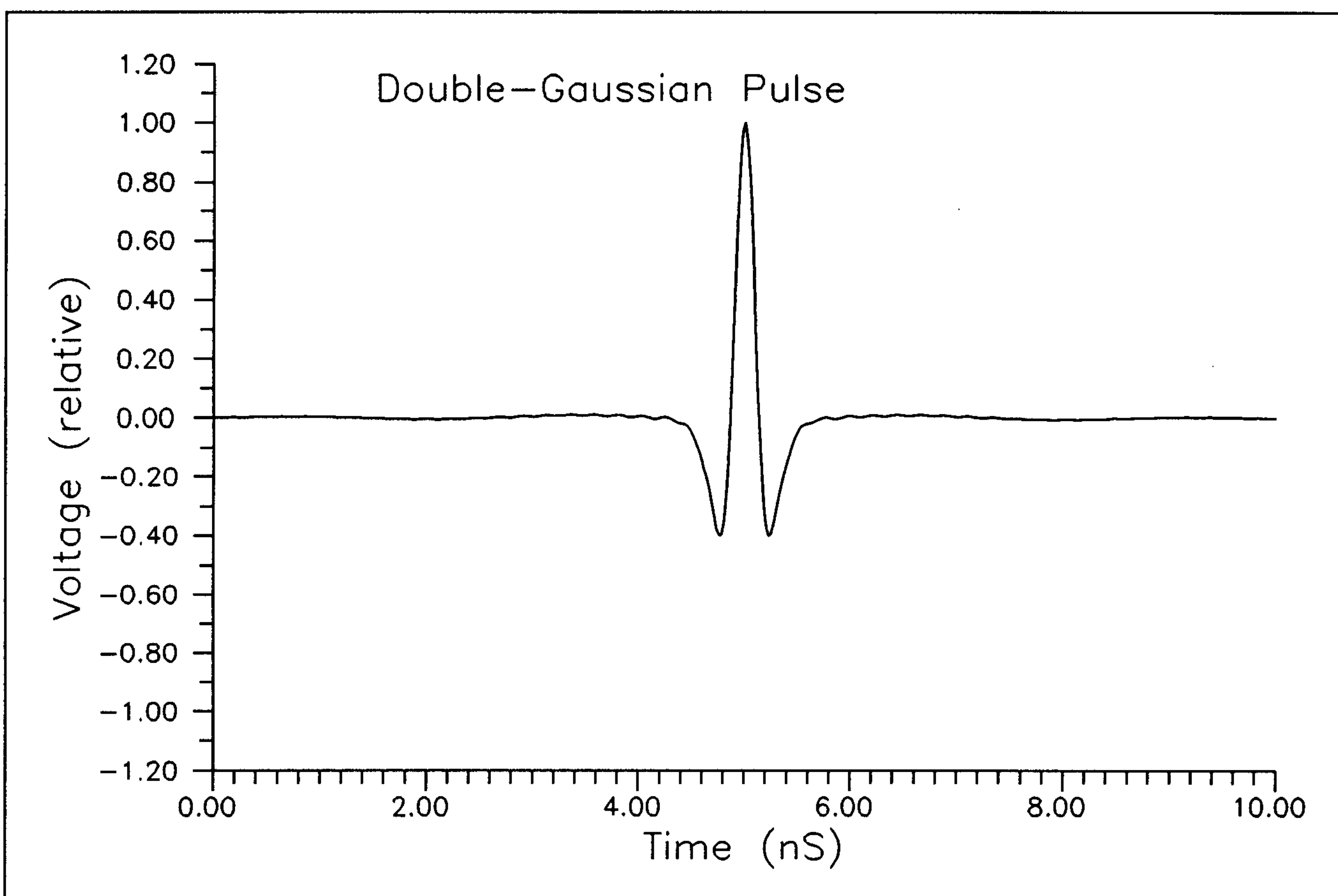

Spectral Background Response
HP8270B Measurement
Voltage Magnitude (relative)
0.0200
0.0100
0.0000
0.00
1.00
2.00
3.00
4.00
5.00
Frequency (GHz)


Temporal Background Measurement
HP8720B Measurement
Voltage (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
−0.20
−0.40
−0.60
−0.80
−1.00
−1.20
0.00
10.00
20.00
30.00
40.00
50.00
Time (nS)

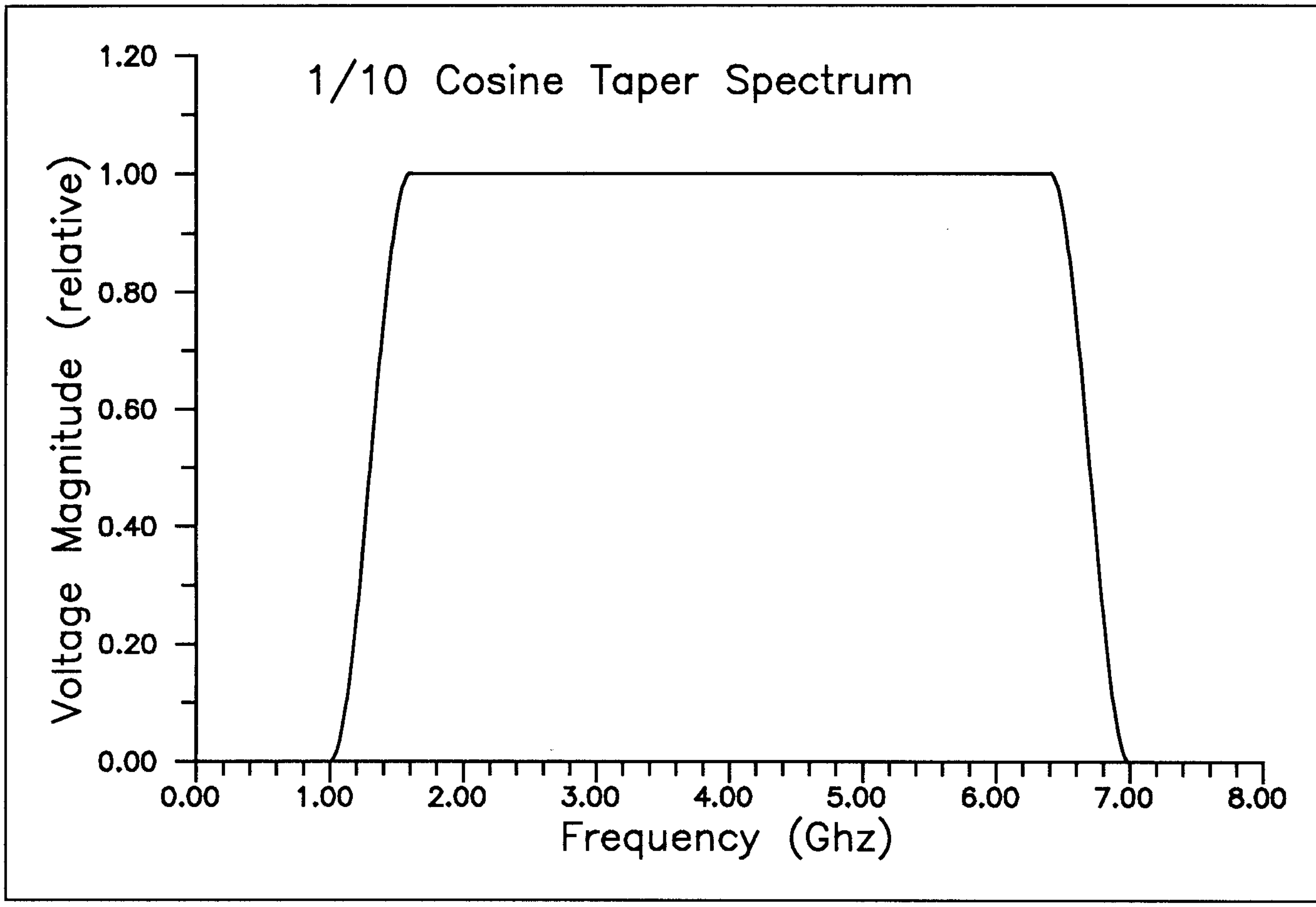
CANONICAL TARGET RESPONSES

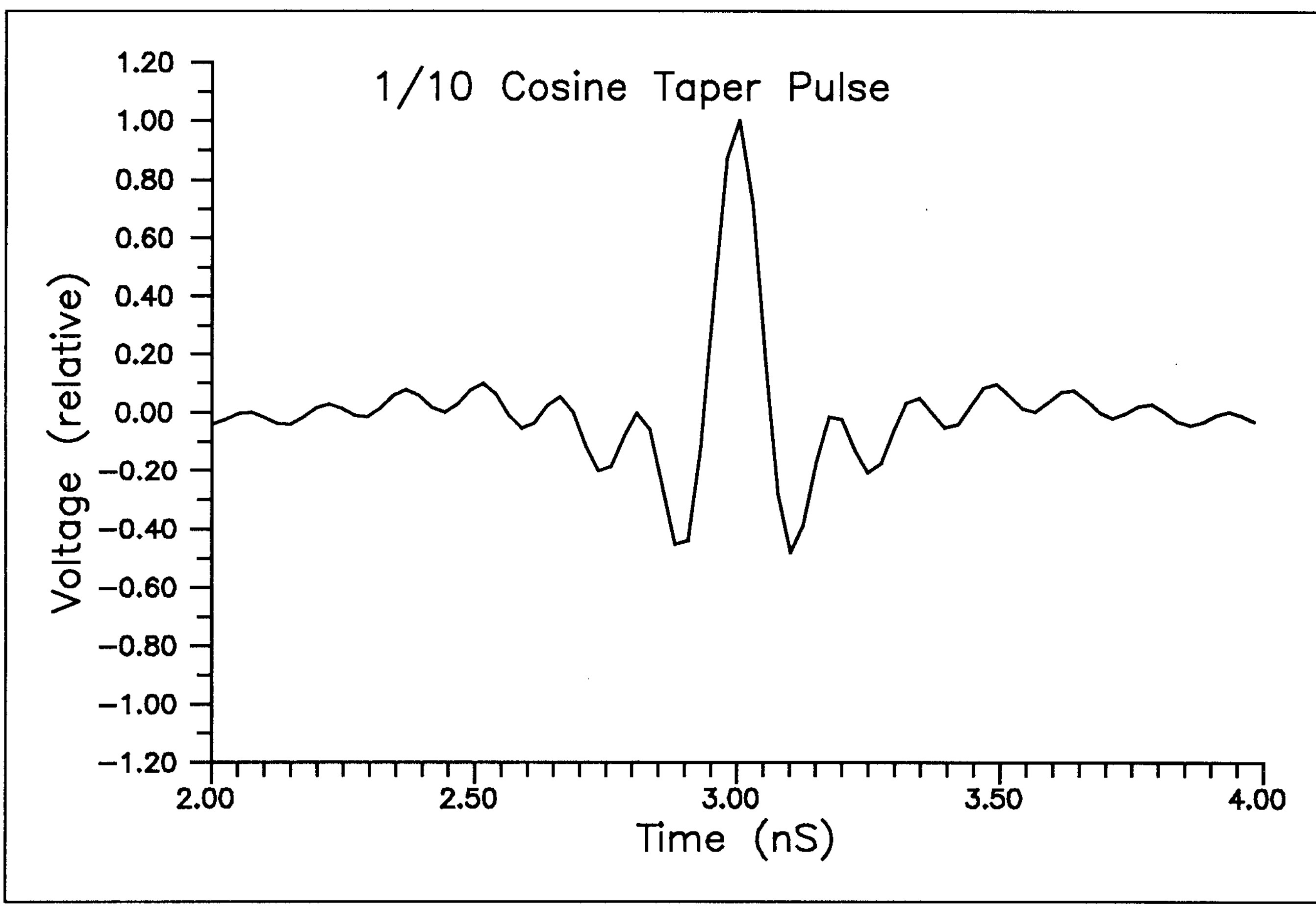


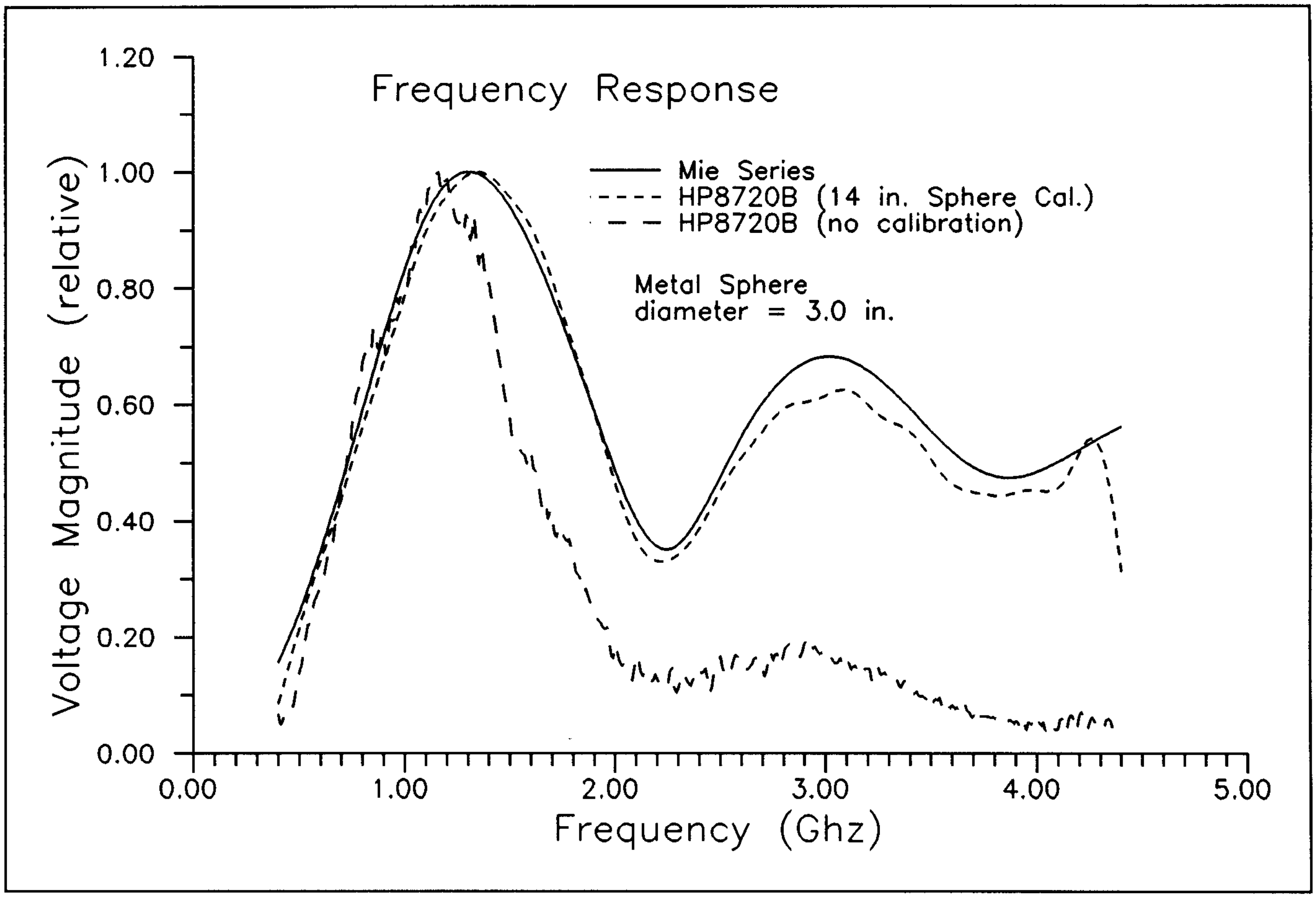
Double-Gaussian Pulse Spectrum
Voltage Magnitude (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00
Frequency (Ghz)



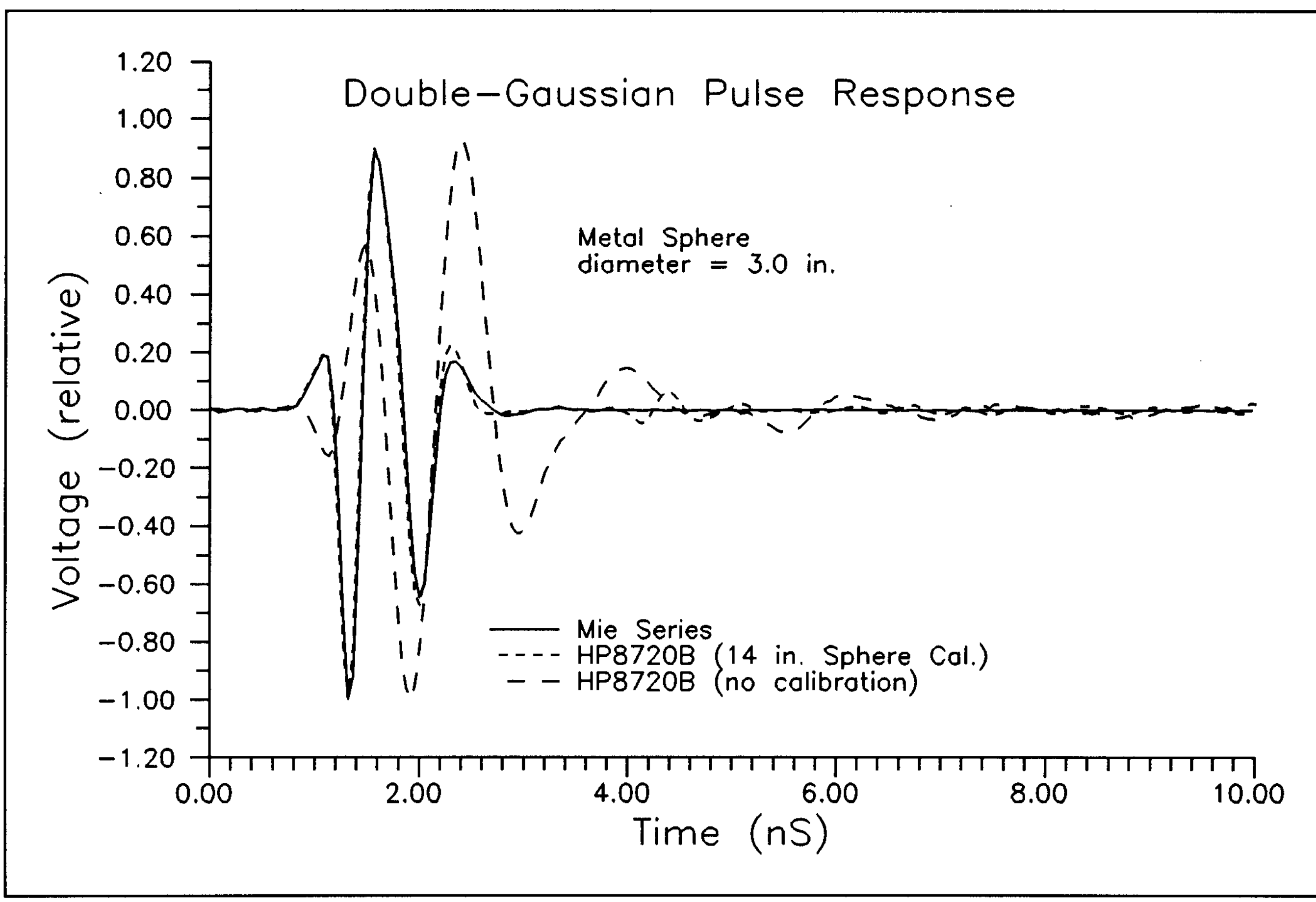
Double-Gaussian Pulse
Voltage (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
−0.20
−0.40
−0.60
−0.80
−1.00
−1.20
0.00
2.00
4.00
6.00
8.00
10.00
Time (nS)


1/10 Cosine Taper Spectrum
Voltage Magnitude (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
Frequency (Ghz)

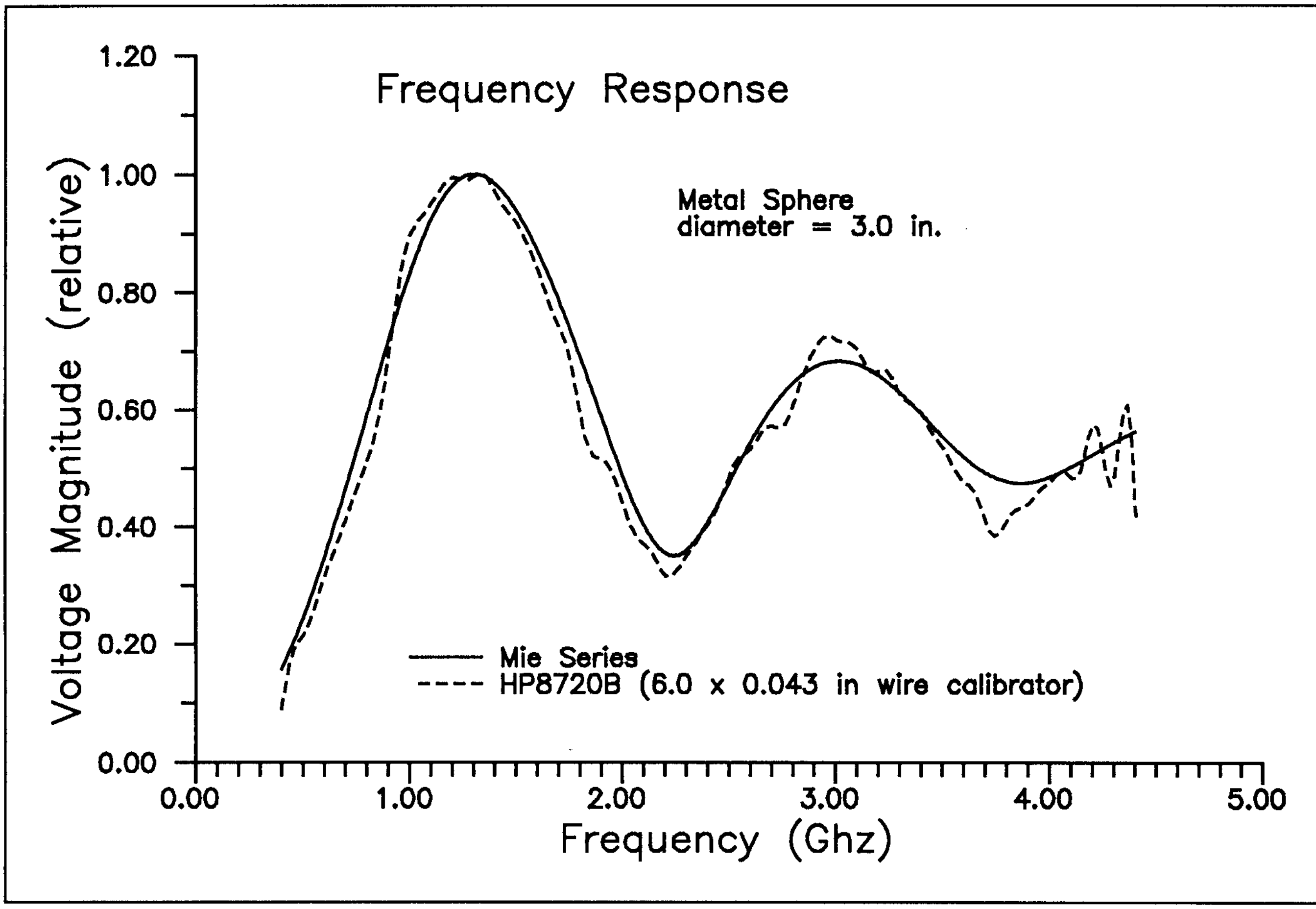

1/10 Cosine Taper Pulse
Voltage (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
−0.20
−0.40
−0.60
−0.80
−1.00
−1.20
2.00
2.50
3.00
3.50
4.00
Time (nS)

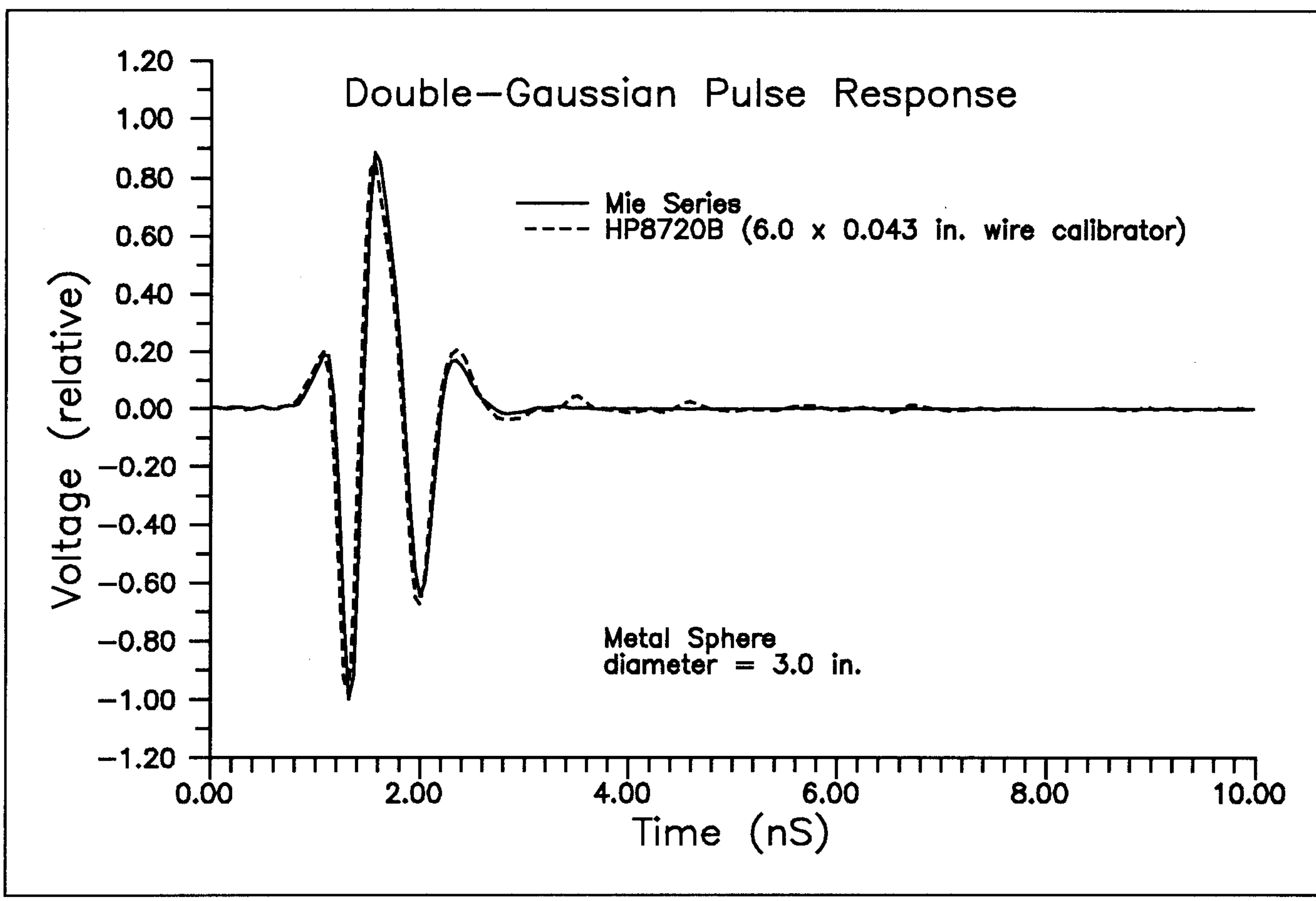


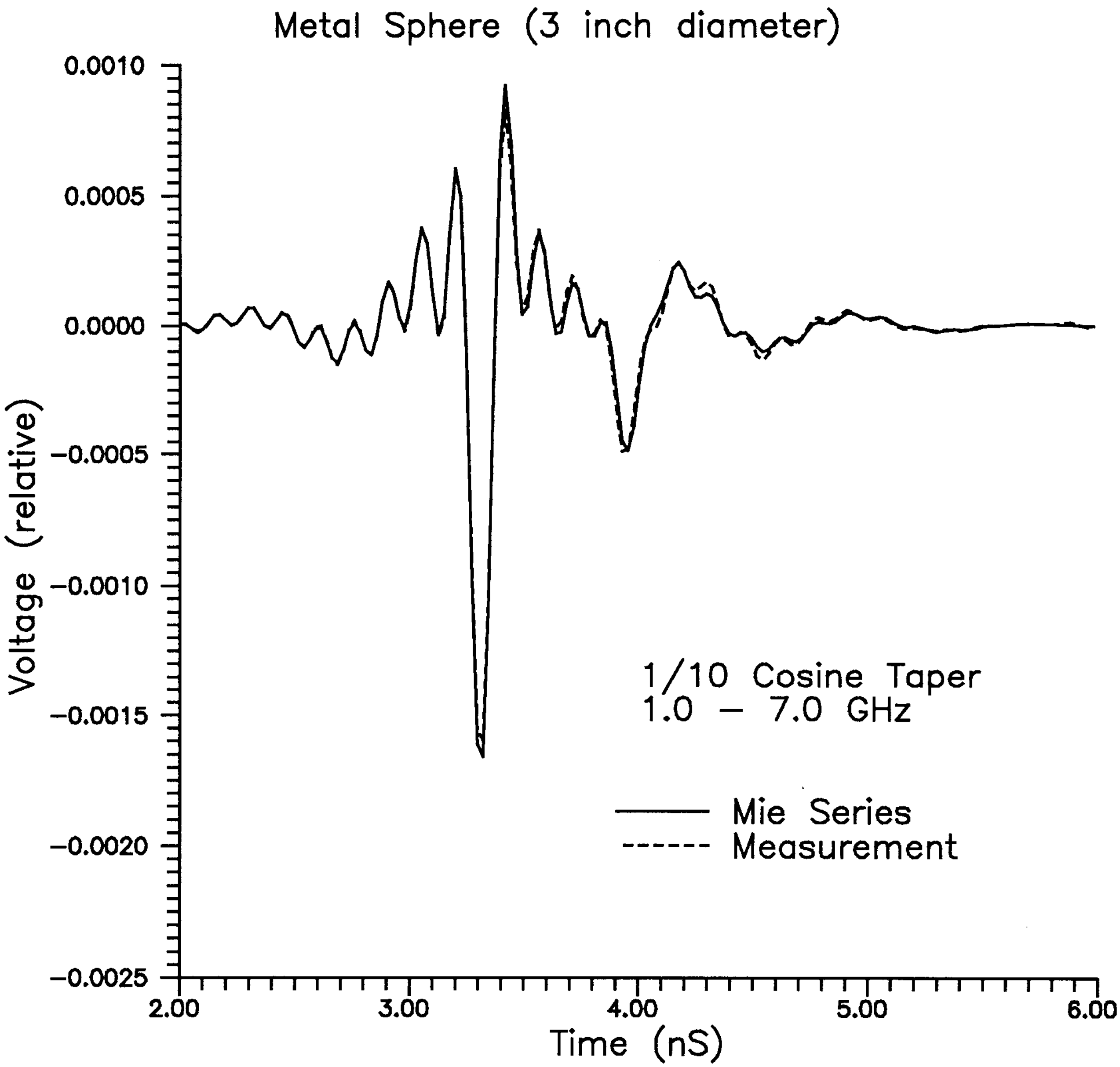
Frequency Response
Mie Series
HP8720B (14 in. Sphere Cal.)
HP8720B (no calibration)
Metal Sphere
diameter = 3.0 in.
Voltage Magnitude (relative)
Frequency (Ghz)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00



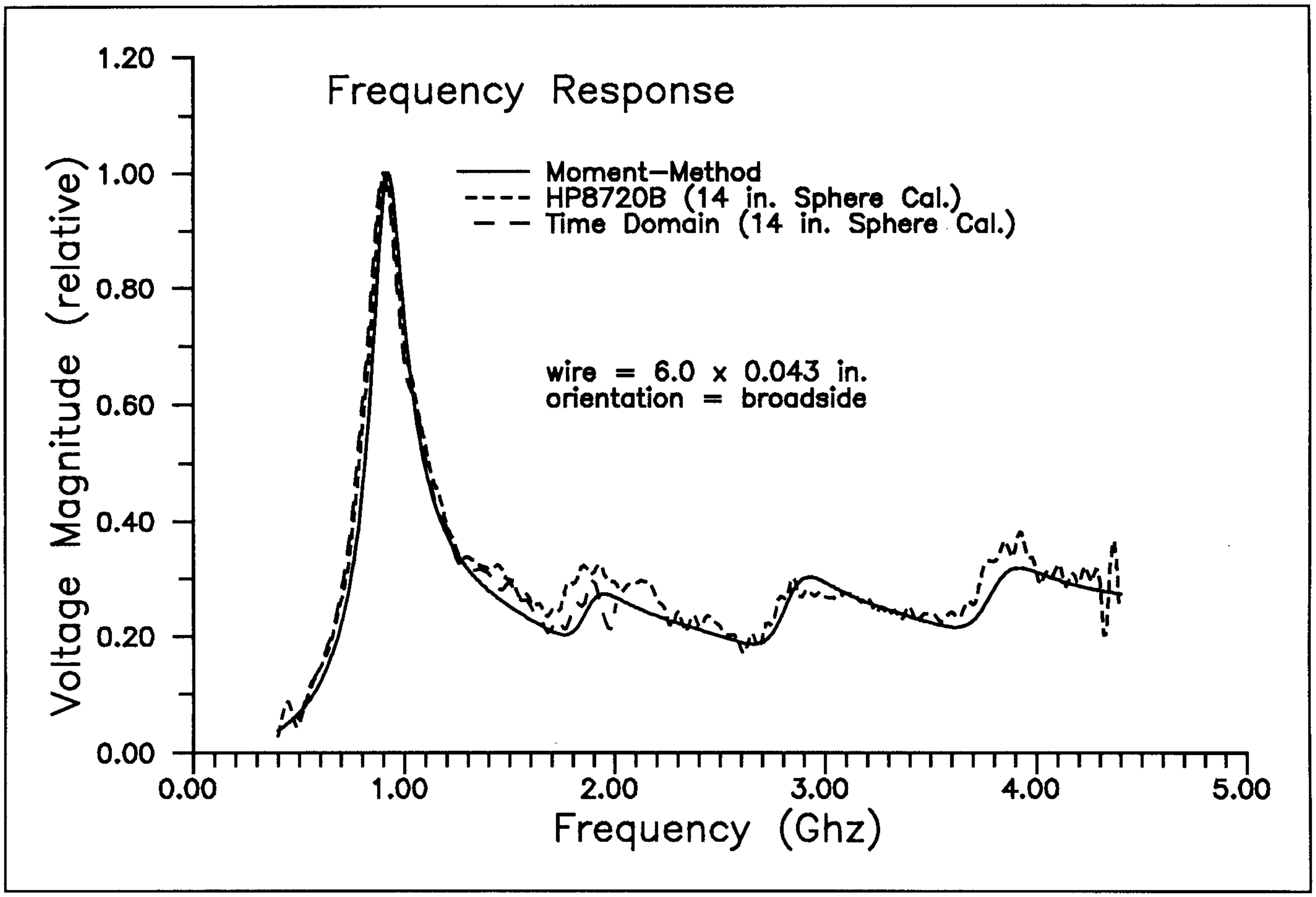
Double-Gaussian Pulse Response
Metal Sphere
diameter = 3.0 in.
Mie Series
HP8720B (14 in. Sphere Cal.)
HP8720B (no calibration)
Voltage (relative)
Time (nS)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
−0.20
−0.40
−0.60
−0.80
−1.00
−1.20
0.00
2.00
4.00
6.00
8.00
10.00

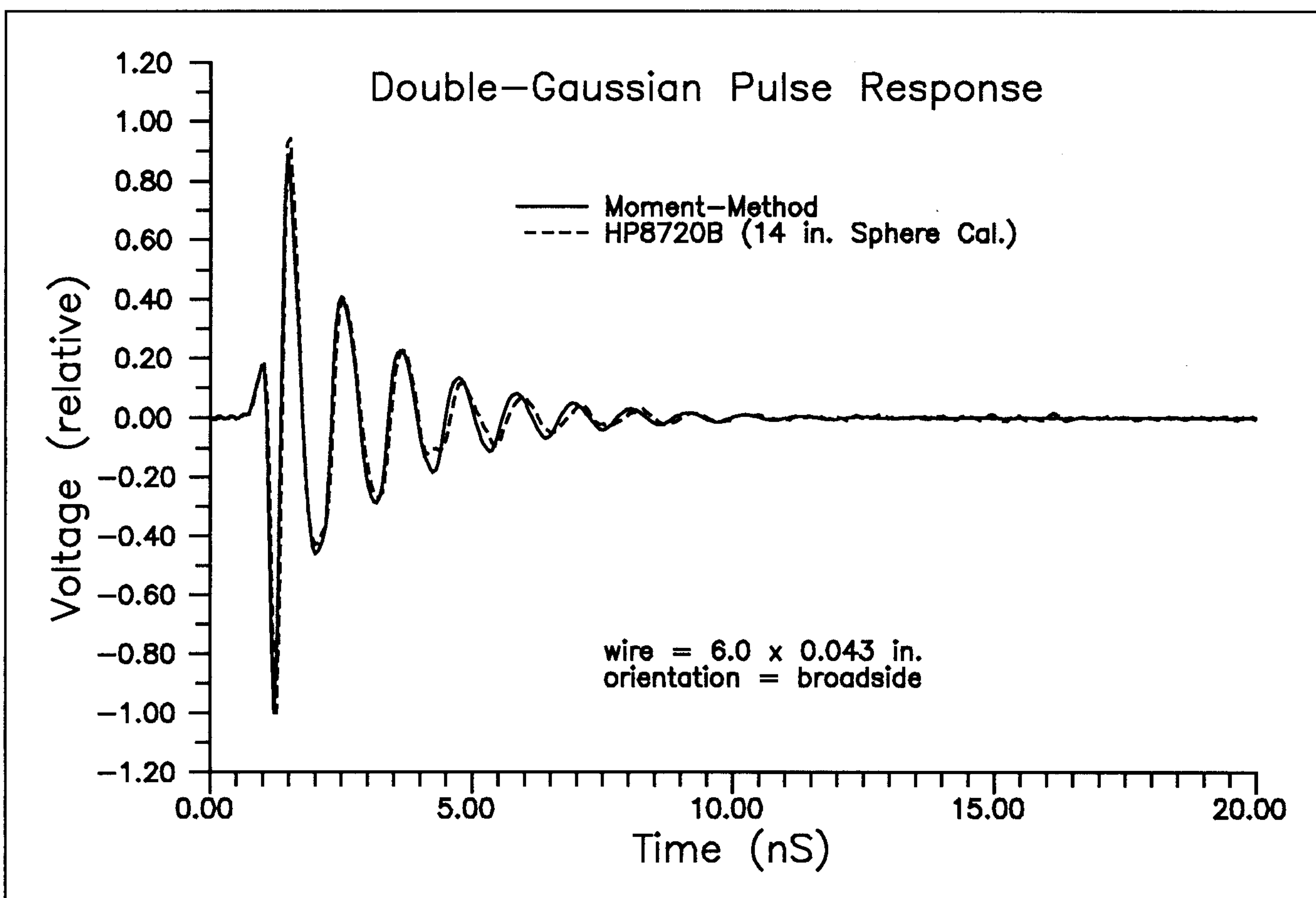

Frequency Response
Metal Sphere
diameter = 3.0 in.
Mie Series
HP8720B (6.0 x 0.043 in wire calibrator)
Voltage Magnitude (relative)
Frequency (Ghz)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00

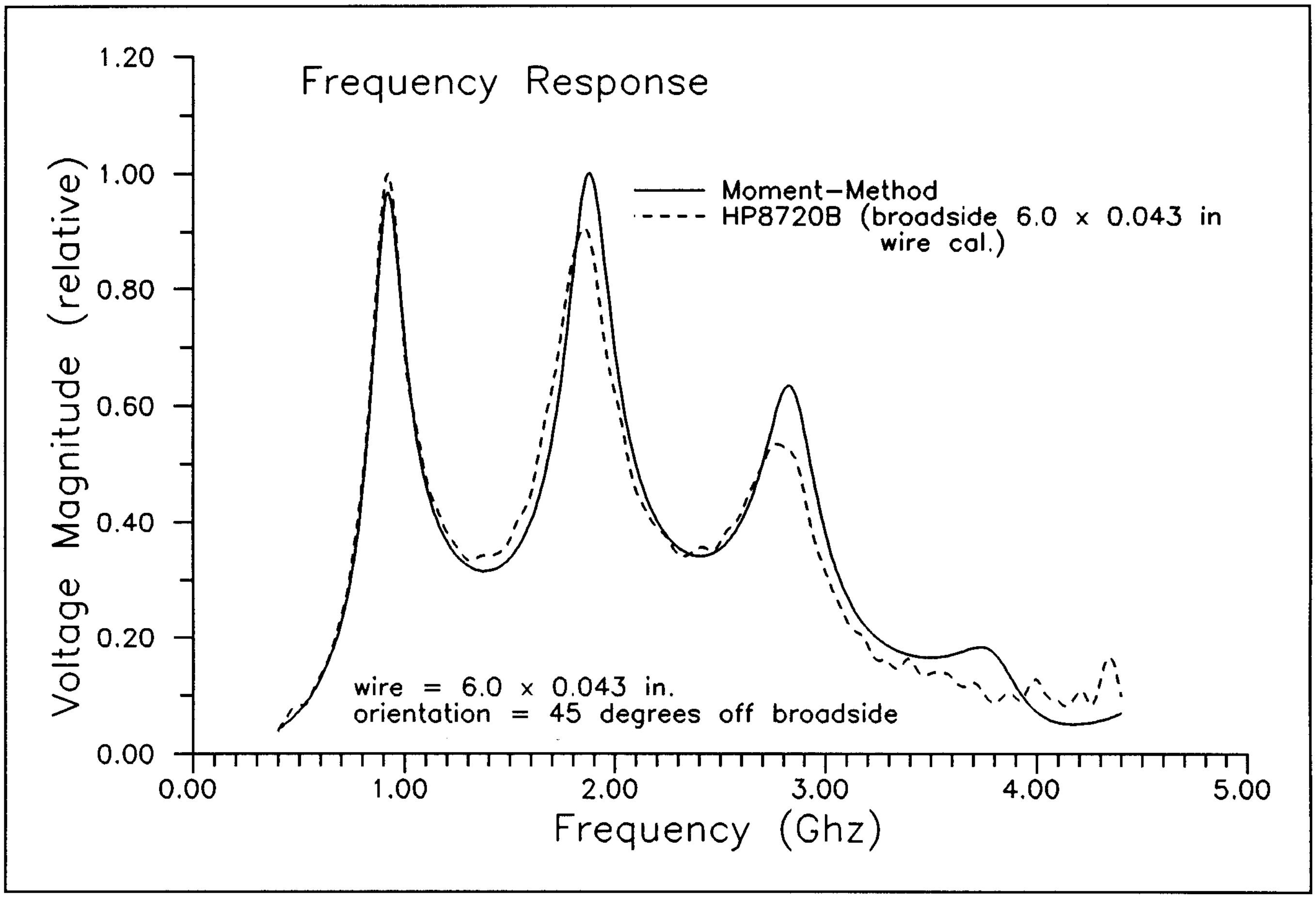

Double-Gaussian Pulse Response
Mie Series
HP8720B (6.0 x 0.043 in. wire calibrator)
Metal Sphere
diameter = 3.0 in.
Voltage (relative)
Time (nS)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
−0.20
−0.40
−0.60
−0.80
−1.00
−1.20
0.00
2.00
4.00
6.00
8.00
10.00

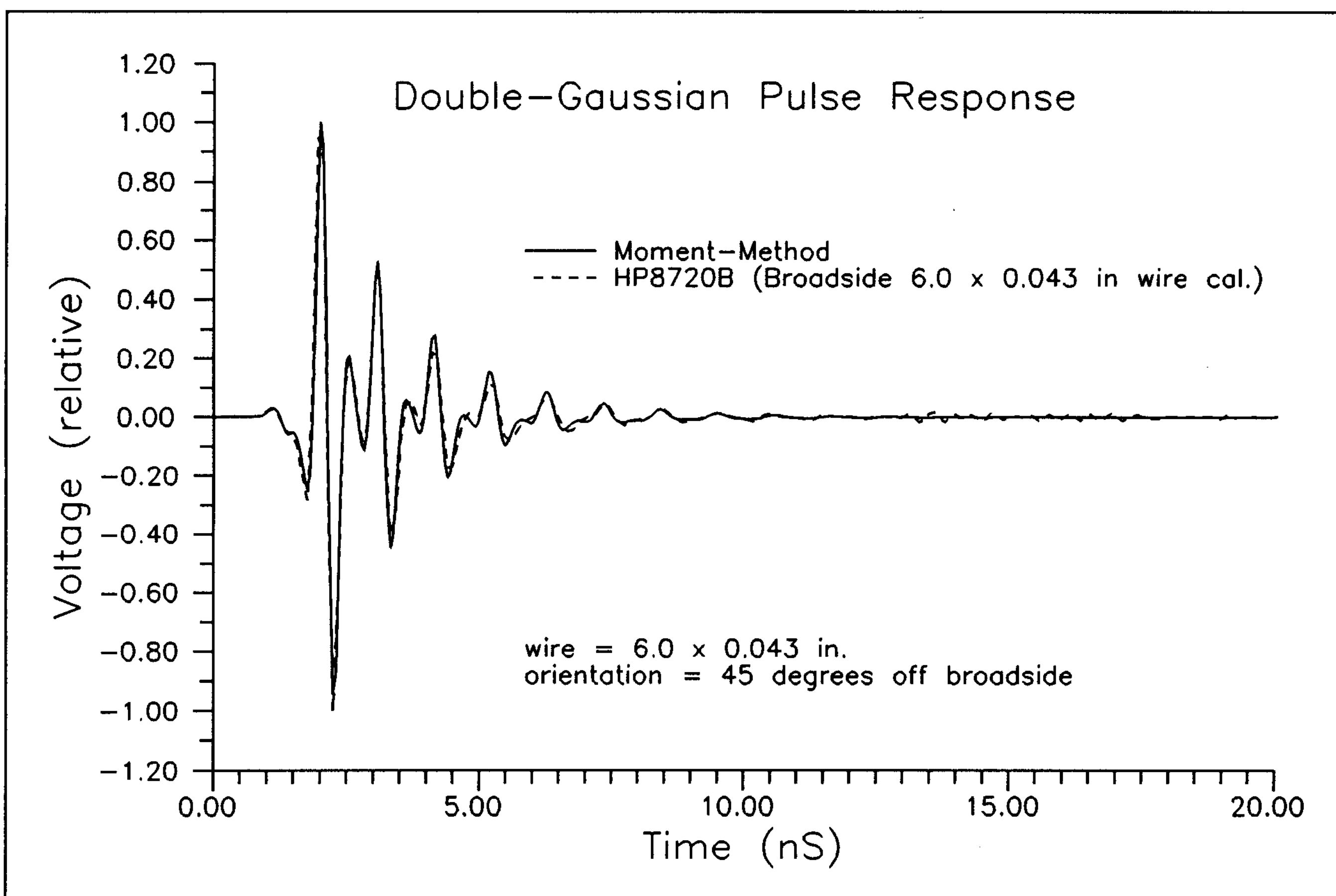


Metal Sphere (3 inch diameter)
0.0010
0.0005
0.0000
−0.0005
−0.0010
−0.0015
−0.0020
−0.0025
Voltage (relative)
2.00
3.00
4.00
5.00
6.00
Time (nS)
1/10 Cosine Taper
1.0 − 7.0 GHz
Mie Series
Measurement

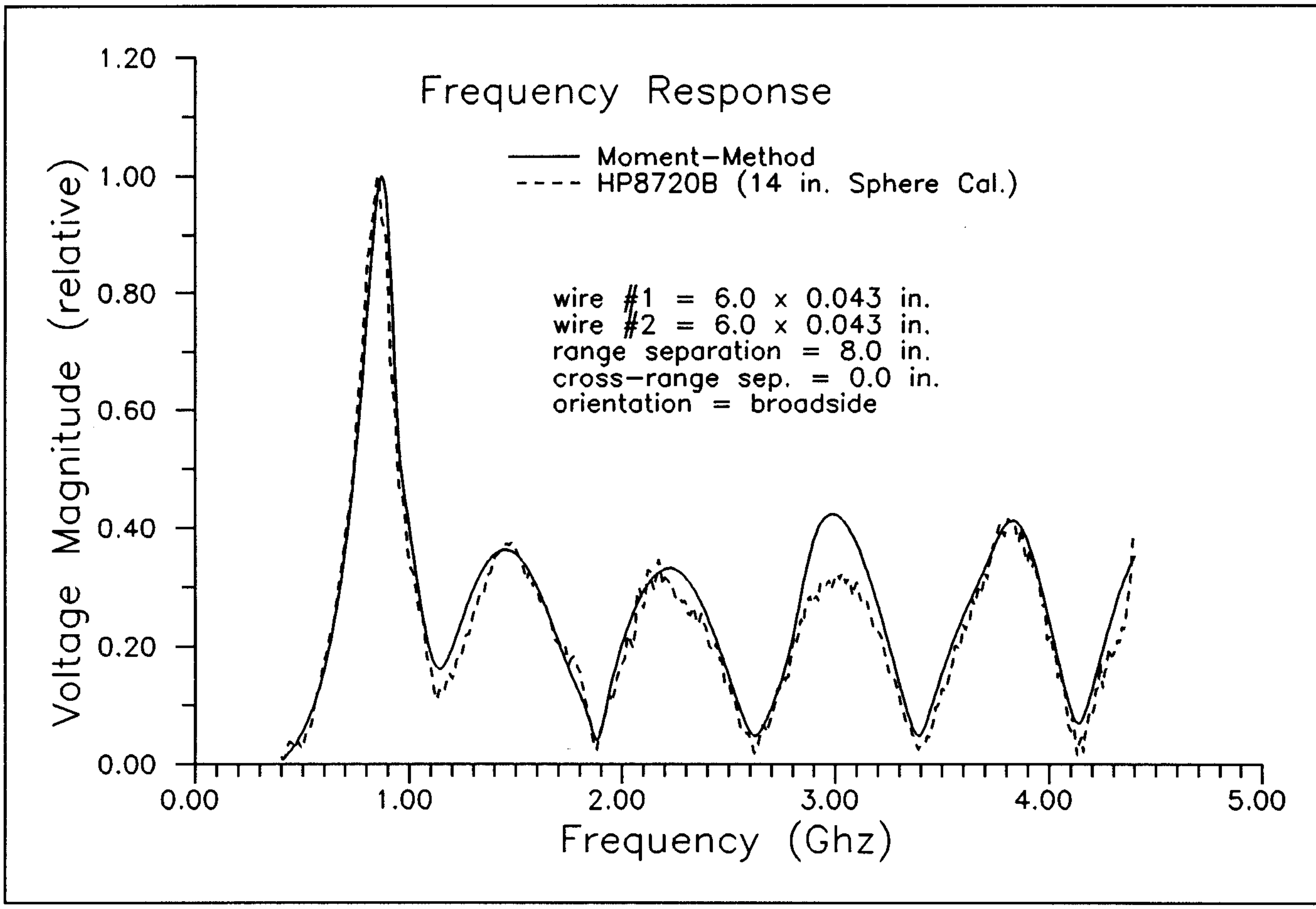

Frequency Response
Moment–Method
HP8720B (14 in. Sphere Cal.)
Time Domain (14 in. Sphere Cal.)
wire = 6.0 x 0.043 in.
orientation = broadside
Voltage Magnitude (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00
Frequency (Ghz)

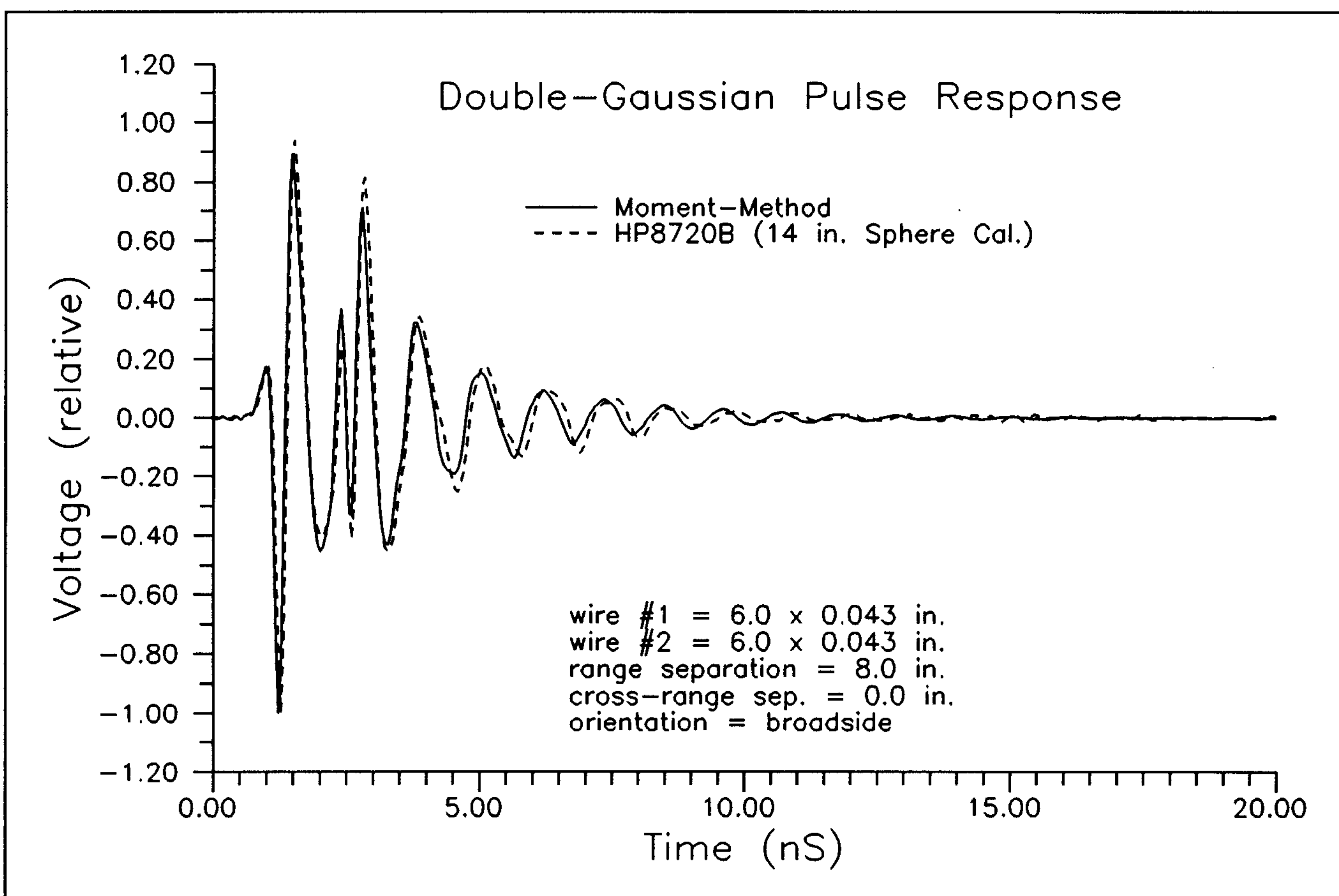

Double–Gaussian Pulse Response
Moment–Method
HP8720B (14 in. Sphere Cal.)
wire = 6.0 x 0.043 in.
orientation = broadside
Voltage (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
−0.20
−0.40
−0.60
−0.80
−1.00
−1.20
0.00
5.00
10.00
15.00
20.00
Time (nS)

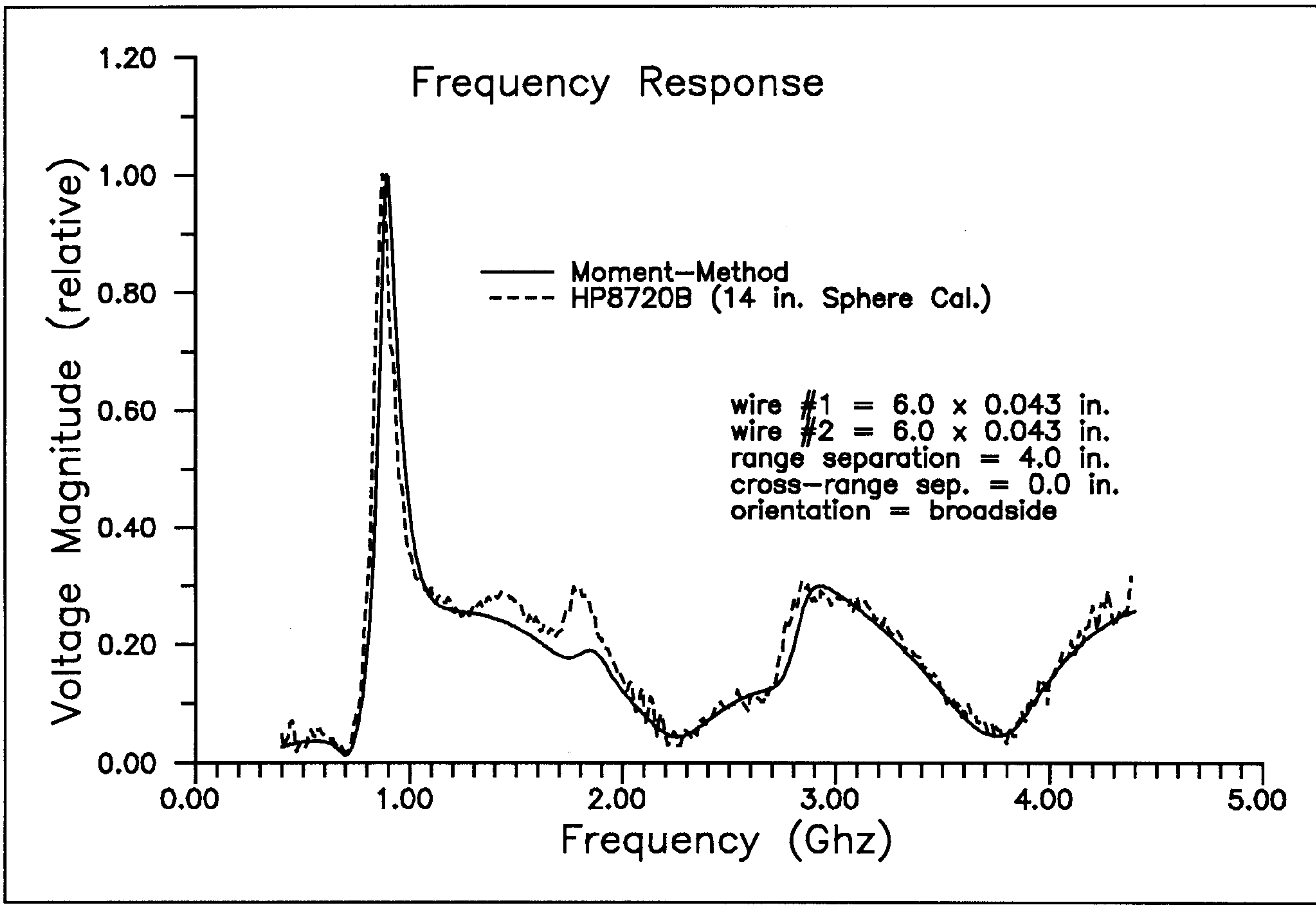

Frequency Response
Moment–Method
HP8720B (broadside 6.0 x 0.043 in wire cal.)
wire = 6.0 x 0.043 in.
orientation = 45 degrees off broadside
Voltage Magnitude (relative)
Frequency (Ghz)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00

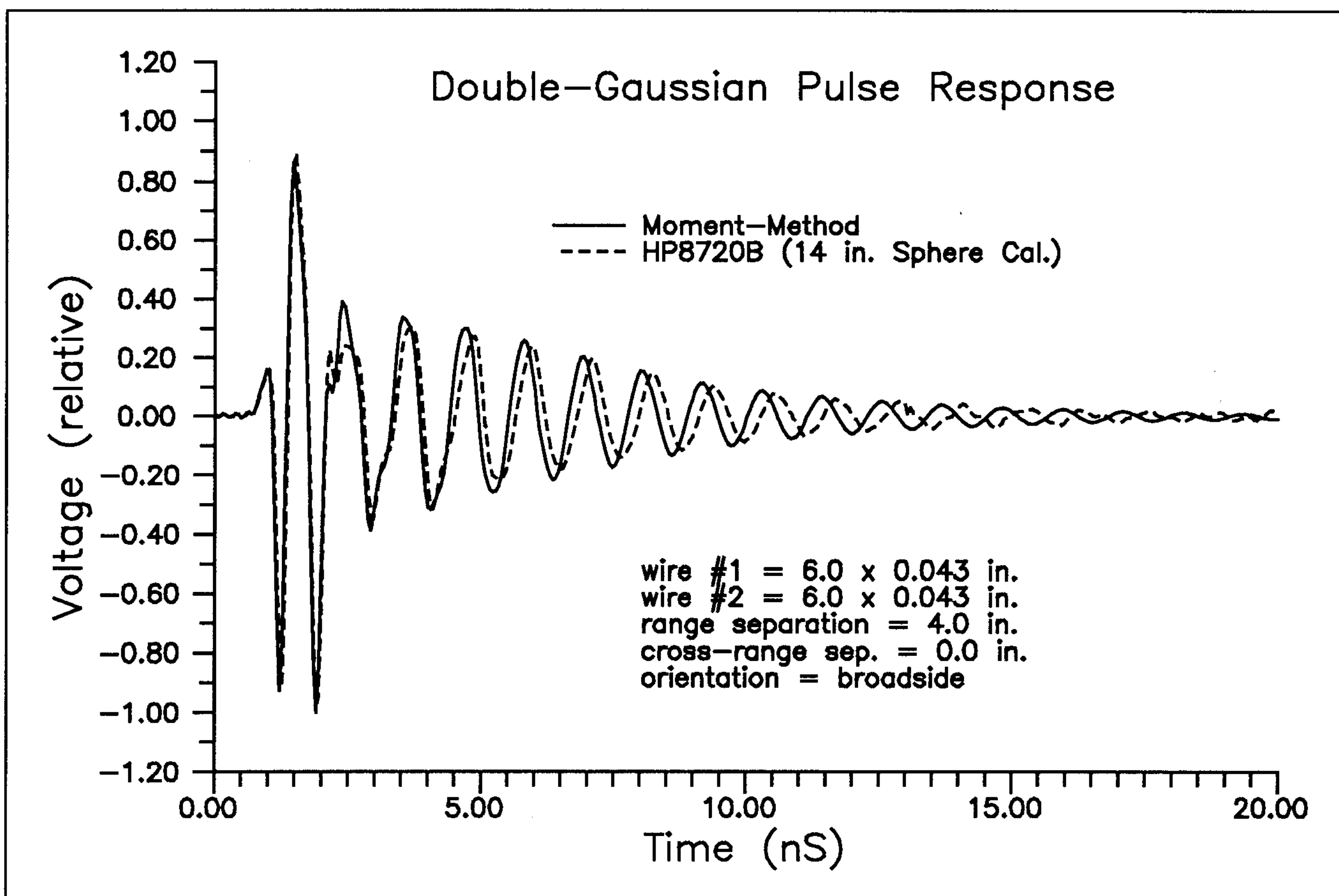

Double–Gaussian Pulse Response
Moment–Method
HP8720B (Broadside 6.0 x 0.043 in wire cal.)
wire = 6.0 x 0.043 in.
orientation = 45 degrees off broadside
Voltage (relative)
Time (nS)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
−0.20
−0.40
−0.60
−0.80
−1.00
−1.20
0.00
5.00
10.00
15.00
20.00

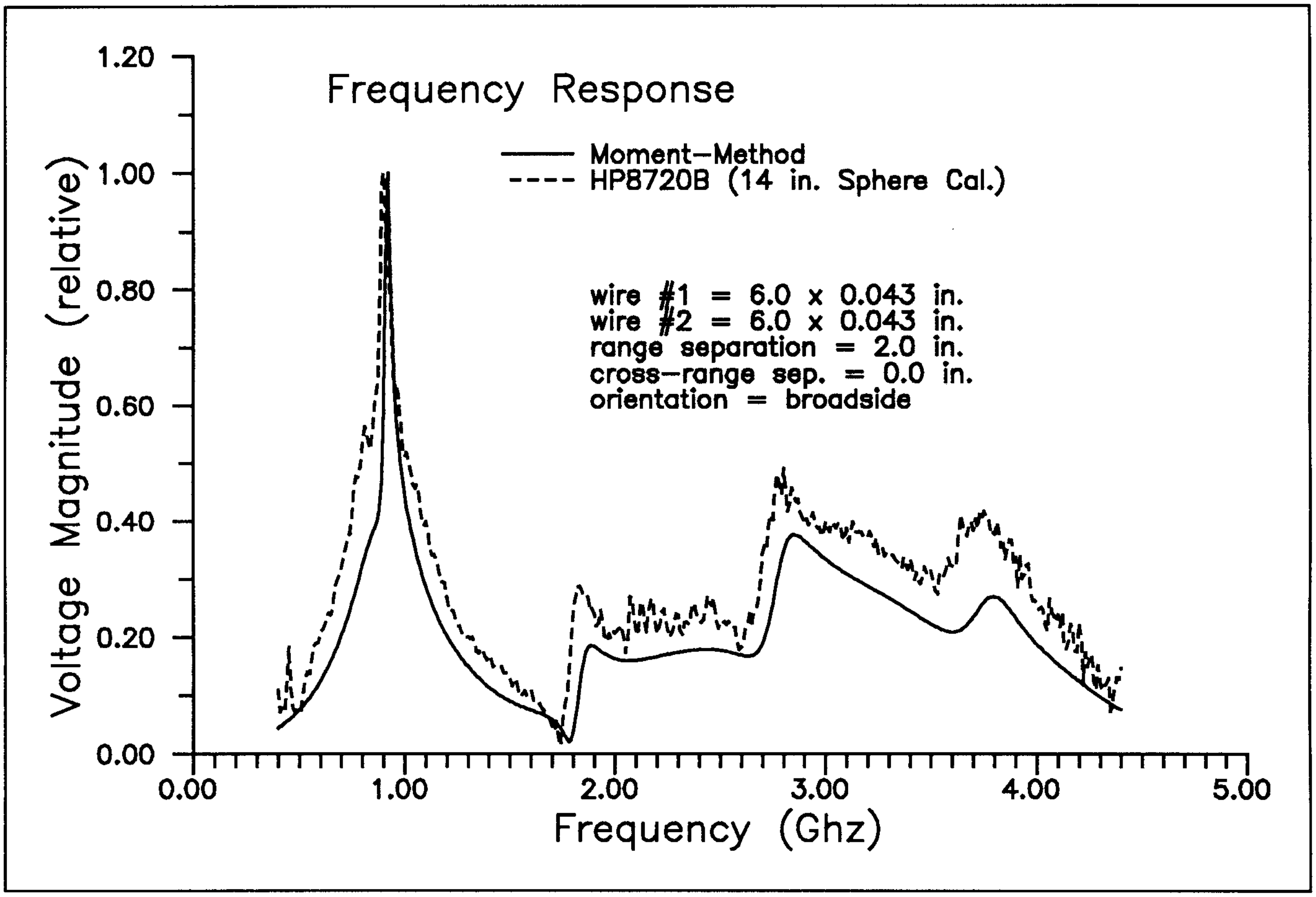
COUPLED WIRES

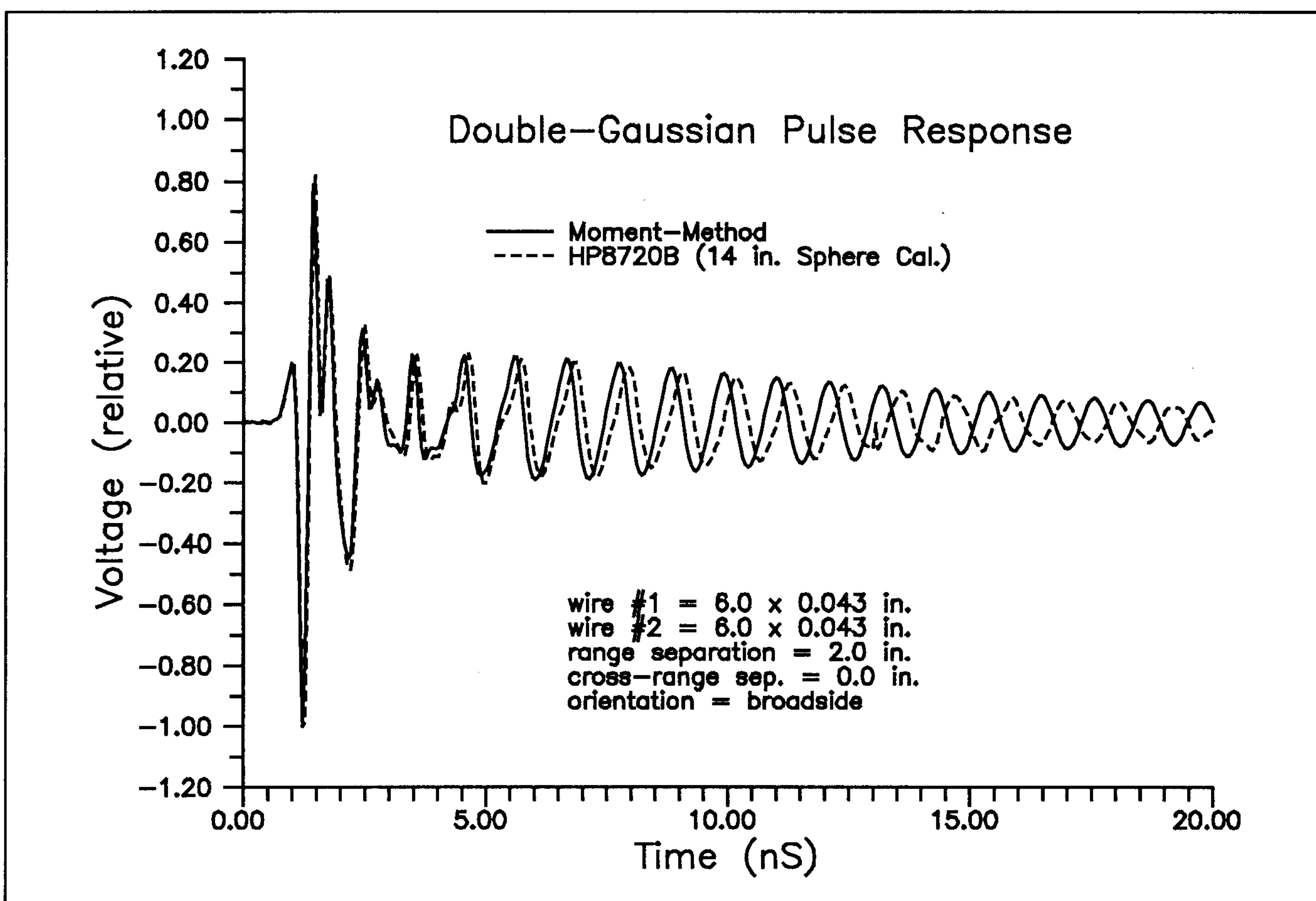

Frequency Response
Moment-Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 8.0 in.
cross-range sep. = 0.0 in.
orientation = broadside
Voltage Magnitude (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00
Frequency (Ghz)

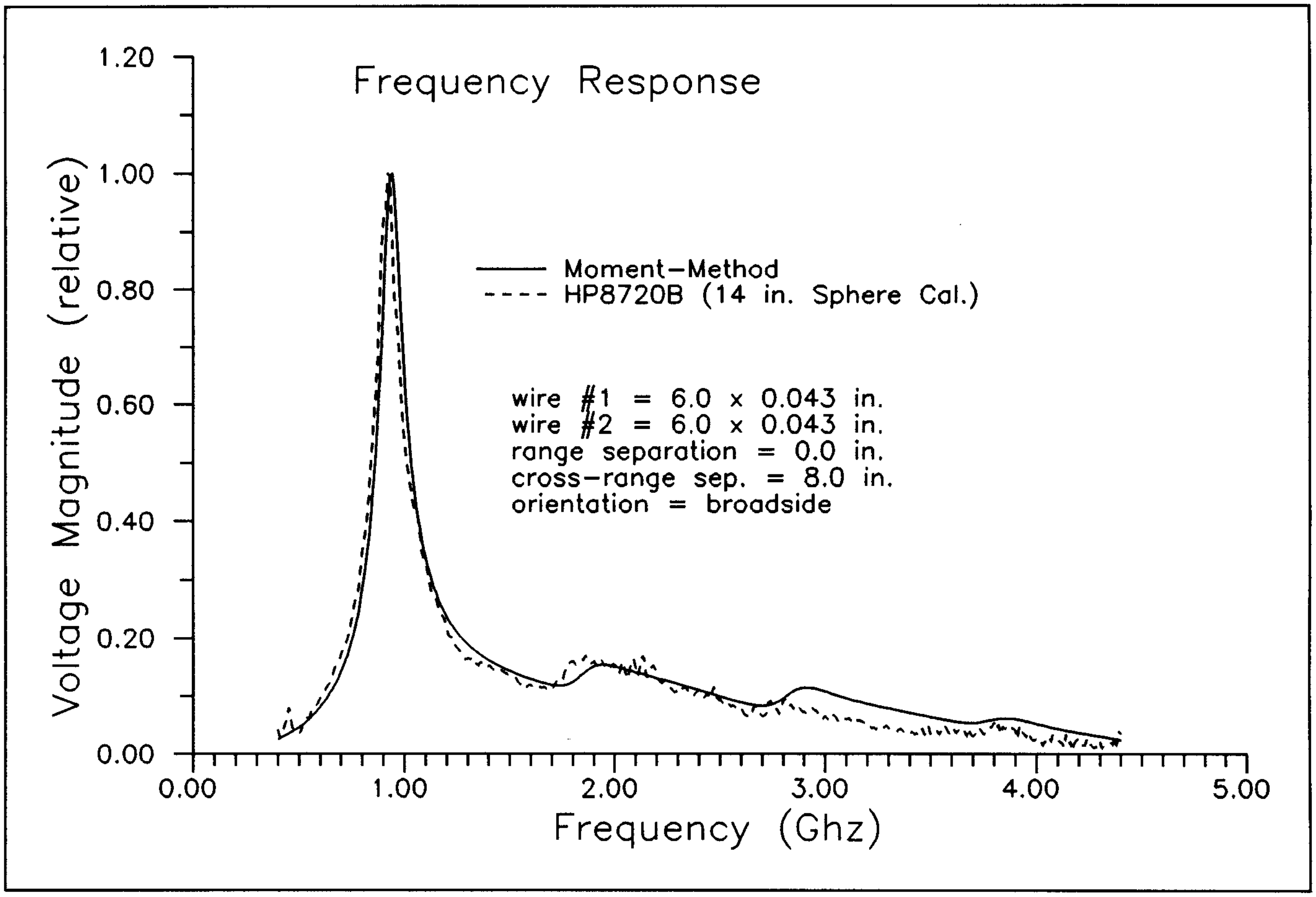

Double-Gaussian Pulse Response
Moment-Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 8.0 in.
cross-range sep. = 0.0 in.
orientation = broadside
Voltage (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
0.00
5.00
10.00
15.00
20.00
Time (nS)

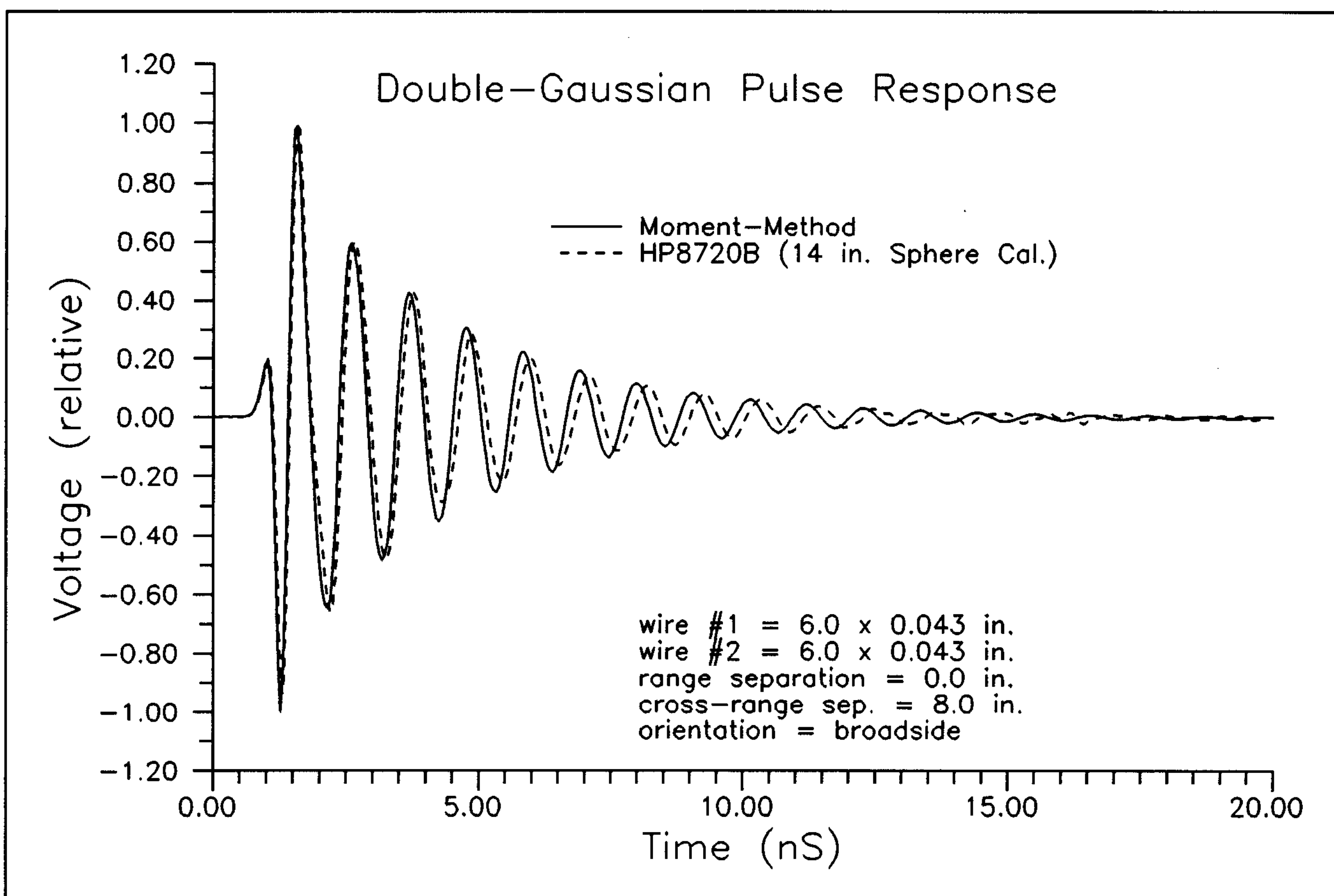

Frequency Response
Voltage Magnitude (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00
Frequency (Ghz)
Moment-Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 4.0 in.
cross-range sep. = 0.0 in.
orientation = broadside

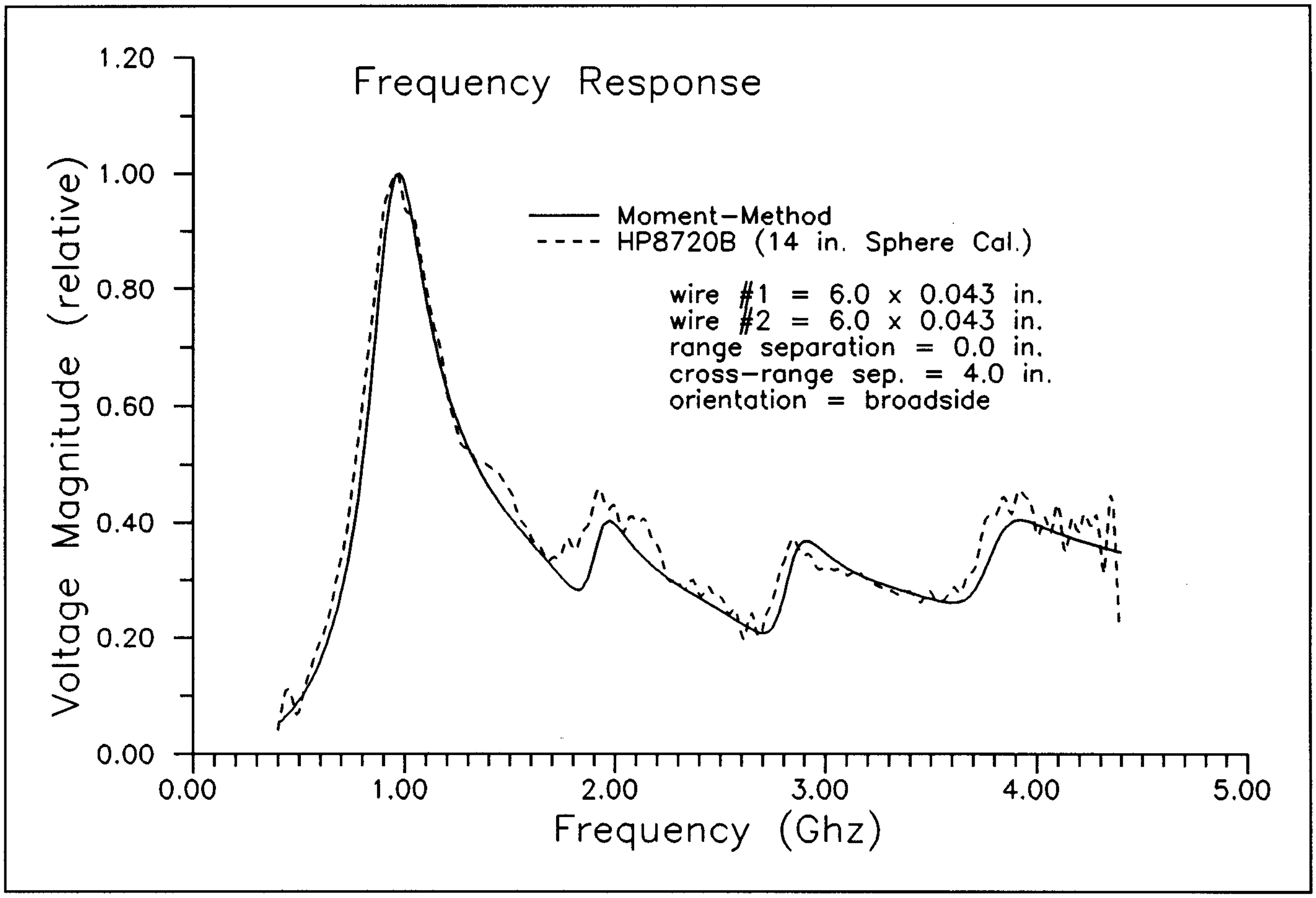

Double-Gaussian Pulse Response
Voltage (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
0.00
5.00
10.00
15.00
20.00
Time (nS)
Moment-Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 4.0 in.
cross-range sep. = 0.0 in.
orientation = broadside

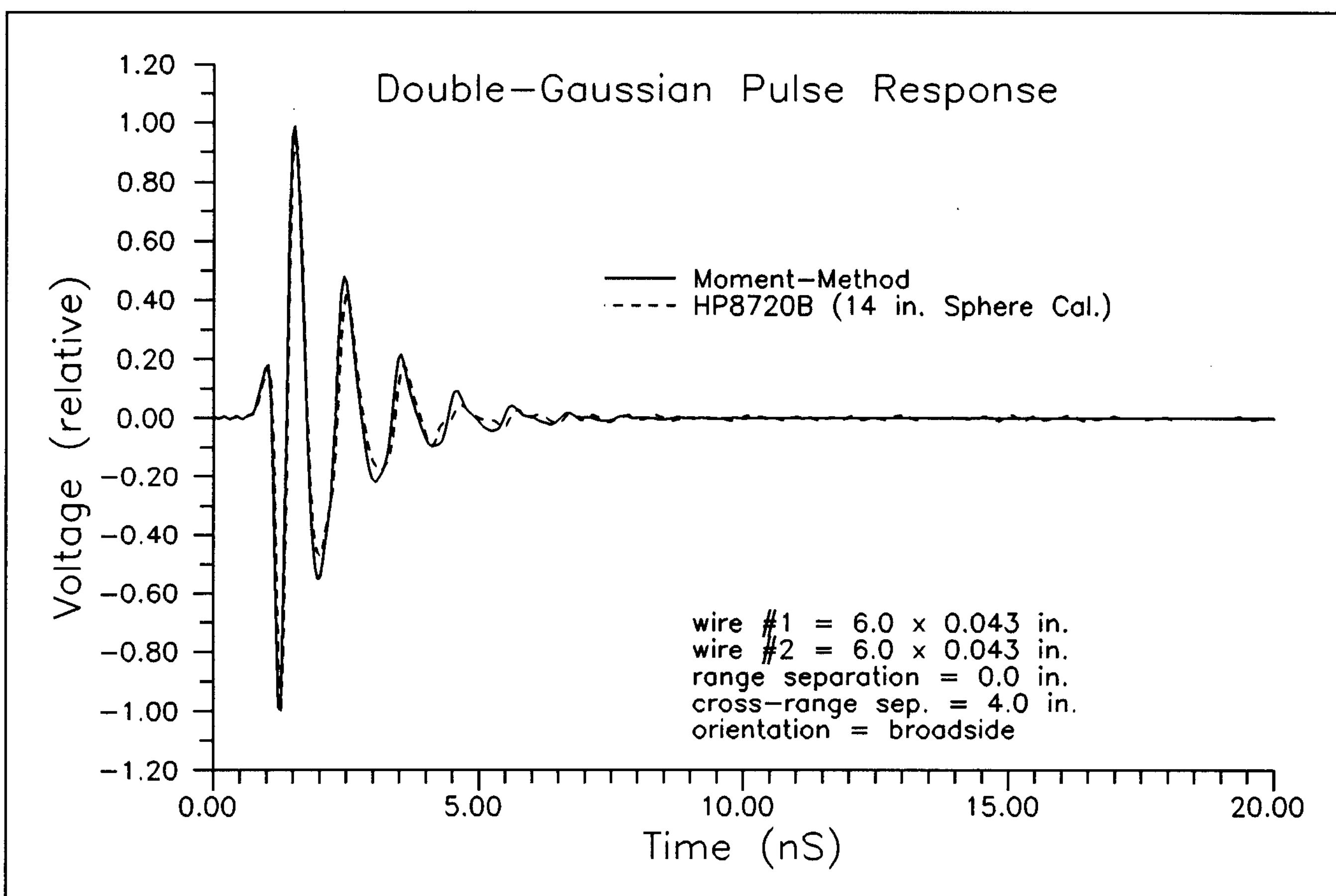

Frequency Response
Moment–Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 2.0 in.
cross–range sep. = 0.0 in.
orientation = broadside
Voltage Magnitude (relative)
Frequency (Ghz)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00

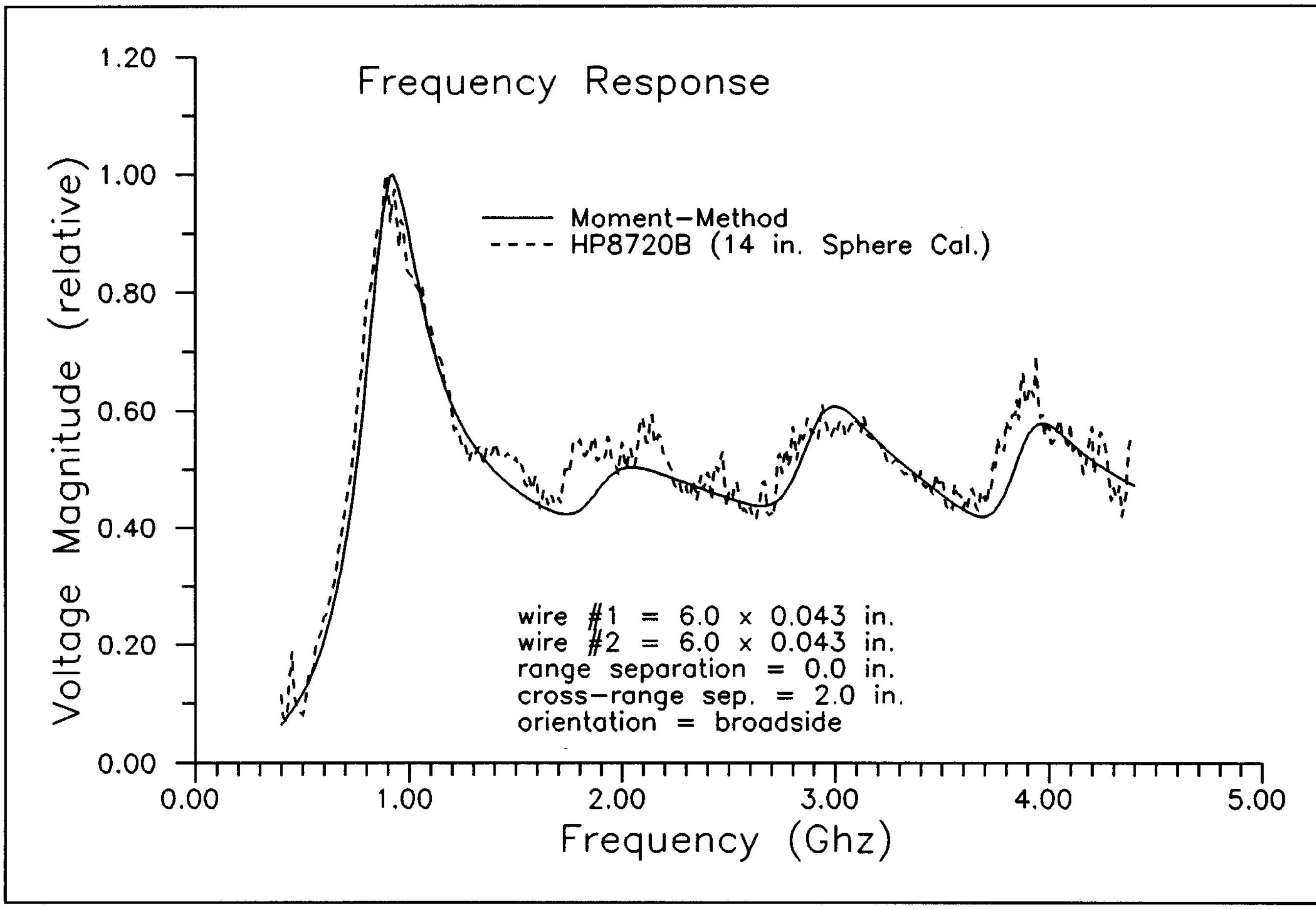

Double–Gaussian Pulse Response
Moment–Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 2.0 in.
cross–range sep. = 0.0 in.
orientation = broadside
Voltage (relative)
Time (nS)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
–0.20
–0.40
–0.60
–0.80
–1.00
–1.20
0.00
5.00
10.00
15.00
20.00

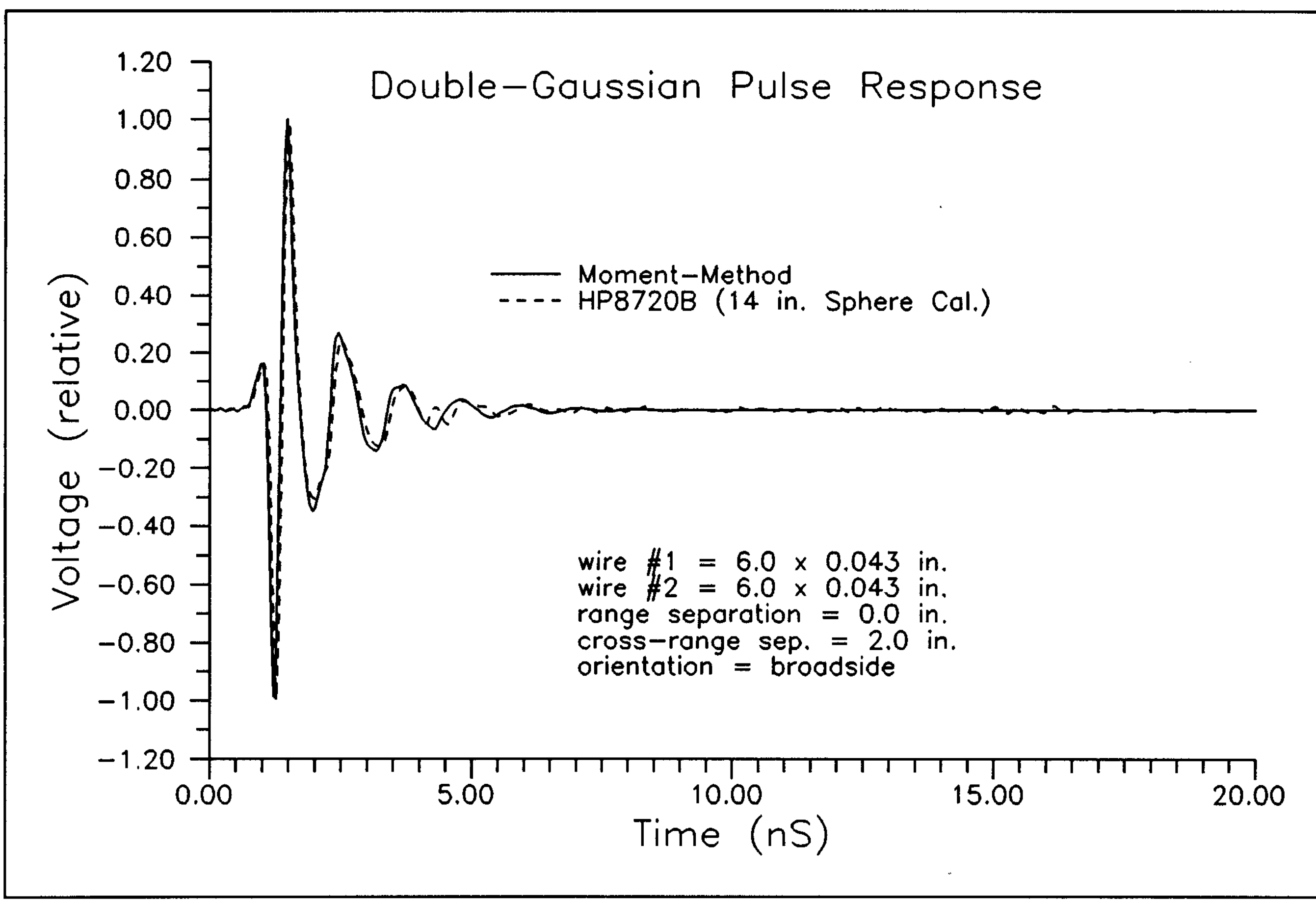

Frequency Response
Moment–Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 0.0 in.
cross–range sep. = 8.0 in.
orientation = broadside
Voltage Magnitude (relative)
Frequency (Ghz)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00


Double–Gaussian Pulse Response
Moment–Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 0.0 in.
cross–range sep. = 8.0 in.
orientation = broadside
Voltage (relative)
Time (nS)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
−0.20
−0.40
−0.60
−0.80
−1.00
−1.20
0.00
5.00
10.00
15.00
20.00

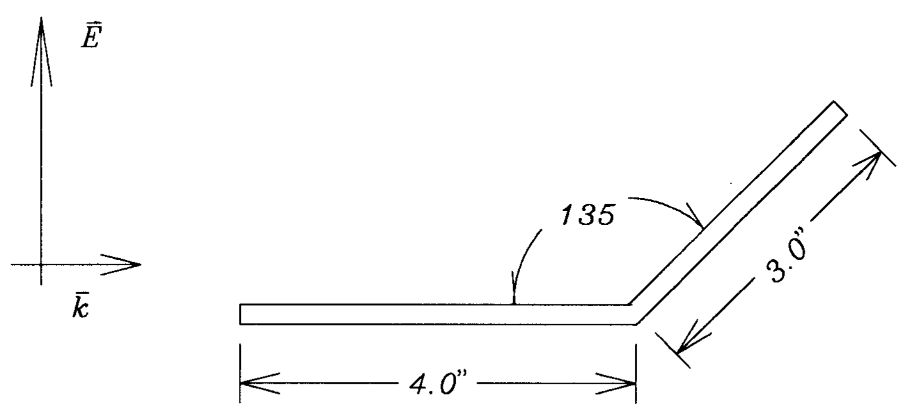

Frequency Response
Voltage Magnitude (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00
Frequency (Ghz)
Moment-Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 0.0 in.
cross-range sep. = 4.0 in.
orientation = broadside

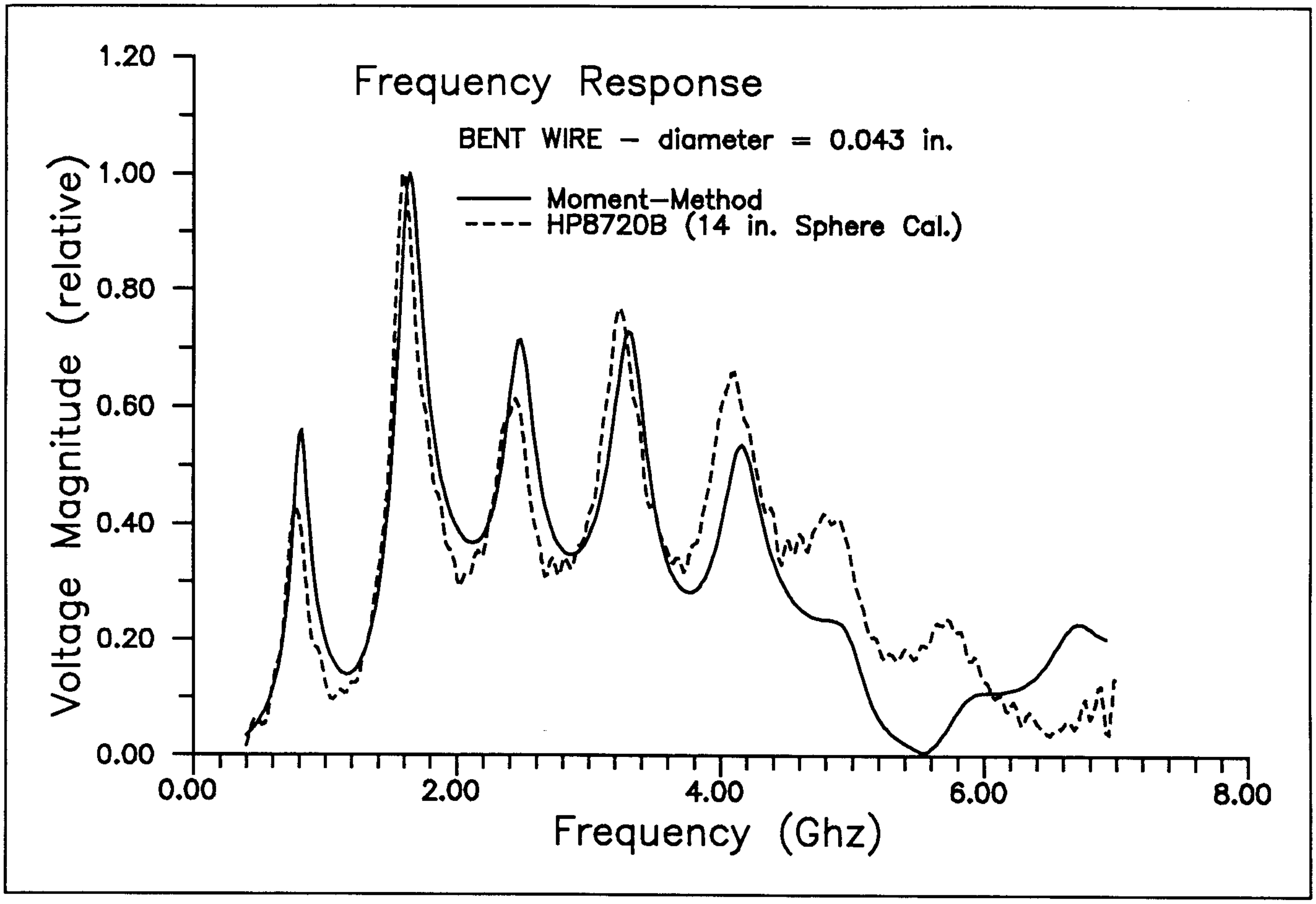

Double-Gaussian Pulse Response
Voltage (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
0.00
5.00
10.00
15.00
20.00
Time (nS)
Moment-Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 0.0 in.
cross-range sep. = 4.0 in.
orientation = broadside


Frequency Response
Moment-Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 0.0 in.
cross-range sep. = 2.0 in.
orientation = broadside
Voltage Magnitude (relative)
Frequency (Ghz)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00

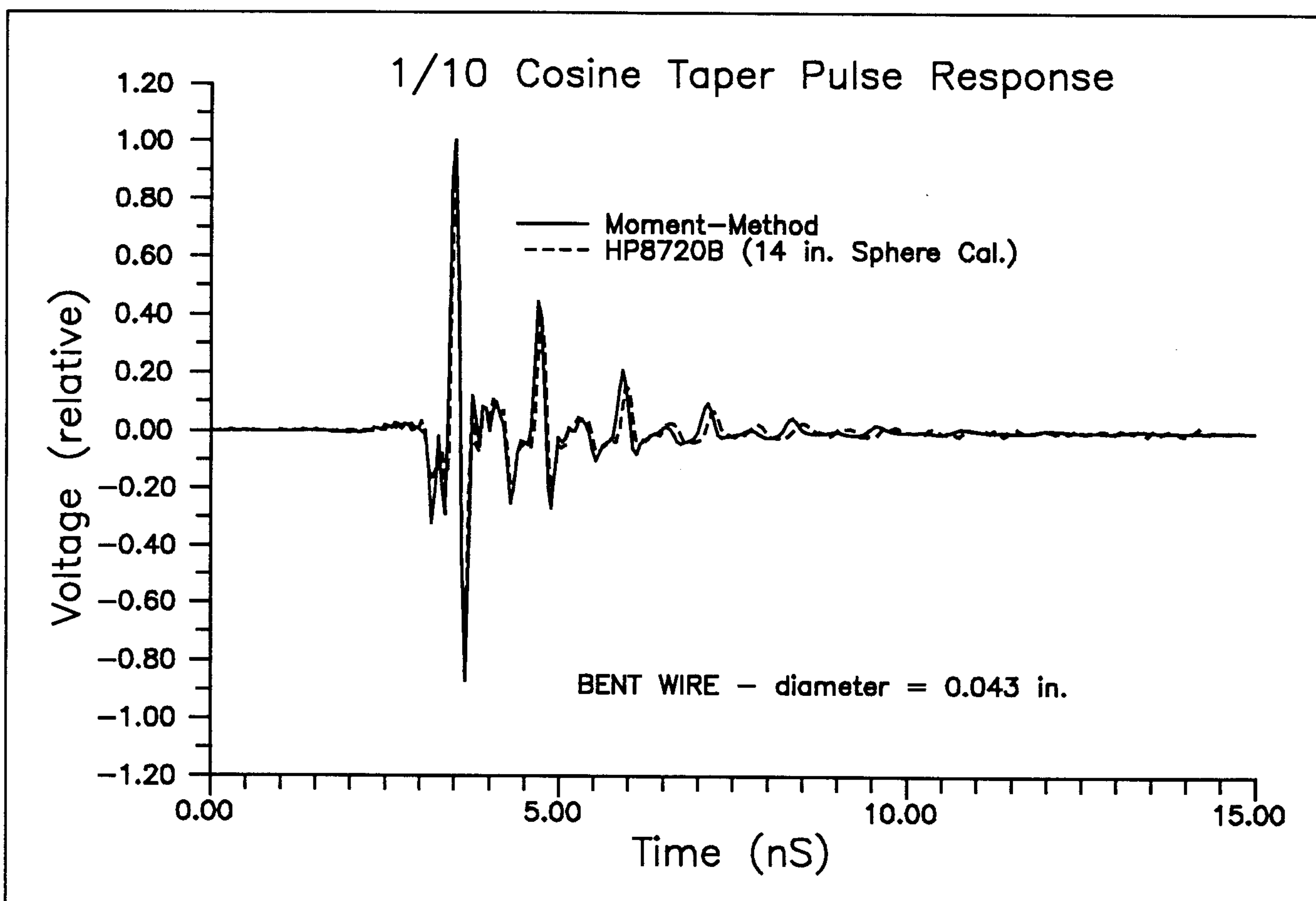

Double-Gaussian Pulse Response
Moment-Method
HP8720B (14 in. Sphere Cal.)
wire #1 = 6.0 x 0.043 in.
wire #2 = 6.0 x 0.043 in.
range separation = 0.0 in.
cross-range sep. = 2.0 in.
orientation = broadside
Voltage (relative)
Time (nS)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
0.00
5.00
10.00
15.00
20.00

BENT WIRE



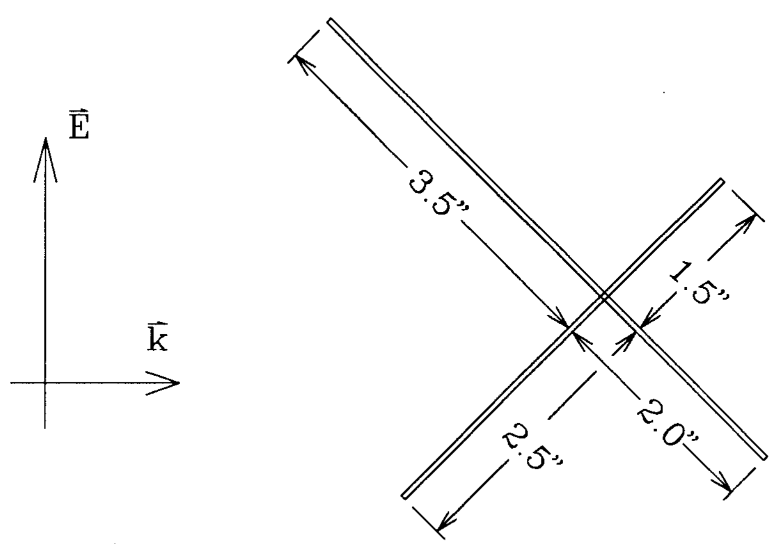


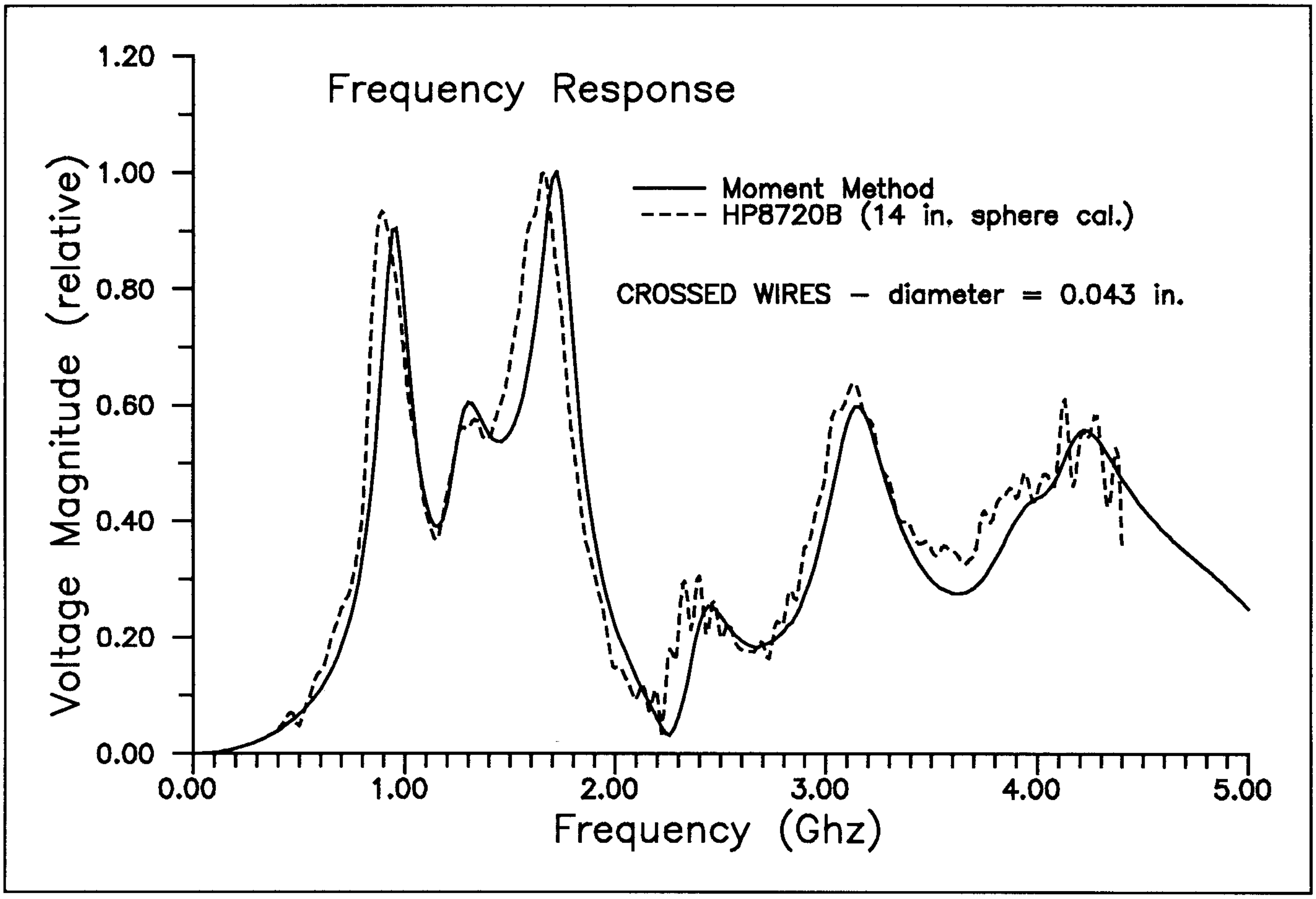
Frequency Response
BENT WIRE – diameter = 0.043 in.
Moment–Method
HP8720B (14 in. Sphere Cal.)
Voltage Magnitude (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
2.00
4.00
6.00
8.00
Frequency (Ghz)

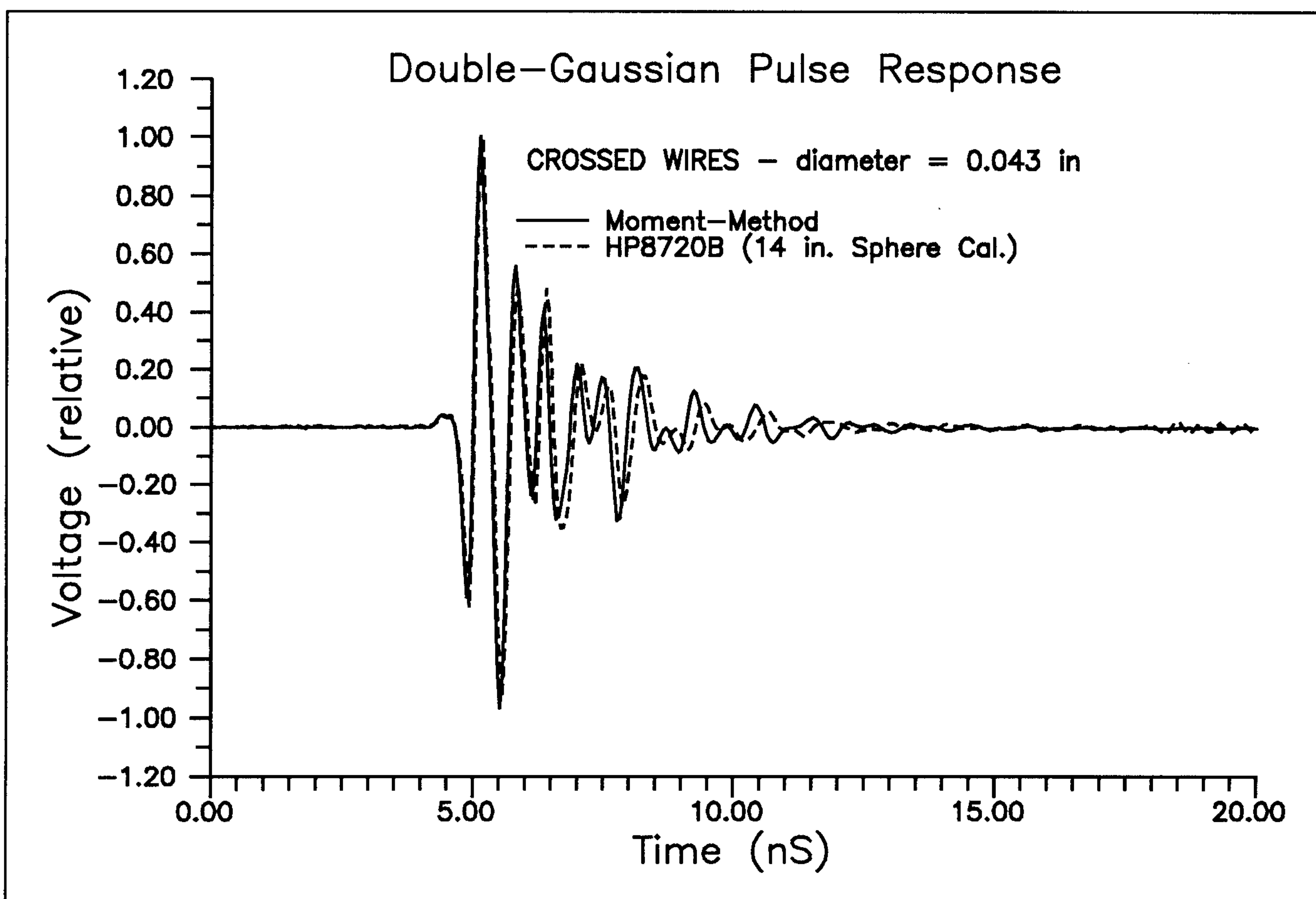


1/10 Cosine Taper Pulse Response
Moment–Method
HP8720B (14 in. Sphere Cal.)
BENT WIRE – diameter = 0.043 in.
Voltage (relative)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
−0.20
−0.40
−0.60
−0.80
−1.00
−1.20
0.00
5.00
10.00
15.00
Time (nS)

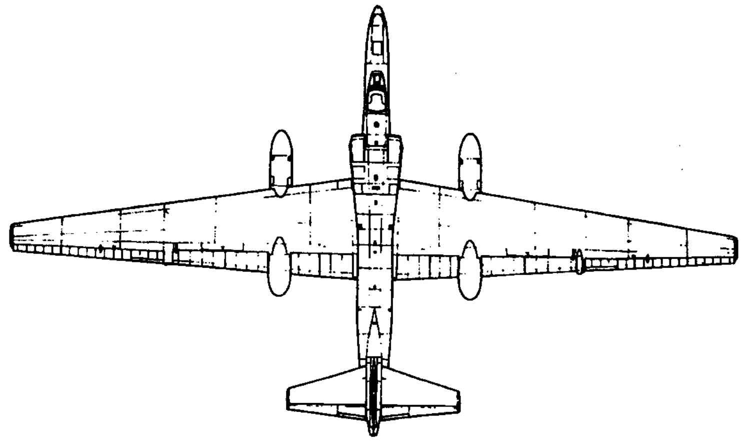
CROSSED WIRES



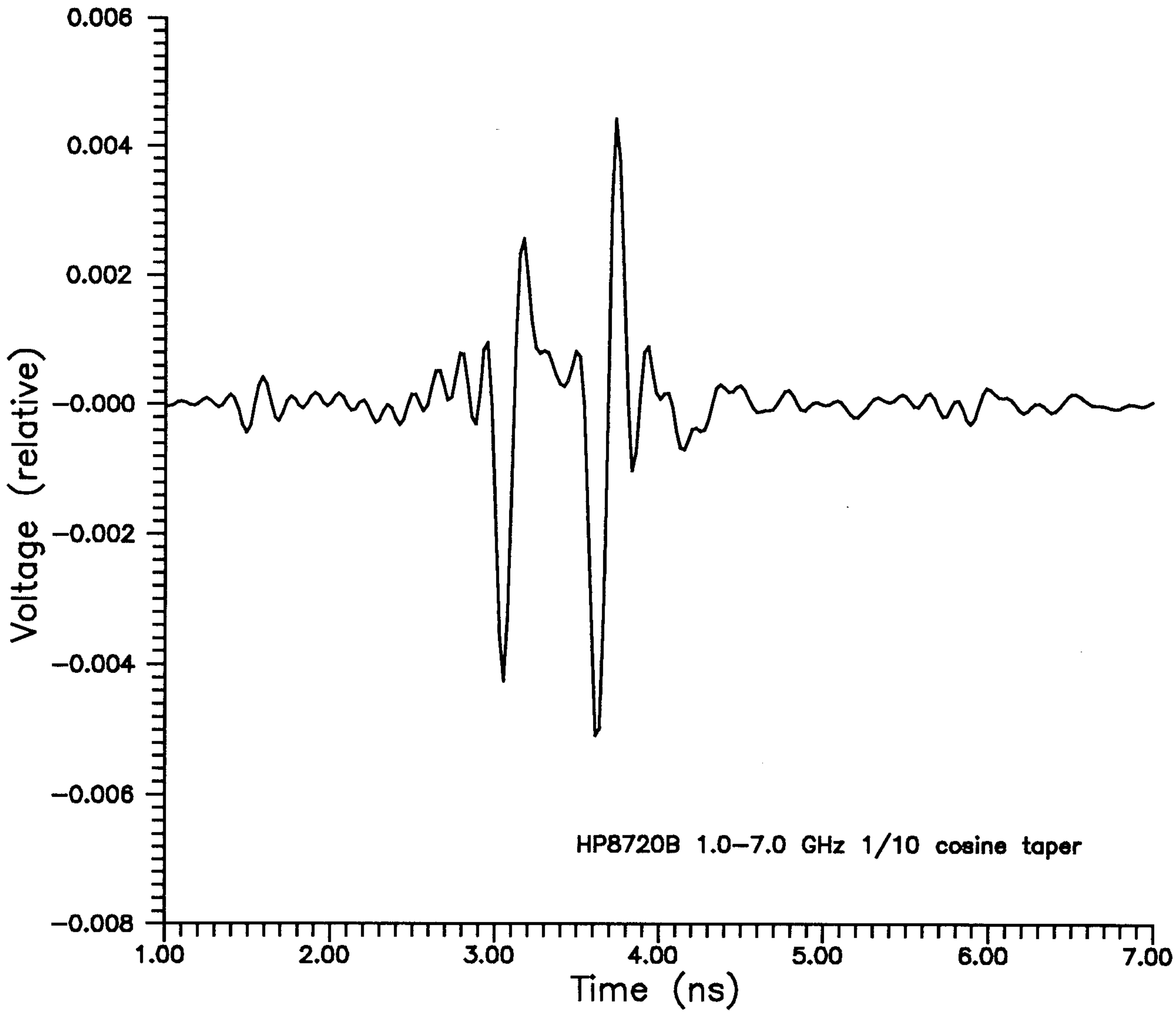

Frequency Response
Moment Method
HP8720B (14 in. sphere cal.)
CROSSED WIRES - diameter = 0.043 in.
Voltage Magnitude (relative)
Frequency (Ghz)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00


Double-Gaussian Pulse Response
CROSSED WIRES - diameter = 0.043 in
Moment-Method
HP8720B (14 in. Sphere Cal.)
Voltage (relative)
Time (nS)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
0.00
5.00
10.00
15.00
20.00

SCALE MODEL AIRCRAFT



1/48 Scale LOCKHEED TR1 : Wing-on Incidence



Conclusions

- Fourier Inversion of swept-frequency measurements is a good alternative to direct time domain measurements.
- Calibration significantly improves the quality of transient measurements.
- Both spheres and wires can be used as calibration targets with good results.
- Good agreement between theory and measurement for canonical targets gives confidence in measurement of complicated targets.
- Coupled wire measurements demonstrate excitation of different SEM system modes.

Future Improvements

- Relocation of antennas for reduced direct coupling.
- Shorter and lower loss cables for extended bandwidth and higher signal-to-noise ratio.
- New antennas to extend high frequency range.