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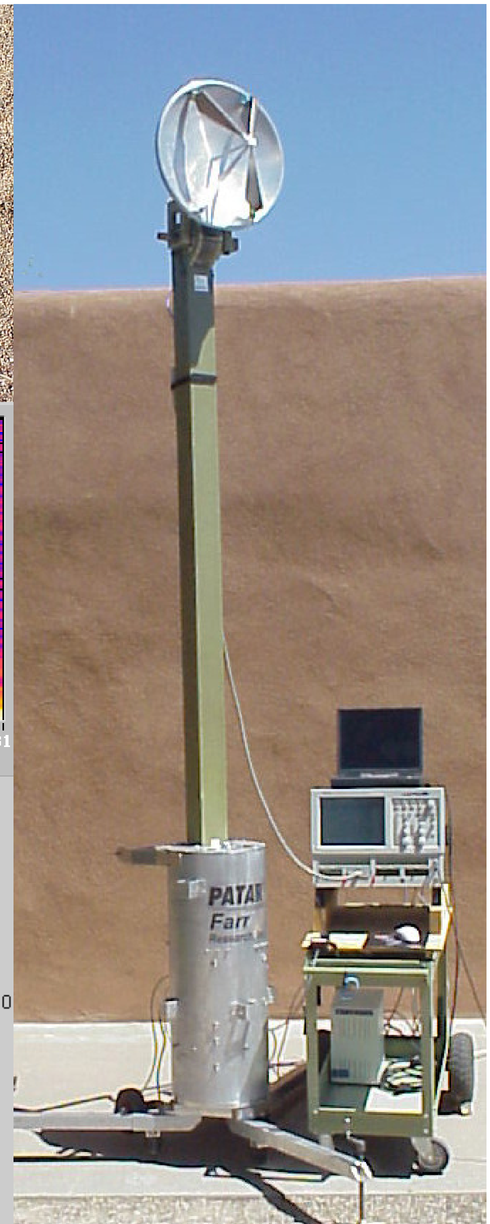
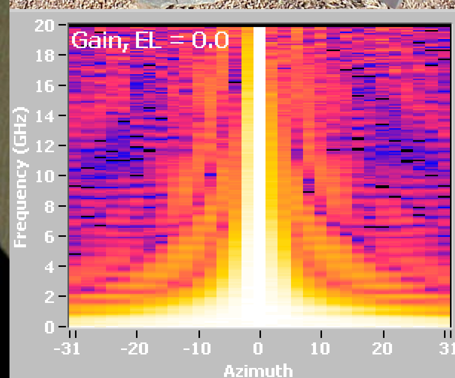
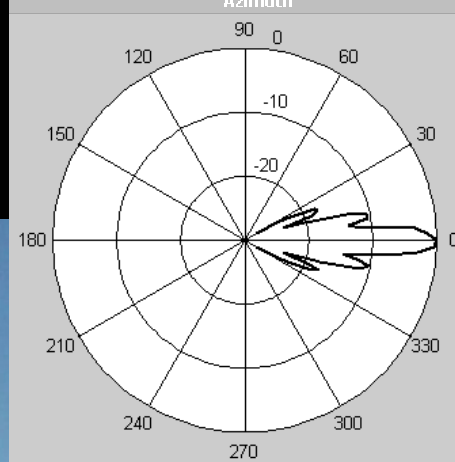
Catalog of UWB Antennas and HV Components
June 2013







New company name.
Same great products!

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Table of Contents

Price List

Model		Price	Delivery
PATAR® Personal Antenna Range		$230,000	6 months
CIRA-2		$32,750	3 months
Universal Clamp for CIRA-2		$300	1 month
IRA-3Q	1.5 ft. diam; incl. shipping case	$16,800	3 months
IRA-8-LV	3 ft. diam.; incl. shipping case	$24,500	4 months
IRA-8-HV	3 ft. diam.; incl. shipping case	$27,200	4 months
IRA-6	5 ft. diam.	$32,500	4 months
TEM-1		$6,600	3 months
TEM-2		$10,500	3 months
VDC-1		$5,250	3 months

Prices are FOB Albuquerque for U.S customers
Prices are EXW (Ex Works) for Foreign customers
Prices may change without notice.
Delivery may be sooner if parts are in stock.
Export license may be required

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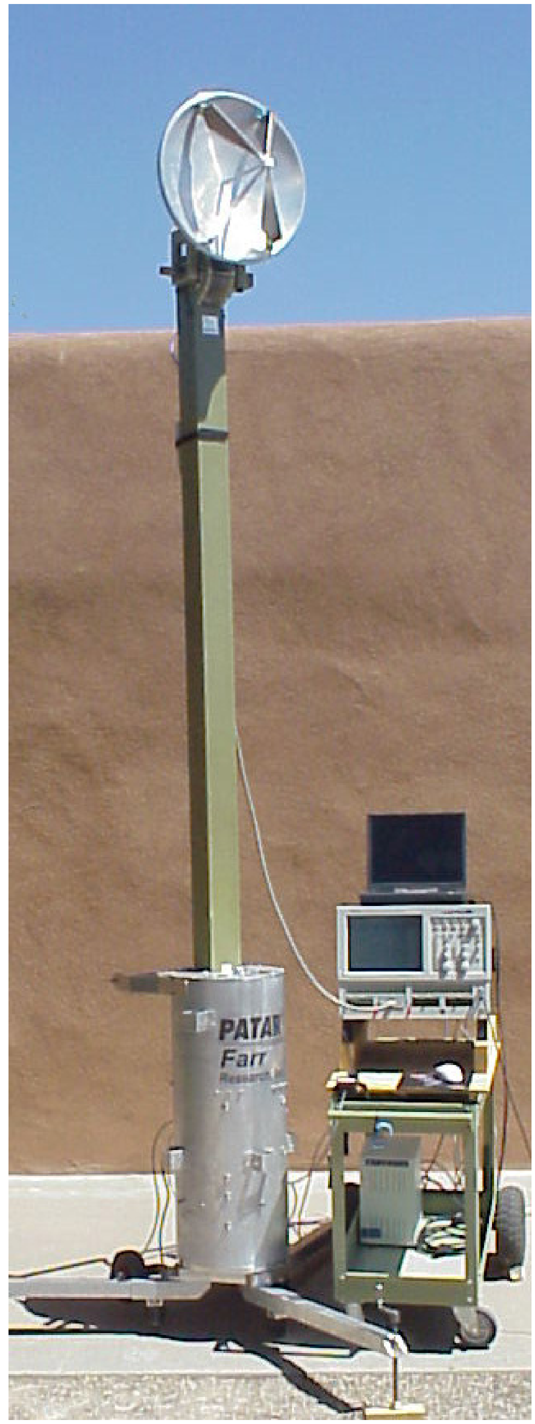
PATAR® PERSONAL ANTENNA RANGE



With the Portable Automatic Time-domain Antenna Range, or *PATAR*® system, we introduce the new product class of ***Personal Antenna Range***. This system provides a convenient and inexpensive method of testing both narrowband and wideband antennas. The nominal frequency range is 900 MHz to 20 GHz, and it characterizes non-dispersive antennas as low as 200 MHz. The entire system is easily stored in a small shed and can be set up outdoors and aligned in less than one hour. A complete antenna measurement, including setup, alignment, teardown, stowage, and signal processing, can be completed within 4 hours. All measurements are made in the time domain.

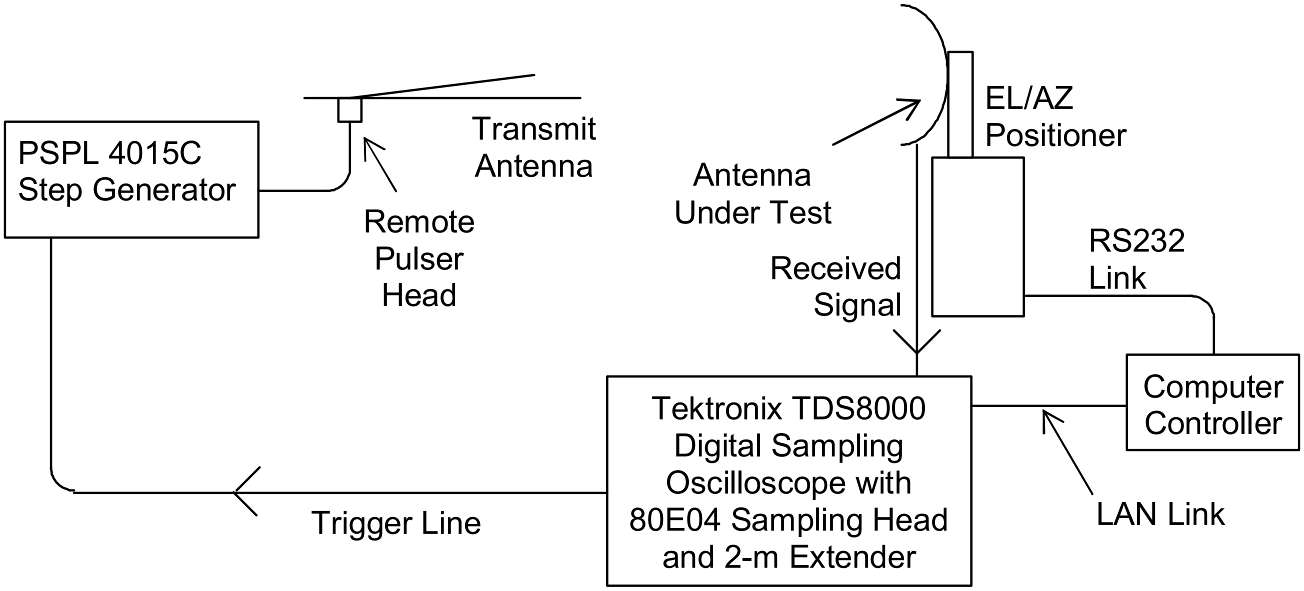
The system includes a fast pulser, a fast sampling oscilloscope, a calibrated field sensor, a customized elevation / azimuth positioner, a computer controller, and software for data acquisition and processing. This range is more easily used outdoors than conventional frequency domain ranges, because the instrumentation is relatively insensitive to temperature stability (although it must be kept above 10˚C, 50˚F). Time-gating is used to eliminate ground bounce from the measurement.

Our customized positioner is portable and easily positioned, leveled, and aligned. It has a precision better than ±0.2 degrees in both azimuth and elevation. The antenna height is fixed at 3 meters, which we found to be the maximum height at which we could conveniently work in a portable system.

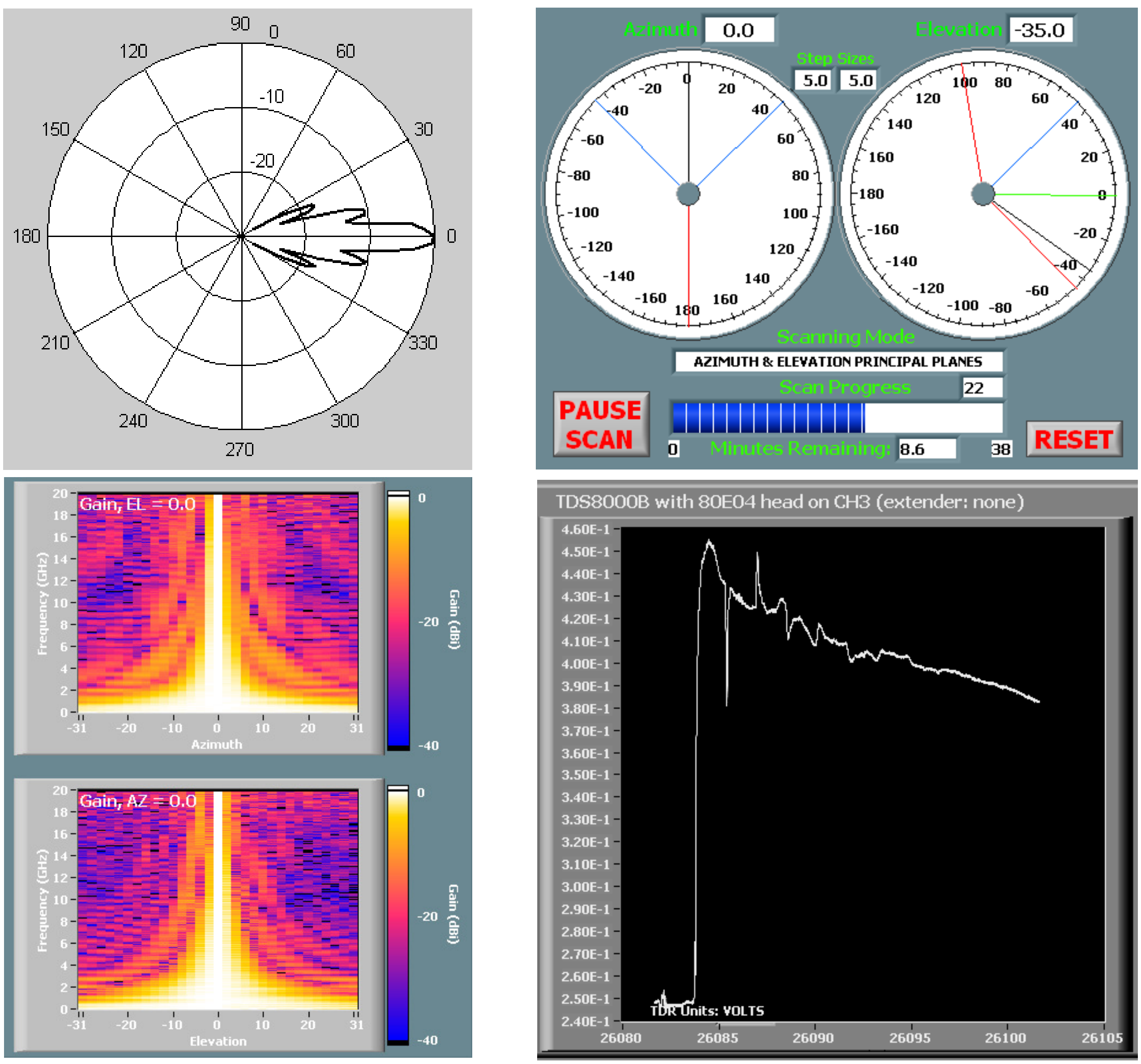
The software includes everything one needs to drive the positioner, acquire the data from the oscilloscope, and process and plot the data. The system output includes antenna impulse response, gain, realized gain, return loss, normalized antenna impulse response, and antenna pattern. This include 1 week of training at a location of the customer's choice. We may also be able to assemble a custom system from your oscilloscope and pulser.

On the following pages we provide a block diagram of the system, screen shots of the software, a list of equipment included with the system, and a set of data that characterizes the system. Prices appear on Page 2.

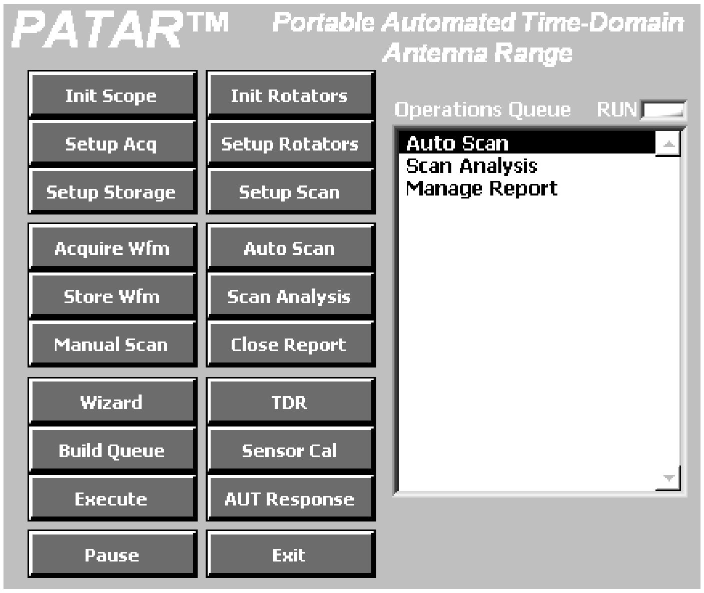
PATAR® System Diagram



Screen Shots from the *PATAR®* Software



Additional Photos and Screen Shots of the *PATAR*® System



PATAR® System Components

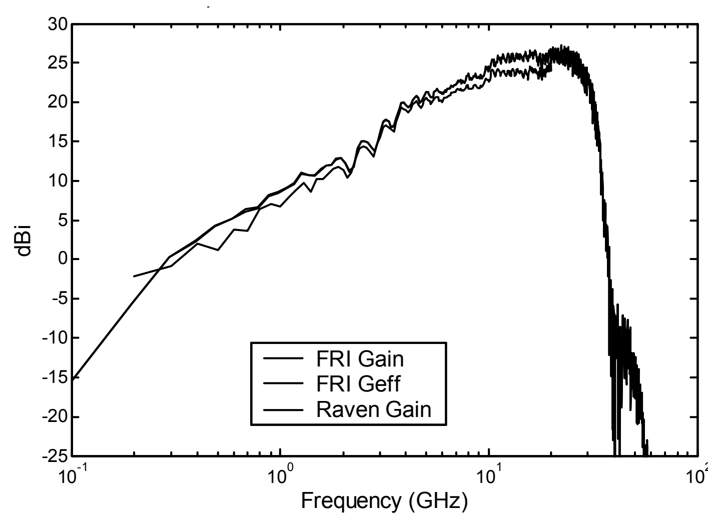
- FRI portable Elevation/Azimuth positioner
- Tektronix model TDS8000B sampling oscilloscope with 80E04 sampling head and 2-meter extension cable
- Picosecond Pulse Lab model 4015D pulser
- Laptop Computer with *PATAR*® Software
- Two Farr Fields TEM-1 sensors for calibration
- Cables, connectors, attenuators, and tripod extension tubes
- Mounting brackets for the pulser and sampling head
- One week of training at a location chosen by the customer

Equipment Provided by the User

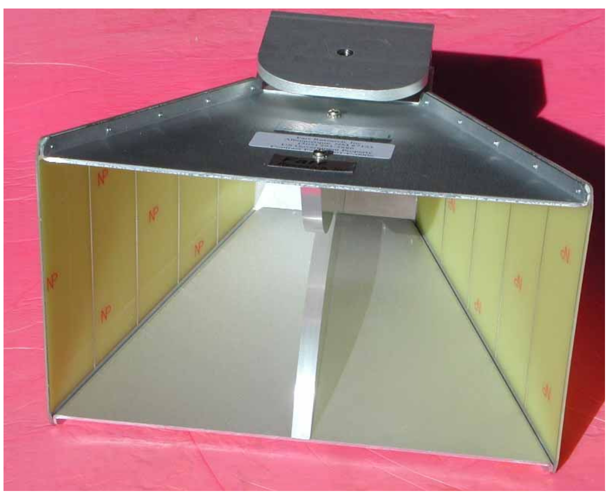
- Tripod & Quick-release plates
- MATLAB® Software(optional) to generate vector graphics instead of bit maps
- Table for oscilloscope and laptop computer

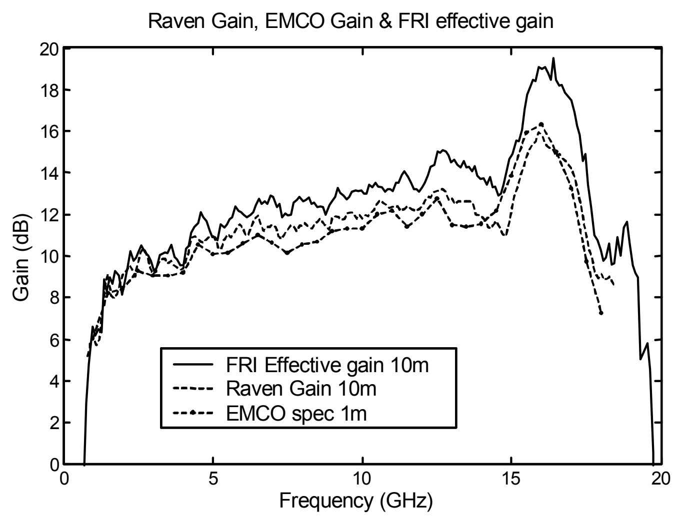
<u>Comparisons of Results From the *PATAR*® System to Other Measurements</u>

IRA-3 Gain Measurements by *PATAR*® System and Raven Engineering

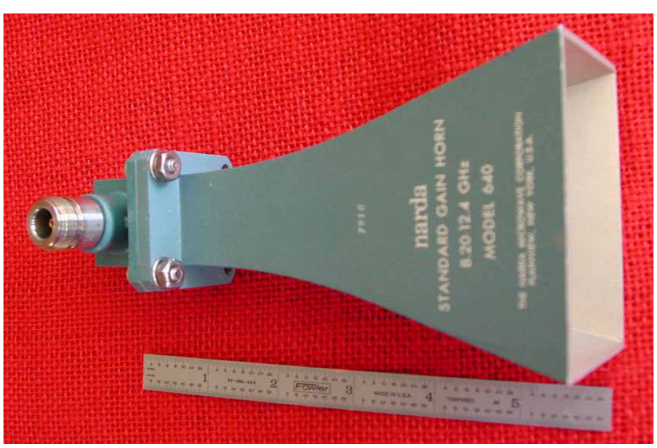


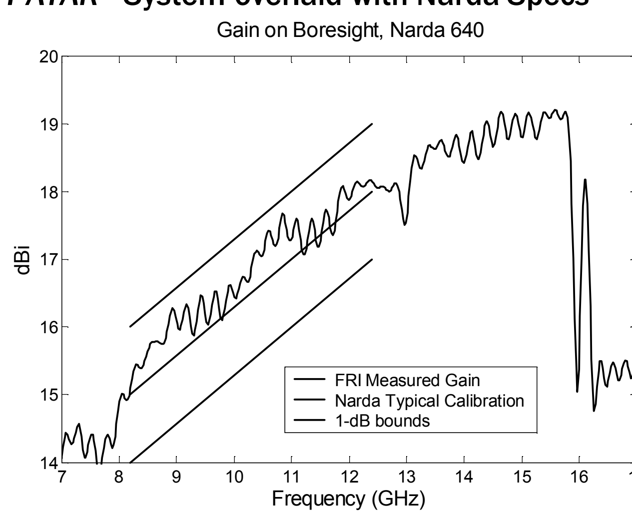
EMCO Model 3115 Measurements by *PATAR*® System, Raven Engineering, and EMCO specs





Narda Model 640 X-Band Horn Measurements by *PATAR*® System overlaid with Narda Specs





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Albuquerque, NM 87123
efarr@Farr-Research.com

(505) 410-7722
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COLLAPSIBLE IMPULSE RADIATING ANTENNA CIRA-2

The Collapsible Impulse Radiating Antenna (CIRA) provides broadband antenna coverage in a single compact package that is easily portable. Our newest version, the CIRA-2, has the feed arms spaced at ±30° from the vertical. This modification improves the gain of the antenna and improves cross polarization (crosspol) rejection.

The antenna has outstanding RF characteristics in both the frequency and time domains. In the time domain, it has an impulse response with **FWHM of 74 ps** and midband effective height of 13.8 cm. The peak gain at 6 GHz is 24 dBi, and the antenna is usable from **150 MHz to 12 GHz**.

The parabolic reflector for the CIRA-2 is 1.22 m (4 feet) in diameter with a focal length of 0.488 m (F/D = 0.4). The reflector is constructed of a very tough electrically conductive mesh fabric. The wind loading on the antenna is low due to the high air permeability of the fabric. The reflector has 12 sections or panels that are supported on an umbrella-like frame with fiberglass stays. The input connector is a 50-ohm SMA connector, and the input impedance is a flat 50 ohms throughout the band. A bracket attached to the splitter enclosure provides a standard 3/8″-16 thread tripod connection. The antenna can be rotated easily to either horizontal or vertical polarization.

The collapsed antenna measures 102 mm (4 in.) diameter x 810 mm (32 in.) long. The antenna weighs 2 kg (4.5 lb.). An optional lightweight tripod and universal clamp are available. The complete package weighs less than 5.5 kg (12 lb.). The antenna can easily be transported and set up by one person.

Calibration data is also provided on a floppy disk, to allow one to deconvolve the impulse response of the antenna.

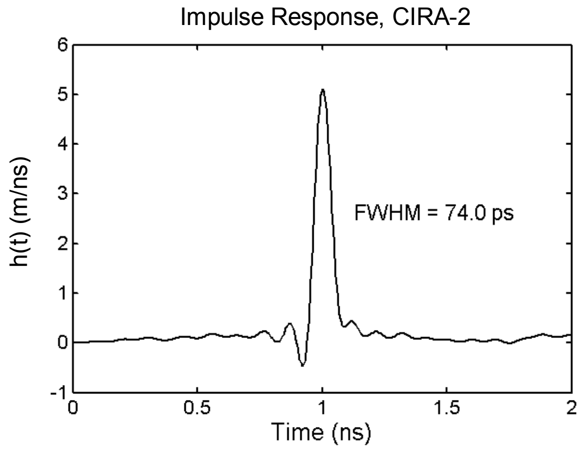
Model CIRA-2

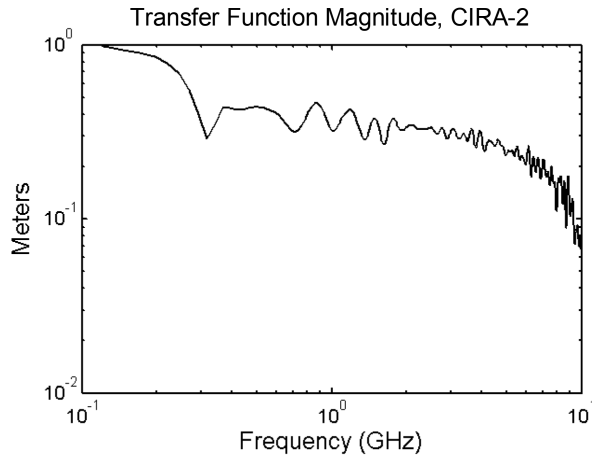
Collapsed CIRA-2 with optional tripod and clamp

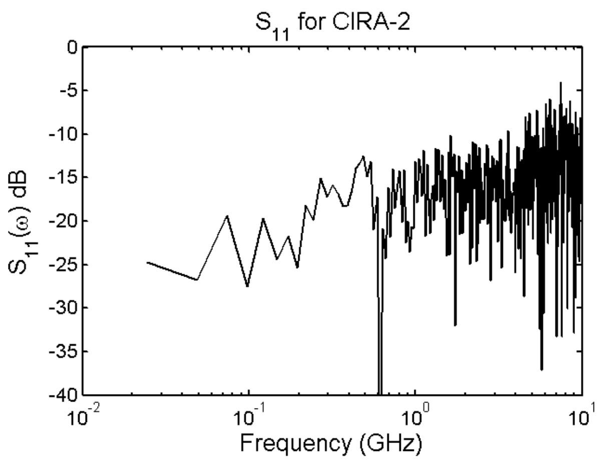
This antenna is protected under U.S. Patent # 6,340,956. Prices appear on Page 2.

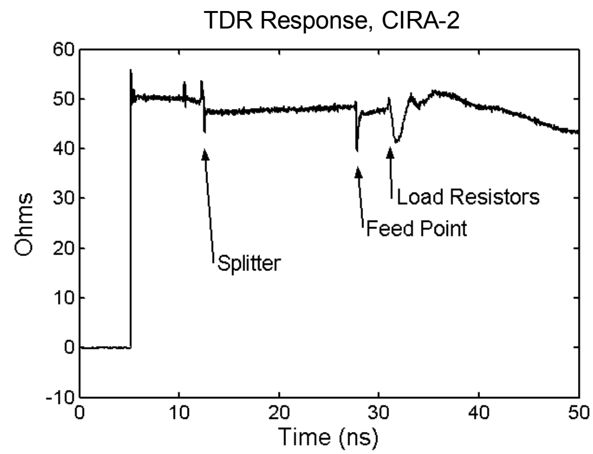
FWHM (ps)	h_{eff}* (m)	3 dB point GHz	Peak Gain (at 6 GHz)	Weight kg (lb.)
74	0.138	10	24 dBi	2 (4.5)

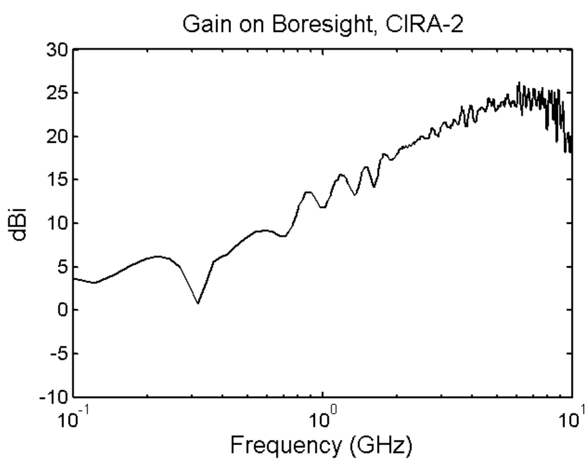
* See Appendix A for definitions

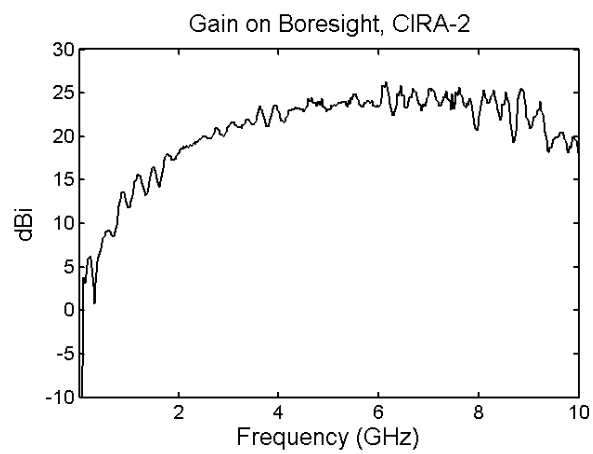

Impulse Response, CIRA-2
h(t) (m/ns)
FWHM = 74.0 ps
Time (ns)

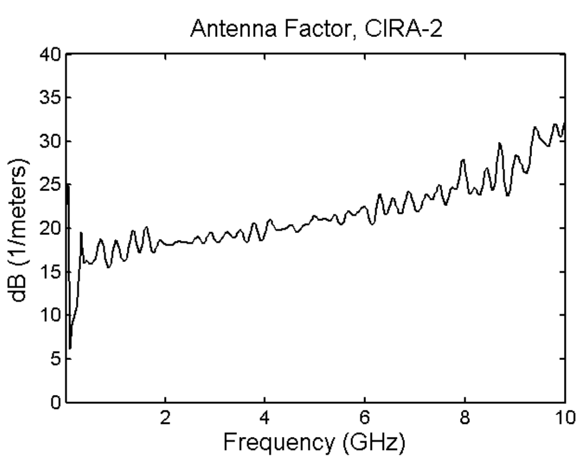

Transfer Function Magnitude, CIRA-2
Meters
Frequency (GHz)

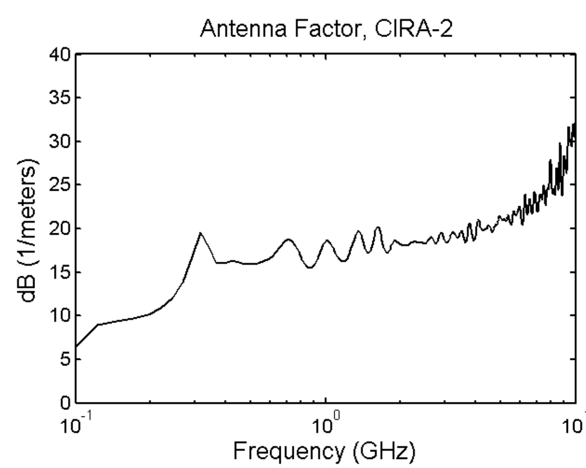

S11 for CIRA-2
S11(ω) dB
Frequency (GHz)


TDR Response, CIRA-2
Ohms
Splitter
Feed Point
Load Resistors
Time (ns)


Gain on Boresight, CIRA-2
dBi
Frequency (GHz)


Gain on Boresight, CIRA-2
dBi
Frequency (GHz)


Antenna Factor, CIRA-2
dB (1/meters)
Frequency (GHz)


Antenna Factor, CIRA-2
dB (1/meters)
Frequency (GHz)

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Fields, LC

1801 Count Fleet St. SE
Albuquerque, NM 87123
efarr@Farr-Research.com

(505) 410-7722
www.Farr-Research.com

IMPULSE RADIATING ANTENNA IRA-3Q, 46-cm

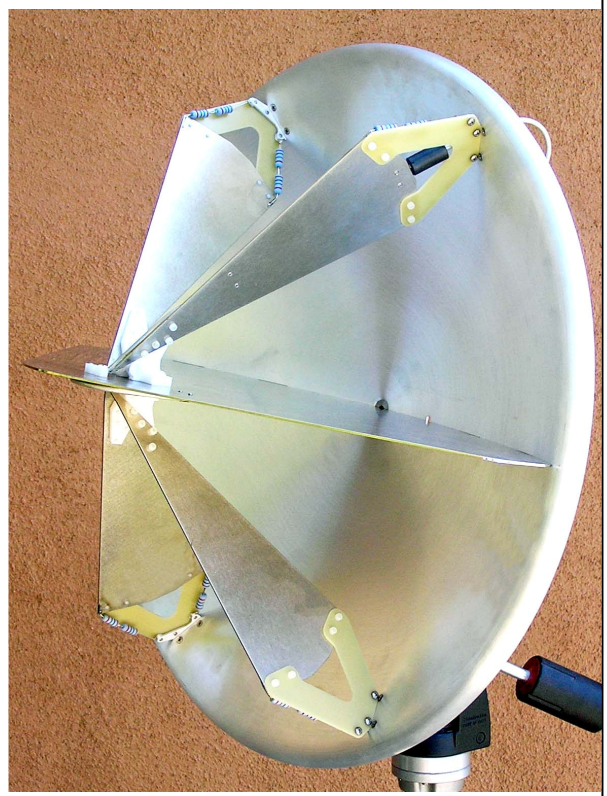
The 18″ diameter Impulse Radiating Antenna (IRA) provides two decades of bandwidth in a single antenna.

Our newest version, the IRA-3Q, has several improvements over earlier versions. It has a ground plane at the plane of symmetry to reduce crosspol and to add ruggedness. It also has added support at the focal point for improved ruggedness. The IRA-3Q has the feed arms positioned at ±30° from vertical, which both improves the gain and reduces the crosspol.

The antenna has outstanding RF characteristics in both the frequency and time domains. In the time domain, it has an impulse response with **FWHM of 38 ps** and mid band effective height of 7.3 cm. In the frequency domain, the peak gain at 16 GHz is 25 dB, and the antenna's frequency range spans from **250 MHz to 18 GHz**.

The reflector for the FRI-IRA-3 is 46 cm (18 in) in diameter with a focal length of 23 cm (F/D = 0.5). The input connector is a 50-ohm female SMA connector, and the input impedance is approximately 50 ohms throughout the band. A standard 1/4″-20 tripod connection is provided.

Model IRA-3Q

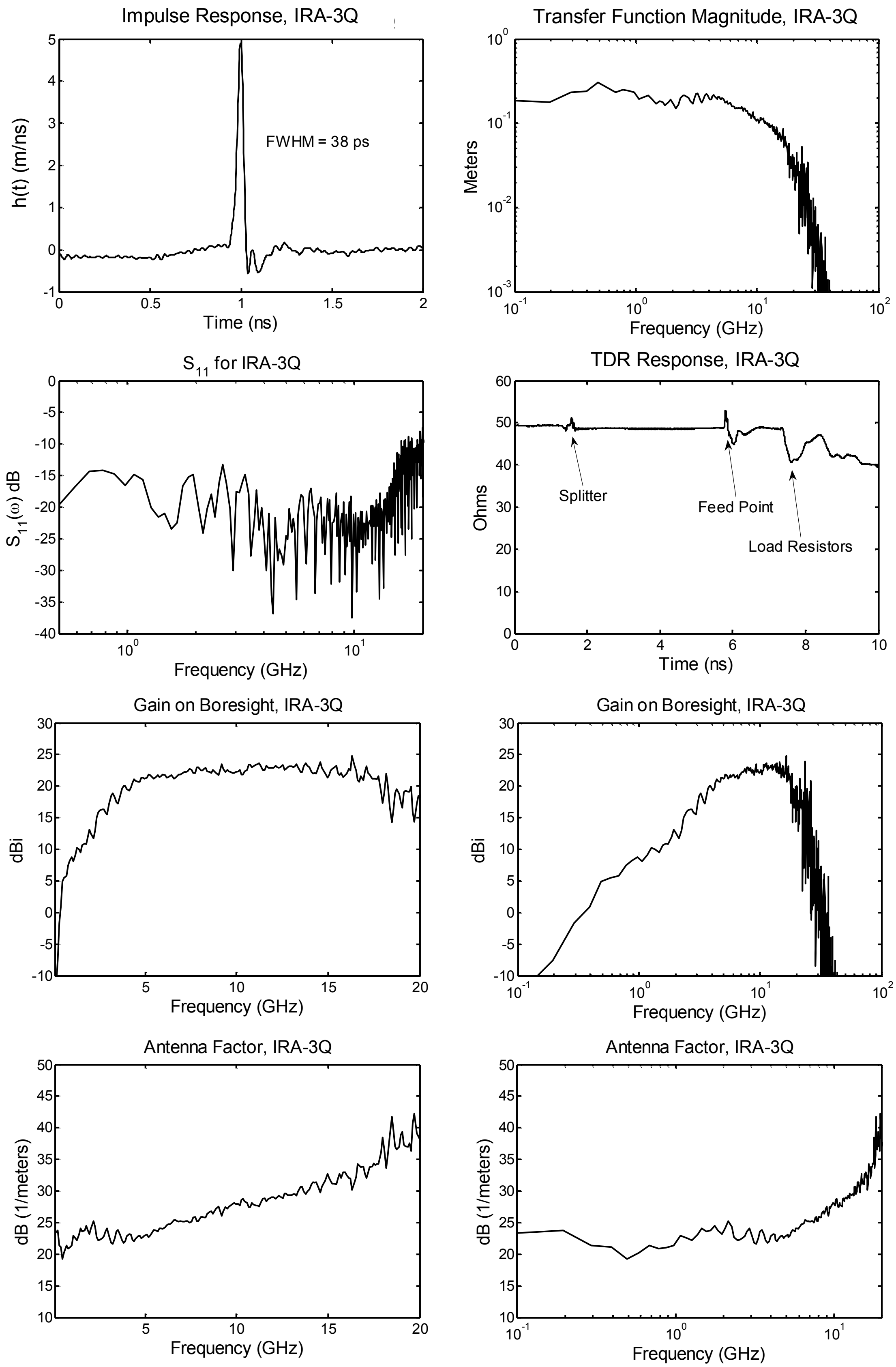


We now use an improved splitter balun with extremely low reflection loss, as shown by the TDR on the following page. Reflections from the splitter are nearly invisible!

Calibration data is provided on a CD to allow one to deconvolve the impulse response of the antenna. The input port is an SMA female connector. Our price includes a high-quality shipping case. Prices appear on Page 2.

FWHM (ps)	h_{eff}* (cm)	3dB point (GHz)	Peak Gain* at 16 GHz	Weight kg (lb.)
38	7.3	18	25 dBi	2.4 (5.3)

* See Appendix A for definitions



Impulse Response, IRA-3Q
h(t) (m/ns)
Time (ns)
FWHM = 38 ps
Transfer Function Magnitude, IRA-3Q
Meters
Frequency (GHz)
S11 for IRA-3Q
S11(ω) dB
Frequency (GHz)
TDR Response, IRA-3Q
Ohms
Time (ns)
Splitter
Feed Point
Load Resistors
Gain on Boresight, IRA-3Q
dBi
Frequency (GHz)
Gain on Boresight, IRA-3Q
dBi
Frequency (GHz)
Antenna Factor, IRA-3Q
dB (1/meters)
Frequency (GHz)
Antenna Factor, IRA-3Q
dB (1/meters)
Frequency (GHz)

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IMPULSE RADIATING ANTENNA IRA-8, 36" (0.91 m), LV and HV Versions

The 36" (0.91-m) diameter Impulse Radiating Antenna (IRA) is a double-size version of our best-selling IRA-3Q. We offer both a low-voltage and higher-voltage version. The LV version is tested for short impulses as high as 10 kV, and the HV version is tested as high as 25 kV.

In the time domain the LV version of the antenna has an impulse response with FWHM of 122 ps and mid band effective height of 12.6 cm. The peak gain is 20 dBi at 4.5 GHz, and the frequency range is 125 MHz to 5 GHz

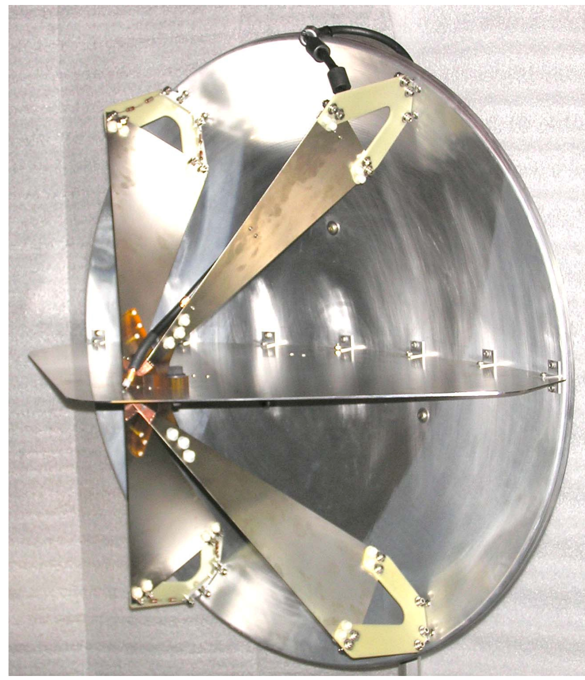
The HV version has an impulse response with FWHM of 142 ps and mid band effective height of 12.6 cm. The peak gain is 15 dBi at 4.5 GHz, and the frequency range is 125 MHz to 5 GHz

The reflector for the FRI-IRA-3 is 36" (0.91 m) in diameter with a focal length of 18" (46 cm), with F/D = 0.5. The input connector is a 50-ohm female N-type connector, and the input impedance is approximately 50 ohms throughout the band. A standard 3/8″-16 tripod connection is provided.

The splitter balun is fabricated from two custom 100-ohm cables that are about the diameter of RG-214, with a narrower center conductor.

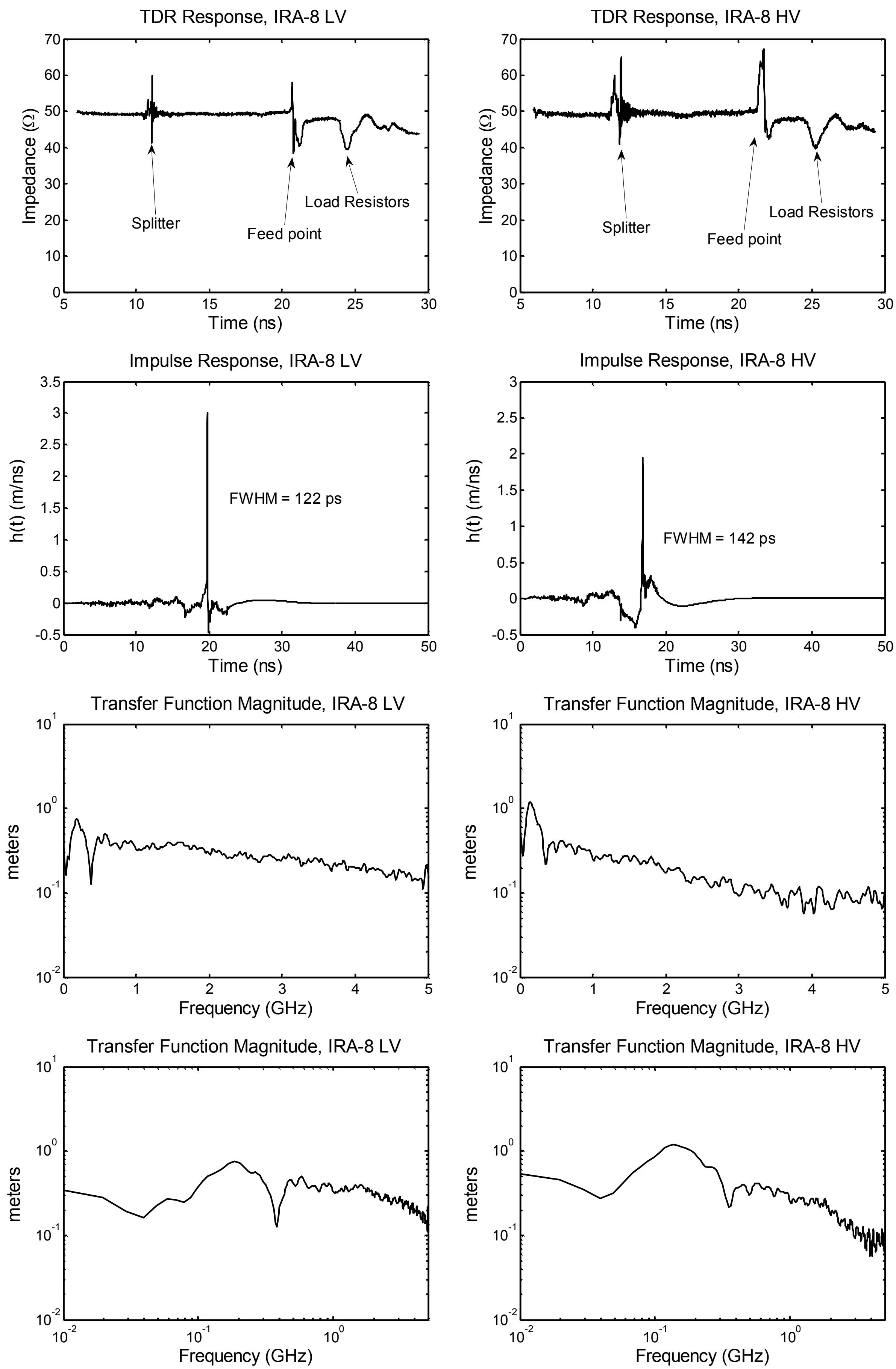
Calibration data is provided on CD to allow one to deconvolve the impulse response of the antenna. The input connector is female, and is either N-type or HN-type, depending on the version. Our price includes a high-quality shipping case. Prices appear on Page 2.

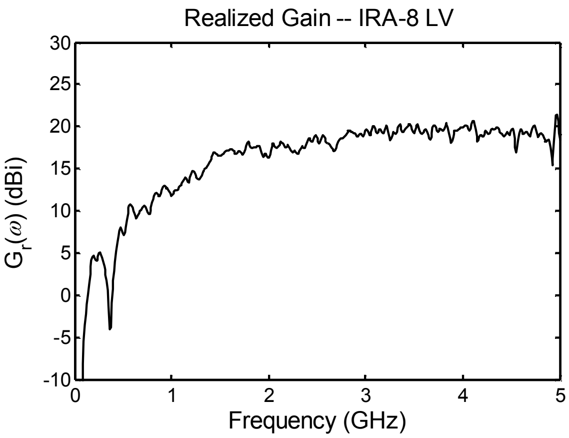
Model IRA-8-LV

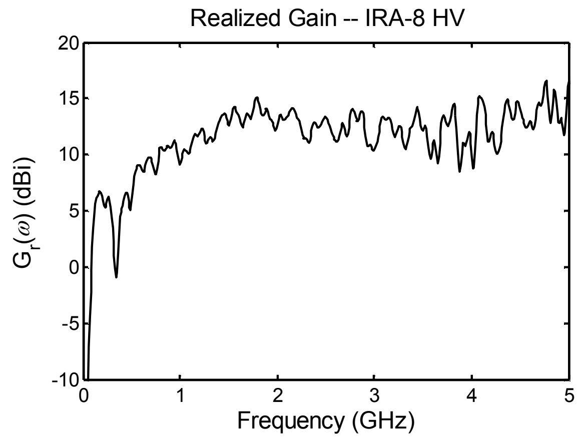


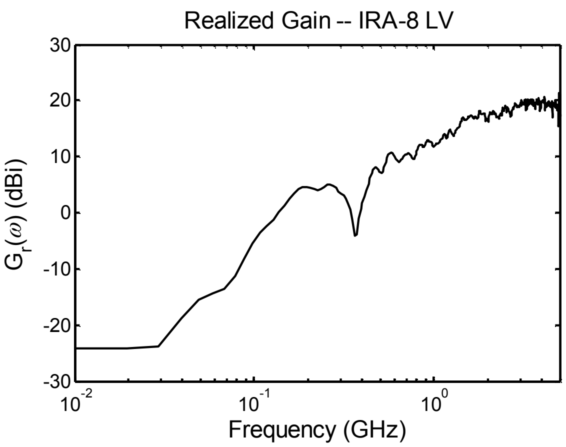
	FWHM (ps)	h_{eff}* (cm)	3dB point (GHz)	Peak Gain* at 4.5 GHz	Weight (est.) kg (lb.)
IRA-8-LV	122	13.4	5	20 dBi	8.2 (18)
IRA-8-HV	142	13.6	5	15 dBi	8.2 (18)

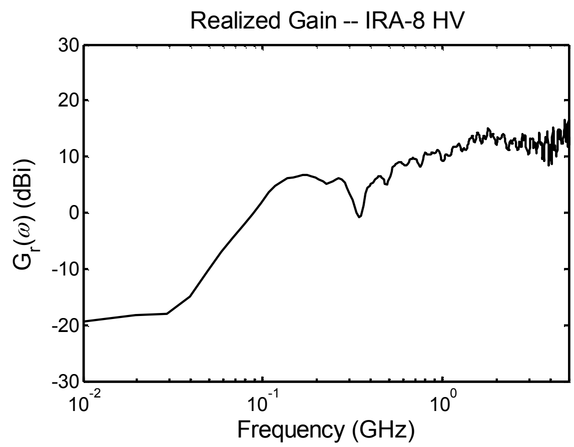
* See Appendix A for definitions

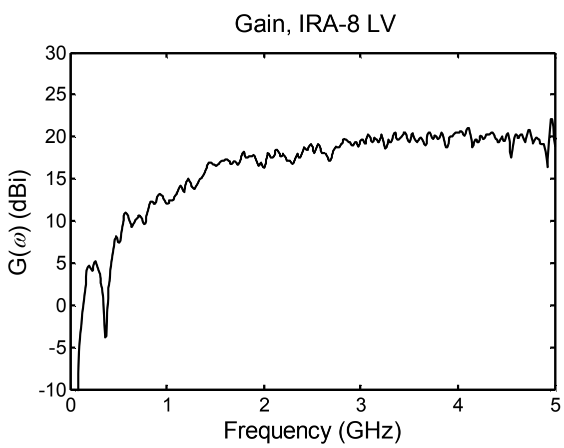

TDR Response, IRA-8 LV
Impedance (Ω)
Time (ns)
Splitter
Feed point
Load Resistors
TDR Response, IRA-8 HV
Impedance (Ω)
Time (ns)
Splitter
Feed point
Load Resistors
Impulse Response, IRA-8 LV
h(t) (m/ns)
FWHM = 122 ps
Time (ns)
Impulse Response, IRA-8 HV
h(t) (m/ns)
FWHM = 142 ps
Time (ns)
Transfer Function Magnitude, IRA-8 LV
meters
Frequency (GHz)
Transfer Function Magnitude, IRA-8 HV
meters
Frequency (GHz)
Transfer Function Magnitude, IRA-8 LV
meters
Frequency (GHz)
Transfer Function Magnitude, IRA-8 HV
meters
Frequency (GHz)

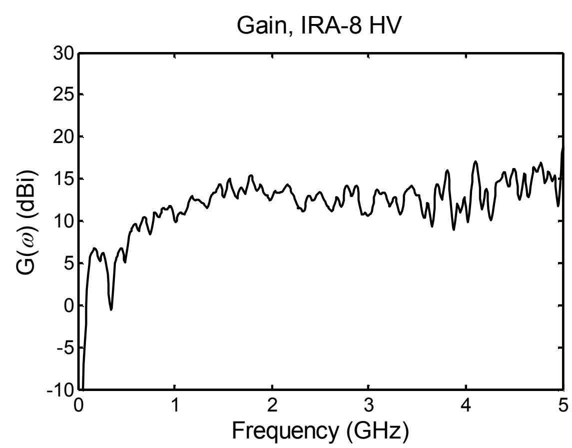

Realized Gain -- IRA-8 LV
$G_r(\omega)$ (dBi)
Frequency (GHz)

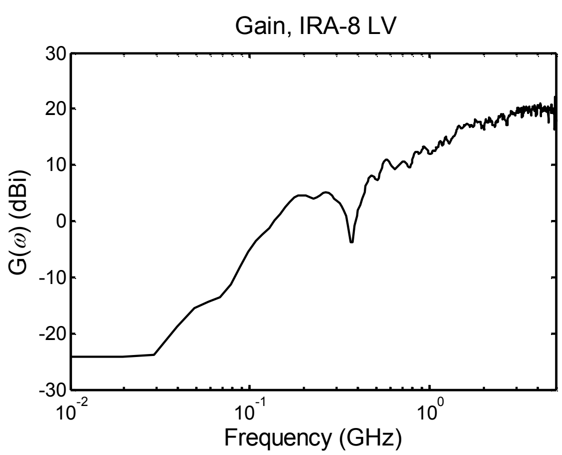

Realized Gain -- IRA-8 HV
$G_r(\omega)$ (dBi)
Frequency (GHz)

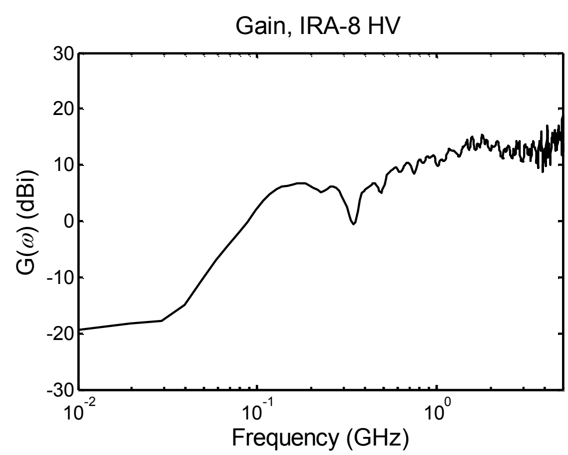

Realized Gain -- IRA-8 LV
$G_r(\omega)$ (dBi)
Frequency (GHz)

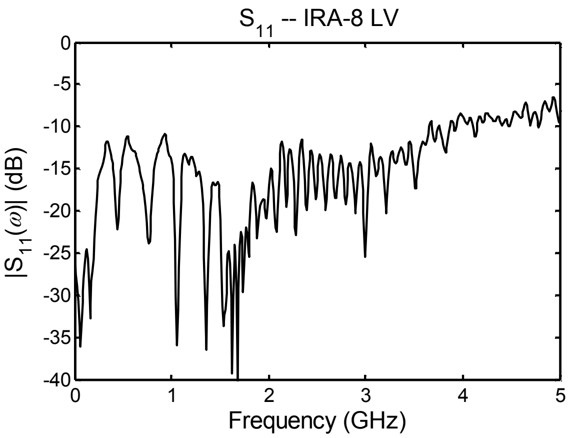

Realized Gain -- IRA-8 HV
$G_r(\omega)$ (dBi)
Frequency (GHz)

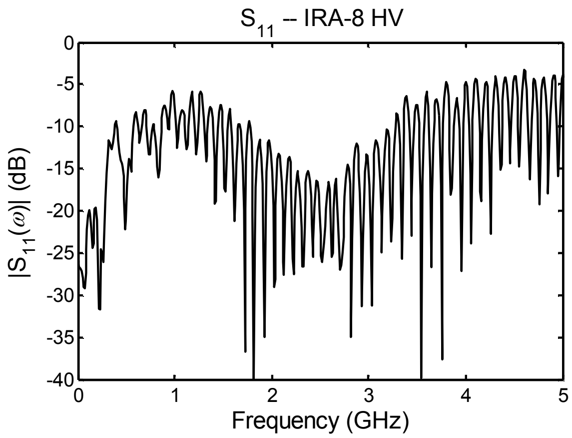

Gain, IRA-8 LV
$G(\omega)$ (dBi)
Frequency (GHz)

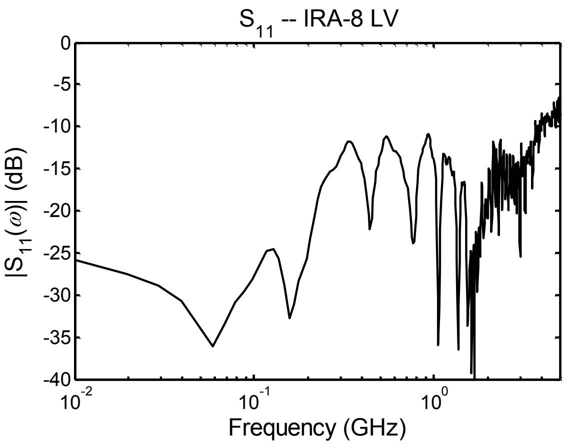

Gain, IRA-8 HV
$G(\omega)$ (dBi)
Frequency (GHz)

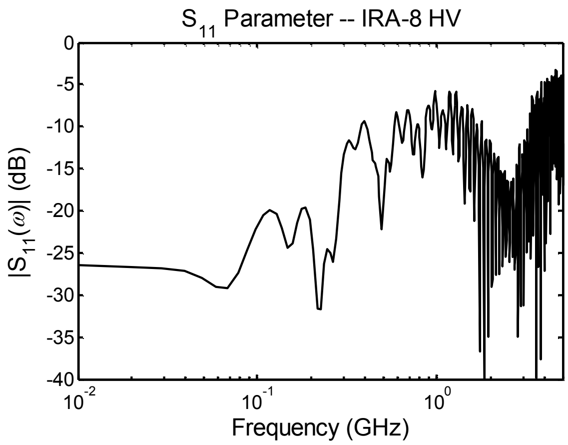

Gain, IRA-8 LV
$G(\omega)$ (dBi)
Frequency (GHz)

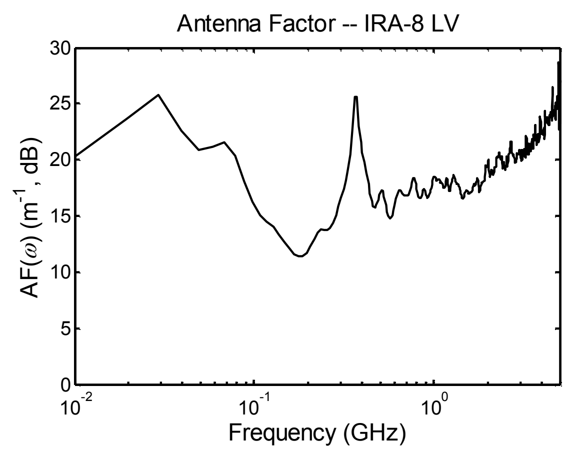

Gain, IRA-8 HV
$G(\omega)$ (dBi)
Frequency (GHz)

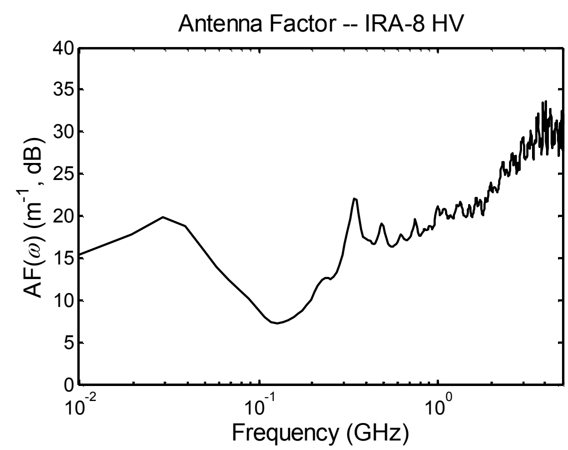

S11 -- IRA-8 LV
|S11(ω)| (dB)
Frequency (GHz)

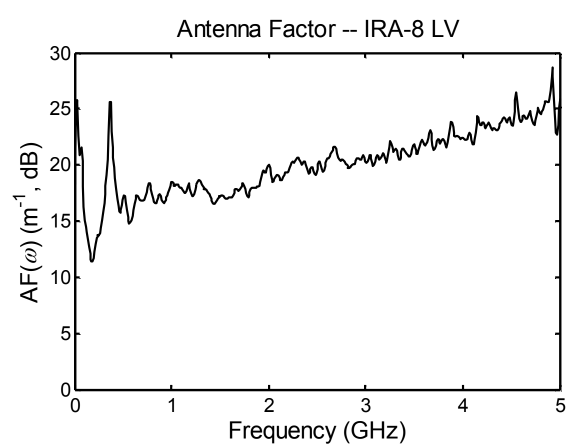

S11 -- IRA-8 HV
|S11(ω)| (dB)
Frequency (GHz)

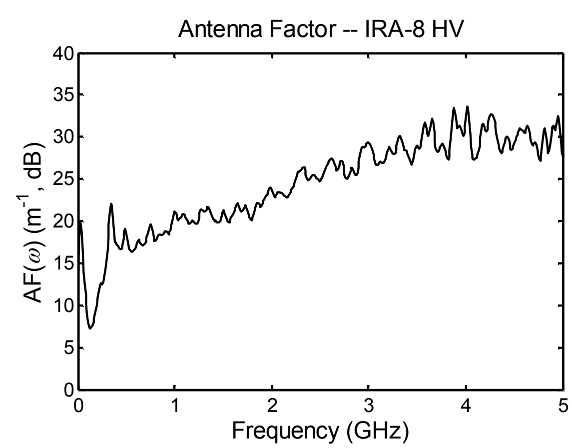

S11 -- IRA-8 LV
|S11(ω)| (dB)
Frequency (GHz)


S11 Parameter -- IRA-8 HV
|S11(ω)| (dB)
Frequency (GHz)


Antenna Factor -- IRA-8 LV
AF(ω) (m-1, dB)
Frequency (GHz)


Antenna Factor -- IRA-8 HV
AF(ω) (m-1, dB)
Frequency (GHz)


Antenna Factor -- IRA-8 LV
AF(ω) (m-1, dB)
Frequency (GHz)


Antenna Factor -- IRA-8 HV
AF(ω) (m-1, dB)
Frequency (GHz)

Farr Fields, LC

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(505) 410-7722
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IMPULSE RADIATING ANTENNA IRA-6, 1.52 m

The IRA-6 is a larger version of the IRA-3Q, with diameter of 1.52 m (5 ft.) and F/D of 0.37.

The IRA-6 has a ground plane and feed arms that are fabricated from aluminum honeycomb, which reduces the weight of these components without compromising strength. These lightweight components reduce stress on the feed point, increasing reliability.

The IRA-6 has feed arms positioned at ±45° to vertical. A version with feed arms positioned at ±30°, is available by custom order.

This antenna has an impulse response with FWHM of 166 ps and mid-band effective height of 0.187 m. In the frequency domain, the peak gain at 3 GHz is 19 dB, and the antenna's frequency range spans from 100 MHz to 5 GHz.

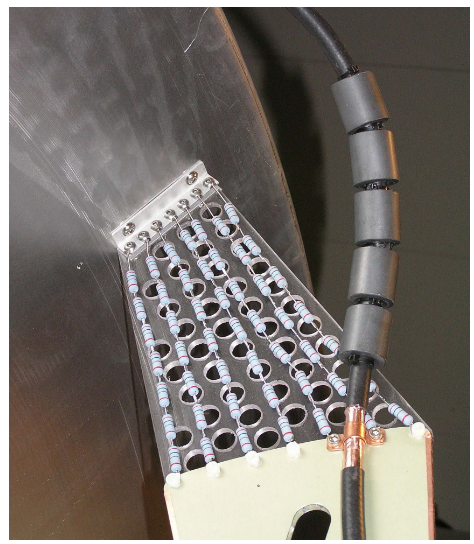
The input impedance is approximately 50 ohms throughout the band. A standard 3/8″-16 tripod connection is provided.

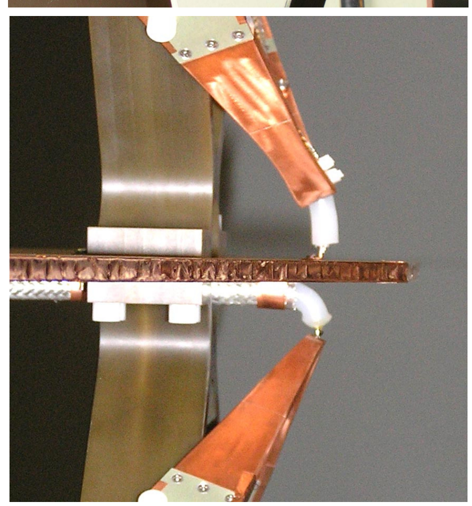
The splitter balun is fabricated from two custom 100-Ω cables that are about the diameter of RG-214, with a narrower center conductor. The splitter is a custom high-voltage design.

Calibration data is provided to allow one to deconvolve the impulse response of the antenna. Additional information on this antenna may be found in [1]

The IRA-6 has been tested to a peak voltage of 25 kV with short pulses, and can likely go higher. Peak voltage is determined by the HN-Type female input connector, because all other parts of the antenna have higher dielectric strength. A version is also available with improved high-end response, with peak voltage of around 10 kV. Prices appear on Page 2.

Model IRA-6





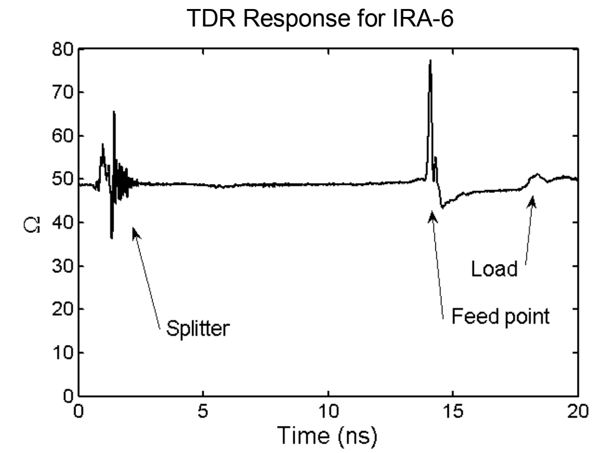
References

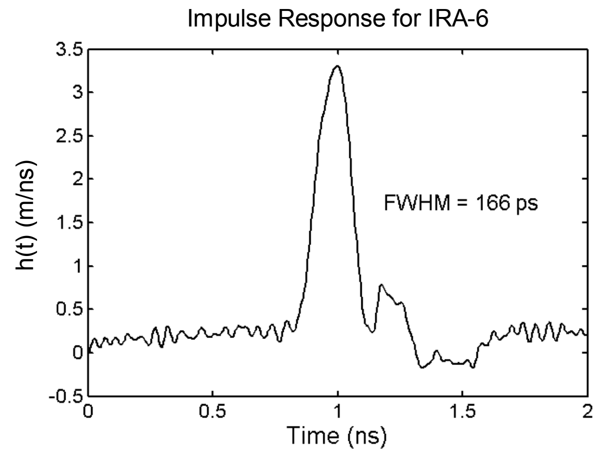
1. L. H. Bowen, *et al*, A High-Voltage Cable-Fed Impulse Radiating Antenna, Sensor and Simulation Note 507, December 2005. Available for download at http://www.farr-research.com/Papers/ssn507.pdf

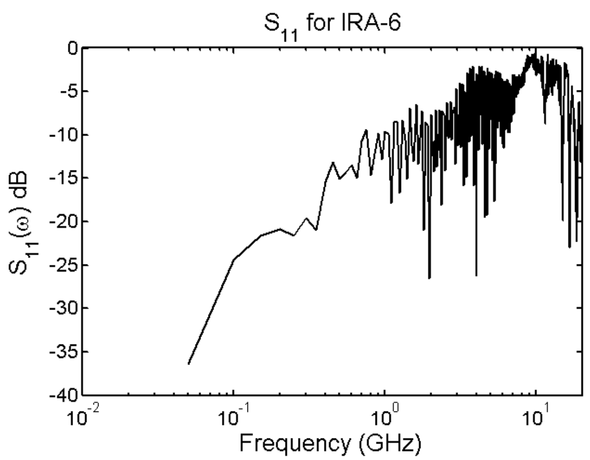
IRA-6 Characteristics

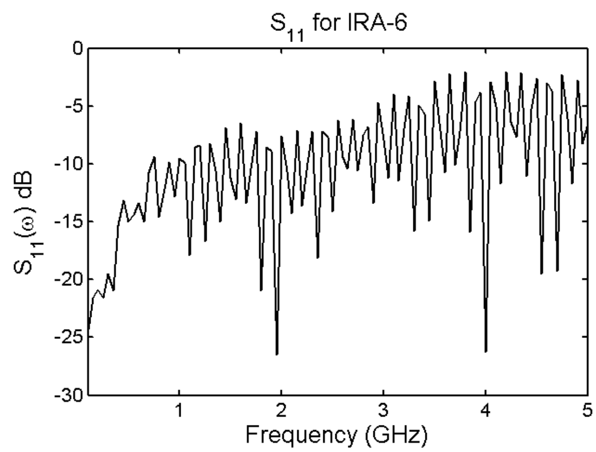
FWHM (ps)	h_{eff}* (m)	3dB point (GHz)	Peak Gain* at 3 GHz	Weight kg (lb.) (est.)
166	0.187	4.5	19 dBi	10 (22)

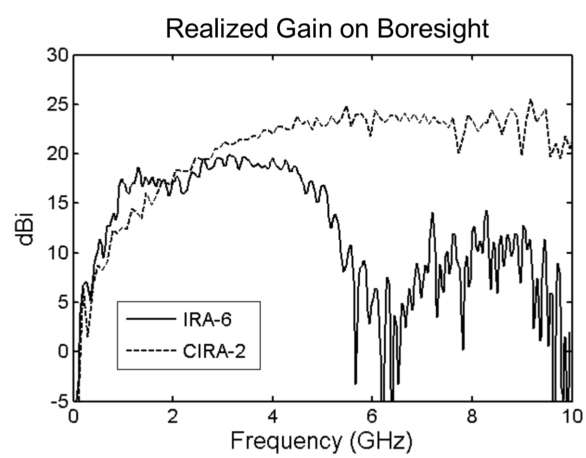
* See Appendix A for definitions

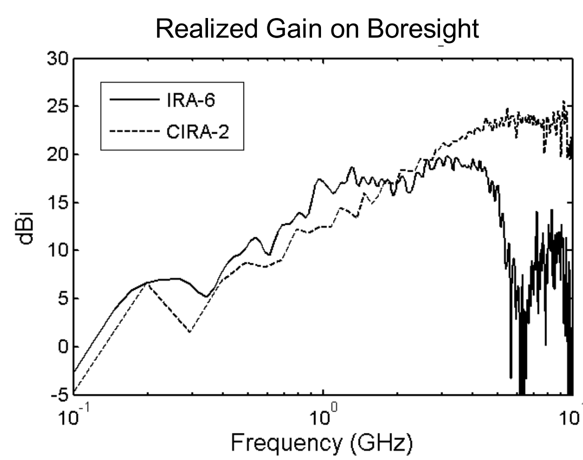












Farr
Fields, LC

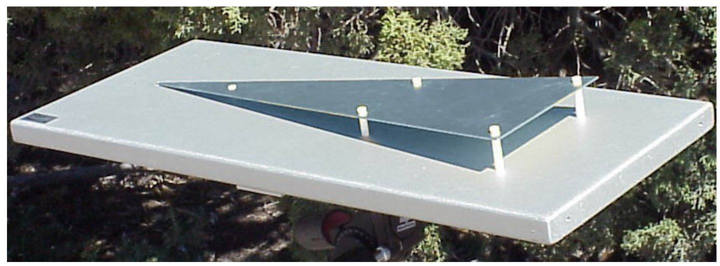
1801 Count Fleet St. SE
Albuquerque, NM 87123
efarr@Farr-Research.com

(505) 410-7722
www.Farr-Research.com

CALIBRATED TEM SENSORS
TEM-1 and TEM-2

The **Farr Fields Calibrated TEM Sensors** are Ultra-Wideband electric field sensors designed for low-dispersion and high sensitivity. These sensors overcome the problem of making fast field measurements with derivative sensors, which have very low sensitivity at high frequencies. These TEM sensors approximately replicate the incident electric field from the boresight direction. Compensation with the measured impulse response (provided on 3½ in. disk in ASCII format) gives a highly accurate representation of the incident field, with about two decades of frequency range.

Model TEM-1



The sensors have an impedance of 50 ohms and are available in two sizes. The larger sensors have better low frequency performance, with some compromise in risetime and high-end bandwidth. The antenna is a half TEM horn mounted on a truncated ground plane. The ground plane is a highly rigid support platform for the antenna with a standard female ¼-20 tripod attachment point for the TEM-1, or 3/8-16 for TEM-2 attachment point on the bottom side. The ground plane is heavy aluminum with a clear alodine finish. A panel-mount SMA female connector is located at the feed point below the ground plane. This arrangement prevents the cable from influencing the measurement.

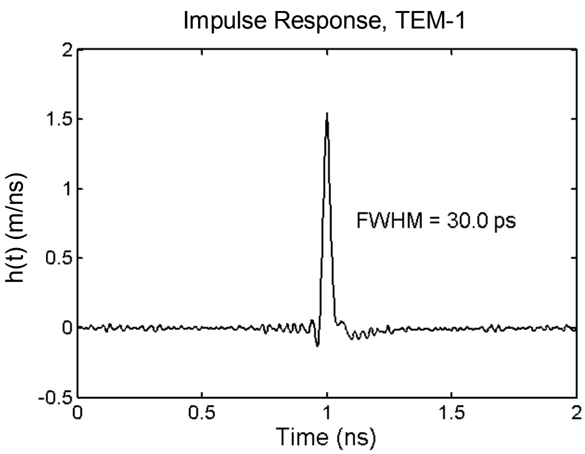
The large sensors have a clear time of 4 ns, and the small sensors have a clear time of 2 ns. Within these times, the scalar approximation for h_{eff} is valid. Beyond these times, that approximation is untested, at the moment, and is a subject of ongoing research. Prices appear on Page 2.

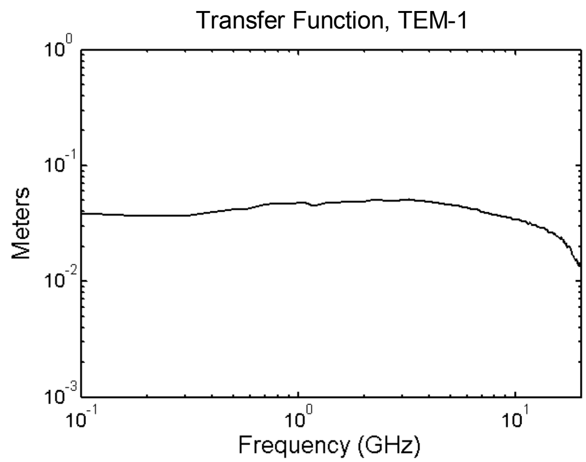
Sensor Characteristics:

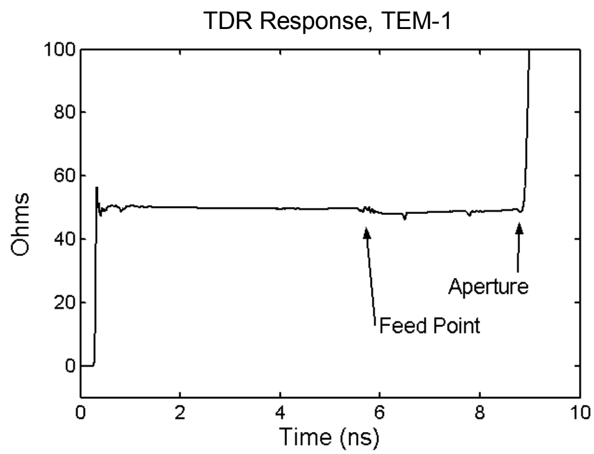
Model Number	Impedance (ohms)	Ground Plane Size in (mm)	Height in (mm)	Weight lb. (kg)
TEM-1	50	10 x 24 (254 x 610)	2.3 (58)	4 (1.8)
TEM-2	50	20 x 48 (508 x 1220)	5.5 (140)	20 (9)

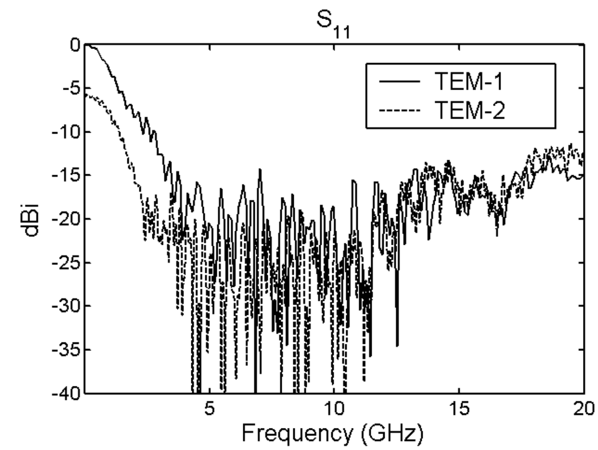
Model Number	FWHM (ps)	h_{eff}* (mm)	3 dB freq. (GHz)	Clear Time (ns)
TEM-1	30	18	20	2 ns
TEM-2	40	35	17	4 ns

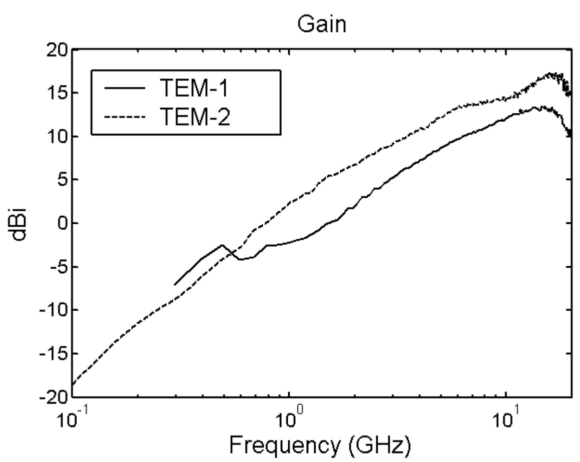
* See Appendix A for definitions

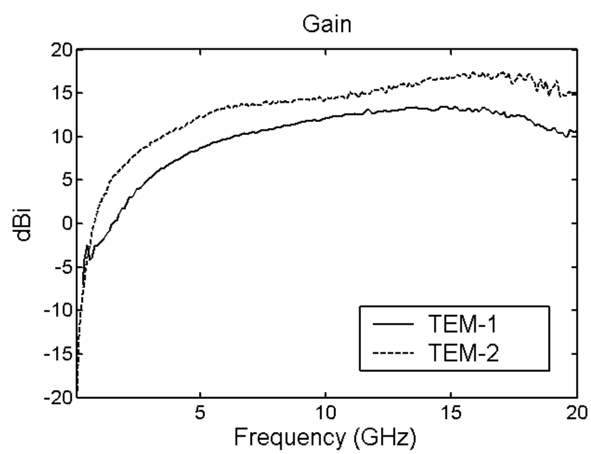

Impulse Response, TEM-1
h(t) (m/ns)
FWHM = 30.0 ps
Time (ns)
2
1.5
1
0.5
0
-0.5
0
0.5
1
1.5
2

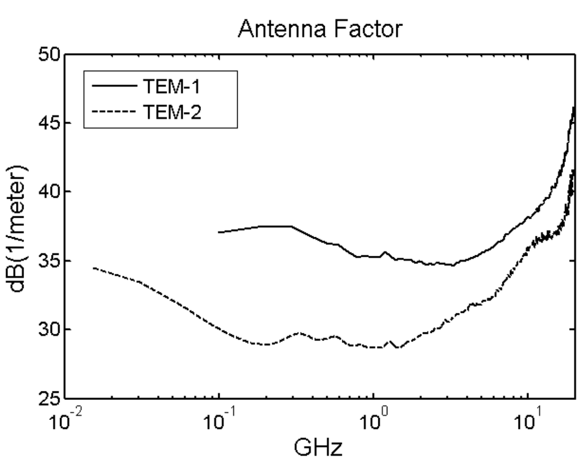

Transfer Function, TEM-1
Meters
Frequency (GHz)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-1}
10^{0}
10^{1}

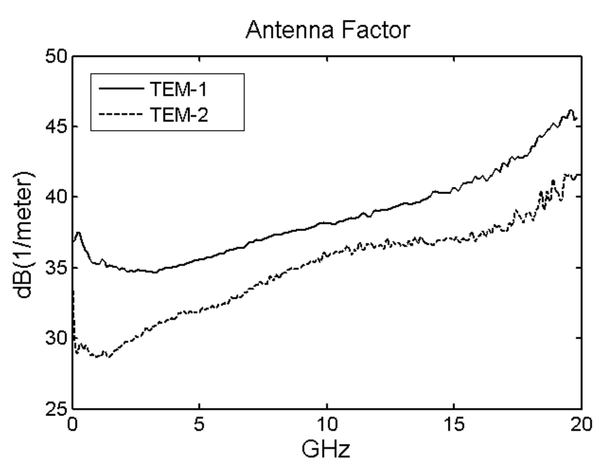

TDR Response, TEM-1
Ohms
Time (ns)
Aperture
Feed Point
100
80
60
40
20
0
0
2
4
6
8
10


S_{11}
dBi
Frequency (GHz)
TEM-1
TEM-2
0
-5
-10
-15
-20
-25
-30
-35
-40
5
10
15
20


Gain
dBi
Frequency (GHz)
TEM-1
TEM-2
20
15
10
5
0
-5
-10
-15
-20
10^{-1}
10^{0}
10^{1}


Gain
dBi
Frequency (GHz)
TEM-1
TEM-2
20
15
10
5
0
-5
-10
-15
-20
5
10
15
20


Antenna Factor
dB(1/meter)
GHz
TEM-1
TEM-2
50
45
40
35
30
25
10^{-2}
10^{-1}
10^{0}
10^{1}


Antenna Factor
dB(1/meter)
GHz
TEM-1
TEM-2
50
45
40
35
30
25
0
5
10
15
20

Farr Fields, LC

1801 Count Fleet St. SE
Albuquerque, NM 87123
efarr@Farr-Research.com

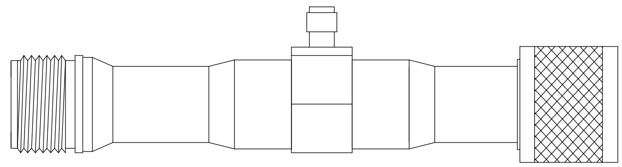
(505) 410-7722
www.Farr-Research.com

CALIBRATED HIGH-VOLTAGE V-DOT CABLE SENSOR VDC-1

Our calibrated High-Voltage V-Dot sensors allow one to monitor cable voltage. The sensor has been tested up to 30 kV with very short (< 5 ns) pulses. The input and output connectors are HN-Type male/female and the monitoring line is SMA female.

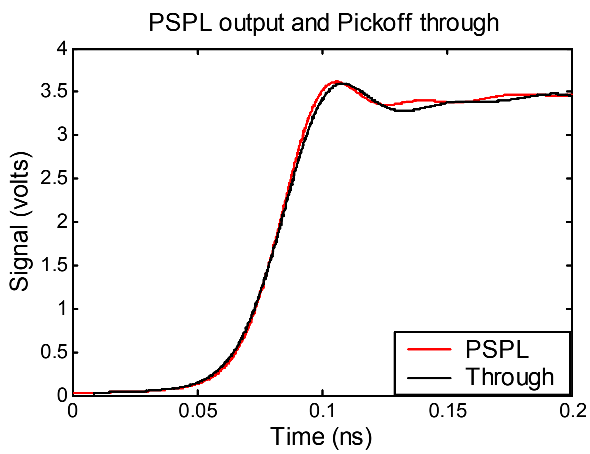
The governing equation is

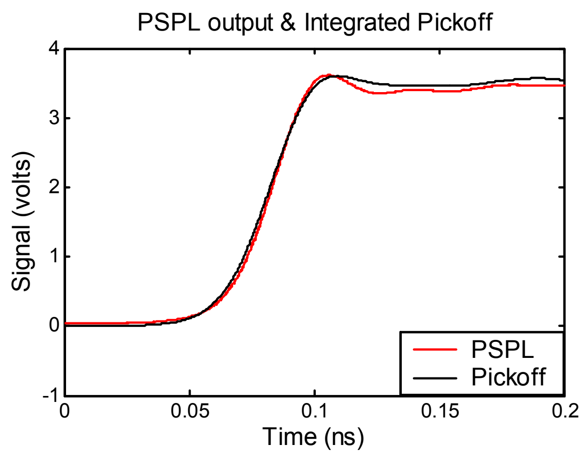
$$V_{sensor} = K \frac{d V_{cable}}{dt}$$

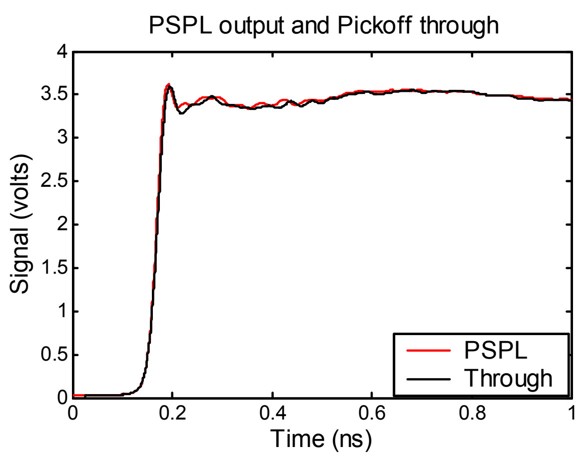


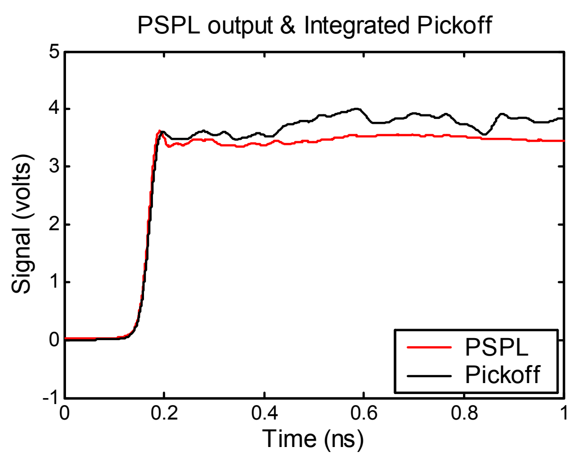
where V_{sensor} is the measured voltage out of the sensor, V_{cable} is the cable voltage one wants to measure, K is a calibration factor that is specified uniquely for each sensor, $K \approx 0.91$ ps.

Below, we show the results of driving the VDC-1 with a PSPL 4015C pulser, with risetime 20 ps. Even at these fast risetimes, there is very little loss of risetime in the cable and sensor signals.

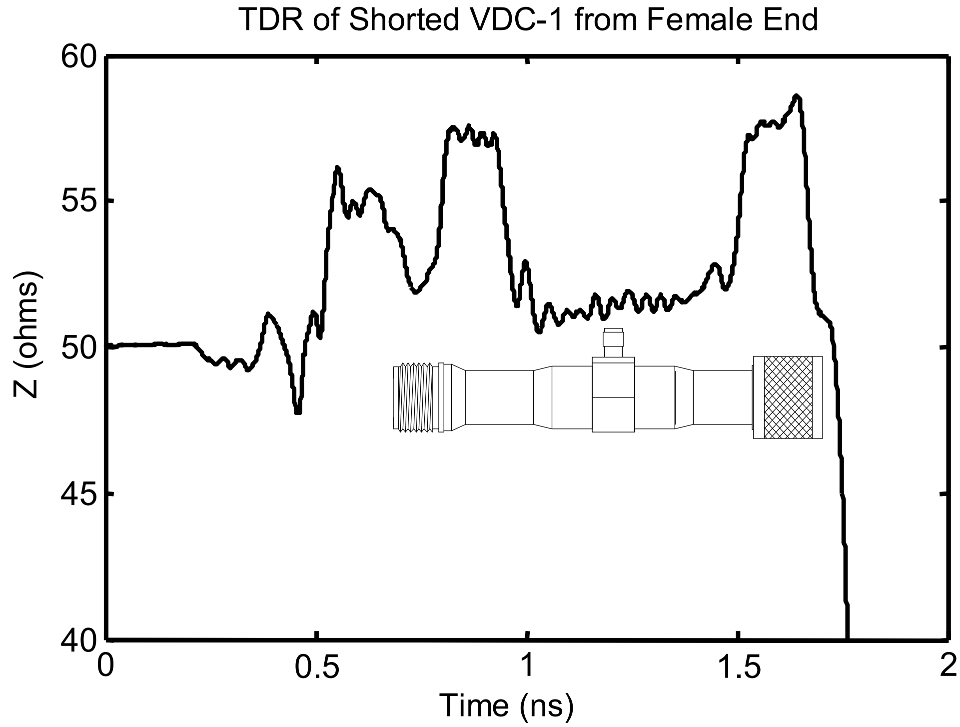








The TDR of the VDC-1 shows very small deviations of the impedance from the ideal of 50 ohms. Most of the deviation is inherent in the HN-Type connectors.



Calibrations are carried out using the procedure described in [1]. Prices appear on Page 2.

1.Everett G. Farr, Lanney, M. Atchley, Donald E. Ellibee, and Larry L. Altgilbers, "A Comparison of Two Sensors Used to Measure High-Voltage, Fast-Risetime Signals in Coaxial Cable," Measurement Note 58, March 2004.

Appendix A: Equations Used in this Catalog

We find it useful to carefully define the quantities used in this catalog that describe our antennas, because the time domain description of antennas is not yet treated in the IEEE standard for antenna definitions [1]. **Note that the some of the terminology and symbols we use have recently changed to match [2].** We have defined a single waveform, $h(t)$, which describes an antenna performance in both transmission and reception. We refer to this as the impulse response in the time domain and transfer function in the frequency domain.

In this format, the reception and transmission equations are expressed on boresight for dominant polarization as [2]

$$\begin{aligned} \frac{V_{rec}(t)}{\sqrt{50\,\Omega}} &= h(t) \circ \frac{E_{inc}(t)}{\sqrt{377\,\Omega}} \\ \frac{E_{rad}(t)}{\sqrt{377\,\Omega}} &= \frac{1}{2\pi c r}\, h(t) \circ \frac{d V_{src}(t)/dt}{\sqrt{50\,\Omega}} \qquad t'' = t - r/c \end{aligned} \quad , \qquad \text{(A.1)}$$

where $V_{rec}(t)$ is the received voltage into a 50-ohm load or oscilloscope, and $V_{src}(t)$ is the source voltage as measured into a 50-ohm load or oscilloscope. Furthermore, $E_{inc}(t)$ is the incident electric field, $E_{rad}(t)$ is the radiated electric field, $h(t)$ is the impulse response of the antenna, r is the distance away from the antenna, c is the speed of light in free space, and "$\circ$" is the convolution operator. These expression may easily be extended to multiple angles and polarizations. In the frequency domain, this is expressed as

$$\begin{aligned} \frac{\tilde{V}_{rec}}{\sqrt{50\,\Omega}} &= \tilde{h}\, \frac{\tilde{E}_{inc}}{\sqrt{377\,\Omega}} \\ \frac{E_{rad}(t)}{\sqrt{377\,\Omega}} &= \frac{j\omega\, e^{-jkr}}{2\pi c r}\, \tilde{h}\, \frac{d\tilde{V}_{src}}{\sqrt{50\,\Omega}} \end{aligned} \quad , \qquad \text{(A.2)}$$

where the tilde indicates a frequency domain waveform, $\tilde{h}$ is the transfer function of the antenna, and $k = \omega/c$. Note that $h(t)$ has units of m/s in the time domain and meters in the frequency domain.

A simpler version of the above equations may be useful if $h(t)$ can be approximated as an impulse with area h_a, or $h(t) \approx h_a \times \delta(t)$. With this approximation, the equations simplify to

$$\begin{aligned} \frac{V_{rec}(t)}{\sqrt{50\,\Omega}} &\approx h_a\, \frac{E_{inc}(t)}{\sqrt{377\,\Omega}} \\ \frac{E_{rad}(t)}{\sqrt{377\,\Omega}} &\approx \frac{h_a}{2\pi c r}\, \frac{d V_{src}(t')/dt}{\sqrt{50\,\Omega}} \qquad t' = t - r/c \ldots \\ h_a &= \int_{\text{Impulse}} h(t)\, dt \end{aligned} \qquad \text{(A.3)}$$

Here, h_a is the impulse area, which is a scalar with units of meters. The integral is taken over the impulsive portion of the impulse response. When one calculates the impulse area from an experimentally measured impulse response, there is always some ambiguity in determining the exact limits of the integration. Note that this approximation is appropriate only at mid-band–it fails both at DC and very high frequencies. Note also that this approximation is most useful for those antennas, such as our TEM sensors, whose impulse response is shaped most like an impulse. The impulse integral, h_a, could be expressed alternatively in terms of an effective height as

$$V_{rec}(t) \approx h_{eff}\ E_{inc}(t) \quad , \qquad h_{eff} = \sqrt{\frac{50\,\Omega}{377\,\Omega}}\ h_a = \frac{h_a}{2.75} \quad . \tag{A.4}$$

Both h_a and h_{eff} have units of meters.

Next, we express antenna performance in terms of realized gain and gain. First, realized gain is expressed in terms of the Fourier transform of $h(t)$ as [2]

$$\widetilde{G}_r = \frac{4\pi}{\lambda^2} |\,\widetilde{h}\,|^2 = \frac{4\pi f^2}{c^2} |\,\widetilde{h}\,|^2 \quad . \tag{A.5}$$

If we assume the antenna's impulse response is approximated by a delta function, $h(t) \approx h_a \times \delta(t)$, then $|\,\widetilde{h}\,| \approx h_a$, and the realized gain is approximately

$$\widetilde{G}_r \approx \frac{4\pi\, h_a{}^2}{\lambda^2} = \frac{4\pi f^2\, h_a{}^2}{c^2} \quad , \tag{A.6}$$

which is valid only at mid-band. The relationship between realized gain and gain in [1] is

$$\widetilde{G} = \widetilde{G}_r \Big/ \left[1 - \left|\widetilde{\Gamma}\right|^2 \right] \quad , \tag{A.7}$$

where $\widetilde{\Gamma}$ is the reflection coefficient looking into the antenna port relative to a 50-ohm impedance. Realized gain is sometimes a more useful measure of antenna performance than gain, because it includes impedance mismatch, which is a critical parameter in this class of antennas.

Finally, we use standard expressions for the antenna factor as

$$AF = \frac{\widetilde{E}_{inc}}{\widetilde{V}_{rec}} \approx \sqrt{\frac{377}{50}}\ \frac{1}{\left|\widetilde{h}\right|} \approx \frac{9.73}{\lambda\sqrt{\widetilde{G}_r}} \quad . \tag{A.8}$$

As before, note that $|\,\widetilde{h}\,|$ may be approximated as h_a at midband.

References

1. IEEE, *IEEE Standard Definition of Terms for Antennas*, IEEE Std 145-1993, Institute for Electrical and Electronics Engineering, Inc., New York, March 1993.
2. E. G. Farr, "A Power Wave Theory of Antennas," Sensor and Simulation Note 564, May 2013.