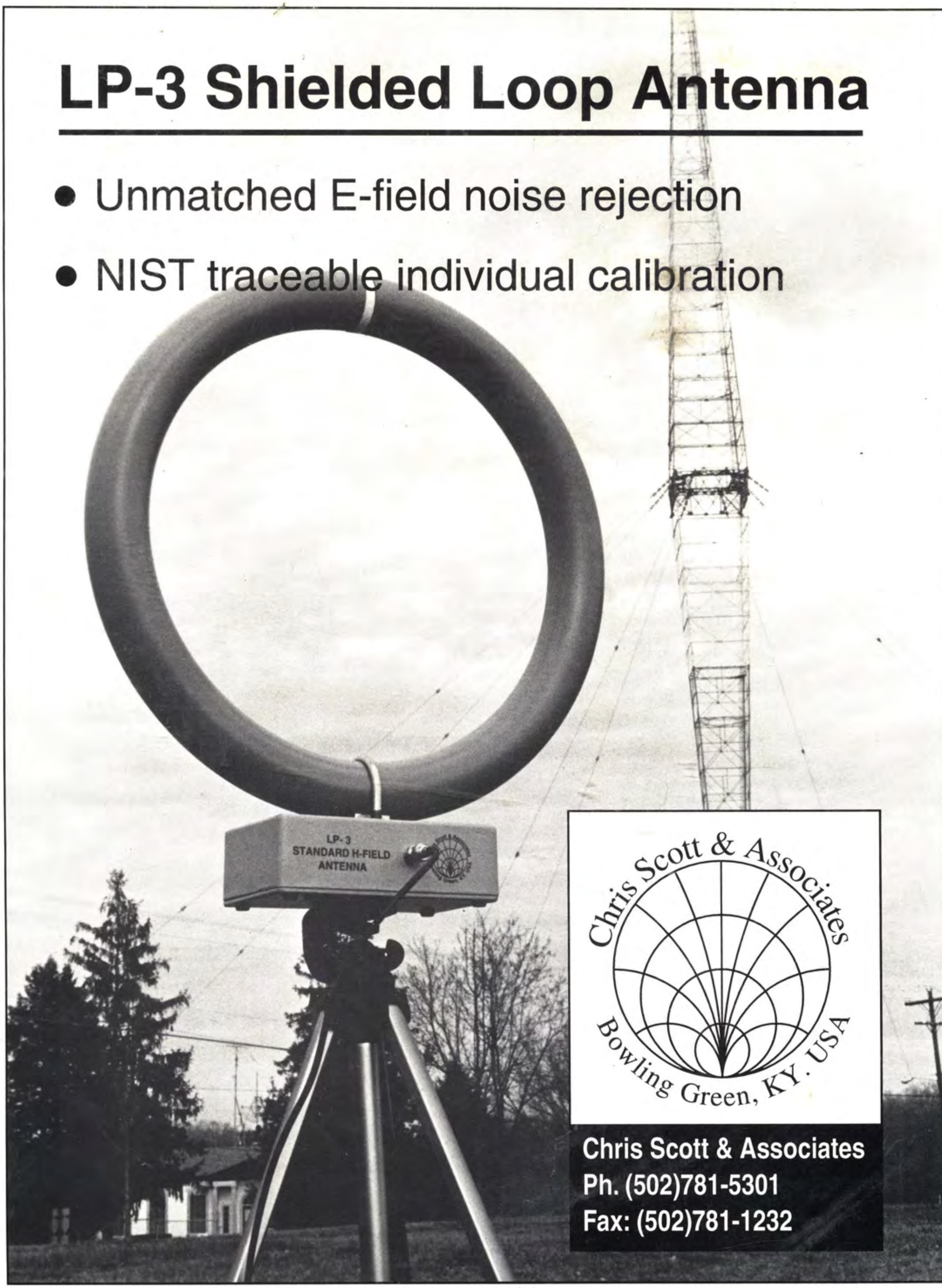
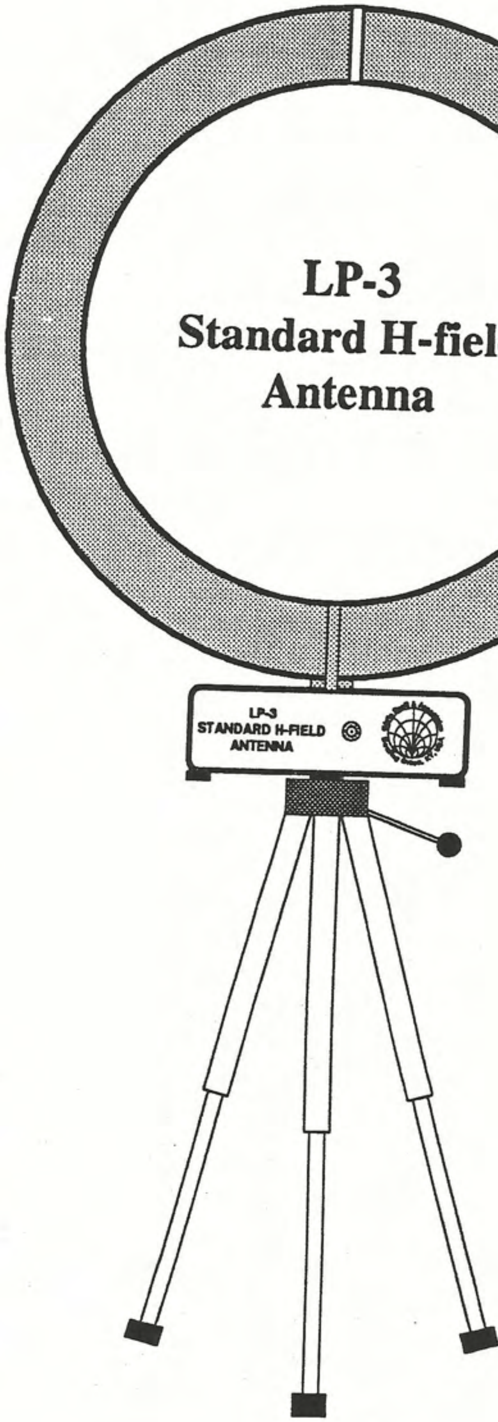

LP-3 Shielded Loop Antenna
• Unmatched E-field noise rejection
• NIST traceable individual calibration
LP-3
STANDARD H-FIELD
ANTENNA
Chris Scott & Associates
Bowling Green, KY. USA
Chris Scott & Associates
Ph. (502)781-5301
Fax: (502)781-1232

LP-3 Series
Standard H-field Antenna
User Manual

Chris Scott & Associates

Bowling Green, KY. USA

LP-3
Standard H-field Antenna



Chris Scott & Associates
Bowling Green, KY. USA

P.O. Box 52
Bowling Green, KY 42102
Fax: (502) 781-1232

LP-3 series Specifications:

Type: Shielded Loop.

Application: Measurement and monitoring of AM broadcast

Response: H-field. (E-field attenuated typically 30 dB)

Frequency range: .5 - 5 MHz.

Impedance: 50 ohms nominal.

Antenna factor: Varies with frequency, calibrated and documented within +/- 1.3 dB.

Termination: Coaxial, BNC

Mounting: Integral bench-top base with 1/4 - 20 female threads for tripod mounting

Polarization: Vertical

Pattern: Figure eight with > 20 dB minima (30 db typical).

Power input rating: Receive only

Optional resonant high-selectivity version available for single-frequency dedicated monitoring applications.

Height: 21"

Weight: 5 lbs

1. Introduction

The LP3-series standard H-field antenna is designed for laboratory and field measurements in the range of .5 - 5 MHz. This antenna allows broadband reception over this range for monitoring and measurement purposes. The electrostatically shielded design provides superior rejection of man-made E-field noise. Tektronix, in their excellent 26W-7062-1 Technical Brief, discusses the advantages of using the shielded loop antenna in conjunction with their 2710 spectrum analyzer for "NRSC Measurements". Excellent symmetry achieves typically a 30 dB null at 90 degrees. Each unit is normally individually calibrated with the final test data included with this manual. A optional tripod is highly recommended for all but the most casual application. With the exception of the -SP (special) model, this antenna is not designed to be permanently mounted on a structure or vehicle outdoors. Under no circumstances should it be used for transmitting.

2. Basic Operation

For measurement of AM broadcast stations, position the antenna approximately one meter above ground using either a tripod or other suitable support. The fine azimuthal adjustment permitted by the tripod mounting allows greater flexibility and adjustability when direction finding and nulling interference sources. Connect the antenna to the receiver input using well-shielded (greater than 99% braid) 50 ohm coaxial cable terminated with a male BNC connector. An eight-foot length of high quality RG-58/AU cable is used during calibration, and is recommended for best absolute level accuracy. The receive instrument's input should be 50 ohms, non-reactive, to maintain proper loop balance and achieve deep nulls. To obtain the actual RF field value in volts / millivolts / microvolts per meter, simply multiply the antenna output voltage value by the calibration factor (multiplier); for example if the output voltage is 10 millivolts and the calibration factor at the affected frequency is 200, the actual H-Field value (expressed as the plane-wave equivalent E-field value) is 200 times 10 = 2000 millivolts = 2 volts per meter. Although amperes per meter is technically correct, E-Field equivalent values are generally used; this conversion is accurate when used in the normal far-field (plane-wave) environment over homogeneous ground, standard with AM field intensity measurement methods.

3. Directional Pattern

This antenna is vertically polarized, and offers high rejection of electrical noise due to it's inherent H-field only pickup. Like most shielded air-core loop antennas, it exhibits a figure-eight pattern with nulls (or minima) perpendicular to the plane of the loop, in the direction and opposite direction that the coaxial connector points. This minima should exceed 20 dB when the antenna is properly terminated. Depending upon the quality of the receiver RF input termination, null depth may reach 40 dB at some frequencies. Normally, the antenna is used with the maxima (plane of loop antenna) oriented toward the signal source. The maxima 3 dB beamwidth is approximately 70 degrees wide, while the minima is only a few degrees making the null useful for direction-finding should the azimuthal bearing of a signal be sought. Naturally there is a 180 degree ambiguity common to all loop-type antennas without external sense antennas for phase reference. The established calibration factor holds only for measurement within + or - 5 degrees of maxima azimuthal orientation. One very useful feature is the ability to deeply null an interference source, greatly improving accuracy of the subject measurements; while ideally the selected measurement location would provide a 90 degree angle between subject and interference, in practice this is not always possible. If the subject pointing angle error is 50 degrees or less, accurate measurements are still achievable by augmenting the calibration factor with secondary angle factor, which is simply the cosine of the angle. For example, assume that the normal maxima factor is 100, and that nulling the interference resulted in a pointing error to the subject of 30 degrees. The cosine of 30 degrees is .866, so the received voltage will be 86.6 % of the value produced when perfectly pointed.

The corrected factor would be: 1 multiplied by the reciprocal of .866: 115.

The table below may be used for approximate values.

Pointing Error	COS	Factor Multiplier
10 degrees	.98	1.02
20 degrees	.94	1.06
30 degrees	.87	1.15
40 degrees	.77	1.30
50 degrees	.64	1.56
60 degrees	.50	2.0 (not recommended)

4. AM Bandwidth measurement

The LP3 series antenna is ideally suited for the AM Bandwidth measurements currently required by the Federal Communications Commission. Although the rules specify approximately 1 kilometer as the distance to the measurement location, experience has shown that maximum accuracy (less noise and interference ambiguity) is attained at the closer distances, particularly when "proofing" stations operating at one-kilowatt and below. Informal inquiries to the standards office at the commission regarding the legality of this practice resulted in (informal) assurance of acceptability. At the time of this compilation there seems to be some movement toward amending the rules to allow greater flexibility in this regard. Generally, as a rule-of-thumb, this distance should be at least a wavelength from the nearest radiator element. Maximum signal-to-noise is desired. Normal field intensity measurement considerations apply, such as avoiding locations in close proximity to electrical distribution systems and other interference sources. In some marginal signal-to-noise locations, proximity to operating automobile ignition systems and / or AC power inverters may contaminate the noise floor and should be avoided. Note also that although the rules specify "no video filter" when using the spectrum analyzer, in practice, a video filter of equal or greater than the selected resolution bandwidth will not slow the video risetime, but can improve the spectral display.

Figure A and B plot the bandwidth of a common solid-state AM transmitter that fails the tests; B shows the same environment with the subject nulled 20 dB. This technique can be useful for verification that the measured energy is actually being radiated by the subject.

5. Harmonic and Spurious Emission measurements

Since the LP-3 antenna is carefully calibrated from .5 through 5 MHz, relational measurements of out-of-band emissions can be made with only slightly less accuracy than with a field-intensity meter. This is done by dividing the spurious or harmonic field value (in millivolts or microvolts per Meter) by the fundamental carrier field value; each measurement must be made under identical conditions, each value corrected by the appropriate calibration factor.
For example, if we obtain 7 millivolts antenna output at 1.0 Mhz, (having converted from dBm) and 5 microvolts antenna output at 2.0 Mhz under identical conditions of antenna alignment etc., and the calibration factor is 350 at 1.0 Mhz and 230 at 2.0 Mhz, the field values are 350 times .007 = 2.45 volts per meter fundamental, and 230 times .000005 = .0011 volts per meter second harmonic. Using the formula 20 times the LOG (.0004 divided by 1.75), we get -66.5 dB suppression. This obviously is inadequate suppression unless the station is operating at very low power!
NOTE: If a spectrum analyzer or other broadband receiver is used for this type measurement, the limited dynamic range of the instrument may handicap this function. Intermodulation products created in the instrument's RF front-end often create the illusion of high harmonic level. A medium-frequency notch filter is often required to reduce the fundamental level to prevent this error. Figure C shows the

Figure A: A well known solid state one kilowatt transmitter operating at 1340 khz fails to meet bandwidth limits in the 60 to 100 khz range. (Tektronix 2712 : 10 dB/div : 20 khz/div)

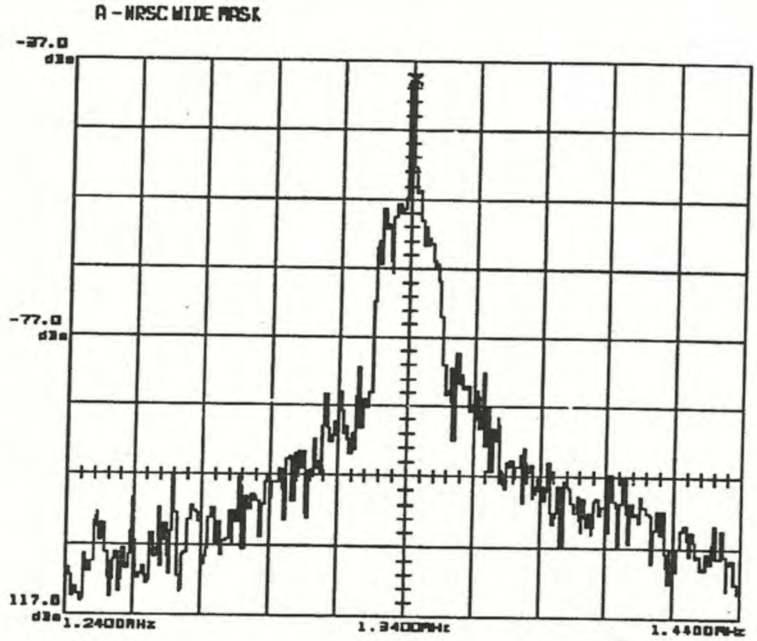


Figure B: The same transmitter and environment as in fig. A, with LP-3 nulling subject station, providing verification of emission source, and recording ambient RF environment.

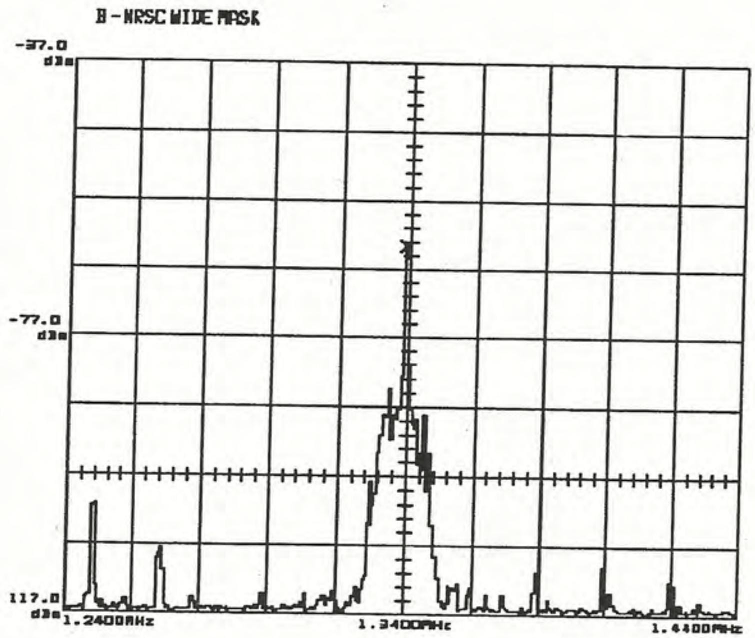
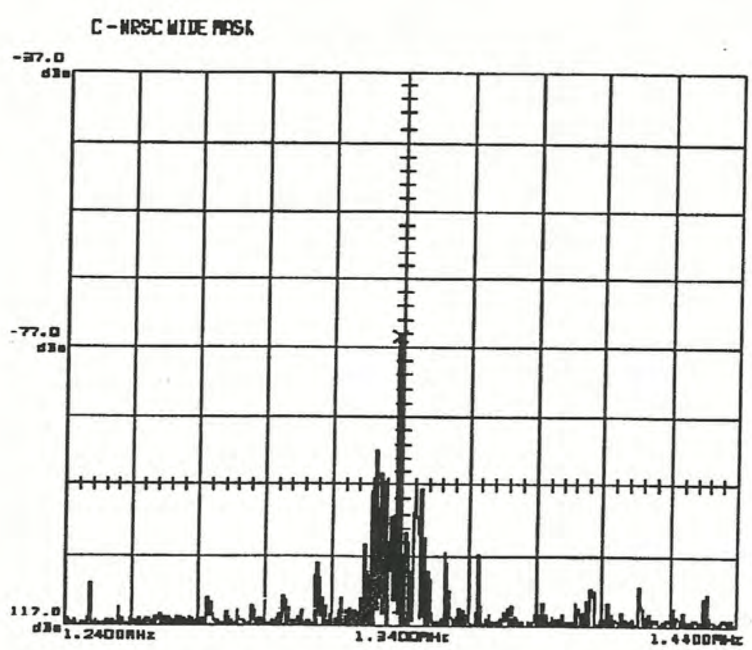


Figure C: Using a Medium Frequency Notch Filter to null fundamental frequency, allowing intermod-free harmonic measurement with spectrum analyzer.



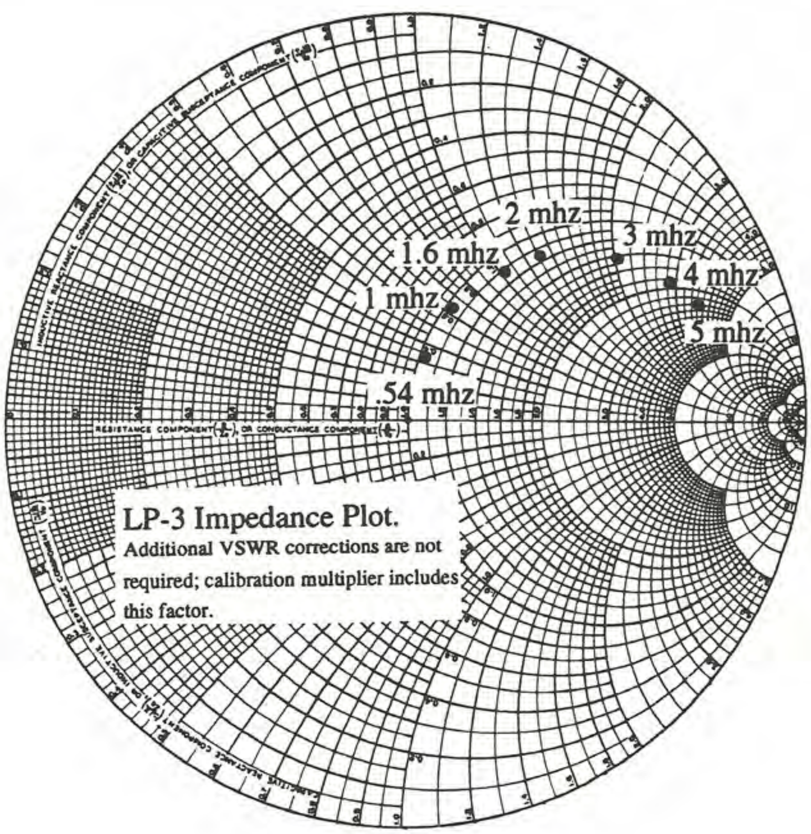
1340 khz carrier nulled with this filter; when the spectrum analyzer is then tuned to sweep the harmonic frequencies, harmonic levels will suffer less than 1 dB insertion loss and will be unaffected by the fundamental. This accessory equipment is available from Chris Scott & Associates.

6. RF Sampling

The LP-3 antenna is also very useful as a close-proximity RF sampling device; connection directly to a scope or frequency counter (beware of potentially high levels) permits low noise coupling while maintaining isolation. In general, proximity to an AM radiator should be kept to at least five feet for low-power stations, and ten feet for stations greater than a kilowatt. When conducting tests in close proximity to the base of an AM broadcast radiator (tower), bear in mind that the RF radiation intensity may be unsafe. A complete treatment of this subject is beyond the scope of this manual, but be aware of the safety requirements unique to the affected site.

7. Re-Calibration

This antenna has been individually calibrated using standard techniques comparable to NIST field-strength meter calibration procedures. Our facilities include a standard medium-frequency magnetic field maintained in close agreement with, and traceable to National Institute of Standards and Technology. The following page details the standard field method. The inherently stable nature of this antenna design, makes re-calibration at yearly intervals unnecessary. However, if the antenna is subjected to abuse in the field, repair and re-calibration is recommended. For organizations which require continuous NIST traceability, the standard re-calibration interval is (24) months. A nominal fee is charged for this service. For reference, the typical LP-3 impedance is plotted below. It maintains a moderate match over the AM broadcast band, and a match typical of broadband electronic countermeasures antennas over the decade of calibration.



LP-3 Impedance Plot.
Additional VSWR corrections are not required; calibration multiplier includes this factor.

7. Plain Language Warranty

We warrant this instrument to be free of defects in materials and workmanship for a period of one year from date of shipment. We guarantee that the instrument meets the specifications published in this manual. Chris Scott & Associates will repair or replace any defective item or material when notified within the warranty period. Prepayment of shipping to our facility and arrangement for a Return Authorization is required.

Specifically Excluded are:

1. Damage during shipping.
2. Damage due to improper use.
3. Instruments which have been modified.
4. Normal wear
5. Re-calibration

This warranty covers <u>only</u> repair or replacement of the defective instrument or affected parts. Chris Scott & Associates assumes <u>NO</u> liability for any damages, losses, or expense resulting directly or indirectly from product use, or any inability to use them separately or in conjunction with other instruments or devices.

Application Note: Improving the accuracy of harmonic measurement using the LP-3 , the AM notch filter and a spectrum analyzer:

This equipment allows accurate harmonic measurements of AM broadcast stations at frequencies up to five Megahertz. Although the insertion loss of the MF-NOTCH filter is considered by some to be negligible at second and third harmonic frequencies, we recommend using .8 dB and 1.2 dB, respectively. Spectrum analyzer accuracy is often degraded to + / - 4 dB when the subject carrier is being displayed in the lower 10 dB (-70 to -80 dB ref) range. Empirical data has shown that increasing gain by 10 dB after notching the fundamental signal often reduces this spectrum analyzer error significantly.

In addition, note that shorter vertical structures will become an appreciable portion of harmonic wavelengths prior to the same action at fundamental frequencies; re-radiation from these structures can easily be detected by ensuring that harmonics are properly nulled when the LP-3 is oriented 90 degrees to the subject's radiator.

Some engineers have reported inaccuracies when near strong FM stations. This is due to the spectrum analyzer being overloaded and generating intermodulation products which appear as high harmonic levels. To prevent these problems, we offer an inexpensive 10 Mhz low pass filter. A similar 175 Mhz high-pass filter is also offered to allow accurate FM harmonic measurements with a dipole and spectrum analyzer.

1-99

dBM in 50 ohms vs voltage

(not dBm to MV/M)

DBM	MV	DBM	MV	DBM	Micro V
0	223.61	-40	2.236	-80	22.36
-1	199.29	-41	1.993	-81	19.93
-2	177.62	-42	1.776	-82	17.76
-3	158.30	-43	1.583	-83	15.83
-4	141.09	-44	1.411	-84	14.11
-5	125.74	-45	1.257	-85	12.57
-6	112.07	-46	1.121	-86	11.21
-7	99.88	-47	.999	-87	9.99
-8	89.02	-48	.890	-88	8.90
-9	79.34	-49	.793	-89	7.93
-10	70.71	-50	.707	-90	7.07
-11	63.02	-51	.630	-91	6.30
-12	56.17	-52	.562	-92	5.62
-13	50.06	-53	.501	-93	5.01
-14	44.62	-54	.446	-94	4.46
-15	39.76	-55	.398	-95	3.98
-16	35.44	-56	.354	-96	3.54
-17	31.59	-57	.316	-97	3.16
-18	28.15	-58	.282	-98	2.82
-19	25.09	-59	.251	-99	2.51
-20	22.36	-60	.224	-100	2.24
-21	19.93	-61	.199	-101	1.99
-22	17.76	-62	.178	-102	1.78
-23	15.83	-63	.158	-103	1.58
-24	14.11	-64	.141	-104	1.41
-25	12.57	-65	.126	-105	1.26
-26	11.21	-66	.112	-106	1.12
-27	9.99	-67	.099	-107	.999
-28	8.90	-68	.089	-108	.890
-29	7.93	-69	.079	-109	.793
-30	7.07	-70	.070	-110	.707
-31	6.30	-71	.063	-111	.630
-32	5.62	-72	.056	-112	.562
-33	5.01	-73	.050	-113	.501
-34	4.46	-74	.044	-114	.446
-35	3.98	-75	.039	-115	.398
-36	3.54	-76	.035	-116	.354
-37	3.16	-77	.031	-117	.316
-38	2.82	-78	.028	-118	.282
-39	2.51	-79	.025	-119	.251

AM EMISSION MEASUREMENT WORKSHEET

Station Call letters ________ Freq __________ KW ______ Omni / DA ________

Time & Date __________ Engineer conducting tests ____________________

Monitor Point Location ____

____

____

Notes: ____

____

BANDWIDTH MEASUREMENTS

Equipment____

Resolution Bandwidth ______________ Video Filter ___________________

Recorded Maximum Levels

	Absolute	Normalized	FCC limit
Carrier	_____	(0)	(0)
10.2 KHz	_____	_____	-25 dBc
20 KHz	_____	_____	-35 dBc
30 KHz	_____	_____	-35 dBc
40 KHz	_____	_____	-45 dBc
50 KHz	_____	_____	-55 dBc
60 Khz	_____	_____	-65 dBc
>75 Khz	_____	_____	43+10 log(watts) or 80

Chris Scott & Associates
Bowling Green, KY. USA

dBm to mv conversion (50 ohms): mv = The square root of: (10 to the power of dBM/10, times 50,000).

$$\text{millivolts} := \sqrt{10^{\frac{dBM}{10}} \cdot 50000}$$

43+10 log(watts) or 80 (Whichever is least attenuation) 5 Kw and above: -80 dBc 2.5 Kw: -77 dBc 1 Kw: -73 dBc 500 watts: -70 dBc 250 watts: -67 dBc less than 158 watts: -65 dBc

HARMONIC DATA

Equipment:: ____________________ Antenna: ____________________

Carrier level: Method of determining reference level:____________________

dBm:______ mV:______ Factor: _______ mV/M:_______

2nd Harmonic frequency _______

dBm:______ mV:______ Factor: _______ mV/M:_______ -dBc:_____

3rd Harmonic frequency _______

dBm:______ mV:______ Factor: _______ mV/M:_______ dBc: _____

CALIBRATION of LP-3 series antennas

Chris Scott & Associates maintains a standard field for frequencies between .25 and 5 mHz, used for calibrating loop antennas and field intensity meters. This standard field is generated by a constant current loop antenna that has stable characteristics, metered by an accurate NIST traceable thermocouple milliammeter. This field is periodically audited by a NIST traceable transfer standard and kept in agreement to NIST within 5%. The methodology for this calibration system was originally published with a refined algorithm by Frank Greene of NIST (then NBS).

The basic formula for using the near field when two loop antennas are aligned co-axially is:

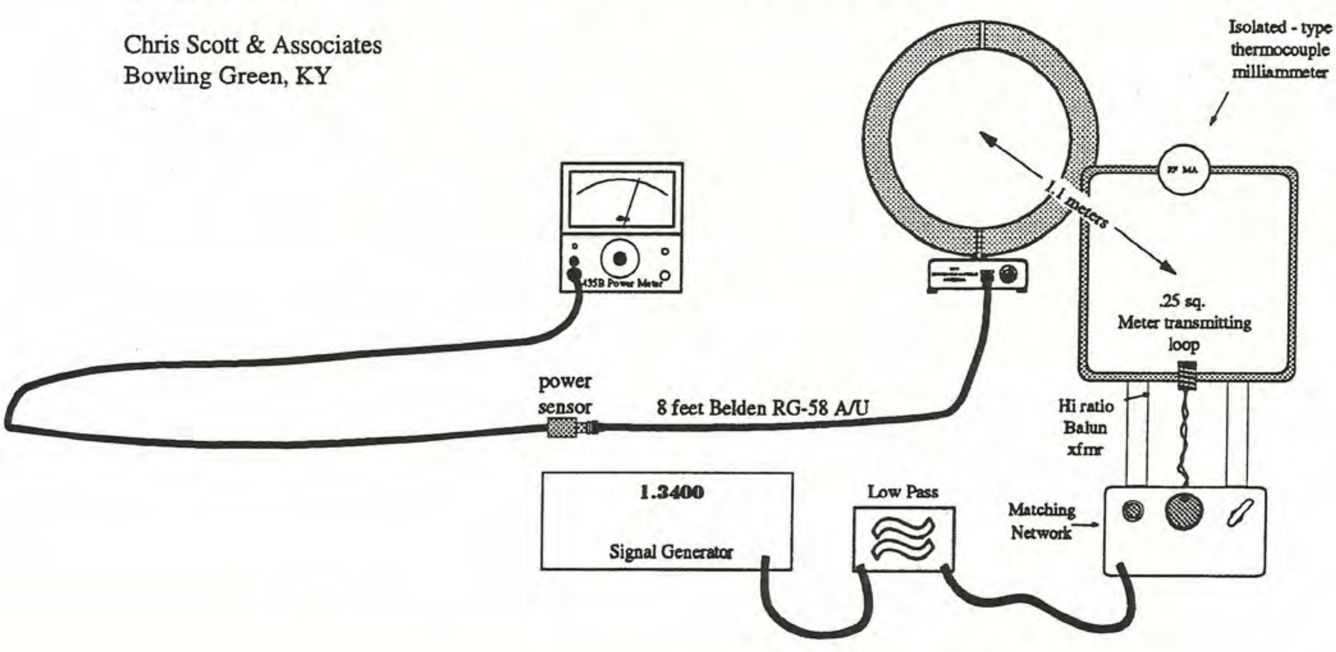
$$Ro := \sqrt{\left(d^2 + r1^2 + r2^2\right)} \qquad VM := \left[\left(\frac{I \cdot S1}{2 \cdot \pi \cdot Ro^3}\right) \cdot \left[\left[1 + 1.875 \cdot \left(\frac{r1 \cdot r2}{Ro^2}\right)^2 + 4.922 \cdot \left(\frac{r1 \cdot r2}{Ro^2}\right)^4\right] \cdot \sqrt{\left(1 + \beta^2 \cdot Ro^2\right)}\right]\right] \cdot ZoFS$$

$MHz := 1$	Frequency	$I := .2$	Transmit loop current
$d := 1.1$	Axial spacing between loops: M	$\beta := \frac{2 \cdot \pi}{\lambda}$	$ZoFS := 376.7304$
$r1 := .282$	Radius of transmit loop: M		
$S1 := .2488$	Area of transmit loop: sq. M	$r2 := .2222$	Radius of receive loop: M

The calculation of the standard field is inherently accurate to within (for volts per meter) .2%. Due however to minor errors in physical measurements, and limits of RF current metrology, 4% is our standard, 5% worst case. Our entire calibration system when considered in it's entirety, results in reliable accuracy to 1.0 dB. Our standard specification for LP-3 series loop antennas is +/- 1.3 dB.

Chris Scott & Associates
Bowling Green, KY

Calibration Setup



Certificate of Calibration

Date: 6/21/99 Serial Number: 252

LP-3 INDIVIDUAL CALIBRATION RECORD

Frequencies included in this measurement series include .5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 and 5.0 MHz. Tables have been linearly interpolated from these calibration points. Specified accuracy is +/- 1.3 dB. These measurements are traceable to National Institute of Standards & Technology, formerly NBS. Additional details of the calibration procedures are on file.

The standard interval of re-calibration for this instrument is (24) months.

Signature:__________________

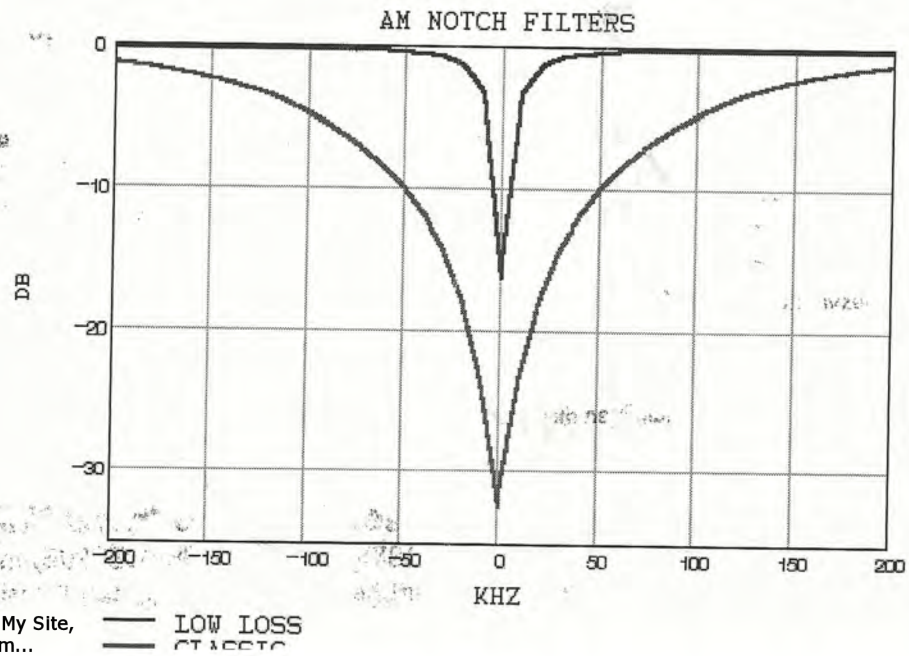
FREQ MHz	FACTOR linterp(Freq,FAC,MHz)
0.5	745
0.6	674
0.7	603
0.8	532
0.9	461
1	390
1.1	371.2
1.2	352.4
1.3	333.6
1.4	314.8
1.5	296
1.6	285.2
1.7	274.4
1.8	263.6
1.9	252.8
2	242
2.1	236.8
2.2	231.6
2.3	226.4
2.4	221.2
2.5	216
2.6	210
2.7	204

FREQ Mhz	FACTOR linterp(Freq,FAC,Mhz)
2.8	198
2.9	192
3	186
3.1	184.2
3.2	182.4
3.3	180.6
3.4	178.8
3.5	177
3.6	175.8
3.7	174.6
3.8	173.4
3.9	172.2
4	171
4.1	170
4.2	169
4.3	168
4.4	167
4.5	166
4.6	165
4.7	164
4.8	163
4.9	162
5	161

Chris Scott & Associates
Bowling Green, KY. USA

AM band Notch filter Instructions

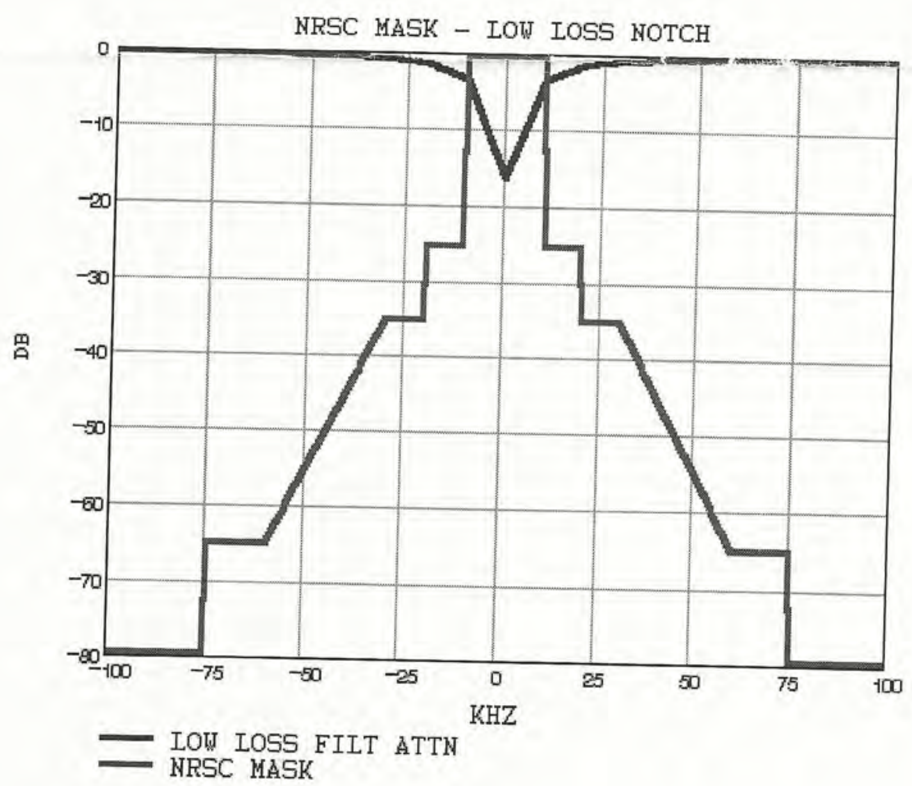
The AM Notch filter is designed to aid emission measurement of U.S. AM broadcast stations using a spectrum analyzer or other calibrated receiver. Accurate measurement of harmonic or spurious levels can be made in the presence of strong fundamental or interfering signals. Optimal Q makes this possible with negligible insertion loss at harmonic frequencies. Typical measured response at one megahertz is shown below. <u>There are three versions available, the classic, the low-loss coupled, and the dual output combined version.</u> The classic is most useful when maximum notch depth is desired, particularly when the desired reception is not close in to the center frequency, as in harmonic measurements. The low-loss version is designed to not only prevent spectrum analyzer overload when measuring harmonic frequencies, but to also be used for NRSC bandwidth measurements, displaying energy below the 70 or 80 db on-screen limit of most spectrum analyzers. Note that with the low-loss version, there is negligible attenuation at + - 75 khz and beyond, but nominally 15 db attenuation at 1 mhz, somewhat less at lower frequencies, somewhat more at higher frequencies. **<u>The combined version integrates both filters, with two outputs</u>**, allowing both the deep notch and the low-loss functions in the same unit. Not shown in the photo; the low-loss output is on an additional centered BNC port. Using the two "output" ports will provide a compromise between the two curves.



Breaking the 80 dB barrier with the LOW-LOSS AM band notch filter

Many modern spectrum analyzers, including the Tektronix 2710 / 2711 / 2712 series have residual phase noise at approximately 78 below the on-screen reference, and have degraded accuracy in the lower 10 db of the display. Some older analyzers are capable of displaying only 70 db on screen. A fundamental rule is that the accuracy of the test equipment must *exceed* the required test limits of the device under test by some margin. Therefore, in order to quantify an 80 db test limit, one must be able to measure *beyond* 80 db.

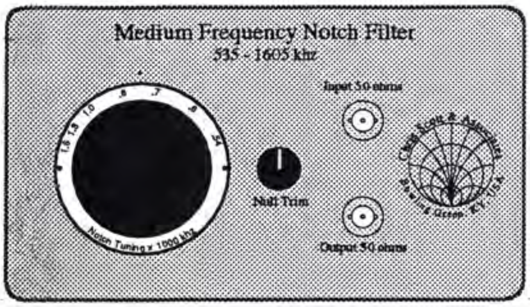
The solution is to reduce the carrier level independently of the measurement subject, which is the sideband energy outside of the center 150 khz spectral area, and then increase the analyzer's sensitivity another ten dB. This places the last 10 db of analyzer resolution squarely between 80 and 90 db, allowing forays down to -88 dbc, keeping in mind the 78 dB sideband noise limitation. The resulting carrier attenuation is noted on the plot. The CS&A low-loss notch filter produces negligible attenuation at + - 75 khz and beyond, allowing direct measurement of sideband energy without filter slope correction factors. Experience also shows that this carrier notch depth is usually sufficient to prevent the intermodulation-induced high harmonic syndrome as well. The attenuation curve relative to the NRSC mask is graphed bellow, with the top trace depicting notch depth, the bottom the NRSC curve.



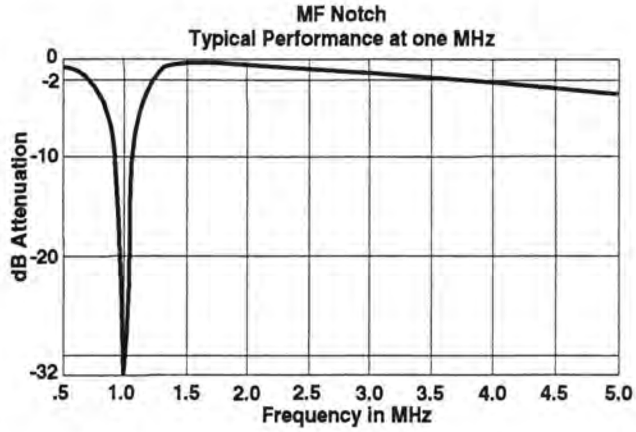
- Frequency range: .535 - 1.705 MHz
- impedance: 50 ohms
- Connectors: BNC
- Maximum VSWR @ 2F notch: 1.3:1
- Maximum attenuation @ 2F notch: .4 db
- Maximum operating level: +30 dBm
- Minimum Notch depth: see graph (typical 1.0 MHz)
- Construction: cast aluminum.

Notch Filter specifications

Dial - Variable AM Notch Filter:



Actual size 7.5 x 4.25 x 2.5 inches

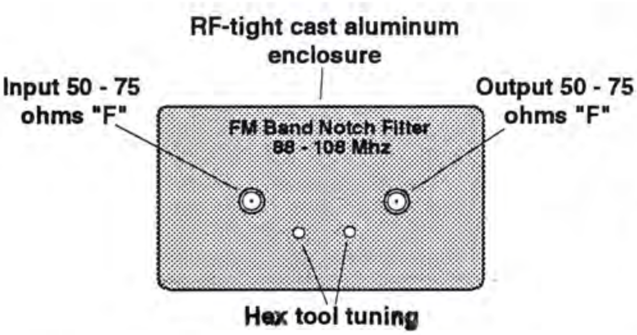


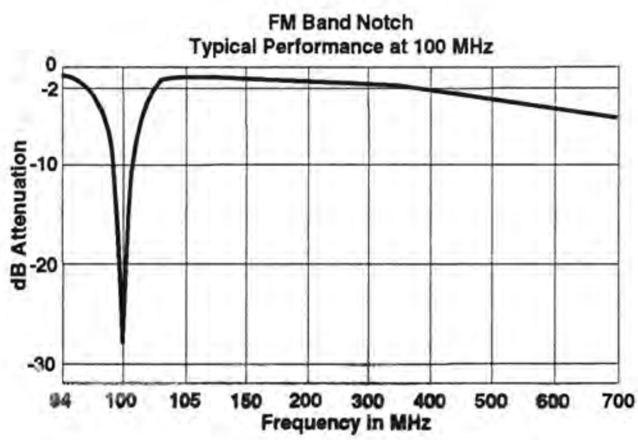
Specifications:
Frequency range: .53 - 1.72 MHz
Input & Output impedance: 50 ohms.
Maximum VSWR @ 2 f Notch: 1.3:1
Maximum attenuation @ 2 f Notch: .8 db
Maximum operating level: +30 dbm
Minimum notch depth: 26 db
Standard connector: BNC
Size: 7.5 x 4.25 x 2.5 in.
Weight: 1.6 lb.
Enclosure: cast aluminum

The Medium Frequency Notch Filter is specifically designed to facilitate emission measurement of U.S. AM broadcast stations using a spectrum analyzer or other calibrated receiver. Accurate measurement of harmonic or spurious levels can be made in the presence of strong fundamental or interfering signals. Optimal high-Q design makes this possible with negligible insertion loss at harmonic frequencies.

Adjustable FM Band Notch Filter

Electrostatically shielded for tough interference cases





Specifications:
Frequency range: 88 - 108 MHz
Input & Output impedance: 50-75 ohms.
Maximum VSWR @ 2 f Notch: 1.3:1
Maximum attenuation @ 2 f Notch: 1 db
Maximum operating level: +20 dbm
Minimum notch depth: 25 db
Connector: "F"
Size: 4.7 x 2.4 x 1.6 in.
Weight: 9 oz.
Enclosure: cast aluminum

The FM Notch Filter is designed to remove single FM broadcast station energy from cable, television, or FM translator receiver applications. In addition, measurement of FM emissions using a spectrum analyzer or other calibrated receiver are made more accurate by reducing front-end intermodulation products. Optimal high-Q design makes this possible with negligible insertion loss at harmonic frequencies.

Chris Scott & Associates, Bowling Green, KY. USA

Chris Scott & Associates
Ph. (502) 781-5301, Fax: (502) 781-1232

Specifications subject to change as performance is improved.