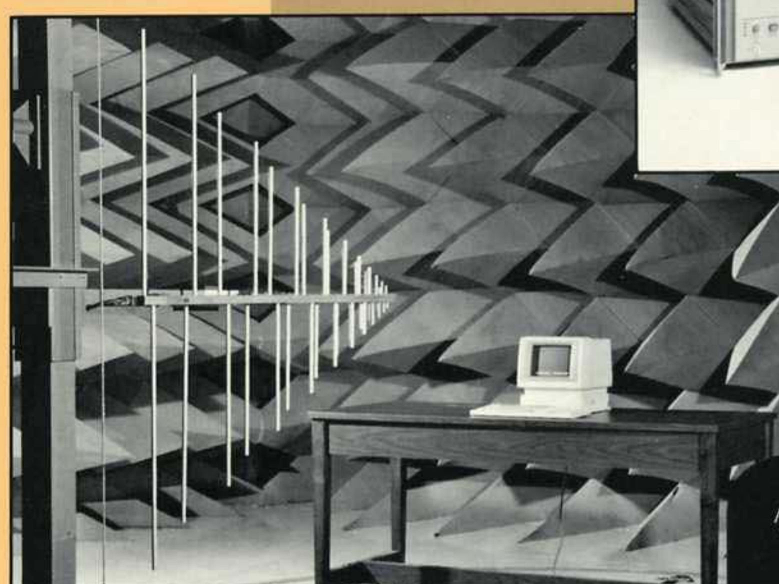
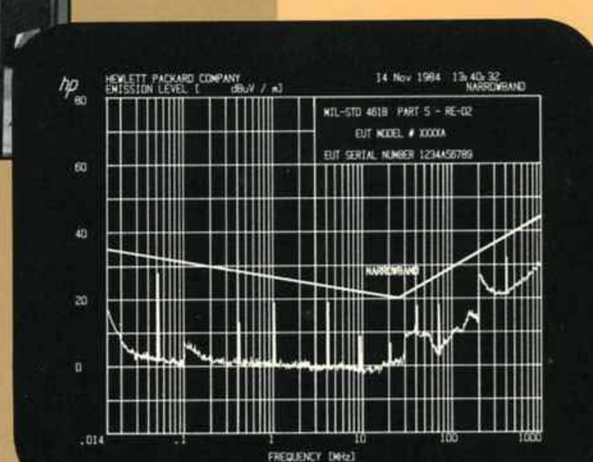
Application Note 330-1

AUTOMATIC MIL-STD EMI TESTING

Using the HP 85864A/B EMI Measurement Software





HEWLETT PACKARD

APPLICATION NOTE 330-1

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Using the HP 85864A/B
EMI Measurement Software

HEWLETT PACKARD

AUGUST 1985

CONTENTS

I INTRODUCTION

BACKGROUND

As the importance of EMC has increased over the years, new standards and procedures have been instituted to approach the goal of true electromagnetic compatibility in all equipment. Fast, accurate measurements which meet existing standards, a must for the EMC engineer, are obtained by using the HP 85864A/B EMI Measurement Software.

This application note describes:

- How to make interference measurements specified in MIL-STD 461B using the HP 85864A/B EMI Measurement Software package.
- How to measure and analyze radiated and conducted interference emitted from equipment under test using HP 8566A/B and HP 8568A/B High Performance Spectrum Analyzers.

PURPOSE

The HP 85864A/B EMI Measurement Software and the HP 8566A/B or HP 8568A/B Spectrum Analyzers measure radiated and conducted interference with fast, accurate results. Together, they reduce the time required to scan a given frequency range and automatically format results. Large portions of the spectrum can be viewed at one time to spot individual interference components or to look for intermittent signals. "Quick look" measurements are also possible, making this an ideal tool to use when designing for EMC. All results can be plotted for a permanent record or stored on a disc for later recall and analysis.

HOW TO USE THIS APPLICATION NOTE

Procedures provided in this application note apply to test methods in MIL-STD 461B requiring a calibrated receiver. General MIL-STD 461B requirements are divided into categories by equipment class as described below:

Part	Equipment and Subsystems Installed...	Class
2	aboard Aircraft (includes Ground Support)	A1
3	aboard Spacecraft and Launch Vehicles	A2
4	in Ground Facilities	A3
5	in Surface Ships	A4
6	in Submarines	A5
7	in Non-critical Ground Areas (Support)	B

These procedures include equipment configuration, control settings, calibration procedures, and information on signal interpretation, spurious response detection, and front end overload.

Although MIL-STD 461B test examples are given, most of these procedures are general in nature and may be used in conjunction with other MIL-STD or EMI specifications. The test methods described are:

CE-03 — Conducted Interference, 15 kHz to 50 MHz, Power and Interconnecting Leads

RE-02 — Radiated Interference, 14 kHz to 10 GHz, Electric Field

The organization of each MIL-STD 461B test procedure covered is essentially the same:

Test procedure organization

1. Instruments and Accessories Used
2. Equipment Configuration
3. Control Settings
4. Test Limits
5. Precautions
6. Signal Identification

The measurement process generally consists of calibrating the analyzer, connecting the signal pickup device, and observing the resultant spectrum display. The specification limits and details of a given method are subject to modification as the standards applicable are changed. The methods presented here will allow you to make these changes with a minimum of difficulty. Details of how to add a test to the EMI software package library are given in Section 4 and Section 5.

NOTE: There are several cases where the HP 8568A/B (100 Hz to 1.5 GHz) is suggested for tests below 1 GHz. Wherever the HP 8568A/B is suggested, the HP 8566A/B (100 Hz to 22 GHz) is a direct substitute.

II MEASUREMENT EQUIPMENT

MINIMUM EQUIPMENT REQUIREMENT

The HP 85864A/B EMI software makes full use of the HP 8566A/B or HP 8568A/B spectrum analyzer capabilities for making EMI measurements. The table below shows the spectrum analyzer and instrument controller requirements for using the EMI software. Any additional equipment required to perform a MIL-STD EMI test is included in the test procedure. The table below lists equipment for expanding the capabilities of the measurement system.

Equipment Needs for HP 85864A/B EMI Software

Required:	
Spectrum Analyzer	HP 8566A/B or 8568A/B
Instrument Controller	HP series 200, Model 236, 226 or 216
Controller Language	BASIC 2.0 + EXTENSIONS or BASIC 3.0
Controller Memory	1.1 Megabyte user-RAM
Recommended:	
RF Preselector	HP 85685A
Attenuator/Switch Driver	HP 11713A (Note 1)
Attenuator (1 dB step)	HP 8494H (Note 1)
Attenuator (10 dB step)	HP 8495H (Note 1)
Graphics Plotter	HP 7475A or 7470A
Graphics Thermal Printer	HP 2673A or 2671G

Note 1: Attenuators and Driver are not needed if preselector is used in measurement system.

CALIBRATING THE SPECTRUM ANALYZER

The HP 8566A/B and 8568A/B spectrum analyzer frequency and amplitude calibration is adjusted from the front panel using the CAL OUTPUT signal as a reference. This calibration should be verified once per day. In order to check this calibration, perform the following steps:

1. Connect the CAL OUTPUT to the analyzer input (RIGHT PORT for the HP 8568).
2. Press the green **INSTR PRESET** key.
3. Press **RECALL** **8**. Adjust the front panel AMPTD ADJ screwdriver adjustment for a marker reading of -10.00 dBm $\pm$ 0.02 dB.
4. Press **RECALL** **9**. Adjust the front panel FREQ ZERO screwdriver adjustment for a maximum signal amplitude.

DISPLAY UNITS AND TRANSDUCER CALIBRATION

The HP 85864A/B EMI software sets the spectrum analyzer display units to dBμV (decibels above 1 μVolt). To convert to other display units, use the Transducer Table. The Transducer Table is reached in the program from page 1 of the Test Setup Table (see Figure 1). You can, for example, enter current probe transfer impedance characteristics into this table to convert the displayed units of measure to dBμA (decibels above 1 μAmp). Note that the display units title on page 2 of the Test Setup Table must also be updated to reflect this change (see Figure 9).

In the same way, Antenna Factors can be added to the table to calibrate the measurement data in dBμV/m (electric field strength). See Figure 2 for examples of transducer tables.

NOTE: All transducer calibration factors assume zero loss in the interconnecting cables and no frequency response variations in any pre-amplifier or attenuator used. To account for cable losses and frequency response variations add these variations to the data entered in the Transducer Table. Figure 1 below shows page 1 of the Test Setup Table. To reach the table, move the selection box to the desired transducer label as shown, and press the 'GET TRANS' key. Figure 2 shows a typical transducer table. The cable losses and frequency response variations are added to the data shown. To load the revised correction factors into the Test Setup Table, press 'LOAD.'

```
TEST SETUP TABLE                                  PG 1 OF 6
************************************************************
LIBRARY FILE: RE-02 -- 14kHz to 1000MHz

DISPLAY TITLE 1:    MIL-STD 461B  PART 5 - RE-02
CONTROL PARAMETERS
  Test Type                              NB/BB
  Freq Uncert (%)                          1
  Min Sweep Time/Oct (sec)                 3
NUMBER PAGES NOTES                         0
NUMBER RANGES                              4
START FREQUENCY (MHz)                    .014

RNG STOP FREQ(MHz)              . TRANSDUCER
*** ************** *********************************
 1              .1    EMCO 3301 - ACTIVE MONOPOLE
 2            30.0    EMCO 3301 - ACTIVE MONOPOLE
 3           200.0  EMCO 3104 - BICONICAL (1 meter)

SCROLL WITH KNOB. SELECT FUNCTION.


   RETURN  |ENTER   |VIEW BB |PRT TBL |SCRATCH
   VIEW CRT|        |PAGE No.|NEXT PG |
```

Figure 1. Test Setup Table, Page 1

```
SIGNAL ANALYSIS -- MKTNG

=============================================
TRANSDUCER TABLE
=============================================

TRANSDUCER TITLE   EMCO 3104 - BICONICAL (1 meter)
SIGN OF TRANSDUCER              PLUS
NUMBER OF POINTS                 37
```

POINT	FREQUENCY(MHz)	TRANSDUCER FACTOR		CABLE LOSS		COMBINED FACTOR
1	20	15.28		.05		15.330
2	25	12.64		.05		12.690
3	30	12.17		.075		12.245
4	35	13.34		.08		13.420
5	40	13.42		.08		13.500
6	45	12.12		.09		12.210
7	50	12.02		1.01		13.030
8	55	13.20		1.01		14.210
9	60	10.29	+	1.03	=	11.320
10	65	8.77		1.03		9.800
11	70	7.18		1.05		8.230
12	75	7.22		1.07		8.290
13	80	10.00		1.08		11.080
14	85	10.26		1.08		11.340
15	90	10.63		1.12		11.750
16	95	11.59		1.12		12.710
17	100	12.19		1.15		13.340
18	105	13.40		1.16		14.560

Figure 2. Example Transducer Tables

BANDWIDTH FACTOR (B) FOR BROADBAND IMPULSE SIGNALS

[Broadband signals and impulse bandwidths are discussed in detail in Appendix A.]

To calibrate the CRT display so that the spectral intensity S of broadband impulse signals can be read directly in dBμV/MHz, the Bandwidth Factor B for the appropriate IF impulse bandwidth BWi is subtracted from the calibrated narrowband amplitude level as follows:

$$B = 20 \log \frac{\text{BWi}}{1\ \text{MHz}} \quad \text{(referenced to 1 MHz bandwidth)}$$

$$S\ (\text{dB}\mu\text{V/MHz}) = V(\text{dB}\mu\text{V}) - B(\text{dBMHz})$$

Example: Impulse bandwidth (BWi) for a typical resolution bandwidth filter of 100 kHz is 150 kHz.

NOTE: Video bandwidth must be 3 times resolution bandwidth, or in this case, 300 kHz.

If the measured amplitude level is 70 dBμV then the corrected reading referenced to 1 MHz impulse bandwidth is:

$$B = 20 \log (150 \text{ kHz}/1 \text{ MHz}) = -16.5 \text{ dBMHz}$$

$$S = 70 \text{ dB}\mu\text{V} - (-16.5 \text{ dBMHz}) = 86.5 \text{ dB}\mu\text{V/MHz}$$

The HP 85864A/B EMI software corrects the amplitude of the measured data to read the spectral intensity in dBμV/MHz for broadband measurements. The 'BWi' functon of the Utility section computes the impulse bandwidth for the spectrum analyzer's IF filters. The BWi function measures the actual resolution bandwidth of the spectrum analyzer and computes the impulse bandwidth and correction factor 'B' for each IF filter (3 MHz to 10 Hz). When finished, the measured impulse bandwidths and the associated bandwidth factors (see Figure 3) are saved on disc. All broadband measurement data is corrected to read in dBμV/MHz using these calibration factors.

Resolution Bandwidth	Reference BW (kHz)	Impulse Bandwidth BW	Impulse Bandwidth FACTOR(dB)
3 MHz	1000.00	4.29 MHz	9.85
1 MHz	1000.00	1.57 MHz	3.90
300 kHz	1000.00	468.00 Hz	-6.60
100 kHz	1000.00	156.00 Hz	-16.10
30 kHz	1000.00	44.60 Hz	-27.00
10 kHz	1000.00	14.90 Hz	-36.50
3 kHz	1000.00	4.54 Hz	-46.90
1 kHz	1000.00	1.53 Hz	-56.30
300 Hz	1000.00	463.00 Hz	-66.70
100 Hz	1000.00	154.00 Hz	-76.20
30 Hz	1000.00	45.80 Hz	-86.80
10 Hz	1000.00	14.00 Hz	-97.10

Figure 3. Example Impulse Bandwidth Data

III LABELING THE DISPLAY

This section illustrates use of the HP 85864A/B EMI software to annotate the spectrum analyzer display and add limit line(s) to the data plot. The enhanced display of measurement data is then ready to photograph or plot for a complete record of the measurement.

ADDING LABELS AND LIMIT LINES

The Test Setup Table test title and the time/date from the controller are always displayed on the test record. Three additional test labels and up to three limit lines can be added to the data display for your test reports. The three user-entered lines available are a company or facility name line and two title lines for adding the name or model number of equipment under test (EUT), the serial number, the operator I.D., etc. The Limit Table in the 'Test Setup' section of the program is used to add up to three limit lines to meet the specification of the test you are performing. The completed table can be added to the Limit Library for later recall and use in any measurement setup. A Mark Trace feature allows a specific signal or area of interest from the final test data to be noted for future reference.

For more information on features of the HP 85864A/B EMI Measurement Software consult the software operation manual.

Labeling the Test Record

1. Entering a facility name.

   From the **Top Level Menu** (see Figure 4)

   - press **UTILITY** softkey
   - press **NAME** softkey
   - type the desired name and press **ENTER**

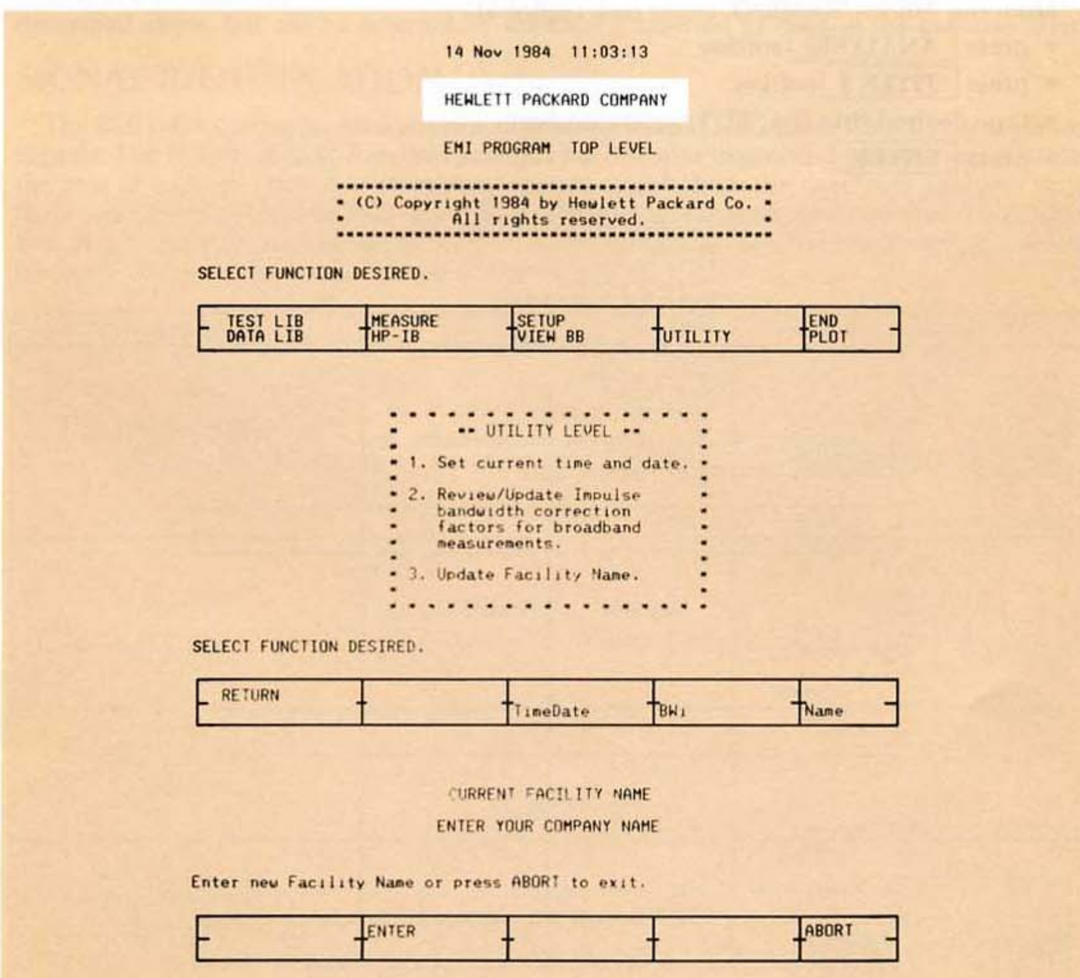


Figure 4. Top Level Menu (a), Utility Menu (b), and Facility Name Entry (c)

2. Entering second title line.
From the **Top Level Menu** (see Figure 4)
- press **MEASURE** softkey
- press **TITLE 2** softkey
- type desired title (i.e., EUT name), press **ENTER**

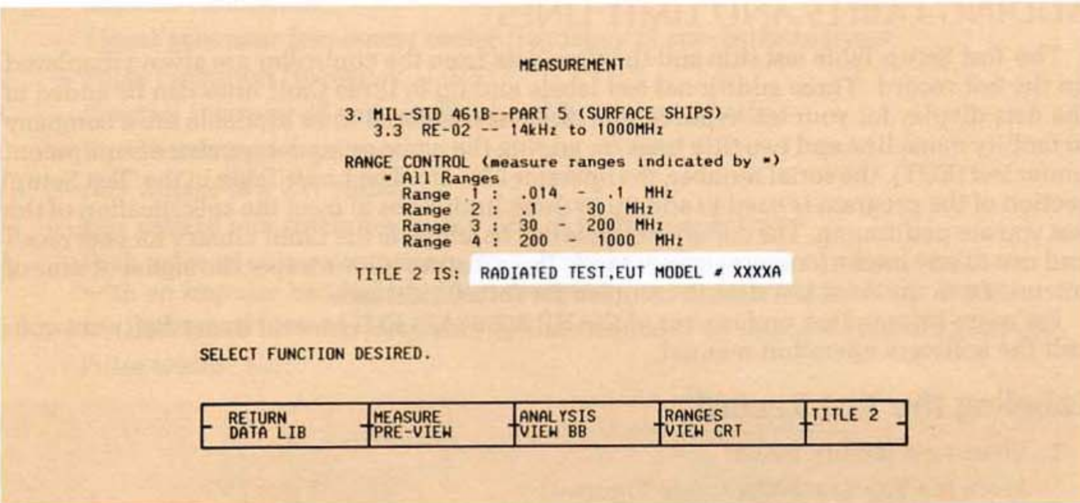


Figure 5. MEASUREMENT Menu Showing Title 2 Entry

3. Entering third title line.
From the **MEASUREMENT** menu (see Figure 5)
- press **ANALYSIS** softkey
- press **TITLE 3** softkey
- type desired title (i.e., EUT serial number)
- press **ENTER**

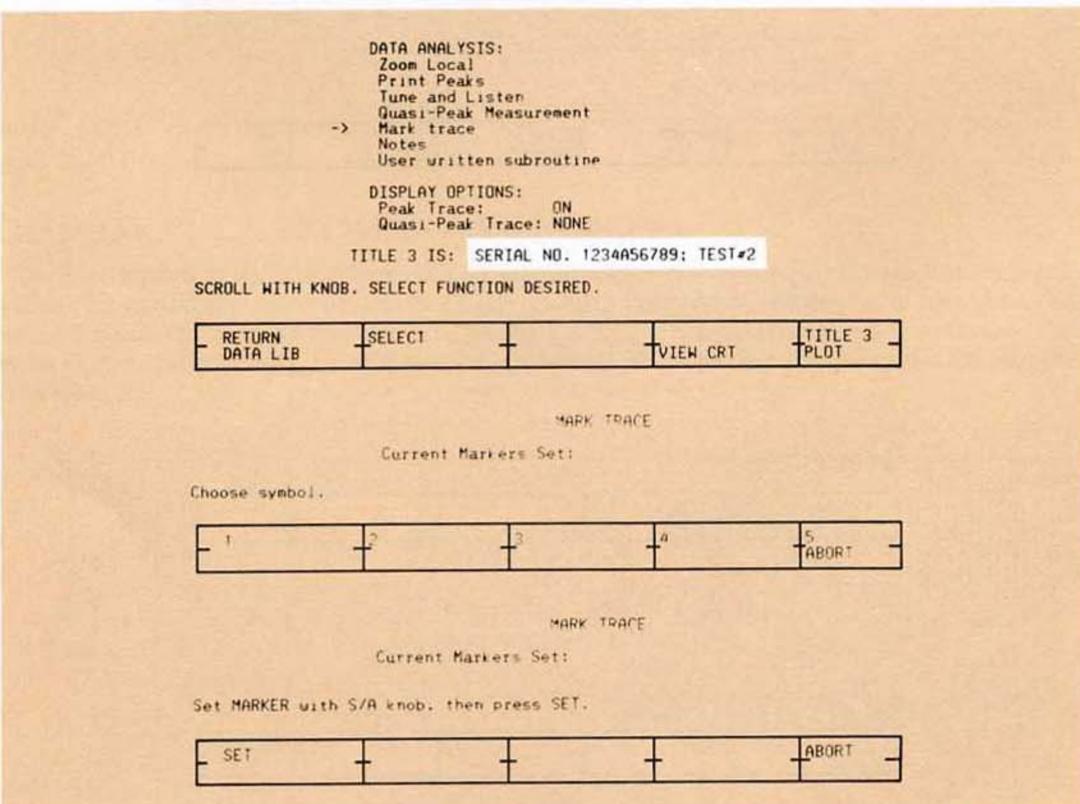


Figure 6. ANALYSIS Menu Showing Title 3 Entry

4. Mark Trace.
   From the **ANALYSIS** menu (see Figure 6)
   - select **MARK TRACE**
   - press **SET** softkey
   - select marker symbol (i.e., number 1 thru 5)
   - place spectrum analyzer marker at desired position, press **ENTER**

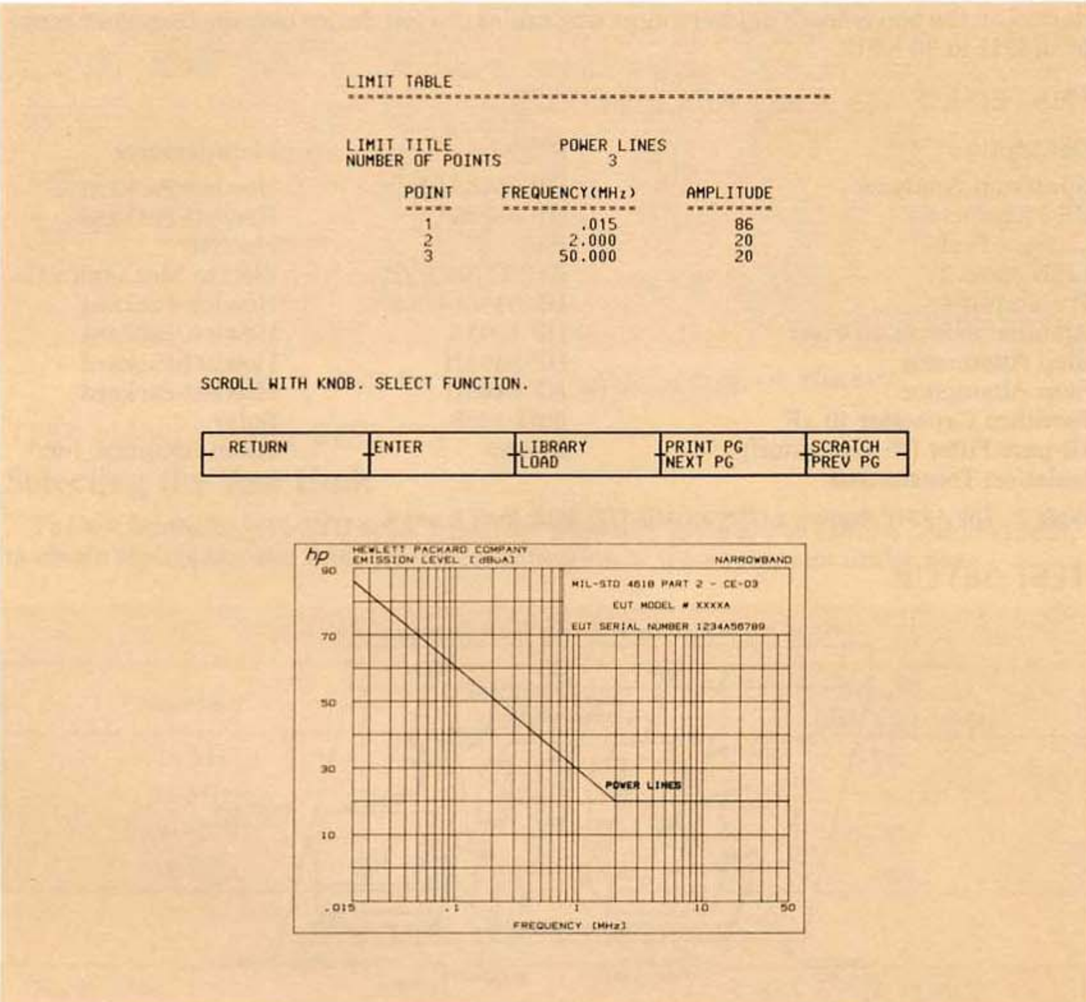


Figure 7. Example Limit Table and Resulting Spectrum Analyzer Display

Entering or Changing a Limit Line

From the **Top Level Menu** (see Figure 4)

- press **SETUP** softkey
- press **NXT PAGE** softkey
- position window at Limit 1 with computer keyboard knob
- press **GET LIMIT** softkey
- enter limit title, number of limit points, the frequency and amplitude of each point
- press **LIBRARY** softkey
- press **SAVE** softkey, and **ENTER**
- press **RETURN** softkey
- press **LOAD** softkey

The new limit has now been added to your Limit Library and your test. Press **RETURN** to get to the **Top Level Menu** to run your test.

IV MIL-STD 461B, CE-03 CONDUCTED EMISSIONS

15 kHz to 50 MHz, POWER and INTERCONNECTING LEADS

This test covers MIL-STD 461B specifications given for evaluating the electromagnetic characteristics of equipment and subsystems. The objective is to measure interference conducted on the power leads or interconnecting cables of a test device over the frequency range of 15 kHz to 50 MHz.

INSTRUMENTS AND ACCESSORIES

Description	Model #	Manufacturer
Spectrum Analyzer	HP 8568A/B	Hewlett-Packard
RF Preselector	HP 85685A	Hewlett-Packard
Current Probe	F-16	Fischer
LISN (note 2)	EMCO 3825/2R	Electro Mechanics Co.
Pre-amplifier	HP 8447A-H64	Hewlett-Packard
Attenuator/Switch Driver	HP 11713A	Hewlett-Packard
Step Attenuator	HP 8494H	Hewlett-Packard
Step Attenuator	HP 8495H	Hewlett-Packard
Feedthru Capacitor 10 μF	6512-106R	Solar
Hi-pass Filter (10 kHz cutoff)	F-2860	Allen Avionics, Inc.
Isolation Transformer		

Note 2. The ARMY requires a LISN for MIL-STD 461B, Parts 2 and 4.

TEST SETUP

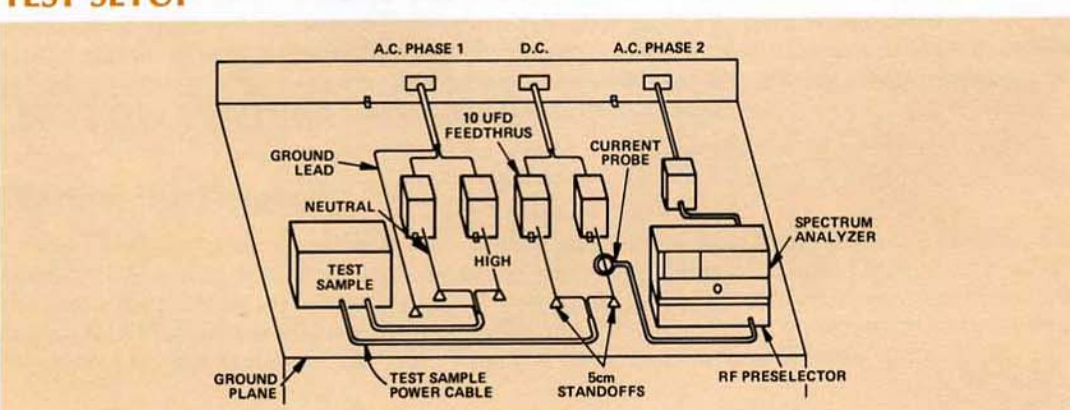


Figure 8. Test Setup for Conducted Emissions Measurements on Power Leads Using a Current Probe

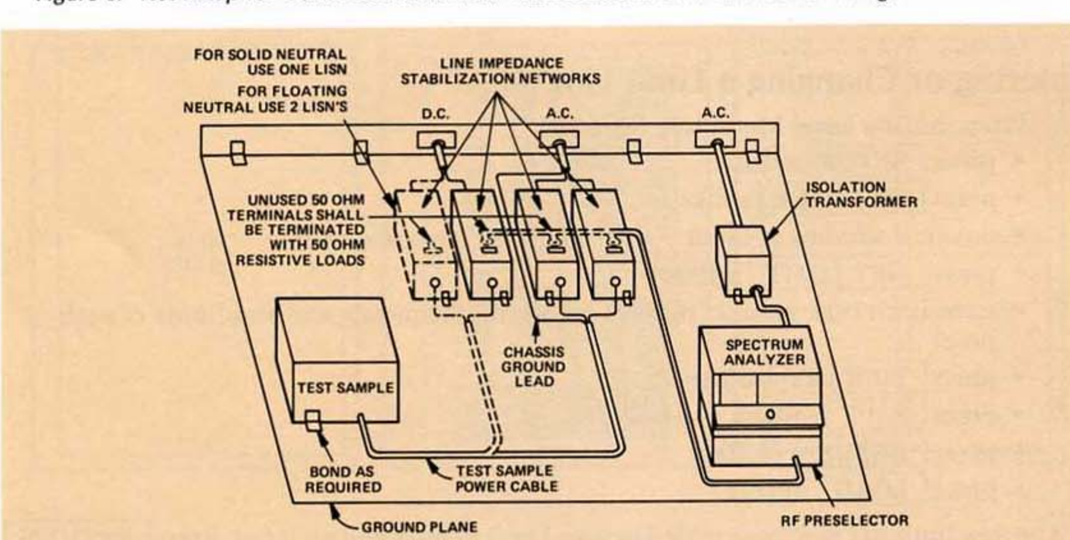


Figure 9. Test Setup for Conducted Emissions Measurements on Power Leads Using a LISN

TEST SETUP TABLE

```
HEWLETT PACKARD COMPANY

*************************************************
TEST SETUP TABLE                         PG 1 OF 4
*************************************************
LIBRARY FILE:   CE-03 -- FOR AC & DC LEADS

DISPLAY TITLE 1:    MIL-STD 461B PART 2 - CE-03
CONTROL PARAMETERS
  Test Type                        NB/BB
  Freq Uncert (%)                    1
  Min Sweep Time/Oct (sec)           3
NUMBER PAGES NOTES                   0
NUMBER RANGES                        2
START FREQUENCY (MHz)              .015

RNG STOP FREQ(MHz)           TRANSDUCER
*** ************** ******************************
 1           .5    CURRENT PROBE - FISCHER F-16
 2         50.0    CURRENT PROBE - FISCHER F-16


*************************************************
DISPLAY INFORMATION                      PG 2 OF 4
*************************************************

                     NARROWBAND     BROADBAND
                     **********     *********
AMPLITUDE INFO
  Units Label           dBuA         dBuA / MHz
  Disp Ref Level        90              130

TEST LIMITS
  Number Limits          1               1
  Limit 1           POWER LINES     POWER LINES
```

```
HEWLETT PACKARD COMPANY

*************************************************
RANGE 1: .015 TO .5 MHz                  PG 3 OF 4
*************************************************
                        NARROWBAND    BROADBAND
AMPLIFIER
  Name                  HP8447A-H64   HP8447A-H64
  Gain (dB)                 28            28
INPUT PORT                 LEFT          LEFT
MSMT STATES
  QP Bandwidth (Hz)       BYPASS        BYPASS
  SA Res Bandw (Hz)        3000          3000
  Video Bandw. (Hz)        30000         30000
  Ref. Level (dBuV)         90            90
  Int. Atten. (dB)          10            10
  Ext. Atten. (dB)          0             0
NO. OF SETUPS               1          same as NB
NO. SWEEPS/SETUP            1          same as NB
FIRST SETUP
  Msg,Sub,Continue    MESSAGE
  Msg:   CONNECT CURRENT PROBE & AMPL TO LFT INPT

*************************************************
RANGE 2: .5 TO 50.0 MHz                  PG 4 OF 4
*************************************************
                        NARROWBAND    BROADBAND
AMPLIFIER
  Name                  HP8447A-H64   HP8447A-H64
  Gain (dB)                 28            28
INPUT PORT                 LEFT          LEFT
MSMT STATES
  QP Bandwidth (Hz)       BYPASS        BYPASS
  SA Res Bandw (Hz)        3000          100E3
  Video Bandw. (Hz)        10000         1.E+6
  Ref. Level (dBuV)         80            80
  Int. Atten. (dB)          10            10
  Ext. Atten. (dB)          0             0
NO. OF SETUPS               1          same as NB
NO. SWEEPS/SETUP            1          same as NB
FIRST SETUP
  Msg,Sub,Continue    CONTINUE
```

Figure 10. CE03 Test Setup Table Supplied with HP 85864A/B

TEST LIMITS AND RESULTS

Selecting the Test Limit

The test limits for MIL-STD 461B, CE-03 are shown in Table 1. Use the selection chart (Table 2) to choose the correct test limit for the method you are using.

Table 1. MIL-STD 461B, CE-03 Limits for Interference Testing

Frequency	a		b		c		d		e	
	NB	BB	NB	BB	NB	BB	NB	BB	NB	BB
15 kHz	86	129	55	95	84	124	65	105	87	138
2 MHz	20	50	20	50	20	50	20	50	20	50
50 MHz	20	50	20	50	20	50	20	50	20	50

NB = Narrowband emissions in dBμA.
BB = Broadband emissions in dBμA/MHz.

Table 2. Limit Selection for MIL-STD 461B, CE-03

COMMAND	Power Leads	EQUIPMENT CLASS			
		A1 & 2	A3	A4 & 5	B**
ARMY & AIR FORCE	DC	a	a	b	e
	AC 400 Hz	a	a	c	c
	AC 60 Hz	a	a	d	d
NAVY	DC	a	b	b	e
	AC 400 Hz	a	c	c	c
	AC 60 Hz	a	d	d	d

**ARMY does not test to Class B specifications unless required by the local Command.

NOTE: The values given in Table 1 are the end points for straight line segments to be drawn on a log frequency plot. Refer to Section III of this note for instructions on entering or changing the limit line values for a specific test.

Hard Copy Output Options

```
SIGNAL ANALYSIS -- MKTNG    22 May 1985   09:52:12
1. MIL-STD 461B--PART 2 (AIRCRAFT)
   1.1  CE-03 -- FOR AC & DC LEADS
TEST TECH #24
INSTRUMENT MODEL NO. X345B
SERIAL NUMBER - 1234-34567
TEST 1.2    --   PLOT NO. 6

PEAKS FOUND ABOVE   10dBuA

PEAK#   FREQ (MHz)   AMPL(dBuA)
  1        .0178        84
  2        .0194        83
  3        .0427        56
  4        .0463        54
  5        .0502        53
  6        .0549        54
  7        .0640        55
  8        .0711        54
  9        .0752        54
 10        .1066        40
 11        .1474        27
 12        .1625        26
 13        .2140        21
 14        .5799        12
 15       1.082         10
 16       1.403         10
 17       3.990         11
```

Figure 11. Example of Print Peaks Output

Print Peaks

The Analysis function, PRINT PEAKS, is used to determine the amplitude and frequency of the peak responses of measured data. The operator is asked to input a threshold in dB, and all responses which exceed this limit are then found. The data is displayed on the controller screen or sent to the system printer (Figure 11). An image of the measurement data plot, viewed on the controller screen, can be sent to a graphics printer by pressing simultaneously the **SHIFT** and **GRAPHICS** keys on the controller keyboard.

Plotting the Display

The PLOT function duplicates on a system plotter the spectrum analyzer display. The operator has a choice of three formats: one, two, or four plots per page (see Figure 12). Narrowband and Broadband data or comparative data plots can be drawn on the same paper. The operator selects the frame for plotting on the multiple plot formats. Up to six (6) different pen colors for drawing each part of the display are available with the PENS function. Different colors may then be chosen for the graticule, the limit line, the data, and the annotation.

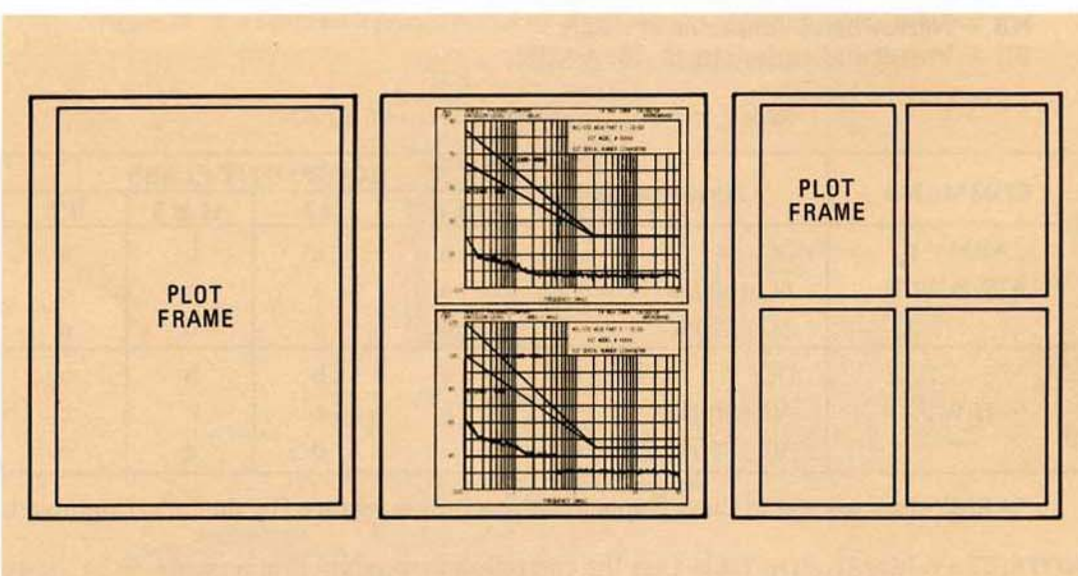


Figure 12. Three Different Plot Formats Available

Adding a Test Setup to the Test Library

If you have modified a test or entered your own test parameters into the Test Setup Table, you need to store the setup in your Test Library. A thorough explanation is found in the software operation manual. The following is the procedure for storing your setup on disc.

- From the **Top Level Menu**, press TEST LIB
- Press STORE
- Select the test file heading desired or add a new header at the prompt
- Enter the name of your test file at the prompt
- Your test setup table will then be added to the library

PRECAUTIONS

Prevent possible damage to the input of the measurement system; follow these steps before connecting the input cable.

- From the **Top Level Menu**, press MEASURE
- Select the PRE-VIEW function
- Select **ALL RANGES** (coupled)
- Set the spectrum analyzer's RF input attenuator to 60 dB
- Connect the input cable to the spectrum analyzer
- Remove attenuation in 10 dB steps while observing the display

Continue to remove attenuation until some signals do not behave linearly (i.e., they do not go up in 10 dB steps) or until 10 dB RF attenuation is reached. Use the least amount of attenuation that allows linear behavior while making the measurement. (Be sure to enter the attenuator setting in the Test Setup Table of the EMI Measurement Software.)

NOTE: If a pre-amplifier is used in the measurement system, execute the same procedure described above but use an external RF attenuator inserted in front of the pre-amplifier.

SIGNAL IDENTIFICATION

The EMI software has an Analysis function called ZOOM LOCAL for identifying measured signals. The ZOOM LOCAL function prompts the operator to position two markers defining the area of interest. Once this frequency span is established, the spectrum analyzer is tuned there and returned to local operator control. A manual measurement and a visual identification of the signal of interest can be made. The signal can be classified as broadband or narrowband by using the tests outlined in Figure 13.

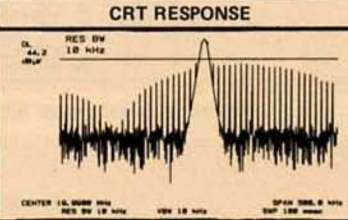
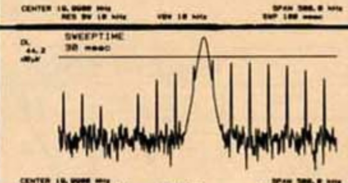
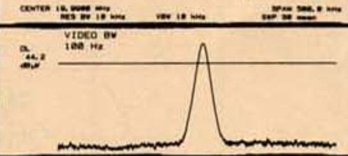
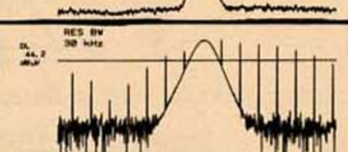
METHODS	NB	BB	CRT RESPONSE
TUNING TEST "TUNE" Δ BW_i	Δ AMPL > 3dB	Δ AMPL < 3dB	
PRF TEST Δ SWEEPTIME	NO Δ SPACING (LINE MODE)	SPACING (PULSE MODE)	
PEAK VS. AVG. DET Δ VIDEO BW	NO Δ AMPL	Δ AMPL	
BANDWIDTH TEST Δ RESOLUTION BW	NO Δ AMPL	Δ AMPL	

Figure 13. Methods for NB and BB Analysis

V MIL-STD 461B, RE-02 RADIATED EMISSIONS

14 kHz to 10 GHz

This test covers MIL-STD 461B specifications given for evaluating the electromagnetic characteristics of equipment and subsystems. The objective of this testing is to measure interference radiating from a test device over the frequency range of 14 kHz to 10 GHz.

INSTRUMENTS AND ACCESSORIES

Description	Model #	Manufacturer
Spectrum Analyzer	HP 8566A/B	Hewlett-Packard
RF Preselector	HP 85685A	Hewlett-Packard
Antennas. . .		
Active Monopole (.014-30 MHz)	EMCO 3301	Electro Mechanics Co.
Biconical (20-200 MHz)	EMCO 3104	Electro Mechanics Co.
Log Spiral (200-1000 MHz)	EMCO 3101	Electro Mechanics Co.
Log Spiral (1-10 GHz)	EMCO 3102	Electro Mechanics Co.
Tripod	EMCO TR-3	Electro Mechanics Co.
Pre-amplifier (10 kHz - 50 MHz)	HP 8447A-H64	Hewlett-Packard
Pre-amplifier (.1-1300 MHz)	HP 8447D	Hewlett-Packard
Pre-amplifier (1-10 GHz)	HP 8349A-H01	Hewlett-Packard
Step Attenuator	HP 8495D	Hewlett-Packard
Feedthru Capacitor 10 μF	6512-106R	Solar

TEST SETUP

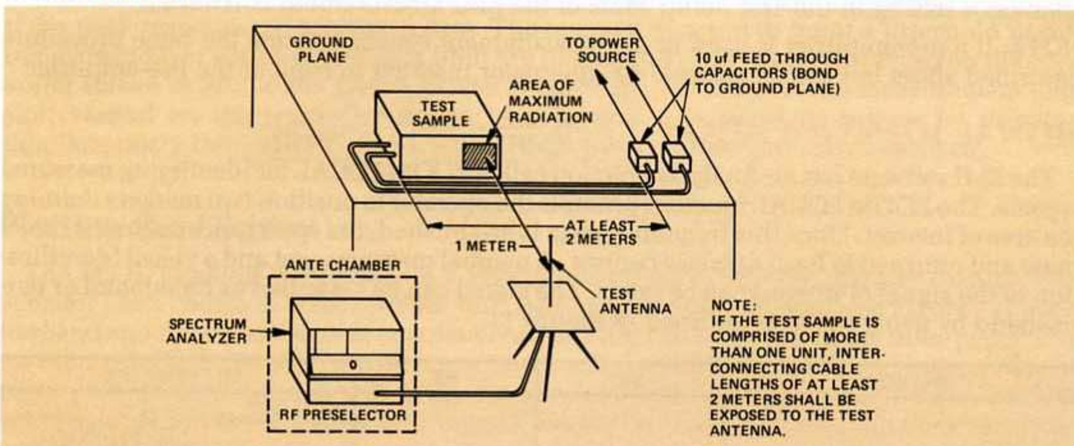


Figure 14. Test Setup for Radiated Emissions Measurements of Nonportable Equipment

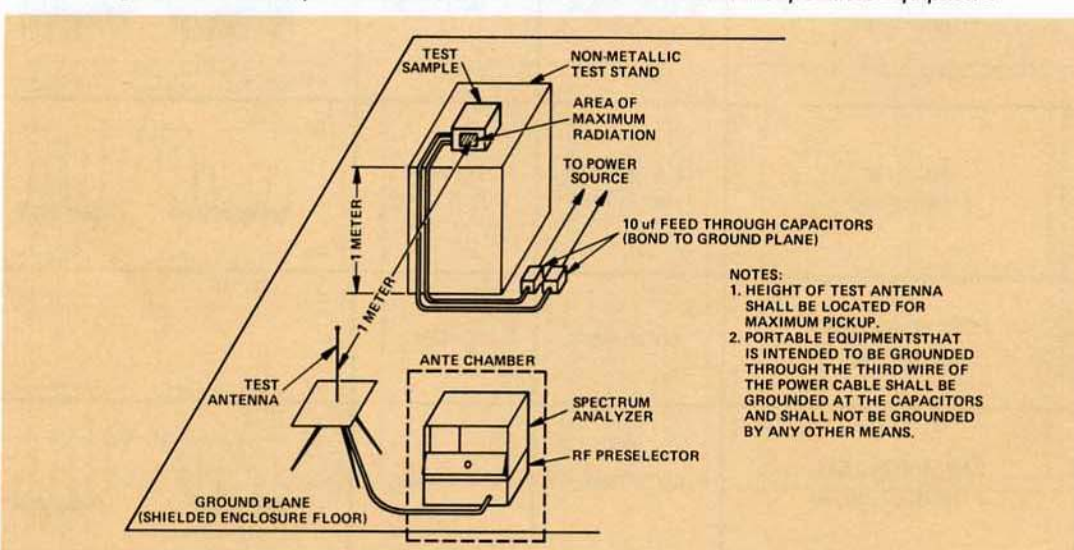


Figure 15. Test Setup for Radiated Emissions Measurements of Portable Equipment

TEST SETUP TABLE

```
HEWLETT PACKARD COMPANY

**************************************************
TEST SETUP TABLE                        PG 1 OF 6
**************************************************
LIBRARY FILE:   RE-02 -- 14kHz to 1000MHz

DISPLAY TITLE 1:   MIL-STD 461B  PART 5 - RE-02
CONTROL PARAMETERS
  Test Type                        NB/BB
  Freq Uncert (%)                    1
  Min Sweep Time/Oct (sec)           3
NUMBER PAGES NOTES                   0
NUMBER RANGES                        4
START FREQUENCY (MHz)              .014

RNG STOP FREQ(MHz)           TRANSDUCER
*** ************** *******************************
 1            .1    EMCO 3301 - ACTIVE MONOPOLE
 2          30.0    EMCO 3301 - ACTIVE MONOPOLE
 3         200.0  EMCO 3104 - BICONICAL (1 meter)
 4        1000.0  EMCO 3101 - LOG SPIRAL(1 meter)


**************************************************
DISPLAY INFORMATION                     PG 2 OF 6
**************************************************

                      NARROWBAND      BROADBAND
                      **********      *********
AMPLITUDE INFO
  Units Label         dBuV / m      dBuV / m / MHz
  Disp Ref Level         80              110

TEST LIMITS
  Number Limits          1               1
  Limit 1            NARROWBAND      BROADBAND
```

```
HEWLETT PACKARD COMPANY

**************************************************
RANGE 1: .014 TO .1 MHz                 PG 3 OF 6
**************************************************
                          NARROWBAND    BROADBAND
AMPLIFIER
  Name                    HP8447A-H64   HP8447A-H64
  Gain (dB)                  28            28
INPUT PORT                  LEFT          LEFT
MSMT STATES
  QP Bandwidth (Hz)        BYPASS        BYPASS
  SA Res Bandw (Hz)         3000          3000
  Video Bandw. (Hz)        30000         30000
  Ref. Level (dBuV)          80            80
  Int. Atten. (dB)           10            10
  Ext. Atten. (dB)           0             0
NO. OF SETUPS                1          same as NB
NO. SWEEPS/SETUP             1          same as NB
FIRST SETUP
  Msg,Sub,Continue      MESSAGE
  Msg:   CONNECT EMCO 3301 & HP8447A TO LFT INPT

**************************************************
RANGE 2: .1 TO 30.0 MHz                 PG 4 OF 6
**************************************************
                          NARROWBAND    BROADBAND
AMPLIFIER
  Name                    HP8447A-H64   HP8447A-H64
  Gain (dB)                  28            28
INPUT PORT                  LEFT          LEFT
MSMT STATES
  QP Bandwidth (Hz)        BYPASS        BYPASS
  SA Res Bandw (Hz)         10E3          10E3
  Video Bandw. (Hz)        100E3         100000
  Ref. Level (dBuV)          80            80
  Int. Atten. (dB)           10            10
  Ext. Atten. (dB)           0             0
NO. OF SETUPS                1          same as NB
NO. SWEEPS/SETUP             1          same as NB
FIRST SETUP
  Msg.Sub.Continue      CONTINUE
```

```
HEWLETT PACKARD COMPANY

**************************************************
RANGE 3: 30.0 TO 200.0 MHz              PG 5 OF 6
**************************************************
                          NARROWBAND    BROADBAND
AMPLIFIER
  Name                     HP8447D       HP8447D
  Gain (dB)                  26            26
INPUT PORT                  RIGHT         RIGHT
MSMT STATES
  QP Bandwidth (Hz)        BYPASS        BYPASS
  SA Res Bandw (Hz)         30E3          30E3
  Video Bandw. (Hz)        300E3         300000
  Ref. Level (dBuV)          80            80
  Int. Atten. (dB)           10            10
  Ext. Atten. (dB)           0             0
NO. OF SETUPS                1          same as NB
NO. SWEEPS/SETUP             1          same as NB
FIRST SETUP
  Msg,Sub,Continue      MESSAGE
  Msg:   CONNECT BICON ANT & HP8447D TO RT INPT

**************************************************
RANGE 4: 200.0 TO 1000.0 MHz            PG 6 OF 6
**************************************************
                          NARROWBAND    BROADBAND
AMPLIFIER
  Name                     HP8447D       HP8447D
  Gain (dB)                  26            26
INPUT PORT                  RIGHT         RIGHT
MSMT STATES
  QP Bandwidth (Hz)        BYPASS        BYPASS
  SA Res Bandw (Hz)         100E3         100E3
  Video Bandw. (Hz)          1E6          1.E+6
  Ref. Level (dBuV)          80            80
  Int. Atten. (dB)           10            10
  Ext. Atten. (dB)           0             0
NO. OF SETUPS                1          same as NB
NO. SWEEPS/SETUP             1          same as NB
FIRST SETUP
  Msg,Sub,Continue      MESSAGE
  Msg:   CONNECT LOG SPIRAL & HP8447D TO RIGHT IN
```

Figure 16. RE-02 Test Setup Table Supplied with the HP 85864A/B

TEST LIMITS AND RESULTS

Selecting the Test Limit

The test limits for MIL-STD 461B, RE-02 are shown in Table 3. Use Table 4, "Add to Limit," to obtain the correct test limit for the classification of the equipment under test.

Table 3. MIL-STD 461B, RE-02 Limits for Interference Testing

Frequency	Narrowband (dBμV/m)	Broadband (dBμV/m/MHz)
14 kHz	35	100
25 MHz	20	64.8
1000 MHz	44.5	70
10 GHz	60	na

Table 4. Add to Limit for MIL-STD 461B, RE-02

Equipment Class	ARMY		NAVY & AIR FORCE	
	NB	BB	NB	BB
A1a, b, g	0 dB	0 dB	10 dB	10 dB
A1c, d, e, f	0 dB	0 dB	10 dB	20 dB
A2a	10 dB	10 dB	10 dB	10 dB
A2b, c	10 dB	20 dB	10 dB	20 dB
A3	0 dB	0 dB*	0 dB**	0 dB
A4	0 dB	0 dB	0 dB	0 dB
A5***	0 dB	0 dB	0 dB	0 dB
B	20 dB	20 dB	20 dB**	20 dB

*ARMY. . . add 20 dB for transients from manually controlled switching

**NAVY. . . add 10 log Power (watts) at the fundamental frequency when average transmitter power > = 10 Watts

***ALL. . . Specification only applies up to 1000 MHz

NOTE: The values given in Table 3 are the end points for straight line segments to be drawn on a log frequency plot. Refer to Section III for instructions for entering or changing the limit line for a specific test.

Hard Copy Output Options

```
SIGNAL ANALYSIS -- MKING   22 May 1985  10:34:10

 2. MIL-STD 461B--PART A (GROUND FACILITIES)
    2.4  RE-02 -- 14kHz to 1000MHz

TEST TECH #24
INSTRUMENT MODEL NO. X345B
SERIAL NUMBER - 1234-34567
TEST 1.2    --  PLOT NO. 6

PEAKS FOUND ABOVE  20dBuV / m

PEAK#  FREQ (MHz)  AMPL(dBuV / m)
  1       .1022      21
  2       .2019      22
  3       .2951      22
  4       .5043      23
  5      1.008       23
  6      1.523       22
  7      2.013       22
  8      3.043       23
  9      4.023       21
 10      4.974       22
 11      6.014       21
 12      7.031       20
 13      9.939       24
 14      15.02       23
 15      20.08       24
 16      25.11       24
 17      30.02       26
 18      156.7       22
 19      200.3       33
```

Figure 17. Example of Print Peaks Output

Print Peaks

The Analysis function, PRINT PEAKS, is used to determine the amplitude and frequency of the peak responses of measured data. The operator is asked to input a threshold in dB, and all responses which exceed this limit are then found. The data is displayed on the controller screen or sent to the system printer. An image of the measurement data plot, viewed on the controller screen, can be sent to a graphics printer by pressing simultaneously the **SHIFT** and **GRAPHICS** keys on the controller keyboard.

Plotting the Display

The PLOT function duplicates on a system plotter the spectrum analyzer display. The operator has a choice of three formats: one, two, or four plots per page. The operator selects the frame for plotting on the multiple plot formats. Up to six (6) different pen colors for drawing each part of the display are available with the PENS function. Different colors may then be chosen for the graticule, the limit line, the data, and the annotation.

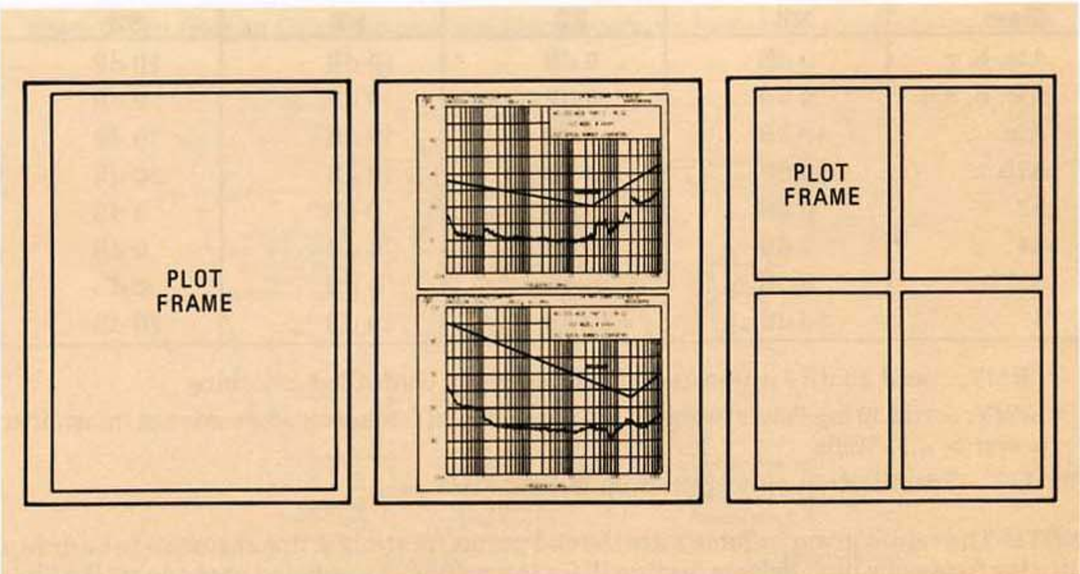


Figure 18. Examples of the Different Plot Formats Available

Adding a Test Setup to the Test Library

If you have modified a test or entered your own test parameters into the Test Setup Table, you need to store the setup in your Test Library. A thorough explanation is found in the software operation manual. The following is the procedure for storing your setup on disc.

- From the **Top Level Menu**, press **TEST LIB**
- Press **STORE**
- Select the test file heading desired or add a new header at the prompt
- Enter the name of your test file at the prompt
- Your test setup table will then be added to the library

PRECAUTIONS

Prevent possible damage to the input of the measurement system; follow these steps before connecting the input cable.

- From the **Top Level Menu**, press **MEASURE**
- Select the **PRE-VIEW** function
- Select **ALL RANGES** (coupled)
- Set the spectrum analyzer's RF input attenuator to 60 dB
- Connect the input cable to the spectrum analyzer
- Remove attenuation in 10 dB steps while observing the display

Continue to remove attenuation until some signals do not behave linearly (i.e., they do not go up in 10 dB steps) or until 10 dB RF attenuation is reached. Use the least amount of attenuation that allows linear behavior while making the measurement. (Be sure to enter the attenuator setting in the Test Setup Table of the EMI Measurement Software.)

NOTE: If a pre-amplifier is used in the measurement system, execute the same procedure described above, but use an external RF attenuator inserted in front of the pre-amplifier.

SIGNAL IDENTIFICATION

The EMI software has an Analysis function called ZOOM LOCAL for identifying measured signals. The ZOOM LOCAL function prompts the operator to position two markers defining the area of interest. Once this frequency span is established, the spectrum analyzer tunes there and returns to local operator control, where manual measurement and visual identification of the signal of interest can be made. The signal can be classified as broadband or narrowband by using the tests outlined in Figure 19.

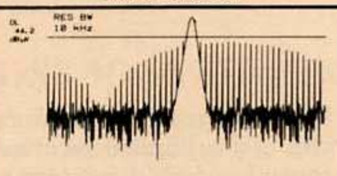
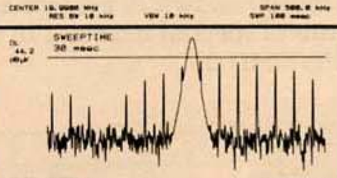
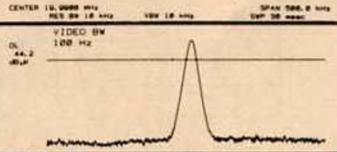
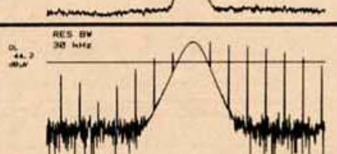
METHODS	NB	BB	CRT RESPONSE
TUNING TEST "TUNE" Δ BW_i	Δ AMPL > 3dB	Δ AMPL < 3dB	
PRF TEST Δ SWEEPTIME	NO Δ SPACING (LINE MODE)	SPACING (PULSE MODE)	
PEAK VS. AVG. DET Δ VIDEO BW	NO Δ AMPL	Δ AMPL	
BANDWIDTH TEST Δ RESOLUTION BW	NO Δ AMPL	Δ AMPL	

Figure 19. Methods for NB and BB Analysis

APPENDIX A
MEASUREMENT OF IMPULSE BANDWIDTH

NOMENCLATURE

BWi — Impulse bandwidth
f_o — Signal generator frequency; center frequency of spectrum analyzer
f_r — Pulse repetition frequency = 1/T
S — Spectral intensity of an impulse signal in rms volts/MHz
T — Time between two pulses
V_1 — rms voltage of a CW signal
V_2 — rms voltage of a single frequency line of impulse spectrum
V_p — Peak value of voltage transients (in volt peak) at the output of a lossless filter with an impulse bandwidth, BWi, created by an impulse signal at the input
$\triangle f$ — $1/\tau$; difference between frequency f_o and frequency of adjacent zero of spectrum
τ — Pulse width; $1/\triangle f$

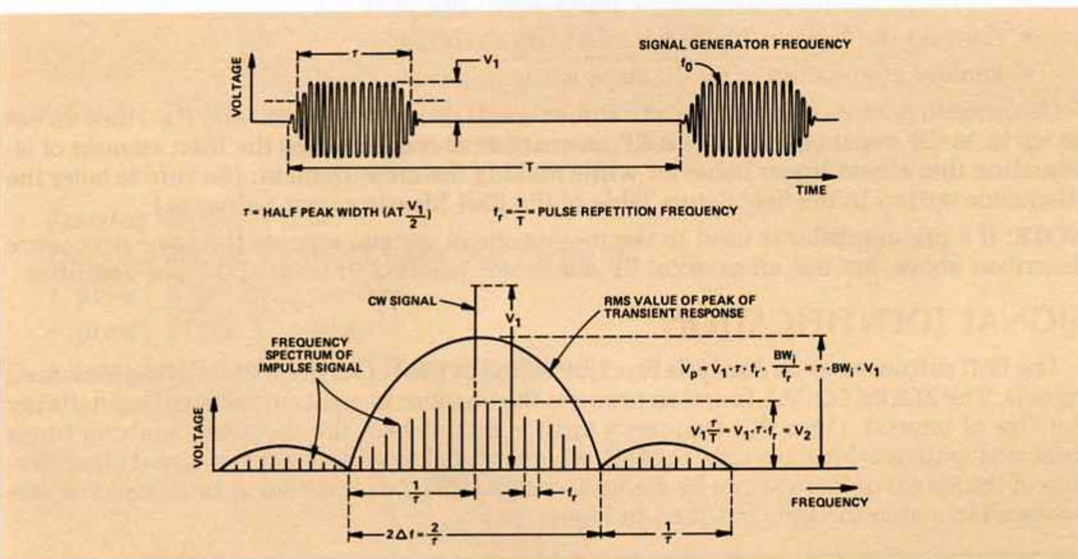


Figure A-1. Definition of Terms

DEFINITION OF BROADBAND SIGNALS

Impulse signals of short duration with a frequency spectrum exceeding the resolution bandwidth of a calibrated receiver and with a repetition frequency substantially less than the receiver bandwidth are termed BROADBAND IMPULSE SIGNALS. They are measured, in terms of spectral intensity, in volts per megahertz or dB above one microvolt per megahertz (dBμV/MHz).

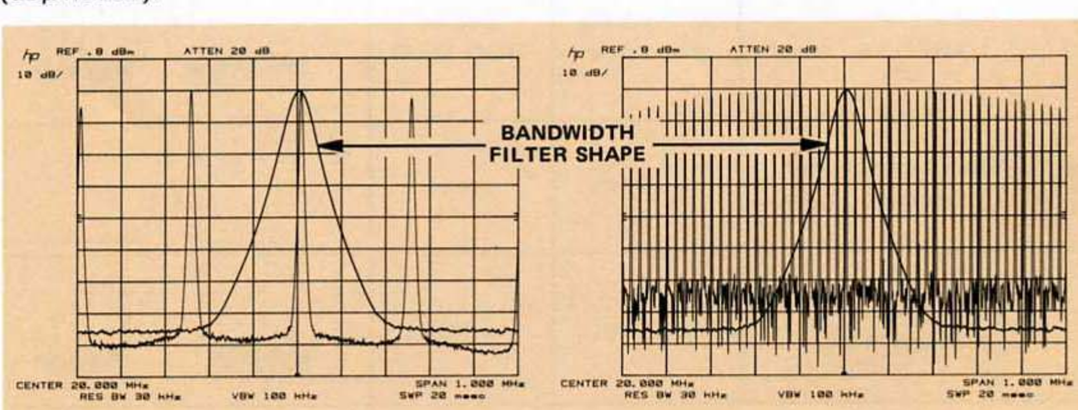


Figure A-2. Narrowband (a) and Broadband (b) Signals

DEFINITION OF IMPULSE BANDWIDTH

Impulse signals cause transient responses in a receiver. The peak value of these responses is proportional to the spectral intensity of the impulse signal and to the bandwidth of the receiver. The exact value of this receiver bandwidth (the "impulse bandwidth") must be known in order to measure broadband impulse signals. Unlike the 3-dB bandwidth, this value is not easily derived from CW response measurements. The transient behavior of the IF filter depends on the exact shape of the frequency response, the design of the bandpass, any logarithmic amplifiers used, the gain-shaping performance, and any video bandwidth used.

Impulse bandwidth (BWi) is specified as the ratio of the peak value of the detected transient (V_p) divided by the spectral intensity of the impulse signal (S) causing the transient:

$$\mathrm{BWi} = \frac{V_p}{S} \tag{1}$$

where spectral intensity and V_p are specified in rms volts.

MEASUREMENT OF IMPULSE BANDWIDTH

Impulse bandwidth is measured directly using calibrated impulse signal sources and equation (1). With certain limitations mechanical line-discharge type impulse calibrators can be used to determine the impulse bandwidth of a receiver. This method, however, tends to overload the front end, even with a tracking preselector, or limit the dynamic range. Therefore the following paragraphs explain another technique.

USE OF A PULSE MODULATED SIGNAL GENERATOR OF KNOWN SPECTRAL INTENSITY

An impulse signal of accurately-known spectral intensity can be generated by modulating a CW signal generator with a pulse generator (such as an HP 8341A and an HP 8116A):

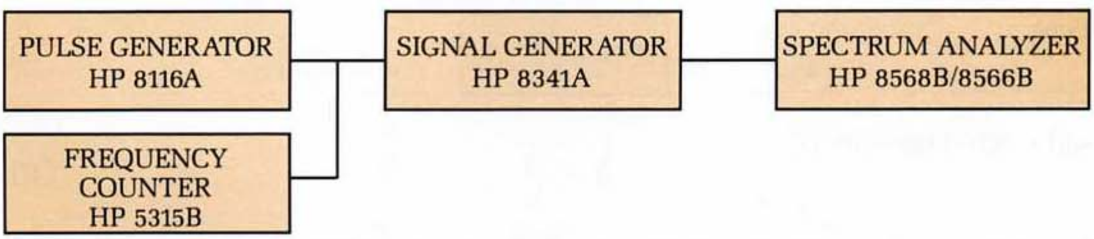


Figure A-3. Impulse Bandwidth Measurement Test Setup

To measure the impulse bandwidth, spectral intensity must be constant over the range of the bandwidth. Therefore, it is necessary to choose an impulse width narrow enough so that the flat portion extends well over the range of the bandwidth measured. The main lobe of the pulsed RF spectrum should exceed 30 times the (BWi) impulse bandwidth.

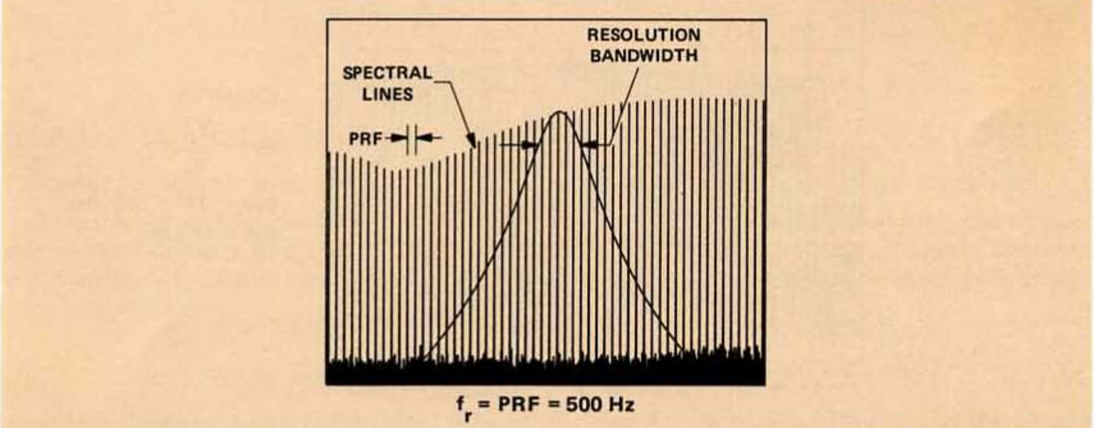


Figure A-4. Impulse Spectral Intensity is Constant over the Receiver Bandwidth

Normally, frequencies outside twice the 3-dB bandwidth have very little effect on the peak voltage of the receiver detector transient response. Thus, it is sufficient to keep this portion flat. If we choose

$$1/\tau > 10\ BW_{3dB} \tag{2}$$

then the relative drop in spectral voltage in the filter pass band will be very small.

DETECTOR TRANSIENT

The voltage peak of the receiver detector transient is the summation of all spectral line voltages within the bandwidth of the detector. Because of the non-linear, phase-versus-frequency characteristic of bandpass filters around the stop-band boundaries, this summation has to take phase (or delay) distortion into account. This is why it is difficult to determine the impulse bandwidth from a measured frequency response alone. We overcome this difficulty with a frequency spectrum which extends well over the range of the bandwidth. This spectrum consists of discrete frequencies a distance fr apart with the same voltage V_2; the peak of the transient response of the detector then becomes

$$V_p = V_2 * m \tag{3}$$

where: $m = \dfrac{BWi}{f_r}$ = number of spectral lines within the impulse bandwidth BWi. (4)

Substituting equation (4), we get:

$$V_p = V_2 * \frac{BWi}{f_r} \tag{5}$$

Thus,

$$\boxed{BWi = \frac{V_p}{V_2} * f_r} \tag{6}$$

and spectral intensity is:

$$S = \frac{V_2}{f_r} \tag{7}$$

Knowing this relationship, the BWi for a resolution bandwidth filter can be measured. The procedure below measures the ratio of the amplitude of V_p to V_2 and measures the pulse rate (f_r). Equation (6) is then used to calculate BWi. See Figure A-5.

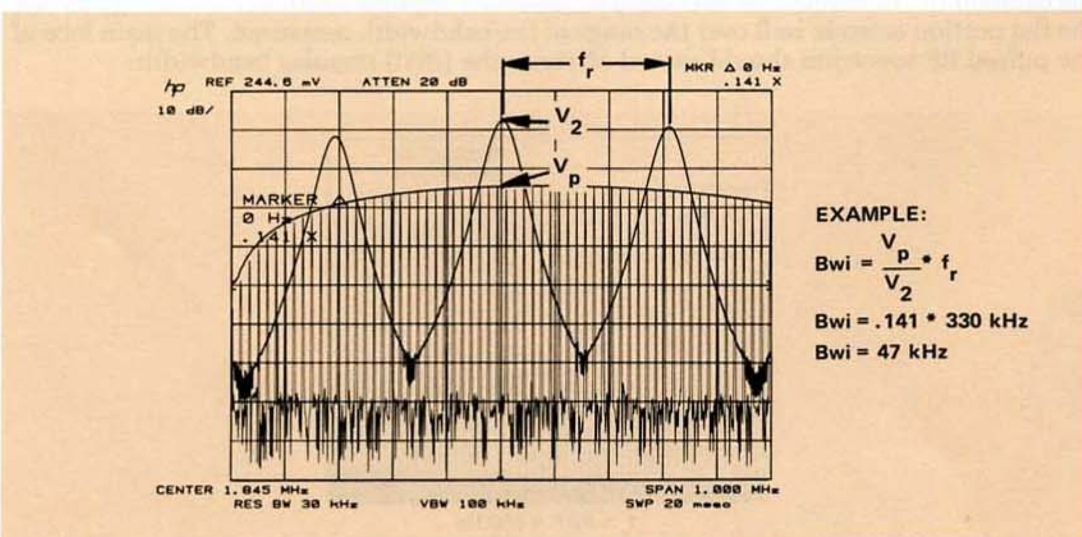


Figure A-5. Measuring Impulse Bandwidth

PROCEDURE FOR MEASURING BWi

1. Set the spectrum analyzer controls as follows:

   Press green **INSTR PRESET** key

CENTER FREQUENCY	1 GHz
REFERENCE LEVEL	70 dBμV
LOG SCALE	10 dB/
LOG DISPLAY UNITS	Volts ('SHIFT' D)

2. Press the **RES BW** key and select desired resolution bandwidth.

3. Press the **VIDEO BW** key and select a video bandwidth at least three (3) times the resolution bandwidth selected in step 2.

4. Press the **FREQUENCY SPAN** key and select a frequency span of five (5) times the resolution bandwidth selected in step 2.

5. Set the pulse generator and signal generator controls as follows:

   pulse generator

AMPLITUDE	5 volts
WAVEFORM	pulse
FREQ (PRF)	3.3 times RES BW
PULSE WIDTH	divide 0.04 by RES BW

   (Example: for 1 kHz bandwidth; PRF = 3.3 kHz, Pulse Width = 40 μsec)

   signal generator

FREQUENCY	1000 MHz
AMPLITUDE	– 10 dBm
MODULATION	PULSE

6. Use the frequency counter to set the PRF of the pulse generator. Position signal on screen, at a convenient display level using the **CENTER FREQ** and **REFERENCE LEVEL** controls.

7. Set **SWEEP TIME** to 20 seconds. Press **CLEAR WRITE** A. Press **MAX HOLD** A.

8. Allow at least one complete sweep, then press **VIEW** A, and **PEAK SEARCH**, **MARKER △**.

9. Change the pulse generator frequency to .3 * RES BW as indicated on the frequency counter.

10. Press **CLEAR WRITE** B. Press **MAX HOLD** B.

NOTE: The spectrum analyzer display should look similar to that shown in Figure A-5. Repeat steps 1 through 4 if the display is different.

11. Allow at least two full sweeps, then press **VIEW** B and **BLANK** A.

12. The MARKER △ reading is the ratio of V_p to V_2. The PRF set in step 5 is used to calculate BWi using equation (6):

$$BWi = \frac{V_p}{V_2} * f_r = \text{MARKER } \triangle * \text{PRF} = \underline{\hspace{6em}}$$

$$B = 20 \log \left(\frac{BWi}{1\text{ MHz}}\right) = \underline{\hspace{6em}} \text{ dB}$$

13. Repeat steps 2 through 12 for all resolution bandwidths of interest.

APPENDIX B

MAXIMUM BROADBAND SIGNAL LIMITATIONS WHEN HP 85685A RF PRESELECTOR IS NOT USED

MAXIMUM BROADBAND SIGNAL THAT CAN BE MEASURED WITHOUT FRONT END OVERLOAD

Impulse signals like those shown in Figure B-1 can overload the spectrum analyzer front end, even though the signal appears on the CRT to be far below full scale. The frequency spectrum of both of these signals has the general form shown in Figure B-2.

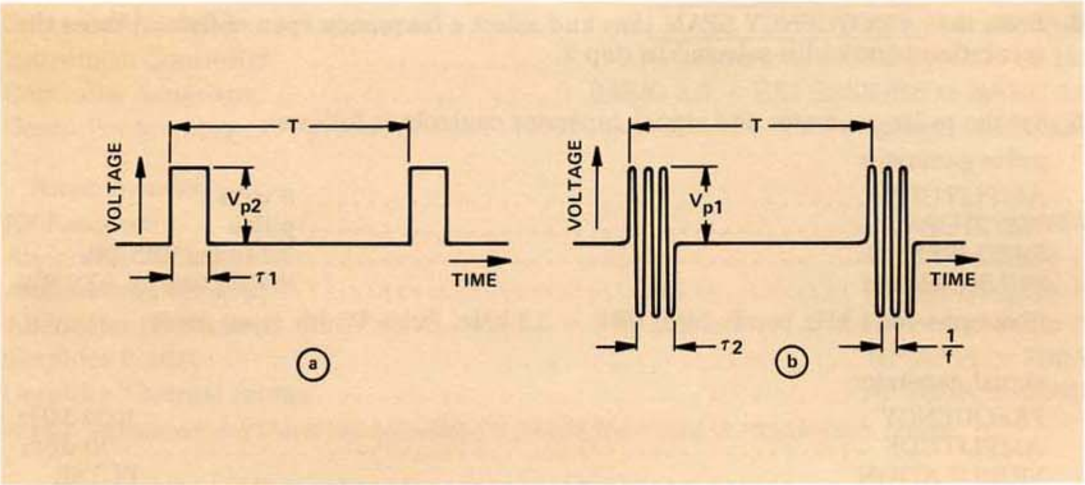


Figure B-1.

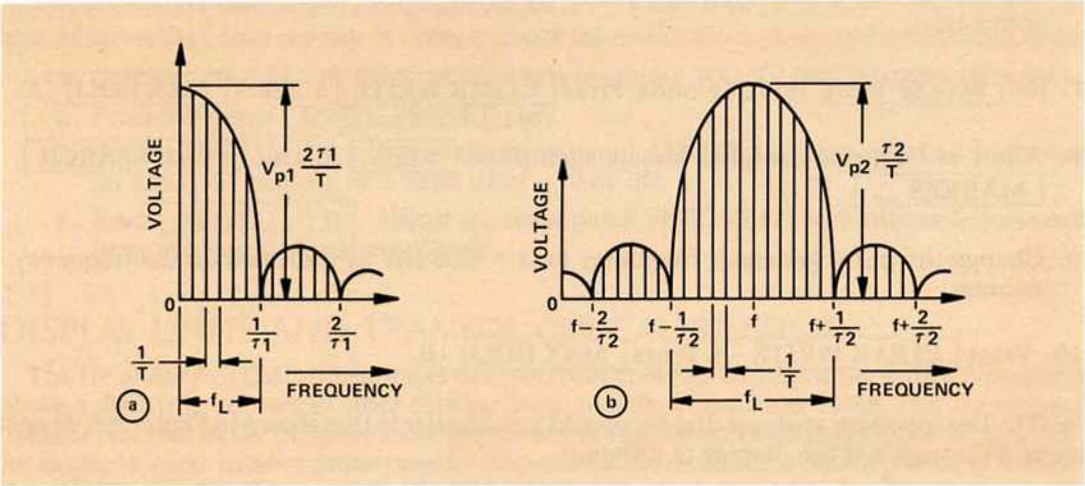


Figure B-2.

The maximum spectral intensity in rms volts is

for Figures B-1a, B-2a

$$S = \frac{V_{p1} * \tau_1 * 2}{T} * \frac{T}{\sqrt{2}} = \sqrt{2}\, V_{p1} * \tau_1 = \sqrt{2}\, \frac{V_{p1}}{f_L} \tag{8}$$

for Figures B-1b, B-2b

$$S = \frac{V_{p2} * \tau_2}{T} * \frac{T}{\sqrt{2}} = \frac{V_{p2} * \tau_2}{\sqrt{2}} = \sqrt{2}\, \frac{V_{p2}}{f_L} \tag{9}$$

Because of the broadband input of an unpreselected spectrum analyzer, the signal appears at the input mixer as shown in Figure B-1. The signal displayed at the CRT, however, appears as

$$V_{out} = S * BWi = \frac{V_p * \sqrt{2} * BWi}{f_L} \tag{10}$$

Therefore, when a narrow IF bandwidth is used, the impulse bandwidth BWi is narrow and the displayed voltage small.

The input voltage Vp (Figure B-1) necessary to overload the front end mixer (defined as the point where its conversion loss has increased 1 dB) is approximately

$$V_{pm} = 0.112\text{V rms (for both HP 8568B and 8566B)}$$

The width of the main lobe, f_L, can be determined from the spectrum analyzer's display of the signal.

When using logarithmic display and vertical calibration in terms of dBμV/MHz, the spectral intensity at which overload starts is from (8) and (9):

$$S = 20 \log \left(\frac{V_{pm}}{1\ \mu V} * \sqrt{2} * \frac{1\text{ MHz}}{f_L}\right) \tag{11}$$

The following table has been calculated from equation (11).

MAXIMUM BROADBAND SIGNAL WITH RESPECT TO MIXER OVERLOAD
(ADD INPUT ATTENUATION SETTING IN dB TO THE VALUES SHOWN)

Width of Signal Main Lobe f_L	Spectral Intensity Maximum dBμV/MHz
1 kHz	164
10 kHz	144
100 kHz	124
1 MHz	104
10 MHz	84
100 MHz	64
1000 MHz	44

Therefore from equation (10) we see that the maximum displayed signal with a 15 kHz impulse bandwidth and a 1 MHz main lobe width should not exceed:

$$\begin{aligned}\text{Max. displayed signal} &= S * BWi \\ &= \frac{S}{\text{dB}\mu\text{V/MHz}} + 20 \log \frac{BWi}{\text{MHz}} \\ &= 104\ \text{dB}\mu\text{V/MHz} + (-36.5\ \text{dB/MHz}) \\ \text{Max. displayed signal} &= 67.5\ \text{dB}\mu\text{V}\end{aligned}$$

Linearity Test

The linearity of the spectrum analyzer can be checked to insure that no overload has occurred by adding RF attenuation to the input and observing the change in displayed signal level.

APPENDIX C
LIST OF RECEIVER SYSTEM SENSITIVITIES

TABLE OF CW SENSITIVITIES

Broadband sensitivities are not listed. They can be obtained by subtracting the bandwidth factor B from the CW sensitivities given in the tables. The video bandwidth of the spectrum analyzer must be set to a value at least three times the resolution bandwidth setting to prevent any effect on the impulse bandwidth. B is found from the equation:

$$B = 20 \log \left[\frac{\text{impulse bandwidth}}{1 \text{ MHz}} \right]$$

Example: If the resolution bandwidth is 100 kHz, and the impulse bandwidth is 156 kHz, and the CW sensitivity is −95 dBm or +12 dBμV.

Broadband sensitivity is:

$$-95 \text{ dBm} - 20 \log \frac{156 \text{ kHz}}{1 \text{ MHz}} = -95 - (-16.1) = -78.9 \text{ dBm/MHz}$$

or

$$+12 \text{ dB}\mu\text{V} - 20 \log \frac{156 \text{ kHz}}{1 \text{ MHz}} = +28.1 \text{ dB}\mu\text{V/MHz}$$

HP 85685A RF Preselector and Spectrum Analyzer		
Frequency	**Noise Figure dB**	**Average Noise Level BW = 10 Hz**
20 Hz – 1 MHz	32 nominal	−132 dBm −25 dBμV
1 MHz – 1500 MHz	19 nominal	−145 dBm −38 dBμV
1.5 GHz – 2 GHz	24 nominal	−140 dBm −33 dBμV

HP 8568A/B Spectrum Analyzer Alone			
Frequency	**Noise Figure**	**Average Noise Level**	
	dB	**BW = 3 MHz**	**BW = 10 Hz**
500 Hz – 1 MHz	52	−57 dBm +50 dBμV	−112 dBm −5 dBμV
1 MHz – 1500 MHz	29	−80 dBm +27 dBμV	−135 dBm −28 dBμV

HP 8566A/B Spectrum Analyzer Alone			
Frequency	**Noise Figure**	**Average Noise Level**	
	dB	**BW = 3 MHz**	**BW = 10 Hz**
1 MHz – 2500 MHz	30	−79 dBm +28 dBμV	−134 dBm −27 dBμV
2 GHz – 5.8 GHz	32	−77 dBm +30 dBμV	−132 dBm −25 dBμV
5.8 GHz – 12.5 GHz	39	−70 dBm +37 dBμV	−125 dBm −18 dBμV
12.5 GHz – 18.6 GHz	45	−64 dBm +43 dBμV	−119 dBm −12 dBμV
18.6 GHz – 22 GHz	50	−59 dBm +48 dBμV	−114 dBm −7 dBμV

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For more information, call your local HP sales office listed in the telephone directory white pages. Ask for the Electronic Instruments Department. Or write to Hewlett-Packard: **U.S.A.** — P.O. Box 10301, Palo Alto, CA 94303-0890. **Europe** — P.O. Box 999, 1180 AZ Amstelveen, the Netherlands. **Canada** — 6877 Goreway Drive, Mississauga, L4V 1M8, Ontario. **Japan** — Yokogawa-Hewlett-Packard Ltd., 3-29-21, Takaido-Higashi, Suginami-ku, Tokyo 168. Elsewhere in the world, write to Hewlett-Packard Intercontinental, 3495 Deer Creek Road, Palo Alto, CA 94304.

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