TECHNIQUES FOR MEASURING NARROWBAND AND BROADBAND EMI SIGNALS USING SPECTRUM ANALYZERS

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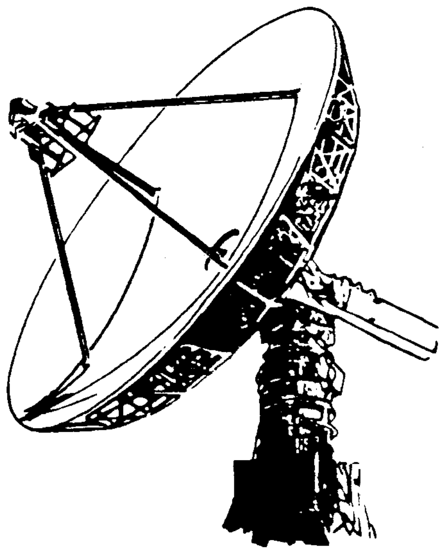

ABSTRACT: The versatility of spectrum analyzers allows electromagnetic interference (EMI) signals to be displayed in a variety of ways for the analysis of specific signal characteristics. Two signal types of particular interest are those classified as narrowband (NB) and broadband (BB) signals. These signals originate from a variety of sources and have different EMI potential. This paper first provides definitions for NB and BB signals and discusses the difficulties involved in measuring each type. The second part of the paper explains how spectrum analyzer controls and detection modes can be used to characterize signals as NB or BB. Finally, commonly-used methods for discriminating between NB and BB signals in both commercial and military testing are discussed, and the implementation of these methods using a spectrum analyzer is described.

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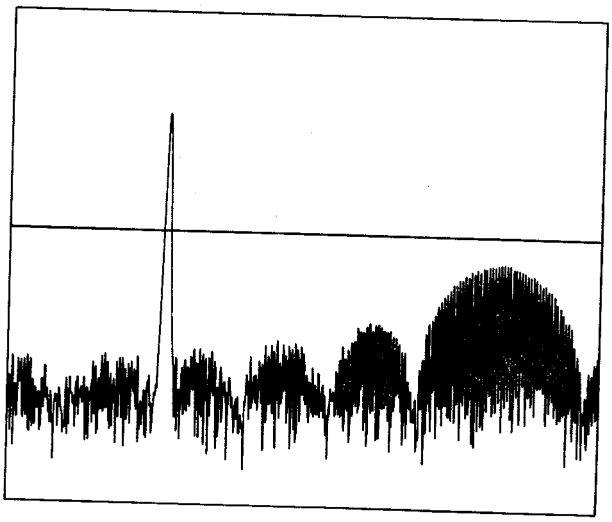


The proper interpretation of signal characteristics depends on an understanding of the measuring instrument used and its control settings. The versatility of spectrum analyzers allows signals to be displayed in a variety of ways for analysis of specific signal characteristics.

Two signal types of particular interest are those classified as Narrowband and Broadband signals. These signals originate from a variety of sources and have different electromagnetic interference (EMI) potential.

ANALYSIS OF NARROWBAND AND BROADBAND SIGNALS

NB/BB SIGNAL CLASSIFICATION

- DEFINITIONS
- COMMERCIAL AND MIL-STD REQUIREMENTS
- MEASUREMENT DIFFICULTIES

SPECTRUM ANALYZER PARAMETERS

- ATTENUATION
- BANDWIDTH
- DETECTION

SPECTRUM ANALYZER APPLICATIONS

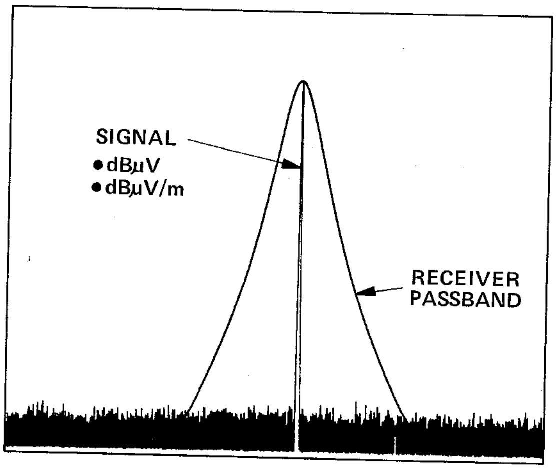
- COMMERCIAL & MIL-STD MEASUREMENTS
- METHODS OF NB & BB SIGNAL ANALYSIS

Today's presentation is divided into three parts. In the first part some background material and definitions will be given on signals classified as narrowband (NB) and broadband (BB).

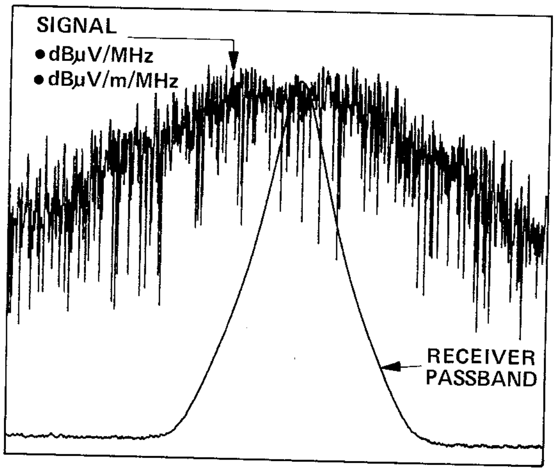
The second part explains spectrum analyzer controls and detection modes and their use in characterizing signals as NB or BB.

Finally, part three describes commonly used NB and BB discrimination methods (Commercial and Military) and their implementation on a spectrum analyzer.

NARROWBAND AND BROADBAND SIGNAL CLASSIFICATION



NARROWBAND SPECTRUM



BROADBAND SPECTRUM

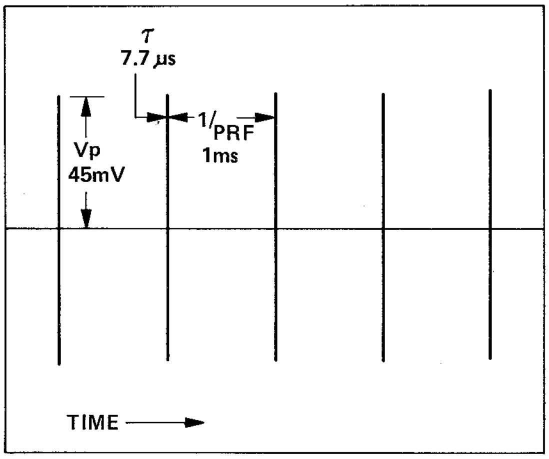
The classification of a signal as either NB or BB is dependent on the signal's occupied frequency spectrum relative to the bandwidth (resolution bandwidth) of the measuring instrument.

Emissions occupying a narrow frequency spectrum relative to the resolution bandwidth are defined as "narrowband". An example of a NB signal is a CW signal.

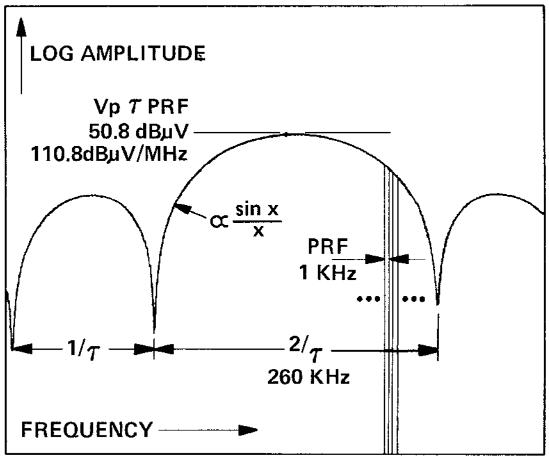
Emissions occupying a broad frequency spectrum relative to the resolution bandwidth are characterized as "broadband". Sources of BB signals can be: impulsive emissions from automobile ignition systems, digital circuits, switching power supplies and random noise.

Common measurement units for NB signals are dBuV (dB above 1 uV) and dBuV/m (field strength). BB emissions measurements require normalization to a reference bandwidth (e.g., 1 MHz). Common BB measurement units are dBuV/MHz and dBuV/m/MHz (field strength).

NB/BB SIGNAL EXAMPLE:
REPETITIVE RF IMPULSES



TIME FUNCTION



FREQUENCY SPECTRUM

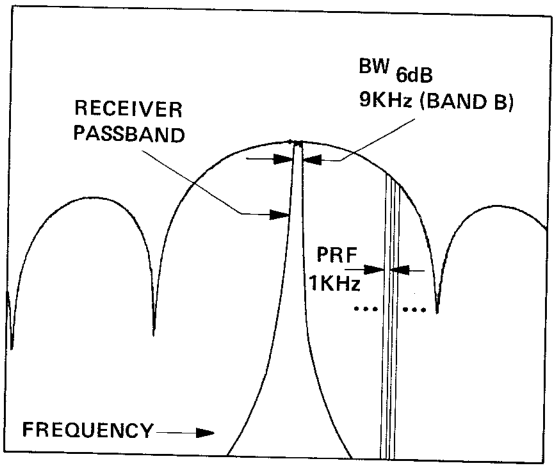
To illustrate the concept of NB and BB signals a repetitive impulse signal will be used.

A repetitive RF pulse in the time domain with pulse width τ , pulse period T (T=1/PRF) and peak amplitude Vp is represented in the frequency domain by a sin x/x envelope. The spacing between the envelope nulls (2nd, 3rd,...lobe) is $1/\tau$, the reciprocal of the pulse width. The maximum amplitude of the main lobe is Vp τ PRF.

COMMERCIAL METHOD FOR EMISSIONS MEASUREMENTS

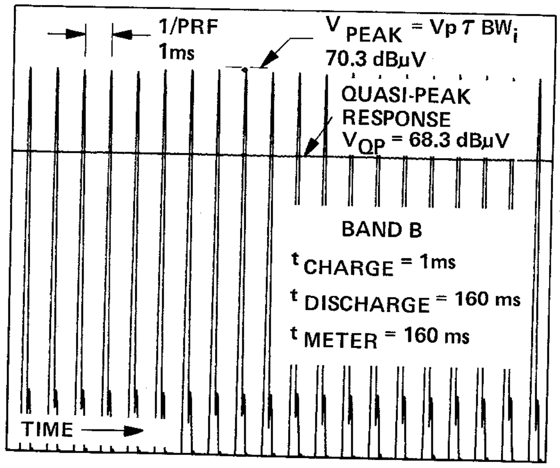
1) SINGLE LIMIT FOR NB & BB SIGNALS

2) SPECIFIED RECEIVER PASSBAND CHARACTERISTICS



9 KHz (-6dB) PASSBAND FOR BAND B (.15-30 MHz)

3) SPECIFIED DETECTOR CHARACTERISTICS: QUASI-PEAK

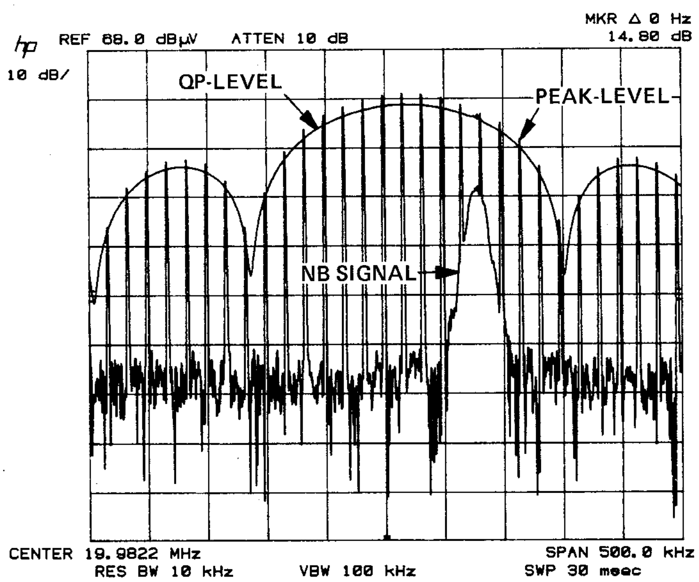


QUASI-PEAK RESPONSE FOR 1 KHz PRF IN BAND B

Commercial regulating agencies (e.g., FCC, VDE) use an emission measurement method which is based on CISPR (Special International Committee on Radio Interference) recommendations. The CISPR method specifies the measuring receiver passband and detector characteristics.

This detector, called a Quasi-Peak detector (or CISPR detector) has specific charge, discharge and meter movement time constants (e.g., t_{charge} = 1 ms, $t_{discharge}$ = 160 ms, t_{meter} = 160 ms). The response of the Quasi-Peak detector is dependent on the pulse repetition frequency (PRF) of the input signal. Signals with a low PRF are considered less "annoying" and therefore have a lower Quasi Peak detector response. Quasi-peak detection and peak detection will have the same response for a CW signal.

QUASI-PEAK DETECTOR MASKS LOWER AMPLITUDE NARROWBAND SIGNAL

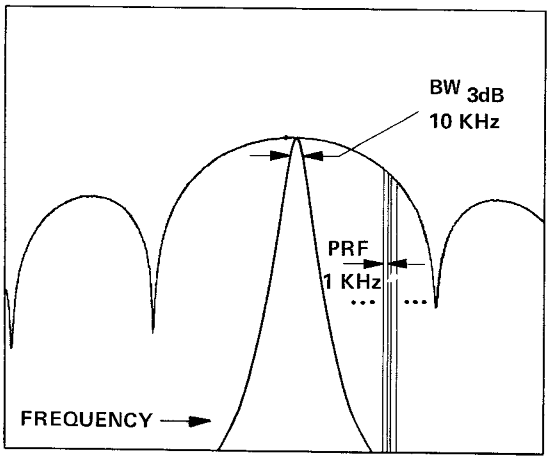


However, specifying the exact receiver characteristics as done in commercial emissions measurements and setting one limit does not guarantee a minimum interference potential. Take the case of a low level CW signal (NB) in the presence of a relatively high impulsive signal (BB). The quasi-peak level meets emissions requirements, but the lower level CW signal can cause considerable interference.

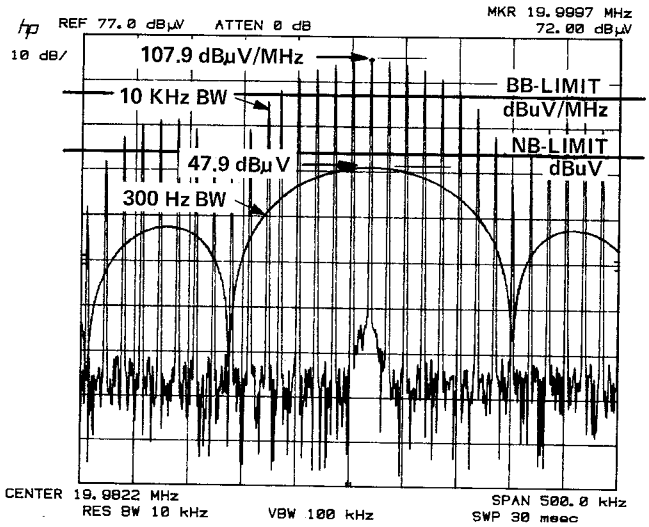
Because of this potential interference problem, agencies regulating emissions on commercial products are considering additional limits and tests to distinguish between NB and BB signals.

MIL–STD METHOD FOR EMISSIONS MEASUREMENTS

1) SEPERATE LIMITS FOR NB & BB SIGNALS
2) SPECIFIED DETECTOR CHARACTERISTIC: PEAK
3) UNSPECIFIED MEASUREMENT BANDWIDTH



BANDWIDTH SELECTION DETERMINES MEASURED SIGNAL AMPLITUDE



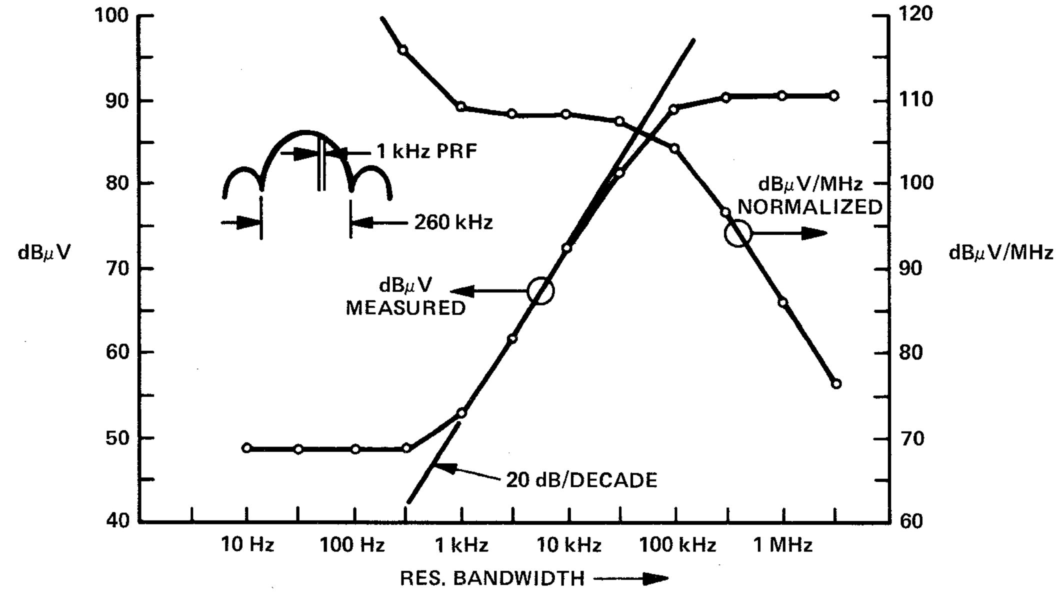
COMPARE MEASURED SIGNAL AMPLITUDE TO NB & BB LIMITS

Unlike the commercial measurement approach, military methods require distinguishing between NB and BB signals. In MIL-STD 461A/B, NB and BB signals have separate limits.

When a signal is determined to be NB its absolute level is determined in dB above 1uV (dBuV) and compared to the NB limit. If a signal is determined to be BB its level must be normalized to a reference bandwidth according to 20 log (BW_i/1 MHz), where BW_i is the impulse bandwidth of the measuring instrument used. This correction factor and BB discrimination methods will be discussed further.

Peak Detection is required for all Military (MIL-STD 461A/B) measurements.

MEASURED SIGNAL AMPLITUDE DEPENDS ON RECEIVER BANDWIDTH

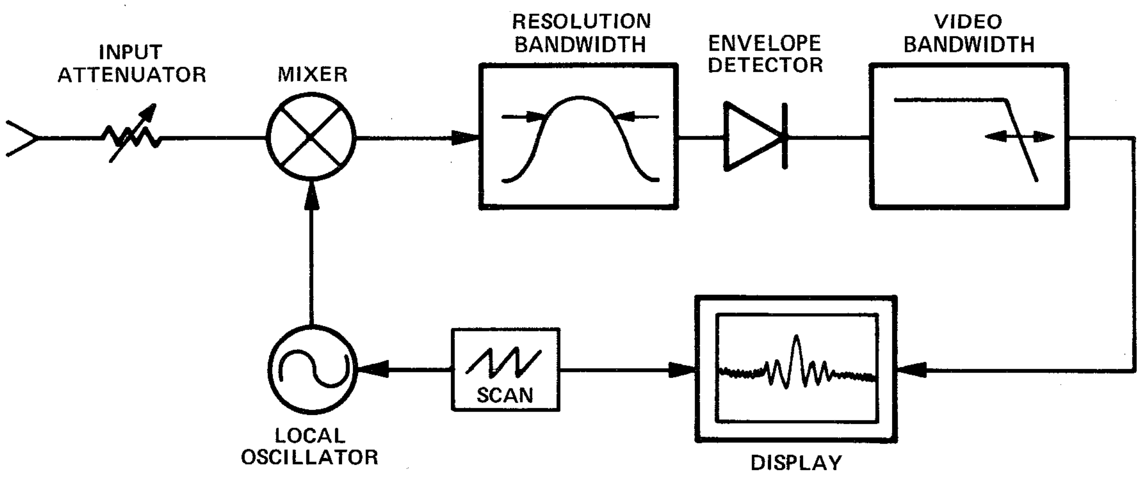


A signal of repetitive RF impulses will give greatly different amplitude readings depending on the receiver resolution bandwidth used.

At narrow bandwidth settings individual spectral lines are measured. As the receiver bandwidth increases more of the signal spectrum is captured with a resulting increase in amplitude reading. Finally, all the signal spectrum is contained within the receiver passband and no further increase in measured amplitude occurs.

When the measurements are normalized to a 1 MHz bandwidth, the resulting spectral intensities in dB uV/MHz also change with bandwidth except for a few bandwidth settings. It becomes difficult, if not arbitrary, which bandwidth to choose for comparing the measured signal to the BB-limit level.

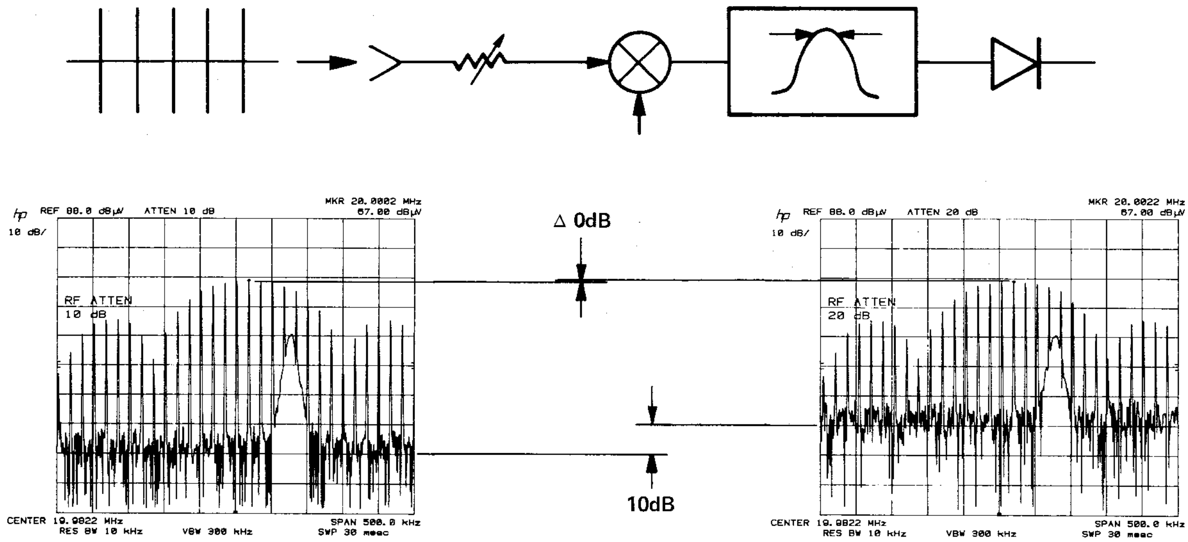
SPECTRUM ANALYZER BLOCK DIAGRAM



- INPUT ATTENUATOR
- RESOLUTION BW
- DETECTION METHODS
- VIDEO BW
- SCAN RATE

Let's look at some important spectrum analyzer parameters which are useful to diagnose NB and BB emission. In the block diagram above, going from left to right, we will review the diagnostic uses of the Input Attenuator, Resolution BW filters, Detection Methods, Video BW filters and variable Frequency Scan Rates.

MIXER OVERLOAD
BY BROADBAND SIGNALS
ATTENUATOR TEST



10 dB ATTENUATION

20 dB ATTENUATION

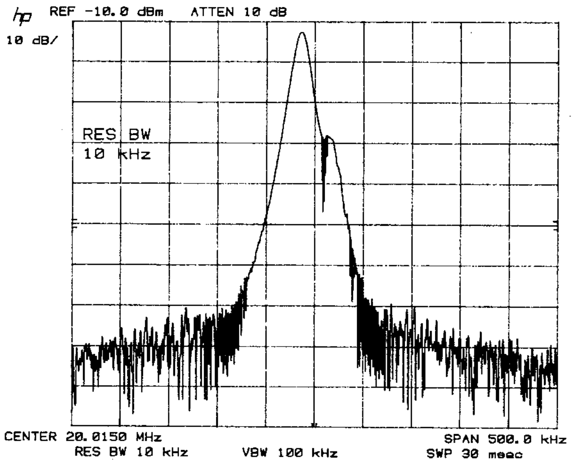
The spectrum analyzer input attenuator (internal) can be used to determine if BB signals at the input are causing input mixer overload.

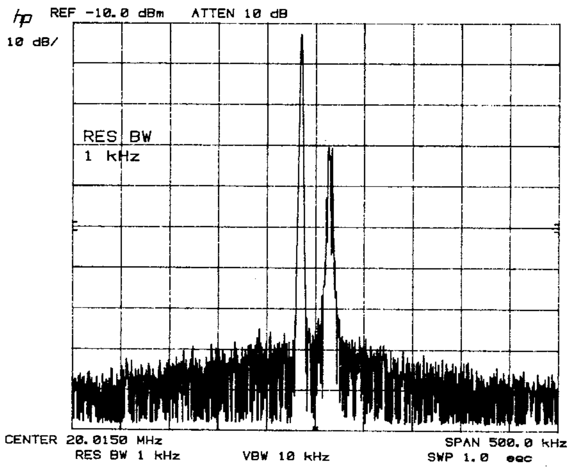
If the attenuation is increased 10 dB the measured signal amplitude on the spectrum analyzer display should not change. An increase in measured amplitude would indicate that the mixer was gain compressing. A signal decrease indicates internally generated harmonic distortion. The spectrum analyzer noise floor will increase by a corresponding 10 dB indicating a reduction in measurement sensitivity. For accurate BB and NB measurements enough input attenuation should be used to get a constant display.

Using an external attenuator enough attenuation should be used to obtain a corresponding dB display change for each dB change in external attenuation.

diagram assumes front-end atten coupled to IF gain

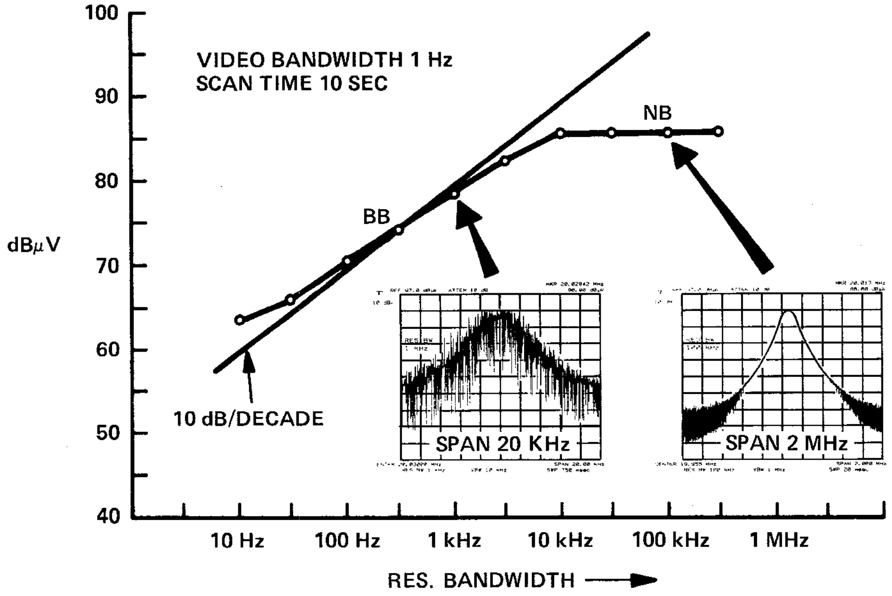
RESOLUTION BANDWIDTH





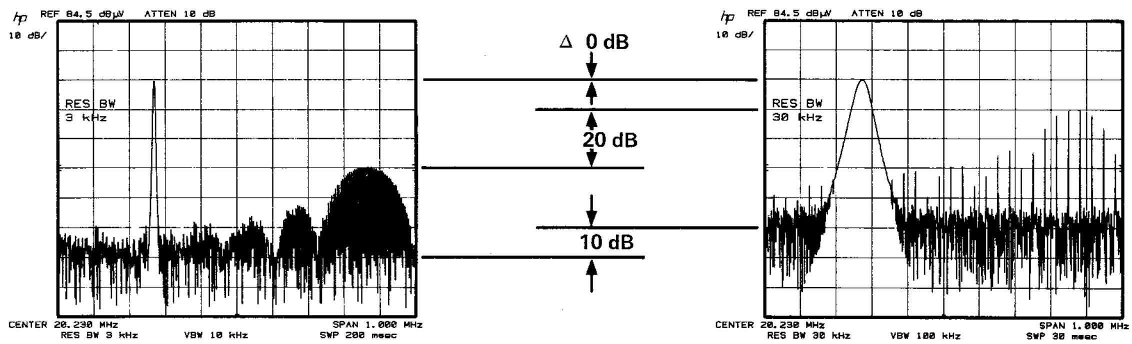
The primary purpose for having a sequence of resolution bandwidth filters in the spectrum analyzer is to be able to resolve adjacent signals of different frequency separations.

THE EFFECT OF RESOLUTION BANDWIDTH ON DIFFERENT TYPES OF SIGNALS



Signals are classified as NB (e.g., CW) if they show no change in maximum displayed amplitude with changes in spectrum analyzer bandwidth. Broadband signals (e.g., noise) however, do exhibit amplitude changes in maximum displayed amplitude as the bandwidth is changed. The resolution bandwidth test is one technique to distinguish between NB and BB signals.

THE EFFECT OF RESOLUTION BANDWIDTH ON DIFFERENT TYPES OF SIGNALS

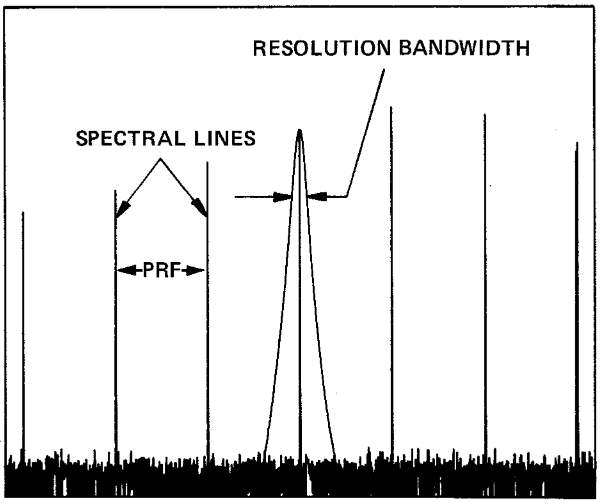


Broadband signals fall into two categories: Impulsive BB and random BB.

- Impulsive BB signals have frequency components which are time coherent (i.e., fixed phase relationships).
- Random BB signals are not time coherent. They are incoherent because they originate from unrelated sources.

Because impulsive signals have voltage vectors which are time coherent and add in-phase, a 10 times change in resolution BW results in a 20 log (Δ BW), or a 20 dB change in amplitude. Random signals, such as noise, do not have voltage vectors in-phase. A 10 times change in resolution BW results in 10 log (Δ BW), or a 10 dB change in amplitude. The peak amplitude of a CW signal does not change with resolution BW.

NARROWBAND SIGNALS ARE DISPLAYED AS SPECTRAL LINES



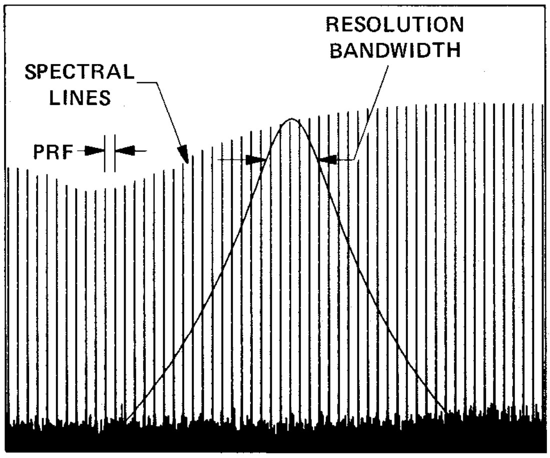
TESTS FOR SPECTRAL LINE MODE:
1. LINE SPACING CHANGES WITH FREQUENCY SPAN
2. DISPLAYED AMPLITUDE INDEPENDENT OF RESOLUTION BANDWIDTH
3. LINE SPACING INDEPENDENT OF SWEEP TIME

Signals are characterized as NB with respect to the spectrum analyzer resolution bandwidth when there is only one spectral component of the signal contained within the filter bandpass. Thus, each spectral component, or line, is individually resolved. The signal is then being viewed on the spectrum analyzer in what is described as the Spectral Line Mode. Three independent tests to determine that a signal is being viewed in the Spectral Line Mode are:

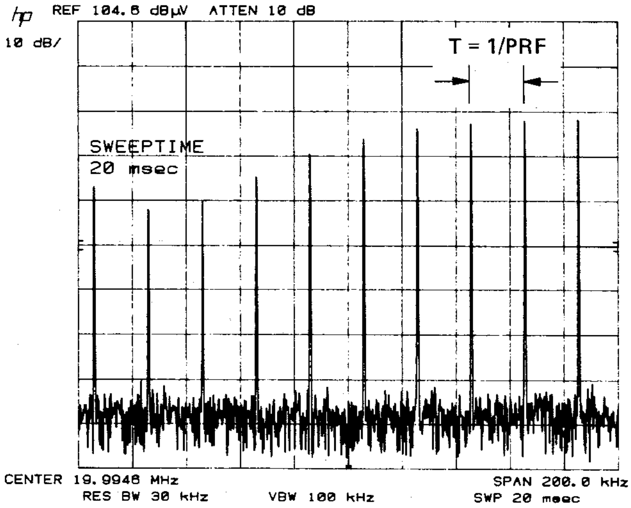
1) Change the SA Span; the displayed line spacing will change.
2) Change the SA Resolution BW; the peak amplitude will remain the same.
3) Change the SA Sweep Time; the line spacing will remain the same.

The PRF is simply the spacing in frequency between two spectral lines.

A LOW PRF SIGNAL WITH MORE THAN ONE SPECTRAL LINE IN THE PASSBAND OF THE ANALYZER



PRF = 500 Hz

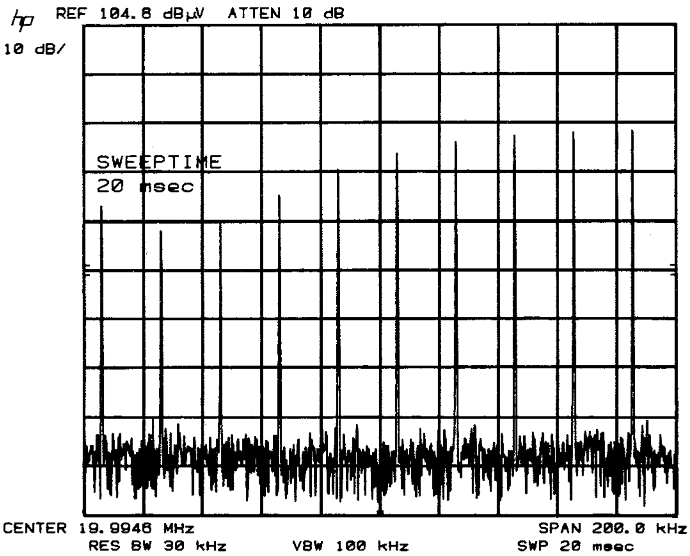


Signals with low PRF's can have many spectral lines within the resolution bandwidth. The analyzer therefore will not resolve individual spectral lines.

The analyzer display appears as a sequence of pulses with amplitudes which are proportional to the envelope of the BB Spectrum. With the analyzer tuned to a particular frequency, the spectral lines contained within the impulse bandwidth around that tuning frequency will add periodically at a rate corresponding to the signal's PRF. As the analyzer is tuned to a different frequency, the maximum pulse amplitude will change in relation to the change in the envelope of the pulse spectrum.

A scanning analyzer will therefore display a pulse every 1/PRF seconds with an amplitude proportional to the spectrum envelope amplitude at the frequency to which the analyzer is tuned.

BROADBAND SIGNALS ARE DISPLAYED AS TIME DOMAIN PULSES



TESTS FOR PULSE MODE

1. PULSE SPACING INDEPENDENT OF FREQUENCY SPAN
2. DISPLAYED AMPLITUDE CHANGES WITH RESOLUTION BANDWIDTH
3. PULSE SPACING CHANGES WITH SWEEP TIME

Broadband signals with more than one spectral line within the bandwidth of the analyzer are displayed as time domain pulses. To determine if the signal is displayed in the Pulse Mode, the same tests that were used for the spectral Line Mode may be applied:

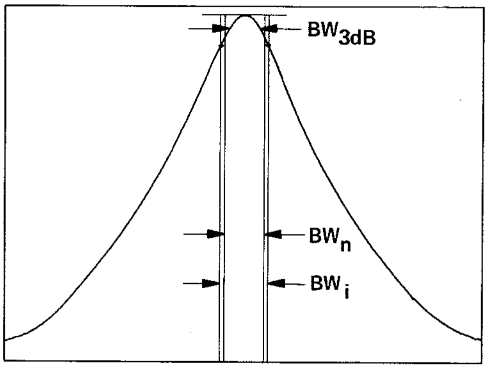
- First, the pulse spacing is independent of Frequency Span because it is a time phenomenon. A response occurs for every pulse at the input to the analyzers.

- Second, the displayed amplitude changes with Resolution Bandwidth. In the pulse mode, the number of spectral components in the passband changes with bandwidth; therefore, the pulse amplitude is proportional to the number of spectral components in the passband.

- Finally, pulse spacing changes with Sweep Time. Since the responses occur at the PRF, the time between each response is the period (T) and the PRF may be calculated as 1/T. If the sweep of the analyzer is not synchronized with the PRF, the responses will move on the display.

While the responses on the CRT result from a time phenomenon, the envelope nevertheless remains a frequency phenomenon provided the spectrum envelope is essentially constant within the analyzer's passband. Therefore, we can determine pulse width from the shape of the displayed envelope.

IMPULSE AND NOISE BANDWIDTH VS. RESOLUTION BANDWIDTH



- IMPULSE BANDWIDTH BW_i IS BANDWIDTH OF RECTANGULAR FILTER WITH SAME PEAK-VOLTAGE PULSE RESPONSE AS ACTUAL FILTER
- NOISE BANDWIDTH BW_n IS BANDWIDTH OF RECTANGULAR FILTER WITH SAME NOISE POWER OUTPUT AS ACTUAL FILTER

FOR SYNCHRONOUSLY TUNED FILTERS:

$BW_i = 1.6\ BW_{3dB}$

$BW_n = 1.1\ BW_{3dB}$

The absolute amplitude measurement of BB signals requires knowledge of the effective analyzer bandwidth in order to normalize the measured amplitude to that of a reference bandwidth.

For coherent BB signals which change 20 dB in amplitude for a factor of 10 change in bandwidth, the measured values are normalized by adding 20 log (BW_i/BW_{REF}) dB. In the case of military (MIL-STD) emissions measurements the reference bandwidth (BW_{Ref}) chosen is 1 MHz. The corrected levels in dB uV/MHz are then compared to the appropriate BB limit.

Random BB signals, such as noise, which exhibit 10 dB amplitude changes for factor 10 changes in bandwidth require correction by adding 10 log (BW_n/BW_{REF}) dB. The reference bandwidth chosen is typically 1 Hz and signals are recorded in units of dBm/Hz or dBuV/$\sqrt{Hz}$.

Note:

1) For absolute amplitude measurements of coherent BB signal the video bandwidth should be set $\geq 10\ BW_{3dB}$ to accurately obtain the peak pulse amplitude.

2) For random BB signals the video bandwidth is set sufficiently smaller than the resolution bandwidth to smooth out signal fluctuations.

DETECTION METHODS

	MILITARY	COMMERCIAL
PEAK	X	
QUASI-PEAK		X
AVERAGE	X	X

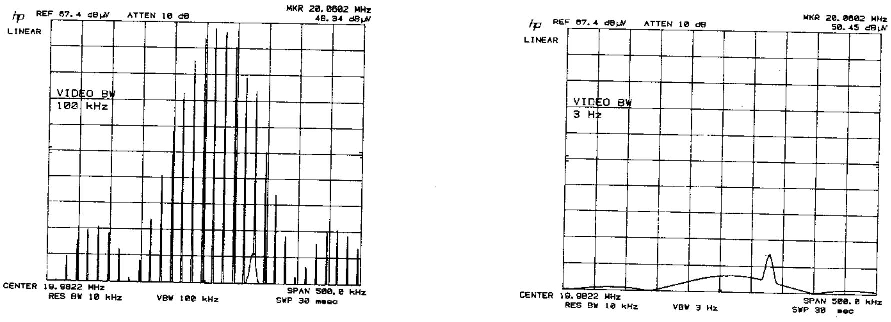
Peak values are obtained when the spectrum analyzer post detection filter (video filter) is set wider than the resolution bandwidth filter. The peak measurement is defined as the measured peak voltage referenced to the RMS value of a sinusoidal calibration signal. Peak detection is the spectrum analyzer's normal detection mode and the most common detection method used to evaluate electromagnetic emissions. Peak detection is used for MIL-STD measurements and commercial diagnostic testing and allows for the fastest measurement time.

For commercial compliance measurements quasi-peak detection is specified and requires the use of the CISPR detector previously discussed. However, peak detection can be used instead because it will always give the worst case (highest) emission level when compared to quasi-peak. If emission levels meet requirements using peak detection, then a quasi-peak measurement is not necessary.

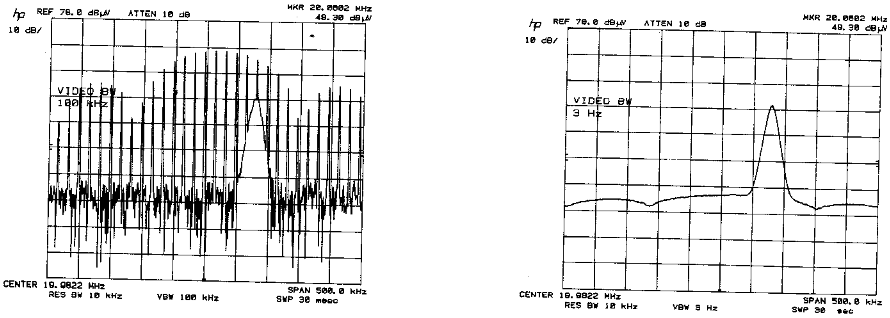
Average detection is obtained using video filtering in the linear amplitude display mode.

VIDEO FILTERING

1. AVERAGE DETECTION IN LINEAR AMPLITUDE MODE



2. DISPLAY SMOOTHING IN LOG AMPLITUDE MODE

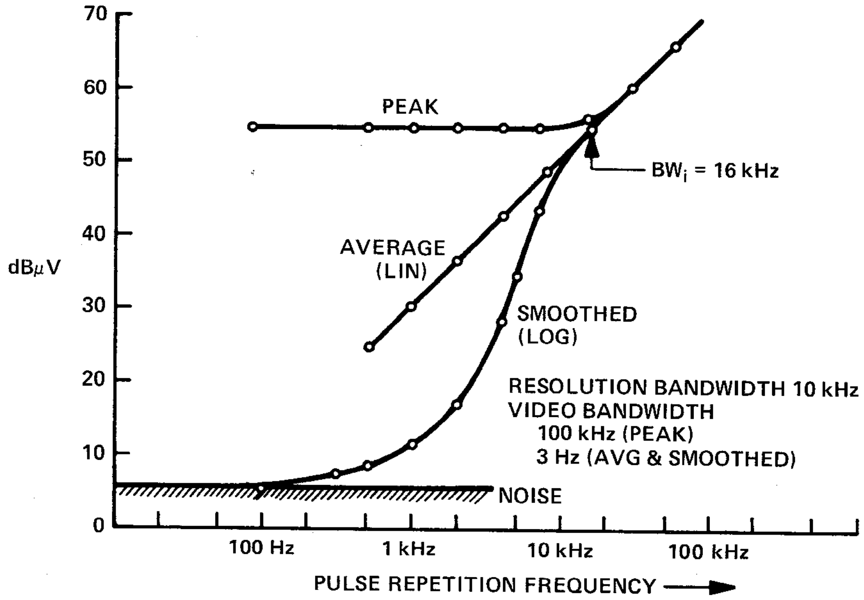


Video (post detection) filtering provides averaging of the higher frequency components (such as noise) at the output of the envelope detector. When the video filter bandwidth is narrower than the resolution bandwidth filter, averaging occurs. Narrowband (e.g., CW) signal amplitudes are not affected by video filtering.

For the true average, the Video BW must be less than the lowest PRF, the frequency sweep must be slow enough to let the filters charge completely and the spectrum analyzer must be in the Linear amplitude display mode.

With the analyzer in the Log amplitude mode, video filtering greatly reduces the amplitude of the impulsive and random broadband signals. The amplitude of narrowband signals is unaffected as shown above.

POST DETECTION VIDEO FILTERING OF IMPULSIVE SIGNALS



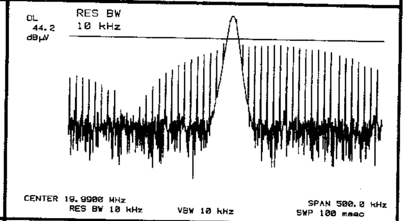
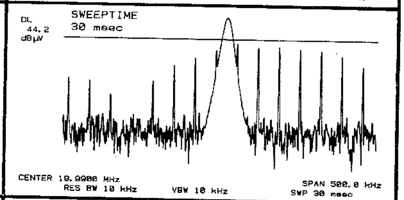
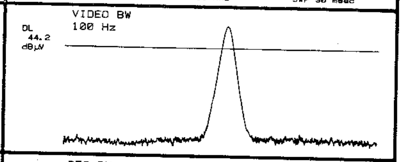
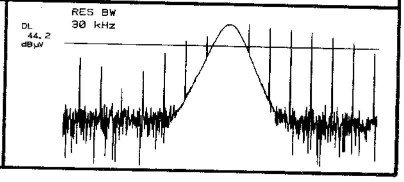
With the analyzer in Linear amplitude mode, video filtering provides the average value of a signal.

In the log amplitude mode the analyzer's video filter smoothes the logarithmically distorted detector output signal.
For BB impulsive signals the smoothed indication is considerably lower than the average value of the impulses. This smoothing effect allows more accurate measurement of the NB component in a mixed NB/BB spectrum. Furthermore, the measurement dynamic range is larger in log mode so that even low level NB signals in the presence of larger amplitude BB signals can be measured.

The video bandwidth needs to be reduced only to the point where the rapid fluctuations of the signal are smoothed. Further reduction will not change the measured value but will increase the required settling, analysis and measurement times.

Note that the ratio of peak to average voltage for a BB impulsive signal with known PRF is the same as the ratio of the receiver impulse bandwidth to the PRF: $V_{peak}/V_{avg}=BW_i/PRF$. This allows for easy determination of BW_i (Example above.)

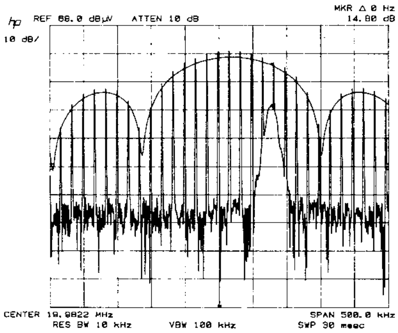
METHODS FOR NB AND BB ANALYSIS

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	

The above methods can easily and quickly be used with a spectrum analyzer to determine if a signal is NB or BB relative to the spectrum analyzer bandwidth.

- Tuning Test - Tune ("look") away $\pm$ Δ BW_i and observe changes in the signal's displayed amplitude
- PRF Test - Use the Sweep Time control (or Span or Res BW) to determine if the signal is being displayed in the Line Mode or Pulse Mode.
- Peak vs. Average- Select a Video BW 3 to 10 times narrower than the resolution BW selected and observe smoothing of BB signals.
- Bandwidth Test - Increase or decrease the Resolution BW and observe amplitude changes of the signals. Changes in amplitude indicate that the signal is BB relative to the spectrum analyer bandwidth.

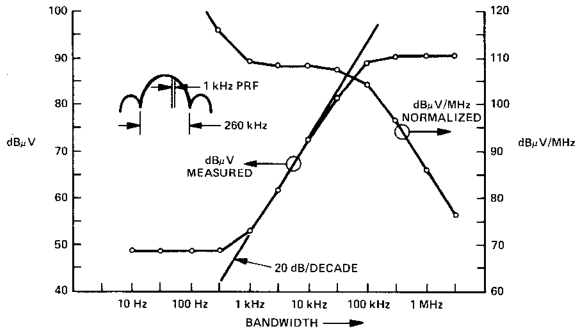
EMI MEASUREMENT DIFFICULTIES



COMMERCIAL

LOW LEVEL NB AND BB SIGNAL

- SA DISPLAY USING PEAK DET
- VIDEO FILTERING FOR AVERAGE DET
- LOG AMPLITUDE FOR INCREASED DYNAMIC RANGE



MIL-STD

NB/BB SIGNAL DISCRIMINATION

- WIDE RANGE OF BW'S AVAILABLE
- FOUR NB/BB DISCRIMINATION METHODS

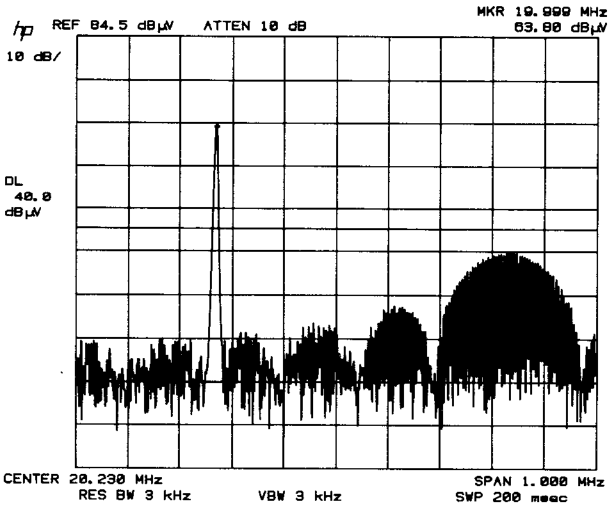
As we have seen, performing Commercial or Military emissions tests can result in unique measurement difficulties.

For Commercial EMI measurements, low level NB (CW) signals with serious interference potential can be "masked" by impulsive signals when Quasi-Peak detection is used. Peak detection allows both NB and BB signals to be observed on the spectrum analyzer display. NB signals can be further "enhanced" on the SA display by using video filtering, especially in the Log amplitude display mode.

Military EMI measurements (MIL-STD 461A,B/462) which require the discrimination between NB and BB signals seldom specify BW's for these measurements. As shown, the normalized BB measurement results are constant only over a specific BW range. The spectrum analyzer's range of BW's and the CRT display aid in the selection of the proper BW's for the measurement of BB signals. Also, the NB/BB analysis methods of Tuning Test, PRF Test, Peak vs. Average Detection and Bandwidth Test can be quickly performed.

Note: SAE-AE4 (formerly Society of Automotive Engineers) is presently reviewing MIL-STD 462 and considering a proposal to establish specific measurement BW's and a single limit to replace the NB and BB emissions limits.

TECHNIQUES FOR MEASURING NARROWBAND AND BROADBAND EMI SIGNALS USING SPECTRUM ANALYZERS



In conclusion, all the NB and BB signal analysis methods described here can be performed easily using a spectrum analyzer. These methods can quickly provide information about NB and BB signal characteristics for both diagnostic and compliance emission measurements.

References

Commercial Test:

1) FCC Rules & Regulations, Vol. II, July 1981, Part 15, Radio Frequency Devices, Sub part J, Appendix A, Section 4.2.2.

2) CISPR Recommendation for Data Processing Equipment and Electronic Office Machines: Limits of Interference and Measurement Methods. (March 1984, Draft in process)

3) Hewlett-Packard Product Note 85650A-1

MIL-STD Test:

3) MIL-STD-462 Application Note: Identification of BB and NB Emissions, 5/1980, Electromagnetic and Interference Compatibility Branch, Wright-Patterson Air Force Base, Ohio 45433.

4) R.B. Cowdell, An analysis of MIL-STD-462 Applicaton Note: Identification of BB and NB Emissions, IEEE Symposium 1983, CH 1838-2/83/0000-0038.

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