Power Spectral Density Measurement Techniques

Presentation to TIA Committee TR41.9
TR41.9-00-02-010
February 22, 2000
Peter Walsh, NCE
Title: Power Spectral Density Measurement Techniques

ABSTRACT: This contribution is offered as an informative presentation on the fundamentals of power spectral density (PSD) including its relationship to total signal power and various measurement techniques.

NOTICE

This contribution has been prepared as general information to TR41.9 Committee Members. The information contained herein is offered as a basis for discussion and should not be misconstrued as an endorsement of any test equipment used to produce the illustrative results or as specific proposal to define a preferred test procedure. Paradyne Corporation specifically reserves the right to add to, amend, or withdraw any statements contained herein.

The contributor grants a free, irrevocable license to the Telecommunications Industry Association (TIA) to incorporate text contained in this contribution and any modifications thereof in the creation of a TIA standards publication; to copyright in TIA’s name any TIA standards publication even though it may include portions of this contribution; and as TIA’s sole discretion to permit others to reproduce in whole or in part the resulting TIA standards publication.
What is Power Spectral Density?

- Recall from High School Physics that density is mass per unit volume. As an example, the approximate density of water is 1 g/cm³, so 100 cubic centimeters of water weighs 100 grams.

- Power Spectral Density (PSD) is simply average noise power per unit of bandwidth. Power is expressed in units of watts. In telephony measurements, power is commonly expressed in logarithmic terms with respect to a milliwatt, i.e., dBm. The unit (volume) of bandwidth is 1 Hz. So PSD may be expressed as dBm/Hz, pronounced, “dBm per Hz.”
How Does PSD Relate to Total Power?

Broadband Access Solutions

- PSD is to Total Power as Density is to Weight.

- All transmission systems have finite power and bandwidth. Let’s consider an ideal system with the following PSD signature.

- At each frequency between 1 and 6 Hz, the PSD is a flat -10 dBm/Hz, or 0.1 mW/Hz. 
  \[ P_{mW} = \log_{10}(P/10), \text{ where } P \text{ is Power in dBm} \]

- System has a bandwidth of 5 Hz, so the total average power can be calculated:
  
  \[ \text{Power} = \text{PSD} \times \text{Bandwidth} = 0.1 \text{ mW/Hz} \times 5 \text{ Hz} \]
  
  \[ \text{Power} = 0.5 \text{ mW} \]
  
  \[ \text{Power (dBm)} = 10 \log( P_{mW} ) = 10\log(0.5) = -3.0 \text{ dBm} \]

- For systems with a nominally flat PSD profile, the following formula may be used:
  
  Total Power = PSD + 10\log(\text{Bandwidth in Hz})
How is PSD Measured?

- PSD is measured using a spectrum analyzer with a balanced input.
- Balanced input can come from a balun transformer or differential amplifier probe bridged with a resistive termination, e.g. 135 ohms.
- Standard will usually specify the resolution bandwidth, e.g. 10 kHz.
- Spectrum Analyzer measures the average value of the total noise power quantized within its bandwidth by making several (100) measurements and computing a corrected average figure of noise density normalized to a 1 Hz bandwidth.
- PSD reading will be accurate if the noise spectrum is relatively flat over the resolution bandwidth and the noise is random.
- PSD may be measured on a discrete frequency or swept frequency basis.
Differential Amplifier versus Balun
Which is Better?

- The is no clear winner as each has its advantages and disadvantages.
- Use either one but be aware of their effects upon the measurement.
- Diff. Amps have a limited dynamic range.
- Diff. Amps when used with a precision resistive load may yield more accurate readings across the entire frequency range.
- Balun transformers have insertion loss that varies over frequency.
- Balun can allow for direct readings without having to apply an impedance correction factor: $\text{dB}_{\text{corr.}} = 10\log(Z_{\text{ref.}} / Z_{\text{meas.}})$.
- Both afford high common mode rejection, essential to making low level PSD measurements, e.g. $< -90 \text{ dBm/Hz.}$
Two Basic Test Configurations - With or Without a Companion Device

- When testing without a companion device, the EUT is directly connected to the prescribed termination, e.g. 135 ohms, and conditioned to transmit its spectrum continuously.
- This method is preferred but not all systems support this mode.
- When testing with a companion device, care must be taken to minimize its effects upon the measurement. You can’t simply connect the units back-to-back as the companion unit will contribute unwanted signal power and also, the companion unit will probably not present an ideal terminating impedance over the wide range of frequencies that must be checked.
- An artificial line may be used to achieve some degree of isolation.
### Example of Discrete Frequency PSD Measurements on an ISDN Basic Rate Transceiver

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>PSD Limit (dBm/Hz)</th>
<th>10 kHz Power Limit (dBm, 135 ohm)</th>
<th>Discrete PSD Reading w/ Balun (dBm/Hz)</th>
<th>Discrete PSD Reading w/ Diff. Amp (dBm/Hz)</th>
<th>Delta PSD (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-30.0</td>
<td>10.0</td>
<td>-33.0</td>
<td>-31.6</td>
<td>-1.4</td>
</tr>
<tr>
<td>20</td>
<td>-30.0</td>
<td>10.0</td>
<td>-32.8</td>
<td>-32.1</td>
<td>-0.7</td>
</tr>
<tr>
<td>30</td>
<td>-30.0</td>
<td>10.0</td>
<td>-33.9</td>
<td>-33.3</td>
<td>-0.6</td>
</tr>
<tr>
<td>40</td>
<td>-30.0</td>
<td>10.0</td>
<td>-37.7</td>
<td>-37.2</td>
<td>-0.5</td>
</tr>
<tr>
<td>50</td>
<td>-30.0</td>
<td>10.0</td>
<td>-38.2</td>
<td>-37.9</td>
<td>-0.3</td>
</tr>
<tr>
<td>60</td>
<td>-33.9</td>
<td>6.1</td>
<td>-41.6</td>
<td>-41.3</td>
<td>-0.3</td>
</tr>
<tr>
<td>70</td>
<td>-37.3</td>
<td>2.7</td>
<td>-46.7</td>
<td>-46.4</td>
<td>-0.3</td>
</tr>
<tr>
<td>80</td>
<td>-40.2</td>
<td>-0.2</td>
<td>-54.8</td>
<td>-54.5</td>
<td>-0.3</td>
</tr>
<tr>
<td>90</td>
<td>-42.7</td>
<td>-2.7</td>
<td>-58.8</td>
<td>-58.7</td>
<td>-0.1</td>
</tr>
<tr>
<td>100</td>
<td>-45.0</td>
<td>-5.0</td>
<td>-53.2</td>
<td>-53.1</td>
<td>-0.1</td>
</tr>
</tbody>
</table>
Example of Swept Frequency PSD Measurements on an ISDN Basic Rate Transceiver

![Graph showing PSD measurements](image)
How does the Video Bandwidth affect Swept Measurements?

ISDN BRI PSD VERSUS T1.601:1998

REF 20.0 dBm
5 dB/DIV
MARKER 11 200.0 Hz
RANGE 25.0 dBm
-32.9 dBm (1Hz)

START 0 Hz
RBW 10 KHz
VBW 30 KHz
STOP 100 000.0 Hz
ST 25.5 SEC

Green plot is the correct PSD measurement.
Blue plot shows excessively high levels due to the high VBW setting. Note the noise reading at the marker frequency does not correlate to the swept frequency display.
How does the Sweep Time affect Swept Measurements?

Blue plot shows abnormally low levels due to the excessively fast sweep time.
Using a High Pass Filter to Achieve Greater Dynamic Range

• Often times the out-of-band portion of the PSD mask is considerably below the in-band level. Consequently, very low level noise measurements must be made at higher frequencies with very high level signals present at the lower frequencies. This limits the dynamic range of the spectrum analyzer to a point where the noise floor may actually be above the specified limit.

• This dilemma may be solved by using a high pass filter whose cutoff frequency is below the start frequency of interest but above that of the EUT’s pass-band. This arrangement attenuates the undesirable signals allowing the spectrum analyzer to use a lower range setting thus increasing its sensitivity. The effects of the HPF upon the measurement must be understood.
Signal Power in a 1 MHz Sliding Window?

PSD (dBm/Hz) vs. Frequency

The dashed red line reflects the -50 dBm power limit over a 1 MHz sliding window. Since the blue trace is below this line, no further testing is required. If spectral components exceeded this line, power would have to be integrated over a 1 MHz window for comparison against the -50 dBm limit. Remember, you can have noise above the dashed line but never above the solid line just as long as the aggregate signal power is not excessive.
Conclusion

- PSD Measurements have long been in the domain of voluntary industry standards. As such, manufacturer’s test results have rarely come into scrutiny. However, as PSD Masks are adopted as regulatory requirements, it becomes even more important to ensure that these measurements are performed in a sound way, to ensure that the results may be reproducible amongst different test labs. The test method must remain flexible, though contain sufficient detail to allow labs to reach the same pass/fail conclusion.