PHASE NOISE MEAS. AND THE 89441A

Step-by-Step Instructions of One Example

DUT: 3325A synthesizer/function generator

Measurement frequency 10.7 MHz, Amplitude: 1.5 dBm, Not phase-locked to HP 89441A

For comparison, all measurements will be made at a 10 kHz offset from the carrier.

89441A key presses follow the text and are shown as:
[**Hardkey**]
  [softkey]
Note: Softkey labels may change slightly due to option configuration.

89441A Setup

RF Vector Mode, Center Frequency = 10.7 MHz, Span = 39.0625 kHz. Use the Counter to accurately measure the carrier frequency and to set the center frequency of the analyzer. Turn the Counter function off when finished (to speed up measurements).

Span is selected to be at least twice the desired max offset of 10 kHz, and a cardinal span of 10 MHz/2^n is chosen to speed averaging. Maximum speed is achieved with the analyzer's maximum number of frequency points (System Utility) equal to the number of points actually selected (ResBW/Window), channel 2 turned off, and calculations on unused traces turned off.

[**Preset**]
  [receiver]
  [RF (2-2650 MHz)]
  [RF (2-2650 MHz) normal]
[**Instrument Mode**]
  [Vector]
[**Frequency**]
  [center]
  10.7
  [MHz]
  [span]
  39.0625
  [kHz]
[**Marker Function**]
  [freq counter **on**]
[**Shift**]
[**Mkr > Peak**]
[**Shift**]
[**Mkr > CF**]
  [freq counter **off**]

Set the input range to the lowest value which does not cause the OV1 (overload channel 1) annunciator to appear in the display.

Using the most sensitive input range possible reduces the noise contribution of the analyzer to the measurement. In some cases a measurement with a modest overrange will work well because small amounts of distortion due to overrange do not affect the measurement. For more details press Help, Range, ch1 range.

[**Range**]
  [ch1 range] use the up and down arrow keys to adjust the range

An auto zero should be performed after we've touched the ADC overload (OV1) region. This clears out potential bad data from the ADC loop. If a CAL is performed (see the step immediately below), this auto zero will be performed automatically.

It is useful to make sure the analyzer is up to a stable temperature and do a CAL at this point. Stable temperature and lack of cal (or other relay) activity provides for most consistent operation of noise subtraction. Disable auto calibration (which might affect noise subtraction) but do not be concerned with auto-zero operations performed during the measurement.

[**System Utility**]
  [single cal]
  [auto cal **off**]

Select RBW Auto/Arb, with # points = 801

   This is a useful default for reasons of frequency resolution and update/average rate. RBW can be set in Fixed mode to more round-number values to make noise bandwidth corrections easier (see example below). # points can be increased for greater frequency resolution at small offsets. RBW filter type can be changed to Gaussian for greater frequency resolution at small offsets. Taking advantage of this greater resolution is best done in the log frequency (Data Format, X-axis) mode.

  [memory usage]
  [configure meas memory]
  [max freq pts]
  801
  [enter]
[**ResBW/Window**]
  [rbw mode **arb**]
  [num freq pts]
  801
  [enter]

Enable averaging, with fast averaging and a number of averages of 300-1000.

   Noise measurements require averaging to reduce variance. Several hundred averages is a good number to shoot for, and in the right conditions the analyzer can perform up to 100 averages/second.

[**Average**]
  [average **on**]
  [num averages]
  1000
  [enter]
  [fast avg **on**]
  [average type]
  [rms (video)]

Measure carrier power in mW and write this number down for later use. Switch Y units back to dBm when finished.

   Using trace math to normalize the measurement to the individual carrier power requires the power to be entered as a constant (K1) in mW.

[**Ref Lvl/Scale**]
  [X & Y units setup]
  [Y units]
  [W]
[Shift]
[Mkr > Peak]   Record the marker power reading in mW.
  [dBm]

Direct Spectrum Measurement Without Noise Subtraction

Enable Band Power Markers with a CF of 10.71 MHz (10 kHz offset from carrier) and BW of 1 kHz.

Band power markers provide some integration (averaging or smoothing effect) of the noise trace, and make correction to a 1 Hz bandwidth easier. The BW should be narrow enough that the trace is relatively flat within the bounds of the BW, and wide enough to provide enough integration or smoothing. A BW of 1/10 to 1/50 of the span is usually a good choice. The presence of discrete spurious within the BW should be avoided.

[**Marker Function**]
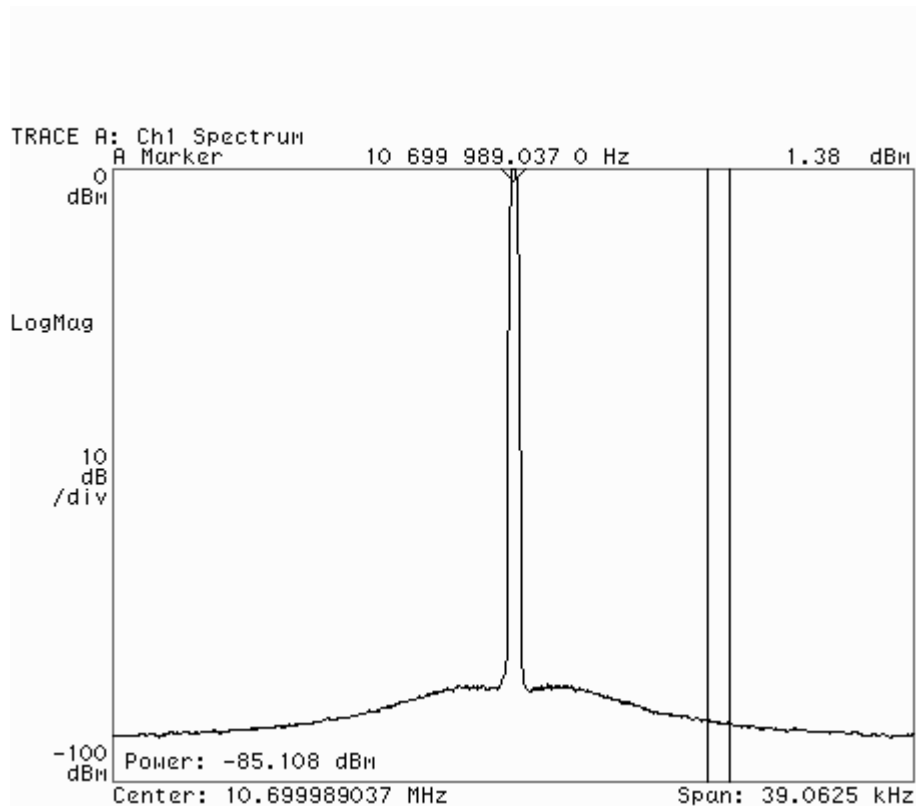 [band power markers]
  [band pwr mkr **on**]
  [band center]
  10.71
  [MHz]
  [band width]
  1
  [kHz]

```
TRACE A: Ch1 Spectrum
       A Marker            10 699 989.037 0 Hz          1.38  dBm
   0
  dBm



LogMag




   10
   dB
  /div




  -100  Power: -85.108 dBm
  dBm
        Center: 10.699989037 MHz              Span: 39.0625 kHz
```

Band power marker reading is –85.108 dBm.

*To arrive at dBC/Hz: Subtract an additional 30 dB to change from 1 kHz BW to 1 Hz. Subtract an additional 1.38 dB to account for the carrier power of 1.38 dBm. Result is **-116.488 dBC/Hz.** This is the sum of the noise contributed by the DUT and the analyzer. Depending on the performance of the DUT compared to that of the analyzer, we may or may not be able to ignore the contribution of the analyzer's noise.*

The phase noise of the analyzer can be disregarded if it is far enough below that of the DUT. 10 dB is a good rule of thumb, as measuring phase noise 10 dB above the analyzer's own noise creates a measurement error (actual measured result is high) of less than 0.5 dB. Refer to product notes 89400-2 and 89400-11.

Make the same measurement with the normal *offset* marker instead of the band power marker. Set the RBW to 200 Hz for ease of calculation.

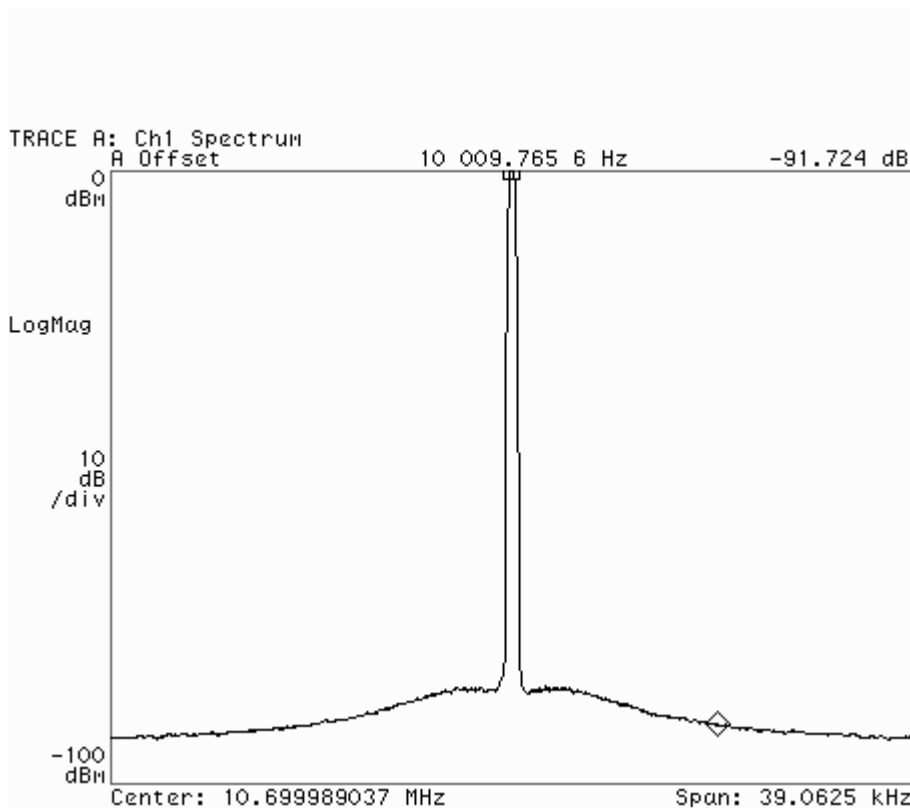[**Marker Function**]
  [band power markers]
  [band power **off**]
[**Marker**]
  [zero offset]
  [enter marker position]
  10.71
  [MHz]

```
TRACE A:  Ch1 Spectrum
        A Offset              10 009.765 6 Hz              -91.724 dB
     0
   dBm



  LogMag




    10
    dB
   /div




  -100
   dBm
       Center: 10.699989037 MHz              Span: 39.0625 kHz
```

Marker reading at 10.71 MHz is –91.724 dB.

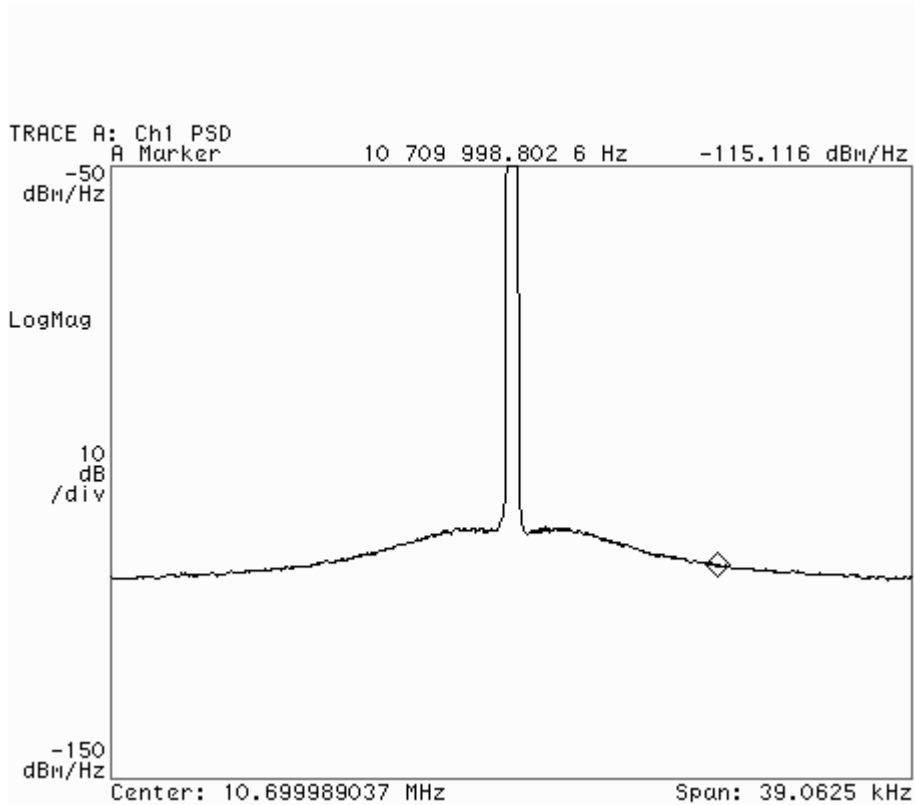*To arrive at dBC/Hz: Subtract an additional 23 dB to change from a 200 Hz RBW to a 1 Hz BW. Result is **–114.724 dBC/Hz.***

Turn the offset marker function off. Make the measurement with the normal marker using PSD as the Measurement Data type.

  [offset mkr **off**]
 [**Measurement Data**]
  [PSD ch1]

```
TRACE A:  Ch1 PSD
        A Marker           10 709 998.802 6 Hz      -115.116 dBm/Hz
    -50
  dBm/Hz

 LogMag



    10
    dB
   /div



   -150
  dBm/Hz
        Center: 10.699989037 MHz           Span: 39.0625 kHz
```

Marker reading is –115.116 dBm/Hz.

*To arrive at dBC/Hz: Carrier power of 1.38 dBm, and this figure is subtracted from the figure above to arrive at a result of **-116.496 dBC/Hz**.*

Make a measurement with the Band Power Marker in the Power Ratio mode of C/No. Move the marker to the carrier and leave the band set at a 10 kHz offset.
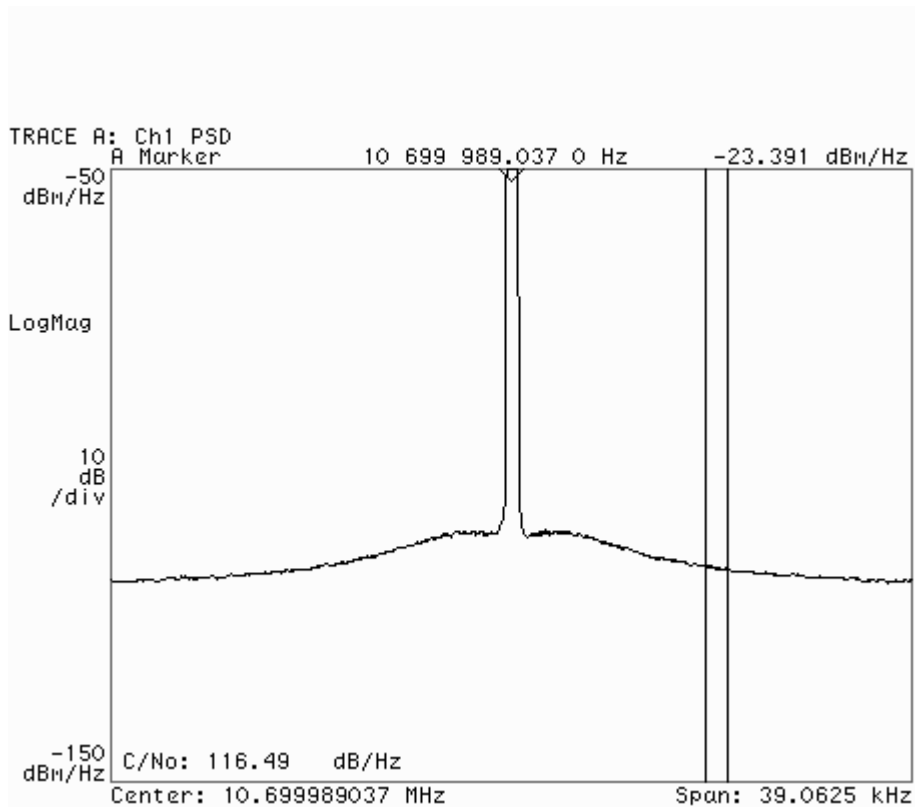
[**Marker Function**]
  [band power markers]
  [band power **on**]
  [power ratio **C/No**]
[**Shift**]
[**Mkr > Peak**]

```
TRACE A: Ch1 PSD
       A Marker        10 699 989.037 0 Hz      -23.391 dBm/Hz
 -50
dBm/Hz


LogMag



 10
 dB
/div





-150
dBm/Hz  C/No: 116.49   dB/Hz
       Center: 10.699989037 MHz        Span: 39.0625 kHz
```

Direct result is **-116.49 dBC/Hz**.

PM Demodulation Measurement Without Noise Subtraction

Select Analog PM Demodulation. Switch the Measurement Data type back to Spectrum of channel 1.
Set the Marker to 10 kHz.

[**Instrument Mode**]
  [demod type]
  [Analog Demodulation]
[**Return**]
  [demodulation setup]
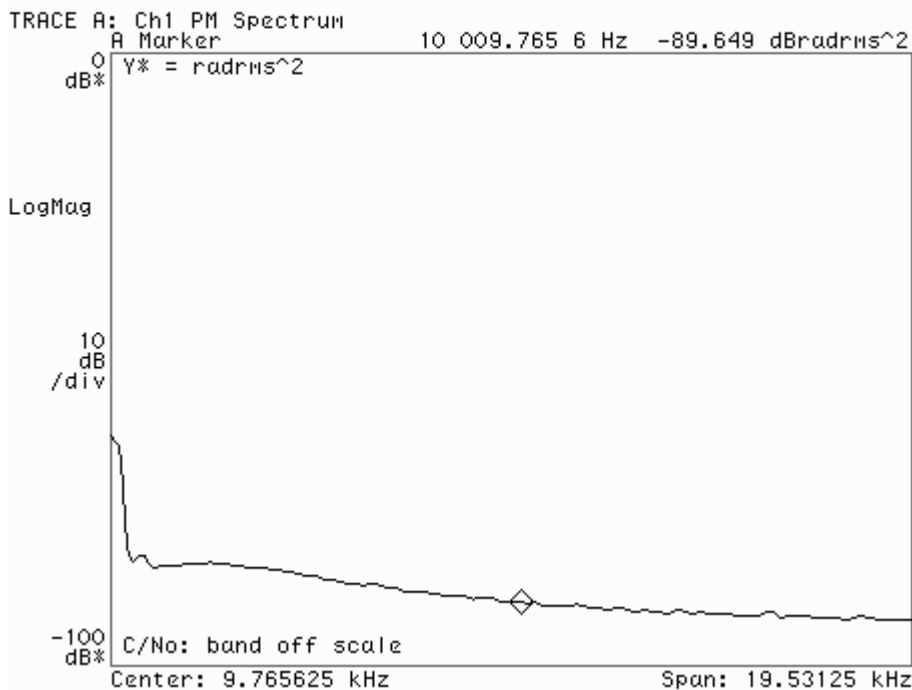 [ch1 result]
  [PM]
[Measurement Data]
  [spectrum ch1]
[Marker]
  [enter marker position]
  10
  [kHz]
[**Meas Restart**]

```
TRACE A: Ch1 PM Spectrum
       A Marker           10 009.765 6 Hz   -89.649 dBradrms^2
    0 | Y* = radrms^2
  dB* |
      |
      |
LogMag|
      |
      |
   10 |
   dB |
  /div|
      |\
      | \
      |  \___
      |      _____
      |                        \___◇_____
      |                                                _____
 -100 | C/No: band off scale
  dB* |
      Center: 9.765625 kHz                  Span: 19.53125 kHz
```

Marker value result is –89.649 dB radrms^2.

*To arrive at dBC/Hz: Subtract 23 dB to account for the 200 Hz RBW and 3 dB to create a single sideband result (to account for the fact that the demod mode places the power from both sidebands into one). Result is **–115.649 dBC/Hz**.*
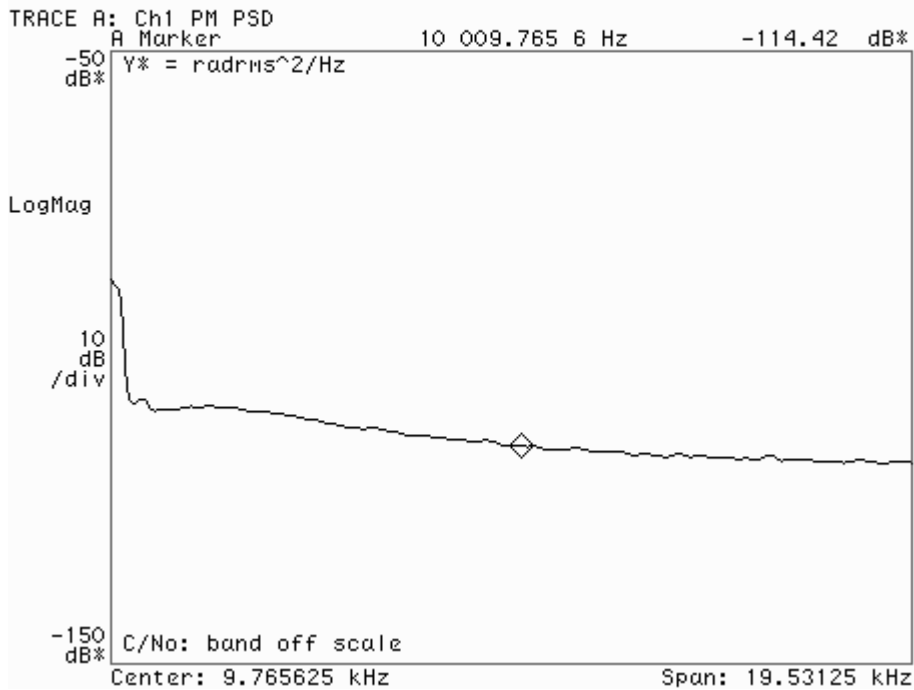
This demod mode result may differ from the direct spectrum mode results for a couple of reasons. First, the demod mode removes AM noise from the measurement while the direct spectrum measurements do not. The assumption that the close-in noise is all phase noise and free of AM noise is not always valid. Secondly, the equivalence between spectrum and demod mode results relies on the "small angle assumption" that SinX = X. This is true for small phase perturbation angles only (sources with "good" phase noise), and may not be true for noisy sources or for measurements very close in to the carrier where noise is higher and perturbations are greater. Where the small angle assumption is not valid, the phase demodulation result should be more accurate.

Measurements are most accurate for signals that are frequency locked or are not drifting. When the signals are not locked or when drift is a problem, the auto carrier function should be used. This will render invalid the first several data points near the carrier (to the left of the display) due to the locking action of the auto carrier function. This will be most apparent when a log-frequency X-axis is used.

Switch Measurement Data to PSD and read a marker value of -114.42 dB radrms^2/Hz.

[**Measurement Data**]
  [PSD ch1]

```
TRACE A: Ch1 PM PSD
       A Marker              10 009.765 6 Hz         -114.42   dB*
   -50 │Y* = radrms^2/Hz
   dB* │

LogMag │



    10 │
    dB │
   /div│



  -150 │C/No: band off scale
   dB* └─────────────────────────────────────────────
        Center: 9.765625 kHz          Span: 19.53125 kHz
```

*To arrive at dBC/Hz: Subtract 3 dB to create a single sideband result of **-117.42 dBC/Hz**. Bear in mind that the noise from the source will vary slightly over time.*

Make a measurement using Band Power Markers. Switch the band power marker from C/No back to Band Power.

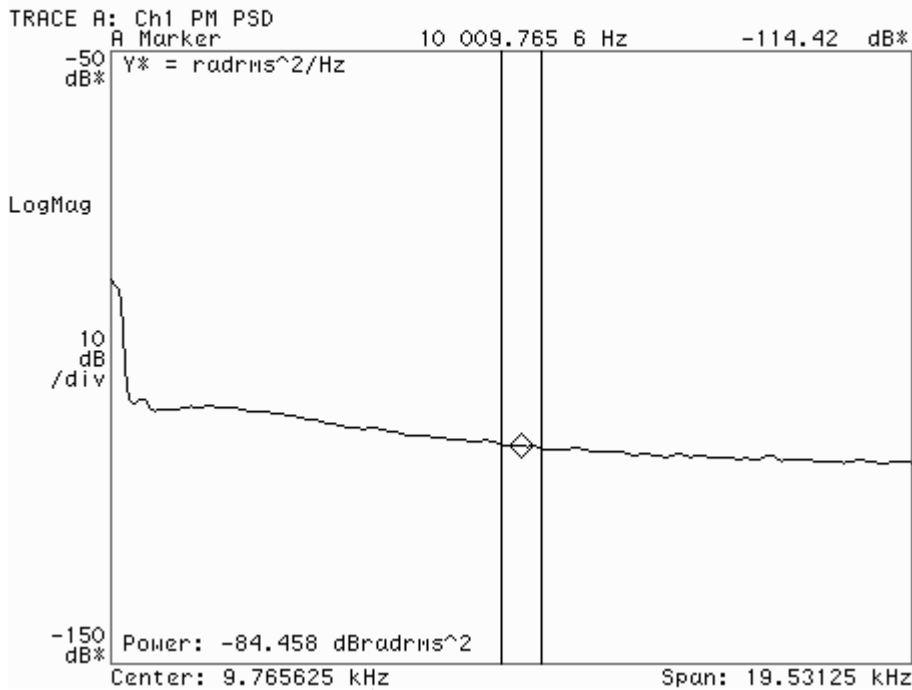[**Marker Function**]
[band power markers]
[band center]
10
[kHz]
[band power]

```
TRACE A: Ch1 PM PSD
        A Marker              10 009.765 6 Hz              -114.42  dB*
    -50  Y* = radrms^2/Hz
    dB*

LogMag




    10
    dB
   /div





  -150  Power: -84.458 dBradrms^2
  dB*
        Center: 9.765625 kHz                Span: 19.53125 kHz
```

Result is -84.458 dB radrms^2.

*To arrive at dBC/Hz: Subtract an additional 30 dB to change from 1 kHz BW to 1 Hz. Subtract an additional 3 dB to create a single sideband result. Result is **-117.458 dBC/Hz.***

A log display can be used for measurements such as this, though it is a visual change only and does not affect the measurement result. For better resolution at small offsets, a larger # points (up to 3200) can be used, along with a Gaussian Main Window (RBW) filter.

Direct Spectrum Measurement With Noise Subtraction

Some measurement results can be improved by removing the influence of the analyzer's own input noise. This noise is first measured, and then removed from subsequent results using trace math.

Set up math: F1 = PSD1/K1 (this is the carrier-power-corrected measurement, *without* noise subtraction.)

F2 = F1 - D1 (this is the power-corrected measurement *with* noise subtraction)

K1 = 1.3911 (real value only, this is the carrier power in mW measured during the initial setup.)

[**Math**]
 [define F1]
 [meas data]
 [PSD ch1]
 [/]
 [constant]
 [K1]
 [enter]
 [define F2]
 [math func]

[F1]
  [-]
  [data reg]
  [D1]
  [enter]
  [define constants]
  [define K1]
  [real part]
  1.3911   (carrier power in mW)
  [enter]

Switch the analyzer from demodulation mode back to vector mode. Disconnect the signal from the input (you may want to connect a 50 Ohm load to the analyzer's RF input for best results), select F1 as the Measurement Data type and Restart the measurement. Wait for at least several hundred averages and save the trace into D1.

[**Instrument Mode**]
  [Vector]
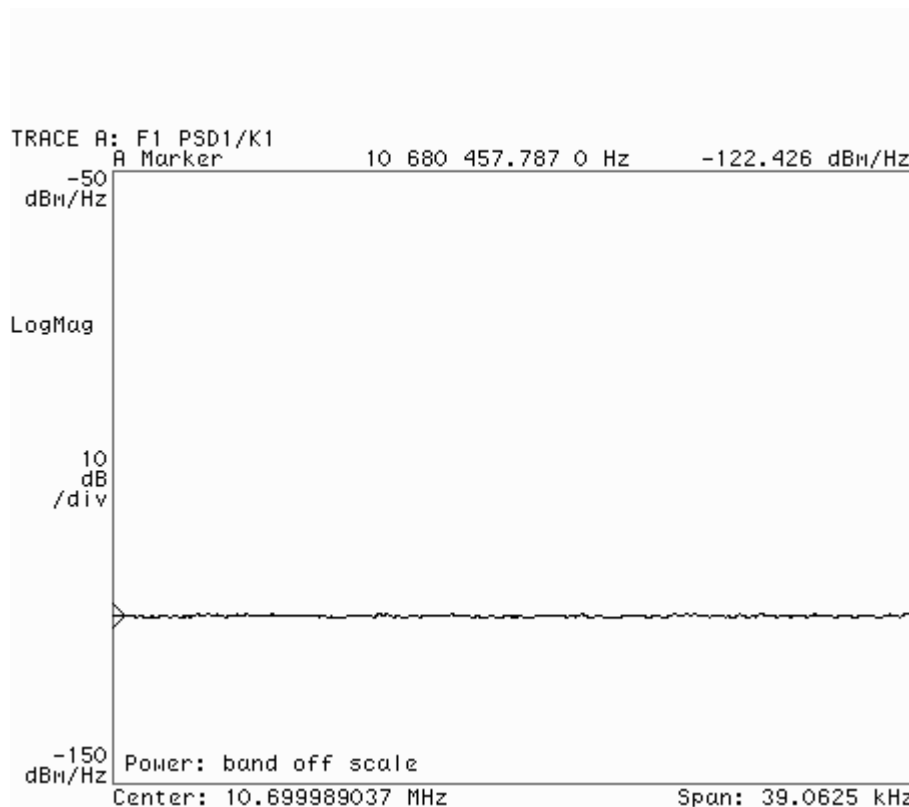[**Measurement Data**]
  [math func]
  [F1]
[**Meas Restart**]   Wait for AVG COMPLETE on the display
[Save/Recall]
  [save trace]
  [into D1]


```
TRACE A: F1 PSD1/K1
       A Marker           10 680 457.787 0 Hz      -122.426 dBm/Hz
   -50
 dBm/Hz



 LogMag




   10
   dB
  /div




  -150  Power: band off scale
 dBm/Hz
       Center: 10.699989037 MHz          Span: 39.0625 kHz
```

D1 is a measurement of the analyzer's residual broadband input noise. Once stored, it can be subtracted from subsequent measurement results through the use of trace math. This measurement

depends on the analyzer's input range, frequency span and center frequency, etc. Therefore it should be repeated (and D1 re-stored) whenever any of the parameters mentioned above are changed.

For comparison, make the measurement *without noise subtraction* in a couple of different ways: Reconnect the input, Restart the measurement and read the marker value at a 10 kHz offset.
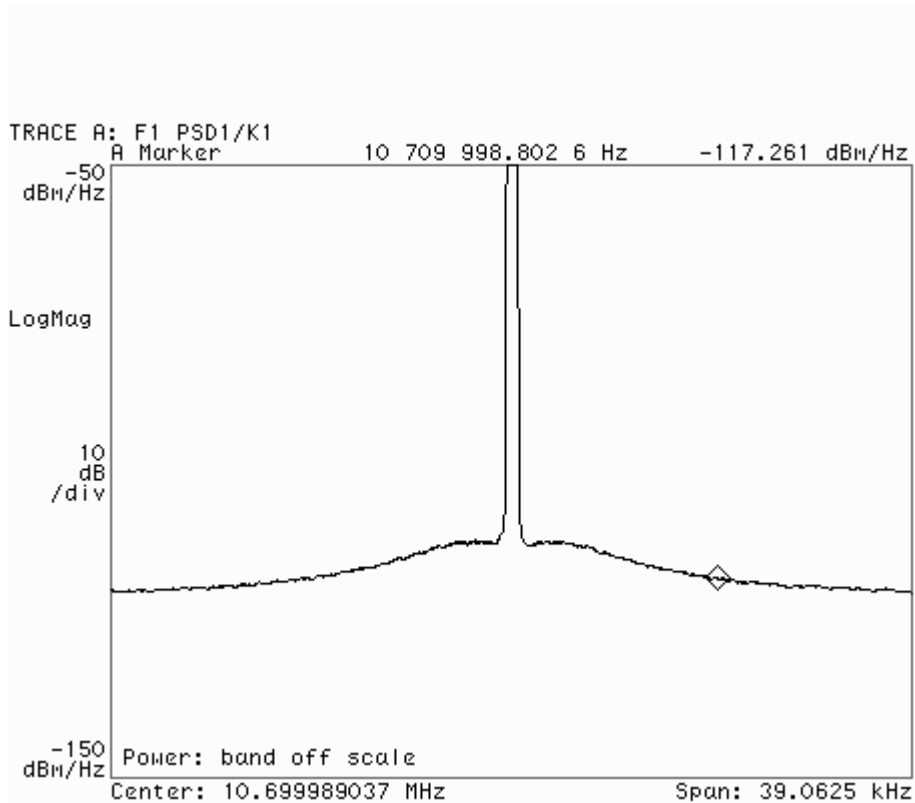
[**Meas Restart**]
[**Marker**]
  [enter marker position]
  10.71
  [MHz]

```
TRACE A: F1 PSD1/K1
         A Marker          10 709 998.802 6 Hz       -117.261 dBм/Hz
    -50
  dBм/Hz

  LogMag




    10
    dB
   /div




   -150  Power: band off scale
  dBм/Hz
        Center: 10.699989037 MHz              Span: 39.0625 kHz
```

Result is -117.261 dBm/Hz.

*With the normalization provided through the use of the math function F1, this result is correctly interpreted as **-117.261 dBC/Hz**. This is a result without noise subtraction.*

Make the same measurement using Band Power Markers. Set the band center to 10.71 MHz.
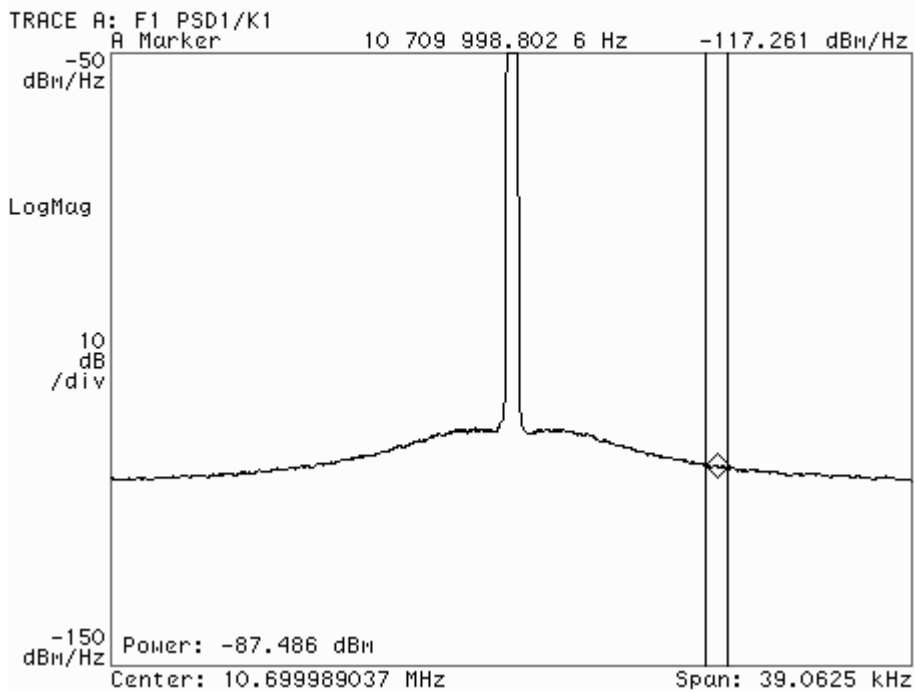
[**Marker Function**]
  [band power markers]
  [band center]
  10.71
  [MHz]

```
TRACE A: F1 PSD1/K1
         A Marker          10 709 998.802 6 Hz        -117.261 dBm/Hz
  -50
 dBm/Hz

LogMag




   10
   dB
  /div




  -150  Power: -87.486 dBm
 dBm/Hz
       Center: 10.699989037 MHz            Span: 39.0625 kHz
```
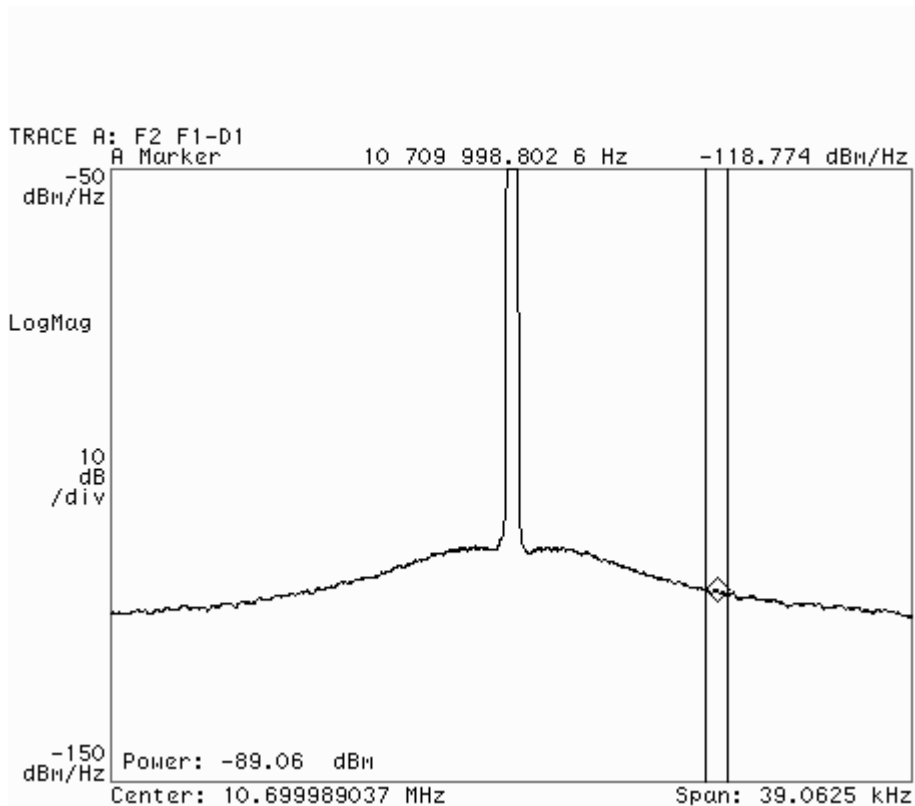
Result is -87.486 dBm.

   To arrive at dBC/Hz: Subtract an additional 30 dB to change from 1 kHz BW to 1 Hz. Result is
   -117.486 dBC/Hz. *This is the result without noise subtraction.*

Now make measurements using noise subtraction. Switch the Measurement Data to function F2.

[**Measurement Data**]
  [math func]
  [F2]

```
TRACE A: F2 F1-D1
        A Marker       10 709 998.802 6 Hz    -118.774 dBм/Hz
  -50
dBм/Hz

LogMag


   10
   dB
  /div




 -150
dBм/Hz  Power: -89.06  dBм
        Center: 10.699989037 MHz            Span: 39.0625 kHz
```

Result read from marker is **–118.774 dBC/Hz** with noise subtraction**.**

This result is lower (better) than the -117.261 dBC/Hz result above because the contribution of the analyzer's own broadband noise floor (perhaps 6 dB lower than these figures) has been reduced by another 10+ dB.

Make the same measurement using Band Power Markers. Result is –89.06 dBm.

To arrive at dBC/Hz: Subtract an additional 30 dB to change from 1 kHz BW to 1 Hz. Result is **-119.06 dBC/Hz** *with noise subtraction.*

PM Demodulation Measurement With Noise Subtraction

Set up math: F3 = PSD1-(D1/K2) (this is a measurement with noise subtraction)

K2 = 0.05 (real value only, this is a constant used to convert between the direct spectrum mode where the analyzer's noise was measured and the analog PM demodulation mode).

[**Math**]
  [define F3]
  [meas data]
  [PSD ch1]
  [-]
  [(]
  [data reg]
  [D1]
  [/]
  [constant]
  [K2]

[enter]
[define constants]
[define K2]
[real part]
0.05
[enter]

Select Analog PM Demodulation and Measurement Data as function F3. Set the Marker to 10 kHz.

[**Instrument Mode**]
  [Demodulation]
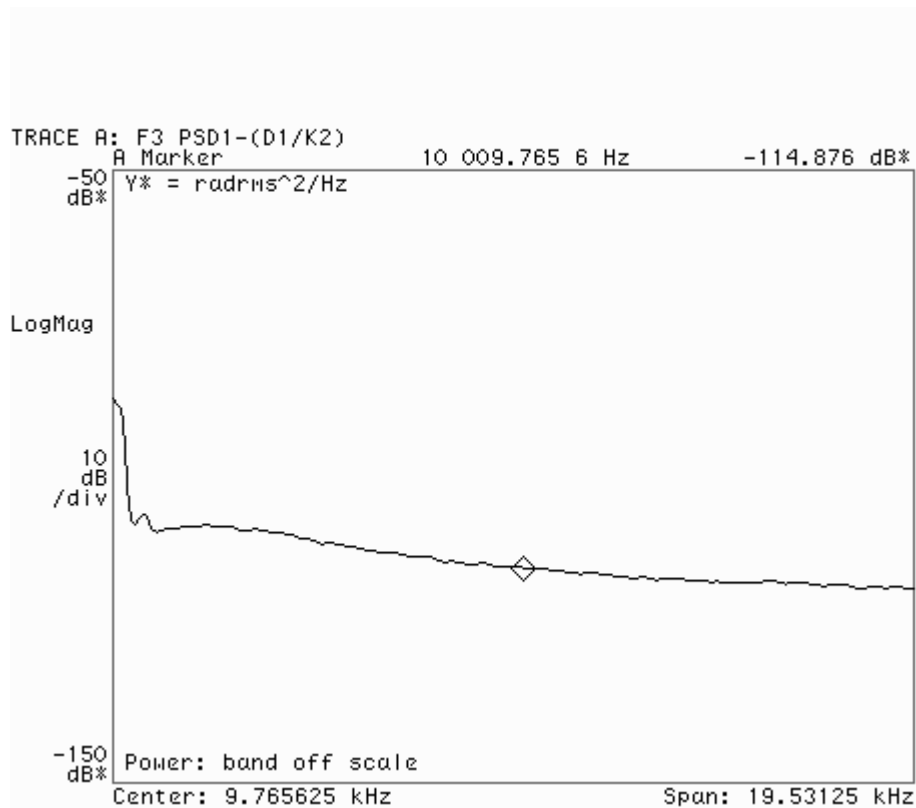[**Measurement Data**]
  [math func]
  [F3]
[**Marker**]
  [enter marker position]
  10
  [kHz]

```
TRACE A: F3 PSD1-(D1/K2)
        A Marker              10 009.765 6 Hz        -114.876 dB*
  -50 | Y* = radrms^2/Hz
  dB* |

LogMag

   10
   dB
  /div

  -150 | Power: band off scale
  dB* |
      Center: 9.765625 kHz              Span: 19.53125 kHz
```

Marker value result is –114.876 dB radrms^2/Hz.

*To arrive at dBC/Hz: Subtract 3 dB to create a single sideband result. Result is –**117.876 dBC/Hz**. with noise subtraction.*

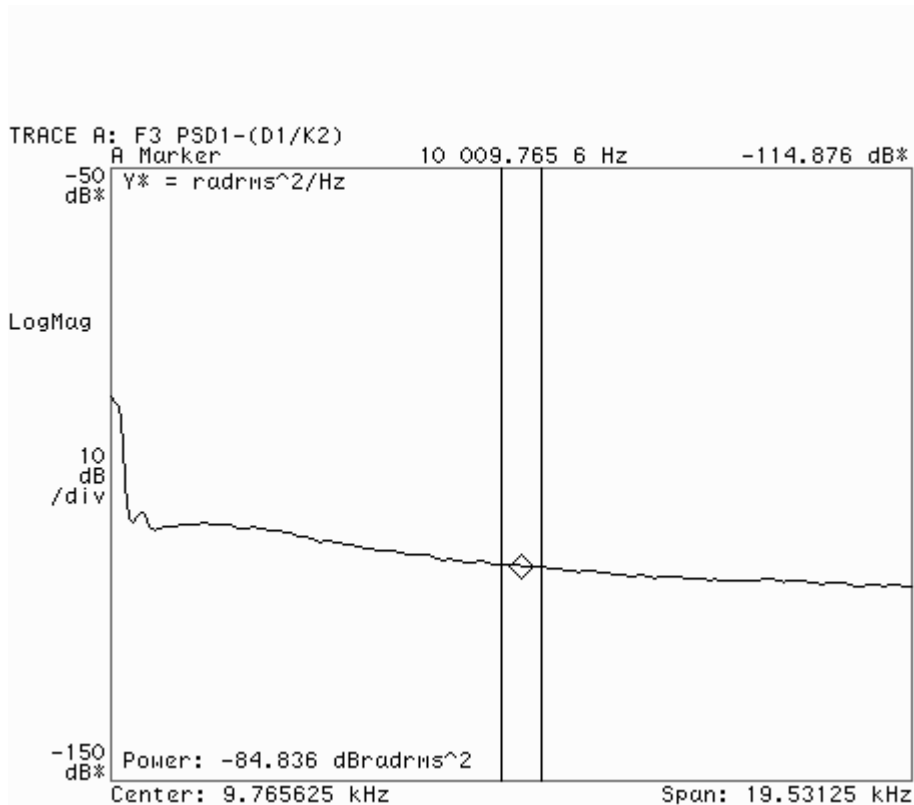Make a measurement using the Band Power Markers at a 10 kHz offset.

[**Marker Function**]
  [band power markers]
  [band center]
  10

[kHz]

```
TRACE A: F3 PSD1-(D1/K2)
         A Marker              10 009.765 6 Hz          -114.876 dB*
  -50  Y* = radrms^2/Hz
  dB*

LogMag




   10
   dB
  /div




 -150  Power: -84.836 dBradrms^2
 dB*
         Center: 9.765625 kHz              Span: 19.53125 kHz
```

Result is -84.836 dB radrms^2

*To arrive at dBC/Hz: Subtract an additional 30 dB to change from 1 kHz BW to 1 Hz. Subtract an additional 3 dB to create a single sideband result. Result is **-117.836 dBC/Hz**. with noise subtraction.*

Notes:

This discussion covers phase noise measurements in the frequency domain only. When using the analog PM demod mode, the data format can be switched to a time-domain form such as the real part. However noise subtraction cannot be used in this mode.

If a time-domain measurement is used (in the PM demod mode), band power markers can also be used on the trace to give an RMS jitter result. RMS SQRT should be selected instead of band power.

For phase jitter measurements (performed with PM demod mode and a time or frequency domain display), especially, it's important to look at the RANGE of frequency offsets that are measured. This means that number of points will affect the measurement. Using more points means a measurement closer to the carrier. Close-in offset is proportional to the time record (and therefore inversely proportional to the number of points). Measurement limit of offset is the span itself.