Technical Note

The Basis of Spectrum Analyzers

The Basis of Spectrum Analyzers

Ver.3.1

Anritsu Corporation

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1. What is a Spectrum Analyzer?

A measuring instrument that displays an electrical signal according to its frequency.

Each frequency component contained in the input signal is displayed as a signal level corresponding to that frequency.

Anritsu Spectrum Analyzer Lineup

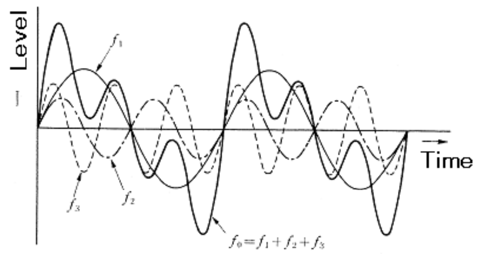
MS266x Series　MS268x Series　MS8608A/09A　MS2781B　MS2711D　MS2721B

2. Measurement Categories

Signal Measurement	**Instrument**
• Power (Level)	Power meter
• Frequency	Frequency counter
• Spectrum	Spectrum analyzer
• Transmission/Refection characteristics	Network analyzer
• Time characteristics	Oscilloscope
• Modulation characteristics	Modulation analyzer

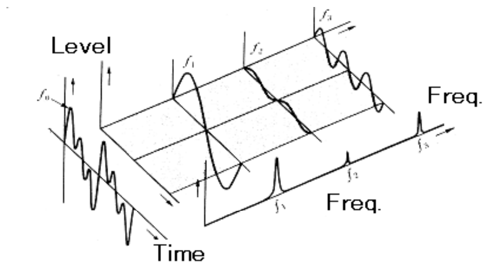
Describing Electrical Signals

Oscilloscope waveforms



Power 0.11mW (-9.6dBm)

Spectrum analyzer waveforms



Frequency	Power (dBm)	(W)
f_0	-10dBm	0.1mW
$2f_0$	-20dBm	0.01mw
$3f_0$	-54dBm	4.0nW
(Sum)		0.11mW

Measurement Categories

Level (amplitude)

Frequency vs. Level
Spectrum analyzer
(Frequency domain)

Time vs. Level
Oscilloscope
(Time domain)

Frequency vs. Time
Modulation analyzer
(Modulation domain)

Frequency

Time

Analysis of Electrical Signals

Time Domain

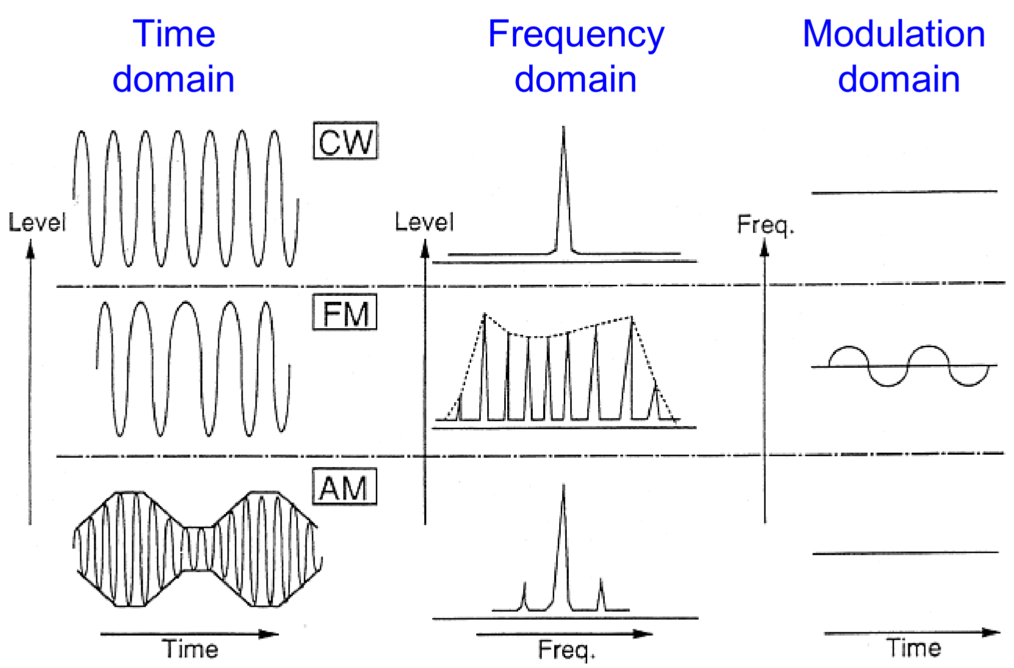
- Changes in time can be seen.
- If a signal has many frequency elements, the analysis is difficult.

Frequency Domain

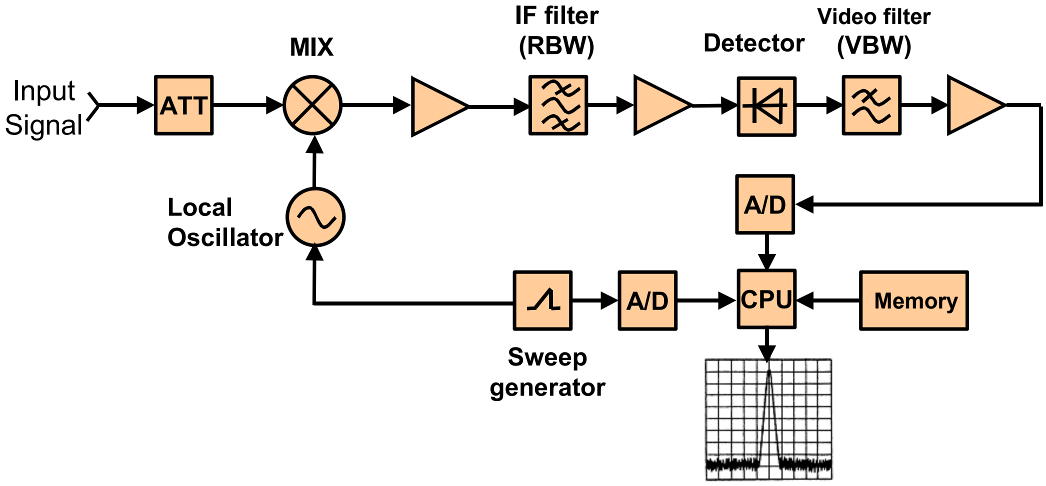
- Each element of a complex signal can be separated easily.
- Low-level distortion signals can be detected.
- Spurious elements can be measured.

Modulation Domain

- Changes in frequency can be seen.
- The modulation accuracy can be analyzed.
- Changes in amplitude cannot be seen.



3. Principals of a Spectrum Analyzer



Block Diagram of the Super-Heterodyne Method

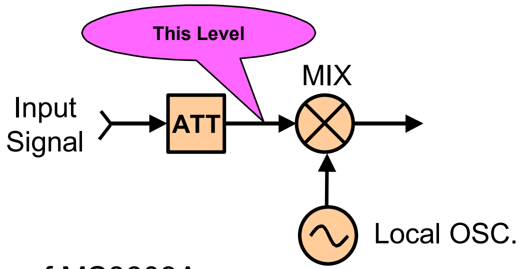
4. Characteristics

4.1 Suitable Input Level
4.2 Maximum Input Level
4.3 Measurement Frequency Range
4.4 Sideband Noise
4.5 Resolution bandwidth for frequency (RBW)
4.6 RBW and Sweep Time
4.7 Detection methods
4.8 Video filter (VBW)
4.9 Dynamic Range
(Average Noise Level, Residual response, Distortion)

4.1 Suitable Input Level

When the signal and local oscillator are added at the mixer input, the suitable input level is the distortion level specification that doesn't influence the measurement. The level relationship between the input signal and the distortion is specified at the mixer input level, not at the input connector.

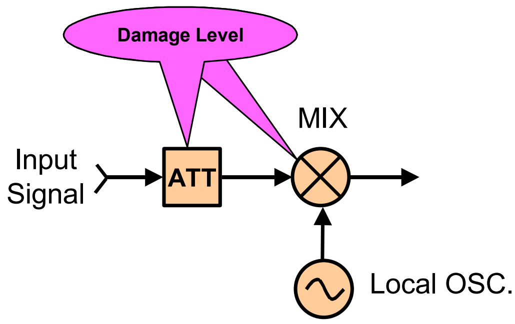
Therefore, the RF attenuator attenuates the input signal to a suitable mixer input level.



e.g The specification of MS8609A.
2nd harmonic distortion ≤ -90dBc at MIX input level -10dBm

4.2 Maximum Input Level

The maximum input level prevents damage to the input circuit. It is based on the input levels to the Attenuator and Mixer.



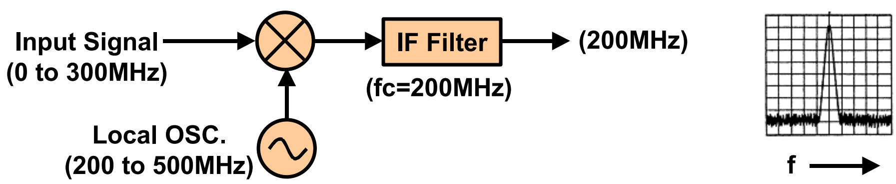
e.g The specification of MS8609A
Maximum input level: +20dBm (Op-32: +30dBm)

4.3 Measurement Frequency Range

The measurement frequency range is determined by the center frequency of the IF filter and the local oscillator frequency range.

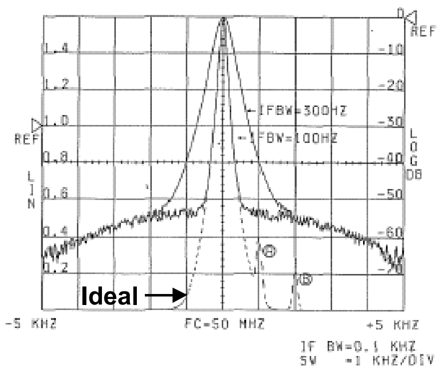
Input Signal Freq. = Local Signal Freq. – IF Freq.

The input signal and the local signal are mixed by the mixer. The mixer output is filtered by the IF filter with center frequency f_c and displayed on the screen.



4.4 Sideband Noise

It appears in the base of the spectrum because of noise in the internal local signal source. Sideband noise shows the signal purity, and the performance of nearby signal analysis is determined by this characteristic. It is specified by how many dB down from the center at an offset of 10kHz (or 100kHz) when the resolution bandwidth (RBW) is narrow enough, and a high purity signal is input.



For the local signal source, the dotted line spectrum is the ideal. However, it actually has sideband noise like the solid line. Masking occurs by the sideband noise when there is a nearby A or B signal and it is not possible to detect it.

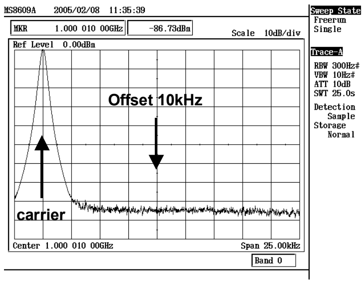
4.4 Sideband Noise

e.g The specification of MS8609A

-108dBc/Hz at offset 10kHz

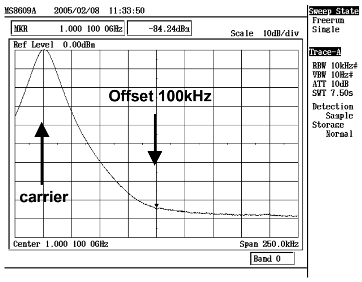
-120dBc/Hz at offset 100kHz

F_0=1GHz, Offset 10kHz, RBW 300Hz, VBW 10Hz



Sideband Noise:
–87dBc / 300Hz → -112dBc / Hz

F_0=1GHz, Offset 100kHz, RBW 10kHz, VBW 10Hz



Sideband Noise:
–84dBc / 10kHz → -124dBc / Hz

4.5 Resolution bandwidth for frequency (RBW)

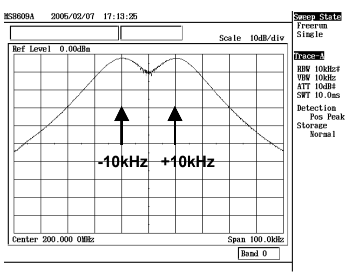
Two input signals can be seen as two spectrum waveforms only if they exceed the 3dB bandwidth of the IF filter.

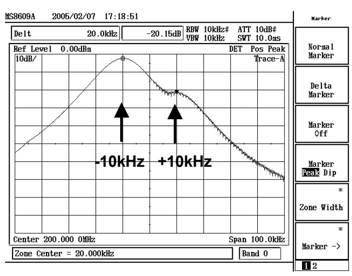
The 3dB bandwidth of this IF filter is called the resolution bandwidth RBW.

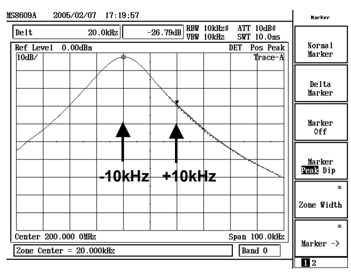
e.g The specification of MS8609A

RBW: 300Hz to 3MHz, 5MHz, 10MHz, 20MHz

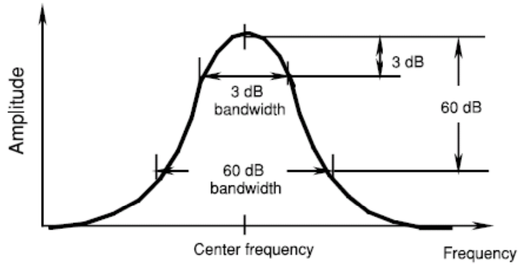
f1=199,990MHz, f2=200,0010MHz at RBW 10KHz







4.5 Resolution bandwidth for frequency (RBW)

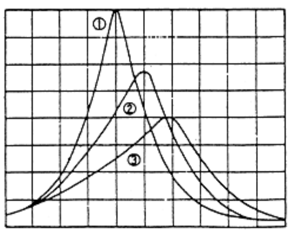


$$\text{Selectivity} = \frac{\text{60dB Bandwidth}}{\text{3dB Bandwidth}}$$

e.g The specification of MS8609A: Selectivity <15 : 1

When a narrow RBW is selected, the 3dB bandwidth and 60dB bandwidth become small, the frequency resolution is greater, the average noise level falls, and you can see low-level signals.

4.6 RBW and Sweep Time



A signal displayed with the proper sweep time is shown in the 1st wave.

The amplitude in the display decreases in the 2nd and 3rd waves when the sweep is made too early, and the frequency shifts.

When the sweep speed is not proper, UNCAL is displayed in the screen.

$$\text{Proper sweep time} = K \times \frac{\text{Frequency span}}{\text{RBW} \times \text{VBW}}$$

(RBW ≥ VBW)

K=3

4.7 Detection methods

Normal: Displays both the maximum level and the minimum level present between the current sample point and the next sample point.

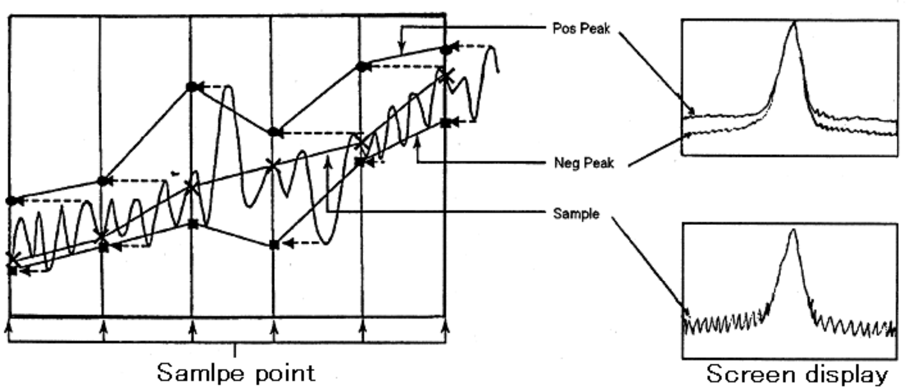
Pos Peak: Displays the maximum level present between the current sample point and the next sample point. Pos Peak is used to measure the peak value of signals near the noise level.

Sample: Displays the instantaneous signal level at each sample point. Sample is used for noise level measurement and time domain measurement.

Neg Peak: Displays the minimum level present between the current sample point and the next sample point.

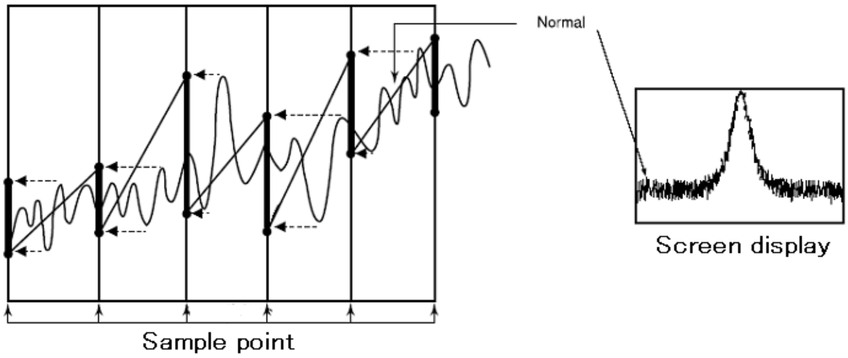
RMS: Displays the root-mean-square (effective) value of the signal input between the current sample point and the next sample point.

4.7 Detection methods



Pos Peak is used for Normal signal measurement, Occupied bandwidth measurement, and Adjacent channel leakage power ratio measurement as a Digital method.
Sample is used for Random noise measurement, Occupied bandwidth measurement, and Adjacent channel leakage power ratio measurement as an Analog method.

4.7 Detection methods



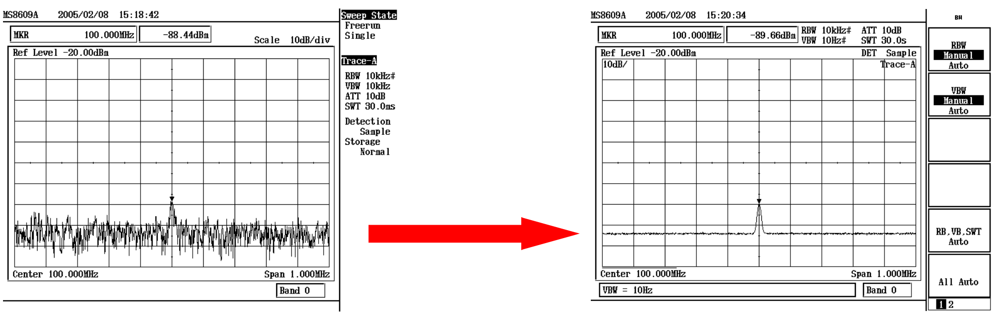
When an early frequency change is seen, such as in pulsed noise, the Sample mode is used.

4.8 Video Filter (VBW)

When a small signal included in noise is measured, this effect is demonstrated.

e.g The specification of MS8609A: 1Hz to 3MHz and Off

VBW 10kHz → **VBW 10Hz**



A noisy signal can be removed by lowering the VBW. However, the signal disappears if VBW is lowered too much when measuring a pulsed signal.

4.9 Dynamic Range

It is the range that can be measured without making it suffer in the noise level, residual responses, and distortion.

However, there is no definition common to all manufacturers, and the value is different depending on what it is based on.

(1) Average Noise Level

(2) Residual response

(3) Distortion: 2nd harmonic Distortion
Two-tone 3rd order Distortion

(1) Average Noise Level

For noise generated internally, a key factor is thermal noise and the noise generated from active elements such as transistors and ICs. Therefore, the average noise level becomes the lower limit of the input signal level that can be measured.

The method of stating the average noise level varies according to the manufacturer. For example, it may be stated in the measurement specification, or the value in change per Hz.

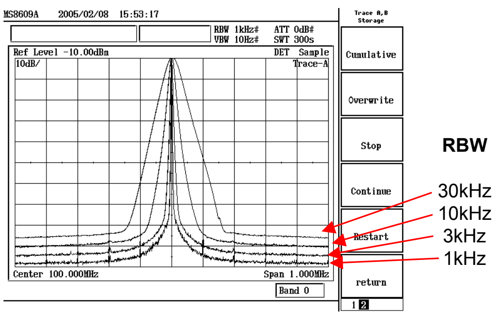
$$Pn \text{ (average level)} = 10 \log_{10}(kTB) + No$$

k: Boltzmann constant (1.38054×10^{-23}J/K), T: Absolute temperature (k), B: IF bandwidth, N_0: Noise figure (active element)

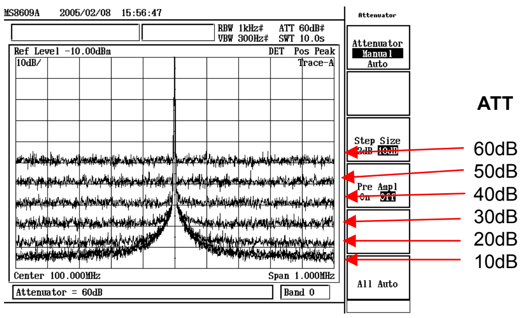
e.g The specification of MS8609A
Average Noise Level $\leq$ -121dBm (f_0=2GHz, RBW 300Hz, ATT 0dB)

The average noise level changes with RBW and ATT

Changing RBW



Changing ATT



The average noise level increases 10dB when RBW value is changed from 1kHz to 10kHz.

The average noise level changes by 10dB when ATT value is changed by 10dB.

(2) Residual response

Residual response is a phenomenon that appears as an input signal on the screen even though there is no real input signal.

Various local oscillators are used internally in spectrum analyzers. Residual response appears when the basic waveform and the harmonic components are mixed, producing the IF frequency.

Residual responses appear in a specific frequency band, and the average noise level relates to all frequency bands.

e.g The specification of MS8609A

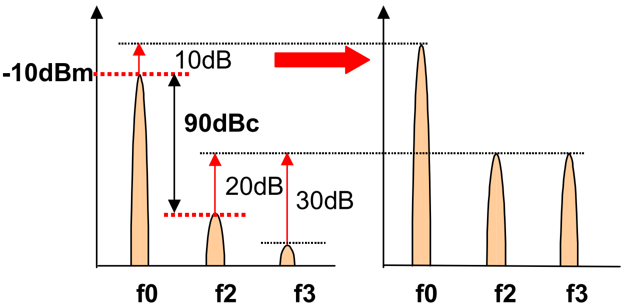
Residual response ≤ -100dBm (f_0=2GHz band)

(3) 2^{nd} harmonic Distortion

The 2^{nd} harmonic and the 3^{rd} harmonic of the input signal occur by the mixer generating distortion when a high level signal is input to the mixer.

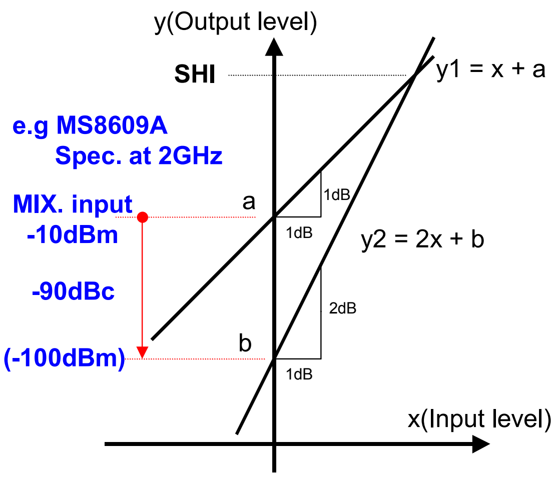
e.g The specification of MS8609A

2^{nd} harmonic distortion ≤ -90dBc (f_0=2GHz, MIX input -10dBm)



When a basic waveform is enlarged by 10dB, the 2nd harmonic distortion grows by 20dB and the 3rd harmonic distortion grows by 30dB.

What is Second Harmonic Intercept point(SHI)?



y1 is 1^{st} tone and y2 is 2^{nd} harmonic distortion.
$y1 = x + a$ (1)
$y2 = 2x + b$ (2)
The intersection between (1) and (2) is SHI.
$x + a = 2x + b \rightarrow x = a - b$
$y = 2a - b$

For MS8609A

1) **2^{nd} harmonic distortion:**
<-90dBc (1.6 to 6.6GHz)
Mixer input: -10dBm
They mean that the absolute value of 2^{nd} harmonic distortion is –100dBm when Mixer input level is –10dBm.

SHI = 2a – b
= 2x(-10) –(-100) = +80dBm

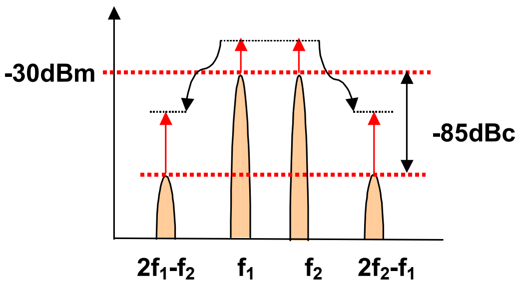
2) **2^{nd} harmonic distortion:**
<-70dBc (0.85 to 1.6GHz)
Mixer input: -30dBm

SHI = 2a – b
= 2x(-30) –(-100) = +40dBm

(4) Two-tone 3rd Order Distortion

When two high-level signals with nearby frequencies are input to the mixer, the two signals influence each other.

As a result, a frequency not contained in the input signal appears. These phenomena are called Two-tone 3rd Order Distortion.



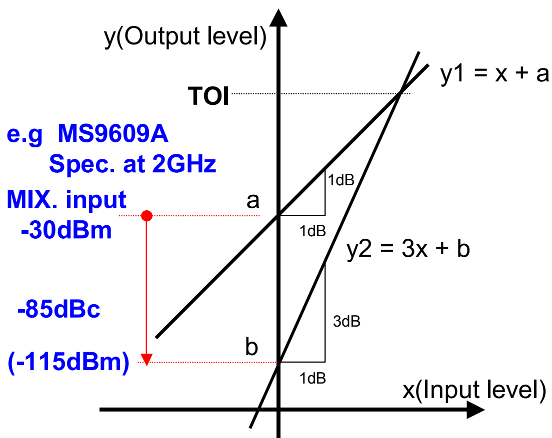
e.g The specification of MS8609A

Two-tone 3rd order distotion ≤ -85dBc

(f_0=2GHz, Offset 50kHz,

MIX input -30dBm)

What is Third Order Intercept point(TOI)?



y1 is 1st tone and y2 is 3rd order distortion.

y1 = x + a (1)

y2 =3 x + b (2)

The intersection between (1) and (2) is TOI.

x + a = 3x + b → x = (a – b)/2

y = (a – b)/2 + a

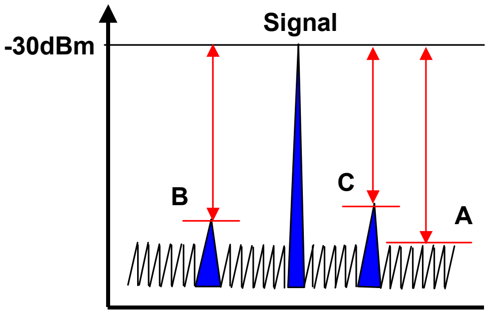
For MS8609A

1) Two-tone 3rd order distortion:
<-85dBc (0.1 to 3.2GHz)
Mixer input: -30dBm
They mean that the absolute value of 3rd order distortion is –115dBm when Mixer input level is –30dBm.
TOI = (a – b)/2 + a
= (-30+115)/2 –30 = +12.5dBm

2) Two-tone 3rd order distortion:
<-80dBc (3.15 to 7.8GHz)
Mixer input: -30dBm
TOI = (a – b)/2 + a
= (-30+110)/2 –30 = +10dBm

3) Two-tone 3rd order distortion:
<-75dBc (7.7 to 13.2GHz)
Mixer input: -30dBm
TOI = (a – b)/2 + a
= (-30+105)/2 –30 = +7.5dBm

4.9 Dynamic Range



e.g The specification of MS8609A

A: Average noise
$\leq$ -121dBm
(f_0=2GHz, RBW300Hz)

B: Residual response
$\leq$ -100dBm (2GHz band)

C: 2nd harmonic distortion
$\leq$ -90dBc at MIX input -10dBm

e.g Input level is -30dBm

A: Average noise
-30dBm –(-121dBm) = 91dB / RBW300Hz → 116dB / RBW1Hz

B: Residual response
-30dBm –(-100dBm) = 70dB

C: 2nd harmonic distortion
20dB + 90dBc = 110dB

5. Application Areas

1. Mobile communications	**Mobile phones, Wireless LANs**
2. Devices	**VCOs, Synthesizers, Mixers, Filters, Amplifiers, Antennas**
3. Satellite broadcasting	**BS, CS, Digital Broadcasting**
4. CATV	**CATV, Analog/Digital TV, Broadcasting, Transmitter Amplifiers, Distributors**
5. EMI	**IEC, EN (Europe), FCC (America), JIS (Japan)**

Specifications are subject to change without notice.

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