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Measuring mmWave Spectrum using External Mixer

Signal Analyzer MS2840A/MS2830A
High Performance Waveguide Mixer (50 to 75 GHz)/(60 to 90 GHz) MA2806A/MA2808A
Harmonic Mixer (26.5 to 325 GHz) MA2740C/50C Series

Contents

1. Introduction

The mmWave band has this name because it uses frequencies with wavelengths from 1 to 10 mm, which in concrete terms means a frequency of 30 GHz to 300 GHz.
Higher frequency signals have stronger linearity but the mmWave band also has high directivity.
In terms of physical characteristics, the mmWave band suffers from large free space attenuation losses, which when coupled with the high directivity makes it an extremely difficult frequency band to use compared to the 800 MHz and 2 GHz bands currently used by applications.
In contrast to the frequency band at 6 GHz and below, which has a limited usable frequency band due to a shortage of available frequencies, the mmWave band supports broadband signals and seems likely to be an essential part of future large capacity wireless communications systems.
This Application Note explains issues in mmWave band measurements, and a new measurement method proposed by Anritsu.

2. mmWave Usage

Wireless communications systems typified by mobile phones are seeing year onyear increases in data traffic. In particular, 5G mobile communications systems targeting traffic volumes of 1000 times that of LTE are being developed. Use of wideband signals is a key element in achieving large capacity communications and attention is focused on the mmWave frequency band supporting broadband signals.
The Shannon-Hartley theorem (below) related to communications capacity in information theory shows how communications capacity increases as the bandwidth of the transmitted signal is widened.

$$\mathrm{C} = B \times Log_2\left(1 + \frac{S}{N}\right)$$

C: $Communications\ capacity$ [bps]
B: B$andwidth$ [Hz]
S: T$otal\ power\ of\ signal\ in\ bandwidth$ [W]
N: T$otal\ power\ of$ noise $in\ bandwidth$ [W]
$\frac{\mathrm{S}}{\mathrm{N}}$: $Signal\ to\ noise\ ratio$

Since recent wireless communications applications have a limited usable frequency band, wireless system development has focused heavily on signal multiplexing, but the frequency resource rich mmWave band has greater potential for larger capacity wireless communications than previous systems by simply doubling or tripling the signal band.

3. mmWave Measurement Methods

This section explains mmWave band spectrum measurement methods. It introduces several methods and explains the features of each.

3.1. Methods using Harmonic Mixers

The conventional method for measuring the mmWave band uses an external harmonic mixer. The harmonic mixer takes the LO signal from a dedicated spectrum analyzer and frequency converts it using an internally generated harmonic waveform. This frequency converted IF signal is returned to the spectrum analyzer to perform analysis. Since the LO signal harmonic is used for frequency conversion, mmWave band signals can be analyzed using a relatively low frequency LO signal, offering a lower cost system configuration than other measurement methods.
On the other hand, this method is limited in use because a preselector cannot be used upstream of the mixer and the mixer response cannot be filtered out (see section 5). In addition, since this method uses frequency conversion using the mixer harmonic response, it suffers from high conversion losses due to the conversion degree, requiring care over the resultant degraded sensitivity of the measuring instrument.

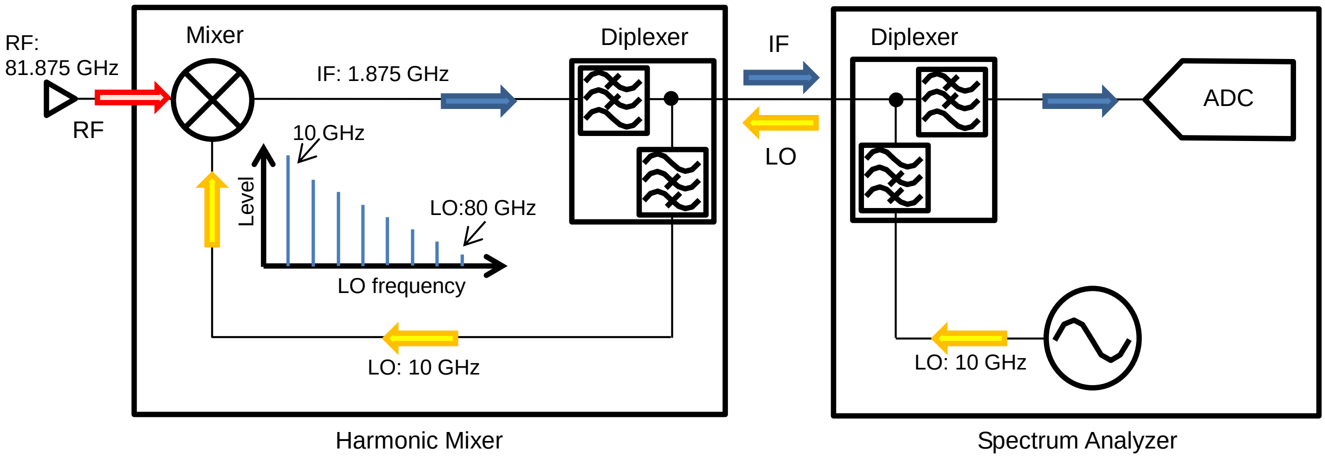


Fig. 1: Harmonic mixer outline

The following line of harmonic mixers supporting different frequencies matching the users' application is available for use as dedicated external mixers with the MS2830A/40A.

Table 1: MA2740/50C series external mixers

Model Name	Frequency Range	Band	Conversion Factor	Conversion Loss (typ.)	Waveguide size
MA2741C	26.5 GHz to 40 GHz	A	4	23	WR28
MA2742C	33 GHz to 50 GHz	Q	5	26	WR22
MA2743C	40 GHz to 60 GHz	U	6	28	WR19
MA2744C	50 GHz to 75 GHz	V	8	32	WR15
MA2745C	60 GHz to 90 GHz	E	9	36	WR12
MA2746C	75 GHz to 110 GHz	W	11	39	WR10
MA2747C	90 GHz to 140 GHz	F	14	40	WR08
MA2748C	110 GHz to 170 GHz	D	17	45	WR06
MA2749C	140 GHz to 220 GHz	G	22	50	WR05
MA2750C	170 GHz to 260 GHz	Y	26	65	WR04
MA2751C	220 GHz to 325 GHz	J	33	70	WR03

3.2. Methods using External Down Converter

In methods using an external down converter, the down converter is upstream of the spectrum analyzer and a synthesizer is provided to supply the LO signal. The mixer used by the down converter is a fundamental wave mixer, rather than a harmonic mixer. Consequently, a multiplier is added to the LO signal path to increase the frequency of the LO signal.

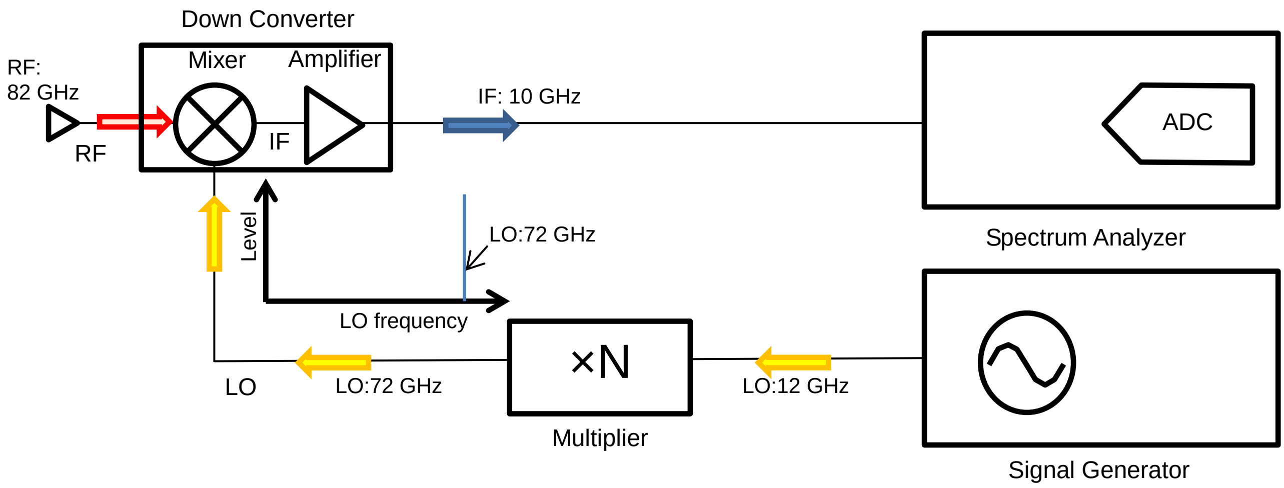


Fig. 2: Down converter outline

When using an external down converter, the IF output of the down converter can be selected as the frequency input to the downstream connected spectrum analyzer. As a result, the signal can be monitored with reduced unwanted response (spurious response) generated by the external down converter.

On the other hand, with measurement methods using an external down converter, selection of any IF signal requires correction of not only the frequency characteristics of the external down converter, but also of the frequency characteristics of the cable connection to the downstream spectrum analyzer. In addition to a mixer for the down converter, both a signal generator and a multiplier are required for the LO signal, creating issues with measurement costs and difficult operation. Moreover, since an unwanted image response is generated by the multiplier in the LO signal path, generation of spurious frequencies must be considered, requiring separately a system matching the measurement frequency.

3.3. Methods using Spectrum Analyzers

The spectrum analyzer features a built in preselector for removing unwanted responses generated by the mixer. Spectrum analyzers for the mmWave band are appearing.
On the other hand, since the spectrum analyzer internal noise figure (NF) increases as frequency rises, it becomes difficult to obtain the required measurement sensitivity. In addition, use of coaxial connectors instead of a waveguide results in problems handling connectors with high connection losses and degraded measurement sensitivity.
Moreover, since these configurations use a preselector, there are limits on the measurable bandwidth.

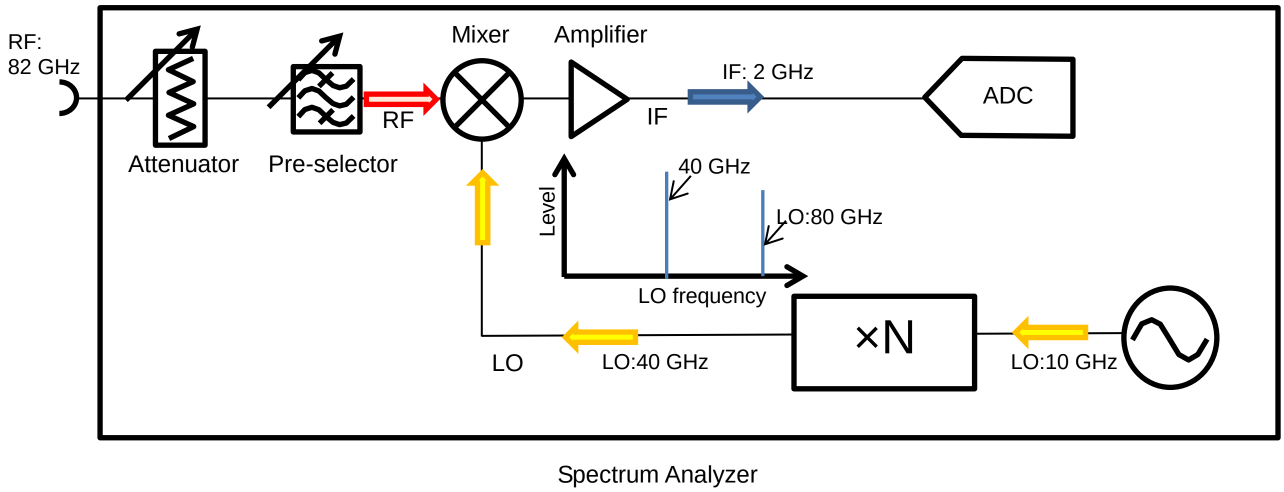


Fig. 3: Spectrum analyzer outline

3.4. Method using High Performance Waveguide Mixer

The High Performance Waveguide Mixer MA2806A/08A connection method uses the same spectrum analyzer LO signal source as when using a harmonic mixer. It has an internal multiplier for the LO signal because the mixer uses a fundamental mixer. This is the same configuration as a down converter.
The IF signal depends on the spectrum analyzer because the connection is the same as a harmonic mixer. As a result, spurious components generated by the mixer are reduced by the Spectrum Analyzer MS2840A and high IF of 1.8755 GHz.
The High Performance Waveguide Mixer combines the advantages of down converter performance with harmonic mixer ease of use.

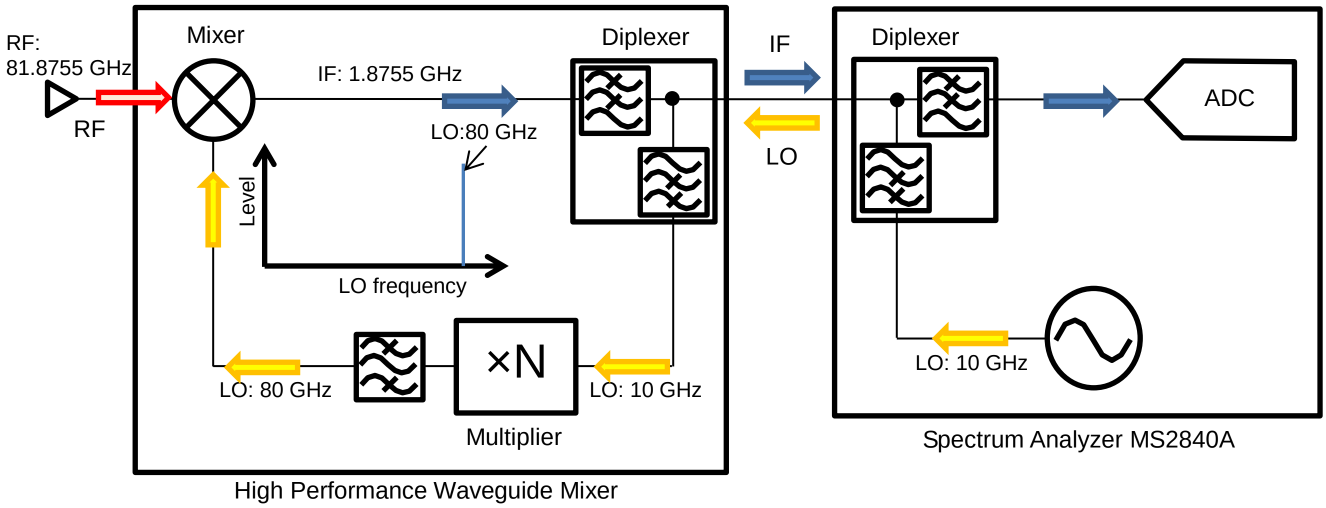


Fig. 4: High Performance Waveguide Mixer outline

For MS2830A, the IF is 1.875 GHz.

4. Required Performance for Measurement System

4.1. Dynamic Range Performance

Capturing wideband mmWave band signals requires better dynamic range performance than other applications.
For example, if we consider a –10 dBm signal with a bandwidth of 2 GHz, the normalized signal spectrum density is –103 dBm/Hz (–10 dBm – 10*log(2 GHz) = –103 dBm/Hz).
Accurate measurement of this type of signal requires a high sensitivity measuring instrument with a sufficiently lower level than –103 dBm.

Fig. 5: CW Signal and wideband signal spectrum density

4.2. Spurious Performance

mmWave band measurements using a harmonic mixer and external down converter require care concerning the spurious performance. In this measurement method, various spurious, such as image response, is generated because no preselector is used. If the user sees spurious in the wanted frequency range, the user must evaluate whether it is caused by the measurement system or by the device under test (DUT).
Moreover, to capture wideband signals, if spurious is generated close to the input signal, there may be concerns about overlap between the wanted signal and spurious, as shown in Fig. 6.

Fig. 6: CW Signal and wideband signal spurious performance

5. Principle of Spurious Generation without using Preselector

5.1. Spurious Generation Principle

Most spurious generated by measurement without using a preselector is caused by the mixer response.
This section explains the mixer response and the principle by which spurious is generated when using a spectrum analyzer.

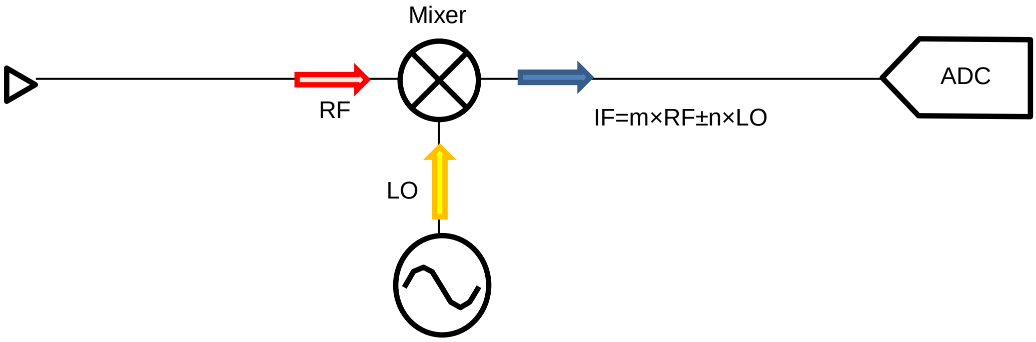


Fig. 7: Mixer response and principle of spurious response

When not using a preselector, the largest spurious is the image response generated by the mixer.
As an example, a LO signal of 59 GHz is generated at an RF signal of 60 GHz and an IF signal of 1 GHz. Conversely an IF signal of 1 GHz is generated even when the LO signal is 61 GHz. Usually, a spectrum analyzer displays the response when LO is 59 GHz as a 60 GHz spectrum, and the response when LO is 61 GHz as a 62 GHz spectrum. However, due to the previously described response, both the 60 GHz and 62 GHz signals are displayed when only a 60 GHz signal is input. The 62 GHz signal displayed at this time is called an image response.
Additionally, the image response is not the only main spurious; as shown by the following formula, the mixer response is an unknown number of signals depending on the mixing degree. Based on the following equation, all IF responses are displayed as spurious on the spectrum analyzer due to the action explained in the image response example.

$$\mathrm{IF} = \mathrm{mRF} \pm \mathrm{nLO}$$

This spurious is called mixer multiple responses. (The image response is one of the mixer multiple responses but is given a separate name because it is the same as the wanted signal.)
Generally, it is known that the conversion loss is smaller as the mixing degree becomes smaller, and the smaller the conversion order, the bigger the unwanted signal level.

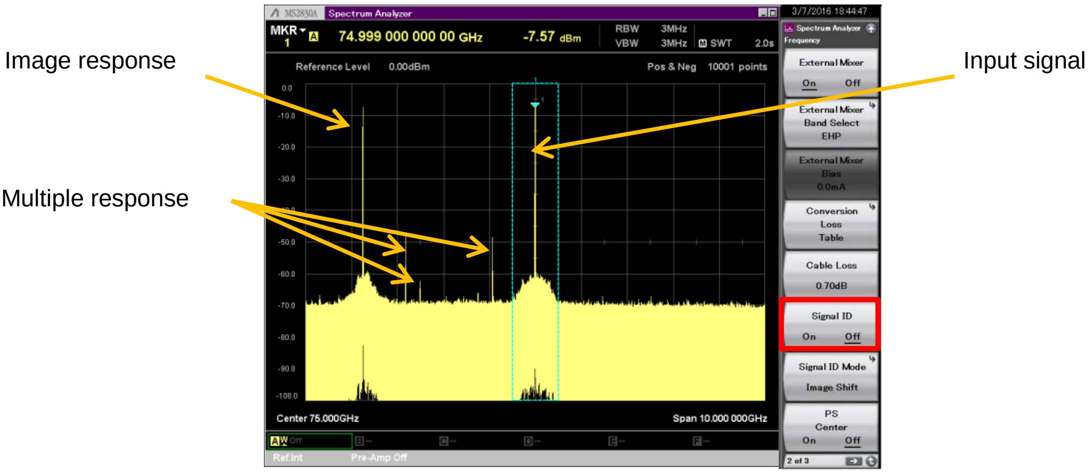


Fig. 8: Image response and multiple response spectrum example

5.2. Signal Recognition Functions

As explained, measurement without a preselector generates unwanted signals. Consequently, the MS2830A/40A has Signal ID and PS functions for recognizing signals. Using these functions makes it possible to filter out displayed signals caused by the measurement system and redundant signals caused by the DUT.

5.2.1. Signal ID Function

The Signal ID function has two subsidiary functions: Image Shift, and Image Suppression.
Both can be used to perform measurement by changing the mixing conditions. When the mixing conditions are changed, the frequency conditions change so the frequency of signals caused by the measurement system changes, but the frequency of the input signal does not change. This property makes it possible to accurately discriminate the input signal to the measuring instrument.
While the Image Shift and the Image Suppression modes both support measurement with changed measurement conditions, unlike the Image Shift mode, which displays the results for alternate measurements at changed mixing conditions, the Image Suppression mode displays only the lower of the two results at both sides for one measurement.

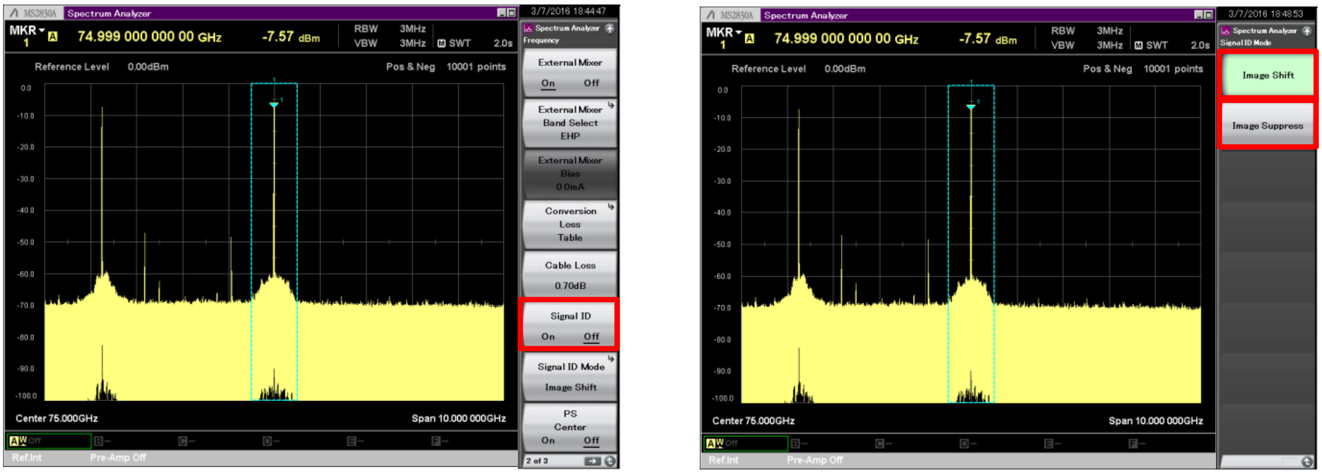
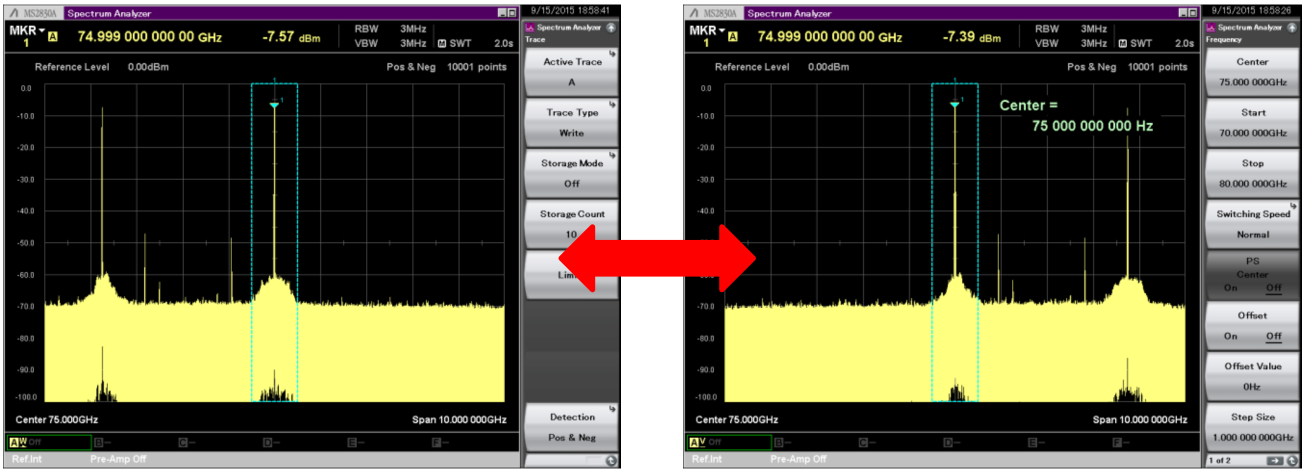


Fig. 9: Signal ID function setting screen



Using Image Shift function, mixing conditions change at each sweep and spurious due to measurement system changes displayed position

Fig. 10: Example of monitored spectrum using Signal ID Image Shift function

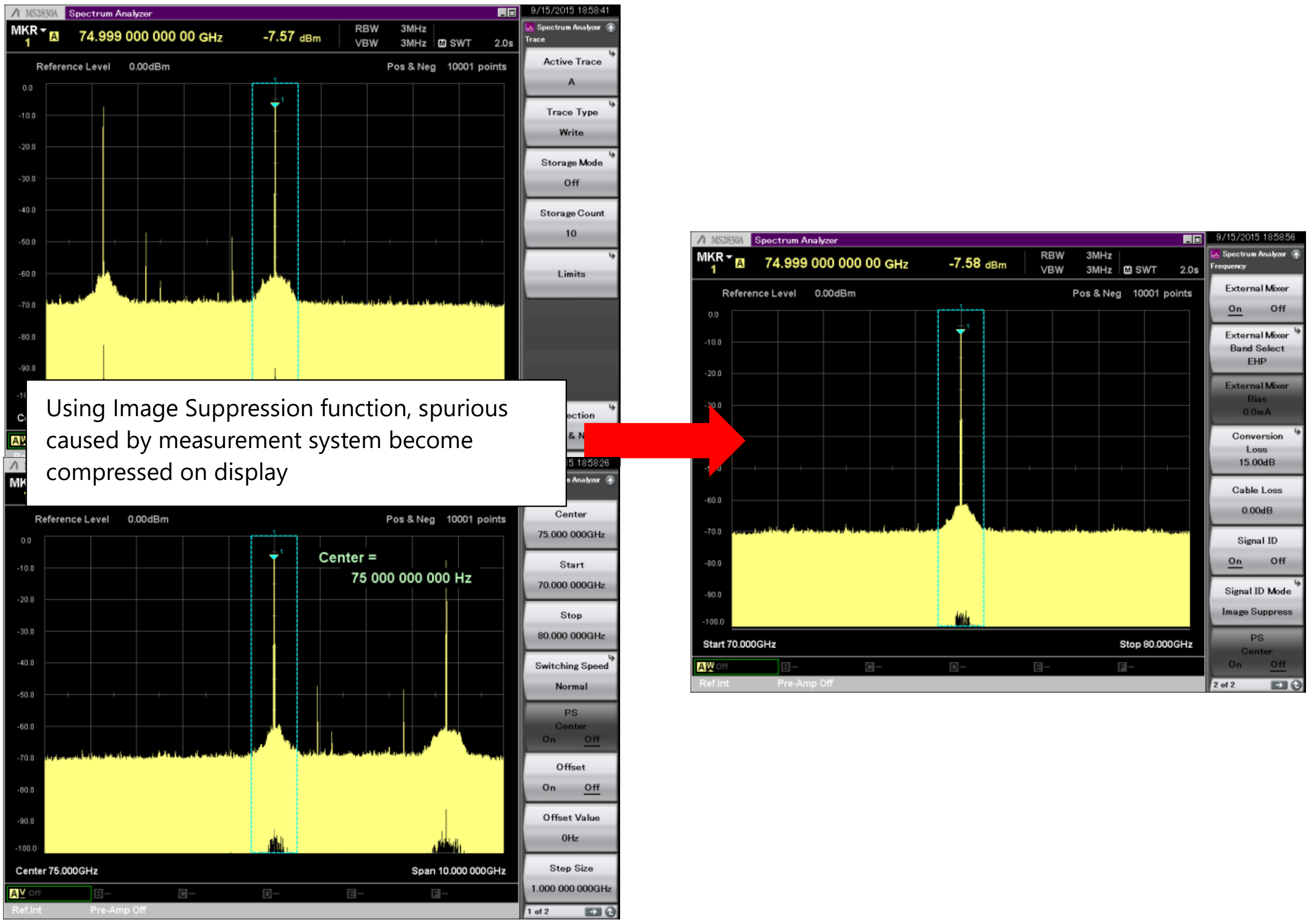


Fig. 11: Example of monitored spectrum using Signal ID Image Suppression function

5.2.2. PS Function

Using the MS2830A/40A with the MA2806A/08A supports the unique PS function for measuring signals without spurious. The PS function requires pre-input of a signal with a known frequency to suppress spurious caused by the measurement system. Not only can it be used to evaluate signals that are hard to measure using the Signal ID function, it can also capture accurate spectrum data.
We recommend using the previously described Signal ID function to capture the frequency of the pre-input signal.

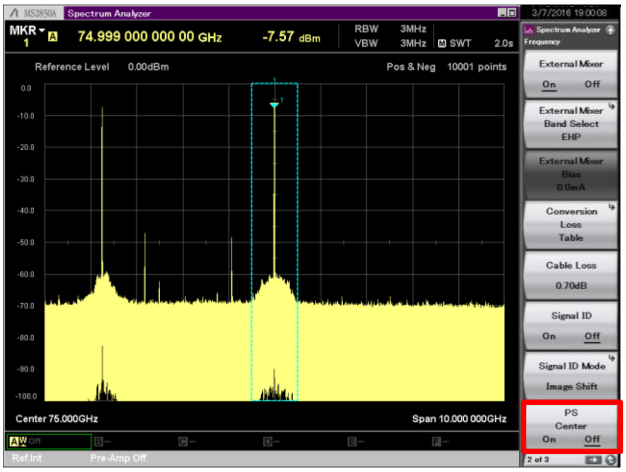


Fig. 12: PS Function setting screen

The PS function makes maximum use of the features of the High Performance Waveguide MA2806A/08A.
Instead of using a harmonic mixer to achieve the required dynamic range performance, the MA2806A/08A performs frequency conversion using a reference wave mixer after first multiplying the LO signal using the LO Multiplier Chain. Use of a reference wave mixer not only achieves a high dynamic range but also suppresses responses generated by the mixer. As a result, generated spurious can be limited to the upper or lower side of the input signal, depending on the polarity of the mixer response. The spurious at any frequency is suppressed in principle by changing the polarity of the mixer response.
For example, when the polarity is negative (LO signal frequency higher than input frequency), an image response appears at a higher frequency than the input. Conversely, when the polarity is positive (LO signal frequency lower than input frequency), an image response appears at a lower frequency than the input. Consequently, an image response at the left side of the measurement screen center is negative polarity, and at the right side is positive polarity, and cannot be measured.
The PS function can only be used with a fundamental mixer; with a harmonic mixer, there is a possibility that other responses occur within the measurement range, so the PS function cannot be used.

LO Polarity: negative

LO polarity: positive

PS Function On

Fig. 13: PS Function outline

5.2.3. Difference between Signal ID and PS Functions

The Signal ID and PS functions are similar in that they both separate spurious caused by the measurement system from the wanted signal but there are several differences between these functions. Having a good understanding of the effects of these functions ensures that the best method is used.

	Signal ID (Image Suppression) Function	PS Function
Advantage	Spurious caused by the measurement system can be distinguished by changing the mixing conditions for measurement.	Signals that fluctuate over time (e.g. chirp) can be measured since spurious can be suppressed in principle.
Disadvantage	When measuring signals that fluctuate over time, sometimes the peak level drops or disappears because Minimum Hold processing is used. With CW signals, although spurious can be isolated, there is a possibility that signals may overlap when changing mixing conditions when there is wideband signal.	Spurious that cannot be suppressed in principle is displayed. *Sometimes high order spurious of about –50 dBc is displayed.

6. Measurement Examples

This section explains how to measure the mmWave band using the Signal Analyzer MS2830A/40A and High Performance Waveguide Mixer MA2806AA/08A. The MS2830A/40A also supports measurements using the MA27xx series of harmonic mixers, but the measurements explained here are limited to using the MA2806A/MA2808A.

6.1. Setup

The MA2806A/08A is connected to the LO output port of the MS2830A/40A.

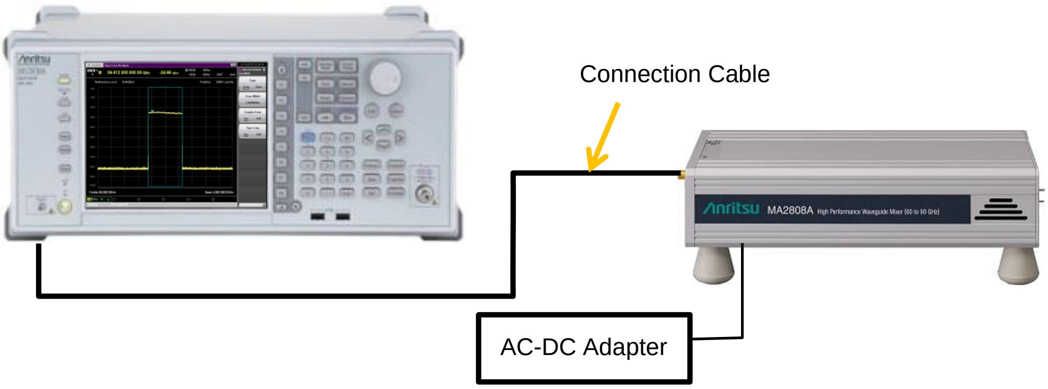
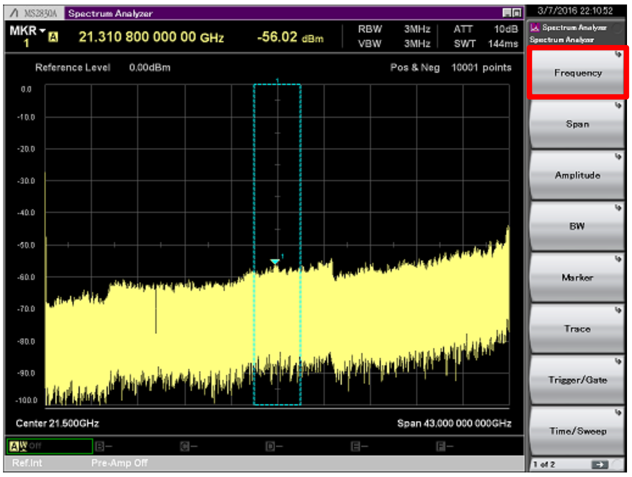
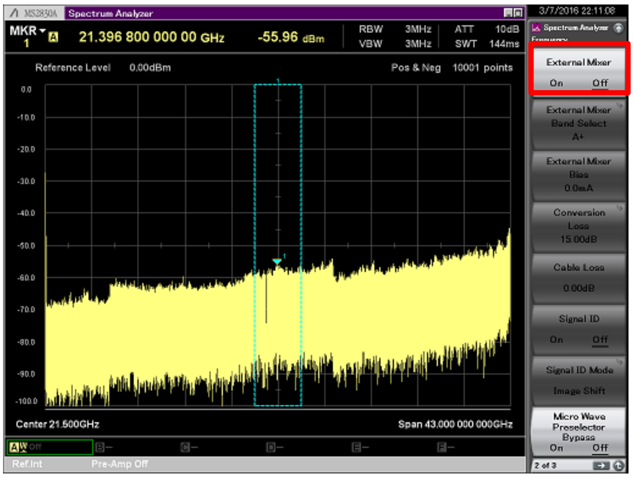


Fig. 14: High Performance Waveguide Mixer MA2808A connection

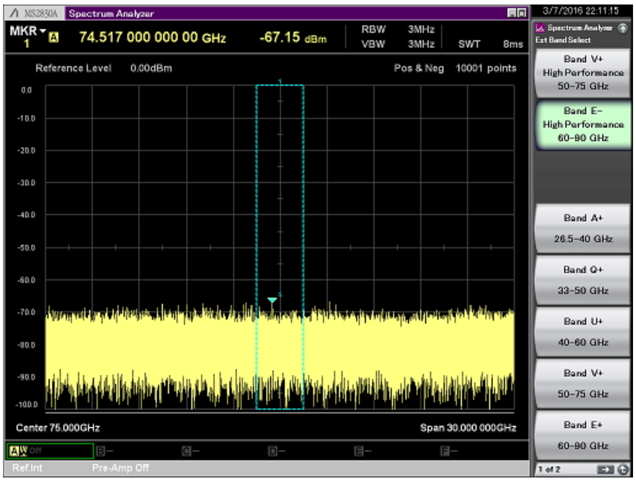
6.2. External Mixer Function Setting Method

The MS2830A/40A External Mixer function is used by enabling it using the External Mixer: On/Off key at the second page of the Frequency key.





After selecting the External Mixer function, the best band(s) matching the mixer to be used are selected and the LO signal matching each band is supplied from the MS2830A/40A to monitor the spectrum.



6.3. Signal Analysis Functions

By using the MS2830A/40A external mixer function, the spectrum analyzer Measure function and signal analyzer functions can be used even when using an external mixer.
The spectrum analyzer Measure function supports SEM, OBW, etc., measurements. In addition, chirp signals, etc., can be analyzed using the signal analyzer functions.

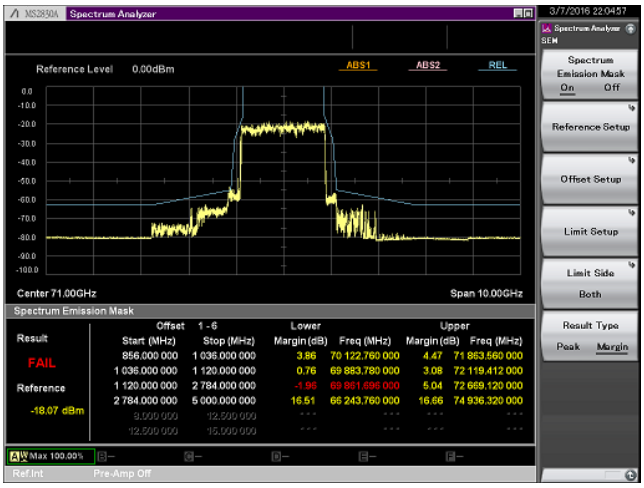


Fig. 15: SEM Measurement function (Measure Function)

Fig. 16: OBW Measurement function (Measure Function)

Fig. 17: SA Function (Spectrum)

Fig. 18: SA Function (Frequency vs Time)

6.4. Phase Noise Measurement Function

Phase noise can be measured when the phase noise measurement option (Opt-010) is installed in the MS2830A/40A. This function can also be used when using the MA2806A/08A and simplifies phase noise measurements in the V-band (50 to 75 GHz) and E-band (60 to 90 GHz).
At a CF of 1 GHz, the MS2840A phase noise function supports performance of −123 dBc/Hz at 10 kHz offset, and −123 dBc/Hz at 100 kHz offset. However, at phase noise measurement using the High Performance Waveguide Mixer, the performance is degraded by 20*log (multiplier) [dB], depending on the multiplier circuit configuration in each model. The MA2806A uses a x8 internal multiplier and the MA2808A uses a x12 internal multiplier, so the phase noise performance is degraded by about 18 dB and 22 dB, respectively.
Figure 19 shows an example of phase noise measurement results at input of a 79GHz signal.

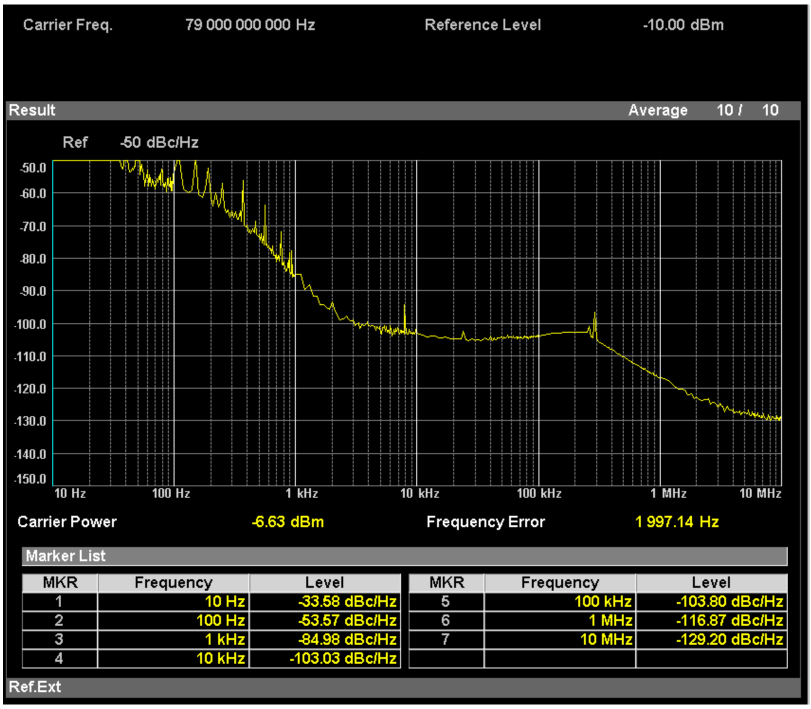


Fig. 19: Phase Noise measurement result example (Input frequency: 79 GHz)

7. mmWave Band Uncertainties and Notes

7.1. Impedance Mismatching

As well as measuring the mmWave band, it is also important to perform accurate measurements to help understand uncertainties due to impedance mismatching.
The RL performance of the MA2806A/08A RF port is <15 dB, which reduces measurement uncertainty due to impedance mismatching.

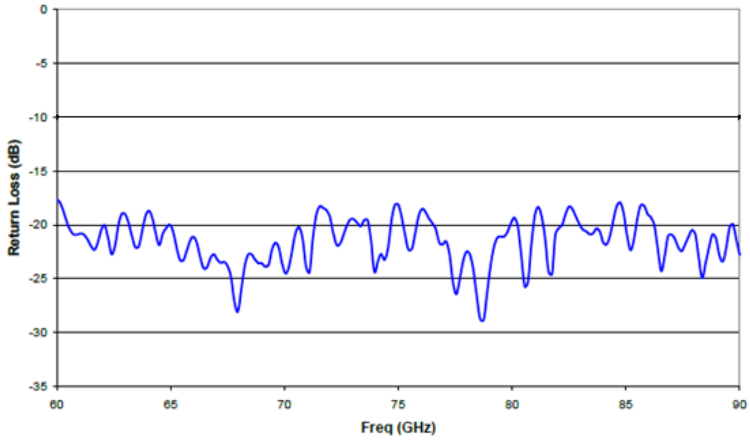


Fig. 20: MA2808A RF port RL characteristics

7.2. Power Measurement

Power is generally measured using a power meter when the power meter measures the total power in the entire receivable frequency range. Consequently, the power of the signal cannot be measured accurately if there is another signal affecting the wanted signal.
To help improve the power measurement accuracy, many users use a spectrum analyzer to pre-check for the presence of spectrum components other than the wanted signal.

7.3. Others

Usually, a waveguide is used as the interface for mmWave band signal measurements. Due to the waveguide construction, there is usually a gap at the connection face, which may degrade the frequency characteristics. Assuring measurements with high reproducibility requires specific connection methods for the waveguide interface.

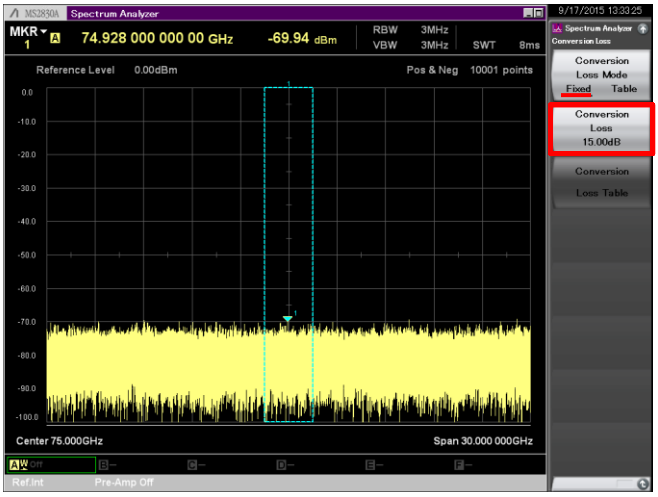
7.4. Correction Functions

The MS2830A/40A external mixer function has the following correction functions.

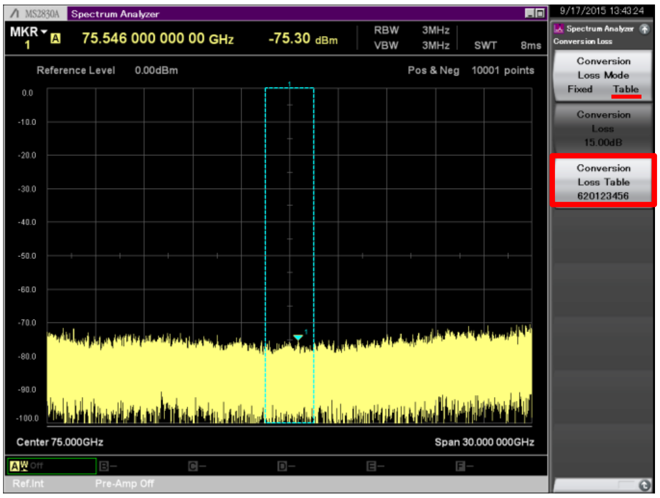
・Conversion Loss
・Cable Loss
・Level Offset
・User Correction

By using each of these correction functions, users can generally improve the accuracy of measurements in the mmWave band.

・Conversion Loss
The conversion loss is a unique value depending on which mixer is used. As a result, this function is used to correct the displayed spectrum level by inputting the conversion loss value.
The Conversion Loss correction function has two modes: Fixed and Table. When the MS2830A/40A is used in combination with the MA2806A/MA2808A, the Table mode can be used.
The mixer frequency characteristics are corrected simply by loading the conversion loss data for the MA2806A/08A being used. These data are read automatically from a USB memory stick shipped with each MA2806A/08A.



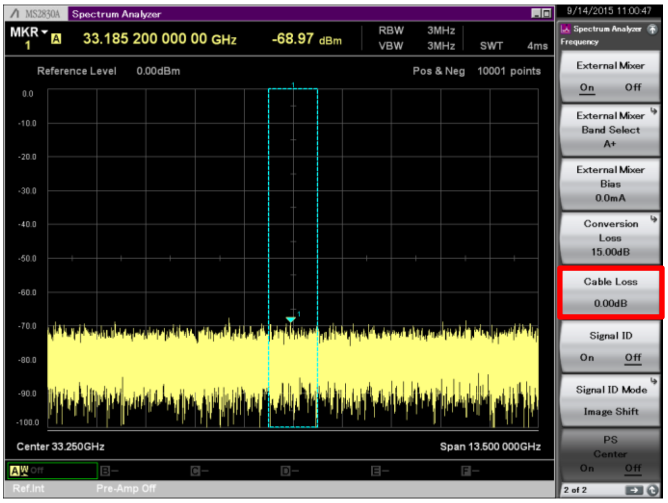
When Fixed mode is selected, any set conversion loss is applied to all frequencies.



When Table Mode is selected the conversion loss for each frequency is applied by referencing the Correction Table.

・Cable Loss

When the MS2830A/40A is used in combination with the MA2806A/08A, the conversion loss parameters can be adjusted using the above described function, but the connection cable between the MS2830A/40A and mixer may differ according to the usage circumstances. As a result, when using a connection cable with a known loss, this function can be used to reflect that known loss in the measurement results.



・Level Offset

Level Offset is a standard function of the MS2830A/40A for setting the screen display offset. It is used for more accurate level display.
In addition, the previously described Cable Loss setting can also be combined with this function.

・User Correction

User Correction is a standard function of the MS2830A/40A. It is used to correct the frequency characteristics of external modules (attenuators, etc.) that cannot be covered by other functions.
It is set at page 2 of the System Configuration menu. Up to 4096 data points can be input as User Correction data.

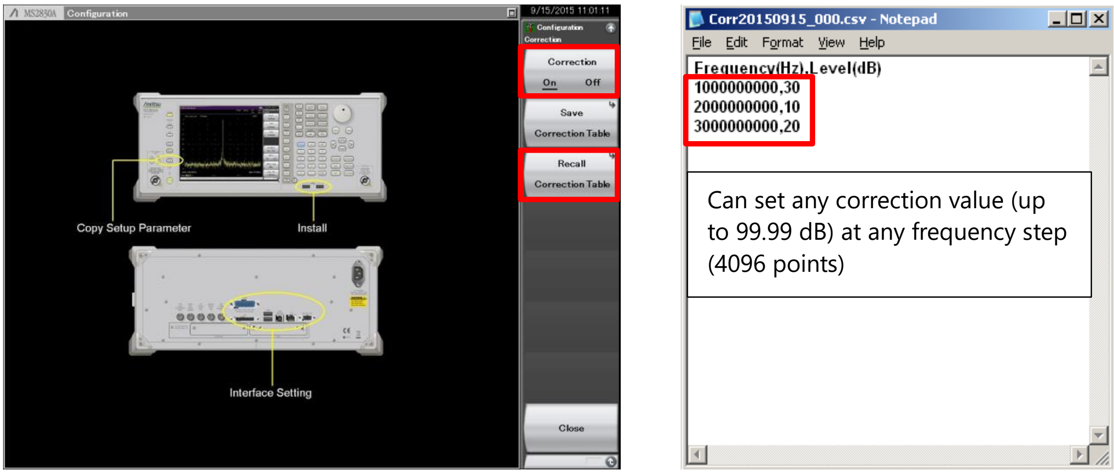


Fig. 21: User Correction function setting screen and settings file

Figure 22 shows an example of using the User Correction function.
When the created Correction Table data is applied, the results are displayed with the added set Offset value for each frequency as shown in Figure 21. The set Offset is applied by linear interpolation between the set frequencies and the Offset value is reflected at the upper and lower frequencies in the domains below the set lower frequency and above the set higher frequency.
In addition to correcting the frequency characteristics of external devices connected to the measuring instrument, this function can also be used when the user wants to make more accurate correction of frequency characteristics.

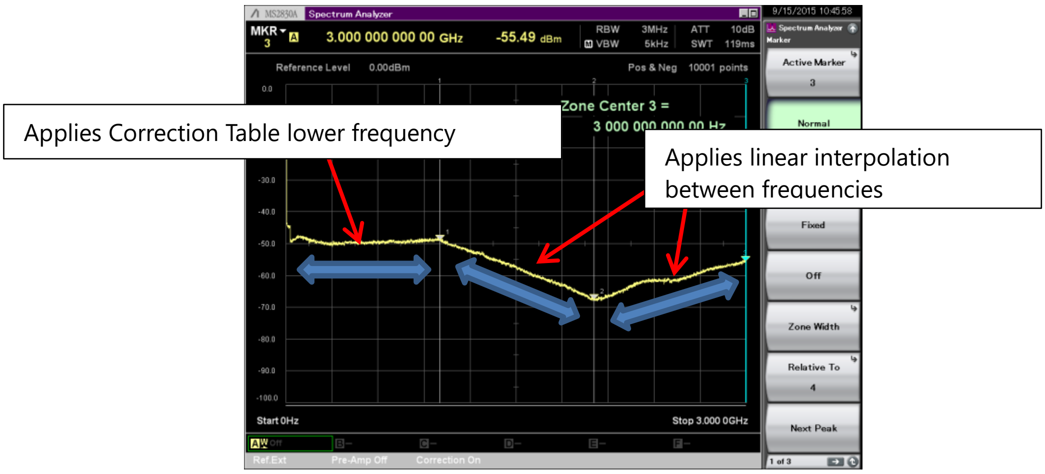


Fig. 22: User Correction function setting screen and settings file

8. Conclusions

This Application Note explains the performance required by mmWave band measuring instruments and the measurement methods. It also introduces the best measurement methods and measuring instrument for the measurement items required by key players in the mmWave band market.
Last, it explains some precautions about mmWave band measurements.
Anritsu's Signal Analyzer MS2830A/40A and High Performance Waveguide MA2806A/08A are ideal measurement solutions supporting developers of mmWave band applications expected to see future widespread adoption.

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