300-GHz Band Spectrum Measurement System with Preselector

Yuji Sekine, Shigeo Arai, Takashi Kawamura

[Summary] Development of wireless communications systems for frequency bands above 100 GHz is progressing to improve the capacity of short-range communications, which are expected to see increasing deployment in the near future. With the increase in wireless communications systems using wide frequency bands, it is no longer possible to ignore radio-wave interference among systems. As a result, there is increasing demand for a high-sensitivity, high-accuracy, spectrum measurement system for measuring spurious generated by wireless equipment. However, in these bands, conventional spectrum measurement systems are unable to adequately separate spurious responses generated in the measurement system from the observed signal, and there is a difficult problem to measure spurious of low-level. We report the development and evaluation of a 300-GHz band spectrum measurement system using a newly developed preselector to solve this problem.

1 Introduction

To increase communications capacity, several research organizations are examining wideband wireless transfer of uncompressed high-definition video using the 120- and 300-GHz bands[1) to 3)]. With the increase in commercial transceivers using wideband wireless communications, it is impossible to ignore the effect of radio-wave frequency interference among each wireless communications systems caused by spurious. As a result, it is necessary to suppress interference among systems as far as possible, and a spectrum measurement system that can accurately measure spurious with high sensitivity is required as an evaluation tool.

At analysis of signals above 100 GHz using a spectrum analyzer, generally analysis is performed by conversion an Radio Frequency (RF) signal to an Intermediate Frequency (IF) signal using a frequency converter, such as an external down converter or harmonic mixer. We consider the case when a signal with different frequency than the observed signal is input simultaneously at the RF connector. In this case, a spurious response problem occurs due to harmonics between the RF signal and Local (LO) signal input to the frequency converter. The IF signal of observed signal and IF signal caused by the signal with different frequency are mixed in the IF frequency range. It is difficult to distinguish the observed signal from spurious response. Conventionally, to separate the observed signal and spurious response, we use a preselector which is composed of YIG Tunable Filters (YTF) using Yttrium Iron Garnet (YIG) in the resonator, or is composed of a filter bank using a waveguide switch. However, when using a YTF at frequencies above 100 GHz, a heavy current circuit is needed to generate a large magnetic field. Moreover, when using a preselector with a waveguide switch, the mechanism is large and there are also issues with large insertion losses, making this method ineligible for use in a spectrum analyzer. To deal with this problem, both 140-GHz band spectrum measurement systems using a preselector based on a Fabry-Perot resonator type tunable filter[4)], and 300-GHz band spectrum measurement systems using a highpass filter[5)] have been reported. This article reports the evaluation results of a 300-GHz band spectrum measurement system using a newly developed filter-bank type preselector.

The system configuration is described first followed by the frequency design, which is an essential technology in separating the spurious response, and the preselector design. Next, the 300-GHz band signal generator (300 GHz SG hereafter) with the suppressed spurious required for evaluating spectrum measurement system performance is described. Last, evaluation results are presented for the 300-GHz band spectrum measurement system using the developed 300 GHz SG.

2 300-GHz Band Spectrum Measurement System

2.1 System Configuration

The configuration of the 300-MHz band spectrum measurement system is shown in Figure 1. The system is composed of a front end, signal generator (MG3697C), microwave spectrum analyzer (MS2840A), and personal computer (PC). To reduce the spurious response, the mixer built-into the front end for frequency conversion should be a fundamental mixer. However, use of a fundamental mixer requires using a LO signal for the frequency band above 200 GHz, making it difficult to generate a LO signal with a sufficient level for operating the mixer. Consequently, this developed 300-GHz band spectrum measurement system uses a sub-harmonic mixer to suppress LO signals above 100 GHz and reduce the spurious response.

The actual system operation is described below. The observed RF signal is input at the front end RF Input connector before passage through the Preselector and input to the sub-harmonic mixer. On the other hand, LO signal for the sub-harmonic mixer is generated by passing the signal from the signal generator and input at the LO Input connector via amplifiers, filters and x3 multiplier. The RF signal is down-converted to the IF signal and passed via the IF amplifier for output from the front end IF Output connector. This IF signal is analyzed by the microwave spectrum analyzer before final display of the 255 to 315 GHz spectrum on the Control PC (Personal Computer) as shown in Figure 1 where f_{RF} is the RF signal frequency, f_{LO} is the mixer LO signal frequency, f_{IF} is the IF signal frequency, and f_{SG} is the signal generator output frequency as local source.

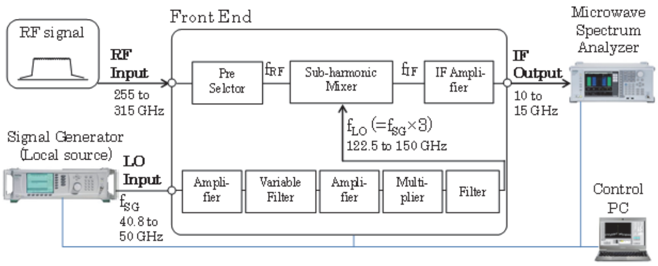


Figure 1 300-GHz Band Spectrum Measurement System Blocks

2.2 Frequency Design

The key technology to reduce the unwanted spurious response of the spectrum measurement system is selection of the LO and IF signal frequencies. In the developed 300-GHz band spectrum measurement system, the observed RF signal is converted ($f_{IF} = |f_{RF} - 2 \times f_{LO}|$) to an IF signal by a sub-harmonic mixer and analyzed by a microwave spectrum analyzer. Consequently, to suppress the spurious response of this system, it is necessary to perform frequency design using a spurious chart to minimize the impact of the microwave spectrum analyzer frequency characteristics. As shown by the investigation results in Table 1, the RF signal range of 255 to 315 GHz is divided into 12 bands of 5 GHz each. Then the LO signal frequency is allocated step-wise to each band and set so that the IF signal at each band is always 10 to 15 GHz. This procedure ensures that the spurious response is always separated from the observed signal. The details of the evaluation results are described below.

Figure 2 shows the frequency components of this spurious response generated by harmonic components for each of the RF and LO signals at the investigated frequency configuration. In this figure, IM(m,n) indicates the generated spurious response $|m \times f_{RF} - n \times f_{LO}|$ at the RF signal (f_{RF}) mth order and the LO signal (f_{LO}) nth order. This figure shows with the results until the f_{RF} third order and f_{LO} seventh order. Here, IM(1,2) indicates the signal that should be observed signal (wanted signal) for $f_{RF}-2\times f_{LO}$. Moreover, −IM(1,2) is indicated by $-(f_{RF}-2\times f_{LO})$, showing the spurious response with same order component as the wanted signal. In this article, the spurious response with same-order component as the wanted signal is called the image response, whereas the spurious responses other than the image response are called multiple response. The horizontal axis in Figure 2 displays the observed frequency of the spectrum and the vertical axis displays the frequency (f_{RF}) of the RF signal input at the RF Input. In the example X in Figure 2, −IM(2,5) components are generated at 257.5 GHz when a 300-GHz signal is input at RF Input. This result confirms that this frequency configuration does not generate unwanted signals (image response and multiple response) intersecting the wanted signal IM(1,2).

Based on these results, selecting the frequency configuration listed in Table 1 should suppress unwanted signals when passing the RF signal to be observed via the preselector, enabling spurious measurement.

Table 1 RF, LO and IF

Band	RF Signal [GHz]	LO Signal [GHz]	IF Signal [GHz]
1	255 to 260	122.5	10 to 15
2	260 to 265	125.0	10 to 15
…	…	…	…
12	310 to 315	150.0	10 to 15

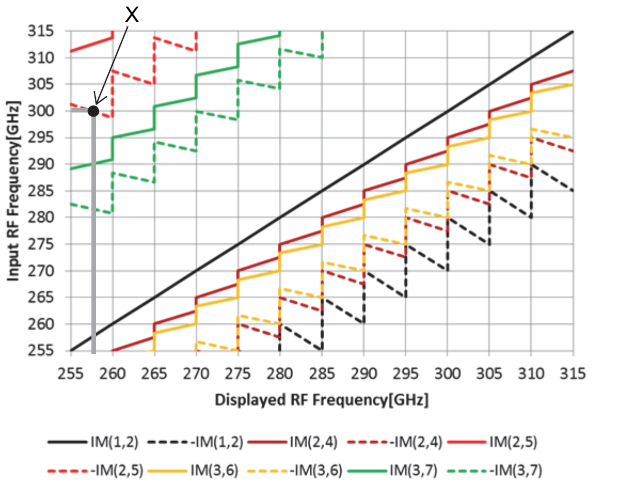
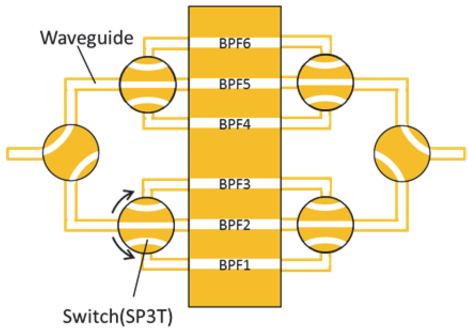


Figure 2 300-GHz Band Spectrum Measurement System Spurious

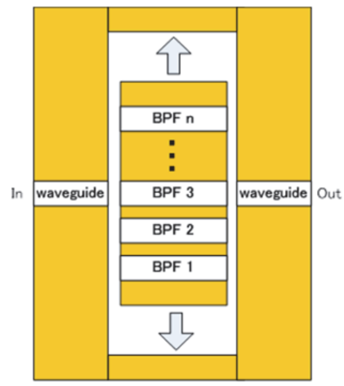
2.3 Preselector

Based on the previously described frequency design results, it was clear that a spectrum analyzer could be designed for spurious measurements by using an appropriate preselector. However, a tunable filter using a Fabry-Perot resonator[4] could not be used as a preselector for a 300-GHz band spectrum measurement system, because this filter suffers from large insertion loss described previously due to the effects of machining accuracy against wavelength and parts assembly issues[6]. Consequently, we adopted a switching-type filter bank using multiple bandpass filters (BPFs hereafter) with different passbands for the 300-GHz band preselector.

Generally, configuring a filter bank by switching BPFs uses a SP3T switch with one input and three output paths as shown in Figure 3(a). Increasing the number of BPFs requires increasing the number of switches, complicating waveguide connections and causing issues with the size of the device. Additionally, increasing the number of BPFs also causes issues with increased insertion loss. Moreover, commercial waveguide switches suffer degraded performance due to wear in moving parts resulting in inadequate durability when used in measuring instruments. As a result, we developed a new type of filter bank shown in Figure 3(b)[7]. This filter bank is designed with multiple BPFs between a one-input to one-output waveguide; the required BPF is selected by moving the filter block horizontally. To ensure that the developed filter bank secures the necessary durability, the face between the waveguide input and output and the filter block was designed with a small gap of about 50 μm. Using this structure prevented degraded performance as a result of wear at the filter block and is expected to assure long life. Moreover, degraded isolation due to the slight gap was suppressed by designing chokes at the waveguide input and output and filter block. This structure successfully implemented a small 300-GHz filter bank with low loss and excellent durability.



(a) Conventional Filter Bank



(b) New Filter Bank

Figure 3 Filter-Bank Type Preselector

The specifications for each BPF are described below. A total of six types of BPF was used with a pass band of about 10 GHz and each BPF covers two 5-GHz bands as shown in Table 1. From the spurious chart (Figure 2), the spurious level is sufficiently low for the IM(2,4) component closest to the wanted signal IM(1,2) frequency and for the next closest IM(3,6) component. Consequently, the attenuation band for each BPF was specified to attenuate spurious components other than these components. As an example, Table 2 and Figure 4 show the BPF specification and measurement results for Band 5 and Band 6 (275 to 285 GHz RF signal). In the required BPF specifications, Character A indicates the S21 and frequency of passband, while B, C, and D indicate the S21 and frequency of rejection band. Figure 5 shows the frequency characteristics for BPF1 (band 1, 2), BPF2 (band

3, 4), BPF3 (band 5, 6), BPF4 (band 7, 8), BPF5 (Band 9, 10), and BPF6 (band 11, 12) of the final fabricated filter bank. Figure 5 confirms that the required specifications are satisfied for each of BPF1 to BPF6.

Table 2 BPF Specifications for Band 5 and Band 6

	S21 [dB]	Frequency [GHz]	Target Spurious Component
A (Passband)	> −5	274.0 to 286.0	—
B (Rejection Band)	< −20	266.6	−IM(3,6), −IM(2,5)
C (Rejection Band)	< −35	260.0	−IM(1,2)
D (Rejection Band)	< −20	298.3	−IM(1,3), −IM(1,3)

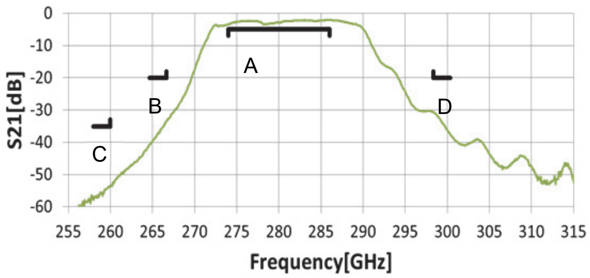


Figure 4 BPF Frequency Characteristics for Band 5 and Band 6

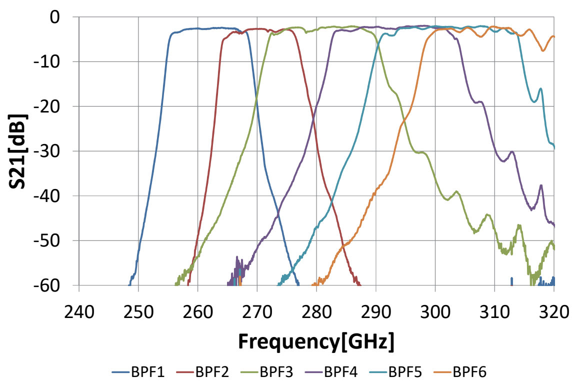


Figure 5 Filter-Bank Frequency Characteristics

3 300-GHz Band Signal Generator

Evaluating the 300-GHz band spectrum measurement system requires a signal generator with adequately suppressed spurious as the reference signal source. Consequently, we designed a 300-GHz band signal generator (300 GHz SG) that could output a low-spurious RF signal in the frequency range of 255 to 315 GHz. This development targeted a design spurious level of −60 dBc.

3.1 300 GHz SG Configuration

Figure 6 shows the block diagram of the developed 300 GHz SG. Signal generator (MG3697C) outputs an RF signal between 42.5 and 52.5 GHz. To reduce the signal generator non-harmonic spurious, the signal is passed via a variable BPF before x6 frequency multiplication in two stages to generate a signal of 255 to 315 GHz. Harmonics and sub-harmonics generated by the multipliers are filtered out by a BPF downstream of each multiplier. The multiplied RF signal is output via a coupler after level-adjustment using a variable attenuator. One of the signals branch by the coupler is converted to voltage by a detector to monitor the output power with a digital multimeter. The signal generator, variable BPF, variable attenuator, and digital multimeter are connected to the PC that sets the frequency and power and monitors the output power, etc. This configuration can instantaneously capture the output power change due to the influence of the external environment and supports level calibration at spectrum analyzer evaluation.

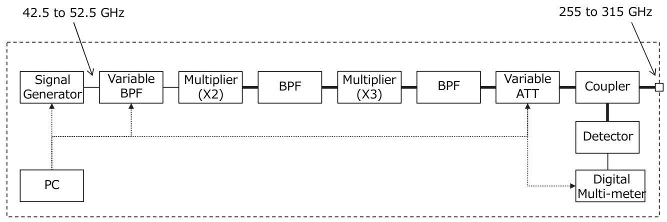


Figure 6 300-GHz Band Signal Generator Blocks

3.2 Output Power

In addition to low spurious, using the 300 GHz SG for the evaluation of 300-GHz band spectrum measurement system also requires a fixed level output power at each frequency. A calorimetric power meter is used to calibrate the 300 GHz SG output power. Since the lower limit of the calorimetric power meter input level is −17 dBm, the 300 GHz SG output power is calibrated as −15 dBm based on a 2-dB margin. To calibrate the 300 GHz SG output power, a calorimetric power meter was connected to the 300 GHz SG output and the variable attenuator was adjusted so that the value displayed by the calorimetric power meter was −15 dBm at each frequency, and the detector voltage value was recorded at the same time.

Figure 7 shows the 300 GHz SG output power frequency characteristics after output power calibration. The same figure confirms a flatness of –15.0 dBm ±0.5 dB in the frequency range of 255 to 315 GHz.

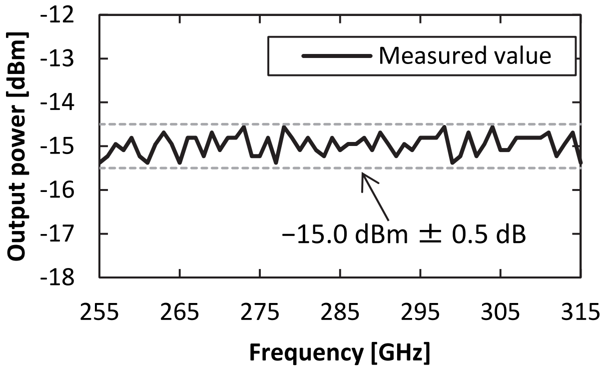


Figure 7 Output Power Characteristics of 300-GHz Band Signal Generator

3.3 Spurious

The 300-GHz band spectrum measurements system was calibrated using the developed 300 GHz SG and the spurious performance of the 300 GHz SG was evaluated using the calibrated 300-GHz band spectrum measurement system.

Figure 8 shows the spurious characteristics. The spurious characteristics in this figure are plotted after removing spurious (image response) caused by the 300-GHz band spectrum measurement system calculated from the spurious generation frequency. The dashed-line in the figure indicates the target value (−60 dBc), showing the obtained performance meets the target value across the entire frequency band.

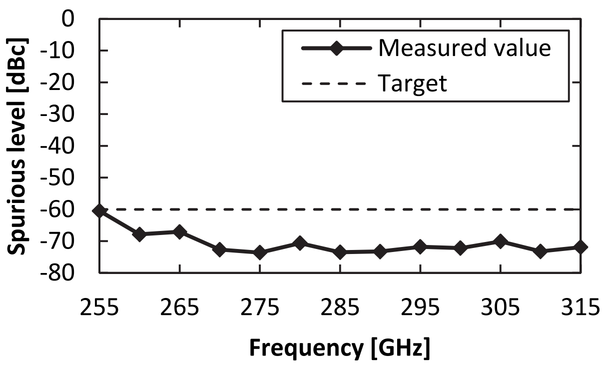
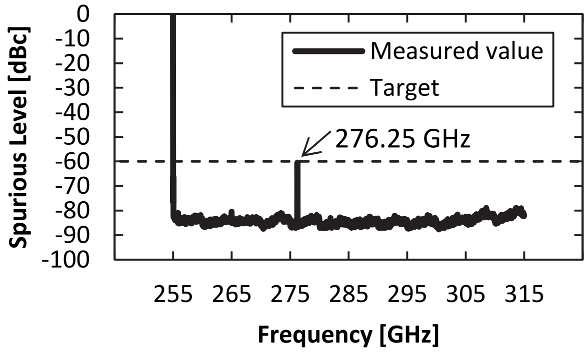
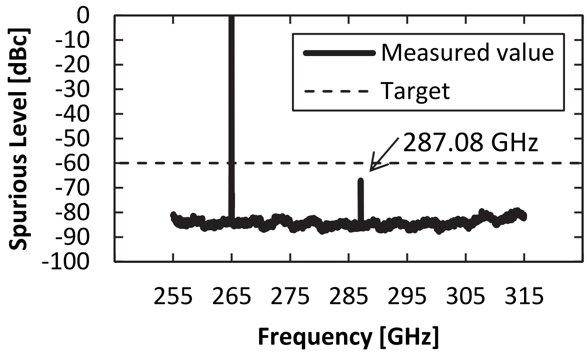


Figure 8 Spurious Characteristics of 300-GHz Band Signal Generator

Figure 9 shows an example of the spectrum when measuring the spurious characteristics. Figure 9(a) shows the spectrum for the 255-GHz output frequency, and Figure 9(b) shows the waveform for the 265-GHz output frequency. From Figure 9(a), the spurious performance reaches the same level as the target value (–60 dBc) indicated by the dashed line at 276.25 GHz. This spurious is clearly due to the signal generator sub-harmonic components. Adding a low-pass filter upstream of the variable BPF to suppress sub-harmonic components further improved the 300 GHz SG spurious performance.



(a) 255-GHz Output Frequency



(b) 265-GHz Output Frequency

Figure 9 300-GHz Band Signal Generator Spectrum

4 Evaluation Results

This section presents the measured results for the image response, multiple response, Display Average Noise Level (DANL), and Third-Order Intercept point (TOI) of the 300-GHz band spectrum measurement system evaluated by connecting the 300 GHz SG. In addition, Figure 10 shows the external appearance of the 300-GHz band spectrum measurement system and 300 GHz SG. Figure 11 shows the spectrum (255 to 315 GHz, 1-MHz RBW) at input of a 280-GHz CW signal from the 300 GHz SG; the sweep time was about 70 s.

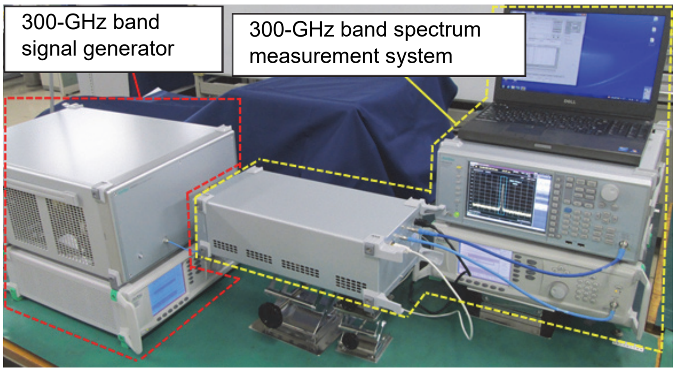


Figure 10 External Appearance of 300-GHz Band Spectrum Measurement System and 300-GHz Signal Generator

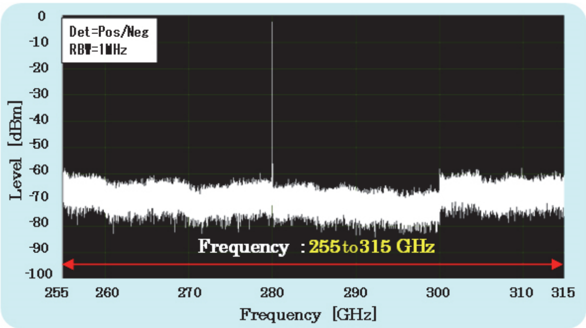


Figure 11 Spectrum (at input of 280-GHz CW signal)

4.1 Image Response and Multiple Response

Figure 12 shows the measured results of image response at input of a signal with a level of −15 dBm. When inputting a signal with a frequency range of 255 to 315 GHz, the graph horizontal frequency axis is shown from 280 GHz because an image response is generated above 280 GHz. For comparison, Figure 12 shows the measured results without pre-selector. In this condition, there is clearly an image response at the same level of 0 dBc as the input signal. On the other hand, the solid line in Figure 12 shows the measurement result for the 300-GHz band spectrum measurement system with built-in preselector. Figure 12 confirms that the image response has a level of less than –35 dBc across the entire used frequency range.

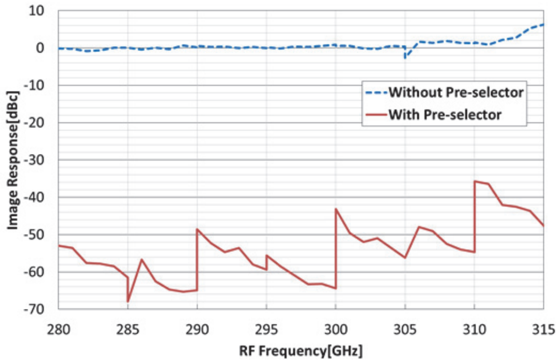
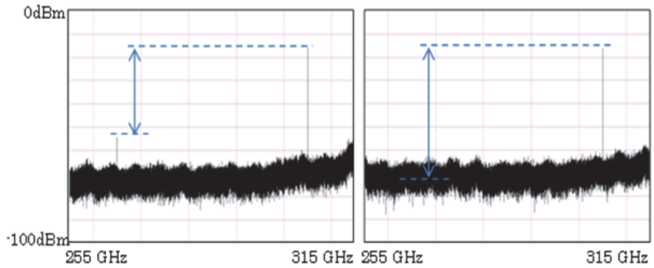


Figure 12 Image Response
(RBW = 1 MHz, Detection Mode = Pos/Neg, Input Level = −15 dBm)

The next section shows the multiple response measurement results. Figure 13 shows the spectrum when the input frequency is 305 GHz and the level is −15 dBm. At an input frequency of 305 GHz, a multiple response occurs at 265 GHz due to the –IM(2,5) components shown in the spurious chart (Figure 2). Attenuation of the multiple response by inserting the preselector is confirmed by comparison of Figures 13(a) and (b) showing the spectrum both without and with the preselector.



(a) Without Preselector (b) With Preselector

Figure 13 Spectrum at Multiple Response Generation
(RBW=1 MHz, Detection Mode = Pos/Neg, Input Level = −15 dBm, Input Frequency = 305 GHz)

Moreover, Figure 14 shows the maximum value of the multiple response at each frequency when the input frequency is changed within the range of 255 to 315 GHz. Without the preselector, the multiple response has a level of about −33 to −40 dBc in the observed frequency range of 255 to 270 GHz. On the other hand, with the preselector the multiple response is suppressed to a level of about −60 dBc. Consequently, we have confirmed that adding the preselector reduces unwanted spurious called image response and multiple response to a great extent.

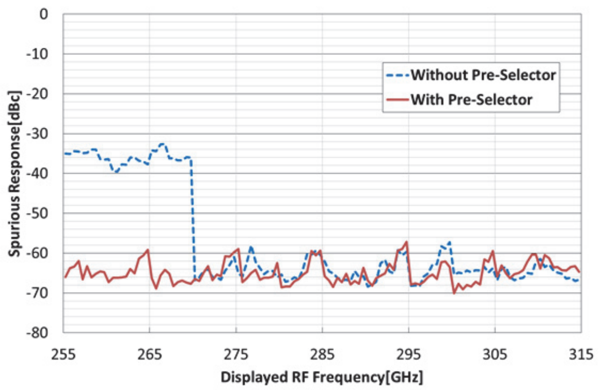


Figure 14 Multiple Response
(RBW = 10 kHz, Detection Mode = Pos/Neg, Input Level = −15 dBm)

4.2 Displayed Average Noise Level (DANL)

The DANL is one index indicating spectrum analyzer noise performance. Measurement is performed by setting the resolution bandwidth of a microwave spectrum analyzer to 300 Hz; Figure 15 shows the results of DANL at equivalent to resolution bandwidth 1 Hz. From this figure, it is clear that the performance is better than −134 dBm/Hz across the entire frequency band. This result confirms that the developed 300-GHz band spectrum measurement system has a sufficiently low DANL compared to results when using an external harmonic mixer.

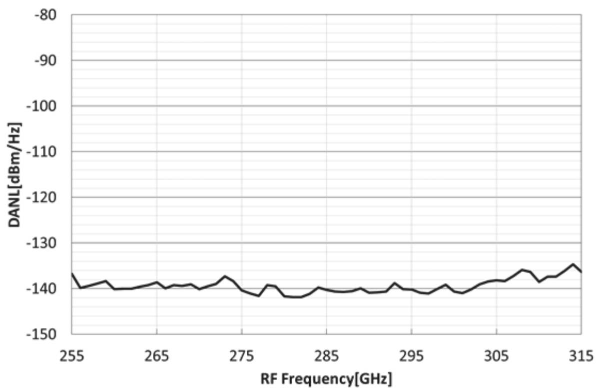


Figure 15 Displayed Average Noise Level
(RBW = 300 Hz, Detection Mode = Sample, ATT = 0 dB)

4.3 Third-Order Intercept Point (TOI)

Figure 16 shows the measured results for TOI performance indicating the intermodulation at two-signal (two-tone) input. We assumed a frequency separation of 10 MHz between the two input signals. The horizontal frequency axis is the center frequency between the two input signal frequencies. The TOI across the entire frequency range was +16 dBm or more. Since the TOI of a general-purpose microwave spectrum analyzer is generally about +10 to +18 dBm, the TOI performance of the 300-GHz band spectrum measurement system satisfies the requirements.

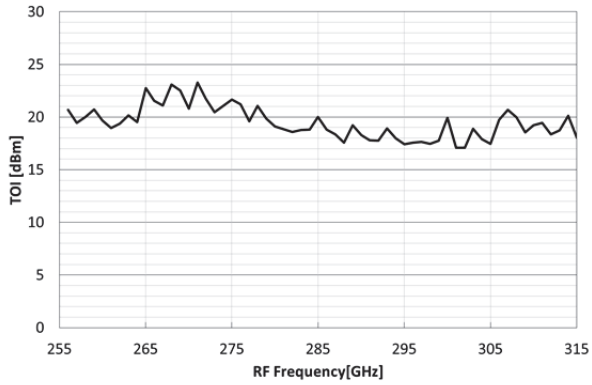


Figure 16 Third-Order Intercept Point
(RBW = 1 MHz, Detection Mode = Pos/Neg, Input Level = −17 dBm/1CW)

5 Conclusions

We have successfully constructed and evaluated the performance of a spectrum measurement system with the first built-in preselector for the 300-GHz band. The measurement results show that the developed system performance achieves an image response of −35 dBc or less, and a multiple response of −60 dBc (typ.). These results confirm that the developed system can separate the observed signal and spurious response, solving a serious issue with previous microwave spectrum measurement systems. In addition, the spectrum measurement system key performance DANL and TOI indices are −134 dBm/Hz, and +16 dBm, respectively.

We are currently examining future methods for reducing the image response even further and increasing the sweep speed.

Acknowledgements

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References

1) A. Hirata, et al: "120 GHz-Band Wireless Link Technologies for Outdoor 10-Gbps Data Transmission", IEEE Trans. Microwave Theory & Tech., 60, 3, pp.881-895 (Mar.2012)

2) K. Katayama, et al: "A 300 GHz CMOS Transmitter With 32-QAM 17.5Gb/s/ch Capability Over Six Channels", IEEE Journal of Solid-State Circuits, Vol.51, No.12, pp.3037-3048 (Dec. 2016)

3) S. Hojin, et al: "Demonstration of KIOSK Data Downloading System at 300 GHz Based on InP MMICs", 2015 International Symposium on Radio-Frequency Integration Technology, No. TH2A-2 (2015)

4) M. Fuse, Y. Kimura, and A. Otani: "Over 100 GHz Millimeter-wave Spectrum Measurement System with Pre-selector", 2014 International Microwave Symposium(IMS), No. TH2D-1 (Jun. 2014)

5) Yuji Sekine, Shigeo Arai, Takashi Kawamura, Masaaki Fuse, Shigenori Mattori, Hanako Noda: "The construction of 300 GHz Millimeter-wave Spectrum Measurement Instrument", IEICE Technical Report, vol.116, no.249, SRW2016-49, pp.31-36 (Oct. 2016)

6) Takashi Kawamura, Shigenori Mattori: "Prototype evaluation 300 GHz band tunable filter", The Papers of Technical Meeting on Instrumentation and Measurement, IEE-Japan, IM-16-45 (Nov. 2016)

7) Takashi Kawamura, Shigenori Mattori: "Evaluation of a 300 GHz band filter bank prototype", The Papers of Technical Meeting on Instrumentation and Measurement, IEE-Japan, IM-17-42 (Nov. 2017)

Authors

Yuji Sekine
Advanced Technology Development Center
Technical Headquarters

Shigeo Arai
Advanced Technology Development Center
Technical Headquarters

Takashi Kawamura
Advanced Technology Development Center
Technical Headquarters