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TECHNICAL REPORT

colour inside

Transmitting equipment for radiocommunication – Radio-over-fibre technologies for spectrum measurement – 100-GHz spectrum measurement equipment

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TRANSMITTING EQUIPMENT FOR RADIOCOMMUNICATION – RADIO-OVER-FIBRE TECHNOLOGIES FOR SPECTRUM MEASUREMENT – 100-GHZ SPECTRUM MEASUREMENT EQUIPMENT

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IEC TR 63100, which is a Technical Report, has been prepared by IEC technical committee 103: Transmitting equipment for radiocommunication:

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
103/157/DTR	103/163/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

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TRANSMITTING EQUIPMENT FOR RADIOCOMMUNICATION – RADIO-OVER-FIBRE TECHNOLOGIES FOR SPECTRUM MEASUREMENT – 100-GHZ SPECTRUM MEASUREMENT EQUIPMENT

1 Scope

This document describes 100-GHz spectrum measurement methods using RoF technologies. It covers the background to measurement over 100 GHz, the configuration of a spectrum analyser, the key technologies, such as mm-wave tunable filter, and RoF-technologies-based local oscillator, and provides some measured examples.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
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3.2 Abbreviated terms

mm-wave	millimeter-wave
ADAS	advanced driving assistant systems
FOD	foreign object and debris
ODU	outdoor unit
IDU	indoor unit
HDTV	high-definition television
MPEG	moving pictures experts group
DUT	device under test
UTC-PD	uni-travelling-carrier photodiode
SD	standard deviation
LSB	lower sideband
USB	upper sideband
DANL	displayed average noise level
TOI	third order intercept
ACLR	adjacent channel leakage power ratio
SNR	signal-to-noise ratio
IR	infra-red
SPA	spectrum analyser

LIDAR	light detection and ranging
RBW	resolution bandwidth
OBW	occupied bandwidth
VBW	video bandwidth
FM CW	frequency modulated continuous wave
ATT	attenuator
ASK	amplitude shift keying
BPSK	binary phase shift keying
QPSK	quadrature phase shift keying
LO	local oscillator
RF	radio frequency
IF	intermediate frequency
RoF Sig Gen	radio over fibre technologies-based local signal generation

4 Background to measurement over 100 GHz

4.1 General

The following applications depend heavily on the development of mm-wave technology:

- IEEE 802.11ad wireless devices;
- automotive radar;
- airport ground radar;
- mobile backhaul;
- uncompressed HD signal transmission.

4.2 IEEE 802.11ad wireless devices

IEEE 802.11ad wireless devices uses the 60-GHz band to implement multi-gigabit speeds, low latency, and secure connections between devices. Popular applications are replacement of display cables, and wireless connection between laptops. IEEE 802.11ad wireless devices should be checked for bandwidth, 60-GHz in-band emissions, and out-of-band emissions up to 130 GHz. However, there is currently no commercial spectrum analyser with a pre-selector to remove unwanted internal frequency responses at bands over 100 GHz.

4.3 Automotive radar

Advanced driving assistant systems (ADAS) are being developed as a key technology for autonomous vehicles. ADAS uses various sensors, including radar, LIDAR and cameras. An ADAS radar detects small objects at high distance, velocity, and angle resolution using wideband FM CW modulation as the key technology. The world radio communication conference of November 2015 (WRC-15), agreed on the use of the contiguous 4-GHz band from 77 GHz to 81 GHz, and that demand for high-resolution mm-wave radar in the 79-GHz band will increase as ADAS becomes more widespread.

4.4 Airport ground radar

Following the Air France Concorde disaster in 2000, which was caused by engine ingress of runway debris, airport operators have been focusing on foreign object and debris (FOD) detection systems. Several technologies, such as cameras, IR, LIDAR, and other sensors are being tested. One candidate is the mm-wave radar because it can detect small metallic objects using converted automotive radar in the 77-GHz and 90-GHz bands. Both bands require a wider bandwidth for finer resolution and the 92-GHz to 100-GHz band could be used for industrial radio location.

4.5 Mobile backhaul

Mobile phones and terminals communicate by connecting to base stations that transfer data to the core network. Data from multiple base stations distributed throughout the communications area is transferred by a network of systems that collect and transfer data using various exchanges and wired and wireless technologies—this is called the "mobile backhaul". Wired technologies use optical fibres featuring larger traffic capacity than wireless and stable communications quality. However, optical fibre can sometimes suffer from installation problems due to difficult geography and high cost. On the other hand, wireless communications are easier and faster to install and at a lower cost. Wireless also has advantages of easier service restoration after disasters. Wireless backhaul equipment is composed of an outdoor unit (ODU) and an indoor unit (IDU). The wireless signal is transmitted and received by antennas on the ODU. The IDU is connected to the network and handles sending/receiving of IF data to/from the ODU, as well as data transmission.

Most wireless backhaul frequency bands are below 38 GHz but some 60-GHz and 70-GHz to 80-GHz bands have been allocated to secure wider bandwidth for implementing larger-capacity and faster transfers. Since frequency bands and applications depend on national laws governing radio, not all bands are available in all regions.

4.6 Uncompressed HD signal transmission

Digital terrestrial television broadcasting is spreading rapidly, typically as high-definition television (HDTV) broadcasts. Transmitting raw HDTV broadcast materials is difficult because uncompressed HDTV signals have a data rate of 1,5 Gbit/s, requiring a wide bandwidth. Broadcasters normally use microwave radio to transmit broadcast materials, but the current transmission capacity is insufficient. Moving pictures experts group (MPEG) signal compression causes latency that adversely affects smooth conversation in live broadcasts. Consequently, TV broadcasters require high-capacity wireless link technology supporting transmission of uncompressed HD signals. Use of 120-GHz band wireless links with a centre frequency of 125 GHz and data transfer up to 10 Gbit/s supports transmission of uncompressed HD signals. It was trialed at the 2008 Beijing Olympics.

5 Spectrum measurement over 100 GHz

5.1 Overview

The developed 100-GHz spectrum analyser supports signals from 110 GHz to 140 GHz; Figure 1 shows its external appearance and Figure 2 shows the block diagram. The design specifications are listed in Table 1.

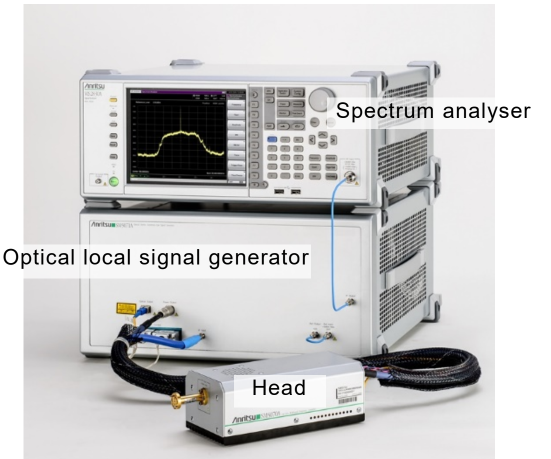


Figure 1 – External appearance of a 100-GHz spectrum analyser

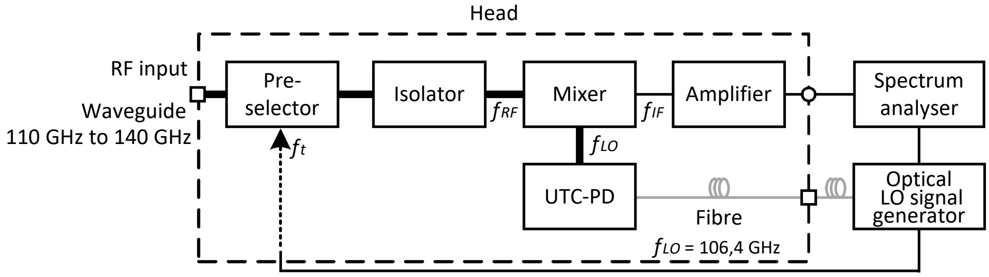


Figure 2 – 100-GHz spectrum analyser block diagram

Table 1 – Design specifications

Frequency band	110 GHz to 140 GHz
SPAN	≤ 30 GHz
DANL	< –140 dBm/Hz
TOI	> +10 dBm
Image response	> 100 dB

The main features are high performance and flexible positioning due to the compact head unit. High performance is achieved using fundamental mixing, a tunable pre-selector (pre-selector), and RoF-technologies-based local signal generation (RoF Sig Gen). Fundamental mixing achieves low noise and fewer multiple responses; the pre-selector achieves low unwanted responses; the RoF Sig Gen decreases unwanted spurious response due to LO signal harmonic components.

The small head unit is easily positioned between the device under test (DUT) and test instruments. Usually, the DUT has a waveguide interface, which can be difficult to position if the test equipment uses a waveguide. The small head unit size is implemented using the RoF Sig Gen feeding a 106,4-GHz optical signal via optical fibre to the head unit. If a local signal over 100 GHz is fed to a head unit, the cable length should be short to prevent cable losses. If a lower-frequency signal is fed to the head unit with multiplication, there should be a multiplier and filters in the head unit, which would be larger than proposed.

5.2 100-GHz spectrum analyser system configuration

As shown in Figure 1, the system is composed of a head unit with WR-08 waveguide input, a commercial spectrum analyser (IF SPA), and RoF Sig Gen. As shown in Figure 2, the head unit is composed of a pre-selector, isolator, mixer, amplifier, and uni-travelling-carrier photodiode (UTC-PD). The mixer uses frequency down-conversion to generate multiple mixing products determined by the LO frequency (f_{LO}) and RF frequency (f_{RF}). The IF frequency (f_{IF}) is obtained as $f_{LO} \pm f_{RF}$. The IF SPA processes the IF signal to display the spectrum. Input of image components to the head unit is reduced by the pre-selector in the head unit.

5.3 Key technologies

5.3.1 General

The key technologies for achieving the design specifications are:

- mm-wave tunable filter;
- RoF-technologies-based local signal generator (RoF Sig Gen).

5.3.2 mm-wave tunable filter

The pre-selector is implemented using a Fabry-Perot resonator, a common optical technology. Figure 3 shows an external view of the pre-selector and operation principle. The pre-selector is composed of a waveguide and actuator. The actuator drives one side of the half mirrors forming the Fabry-Perot resonator inside the waveguides to control the tuning frequency f_{TUNE} by changing the oscillator length L. Figure 4 shows the pre-selector frequency characteristics. The pre-selector maximum insertion loss is 5 dB at a bandwidth of 30 GHz. Figure 5 shows the rejection at 10 GHz is more than 30 dB, and the 3-dB bandwidth is around 400 MHz when the oscillator length L is 1,3 mm.

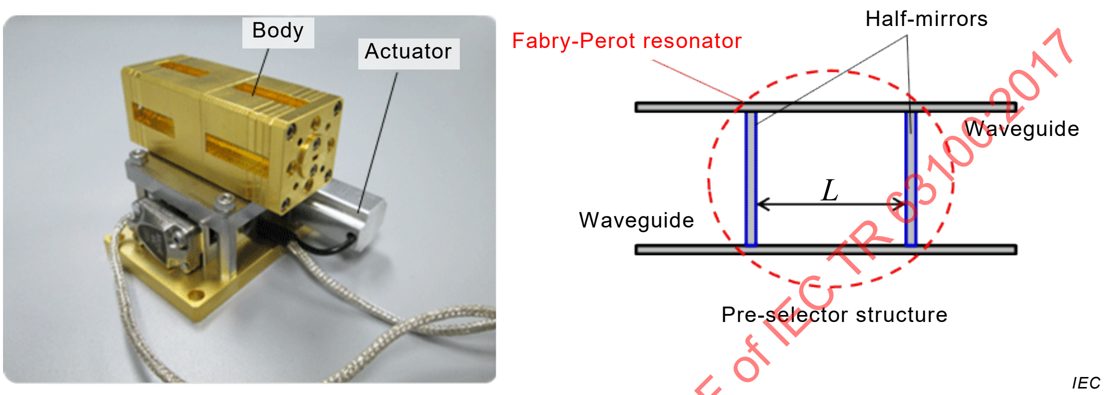


Figure 3 – Fabry-Perot tunable filter

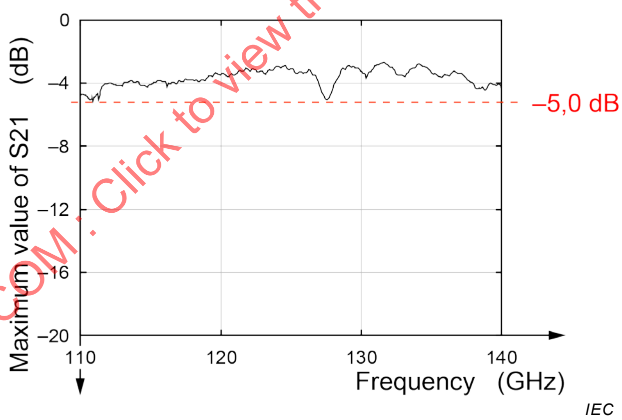


Figure 4 – Pre-selector frequency characteristics

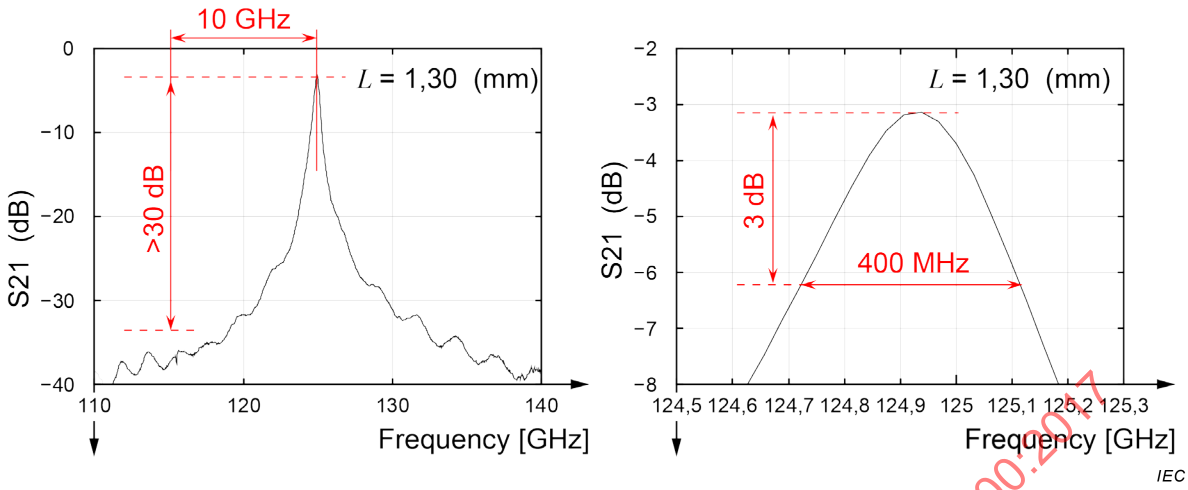


Figure 5 – S21 transmission characteristics

5.3.3 RoF-technologies-based local signal generator (RoF Sig Gen)

Figure 6 shows the RoF Sig Gen block diagram; the signal is generated in two steps. First, an optical 2-tone signal with a frequency difference of four times the signal frequency *f*m (26,6 GHz) is generated from the RF signal generator. This optical 2-tone signal is then converted by the UTC-PD in the head unit to an electrical local signal corresponding to the frequency difference (4 × *f*m). This method enables easy generation of a high-frequency mm-wave signal and reduces the head unit size.

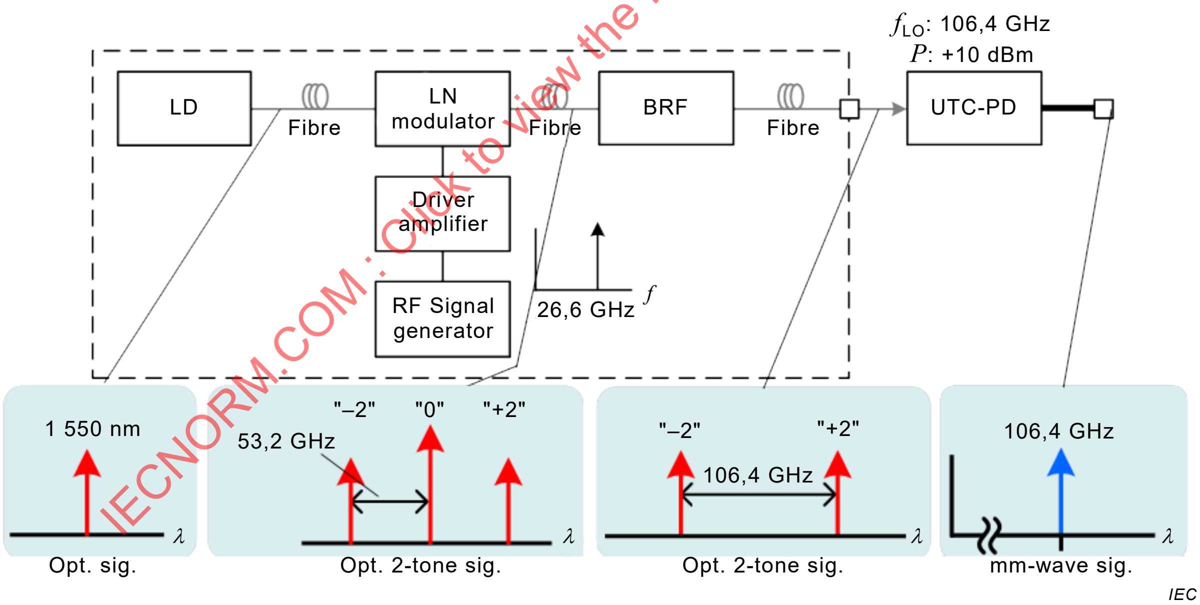


Figure 6 – RoF Sig Gen block diagram

Figure 7 compares the maximum level ratio of the harmonics and sub-harmonics (1 × *f*m, 2 × *f*m, 3 × *f*m, 5 × *f*m, … *n* × *f*m) with the wanted signal level (3 × *f*m) for three multiplication methods: RoF Sig Gen, passive electrical, and active electrical. When using an electrical multiplier, the ratio of the maximum harmonics to wanted signal is about −3 dBc at worst; using RoF Sig Gen, the ratio of harmonics to wanted signal is about −60 dBc at worst. Using the multiplied signal as the SPA LO signal shows the harmonic components as spurious. Filters are needed to reduce the level of unwanted signal components. RoF Sig Gen can generate a pure signal to reduce the level of harmonic components, meaning the RoF Sig Gen method achieves higher signal purity and reduces SPA size.

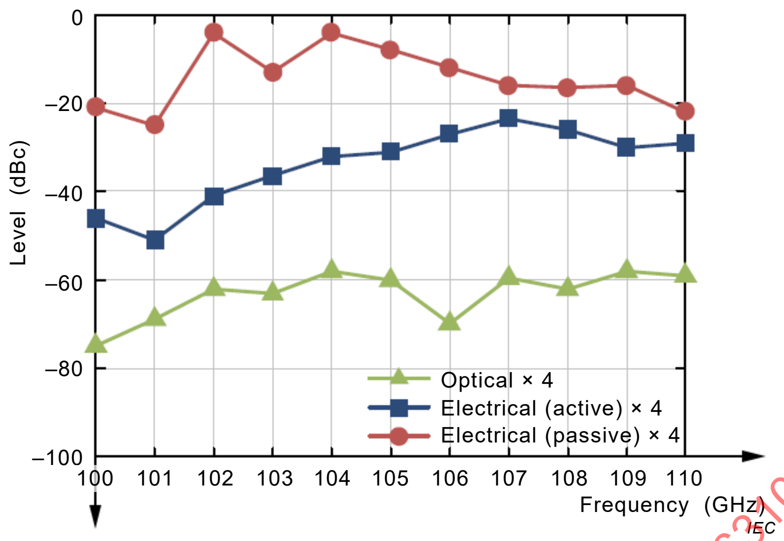


Figure 7 – Comparison of harmonic component levels

5.4 Performance of 100-GHz spectrum analyser

5.4.1 General

The 100-GHz spectrum analyser was calibrated before evaluating performance.

5.4.2 Level calibration

Figure 8 shows the level calibration configuration. The signal generator outputs a signal with a frequency of 36,6 GHz to 46,7 GHz to the frequency converter which multiplies the signal to 109,9 GHz to 140,1 GHz. The controller adjusts the level of the signal from the frequency converter to –15 dBm. The output level is measured simultaneously by the power meter and calorie meter to copy the level from the calorie meter to the power meter. This procedure supports faster calibration by measuring the output level from the frequency converter using the power meter.

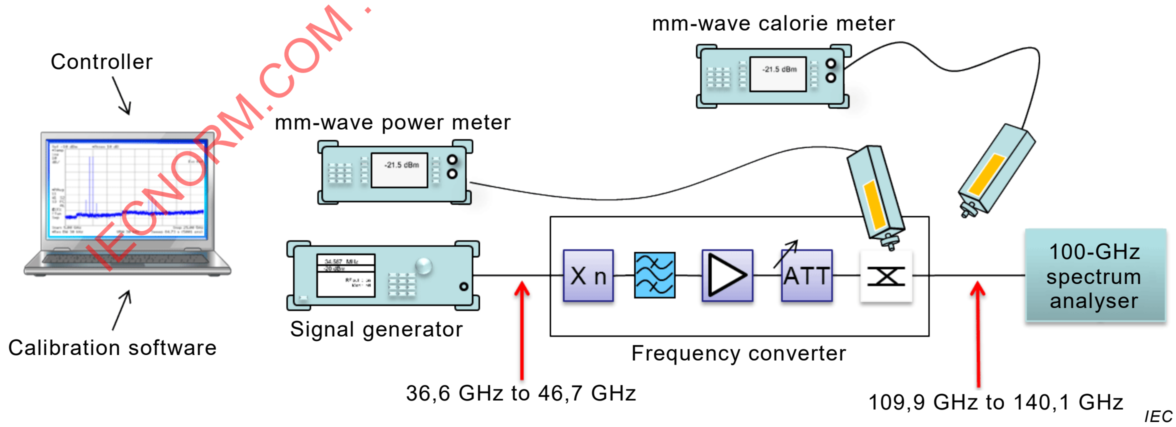


Figure 8 – Level calibration system

The standard deviation (SD) of the calibration result is shown in Figure 9. The SD of the measured value is within the calculation range, indicating this calibration method works well. Figure 10 compares the level before and after calibration. Before calibration, the frequency response level over the 30-GHz band is about 10 dB; after calibration, the frequency response is ±1dB.

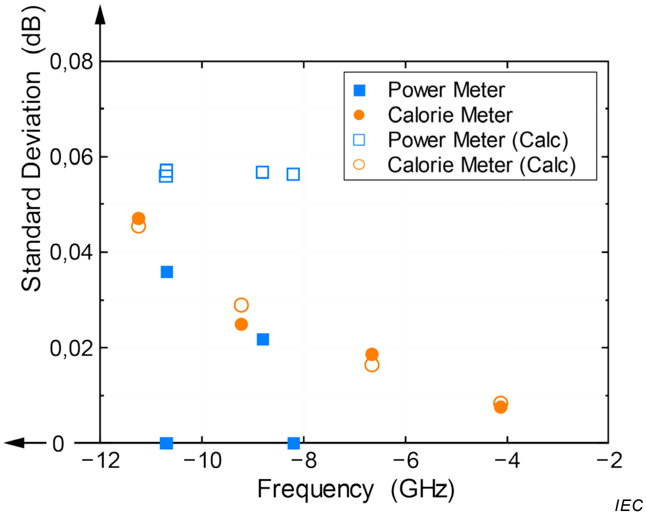


Figure 9 – Standard deviation of calibration

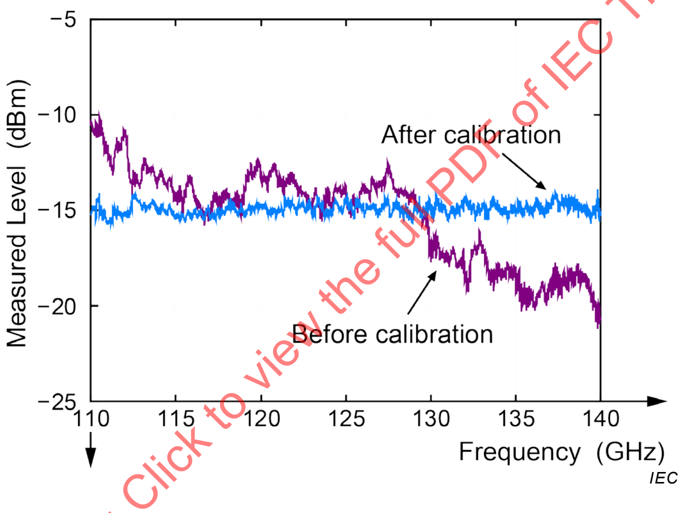


Figure 10 – Calibration result

5.4.3 Spectrum measurement

Figure 11 shows the measured spectrum for a 120-GHz CW signal. The measurement time is 15 s over a 30-GHz band while sweeping with the pre-selector and SPA synchronized. Sweep time which is shown in Figure 11 as 100 ms is the time for sweep which selected the RBW and span, and it does not include control time such as the sweeping pre-selector.

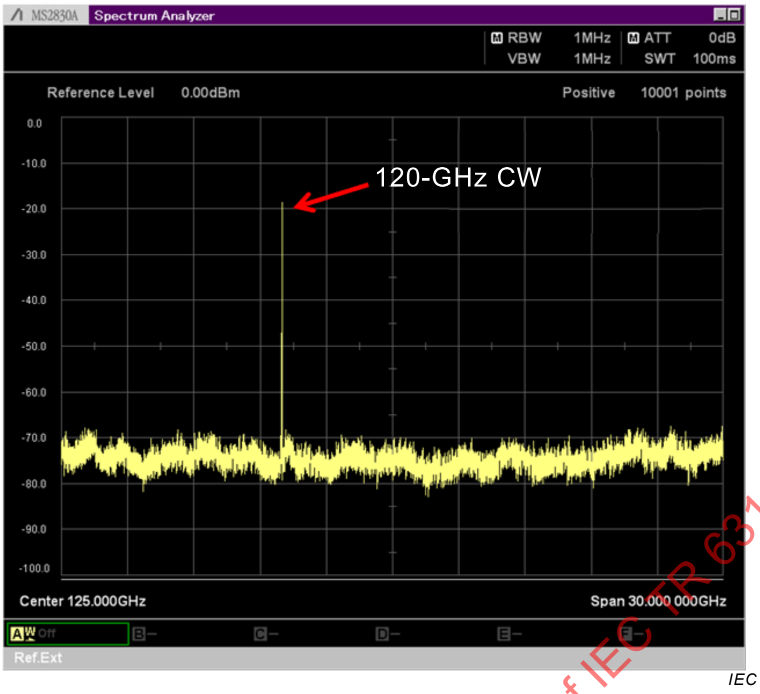


Figure 11 – Spectrum measurement

5.4.4 Image response

The image response is a key index of SPA performance. The SPA mixer converts f_{RF} to f_{IF}. The f_{RF} equals f_{LO} + f_{IF} or f_{LO} - f_{IF}. The polarity depends on the system design. In this system, f_{RF} equals f_{LO} + f_{IF}. In this case, f_{LO} - f_{IF} is the image and the response can be seen at f_{IF} without a pre-selector in the system. The relationship between f_{RF}, f_{LO}, f_{IF}, and the image response is shown in Figure 12.

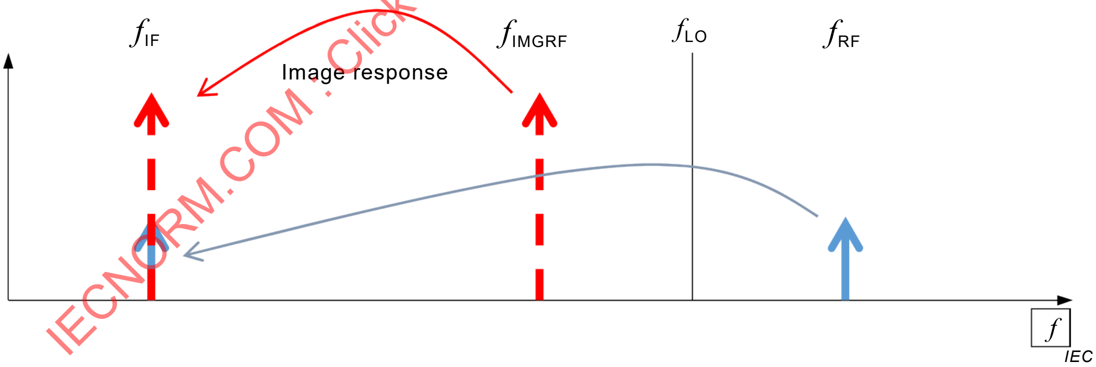
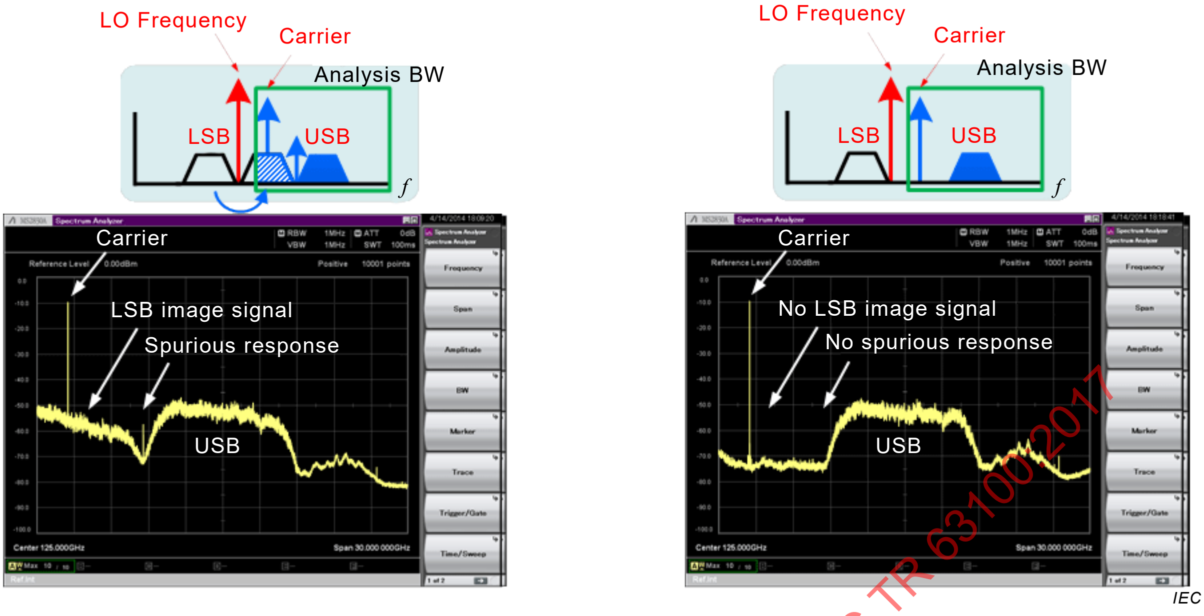


Figure 12 – Image response

Figure 13 compares image responses. The target is a QPSK-modulation signal with a 125-GHz centre frequency, 10 Gsymbols/s symbol rate, and 0,3 roll-off rate. Figure 13a) shows the measured results without a pre-selector; there is a lower sideband (LSB) image response near 112,5 GHz and distortion components due to the carrier are also observed as spurious near 118,5 GHz. These unwanted responses cannot be separated from the existing signal response. Figure 13b) shows the measured results with a pre-selector; the carrier and upper sideband (USB) are observed correctly in the measured frequency range. These results show that using a pre-selector in this system supports measurement without image signal components and spurious response.



a) Without pre-selector b) With pre-selector

Figure 13 – Image response comparison

Table 2 lists the measured image response. The pre-selector has an effect of more than -110 dB on the image response, easily separating the existing signal and image response.

Table 2 – Measured image response

Frequency (GHz)	**Image frequency** (GHz)	**Signal level** (dBm)	**Image component** (dBm)	**Image response** (dB)
102,7	110,1	-28	-140	< -110

5.4.5 Displayed average noise level

The displayed average noise level (DANL) is an important index of SPA performance indicating the SPA average noise level display. It is the lowest signal level that can be observed by the SPA.

Figure 14 shows the DANL of this system. The DANL is lower than –140 dBm/Hz even over 100 GHz, which is equivalent without a pre-amplifier to the performance of RF spectrum analysers.

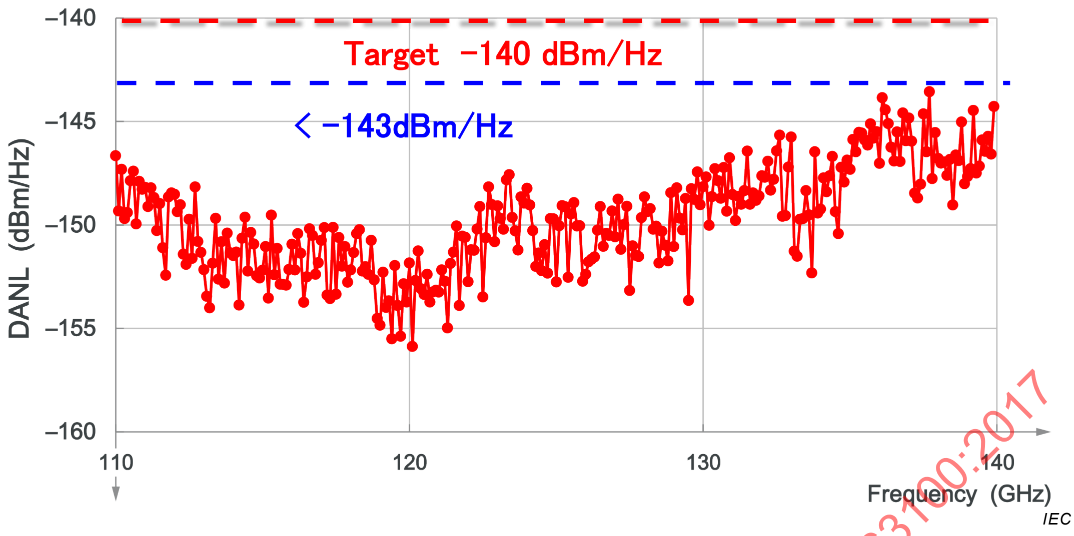


Figure 14 – Displayed average noise level

5.4.6 Third order intercept point

Non-linear circuits generate harmonic components. The third order intercept (TOI) point is the value where the levels of the fundamental components and distortion are the same. Devices with a high TOI have high linearity. The combination of TOI and DANL determines the SPA dynamic range, so the balance is important. A SPA with better TOI measures a signal with less distortion. The TOI is important when observing the adjacent channel leakage power ratio (ACLR) of modern transmitters because ACLR indicates the degree of interference with neighboring channels. When measuring ACLR using a SPA, the SPA's TOI performance shall be better than the transmitter's distortion performance. Figure 15 shows the TOI definition. When two signals, f_1 and f_2, are input to a non-linear device, distortion signals are observed. The components, 2 × f_1–f_2, 2 × f_2–f_1 are third-order distortion components. Any increase (n) in the device fundamental level doubles (2n) the third-order distortion level.

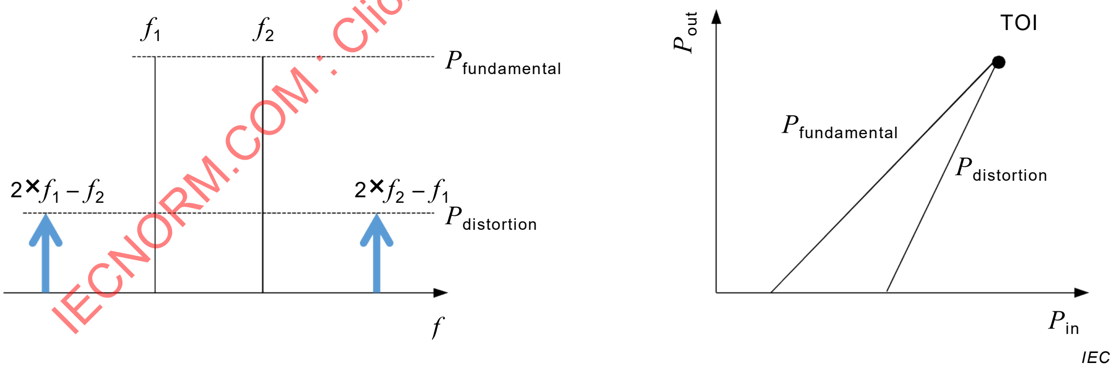


Figure 15 – Third order intercept point

Figure 16 shows the measured TOI for this system. Each measured data point is plotted for the centre frequency of two signals. This result shows two offset frequency patterns, 100 MHz, 500 MHz, and the upper and lower sides of intermodulation signals. The TOI is more than 17 dBm in these test configurations. A high TOI level for a 500-MHz offset is achieved using a pre-selector. When observing intermodulation signals with a 500-MHz offset for two input signals of 114,75 GHz and 115,25 GHz with a centre frequency of 115 GHz, the two input signals are 114,75 GHz and 115,25 GHz, the lower-side intermodulation is 114,25 GHz. In this case, the SPA's centre frequency is 114,25 GHz. The pre-selector 3-dB bandwidth is around 400 MHz and the higher input signal (115,25 GHz) is out-of-band. Therefore, the intermodulation generated in a 100-GHz spectrum analyser due to the input signals 114,75 GHz and 115,25 GHz is a very low level.

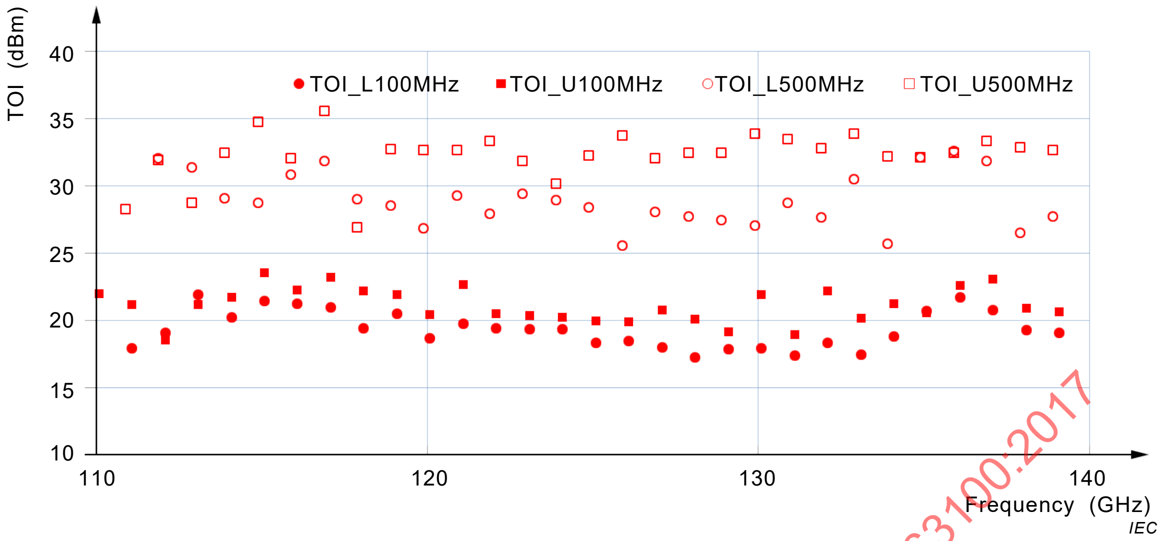


Figure 16 – TOI measurement result

5.4.7 Residual response

The residual response is the displayed level when there is no input. Residual response is caused by unwanted components in the local signal, and poor isolation between signals in digital and analog circuits. The measured residual response is shown in Figure 17; Table 3 shows the IF SPA setup. The calculated measurement system limit in the positive detection is –95 dBm. Because the SPA RBW is 3 kHz and the DANL is lower than –140 dBm/Hz in the RMS detection. The maximum residual response is –93 dBm at 133 GHz due to harmonic components in the local signal. As shown in Figure 17, even if the level of unwanted components in the local signal is less than –60 dBc as shown in Figure 7, spurious components are generated by inter-mixing in the mixer due to harmonic components in the local signal.

Table 3 – SPA setting at residual response measurement

Parameter	Value
Reference level	–80 dBm
ATT	0 dB
Detection	Positive
RBW	3 kHz
VBW	3 kHz

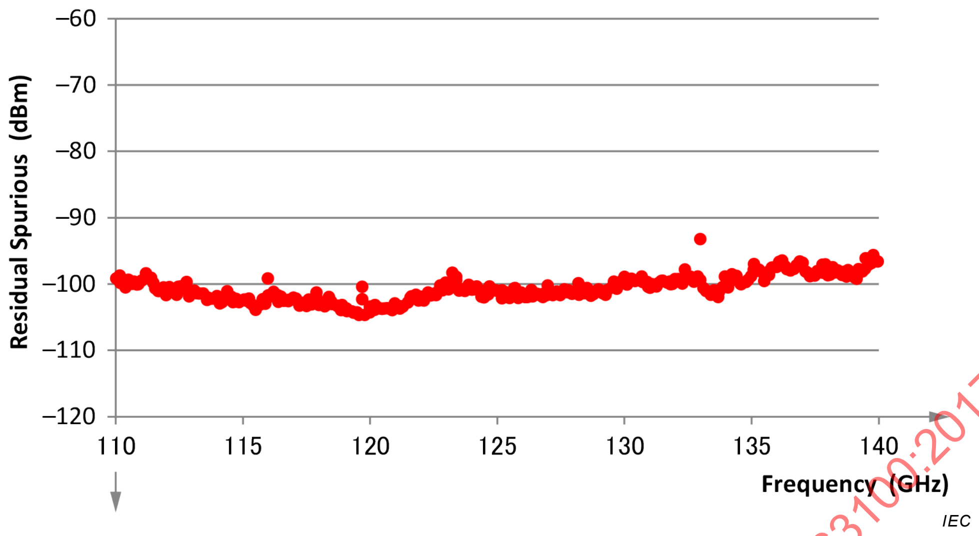


Figure 17 – Residual spurious response

6 Measurement examples

6.1 120-GHz mm-wave link

To evaluate the system efficiency in actual usage, we measured a 120-GHz mm-wave link used for transmission of uncompressed HD signals as explained in 4.6. Before measurement, we used an attenuator to adjust the input level to the 100-GHz spectrum analyser to –1,2 dBm to reduce distortion in the spectrum analyser and prevent damage. Figure 18 shows the block diagram of the measurement system in blue for the transmitter, and orange for the test equipment.

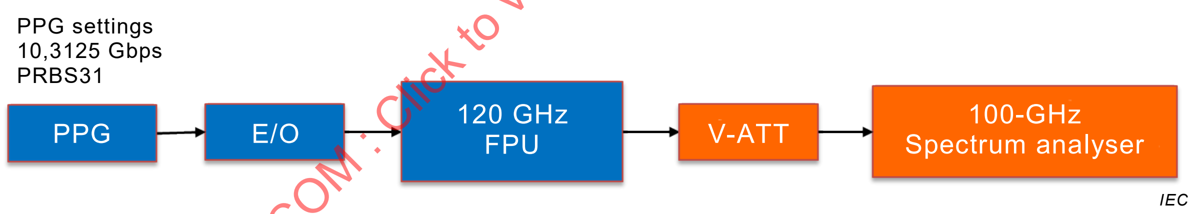


Figure 18 – Measurement system block diagram

Table 4 – 120-GHz mm-wave link specifications

Allocated frequency	116 GHz to 134 GHz
Modulation	ASK, BPSK, QPSK
Maximum antenna power	≤ 1 W
Permissible antenna power	Upper 50 %, Lower 50 %
Occupied frequency band	≤ 17,5 GHz
Frequency error	≤ 200 ppm
Unwanted spurious power	Out-of-band unwanted emissions ≤ 100 μW Unwanted emissions in spurious band ≤ 50 μW
Secondary emissions by receiver	≤ 50 μW