Development of TRX Test Module MU887002A for High-Efficiency Smartphone Manufacturing

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[Summary] Commercial fifth-generation (5G) mobile communications systems are expected to be widely deployed in the near future. As a result, 5G-smartphone shipments are expected to increase massively. On the other hand, production times are becoming longer, and infrastructure costs are increasing due to the increasing numbers of antennas in 5G smartphones, causing manufacturers challenges requiring urgent solutions. To solve these challenges, we have developed the TRX Test Module MU887002A with 24 RF test ports for installation in the Universal Wireless Test Set MT8870A to meet future growing test requirements.

1 Introduction

With the 5G mobile communications rollout, deployment of new social infrastructure, such as eMBB (enhanced Mobile BroadBand), URLLC (Ultra-Reliable and Low Latency Communications), and mMTC (massive Machine Type Communications), is being examined. Commercial 5G mobile smartphone services are starting, and 5G smartphone subscribers are expected to reach close to 1 billion by 2022 with smartphones making up 45% of all cellphone shipments.

The 3GPP Release 15 standard regulating actual 5G specifications prioritizes eMBB to achieve the ultra-high-speed large-capacity communications required by 5G. Release 15 introduces new technologies facilitating fast and large-capacity communications by specifying new frequency bands as well as wider bands. 5G smartphones supporting these requirements will have higher functions and performance, especially with the near doubling of internal antennas compared to previous configurations.

In these circumstances, testing more antennas raises challenges for smartphone manufacturers to face longer production times, so there is an urgent need to develop measuring instruments for production lines that would help cut test times and improve line throughput.

Anritsu has been bringing conventional modules such as the MU887000A and MU887001A for the MT8870A[1)] to the market to help optimize manufacturing of mobile communications devices. However, it was essential to further increase the number of RF test ports in order to improve the efficiency of manufacturing 5G-compatible smartphones. Against this background, we have developed the MU887002A, a single module with 24 RF test ports (Figure 1).

Figure 1 MT8870A Front Panel (with two MU887002A modules installed)

As a result, not only cellular mobile systems but also WLAN (Wireless LAN), Bluetooth, and GNSS (Global Navigation Satellite System) can be measured in one stage to improve smartphone production efficiency, while also supporting high-density and high-speed production lines. Furthermore, the MU887002A expands the maximum output level from −10 dBm to 0 dBm (CW, ≤3800 MHz), as well as the TRx bandwidth from 160 MHz to 200 MHz to meet future test requirements.

2 Development Concepts

We focused on the following development concepts to create a new module at the same market price as current instruments used in the manufacturing field but can reduce test times by two-thirds while having equivalent or better functions and performance as well as future expandability.

2.1 Multiport Support and Cost Reduction

To cut test times by two-thirds, 12 RF test ports were incorporated in the new design, three times as many as previously used. Additionally, the design concept aimed to achieve both the increasing of ports and lowering of costs by sharing parts like the CPU. A total of 24 RF test ports is implemented in the same physical space occupied by two conventional modules.

2.2 Compatibility with Conventional Modules

Facilitating a smooth transition to the MU887002A from the earlier modules required maintaining backwards compatibility.

As previously described, the MU887002A incorporates the functions of two conventional modules into one new module. However, offering the same control as two conventional modules required designing one TRx measurement function section (TRX1) equivalent to the left-side of the module, as well as a second TRx measurement function section (TRX2) equivalent to the right-side of the module. TRX1 and TRX2 can be controlled separately.

Additionally, maintaining fully functional and remote-command compatibility with conventional modules required source-code improvements closely related to the user interface, as well as a software structure supporting hardware differences.

Based on these concepts, users can change the production-line configuration without changing optimized inspection and test sequences that make use of typical functions of conventional modules. Using previous typical functions, the test procedure is pre-set at the wireless equipment and test instrument to execute tests by high-speed sequential measurement (list mode). Moreover, when measuring multiple antennas at once, the test module has multiple virtual machines (RF-Semaphore function) to shorten measurement time by switching between them.

2.3 Higher Measurement Efficiency

To optimize Rx tests, we designed a Broadcast function that could not be implemented in conventional modules. This function outputs the same signals simultaneously from all MU887002A RF test ports. Conventional Rx sensitivity tests input signals sequentially one at a time to the wireless device antenna connector. However, using the Broadcast function, the same signal can be input simultaneously to multiple antennas of one wireless device or multiple antennas of multiple wireless devices to shorten measurement times and cut the number of measuring instruments.

For the Tx test, to use available internal space more efficiently, it is necessary to analyze signals from two TRx modules using one CPU operating in parallel, causing challenges with slow measurement speed. To solve this issue, we implemented direct memory access (DMA) transfer for the hardware scatter/gather method to cut measurement time by centralizing CPU resources at analysis processing and by using a high-speed CPU.

2.4 Expandability

To easily change and add functions in software without changing hardware when supporting new standards for both next-generation and current systems, we used a Field Programmable Gate Array (FPGA) design for signal processing and hardware control.

In addition, to meet future requirements and support the need to measure wider-band signals, we upgraded to support TRx measurement of 200-MHz bandwidth signals as the standard.

3 Hardware

This section describes the MU887002A hardware circuit blocks and functions.

3.1 Circuit Structure

The MU887002A can be broadly divided into two frontends with 12 RF test ports each, two RF transceivers, and one baseband. Figure 2 shows the circuit block diagram.

(1) Frontends

To implement 12 RF test ports at the frontend, the key factors considered were how to save space while obtaining the required performance and functions.

As shown in Figure 1, the RF test ports are arranged in a 6 × 4 layout to make best use of front-panel space and facilitate easy RF cable connection and disconnection.

Furthermore, we abandoned the semi-rigid cables between the N-connectors on the front panel and the printed circuit board (PCB) of earlier modules. Instead we used N-connectors with good connection/disconnection durability mounted directly to the PCB, helping eliminate dead space and securing space for the frontend PCB.

Moreover, miniaturizing the divider offered more space for parts; implementing amplifiers for all Tx circuits as well as a level-adjustment circuit achieved a maximum output level of 0 dBm (CW, ≤3800 MHz) and a level-adjustment resolution of ±0.02 dB for each RF test port when using the Broadcast function. In turn, we were able to fabricate a signal generator with a high output and high-level accuracy.

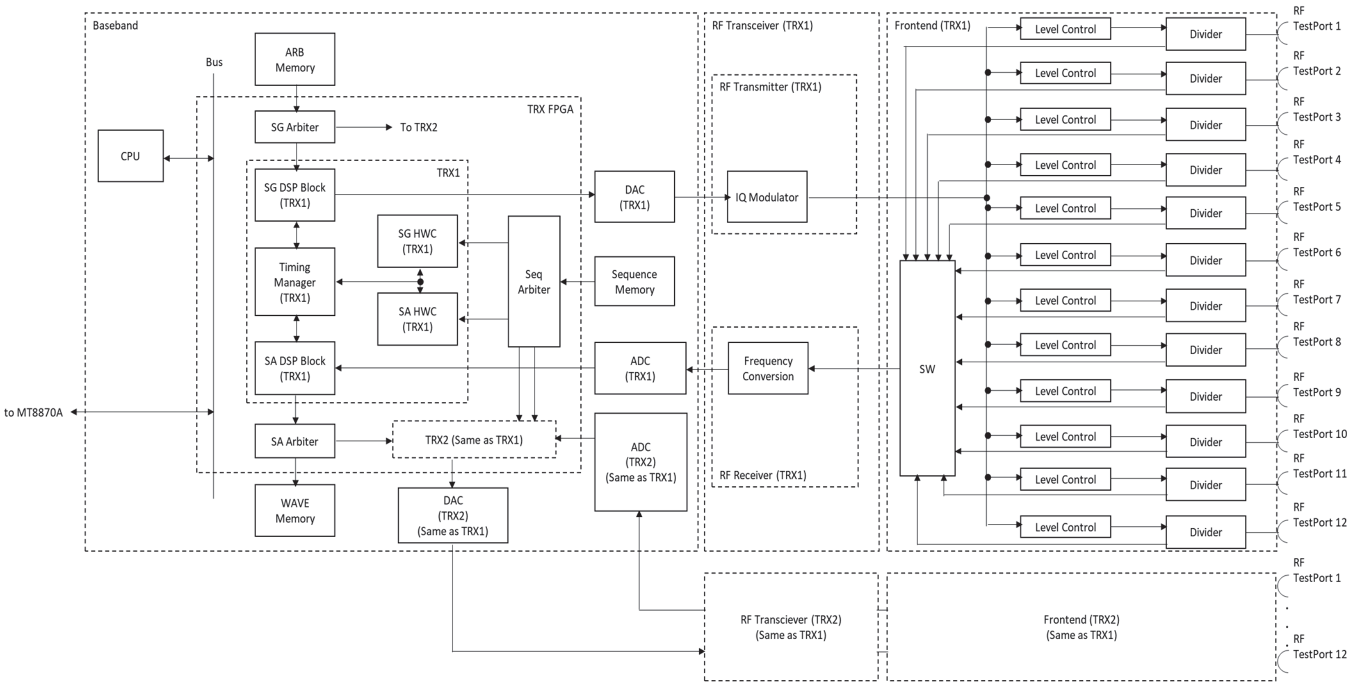

Figure 2 MU887002A Block Diagram

(2) RF Transceivers

To obtain sufficient space for the RF transceiver hardware while cutting costs, the key factors considered were circuit size reduction and PCB material selection.

To downsize the circuits, we limited the RF range to that required by mobile communications and re-examined the frequency conversion circuit design to eliminate the TRx circuit down and upconverter circuits. In addition, by handling fine frequency conversion at the Numerically Controlled Oscillator (NCO) provided in the Signal Analyzer (SA)/Signal Generator (SG) DSP Block in the signal processing FPGA (TRX FPGA), it became possible to use a small PLL IC combining a Voltage Controlled Oscillator (VCO) and multiple Phase Locked Loops (PLL) used generally until now for Local signal generation. As a result, we were able to reduce circuit space.

With respect to the PCB materials, although GHz-band circuits generally use high-performance boards for high frequencies, we were able to cut costs by using a general glass-epoxy PCB by designing a wiring pattern taking parasitic capacity and path loss into consideration.

(3) Baseband

To secure adequate space for the baseband hardware, the key factors considered were circuit size reduction and securing high measurement speed.

To reduce space, we incorporated output waveform pattern memory, input waveform memory, and list mode memory each with twice the capacity of conventional modules. By sharing them between TRX1 and TRX2, we allowed simultaneous parallel processing of TRX1 and TRX2 signals.

Moreover, to further save space, only one main CPU and one TRX FPGA are used. However, to prevent processing-speed delays using these, a high-speed CPU for high-speed measurement has been adopted along with internal high-speed interfaces, such as between the above-described memories and the TRX FPGA. As a result, faster measurement than the conventional module can be performed.

3.2 Function Outline

(1) Transmitter

Since the transmitter outputs a modulated signal, IQ data is generated from predetermined data read from the ARBitrary waveform Generator (ARB) memory in the SG DSP block of the TRX FPGA. This IQ data is converted to an analog signal by the Digital Analog Converter (DAC) and orthogonally modulated by the IQ Modulator to generate a signal with a frequency of 400 MHz to 6 GHz.

The TRX FPGA SG DSP block implementing the ARB function has a clock-generation function with a setting resolution matching the various communication-system sampling rates.

Although the ARB memory for saving waveforms is 4 GB large enough to replay many waveforms, we have implemented a sequence function that can repeatedly play-over any connected waveform data. Since cellular wireless devices operate by synchronizing with a synchronization signal transmitted from the base station, a signal simulating a base station must be output using the ARB function. However, this signal data is a mixture of long- and short-period patterns as well the same patterns repeated over. In this case, the sequence function can greatly reduce the amount of data by assembling the sequence determining the waveform data for 1 cycle and the replay pattern order. Moreover, when replaying partly different signal patterns, this function can display just the differences in the partial waveform data and sequence data.

Lastly, for wideband signals, in-band flatness can lead to level errors. Consequently, the SG DSP Block has an in-band amplitude flatness calibration function supporting a true in-band flatness of ±1.5 dB for up to 200-MHz band signals.

(2) Receiver

After the signal to be measured is input to the receiver frontend and down-converted to the Intermediate Frequency (IF) by the frequency converter, it is converted to a digital IF signal by the Analog Digital Converter (ADC) and sent to the TRX FPGA SA DSP Block.

Aside from supporting wideband measurement, measurement of existing communications service types is also necessary. These systems have a downlink signal at some frequency 20 or 30 MHz from the uplink signal. In other words, in-band measurement requires filtering to cut this downlink signal. While securing the necessary bandwidth for measurement, the best band-limiting filter for each analysis bandwidth is also used to remove signals not wanted for analysis.

The SA DSP Block performs in-band calibration according to the digital IF signal to convert to the best sampling rate for analysis from 250 MHz to 1 MHz after having converted it to IQ data by orthogonal-modulation processing. After sampling-rate conversion, simultaneously with conversion to floating decimal point IQ data, calibration is executed according to the hardware settings then the true-level IQ data is transferred to the waveform memory. Since the true-level IQ data is in floating decimal point format, there is no need to subsequently perform data conversion and calibration processing when analysis processing is next executed in software. This facilitates high-speed analysis.

To further increase analysis speeds, we eliminated the signal-search and power-measurement processes at analysis processing by adding a real-time power measurement function with trigger detection using changes in signal level and registration of trigger timing for waveform data.

(3) Full Duplex Function

Despite the MU887002A having 24 RF test ports, all of them are full duplex and capable of simultaneous input and output of Tx and Rx signals. As a result, although the Tx and Rx channels are coupled by a divider, the design assures excellent isolation between the channels. The cross-channel impact between the Tx and Rx sides is less than 0.1 dB and both channels can be controlled independently.

(4) Hardware Control

The Hardware Controller for Signal Generator (SG HWC) and Hardware Controller for Signal Analyzer (SA HWC) in the TRX FPGA execute all hardware settings.

Even though regular hardware settings are executed by commands from the CPU, list-mode operations are executed without CPU intervention by allowing the two SG and SA HWC functions to cooperate with the timing manager.

At list-mode operation, the sequence data constructed using the hardware settings and setting timings are pre-stored in the sequence memory; the SA/SG HWC set the hardware according to that sequence data. The timing manager supplies the operation timing to the SA/SG HWC. This timing manager is connected to both the SG DSP Block and SA DSP Block and all trigger data is collected by the timing manager. Additionally, the timing manager has multiple timer functions for generating periodic triggers. These periodic triggers can be used to generate frame and slot timings matching each type of communications system by setting the hardware. Both high speeds and flexible settings are facilitated by these functions and configurations.

4 Software

This section describes the MU887002A software as well as software for controlling the MU887002A.

4.1 MU887002A Software

Figure 3 shows the MU887002A software blocks.

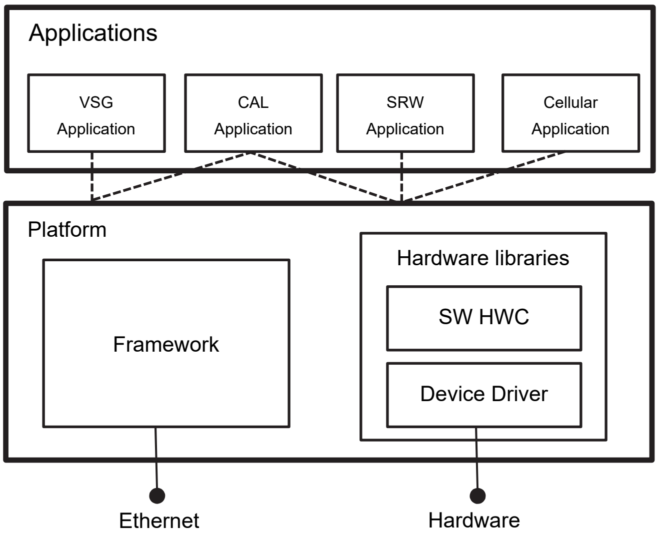

Figure 3 MU887002A Software Structure

The installed MU887002A software is composed of platform and application software. At development of the MU887002A, since it was important from the viewpoint of compatibility with conventional modules to keep previous functions so users could run existing test sequences without making changes, the platform software was designed to support MU887002A hardware changes while the application software maintains full compatibility with earlier modules.

(1) Platform

The platform software is composed of framework and hardware libraries.

The framework handle processing of remote communications commands over Ethernet, management of data for the main MT8870A unit, and management of applications.

The hardware libraries provide application programming interfaces (APIs) for controlling hardware in the MU887002A and passing data between hardware and applications. To execute tests in the list mode, when applications set the sequence data, such as frequency, level, and time, the Hardware Controller in Software (SW HWC) converts this data to hardware setting values then sets them in the hardware. The device drivers handle the interface with the actual hardware as well as the passing of analysis data to applications.

The MU887002A software is designed to detect hardware changes from earlier modules in the hardware libraries. To ensure that there is no impact on applications, full compatibility with conventional modules is implemented by taking care not to change interfaces with applications.

(2) Applications

Applications have a section for implementing signal generation and analysis processing according to remote commands. There are four types of application within the application software: VSG Application, Cellular Application, SRW (Short Range Wireless) Application, and CAL (Calibration) Application.

The VSG Application contains the function for generating any waveform to perform Rx measurements for any type of communications system. The Cellular Application and SRW Application execute Tx measurements for each type of communications system. The CAL Application performs calibration of the MU887002A internal temperature characteristics and changes due to aging. Transmitter calibration uses the level-adjustment circuit in each RF test port of the frontend; receiver calibration is executed by looping-back the Tx signal in the MU887002A.

When developing the MU887002A, based on the need for full compatibility with conventional modules, the Cellular Application and SRW Application designs were changed as little as possible. Changes to the source code of applications for earlier modules were limited mostly to the CAL Application and we managed to achieve a source-code reuse rate of 97% to assure backwards compatibility.

4.2 MU887002A Control Software

(1) CombiView

Since the MT8870A and MU887002A do not have a built-in display function like other instruments, manual operations must be performed from an external PC. These operations use the same CombiView MX880050A software, which is common to the MU887000A, MU887001A, and MU887002A.

To support the MU887002A Broadcast function, we added a function for selecting multiple output ports (Figure 4).

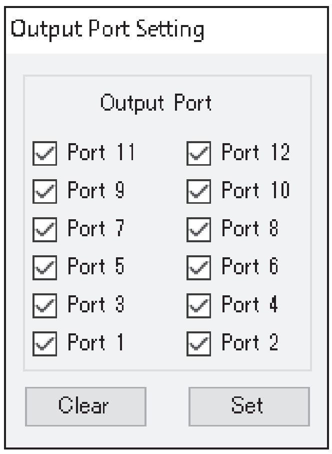

Figure 4 CombiView Output Port Setting Screen

(2) Utility Tools

To perform maintenance, such as installing license keys for the MT8870A and MU887002A, upgrading software, and updating waveform files using the VSG Application, we have added the Utility Tools MX887900A software running on an external PC in the same manner as CombiView and common to the MU887000A, MU887001A, and MU887002A.

The software installer is designed to be compatible with earlier modules and supports all-at-once installation irrespective of which modules are installed in the MT8870A.

5 Improving Measurement Efficiency

5.1 Broadcast Function

As described previously, we implemented a Broadcast function for the MU887002A to output the same signals simultaneously from all RF test ports, shortening test times and reducing the number of required measuring instruments.

When using the Broadcast function, it is necessary to set different external-loss compensation values at each test port since each RF cable connecting each RF test port to the antenna connector of the device under evaluation has different frequency characteristics. When using the MU887002A with a built-in level-adjustment circuit at each RF test port, differences in external losses between test ports can be adjusted by up to 8 dB.

5.2 Measurement Speed

Unlike conventional modules in which measurement time was shortened by performing analysis processing while capturing the measured signal, the MU887002A achieves faster measurement speeds by using the hardware scatter/gather DMA method to transfer analysis data without using CPU resources. In turn, as many as possible CPU resources can be allocated to analysis, helping implement faster measurement.

Table 1 compares measurement times with conventional modules. When comparing only with TRX1, the MU887002A measurement time is about half that of earlier modules due to making maximum use of multi-core CPU performance with parallel processing. Even when performing simultaneous measurements using TRX1 and TRX2, the results are still obtained faster.

Table 1 Comparison of Measurement Times (5G NR FDD × 20 measurements)

	MU887000A/MU887001A	MU887002A
Number of Ports	4	12 × 2
TRX1 Only	372 to 600 ms	279 ms
TRX1/2	—	340 ms

6 Main Specifications

Table 2 lists the main specifications of the MU887002A.

7 Conclusions

We have developed the new MU887002A measurement module for the MT8870A to support more efficient tests of wireless performance for future wireless devices with more built-in antennas. Due to this development, not only does this module help increase line efficiency for mass-produced wireless devices while cutting infrastructure equipment costs, it also saves space on production lines.

Future development is focusing on new measurement methods to shorten production times as well as providing timely effective solutions meeting customers' needs for manufacturing wireless equipment supporting future new communications systems.

References

1) Makoto Nishizawa, Yasunori Yamada, Mamoru Iwamoto: "Development of MT8870A Universal Wireless Test Set", Anritsu Technical Review No.22 (Sep. 2014)

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Table 2 Main Specifications of TRX Test Module MU887002A

Connectors	RF Test Ports	TRX 1: Test Port 1 to 12 TRX 2: Test Port 1 to 12
	Connector	N (female)
	Impedance	50 Ω (Nominal)
	VSWR	<1.4 (20° to 30°C) 400 MHz ≤ Frequency < 450 MHz <1.3 (20° to 30°C) 450 MHz ≤ Frequency ≤ 2700 MHz <1.4 (20° to 30°C) 2700 MHz < Frequency ≤ 3800 MHz <1.4 (20° to 30°C) 3800 MHz < Frequency ≤ 6000 MHz
	Max. Input Level	+35 dBm
Signal Generator	Frequency Range	400 to 6000 MHz
	Frequency Resolution	1 Hz
	Level Setting Range	−130 to 0 dBm
	Level Setting Resolution	0.1 dB
	Level Accuracy	CW, after calibration 400 MHz ≤ Frequency ≤ 3800 MHz, −120 dBm ≤ Output level ≤ −5 dBm ±0.7 dB (typ.) ±1.0 dB (20° to 30°C) 3800 MHz < Frequency ≤ 6000 MHz, −100 dBm ≤ Output level ≤ −8 dBm ±1.0 dB (typ.) ±1.3 dB (20° to 30°C)
	Level Linearity at Cable Loss Setting	At Broadcast and different cable loss value for each test port referenced to 0 dB cable loss, ±0.2 dB (typ.) However, at difference in external cable loss between test ports ≤ 8 dB
	Output Level Deviation	At Broadcast ≤0.6 dB (nominal)
	Harmonic Distortion	800 MHz ≤ Harmonic frequency ≤ 6000 MHz, −120 dBm ≤ Output level ≤ −5 dBm, at CW <−25 dBc
	Vector Modulation Bandwidth	200 MHz max.
Signal Analyzer	Frequency Range	400 to 6000 MHz
	Frequency Resolution	1 Hz
	Level Setting Range	−65 to +35 dBm (CW)
	Level Setting Resolution	0.1 dB
	Level Accuracy	CW, Measurement bandwidth = 300 kHz, RBW = 100 kHz, after calibration Signal to be measured at same frequency as set frequency Signal to be measured at same level as set level 400 MHz ≤ Frequency ≤ 3800 MHz ±0.3 dB (typ.) −30 dBm ≤ Level ≤ +35 dBm ±0.5 dB (20° to 30°C) −30 dBm ≤ Level ≤ +35 dBm ±0.7 dB (20° to 30°C) −55 dBm ≤ Level < −30 dBm ±0.9 dB (20° to 30°C) −65 dBm ≤ Level < −55 dBm 3800 MHz < Frequency ≤ 6000 MHz ±0.7 dB (20° to 30°C) −30 dBm ≤ Level ≤ +35 dBm ±0.9 dB (20° to 30°C) −55 dBm ≤ Level < −30 dBm ±1.1 dB (20° to 30°C) −65 dBm ≤ Level < −55 dBm
	Level Linearity	CW, Measurement bandwidth = 300 kHz, RBW = 100 kHz ±0.2 dB (20° to 30°C) 0 to −40 dB, Input level ≥ −55 dBm ±0.4 dB (20° to 30°C) 0 to −40 dB, Input level ≥ −65 dBm

	Maximum Analysis Bandwidth	25 MHz (10 MHz ≤ Setting frequency < 500 MHz) 80 MHz (500 MHz ≤ Setting frequency < 1900 MHz) 200 MHz (1900 MHz ≤ Setting frequency ≤ 6000 MHz) However, measurement results out of guaranteed range when (Setting frequency – Analysis bandwidth/2) < 400 MHz, 6000 MHz < (Setting frequency + Analysis bandwidth/2)
Others	Trigger Function	Trigger signal I/O via MT8870A back-panel Trigger connector
	Remote Control	Internet: Remote control via MT8870A interface
	Dimensions	181 (W) × 193.6 (H) × 325 (D) mm (excluding projections)
	Mass	≤12.5 kg
	Operating Temperature Range	+5° to +40°C
	Storage Temperature Range	−20° to +60°C