Impedance Analyzer IM7580

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***Abstract*—The Impedance Analyzer IM7580 can measure the impedance of electronic components operating at frequencies from 1 MHz to 300 MHz. The instrument performs measurement faster and at a higher level of stability than legacy models. This paper introduces the product's functionality, features, architecture, and other characteristics.**

I. INTRODUCTION

As the computerization of society continue to progress, the speed of transmission lines, including those using high-speed differential transmission technology, continues to rise, making it possible to send and receive ever-larger amounts of data. At the same time, manufacturers are developing increasingly high-frequency variants of electronic components such as common-mode filters and ferrite cores, which are used to improve skew (shifts in delay time) and to counteract noise on high-speed transmission lines. Finally, smaller power supplies must be developed for mobile phones and computers in order to facilitate the continued miniaturization of those devices, and the switching frequencies of DC-DC converters are being increased as one way to resolve those challenges.

The manufacturers of these electronic components need to measure them using high frequencies as part of the development process and during shipping inspections, necessitating high-speed measuring instruments in order to improve productivity during such inspections. To meet these needs, Hioki developed the Impedance Analyzer IM7580, which delivers high-frequency, high-speed measurement and testing capabilities.

II. OVERVIEW

As increasingly high-frequency electronic components continue to be developed, they are required to deliver high levels of performance and reliability, even as their prices fall. As a result, the instruments used to measure these electronic components must operate at high speeds and with a high degree of precision. Since the LCR HiTester 3535 that was launched in 2002 (with a frequency range of 100 kHz to 120 MHz) did not adequately fulfill these requirements, Hioki developed the IM7580.

The IM7580 is an impedance analyzer capable of high-frequency impedance measurement at frequencies from 1 MHz to 300 MHz. The instrument is capable of up testing at high-speeds of up to 0.5 ms while delivering repeatability that is at least one order of magnitude greater than that of the 3535.

Appearance of the IM7580

Since this one instrument provides functionality to operate both as an LCR meter that takes measurements at a single frequency and as an analyzer that sweeps through multiple frequencies or measurement signal levels, it can be used in a broad range of fields, from research and development to production line applications.

III. FEATURES

The IM7580 provides the following functionality and features:

1) *High-frequency measurement at up to 300 MHz*

The IM7580 is capable of high-frequency impedance measurement at frequencies from 1 MHz to 300 MHz. Although its predecessor model, the 3535, could only apply a measurement signal of 1 V rms at a maximum frequency of 10 MHz, the IM7580 can apply 1 V rms at up to 300 MHz.

2) *High-speed measurement at speeds of up to 0.5 ms*

The IM7580 is a high-speed performer. With analog measurement times as fast as 0.5 ms, the instrument can quickly test large quantities of electronic components to dramatically boost productivity on production lines.

3) *High-precision measurement*

The IM7580 delivers repeatability that is an order of magnitude better than legacy models.

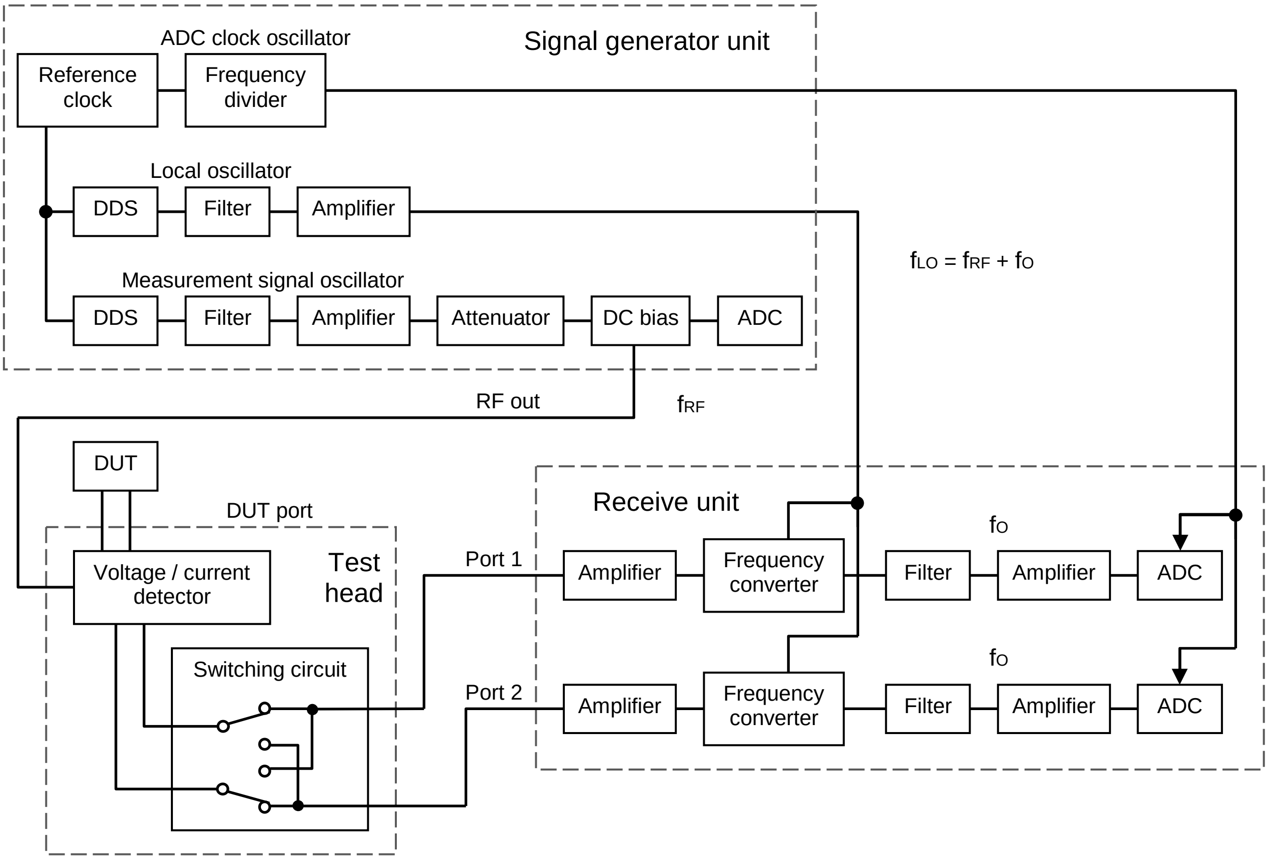

Fig. 1. Block Diagram (Analog circuits)

Operators can reduce measurement errors with the instrument's open, short, and load calibration.

4) Compact size

The IM7580 features a half-rack-size enclosure. This compact design allows operators to build smaller automatic testing systems that incorporate multiple embedded IM7580s.

Since its test head is also smaller than those on legacy models, the test head can be installed close to electrodes when mounting the instrument in an automatic testing system, reducing errors caused by long cable runs.

5) Contact check function

The reliability of measured values can be increased by means of a contact check function (available for use with inductors) based on DC resistance measurement.

6) Analyzer function

The IM7580 can perform sweep measurement by frequency and level for four measurement parameters. The operator can select from among various methods for displaying the results, including separate graph displays for each of the four parameters.

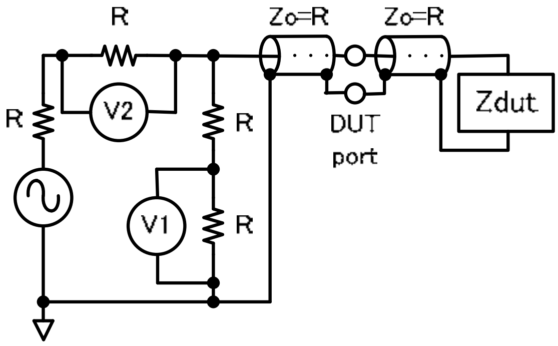

Fig. 2. RF I-V Method

IV. ARCHITECTURE

A. Analog Circuits

Fig. 1 provides a block diagram for the IM7580's analog circuits.

1) Measurement principle

The IM7580 uses the RF I-V method as its measurement principle. The RF I-V method is based on the I-V method, which measures impedance by measuring the voltage across the measurement target Zdut as well as the voltage across a current-sensing resistor placed in series with Zdut. The RF

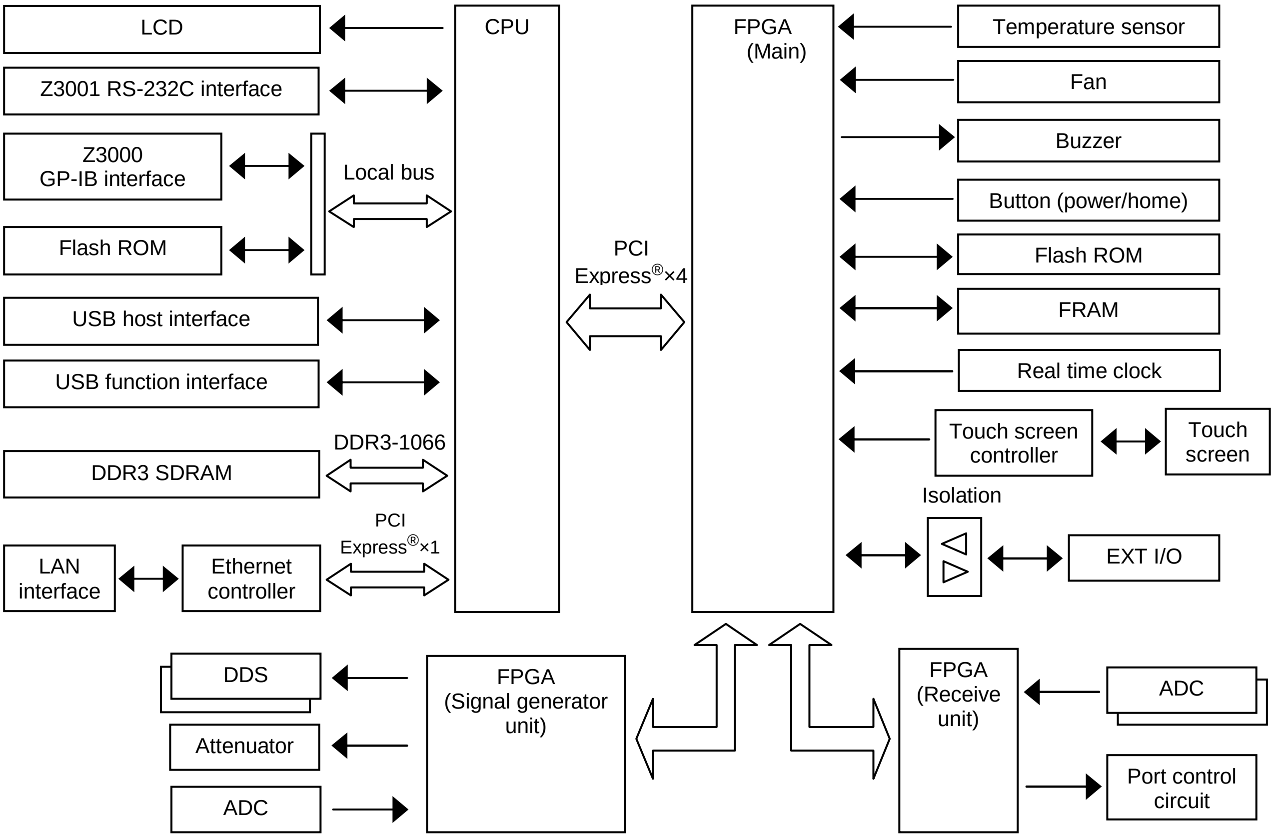

Fig. 3. Block Diagram (Digital circuits)

I-V method enables impedance measurement at high frequencies—a task that is difficult to accomplish with the I-V method—by using a circuit matched to the characteristic impedance of a coaxial line and a high-frequency coaxial connector.

Fig. 2 illustrates the underlying measurement principle. A signal corresponding to the current is detected based on the voltage V2 across a resistor placed in series between the signal source and Zdut, and the signal corresponding to the voltage is detected based on the voltage V1 across a resistor placed in parallel with Zdut.

Since the impedance when the measurement circuit side as seen from the device under test (DUT) port is matched to the value R, it is possible to detect high-frequency signals.

2) Signal generator unit

The measurement signal, frequency conversion signal, and A/D conversion clock signal are all generated from a single reference signal source. The measurement signal, which is output from RF OUT, is a 1 MHz to 300 MHz, −40 dBm to +7 dBm signal obtained by controlling the amplitude of a sine wave signal generated by a direct digital synthesizer (DDS) with a variable attenuator. A +0.1 V (when open) DC voltage can be added to the measurement signal by a DC bias circuit. DC resistance can then be measured when changes in this DC voltage are detected by the A/D converter (ADC). The frequency conversion signal is used in frequency conversion by the receive unit. Although, like the measurement signal, the frequency conversion signal is generated by DDS, its frequency is set so that it maintains a constant offset relative to the measurement signal. The ADC clock signal, which is used by the receive unit's ADC, is generated by dividing the reference signal.

3) Test head

In accordance with the RF I-V method, current and voltage signals are detected using a circuit that matches the characteristic impedance of a coaxial line with the impedance of the measurement circuit as seen from the DUT port. The current signal is detected by means of balance-unbalance conversion using a low-loss transformer. Since the actual test head can be extended from the signal source with a coaxial cable, the circuit architecture allows impedance matching with not only the DUT port, but also RF OUT.

4) Receive unit

The receive unit captures the voltage detection signal and current detection signal output by the test head and converts them into digital data. The two detection signals are input to the Port 1 and Port 2 receive circuits, respectively. Each port has an identical receive circuit, and the correspondence between the ports and detection signals is controlled by the test head signal switching circuit.

During measurement, first the voltage detection signal is input to Port 1, and then the current detection signal is input to Port 2. The two detection signals are amplified to a suitable signal level by an amplification circuit, and their frequencies are converted to a frequency (f_o) representing the difference between f_{RF} and f_{LO}. Following the frequency conversion process, these detection signals are converted into digital data by the ADC. Next, the detection signals being input to Port 1 and Port 2 are switched, and the operation described above is repeated.

In this way, by making two measurements while switching the circuits through which the voltage detection signal and current detection signal pass, the receive block corrects for the amplitude error and phase error that exist in the measurement circuit. This correction process is described in “5.2 Improved Temperature Characteristics” below.

B. *Digital Circuits*

Fig. 3 provides a block diagram for the IM7580’s digital circuits.

Hioki chose a 32-bit dual-core CPU to shorten measurement times and improve the instrument’s overall performance. It also provided independent DDR3-SDRAM, PCI Express®, USB 2.0, and local bus as the external bus interfaces to the CPU to make possible the transfer of large amounts of data.

Each CPU core uses an operating clock frequency of 533 MHz and communicates with the DDR3-SDRAM that serves as its working memory at a signal speed of 1,066 Mbps × 32 bits. The field programmable gate array (FPGA), whose functionality includes controlling the analog circuits, is connected via PCI Express® (×4), which enables high-speed data transfers at a signal speed of 2.5 Gbps × 4.

Hioki’s design uses a total of three FPGAs, adding small-scale FPGAs used by the signal generation unit and the receive unit to the main FPGA that communicates with the CPU. By locating an FPGA close to each analog circuit so as to minimize the length of the wires that carry control signals, it has reduced the amount of noise radiated from the signal lines.

Hioki also used LVDS SerDes (SERializer/DESerializer) between the FPGAs to reduce the number of signal lines that would need to be routed over long distances and to reduce noise radiated from those signal lines.

V. PERFORMANCE AND FUNCTIONALITY

A. *Repeatability*[2]

The IM7580’s predecessor model (3535) used a digitally-controlled, automatically balanced bridge method to measure impedance by varying the amplitude ratio and phase difference between the H measurement terminal’s oscillator and the L measurement terminal’s oscillator in order to balance the bridge. However, multiple measurements were necessary in order to balance the bridge, and only a small portion of the measurement time was taken up by the integration process, causing degraded repeatability. The RF I-V method used by the IM7580 does not require measurement to balance the bridge, and most of the measurement time is allocated to integration, boosting repeatability while making possible high-speed measurement.

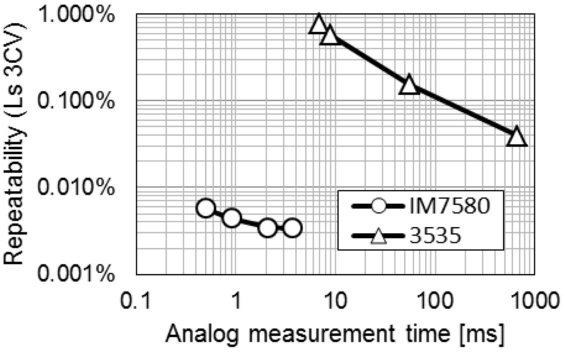

Fig. 4. Inductor (100 nH) Repeatability

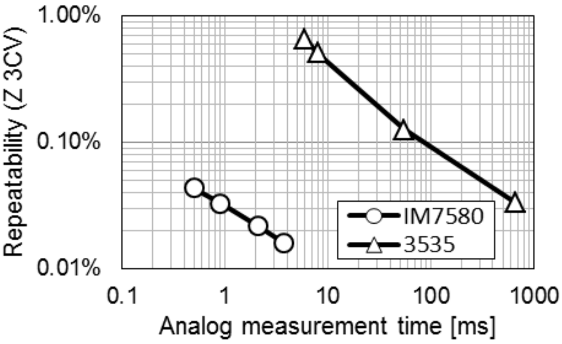

Fig. 5. Ferrite Bead (600 Ω) Repeatability

Figs. 4 and 5 illustrate the repeatability (3CV = 3 × standard deviation / mean value) exhibited by 100 measurements of a 100 nH inductor (Fig. 4) and a ferrite bead (Fig. 5) at a measurement frequency of 100 MHz and a measurement signal level of +1 dBm (0.5 V). These results demonstrate that the IM7580’s repeatability has been greatly improved over that of the 3535.

B. *Improved Temperature Characteristics*[3]

By switching signal circuits for the current detection signal and voltage detection signal, the IM7580 is able to measure impedance and phase angle while correcting for circuit errors in the receive circuits. Since the circuits are switched for each measurement, it is also possible to compensate for the circuits’ temperature drift and variations over time as shown below.

The measured impedance Z and phase angle θ can be expressed as follows, where V and θv indicate the amplitude and phase angle of the voltage detection signal, respectively, and I and θi indicate the amplitude and phase angle of the current detection signal, respectively:

$$Z = \frac{V}{I} \qquad (1)$$

$$\theta = \theta v - \theta i \qquad (2)$$

The voltage V_1 detected at Port 1, the current I_1 detected at Port 2, the impedance Z_1, and the phase angle θ_1 can be expressed as follows, where ω indicates the measurement signal's angular frequency; A and α the amplitude error and phase error occurring in the Port 1 receive circuit, respectively; and B and β the amplitude error and phase error occurring in the Port 2 receive circuit, respectively. The equations assume that there is no circuit error in the test head.

$$V_1 = AV\sin(\omega t + \theta v + \alpha) \qquad (3)$$

$$I_1 = BI\sin(\omega t + \theta i + \beta) \qquad (4)$$

$$Z_1 = \frac{V_1}{I_1} = \frac{A}{B}Z \qquad (5)$$

$$\theta_1 = \theta v + \alpha - \theta i - \beta = \theta + \alpha - \beta \qquad (6)$$

When the circuits are switched so that current is detected at Port 1 and voltage is detected at Port 2, the detected voltage V_2, the detected current I_2, the impedance Z_2, and the phase angle θ_2 can be expressed as follows:

$$V_2 = BV\sin(\omega t + \theta v + \beta) \qquad (7)$$

$$I_2 = AI\sin(\omega t + \theta i + \alpha) \qquad (8)$$

$$Z_2 = \frac{V_2}{I_2} = \frac{B}{A}Z \qquad (9)$$

$$\theta_2 = \theta v + \beta - \theta i - \alpha - = \theta - \alpha + \beta \qquad (10)$$

The averages $Zavg$ and θavg are then calculated from Z_1, Z_2, θ_1, and θ_2:

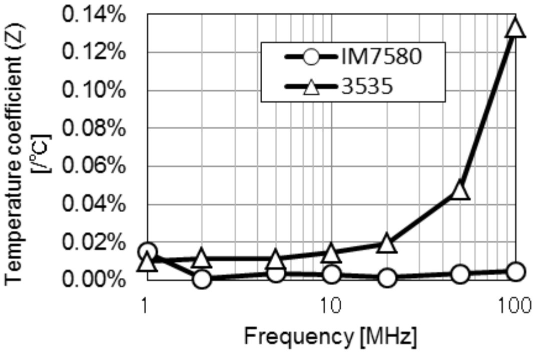

Fig. 6. Temperature Coefficients (100 Ω)

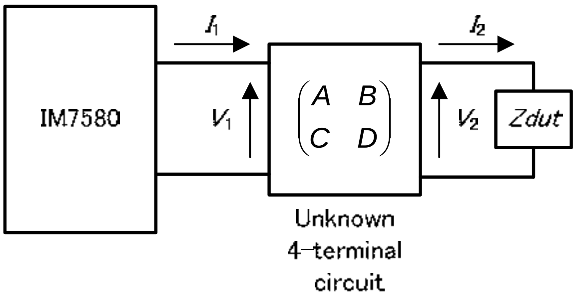

Fig. 7. Open, Short, and Load Calibration

$$Zavg = \sqrt{Z_1 \cdot Z_2} = \sqrt{\frac{A}{B}Z \cdot \frac{B}{A}Z} = Z \qquad (11)$$

$$\theta avg = \frac{\theta_1 + \theta_2}{2} = \frac{\theta + \alpha - \beta + \theta - \alpha + \beta}{2} = \theta \qquad (12)$$

In this way, the amplitude errors A and B and the phase errors α and β that occur in the receive circuits cancel each other out.

Fig. 6 provides a graph of the temperature coefficient of impedance measured values when measuring 100 Ω. The graph illustrates how the effect of variations in the environmental temperature at measurement frequencies of 50 MHz and higher has been greatly reduced in the IM7580 compared to the legacy model 3535.

C. *Calibration*

1) *Open, short, and load calibration*

When there is a four-terminal circuit network consisting of cables, fixtures, or other components between the measuring instrument and the measurement target, an error component is introduced into impedance as measured by the instrument due to the effects of the four-terminal circuit network. It is possible to calculate the parameters of the four-terminal circuit network and correct this measurement error by means of open, short, and load calibration, which measures a standard device with a known value.

As illustrated in Fig. 7, the four-terminal circuit network between the measuring instrument and the measurement target can be expressed as an F matrix (with parameters *A*, *B*, *C*, and *D*). Parameters are defined as follows:

Zom: Measured value when the measuring terminals are open
Zsm: Measured value when the measuring terminals are shorted
Zlm: Measured value when the standard device is measured
Zl: Standard device defined value
Zxm: IM7580 measured value
Zdut: Impedance value after correction

Using V_1, I_1, V_2, and I_2 in Fig. 7:

$$\begin{pmatrix} V_1 \\ I_1 \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} V_2 \\ I_2 \end{pmatrix} \tag{13}$$

$$Zdut = \frac{V_2}{I_2} \tag{14}$$

$$\begin{aligned} Zxm &= \frac{V_1}{I_1} = \frac{AV_2 + BI_2}{CV_2 + DI_2} \\ &= \frac{AZdut + B}{CZdut + D} \end{aligned} \tag{15}$$

The F matrix can be solved to derive the following correction equation:

$$Zdut = Zl \frac{(Zom - Zlm)(Zxm - Zsm)}{(Zlm - Zsm)(Zom - Zxm)} \tag{16}$$

All parameters are complex numbers.

This correction equation has been derived under the conditions of an ideal open state (G = 0, B = 0) and an ideal short state (Rs = 0, X = 0). The IM7580 allows non-ideal defined values to be entered for both open and short conditions.

2) Electrical length correction

When extending the measuring terminals with a coaxial line, the impedance as seen from the calibration terminals varies with the signal's propagation distance (electrical length) and the impedance of the measurement terminals. If the line's electrical characteristics and the electrical length are known, the measurement terminal's impedance can be corrected as described below based on the measured value at the calibration terminals and the electrical length. Parameters are defined as follows:

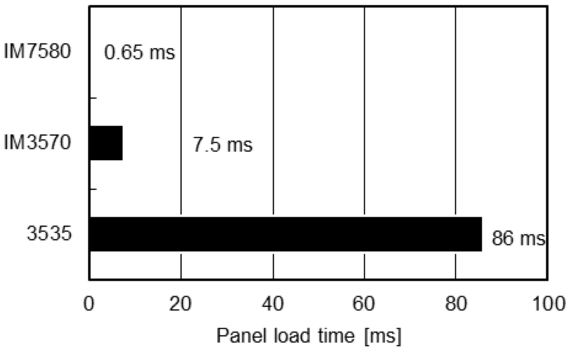

Fig. 8. Panel Load Times

TABLE I. SWEEP TIMES

Model	Sweep time [ms]	Meas. time [ms]
IM7580	417	0.5
IM3570	518	0.164 to 0.5

Sweep time: 801 points from 1 MHz to 5 MHz
Measurement time: Analog measurement time per point

Zo: Characteristic impedance of the coaxial line
Le: Electrical length of the coaxial line
Zxm: IM7580 measured value
Zdut: Impedance value after correction
c: Speed of light in a vacuum
ω: Angular frequency

$$Zdut = Zo \frac{Zxm - jZo \tan(\omega Le / c)}{Zo - jZxm \tan(\omega Le / c)} \tag{17}$$

All parameters are complex numbers.

Since this electrical length correction only corrects phase error, it is valid only with short signal propagation distances when propagation loss can be ignored.

D. Faster Panel Load Times

Loading panels (changing measurement conditions by loading previously saved settings) is faster on the IM7580 as a result of improvements to its hardware architecture and software algorithms (see Fig. 8). Improvement of algorithms so as to minimize memory reads and writes and shortening of processing times through faster stabilization of hardware control have made the IM7580 more than 100 times faster than the legacy model 3535 and more than 10 times faster than the Impedance Analyzer IM3570 (an impedance analyzer operating at up to 5 MHz that was launched in 2010).

E. Faster Sweep Times

The IM3570 offers faster analog measurement times than the IM7580 (see TABLE I). However, the IM7580 delivers faster sweep times under the same conditions. The latter instrument is able to achieve 20% faster operation thanks to faster hardware configuration changes and other improvements.

VI. CONCLUSION

The IM7580 is a high-frequency impedance analyzer that delivers high-speed, high-stability performance. Hioki expects the instrument to find broad use in settings ranging from research and development to production line applications for electronic components, which operate at increasingly high frequencies.

Impedance Analyzer IM7580

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[*1] Engineering Division 3, Engineering Department