DA00054290-001

WIDEBAND DIGITAL LOCK-IN AMPLIFIER

LI 5655 / LI 5660

Specifications

NF Corporation

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NF Corporation

1. Outline

The "LI 5655 / LI 5660 WIDEBAND DIGITAL LOCK-IN AMPLIFIER" is a dual phase, dual frequency lock-in amplifier with a frequency range of 0.5 Hz to 11 MHz. (with the LI5655, 0.5 Hz to 3 MHz)

It can be widely used to measure the magnitude and phase of a small AC signal buried in noise, taking advantage of the following features.

For details on the basic functions and terms of a lock-in amplifier, ☞ "4. Operating Principles and Block Diagram"

1.1 Features

- Wideband

  A signal of up to 3 MHz of voltage input can be measured. With the LI 5660, up to 11 MHz can be used by using a special input connector (HF) (there are some functional restrictions).
  The -3 dB bandwidth for current input is 1 MHz (nominal value when signal source capacity + connection cable capacity = 150 pF).
- Variety of Reference Signals

  In addition to a synchronous function with general external reference signals and internal oscillator, and measured signals without a reference signal, a signal can be synchronized with the frequency reference of other devices using an external 10 MHz (10 MHz IN connector).
- Variety of Detection Functions

  In addition to general harmonic measurement, the following functions are provided.

  a) Fractional Harmonic Measurement

  In addition to the harmonic, a frequency of a submultiple of the fundamental wave (x 1 / 1 to 63 / 63) can be measured.

  b) Dual Frequency Simultaneous Measurement

  Two sets of dual phase sensitive detectors enable two frequency components included in a single input signal to be measured simultaneously. Two-component ratio operation (RATIO) and cascade-connection of detectors are also possible.
- Digital Processing Ensures High Stability and Superior Dynamic Reserve

  Phase detection and subsequent processing are performed digitally. Output zero drift at high gains is smaller than the analog system, and up to 100 dB dynamic reserve can be obtained (measurement can be performed with a noise 100,000 times larger than the sensitivity, namely the signal full scale).
- High-speed Smooth Output Response

  The maximum update rate is approximately 1.5 M samples/s, and the amplitude resolution is 16 bits.
- High-speed Locking Even at Low Frequencies

  It takes just about two cycles to lock on to the reference signal even at low frequencies. Furthermore, a moving average filter synchronized with the signal cycle obtains a high-speed response with a small ripple.
- 10 Vrms signal input (LI5660 only)

  A signal of up to 10 Vrms can be measured (C connector). A large signal output of an external preamplifier can also be input.
- Remote Control

  USB, GPIB, RS-232, and LAN are available, which facilitate incorporation into automatic measurement systems. The maximum transfer rate of measured values is 100 k samples/s (USB).

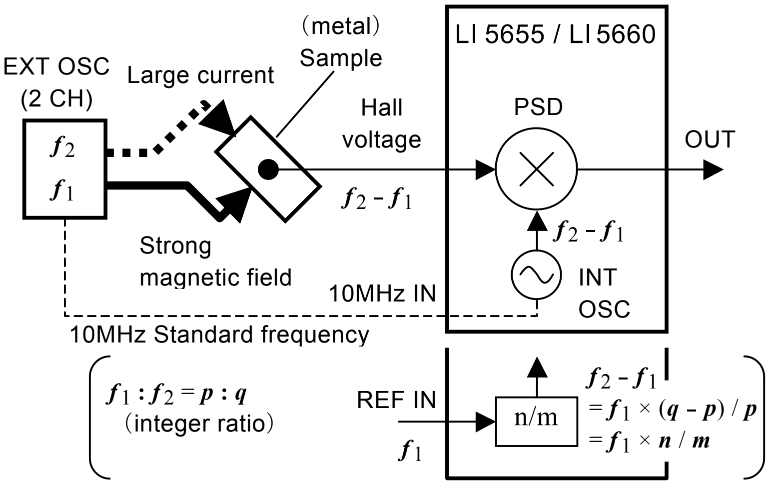
- Thin Design
  The height is 88 mm (2U) so it can easily be mounted in a rack.

1.2 Applications

The LI5655 / LI5660 can be used in the following fields, taking advantage of its features.

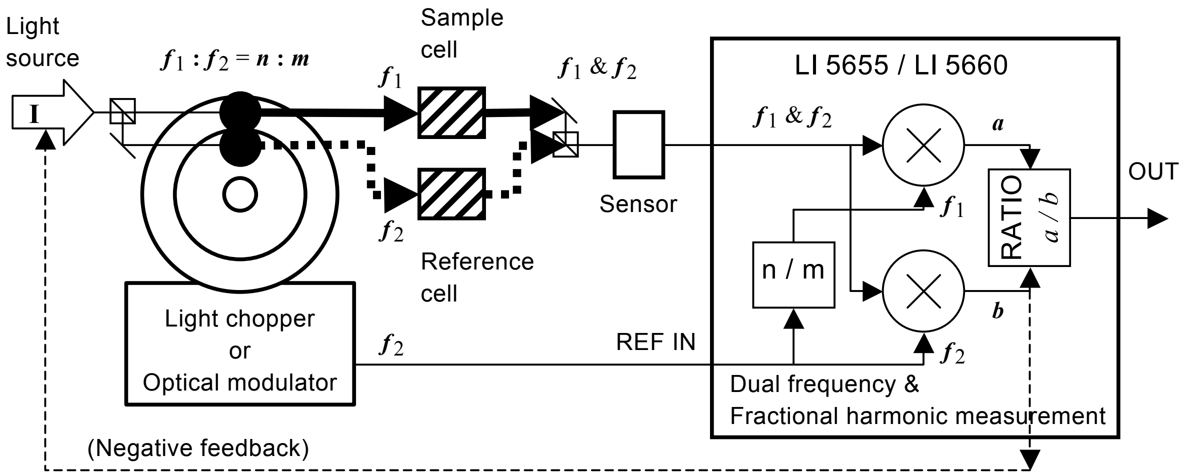
- Scanning probe microscope signal detection
- Spectroscopy (material science using Auger electron spectroscopy, photoacoustic spectroscopy, Raman spectroscopy, etc.)
- Measurement of optical properties (intensity, absorption, scattering, transmission, etc.)
- Optical application measurements (optical gyro, detection of distance, speed, vibration, etc.)
- Magnetic measurements (evaluation of magnetic materials, vibration-type magnetometer, magnetic detection using SQUID)
- Hall coefficient measurement
- Evaluation of various sensors (measurements of physical quantities detected by optical, magnetic, and piezoelectric elements, chemical changes, etc.)
- Null detection with impedance bridge
- Impedance measurements (minute impedance, minute capacity, chemical impedance)
- Thermal diffusivity measurement of thin film materials

Ex. 1. Hall coefficient measurement (Difference frequency signal measurement)



With 10 MHz synchronous or fractional harmonic measurement, to avoid crosstalk with an external reference signal, it is possible to measure the very small difference frequency signal generated as the product of the two signals. There is no need to provide an external reference signal (difference frequency).

Ex. 2. Light transmission measurements (suppression of illuminant fluctuation)



By dual-frequency simultaneous and fractional harmonic measurement, a single LI5655 / LI5660 corrects the fluctuation of light sources and sensors using the dual beam method (ratio measurement) and applies negative feedback simultaneously to stabilize the strength of the light source.

2. Configuration

2.1 Package Contents

The LI5655 / LI5660 product package contains the following.

Main unit	1
Instruction manual (Operations)	1
CD-ROM (Drivers for remote control, etc)	1
Power cord set (3-pin/2 m)	1
Fuse (time lag, φ5.2 × 20 mm)	1
Protective cap (for current input connector)	1

2.2 Supplied CD-ROM contents

- LI5655 / LI5660 Instruction manual (Operations)

  Describes basic matters such as LI5655 / LI5660 panel operation procedures, specifications and maintenance in PDF format.

- LI5655 / LI5660 Instruction manual (Remote Control)

  Describes how to remote control the LI5655 / LI5660 (in PDF format).

- IVI (Interchangeable Virtual Instruments) driver

  Driver for handling the main commands and queries in the LI5655 / LI5660, which can be used in various programming languages. In LabVIEW, the IVI driver can be imported and converted to ".vi" or ".llb".

- Sample programs

  Show examples of controlling the LI5655 / LI5660 using programming languages such as C# and VB.NET and various interfaces.

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3. Specification

Nominal, Typical, Supplement and Approximate values

These values show the supplemental data of this product and these do not guarantee the performance.

3.1 Measured signal system

*1. The C and HF connectors are present only on the LI5660, and not on the LI5655. Therefore, specifications regarding C and HF connectors apply only to the LI5660.

a) Voltage Measurement

Input connector	BNC (Front panel A, B, C,*1 HF*1)	
	Use B for A-B (differential input).	
Input type	A, C*1, HF*1	single-end,
	A–B	differential

Frequency range

A, A–B, C*1	0.5 Hz to 3 MHz
HF*1	10 kHz to 11 MHz

Sensitivity

A, A-B	10 nV to 1 V f.s. (1-2-5 sequence)
C*1	1 mV to 10 V f.s. (1-2-5 sequence)
HF*1	1 mV to 1 V f.s. (1-2-5 sequence)

- 1-2-5 sequence in repeating progression
  1, 2, 5, 10, 20, 50, 100, 200, 500, ...

Voltage accuracy

A, A–B
±0.5 % (1 kHz, signal level ≧ 1 mV, 23 ±5°C)*2
±2 % (1 kHz, signal level ≧ 1 μV)*2
±0.5 % (≦20 kHz, sensitivity 100 mV to 1 V at 23 ±5°C)*3
±1 % (≦50 kHz, sensitivity 100 mV to 1 V)*3
±2 % (≦100 kHz, sensitivity 100 mV to 1 V)*3
±3 % (≦1 MHz, sensitivity 100 mV to 1 V)*3
±5 % (≦3 MHz, sensitivity 100 mV to 1 V)*3

*2. with at least 30 % full-scale signal (sensitivity), dynamic reserve LOW
*3. with DC coupling, dynamic reserve LOW and full-scale signal
For details about dynamic Reserve,
☞ "3.2 Phase sensitive detector section" c) Dynamic Reserve (DR)

C*1
±0.5 % (≦20 kHz)
±1 % （≦50 kHz)
±2 % (≦100 kHz)
±3 % (≦1 MHz)
±5 % (≦3 MHz)
1 V to 10 V sensitivity, with full-scale signal, dynamic reserve LOW, full-scale signal

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HF*[1] ±3 % (≦1 MHz, input impedance 1 MΩ)
±5 % (≦3 MHz, input impedance 1 MΩ)
±7 % (≦10 MHz, input impedance 50 Ω)
±14 % (≦11 MHz, input impedance 50 Ω)
Dynamic reserve LOW, sensitivity 100 mV to 1 V, full-scale signal

Voltage accuracy temperature drift

A, A−B ± 100 ppm / °C (supplementary value)
f: 1 kHz, dynamic reserve LOW, A input, sensitivity 1V, signal level 100 % of full-scale sensitivity

Input impedance

A, B 10 MΩ (nominal value), 50 pF in parallel (supplementary value)

C*[1] 1 MΩ (nominal value), 50 pF in parallel (supplementary value)

HF*[1] 1 MΩ (nominal value), 50 pF in parallel (supplementary value)
| 50 Ω (nominal value)

Input referred noise

A, A−B 4.5 nV/√Hz (supplementary value)
dynamic reserve LOW, Sensitivity 1mV or less, frequency 1 kHz, input short

Common-mode rejection ratio

A−B at least 100 dB
AC coupling, 50 Hz to 1 kHz, signal source impedance 0 Ω,
dynamic reserve LOW and sensitivity 20 mV or less (or MED and 2 mV or less)

Harmonic distortion

A, A−B −80 dBc or less (10 Hz to 5 kHz, 2-3rd order harmonics, each order)
dynamic reserve LOW, sensitivity 1V, signal level 30 % of full-scale sensitivity

Maximum input voltage (linear operating range)

A, B, A−B ± 3 V (Each connector voltage and differential voltage at DC coupling)
dynamic reserve HIGH, sensitivity 1 V

C*[1] ± 30 V
dynamic reserve HIGH, sensitivity 10 V

HF*[1] ± 3V
dynamic reserve HIGH, sensitivity 1 V

Nondestructive maximum input voltage

A, B	AC coupling: 10 Vrms, sine wave, ±42 V DC DC coupling: ±14 V When a signal is over-range, the internal signal protection circuit temporarily disconnects the input connector.
C*[1]	±42 V
HF*[1]	±5 V

b) Current measurement

Input connector	BNC (front panel I)
Input type	Single-end
Frequency range	0.5 Hz to maximum values shown in the table below (nominal values, 3 dB reduction frequency)

Cs*[4]	Conversion Gain	
	1 M (10^6) [V/A]	100 M (10^8) [V/A]
None	1 MHz	10 kHz
150 pF	1 MHz	10 kHz
1000 pF	150 kHz	1.5 kHz

*4. Signal Source + Connection Cable Capacitance

Sensitivity	100 fA to 1 μA f.s. (with 1 M V/A conversion gain) 10 fA to 10 nA f.s. (with 100 M V/A conversion gain) both in 1-2-5 sequence
Current accuracy	±1 % at 23 ±5°C, dynamic reserve LOW, sensitivity 1 μA (1 M V/A conversion gain at 1 kHz) as well as sensitivity 10 nA (100 M V/A conversion gain at 125 Hz), 30 % or more of full-scale sensitivity signal Both are supplementary values

Current accuracy temperature drift

± 150 ppm / ℃

dynamic reserve LOW, supplementary value for(conversion gain 1 M [V/A], 1kHz) and (conversion gain 100M [V/A], 125 Hz)

Input referred noise	150 fA/$\sqrt{\text{Hz}}$ (1 M V/A conversion gain at 1 kHz) 15 fA/$\sqrt{\text{Hz}}$ (100 M V/A conversion gain at 125 Hz) Both are supplementary values
Input impedance	1 kΩ (1 M V/A conversion gain) 100 kΩ (100 M V/A conversion gain) Both are supplementary values

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Maximum input current (linear operating range)

±3 μA

With DC coupling, dynamic reserve HIGH, conversion gain 1 M [V/A], sensitivity 1μA

Non-destructive maximum input current

±10 mA

c) Noise density measurement

Sensitivity	Voltage	20 nV/$\sqrt{\text{Hz}}$ to 1 V/$\sqrt{\text{Hz}}$ (at inputs A, A-B)
		1 mV/$\sqrt{\text{Hz}}$ to 10 V/$\sqrt{\text{Hz}}$ (at input C *[1])
		1 mV/$\sqrt{\text{Hz}}$ to 1 V/$\sqrt{\text{Hz}}$ (at HF input *[1])
	Current	1 pA/$\sqrt{\text{Hz}}$ to 1 μA/$\sqrt{\text{Hz}}$ (with 1 M V/A at input I)
		100 fA/$\sqrt{\text{Hz}}$ to 10 nA/$\sqrt{\text{Hz}}$ (with 100 M V/A at input I)
		All in 1-2-5 sequence

d) Input Coupling*[1]	A, A-B:	AC/DC switching
		AC coupling with two-stage cascaded 1st order HPF
		HPF fc: 0.1Hz (nominal value)
	I:	AC/DC switching, after converting the voltage
	C*[1]:	DC (Always automatically cancel DC component)
	HF*[1]:	AC
		fc: 1kHz (nominal value),
		when input impedance is 50Ω, the AC-couple stage is positioned after the 50Ω termination one.

e) Input Ground	FLOAT / CONNECT (to chassis) switching	
	Withstand voltage	: ± 1 Vpk max. (DC+AC)
	Impedance to chassis (nominal value)	: 10 kΩ (float), 11Ω (connected to the chassis)

Remarks: The outer contacts of input connectors A, B, C*[1], HF*[1], I and the preamp power supply output (PREAMP POWER) ground line (0 V) are connected together internally.
Other input and output signal grounds that are not specified otherwise are connected to the chassis.

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f) Line Filter

rejection frequency (fundamental)

50 Hz | 60Hz switching

Function

- Through
- Fundamental rejection (50 Hz or 60Hz)
- 2 nd order harmonics rejection (100Hz or 120Hz)
- Both of Fundamental and 2 nd order harmonics rejection

Attention

20 dB or more (at f_0)

Restrictions

When using the input C*[1] and HF*[1], Line filter is disable regardless of Line filter settings.

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3.2 Phase Sensitive Detector Section

*1. The C and HF connectors are present only on the LI5660, and not on the LI5655.
Therefore, specifications regarding C and HF connectors apply only to the LI5660.

a) Phase Sensitive Detector (PSD)

2 phase (Rcos θ, Rsin θ), Dual PSD (primary PSD, secondary PSD).

Settings Items	Primary PSD	Secondary PSD
Sensitivity	Individual	Individual*2
Time Constant	Individual	Individual
Phase	Individual	Individual
XY Offset	Individual	Individual
Dynamic Reserve	Individual	Common with Primary PSD

*2. The sensitivity of the secondary PSD is limited by that of the primary PSD.
The sensitivity setting of the secondary PSD can be higher than that of the primary PSD, but cannot be lower. (For example, if primary PSD sensitivity is 1 mV, secondary PSD sensitivity can be set to 500 μV, but not 2 mV.)

b) Detection Modes

Detection Mode	Measurement Frequency	
	primary PSD	secondary PSD
SINGLE*3	fundamental / fractional harmonic	None
DUAL1*4	fundamental / fractional harmonic	fundamental / harmonic
DUAL2*5	primary frequency	secondary frequency
CASCADE*6	primary frequency	secondary frequency

*3. 2-phase detection is at one frequency.

*4. The fundamental and a harmonic component of one input signal are measured simultaneously.

*5. Two independent frequency components (primary and secondary) of one input signal are measured simultaneously.

*6. The secondary PSD is connected in cascade with the primary PSD, so after a signal is detected by the primary PSD, it is further detected by the secondary PSD.

For details about the primary and secondary frequencies, ☞ "3.3 Reference Signal System" c) Internal Oscillators.

c) Dynamic Reserve (DR)

Effective Range 100 dB or more (supplementary value)

Settings LOW/MEDIUM/HIGH 3-point switching (common in primary PSD and secondary PSD)

The actual value changes according to sensitivity and dynamic reserve settings, frequency difference between signals and noise, and time constant filter setting. The following table shows nominal values at frequencies for which noise is sufficiently attenuated by the time constant filter. Settings that exceed 100 dB require a large time constant, and drift and measurement value errors may become larger.

- dynamic reserve (DR) definition
  DR = Maximum acceptable noise level ÷ Sensitivity (full-scale signal)
  The following table shows dynamic reserve (DR) values at the primary PSD.

Inputs: A, A-B, I

DR Setting			LOW		MEDIUM		HIGH	
Sensitivity (each input)			AC Gain dB	DR dB	AC Gain dB	DR dB	AC Gain dB	DR dB
I (1M)	I (100M)	A, A-B						
1 µA	10 nA	1 V	0	6	0	6	0	6
500 nA	5 nA	500 mV	6	6	0	12	0	12
200 nA	2 nA	200 mV	14	6	6	14	0	20
100 nA	1 nA	100 mV	20	6	12	14	0	26
50 nA	500 pA	50 mV	26	6	14	18	0	32
20 nA	200 pA	20 mV	34	6	20	20	0	40
10 nA	100 pA	10 mV	40	6	26	20	0	46
5 nA	50 pA	5 mV	42	10	32	20	0	52
2 nA	20 pA	2 mV	48	12	32	28	0	60
1 nA	10 pA	1 mV	54	12	32	34	0	66
500 pA	5 pA	500 µV	56	16	32	40	0	72
200 pA	2 pA	200 µV	56	24	32	48	0	80
100 pA	1 pA	100 µV	56	30	32	54	0	86
50 pA	500 fA	50 µV	56	36	32	60	0	92
20 pA	200 fA	20 µV	56	44	32	68	0	100
10 pA	100 fA	10 µV	56	50	32	74	0	106
5 pA	50 fA	5 µV	56	56	32	80	0	112
2 pA	20 fA	2 µV	56	64	32	88	0	120
1 pA	10 fA	1 µV	56	70	32	94	0	126
500 fA	– – –	500 nV	56	76	32	100	0	132
200 fA	– – –	200 nV	56	84	32	108	0	140
100 fA	– – –	100 nV	56	90	32	114	0	146
– – –	– – –	50 nV	56	96	32	120	0	152
– – –	– – –	20 nV	56	104	32	128	0	160
– – –	– – –	10 nV	56	110	32	134	0	166

AC Gain: Gain ahead of the phase sensitive detector (PSD)
(common to primary and secondary PSDs)
Gain dB = $20 \times \log_{10}$ (linear gain) dB
Example: 10 times → $20 \times \log_{10} 10 = 20$ dB

Input: C*[1]

DR Setting	LOW		MEDIUM		HIGH	
Sensitivity (Connector C)	AC Gain dB	DR dB	AC Gain dB	DR dB	AC Gain dB	DR dB
10 V	0	6	0	6	0	6
5 V	6	6	0	12	0	12
2 V	14	6	6	14	0	20
1 V	14	12	6	20	0	26
500 mV	14	18	6	26	0	32
200 mV	14	26	6	34	0	40
100 mV	14	32	6	40	0	46
50 mV	14	38	6	46	0	52
20 mV	14	46	6	54	0	60
10 mV	14	52	6	60	0	66
5 mV	14	58	6	66	0	72
2 mV	14	66	6	74	0	80
1 mV	14	72	6	80	0	86

Input: HF*[1]

DR Setting	LOW		MEDIUM		HIGH	
Sensitivity (HF Connector)	AC Gain dB	DR dB	AC Gain dB	DR dB	AC Gain dB	DR dB
1 V	0	6	0	6	0	6
500 mV	6	6	0	12	0	12
200 mV	14	6	6	14	0	20
100 mV	20	6	6	20	0	26
50 mV	20	12	6	26	0	32
20 mV	20	20	6	34	0	40
10 mV	20	26	6	40	0	46
5 mV	20	32	6	46	0	52
2 mV	20	40	6	54	0	60
1 mV	20	46	6	60	0	66

Secondary PSD dynamic reserve includes the sensitivity ratio of the primary PSD's dynamic reserve.

Secondary PSD DR = primary PSD DR + $20\times\log_{10}$ (primary PSD sensitivity ÷ secondary PSD sensitivity) dB

Ex.) Input A, DR set to HIGH, primary PSD sensitivity 2 mV (DR value: 60 dB),

When secondary PSD sensitivity is 1 mV

secondary PSD DR = 60 dB + $20\times\log_{10}$ (2 mV÷1 mV) dB = 66 dB

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d) Time Constant Filter

Time constant	1 µs to 50 ks (1-2-5 sequence)
Attenuation slope	6, 12, 18, 24 dB/oct
Synchronous filter	on/off

- About the Time Constant Filter

  A cascaded first-order low-pass filter suppresses noise and ripple associated with phase detection.

  This digital low-pass filter exhibits the same exponential response as an analog filter.

  The time constant setting determines the response time of the first-order low-pass filter, and the attenuator slope is determined by the filter cascade (6 dB/oct per step).

  The higher each setting, the greater the noise and ripple rejection ratio.

  The following types of synchronous filter are available.

- About the Synchronous Filter

  This is an integer-period moving-average filter.

  Ripple caused by detection is greatly reduced, and the output is nearly settled in the averaging interval (integer period), so the time constant can be reduced (to obtain faster response).

  However, at higher signal frequencies, ripple suppression may be insufficient.

e) Others

Phase noise	0.001° rms (at 1 kHz, 18 dB/oct or greater attenuation slope)
	0.003° rms (at 100 kHz, 12 dB/oct or greater attenuation slope)
	0.01° rms (at 3 MHz, 12 dB/oct or greater attenuation slope)
	Supplementary value; reference signal is external sine wave 1Vrms, time constant 100ms, synchronization filter off
Phase temperature drift	±0.01°/°C (from 100 Hz to 10 kHz)
	±0.03°/°C (from 10 kHz to 100 kHz)
	±0.2°/°C (from 100 kHz to 3 MHz)
	Supplementary value when input signal (A connector) and external reference signal (REF IN connector) are both Sine wave 1Vrms.

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3.3 Reference Signal System

*1. The C and HF connectors are present only on the LI5660, and not on the LI5655.
Therefore, specifications regarding C and HF connectors apply only to the LI5660.

a) Reference signal source

REN IN	external reference signal*2
INT OSC	interenal oscillator
SIGNAL	measured signal*3

In SIGNAL, the reference signal is so synchronized with an input signal that the phase measurement value becomes zero.

*2 : The external reference signal is used as the primary PSD's reference frequency at SINGLE, DUAL1, and DUAL2, and is used as the secondary one at CASCADE.

*3 : This mode cannot be used when input HF is selected

b) External reference signal

Waveform

- SIN POS: The waveform crosses the threshold level only twice per period. The negative to positive crossing of the mean value is established as 0°.
- TTL POS: The square wave crosses the threshold level only twice per period. The rising edge is 0°.
- TTL NEG: The square wave crosses the threshold level only twice per period. The falling edge is 0°.

Input connector: BNC (front panel REF IN)

Input impedance: 1 MΩ (nominal value), 100 pF in parallel (supplementary value)

Input voltage range:
- SIN: 0.3 to 20 Vp-p (sine wave)
- TTL: 0 to 5 V, High 2.6 V or more, Low 0.8 V or less (square wave)

Pulse width (square wave)
40 ns or more (both high and low levels)

Nondestructive maximum input voltage
±15 V

Synchronization frequency range
per following table

Signal Input	Detection Mode	External Reference Signal Waveform	Synchronous Frequency Range
A A-B C *1 I	SINGLE DUAL1 DUAL2 CASCADE	SIN POS TTL POS TTL NEG	0.3 Hz to 3.2 MHz
HF *1	SINGLE DUAL1 DUAL2	TTL POS TTL NEG	8 kHz to 11.5 MHz
	CASCADE	SIN POS TTL POS TTL NEG	0.3 Hz to 3.2 MHz

Synchronization time 2 periods + 50 ms (supplementary value)

Frequency display resolution
6 digits (to 0.1 mHz below 100 Hz)

Frequency measurement accuracy
±(40 ppm + 1 count)

c) Internal Oscillator*[1]

Frequency (primary and secondary)
setting range 0.3 Hz to 11.5 MHz
For A, A-B, C*[1], and I inputs, 0.3 Hz to 3.2 MHz
with HF*[1] input, 8 kHz to 11.5 MHz

Resolution 6 digits (to 0.1 mHz below 100 Hz)
Accuracy ±40 ppm

For numerical value settings, frequency is stable immediately after setting.

- About primary and secondary frequencies

  Two distinct frequencies are generated for DUAL2 and CASCADE detection modes. The primary frequency is that of the internal oscillator connected to the primary PSD. The secondary frequency is that of the internal oscillator connected to the secondary PSD.

Reference frequency source
Internal / external switching
10 MHz reference frequency for frequency synthesis is provided from an external oscillator, and can be used to synchronize with the reference frequency. Therefore, even if no external reference signal (REF IN) is available, synchronization is available by numerical frequency setting of the internal oscillator.

External reference frequency

Input connector	BNC (Rear panel 10MHz IN)
Frequency range	10 MHz ±0.2 %
Waveform	Sine or square wave (45 to 55 % duty cycle)
Signal level	0.5 Vp-p to 5 Vp-p
Non-destructive maximum input voltage	10 Vp-p
Input impedance	1 kΩ (nominal value)
Input coupling	AC
Withstand voltage (Allowed voltage to ground)	±42 Vpeak max (DC+AC)

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Sine wave output

Output Connector BNC (front panel OSC OUT)

Frequency primary frequency (with detection mode SINGLE, DUAL1)

primary frequency or secondary frequency (With detection mode DUAL2, CASCADE, can be selected)

Amplitude Per following table

Range	10 mV	100 mV	1V
Extent	0 to 10.00 mVrms	0 to 100.0 mVrms	0 to 1.000 Vrms
Resolution	0.01 mVrms	0.1 mVrms	0.001 Vrms

Amplitude accuracy

±(2 % of setting + 1 mV) ≦ 20 kHz

±(3 % of setting + 1 mV) ≦ 100 kHz

±(4 % of setting + 2 mV) ≦ 1 MHz

±(7 % of setting + 5 mV) ≦ 3 MHz

When > 3.2 MHz, 0 Vrms regardless of the setting.

Maximum output current

±15 mA

Load: Resistor connected to signal ground. Following is the same.

Output impedance 50 Ω (nominal value)

Harmonic distortion −80 dBc or less (20 Hz to 5 kHz)*4

−70 dBc or less (5 kHz to 100 kHz)*4

−60 dBc or less (100 kHz to 1 MHz)*5

−50 dBc or less (1 MHz to 3 MHz)*5

Output voltage setting 1Vrms

*4 : No load, supplementary value for each of 2nd to 5th order harmonic

*5 : 50 Ω load, supplementary value for each of 2nd and 3rd order harmonic

Square wave output

Output Connector BNC (rear panel REF OUT)

Frequency Same as sine wave output

Signal level TTL (0 to 3.3 V nominal, no load), ±8 mA max

Restriction Above 3.2 MHz and with 0 Vrms sine amplitude, output is unstable (fixed at high or low level).

d) Harmonic measurement

Detection mode SINGLE

The primary frequency to the PSD is n/m times of reference signal frequency.

n range (harmonic) 1 to 63

m range (sub harmonic) 1 to 63

Detection mode DUAL1

The primary frequency to the primary PSD is n/m times of the reference signal frequency.

The secondary frequency to the secondary PSD is n times of the reference signal frequency.

n PRI range (harmonics number of primary PSD) 1 to 63

m PRI range (sub harmonics number of primary PSD) 1 to 63

n SEC range (harmonics number of secondary PSD) 1 to 63

Harmonics are measured under the following conditions.

Reference Signal Source	Fundamental frequency range	Harmonic frequency range
REF IN	Synchronization frequency range to external reference signal	Same as at left
INT OSC	Internal oscillator frequency setting range	Same as at left
SIGNAL	Synchronization frequency range to external reference signal	Regardless of n, m settings, always operates at n = 1 and m = 1

e) Phase Adjustment

Phase shift amount Range −180.000° to +179.999°

Resolution 0.001°

f) Others

Orthogonality ±0.001° or better (supplementary value)

Phase accuracy ±1° (DC coupling, ≦10 kHz)

±2° (DC coupling, ≦ 100 kHz)

±5° (DC coupling, ≦ 1 MHz)

±10° (DC coupling, ≦ 3 MHz)

Reference signal source = REF IN

Signal input connector A (sensitivity 1 V),

Supplementary value; at Sine wave 1Vrms, both A input and external reference signal input

3.4 Arithmetic Processing

The following calculations are available for measurement values X, Y and R.

For measurement values X, Y and R, ☞ "3.5 Measured Value Output and Display Section"

a) Offset adjustment

Control Enable/Disable

Range X, Y: sensitivity of ± 105% (resolution 0.001%)

Both of primary PSD and secondary PSD can be set

- About Offset Adjustment

  This function enables deduction of a certain amount from the detectors' X and Y outputs. Use it to cancel crosstalk components contained in the input. Also, by setting X and Y near zero, the following expansion capabilities can be used to improve the apparent sensitivity and resolution, enabling measurement of small changes.

b) Expansion

EXPAND

X, R: 1, 10, 100 (Ratio of X and R is common)

Y: 1, 10, 100

Primary PSD and secondary PSD can be set individual

Apparent sensitivity (signal F. S.) is 1 / EXPAND magnification

Unusable when normalize or ratio arithmetic processing is running.

c) Normalize

Select from the following

None

% value = (measured value / standard value) x 100

dB value = $20 \times \log_{10}$ | measurement values / standard values |

% FS value = (measured value / sensitivity) × 100

When detection mode is SINGLE, DUAL1, DUAL2,

the above measurement value = primary PSD output (X or R)

When detection mode is CASCADE,

the above measurement value = secondary PSD output (X or R)

Standard value range

Voltage : 1nV to 10V

current : 1fA to 1μA

resolution : 6-digit

Unusable when EXPAND or Ratio arithmetic processing is running.

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d) Ratio

Select from the following

- None
- ratio = K × A ÷ B

K: range 0.1 to 10 (resolution 0.00001)

A, B: Select from a combination of the below

A (measured value)	B (standard value)	detection mode
primary PSD output (X, Y, R) / sensitivity	AUX IN 1 measured value / 10 V	SINGLE DUAL1 DUAL2
primary PSD output (X, Y, R) / sensitivity	secondary PSD X output / sensitivity	DUAL1 DUAL2
secondary PSD output (X, Y, R) / sensitivity	AUX IN 1 measured value / 10 V	CASCADE

Maximum update rate of B is about 10 k samples/s.

When executing expansion or normalizing or ratio arithmetic procesing cannot be performed.

- About the Ratio

  This is the ratio of measured value A to standard value B. Determining the ratio enables canceling out characteristic variation of the parts common to the measurement and standard systems (signal source, path and sensor).

  For a usage example, ☞ "1.2 Applications" Ex. 2. Light transmission measurements

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3.5 Measured Value Output and Display Section

a) Parameter

Select from the following.

Output/Display	Detection Mode	
	SINGLE	DUAL1 DUAL2, CASCADE
DATA1	X, R, AUX IN 1, NOISE	X_p,R_p,Y_p, θ_p ,X_s, R_s,AUX IN 1, NOISE
DATA2	Y, θ, AUX IN 1, AUX IN 2	Y_p,θ_p,X_s,R_s, Y_s,θ_s,AUX IN 1, AUX IN 2
DATA3	X, R	X_p,R_p,Y_p, θ_p ,X_s, R_s
DATA4	Y, θ	Y_p,θ_p,X_s,R_s, Y_s,θ_s
Remarks: X, Y, R, θ suffix	n: Harmonic (At harmonic value settings, n as a suffix. Ex.: Xn)	p: primary PSD s: secondary PSD n: Harmonic (At harmonic value settings, n as a suffix. Ex.: Xpn)

X	In-phase component (=R cos θ)
Y	Quadrature component (=R sin θ)
R	Signal amplitude
θ	Signal phase
NOISE	Noise density (primary PSD only)
AUX IN 1	DC voltage (rear panel AUX IN 1)
AUX IN 2	DC voltage (rear panel AUX IN 2)

b) Analog output

Front Panel

- Output connectors: BNC (DATA OUT 1, DATA OUT2: corresponding to DATA1 and 2)
- Maximum update rate: 312.5 k samples/s.

Rear Panel

- Output connectors: BNC (DATA OUT 3, DATA OUT4: corresponding to DATA3 and 4)
- Maximum update rate: 1.5625 M samples/s.

Common Specifications

- Full-scale voltage: ±10 V (bipolar signals), +10 V (unipolar signals)
- Output voltage range: ±12 V (no-load)
- Max output current: ±10 mA
- Output impedance: 470 Ω (nominal value)
- Output voltage accuracy

  ±(0.3 % + 10 mV), versus measured value corresponding voltage

  Refer to the rightmost column of the table in part "e) Numeric display" for measured values corresponding voltage values.

c) Measurement screen display

Select the screen to display measurement values from the following.

Normal : show the measured values (DATA1, DATA2) and key settings

Large : enlarged display the measured values (DATA1, DATA2)

Fine : show the measured values (DATA1, DATA2, DATA3, DATA4) and advanced settings

d) Bar Graphs

On Normal and Large measurement screens, displays measured values as bar graphs as well as numerical values.

e) Numeric display

Parameter	Numeric display		Measurement value for the full scale voltage of the analog output
	Range	Resolution	
X, Y	Sensitivity / EXPAND (±120%)	6 digits, at full-scale sensitivity	±Sensitivity /EXPAND
R	Sensitivity / EXPAND (0 to 120 %)	6 digits, at full-scale sensitivity	Sensitivity /EXPAND
θ	−180.000 to +179.999°	0.001°	± 180 °
NOISE (Noise dencity)	Sensitivity 0 to 120 %	6 digits, at full-scale sensitivity	Sensitivity
AUX IN 1, 2	± 12 V	0.001 V	± 10 V
Ratios	± 2.4	0.00001	± 2
Normalize %	± 240 %	0.001 %	± 200 %
Normalize % of f.s.	± 120 % of FS	0.001 % of FS	± 100 % of FS
Normalize dB	± 120 dB	0.001 dB	± 100 dB

3.6 Monitor Output

Monitor signal Phase sensitive detector input signal

Output connector BNC (front panel MONITOR OUT)

Maximum output voltage ±3 V (no-load)

Output is approximately AC Gain times the input.

For details of AC Gain, ☞ "3.2 Phase Sensitive Detection Section" c) Dynamic Reserve (DR)

Max output current ±20 mA

Output impedance 50 Ω (nominal value)

3.7 Auxiliary Input (DC Voltage Measurement)

Number of channels 2

Input connectors BNC (rear panel AUX IN 1, 2)

Maximum allowable input voltage (linear operating range)

±12 V

Nondestructive maximum input voltage

±42 V

Input impedance 1 MΩ (nominal value), 50 pF in parallel (supplementary value)
When signal ground is at chassis potential.

Voltage measurement accuracy

± (0.3 % + 10 mV), when the input ground is equal to the chassis potential

Frequency bandwidth Highest: 5 kHz (-3 dB) (supplementary value)

Sampling rate Highest: 125 k samples/s

Floating characteristics Signal Ground

Maximum voltage to ground (non-destructive)

± 42Vpk max. (DC+AC)

Ground impedance

1MΩ (nominal value)

Signal

Maximum voltage to ground (non-destructive)

± 42Vpk max. (DC+AC)

3.8 Auxiliary Output (DC Voltage Output)

Number of channels 2

Output connectors BNC (rear panel AUX OUT 1, 2)

Output voltage range ±10.500 V (0.001 V resolution)

Maximum output current

±5 mA

Output impedance 1 kΩ (nominal value)

Output voltage accuracy

± (0.3 % + 10 mV), no-load

3.9 Automatic Setting Items

Item	Function
Measurement	Perform the following items "time constant", "sensitivity", "phase"
Time constant	Set the time constant and attenuation slope corresponding to the frequency of the reference signal.
Sensitivity	Set the sensitivity , and dynamic reserve according to the input signal.
Phase	Set the phase shift value as Y and phase output θ to a zero.
Offset	Set each offset value, X and Y outputs to a zero.

3.10 Data Memory

Record data — For each sample data, select arbitrary up to five words from the following recorded data

Recording data	Words	Data Resolution
STATUS	1 Word	16 bits
DATA 1	1 Word	16 bits
DATA 2	1 Word	16 bits
DATA 3	1 Word	16 bits
DATA 4	1 Word	16 bits
Reference Signal Frequency	2 Words	32 bits

STATUS detects the following signals.

- UNLOCK (Unsynchronization)
- PROTECT (Input A or B overload)
- INPUT (pre PSD overload)
- OUTPUT (post PSD overload)
- AUX (AUX input overload)

Recording capacity — Buffers 1, 2: 16 to 8192 samples
Buffer 3: 16 to 65536 sample (FIFO)

Trigger signal — Internal timer / External trigger / Remote control commands / Manual trigger
1 sample recorded when trigger signal is received

Sampling interval — Internal timer
Range : 1.92µs to 20s, repeated at equal intervals,
Resolution : 640ns, 6 digit max.
External trigger / Remote control commands / Manual trigger
Range : ≥ 2.6µs arbitrary intervals,
Trigger jitter : 640ns (nominal value)

External trigger — Input connector: BNC (rear panel TRIG IN)
Signal level: TTL (High 2.6V or more, LOW 0.8V or less)
Minimum pulse width: 500ns (both high and low level)
Effective edge: Falling
Input impedance: 10kΩ (nominal value)
Nondestructive maximum input voltage
±15 V

Trigger delay time — Range: 0 to 100 s
Resolution: 640 ns, 6 digits max
Data is recorded after the delay time has elapsed.

Operation — By remote control.
Can not operate from panel (only manual triggering is possible).

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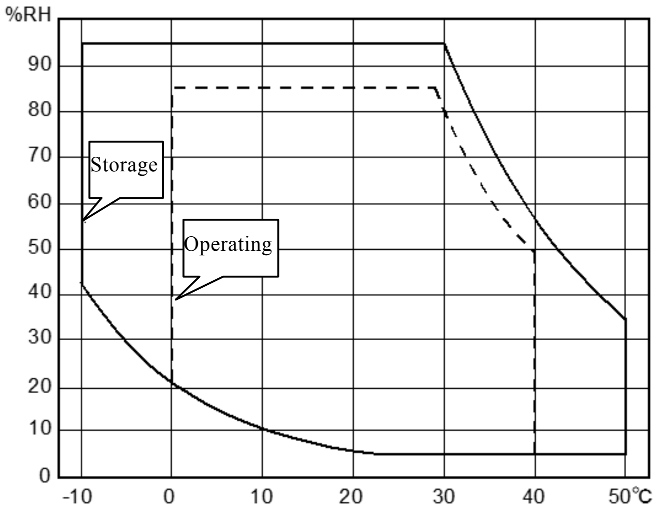
3.11 Remote Control Interface

USB	USBTMC, USB 2.0 HiSpeed
RS-232	Baud rate 4800, 9600, 19200, 38400, 57600, 115200, 230400 bps Cable and controller characteristics can inhibit communication speeds over 19200 bps. Flow control None, Software (X-ON/X-OFF), Hardware (RTS/CTS)
GPIB	Compliance standards IEEE 488.1, IEEE 488.2
LAN	10BASE-T and 100BASE-TX, TCP/IP

3.12 General Specifications

- Display: 4.3-inch WQVGA, color LCD
- Power supply: AC 100 V ± 10 % / 120 V ± 10 % / 230 V+10 %, - 14 %
  However 250 V or less
  50 Hz / 60 Hz ± 2 Hz, power consumption 75 VA or less
  Overvoltage category Ⅱ
- Environmental conditions

Operating	Temperature	0 to +40°C
	Humidity range	5 to 85% RH, absolute humidity 1 to 25g/m^3, non-condensing
	Altitude	2000 m or less
Storage	Temperature	–10 to +50°C
	Humidity	5 to 95% RH, absolute humidity 1 to 29g/m^3, non-condensing



- Pollution degree: 2 (indoor use)
- Warm-up time: 30 miniutes
- Setting memory: 9 sets
- Resume: Return to the last settings at power-on state
- Power output for preamp: ± 15 V (nominal value)
  100 mA max.(rear panel PREAMP POWER)
- Key-Lock: Present (On, Off)
- Lamp control: Present (On, Off)
  Remarks: Cooling fan is always on. It cannot be turned off.
- RoHS: Directive 2011/65/EU
- Safety and EMC: EN 61010-1:2010, EN61010-2-030:2010,
  EN 61326-1:2013, EN 61326-2-1:2013
  Remarks: Applies to products with CE marking displayed on the rear panel.
- External dimensions: 430(W) × 88(H) × 400(D) mm, excluding protrusions
- Weight: Approx. 7.5 kg, except for accessories

4. Operating Principles and Block Diagram

A lock-in amplifier is a device that uses the difference of the frequencies to separate signal and noise and amplify the signal. In this way, it works as a narrow-band filter and tuned amplifier in which the center frequency follows the signal.

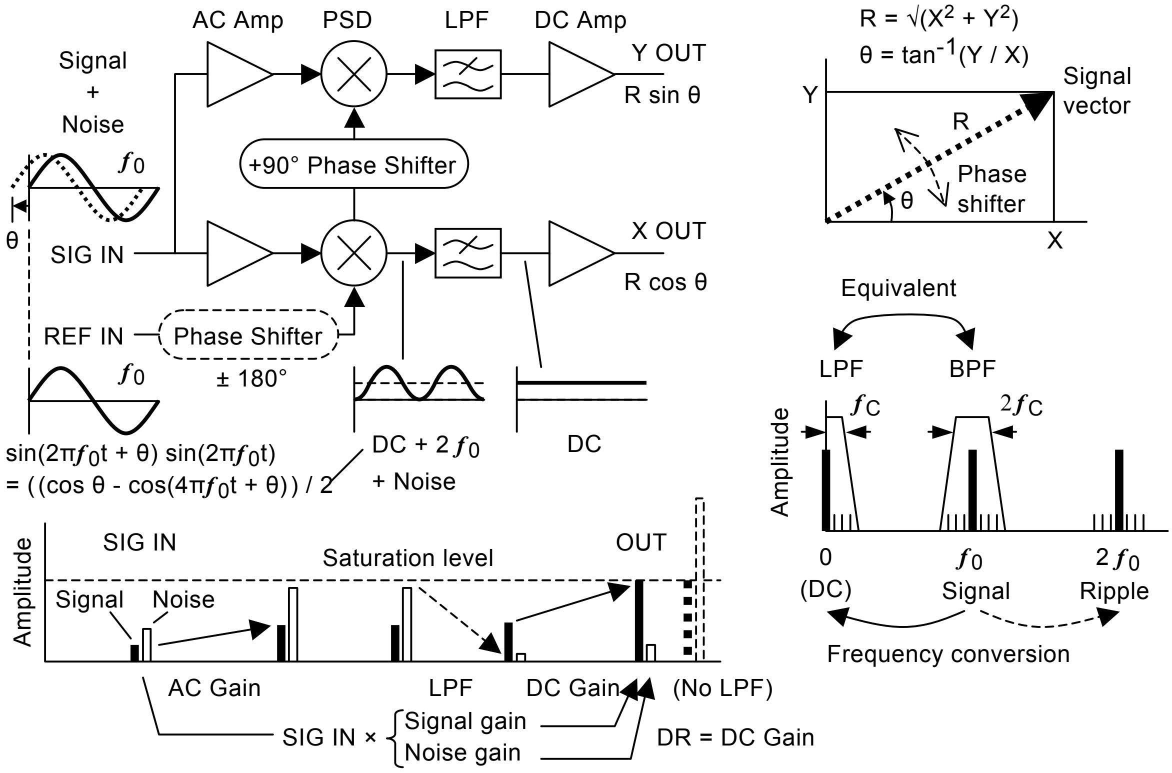


Figure 4-1 Lock-In Amplifier Basic Principles

First, the signal containing noise is frequency-converted to DC using the phase-sensitive detector (PSD). Noise in the vicinity of the signal frequency is also converted into nearby DC. Then, noise and ripple caused by the detection are removed by the low-pass filter (LPF) to obtain DC components. When this is returned to the original frequency, the equivalent bandwidth is equal to the band pass filter (BPF) that is double the cutoff frequency (f_C) of the LPF. Increasing the filter time constant (response time) and attenuation slope (number of stages), lowers fc and removes the noise. After the LPF removes the noise, the signal can be amplified without being saturated by the noise. In other words, measurement becomes possible in environments where the noise is larger than the signal. AC gain before phase detection and DC gain after phase detection are determined by the sensitivity (signal full-scale) and dynamic reserve (DR) settings. (DR value = maximum acceptable noise level/sensitivity).

A lock-in amplifier needs a reference signal (REF IN) as the reference of the frequency and phase.

The PSD is a multiplier of the signal to be measured and the reference signal (both being sine waves at the same frequency), and its output (DC) depends on measured signal size R and phase difference θ with the reference signal (it's "phase sensitive"). The amplitude of a reference signal applied to the PSD is constant, and the phase can be shifted.

The two-phase lock-in amplifier contains two PSDs and works as a vector voltmeter that can obtain two orthogonal components X and Y (in other words, R and θ) at the same time.
As the LI5655 / LI5660 are dual systems equipped with two PSDs, two frequency components in one input signal can be measured at the same time. The two PSDs can be connected in cascade configuration.

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The internal oscillator (INT OSC) is normally synchronized with the external reference signal (REF IN) by a PLL (phase-locked loop) to supply the reference signal to the PSD. A function is also provided to set the frequency as a numerical value, and to supply its harmonic to the PSD as a reference signal.

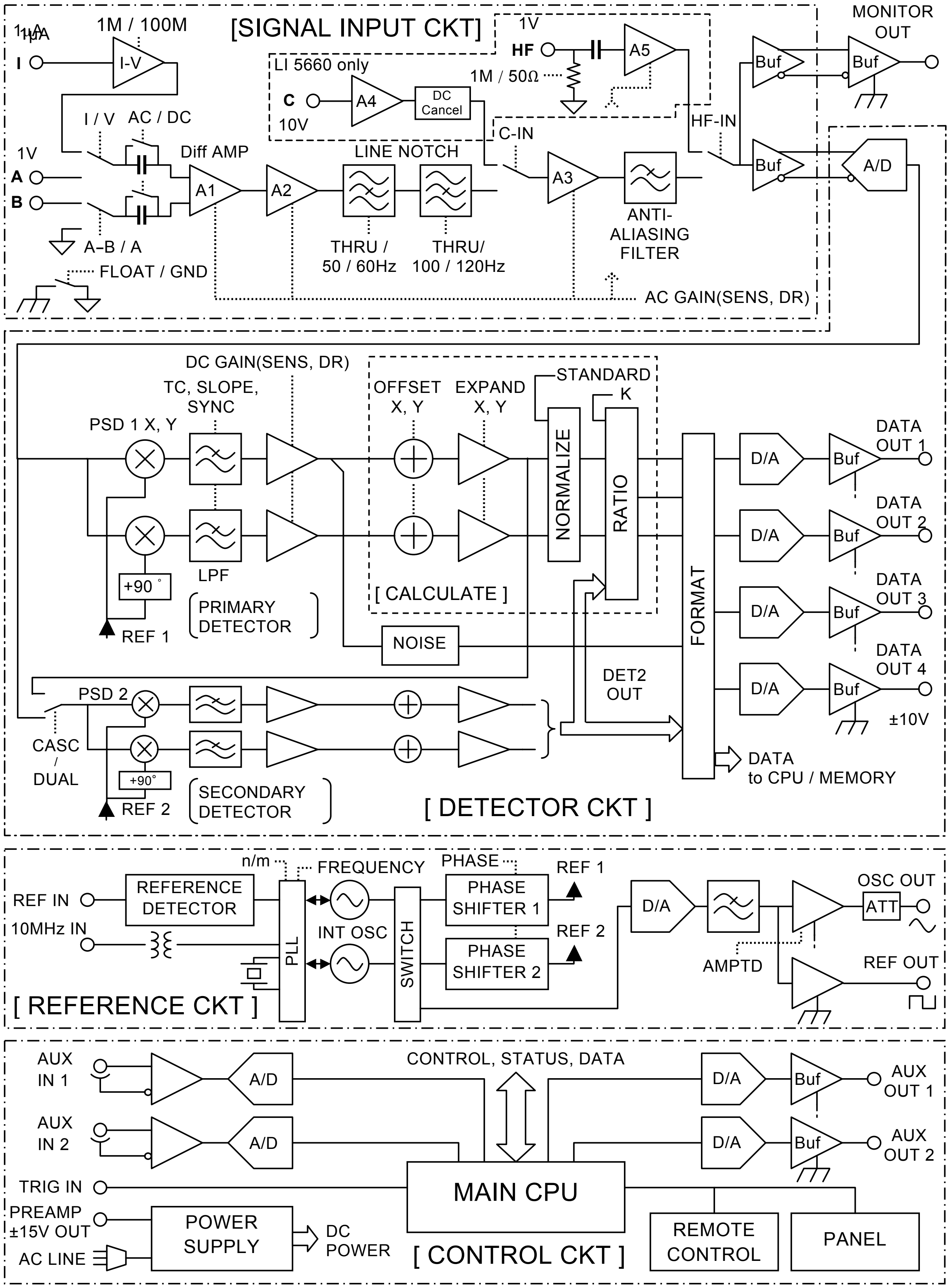
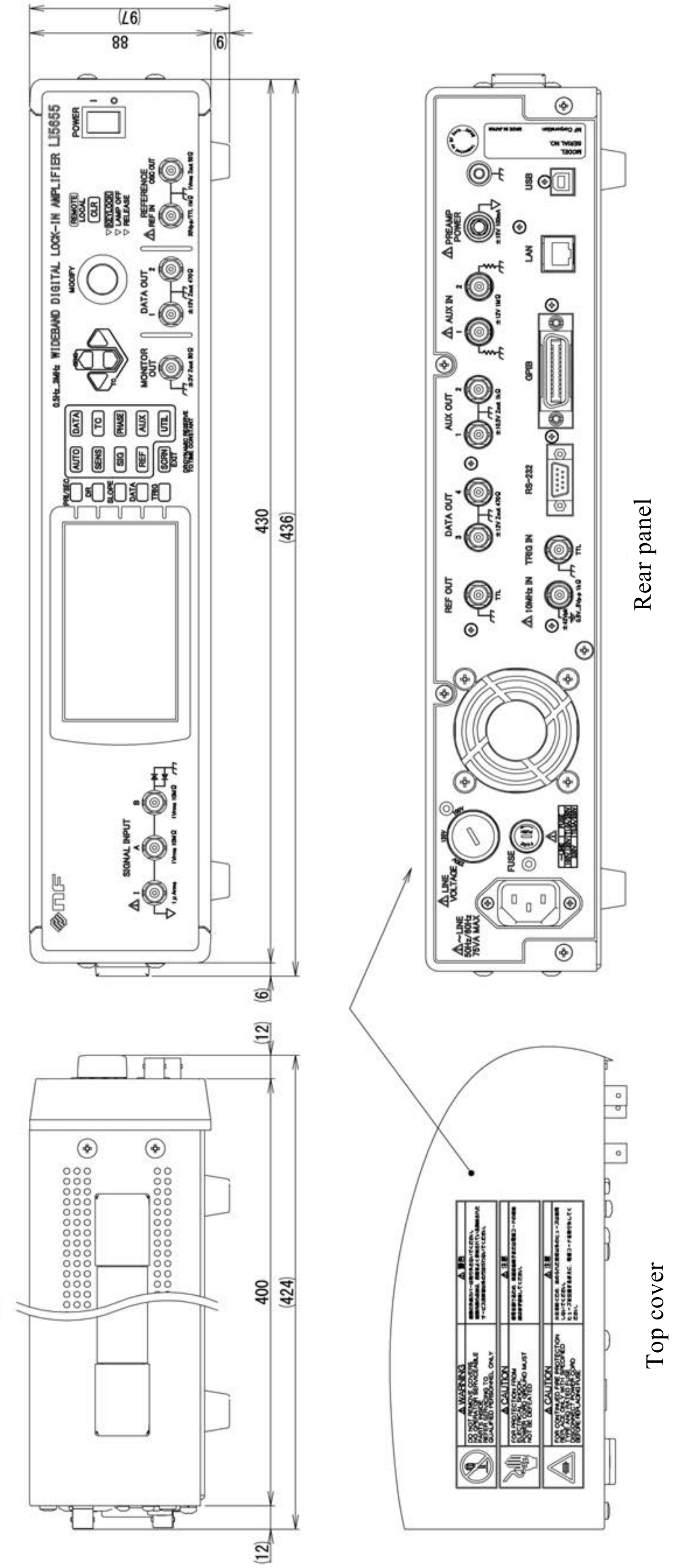


Figure 4-2 LI5655 / LI5660 Block Diagram

5. External dimensions diagram



Surface treatment
Front panel: Ultralight-gray plastic sheet (Munsell 6PB9.2/0.1 semi-gloss)
Rear panel: Light-gray coating (Munsell 6PB7.6/1.2 semi-gloss)
Cover: Light-gray leather-tone coating (Munsell 6PB7.6/1.2 leather tone)

Figure 5-1 LI5655 External Dimensions Diagram

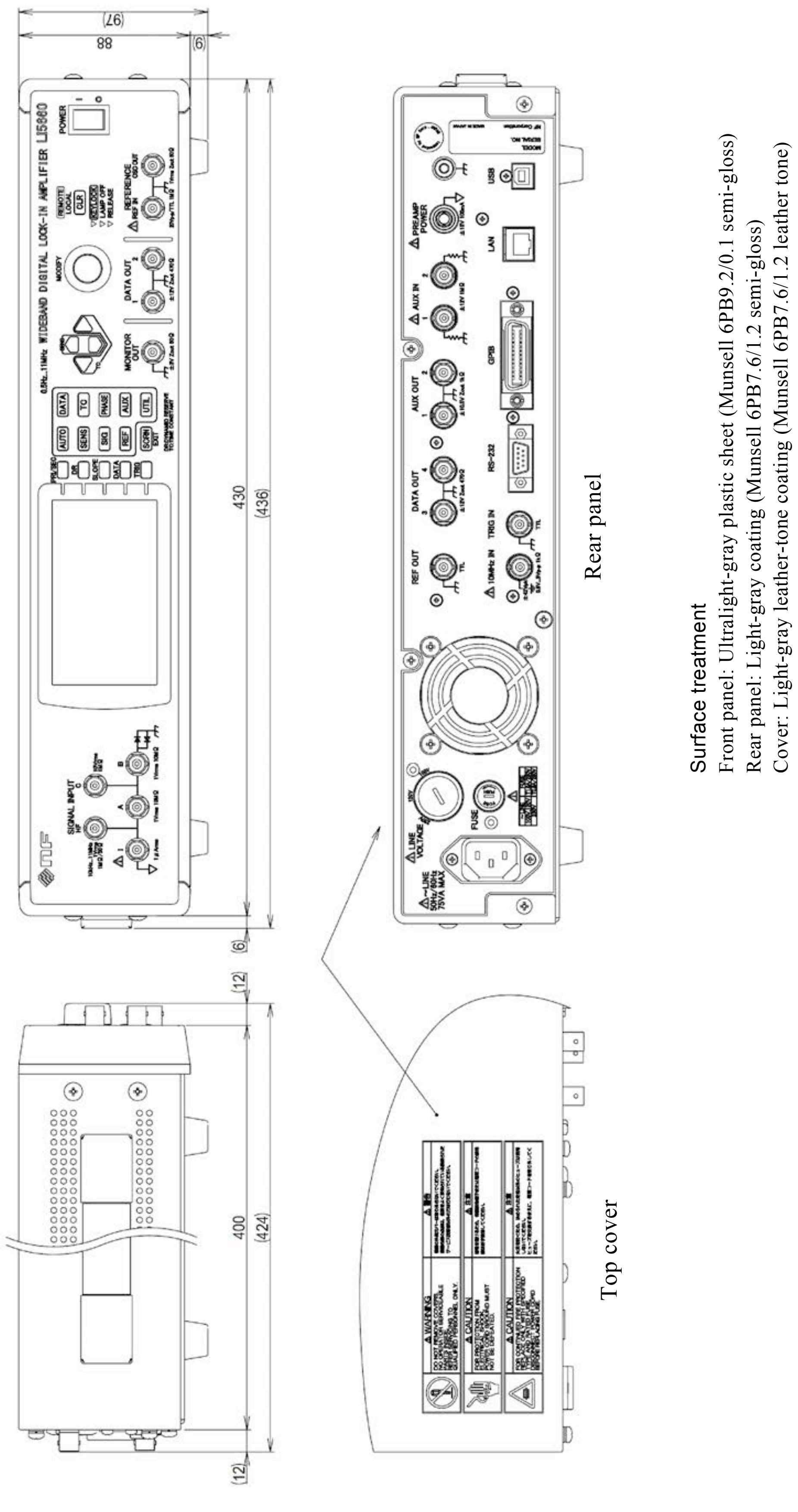


Figure 5-2 LI5660 External Dimensions Diagram

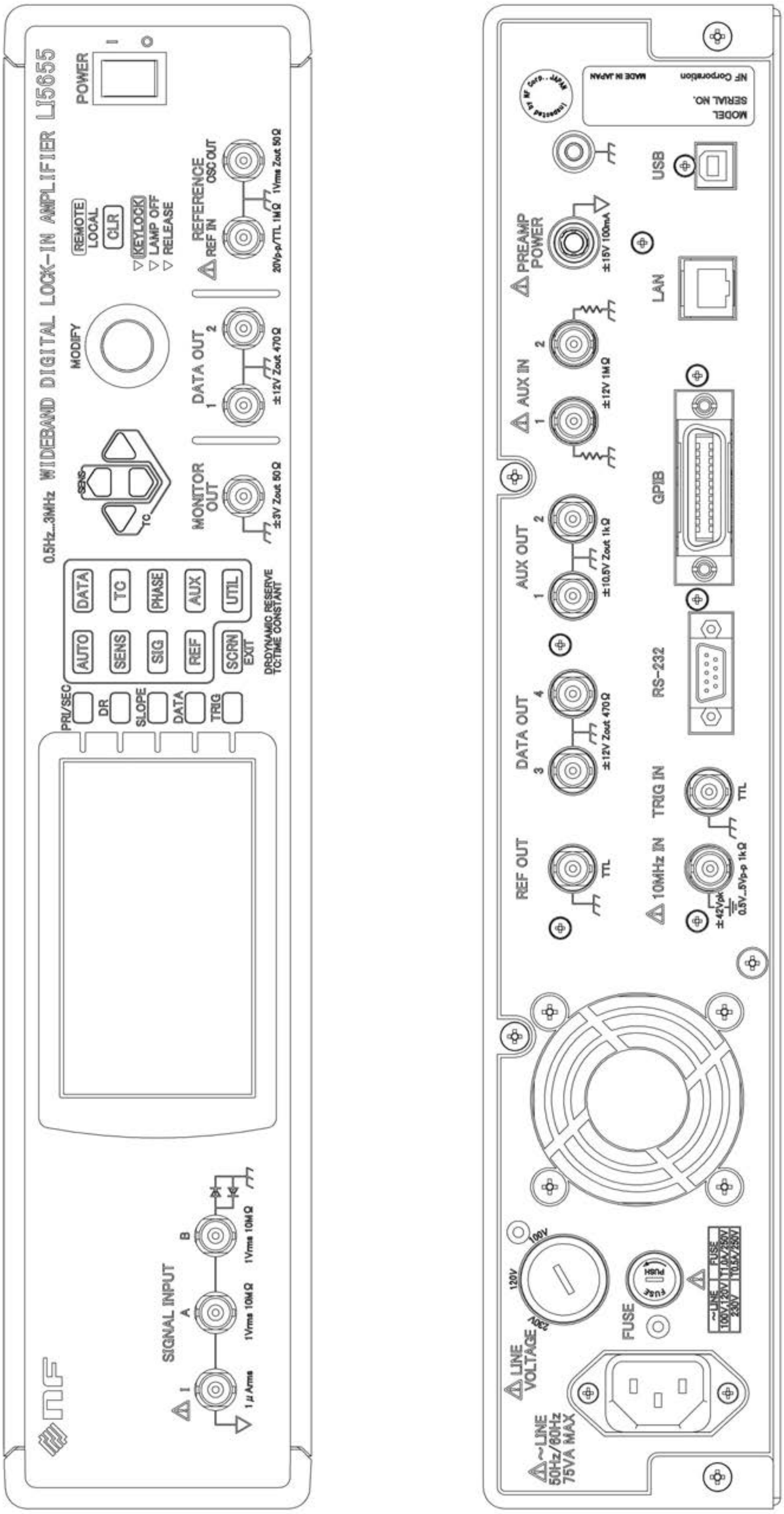


Figure 5-3 LI5655 Panel Diagram

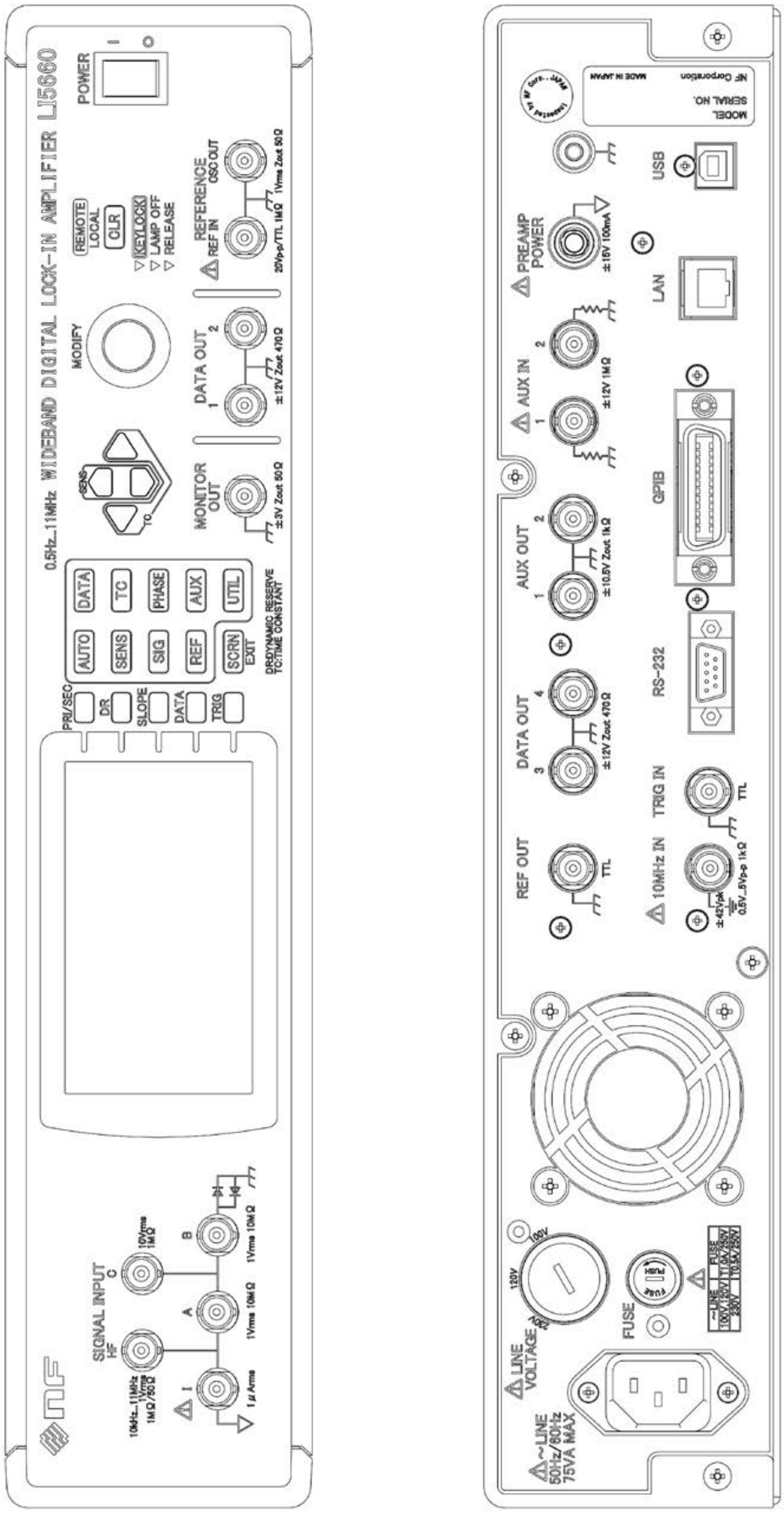


Figure 5-4 LI5660 Panel Diagram

LI5655 / LI5660 Specifications

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