Dear customer

ROHM Co., Ltd. ("ROHM"), on the 1st day of April, 2024,
has absorbed into merger with 100%-owned subsidiary of LAPIS Technology Co., Ltd.

Therefore, all references to "LAPIS Technology Co., Ltd.", "LAPIS Technology" and/or "LAPIS" in this document shall be replaced with "ROHM Co., Ltd."
Furthermore, there are no changes to the documents relating to our products other than the company name, the company trademark, logo, etc.

Thank you for your understanding.

ROHM Co., Ltd.
April 1, 2024

Dear customer

LAPIS Semiconductor Co., Ltd. ("LAPIS Semiconductor"), on the 1st day of October, 2020, implemented the incorporation-type company split (shinsetsu-bunkatsu) in which LAPIS established a new company, LAPIS Technology Co., Ltd. (“LAPIS Technology”) and LAPIS Technology succeeded LAPIS Semiconductor’s LSI business.

Therefore, all references to "LAPIS Semiconductor Co., Ltd.", "LAPIS Semiconductor" and/or "LAPIS" in this document shall be replaced with "LAPIS Technology Co., Ltd."

Furthermore, there are no changes to the documents relating to our products other than the company name, the company trademark, logo, etc.

Thank you for your understanding.

LAPIS Technology Co., Ltd.
October 1, 2020

FEXL7396DG-09

ML7396 Family LSIs
Hardware Design Manual

Issue Date: Oct. 3rd 2017

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Introduction

This hardware design manual contains hardware information that should be referenced when designing ML7396 family devices (Hereafter ML7396). And also contains the measurement conditions and example of measurement results of RF characteristics.

Target product:

ML7396 (920 MHz band)
ML7396A (915 MHz band)
ML7396B (920 MHz band)
ML7396E (868 MHz band)
ML7396D (920 MHz band)

The following related manual is available and should be referenced as needed

- ML7396A/B/E/D data sheet

Notation

Classification	Notation	Description
● Numeric value	0x*nn*	Represents a hexadecimal number.
	0b*nnnn*	Represents a binary number.
● Address	0x*nnnn_nnnn*	Represents a hexadecimal number. (indicates 0xnnnnnnnn)
● Unit	word, W	1 word = 32 bits
	byte, B	1 byte = 8 bits
	Mega, M	10^6
	Kilo, K (uppercase)	2^{10}=1024
	Kilo, k (lowercase)	10^3=1000
	Milli, m	10^{-3}
	Micro, µ	10^{-6}
	Nano, n	10^{-9}
	Second, s (lowercase)	Second
● Terminology	"H" level	Signal level on the high voltage side; indicates the voltage level of V_{IH} and V_{OH} as defined in electrical characteristics.
	"L" level	Signal level on the low voltage side; indicates the voltage level of V_{IL} and V_{OL} as defined in electrical characteristics.

● Register description

Read/write attribute: R indicates read-enabled; W indicates write-enabled.

MSB: Most significant bit in an 8-bit register (memory)

LSB: Least significant bit in an 8-bit register (memory)

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1. Placing decoupling capacitors

Place decoupling capacitors between each power pins and GND as shown in Figure 1.1.

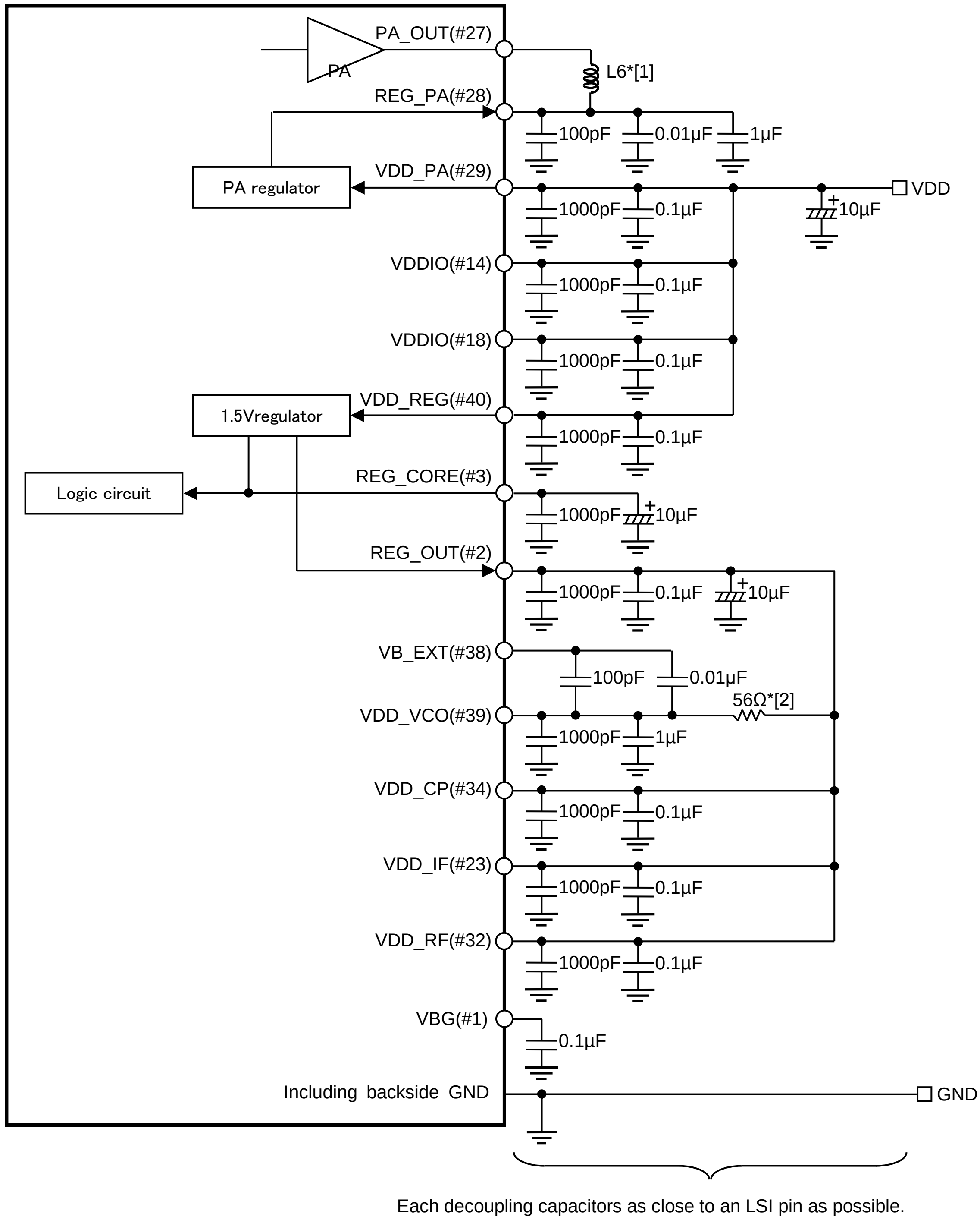


Figure 1.1 Power Supply Block Diagram

*[1] The supply voltage for the PA_OUT pin (#27) should be provided the DC bias through the inductor (L6)

*[2] The noise coming from the VDD_VCO pin (#39) will increases the phase noise level. The Adjacent Channel Power Ratio (ACPR) and spurious performance may be improved by adjusting a resister value (56Ω).

Notes the following when placing decoupling capacitors:

1. The VDD and GND traces should be wider than other signal line traces to reduce the resister element.

2. Decoupling capacitor should be placed as close to an LSI pin as possible.

3. The smaller capacitor should be closer to an LSI pin than other capacitors.

4. .VDDIO (#14)(#18), VDD_PA (#29), VDD_REG (#40) pins connected to the VDD share the trace. and placing a 10μF decoupling capacitor.

5. A 10 μF decoupling capacitor should be placed to both the REG_CORE (#3) and the REG_OUT (#2) pins to stabilize 1.5V regulator. A 10uF capacitor is recommended tantalum capacitor because it has low leak current. If it doesn’t care leak current, any kind capacitor could be used.

6. It is recommended to place a 1000 pF multilayer ceramic capacitor in parallel with a 10 μF tantalum capacitor to both the REG_CORE (#3) and the REG_OUT (#2) pins.

7. The VBG (#1) pin is a reference voltage output pin of band-gap reference circuit. Placing a 0.1μF multilayer ceramic capacitor to the VBG (#1) pin to reduce the noise from the band-gap reference circuit.

8. In general, ceramic capacitors have specific temperature and voltage characteristics. Select the best capacitor for the operating voltage and temperature of your specific application. It is recommended that decoupling capacitor use a CH (temperature compensating) or a B (high dielectric constant type) of temperature characteristics.

9. ML7396 support low power consumption mode (SLEEP MODE). In this mode, the consumption current of the LSI is around 0.9μA. Therefore the leak current of decoupling capacitors will impact on the consumption current of your specific circuit. It is recommended to select the low leak current capacitor to develop low consumption circuit board and system.

2. Crystal Oscillator circuit

Figure 2.1 shows a configuration example of the crystal oscillator circuit.

Capacitors should be connected to XIN (#4) and XOUT (#5) pins to stabilize 36MHz crystal oscillator circuit. To determine the component values, the oscillator circuit evaluation on your designing board is required, since the stray capacitor of the board will be influenced.

Amplitude level, oscillation margin, frequency accuracy and oscillator circuit start-up time should be considered and evaluated.

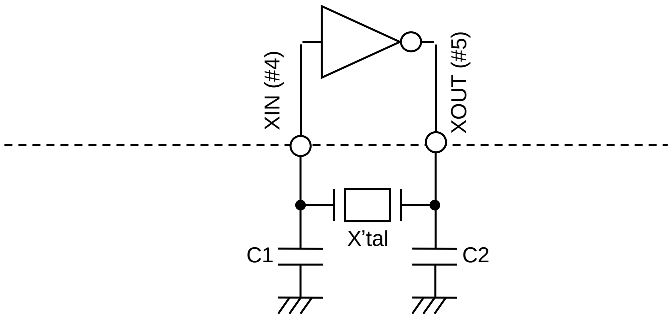


Figure 2.1 Crystal Oscillator circuit configurations

2.1. Circuit component values for crystal oscillator circuit

It is recommended to ask your oscillator manufacturer to evaluate the matching component values on the assembled board. The following tables show the matching component values with LAPIS Semiconductor RF board as reference.

Table 2.1.1 Representative matching component values

Oscillator Type	Frequency (MHz)	Equivalent series resister max[Ω]	Load capacitor (pF)	Component Values		Operating Condition	
				C1(pF)	C2(pF)	Power supply voltage range VDDIO(V)	Temperature range (C)
FCX-06	36	60	4.2	3	3	1.8 to 3.6	-40 to +85
NX2016SA	36	60	7	6	6	1.8 to 3.6	-40 to +85

[Note] These component values appropriate for use on the LAPIS Semiconductor's RF board. It is not guaranteed to obtain same result on your specific board.

2.2. Notes on the crystal oscillator circuit configuration

Note the following when designing the crystal oscillator circuit.

1. The capacitors value of C1 and C2 depends on the crystal oscillator specification.

2. C1 and C2 should be placed as close as possible to the XIN (#4) and the XOUT (#5) pins to suppress parasitic LCR and stabilize the oscillator.

3. The 36 MHz reference clock should keep accuracy within ±20ppm under all condition including temperature variations, power supply voltage variation and aging changes.

4. Do not place the crystal oscillator circuit across other signal lines.

5. Do not trace signal lines where large current flow around the crystal oscillator circuit.

6. For the oscillator circuit capacitors, make sure the potential of the ground points is always equal to that of the GND. Do not connect the capacitors to GNDs where large current flow.

7. Do not take oscillation signals from the oscillator circuit.

8. Oscillation frequency is changed by variation value of ESR (Equivalent Series Resistance) in crystal. Oscillation frequency can be adjusted by [OSC_ADJ] register (B0 0x0B).

3. When a TCXO used

Please use a TCXO that satisfy the following specification.

- Output load: 10kΩ//10pF
- Output level: 0.8Vpp to 1.5Vpp
- Frequency accuracy: below ±20ppm

The ML7396 has integrated bias circuit and the DC bias is applied to the TCXO (#6) pin. A 1000pF capacitor should be placed on the TCXO line as following.

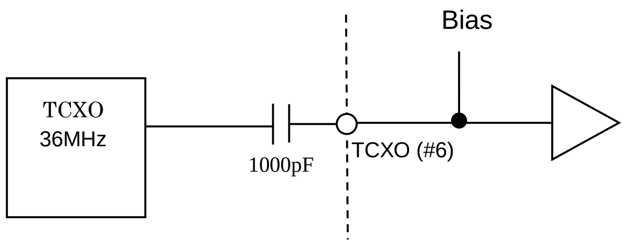


Figure 3.1 External oscillator circuit configurations

4. PLL loop filter

Figure 4.1 shows a configuration example of the PLL loop filter circuit. C8 and R3 values depend on the data rate to satisfy phase noise feature. The recommend values are listed in Table 4.1.

It is recommended to select the components with flat temperature characteristics and temperature coefficient is managed. Capacitors, do not select high dielectric type and semiconductor type, so there is low accuracy and non-linear temperature characteristics.

In order to prevent noise, the loop filter components (C8, R3 and C9) should be placed as close to the LP1 (#33) pin as possible, recommends within 5 mm. Do not trace signal lines that become a noise source like a reference clock line, around the loop filter.

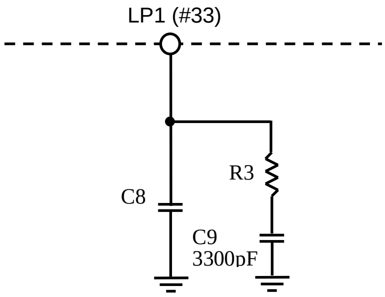


Figure 4.1 PLL loop filter circuit configurations

Table 4.1 Representative component values for the loop filter

	Data Rate	
	≤ 200kbps	400kbps
C8	47pF	10pF
C9	3300pF	3300pF
R3	8.2kΩ	13kΩ

5. VCO

Figure 5.1 shows a configuration example of the VCO tank circuit. VCO oscillator frequency calculated as follows:

$$F = \frac{1}{2\pi\sqrt{LC}}$$

The L in the above equation will be the sum of the inductor L1, the line inductance of the PCB and the internal inductance of the ML7396. And the C will be the sum of the capacitor C1, the line capacitor of the PCB and the internal capacitor (including calibration capacitor) of the ML7396.

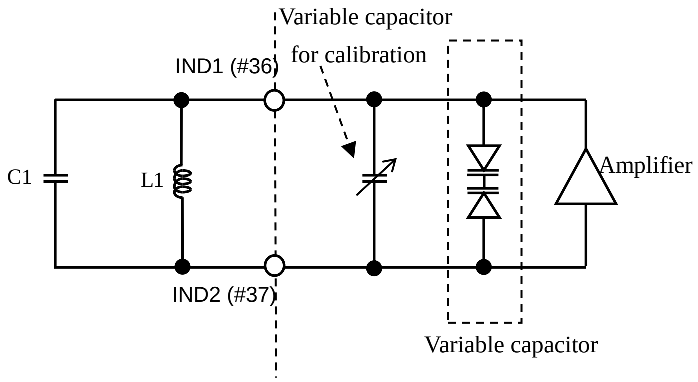


Figure 5.1 VCO tank circuit configurations

5.1. Adjusting component values for VCO tank

Adjustment procedure of the VCO tank components is as below:

1. Execute the VCO calibration with the following condition.
   - Set the frequency to the center of usingfrequency range.
   - In the idle state with the room temperature.

2. Adjust the L1 and C1 values so that the calibration value obtained by [VCO_CAL] register (B0 0x1C) becomes close to “64” (decimal).
   - Reducing one or both L1 and C1 values if decreasing the VCO_CAL value.
   - Increasing one or both L1 and C1 values if increasing the VCO_CAL value.

[Note] In order to lock the PLL, the VCO_CAL value is required to be in the range from 1 to 126 (decimal) under all conditions.

The frequency range that PLL can lock, VCO phase noise and the temperature feature depend on the L1, C1 values. It is recommended to evaluate these characteristics when L1 and C1 values is fixed.

Table 5.1.1 Representative component values for operating frequency

	868MHz band	915MHz band	920MHz band
L1	4.7nH	4.3nH	3.9nH
C1	4.3pF	3.9pF	4.3pF

[Note] These component values appropriate for use on the LAPIS Semiconductor’s RF board. It is not guaranteed to obtain same result on your specific board.

5.2. Note on the VCO tank circuit

Note the following when designing the VCO tank circuit.

1. In order to stable VCO oscillation, the VCO tank components (L1 and C1) should be placed as close to the IND1 (#36) and IND2 (#37) pins as possible, recommends within 2 mm. Since the line inductance and capacitance of PCB will effect to the oscillation frequency.
2. ML7396 maximum output power is more than 20mW. As shown in the Figure 5.2.1, high output will flow on the transmission path from PA_OUT (#27) pin. If this output affects on VCO tank circuit, it may cause the PLL unlock. So be careful the followings:

   2.1. VCO tank inductor L1 and PA choke inductor L6 should be placed so that their positional relationship becomes the 90 degrees to avoid their coupling (Refer to Table 5.3).

   2.2. L1 and L6 should be placed close to their connect pins of ML7396. They should not be placed close to each other..

   2.3. RF maching circuit should not be close to the L1.

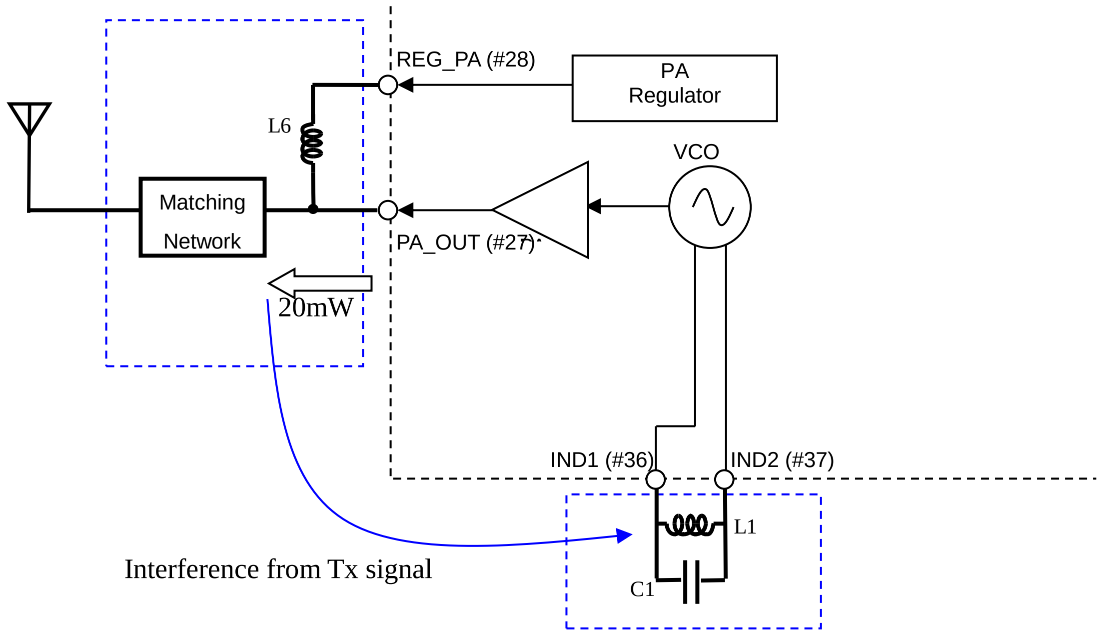


Figure 5.2.1 Notes on the VCO tank circuit

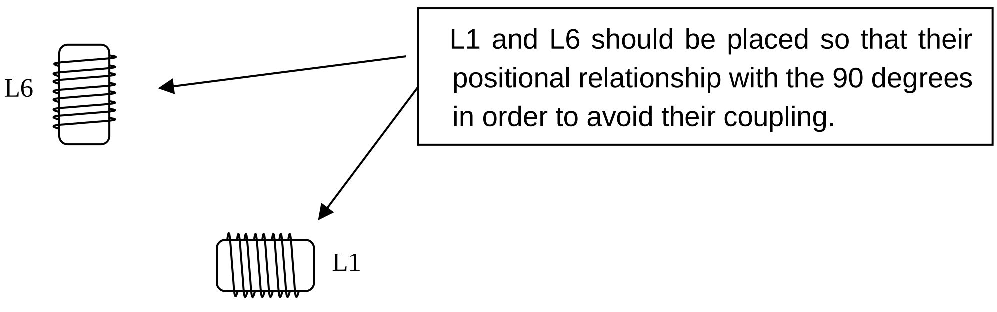


Figure 5.2.2 Recommended placement of L1 and L6

6. RF matching component values

Table 6.1 shows the measured impedance of the PA_OUT (#27) pin and the LNA_P (#30) pin at 925MHz.. These impedances were measured at LSI pins without matching circuits. Please adjust matching circuit so that the impedance at the antenna edge is 50 Ω. These impedances are presented as a reference.

Table 6.1 Measured RF impedance at 925MHz operation

		R+jX [Ω]
Tx (PA_OUT pin)	13dBm	14.85 - j0.75
	10dBm	14.9 - j2.6
	0dBm	1.85 - j18.6
Rx (LNA_P pin)		5.85 - j73.25

[Note] These component values appropriate for use on the LAPIS Semiconductor's RF board. It is not guaranteed to obtain same result on your specific board.

6.1. Transmission matching circuit

Figure 6.1.1 shows the transmission maching circuit configuraltions. The REG_PA (#28) pin provides the DC bias to the PA_OUT(#27) pin. This DC bias should be provided through the inductor (L6). The parallel resonant circuit (L8,C48) and series resonant circuits (L9,C49 and L11,C51) are the trap filter to suppress harmonics.

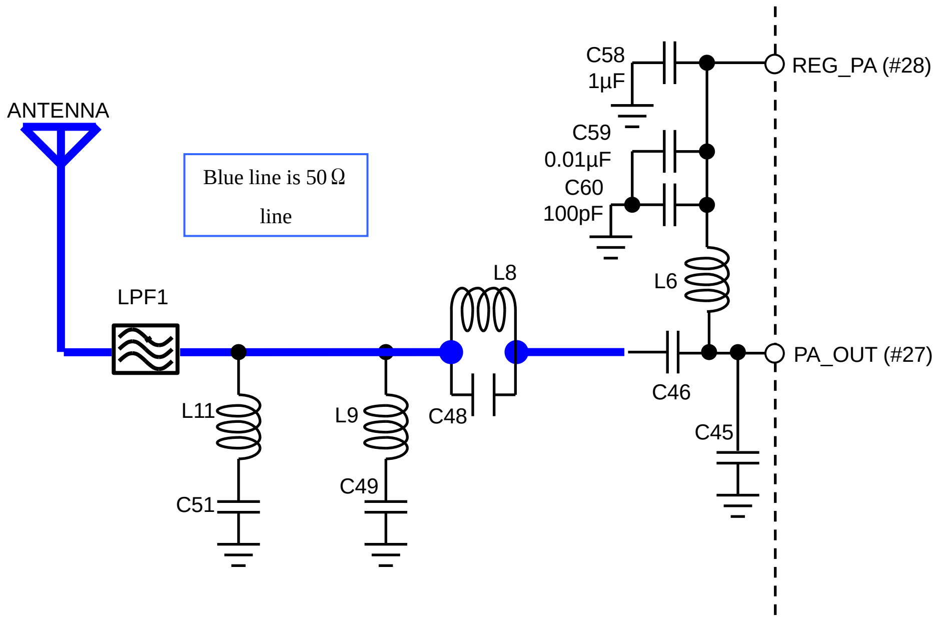


Figure 6.1.1 Transmission matching circuit configurations

Table 6.1.1 shows the representative component values for the transmission matching circuit at each operating frrequency.

Table 6.1.1 Representative component values for Tx matching circuits

	868MHz band	915MHz band	920MHz band
C45	2.2pF	2.2pF	2.2pF
C46	120pF	120pF	120pF
C48	1.0pF	0.8pF	0.8pF
C49	2.4pF	2.2pF	2.2pF
C51	0.3pF	0.3pF	0.3pF
L6	9.5nH	9.5nH	9.5nH
L8	3.6nH	3.6nH	3.6nH
L9	2.9nH	2.9nH	2.9nH
L11	1.5nH	1.5nH	1.5nH
LPF1	0Ω (short)	DEA160915LT-1169	0Ω (short)

[Note] These component values appropriate for use on the LAPIS Semiconductor’s RF board. It is not guaranteed to obtain same result on your specific board.

6.2. Reception matching circuit

Figure 6.2.1 shows the reception maching circuit configuraltions. T-type matching circuit consists of C44, C43 and L4.

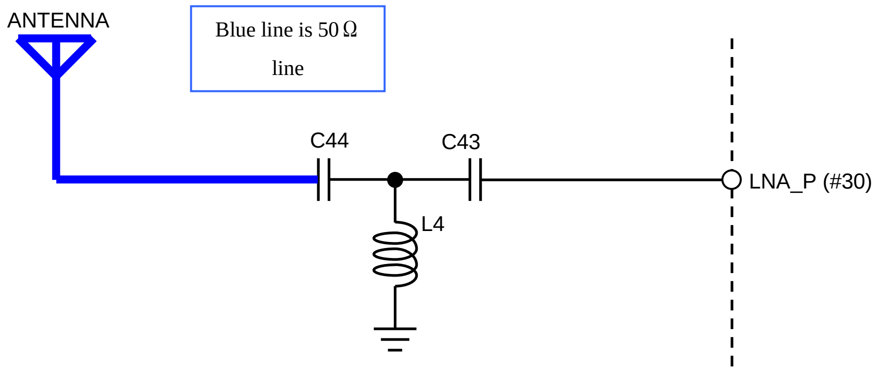


Figure 6.2.1 Reception matching circuit configurations

Table 6.2.1 shows the representative component values for Rx matching circuit at each operating frrequency.

Table 6.2.1 Representative component values for Rx matching circuits

	868MHz band	915MHz band	920MHz band
C43	100pF	100pF	100pF
C44	0.9pF	0.6pF	0.6pF
L4	11nH	10nH	10nH

[Note] These component values appropriate for use on the LAPIS Semiconductor’s RF board. It is not guaranteed to obtain same result on your specific board.

6.3. 250mW transmission circuit on 920MHz band

250mW output is permitted at specified 920MHz band in ARIB STD-T108 (Japan). 250mW transmission circuit is realized connecting power amplifier circuit that is configured with discrete components to PA_OUT (#27) pin.

Figure 6.3.1 shows the 250mW transmission circuit configuration.

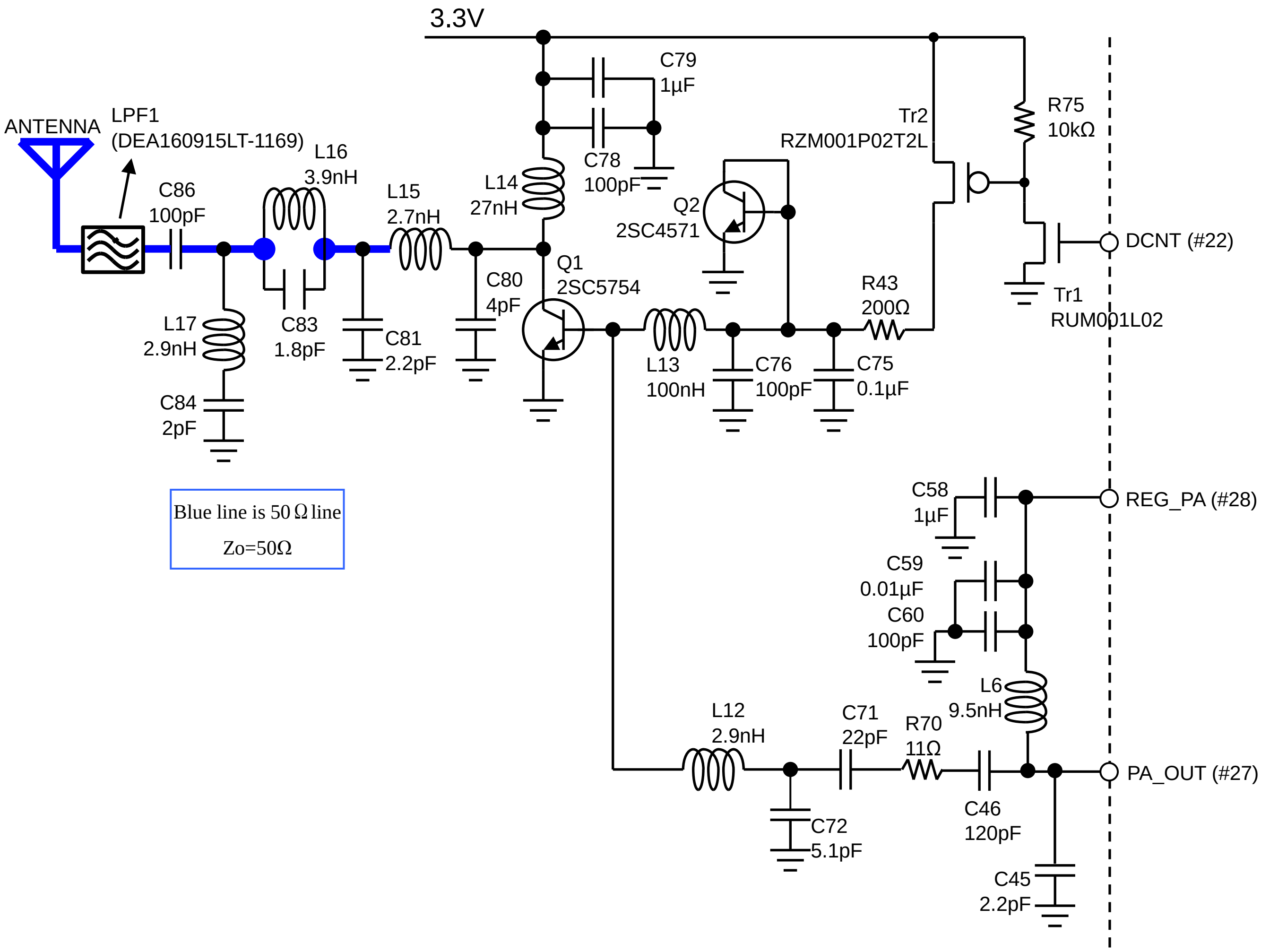


Figure 6.3.1 250mW transmission circuit configurations

[Note] The Q2 should be placed as close to the Q1 as possible, since the Q2 is a temperature compensated circuit.

7. Antenna Switch

Figure 7.1 shows the antenna switch configuration for using 2-diversity function. When the 2-diversity function is not used, a DPDT switch IC is replaced by a SPDT.

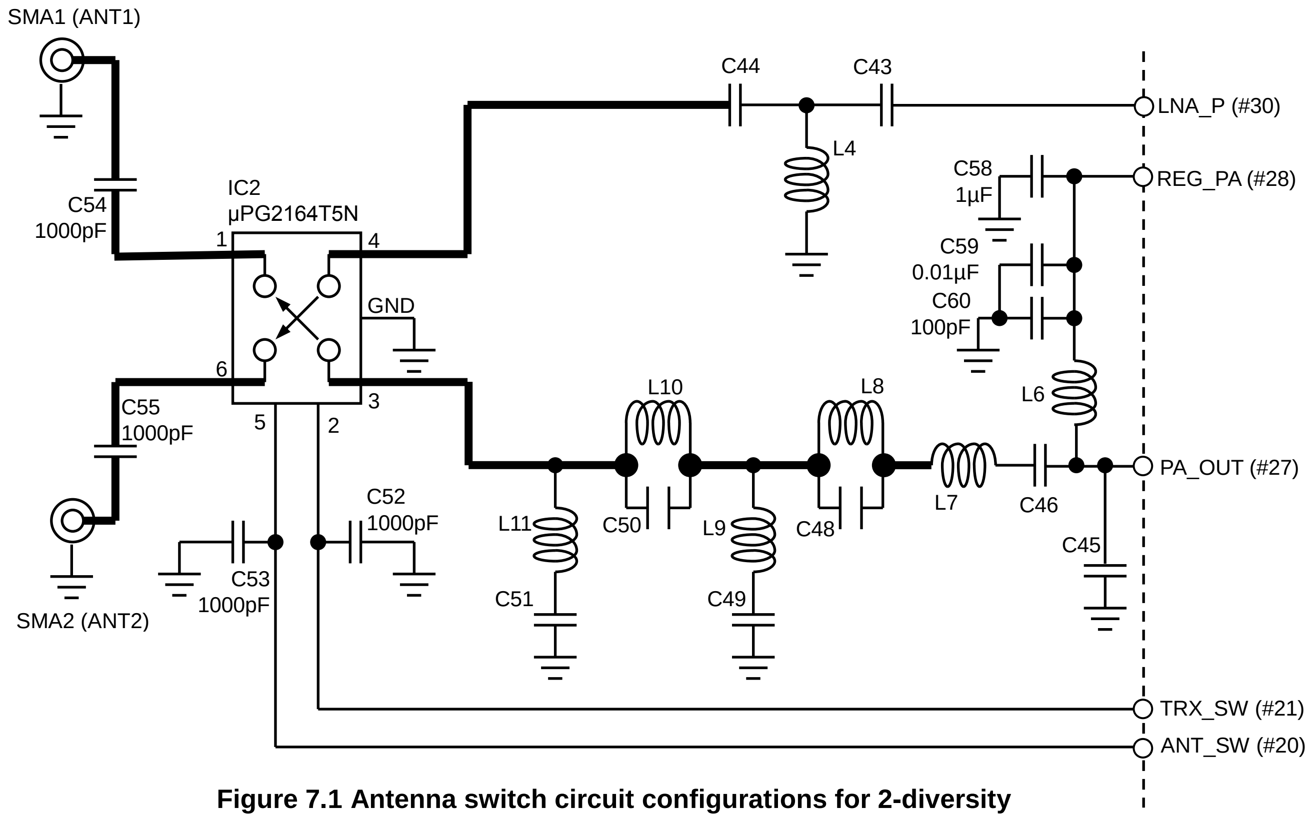


Figure 7.1 Antenna switch circuit configurations for 2-diversity

8. Temperature measurement

ML7396 has thermometer. When using the implemented thermometer, place a 75kΩ resister between A_MON (#24) pin and the ground.It is recommended to use a high accuracy resistor with well temperature characteristics.

When the implemented thermometer is not used, leave the A_MON (#24) pin to “OPEN”.

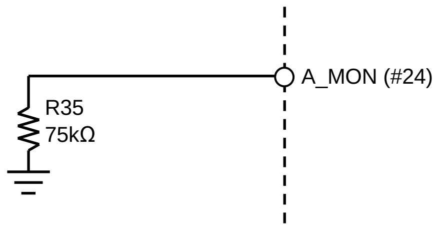


Figure 8.1 A_MON (#24) configurations for using implemented thermometer

9. Notes on selecting external parts (recommendations)

- Anntenna

It is recommended to use an antenna with the specifications shown in Table 9.1.

Select an antenna with the best directive characteristics for your specific operating, environmental and installation condition. Since antennas are affected by installation conditions such as GND, external factors should always be taken into account.

It is recommended to ask the manufacturer of the selected antenna for installation details in relation to various factors, including the shape and stray capacitance of the board to be used.

Table 9.1 Antenna

Frequency band	920MHz band
VSWR	2.0MAX
Nominal Impedance	50Ω

- Inductors

Use inductors with high Q. It is recommended to use LQW15AN series (manufactured by Murata Manufacturing Co. Ltd) or equivalent.

- Capacitors

Use capacitors with a CH (temperature compensating) or a B (high dielectric constant type) of temperature characteristics. It is recommended to use capacitors of 0 ± 60 ppm/°C or less for areas that affect high frequency characteristics.

- Resistors

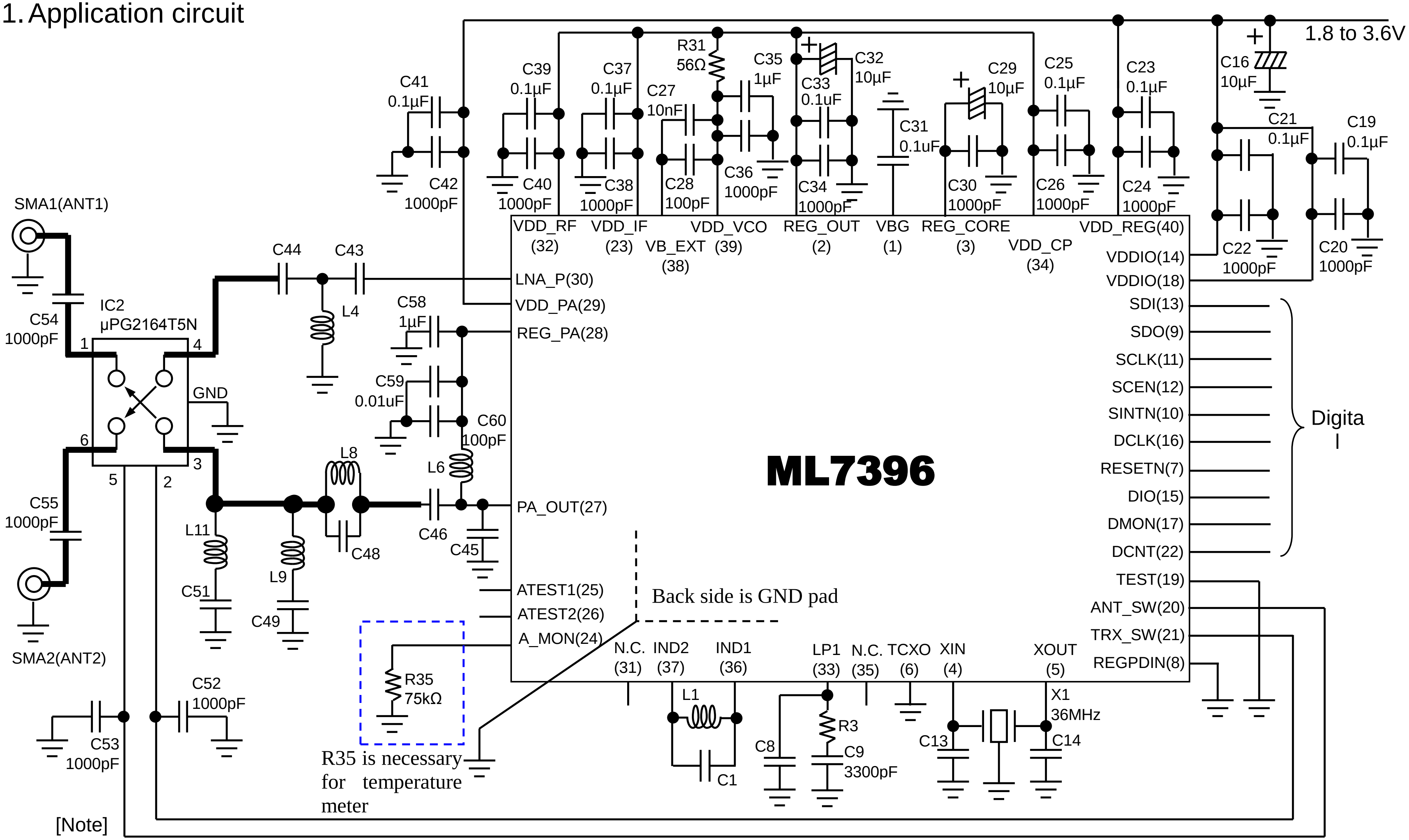
Use resistors for which the resistance variation are small when the temperature changes.

10. Notes on board artworks (recommendations)

10.1. GND

About IC's back side GND pad, the number of through-hole to board GND plane should be placed more than 12. And drawing GND line width should be more wide as much as possible. Almost of L2 layer should be GND plane for double-layered board.

11. Application circuit



[Note]

·These component values are the reference value. LAPIS Semiconductor does not guarantee the values.

·Connect the TCXO (#6) pin to the GND when using crystal oscillator. Connect the XIN (#4) and the XOUT (#5) pins to the GND when using TCXO.

12. Bill of Materials

Component	Value	Vendors	Remarks
L1	4.7nH 4.3nH 3.9nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005) The value depends on the operating frequency. *1
L4	10nH 11nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005) The value depends on the operating frequency. *2
L6	9.5nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005)
L8	3.6nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005)
L9	2.9nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005)
L11	1.5nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005)
C1	3.9pF 4.3pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005) The value depends on the operating frequency. *1
C8	47pF 10pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005) The value depends on the operating data rate. *3
C9	3300pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C13	6pF 3pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005) The value depends on the using crystal. *4
C14	6pF 3pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005) The value depends on the using crystal. *4
C16	10µF	NEC TOKIN Corporation	NEC E/SV or equivalent. (over 10V specification)
C19	0.1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C20	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C21	0.1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C22	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C23	0.1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C24	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C25	0.1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C26	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C27	0.01µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C28	100pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C29	10µF	NEC TOKIN Corporation	NEC E/SV or equivalent. (over 10V specification)
C30	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C31	0.01µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C32	10µF	NEC TOKIN Corporation	NEC E/SV or equivalent. (over 10V specification)
C33	0.1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C34	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C35	1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C36	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C37	0.1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C38	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C39	0.1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)

(Continued)

Component	Value	Vendors	Remarks
C40	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C41	0.1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C42	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C43	100pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C44	0.6pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
	0.9pF		The value depends on the operating frequency. *2
C45	2.2pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C46	120pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C48	1.0pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
	0.8pF		The value depends on the operating frequency. *5
C49	2.4pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
	2.2pF		The value depends on the operating frequency. *5
C51	0.3pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C52	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C53	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C54	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C55	1000pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C58	1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C59	0.01µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C60	100pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
R3	8.2kΩ	KOA Corporation	RK73B 1E or equivalent. (1005)
	13kΩ		The value depends on the operating data rate. *3
R31	56Ω	KOA Corporation	RK73B 1E or equivalent. (1005)
R35	75kΩ	KOA Corporation	RK73B 1E or equivalent. (1005)
LPF1	DEA60915LT-11691	TDK Corporation	Low Pass Filter The component depends on the operating frequency. *5
	0Ω		
IC1	ML7396x	LAPIS Semiconductor Co., Ltd.	RF LSI
IC2	µPG2164T5N	Renesas Electronics Corporation	DPDT RF Switch
	HWS503	Hexawave	
X1	NX2016SA	Nihon Dempa Kogyou Co., Ltd.	36MHz Crystal Unit
	FCX-06	River Eletec Corporation	

*1: Please refer the Table 5.1.1 in the section 5.1.
*2: Please refer the Table 6.2.1 in the section 6.2.
*3: Please refer the Table 4.1 in the section 4
*4: Please refer the Table 2.1.1 in the section 2.1
*5: Please refer the Table 6.1.1 in the section 6.1.

[Note]
These component values are the reference value. LAPIS Semiconductor does not guarantee the evaluation result.

The following table shows the bill of materials for 250mW transmission circuit. Please refer section 6.3.

Component	Value	Vendors	Remarks
L6	9.5nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005)
L8	N.M.	-	-
L9	N.M.	-	-
L11	N.M.	-	-
L12	2.9nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005)
L13	100nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005)
L14	27nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005)
L15	2.7nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005)
L16	3.9nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005)
L17	2.9nH	Murata Manufacturing Co., Ltd	LQW15AN or equivalent. (1005)
C45	2.2pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C46	120pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C48	N.M.	-	
C49	N.M.	-	
C51	N.M.	-	
C58	1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C59	0.01µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C60	100pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C71	22pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C72	5.1pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C75	0.1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C76	100pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C78	100pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C79	1µF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C80	4pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C81	2.2pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C83	1.8pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C84	2.0pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
C86	100pF	Murata Manufacturing Co., Ltd	GRM155 or equivalent. (1005)
R70	11Ω	KOA Corporation	RK73B 1E or equivalent. (1005)
R75	10kΩ	KOA Corporation	RK73B 1E or equivalent. (1005)
LPF1	DEA160915LT-1169	TDK Corporation	Low Pass Filter
Q1	2SC5754	Renesas Electronics Corporation	NPN Silicon RF Transistor
Q2	2SC4571	Renesas Electronics Corporation	NPN Silicon Transistor
Tr1	RUM001L02	Rohm Co., Ltd	Nch MOSFET
Tr2	RZM001P02T2L	Rohm Co., Ltd.	Pch MOSFET

13. RF characteristics measurement

13.1. Measurement configuration

Typical transmission and receiver characteristics measurment configurations are shown in this section.
Table 13.1 shows the equipment list that LAPIS semiconductor used to measure RF characteristics.

Table 13.1 Equipment list for RF characteristics measurement (Reference)

Equipment	Type	Vendor
Spectrum Analyzer	E4405B	Agilent
Signal Generator	E4432B (UN8 Option)	Agilent
Bit Error Rate Meter	KBM6010	Kikusui Electronics
DC power supply	E3640A	Agilent
Fading simulator	SR5500	Spirent

13.1.1. Transmission characteristics measurement

Figure 13.1.1 shows the generic transmission characteristics measurment configuration.
Followings can be measured with this configulation:

1) Transmission Power
2) Occupied Band Width
3) Adjacent Channle Leakage Power
4) Spurious Emissions
5) RX Spurious Emissions

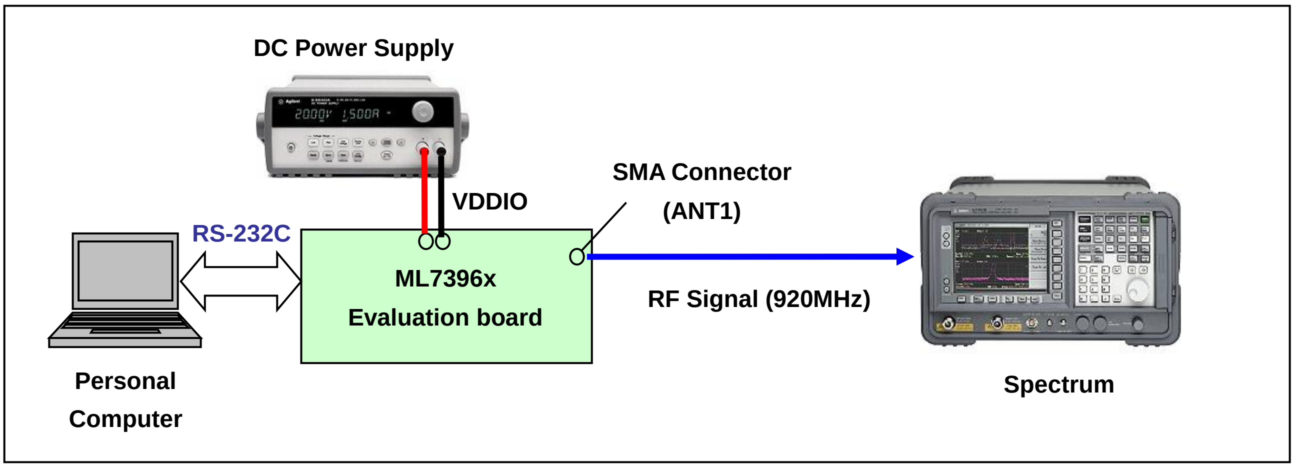


Figure 13.1.1 Generic transmission characteristics measurement configurations

13.1.2. Receiver characteristics measurement

Figure 13.1.2.1 shows the generic receiver characteristics measurment configuration.
Followings can be measured with this configuration:
1) Receiver Sensitivity (BER)
2) Receiving Energy Detection Range

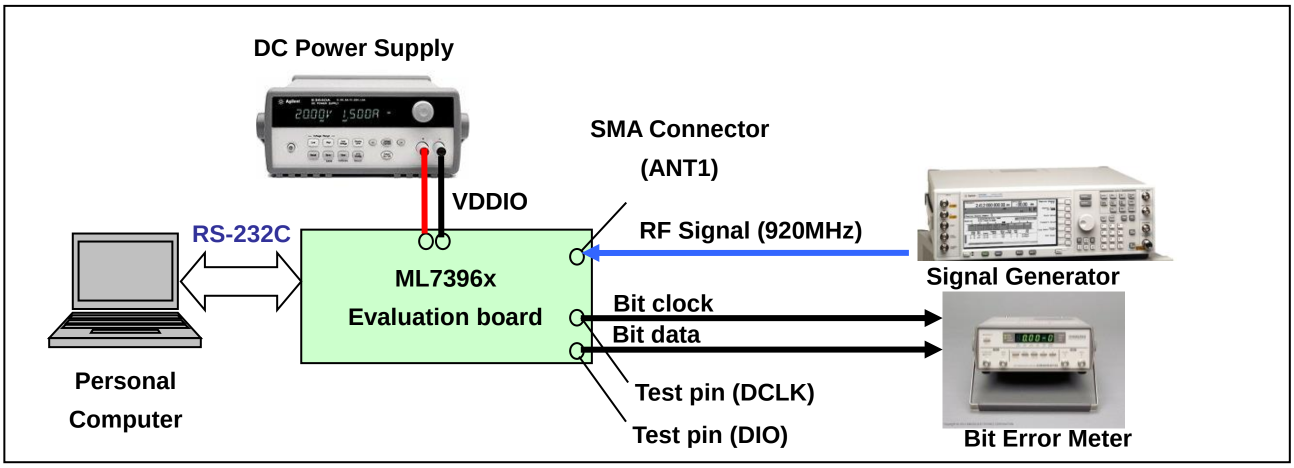


Figure 13.1.2.1 Generic receiver characteristics measurement configurations

Figure 13.1.2.2 shows the generic interference characteristics measurment configuration.
Followings can be measured with this configuration:
1) Adjacent Channel Rejection (±1CH)
2) Alternate Channle Rejection (±2CH)
3) Blocking
4) Suprious Response

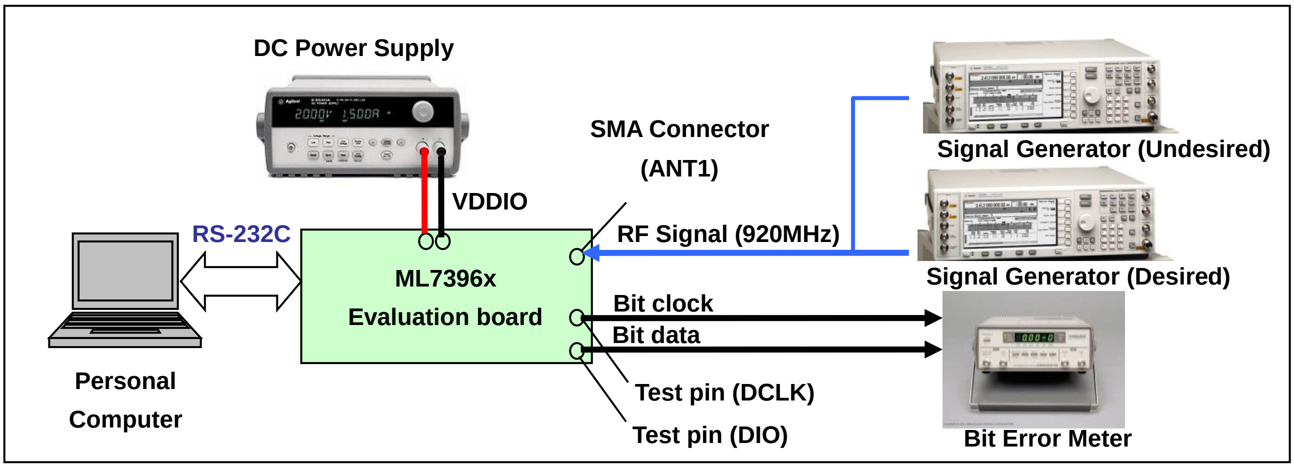


Figure 13.1.2.2 Generic interference characteristics measurement configurations

Figure 13.1.2.3 shows the generic fading characteristics measurement configuration.

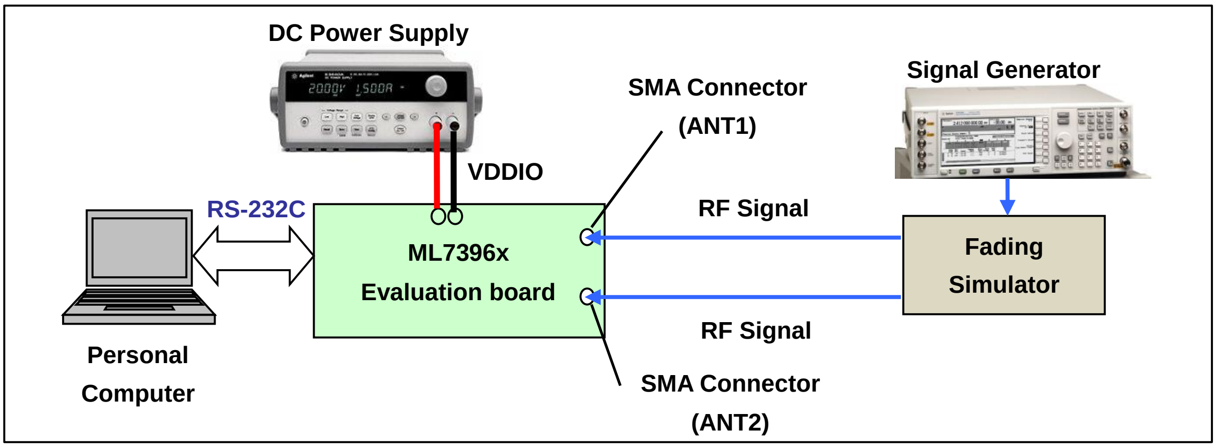


Figure 13.1.2.3 Generic fading characteristics measurement configurations

13.2. Measurement condition

The measurement conditions are in accordance with the TELEC-T245 and IEEE 802.15.4g. Some test have been measured by an alternative method. For test items that measurement condition has not been defined in either specifications, LAPIS semiconductor has set the condition as proprietary.

Table 13.2.1 shows the test items and the relevant measurement condition.

Table 13.2.1 Test item and the specification that defines the measurement condition

Test Items	Relevant measurement condition	Register setting	Target product
Transmission Power	TELEC-T245	v2.7(2012/1/17 released) (note) same as 100kbps setting1 in v1.1.170922	ML7396B
Occupied Band Width			
Adjacent Channel Leakage Power			
Spurious Emissions			
Rx Spurious Emissions			
Receiver Sensitivity	IEEE 802.15.4g Measuring BER instead of PER.		
Adjacent Channel Rejection	IEEE 802.15.4g Undesired signal is modulated wave instead of CW		
Alternate Channel Rejection			
Blocking (Spurious Response)	LAPIS proprietary		
Receiving Energy Detection Range	IEEE 802.15.4g		
Fading	LAPIS proprietary	v1.1.170922(2017/9/29 released)	ML7396D

13.2.1. Transmission Power

ML7396 setting;

Rate:	Set 100 kbps at [DATA_SET] register (Bank 0 0x47)
Test_Mode:	Set PN9 (Continuous Transmission) at [RF_TEST_MODE]register (Bank 0 0x0C)
RF_Status:	Set 0x09 (TX_ON) to the [RF_STATUS] register (Bank 0 0x6C)

Spectrum anlyzer setting;

CenterFreq:	Operating Frequency	**VBW:**	3 MHz
Mode:	BurstPower(Average)	**Span:**	0 Hz
Detector:	Samp	**Sweep:**	Single
RefLevel:	20 dBm	**SweepTime:**	200 msec
Att:	30 dB	**Data Points:**	1001 pts
RBW:	1 MHz		

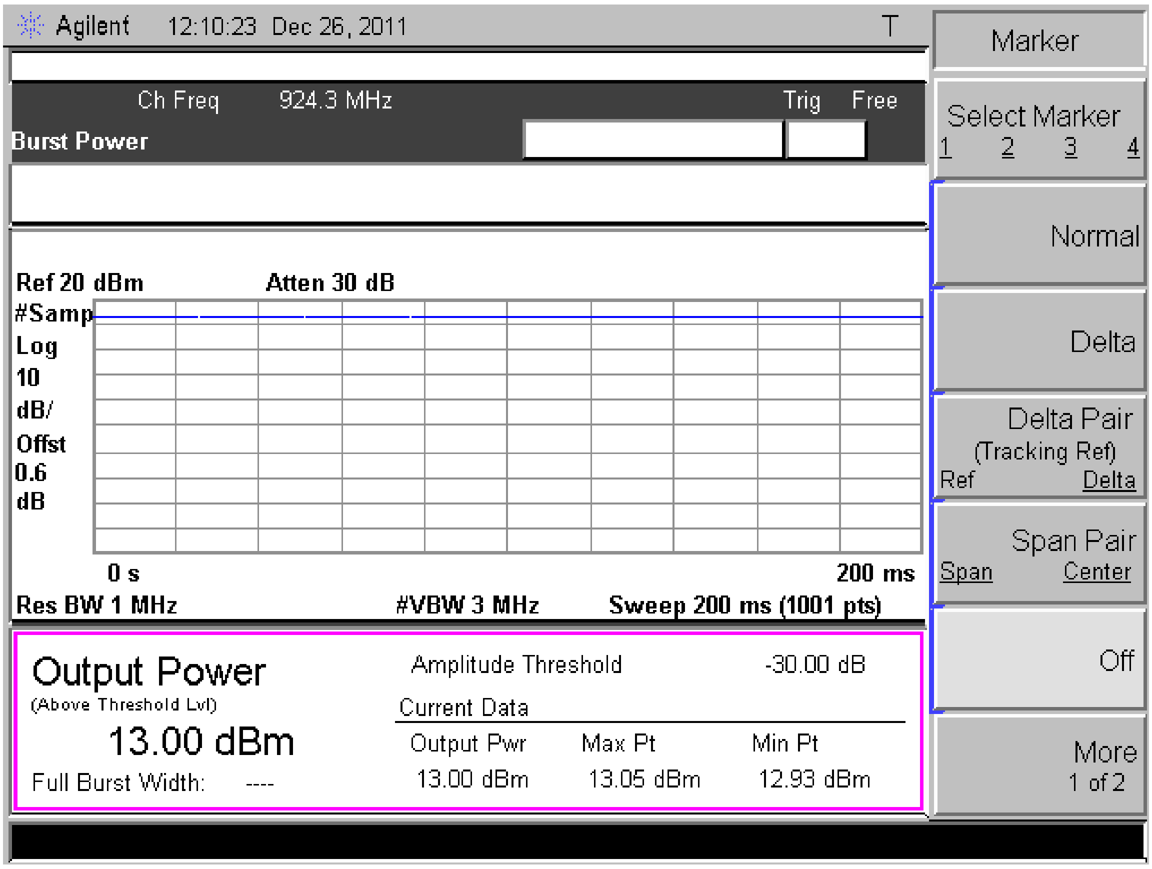


Figure 13.2.1 Example of transmission power measurement

13.2.2. Occupied Band Width

ML7396 setting;

Rate:	Set 100 kbps at [DATA_SET] register (Bank 0 0x47)
Test_Mode:	Set PN9 (Continuous Transmission) at [RF_TEST_MODE]register (Bank 0 0x0C)
RF_Status:	Set 0x09 (TX_ON) to the [RF_STATUS] register (Bank 0 0x6C)

Spectrum anlyzer setting;

CenterFreq:	Operating Frequency	**VBW:**	3 kHz
Mode:	OBW(99%)	**Span:**	1 MHz
Detector:	Peak	**Sweep:**	Continuous
RefLevel:	20 dBm	**SweepTime:**	200 msec
Att:	30 dB	**Data Points:**	1001 pts
RBW:	3 kHz	**View:**	MaxHold

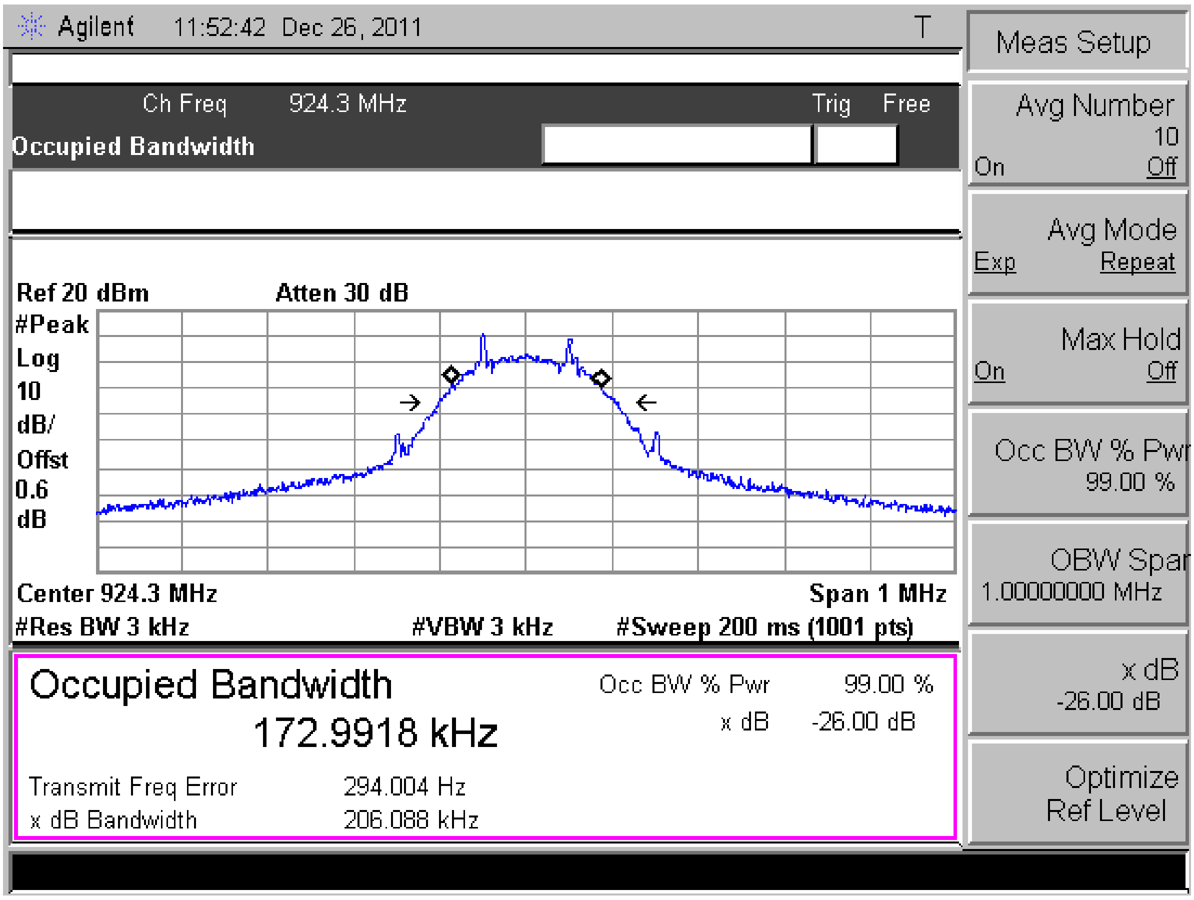


Figure 13.2.2 Example of occupied band width measurement

13.2.3. Adjacent Channel Leakage Power

ML7396 setting;

Rate:	Set 100 kbps at [DATA_SET] register (Bank 0 0x47)
Test_Mode:	Set PN9 (Continuous Transmission) at [RF_TEST_MODE]register (Bank 0 0x0C)
RF_Status:	Set 0x09 (TX_ON) to the [RF_STATUS] register (Bank 0 0x6C)

Spectrum anlyzer setting;

CenterFreq:	Operating Frequency	**RBW:**	1 kHz
Mode:	ACP	**VBW:**	3 kHz
OffsetFreq:	400 kHz	**Span:**	1 MHz
RefBW:	199 kHz	**Sweep:**	Single
Detector:	Peak	**SweepTime:**	1.036 sec
RefLevel:	10 dBm	**Data Points:**	1001 pts
Att:	20 dB		

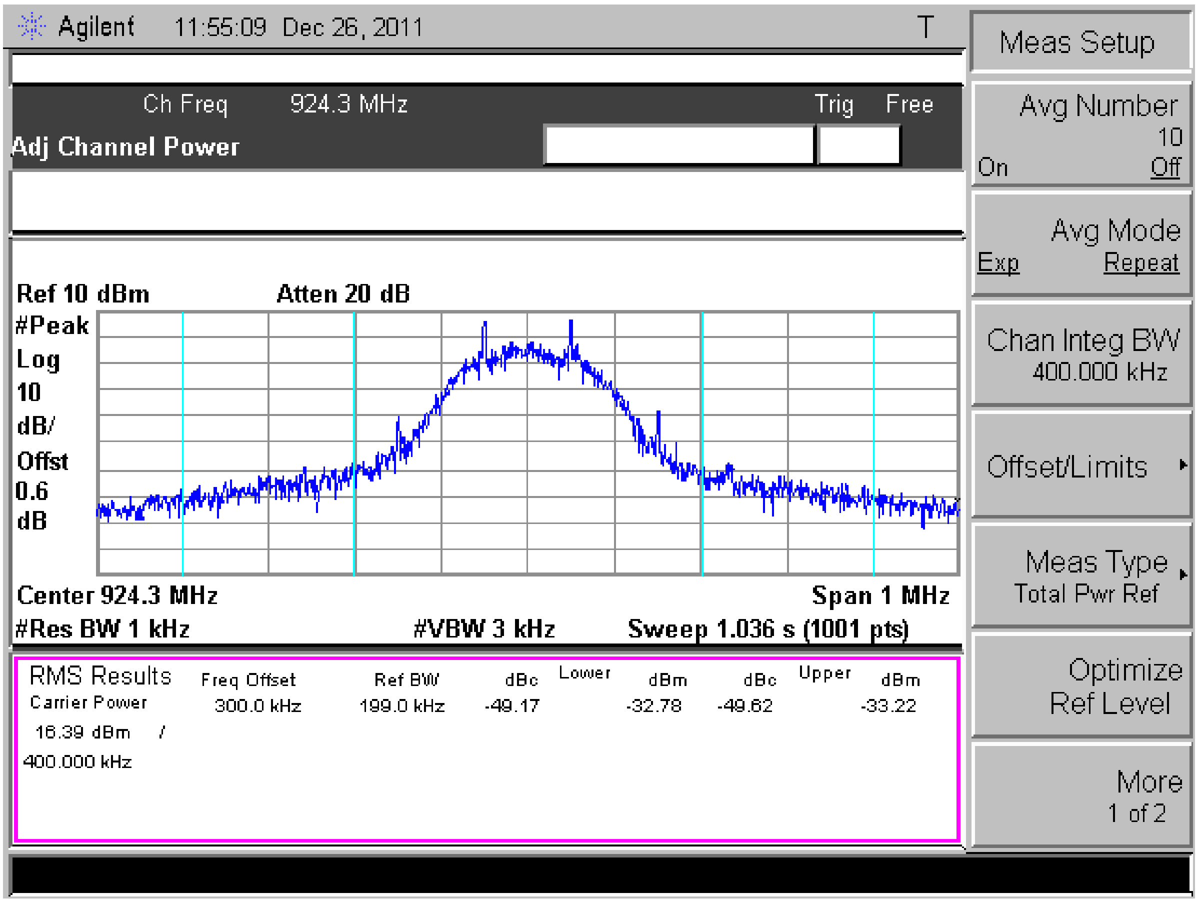


Figure 13.2.3 Example of adjacent channel leakage power measurement

13.2.4. Spurious Emissions

ML7396 setting;

Rate:	Set 100 kbps at [DATA_SET] register (Bank 0 0x47)
Test_Mode:	Set PN9 (Continuous Transmission) at [RF_TEST_MODE]register (Bank 0 0x0C)
RF_Status:	Set 0x09 (TX_ON) to the [RF_STATUS] register (Bank 0 0x6C)

Spectrum anlyzer setting;

CenterFreq:	Harmonics Frequency	**RBW:**	1 MHz
Mode:	BurstPower(Average)	**VBW:**	1 MHz
Detector:	Peak	**Span:**	0 Hz
RefBW:	199 kHz	**Sweep:**	Single
RefLevel:	-20 dBm	**SweepTime:**	200 msec
Att:	5 dB	**Data Points:**	1001 pts

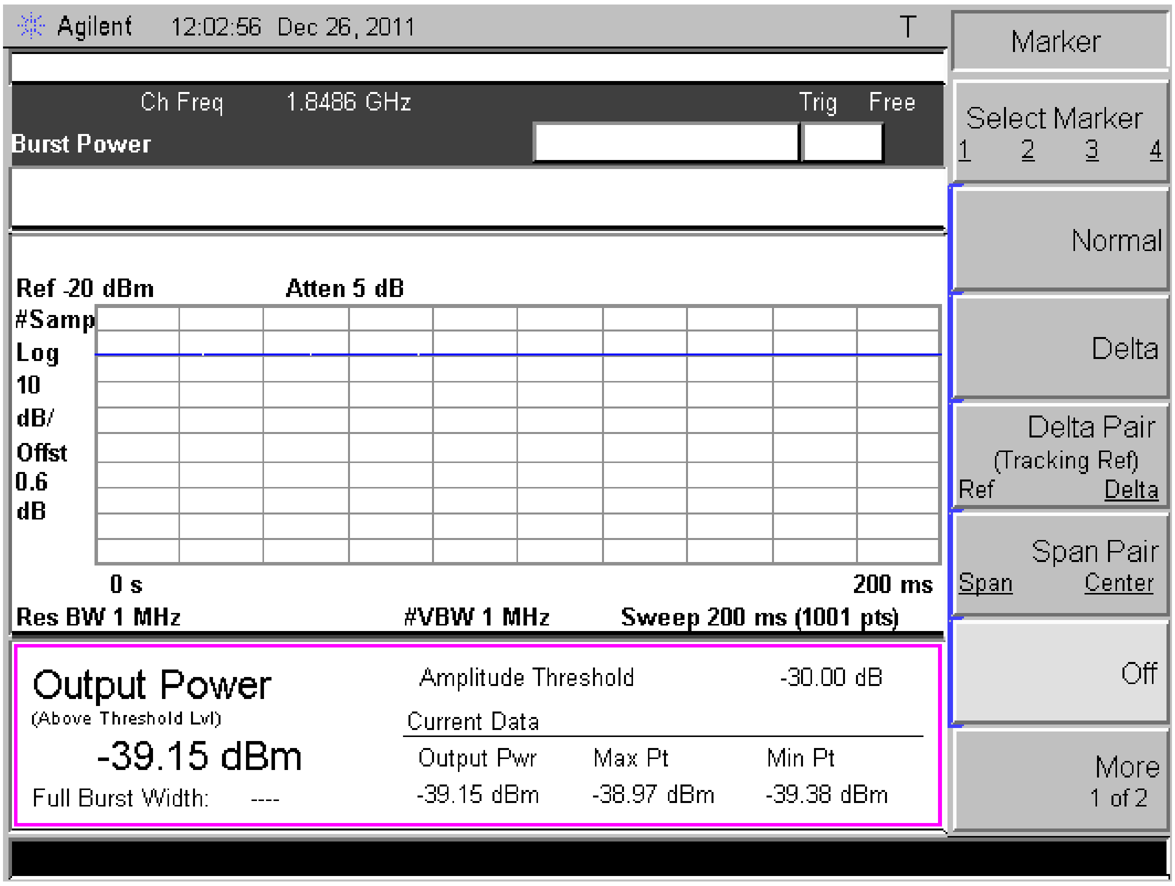


Figure 13.2.4 Example of spurious emissions (Harmonics) measurement

13.2.5. Receiver Sensitivity

Receiver sensitivity definition is BER = 0.1%, since IEEE 802.15.4g defines PER=1%.

ML7396 setting;

Enable DIO mode: Set 0x01 to the [PLL_MON/DIO_SEL] register (Bank 0 0x69)
Enable BER mode: Set 0x80 to the [DEMOD_SET] register (Bank 1 0x01)
Enable BER sync.: Set 0x00 to the [SYNCE_MODE] register (Bank 2 0x12)
Set BER demod: Set 0x10 to the Bank 2 0x0A register
Rate: Set 100 kbps at [DATA_SET] register (Bank 0 0x47)
RF_Status: Set 0x06 (RX_ON) to the [RF_STATUS] register (Bank 0 0x6C)

Signal generator setting;

Freq:	Operating Frequency	**Rate:**	100 kbps
Mod:	2-Lvl FSK	**Fdev:**	50 kHz
Data:	PN9	**Filter:**	Gaussian (BT=0.5)

Bit error meter setting;

Data: PN9 **Samples:** 1e+5

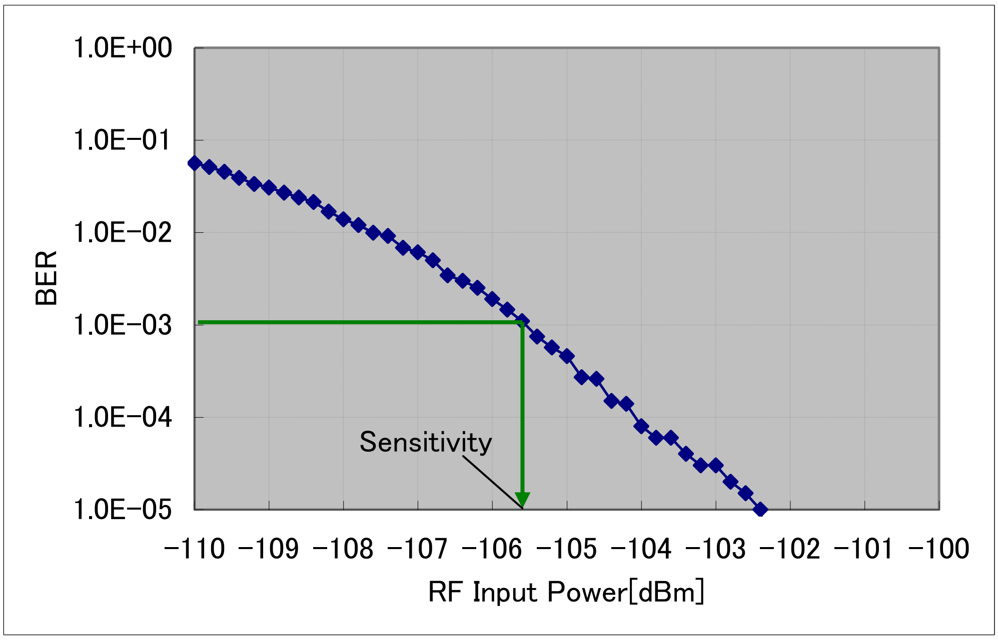


Figure 13.2.5 Example of receiver sensitivity measurement

13.2.6. Adjacent/Alternate Channel Rejection

Receiver sensitivity definition is BER = 0.1%, since IEEE 802.15.4g defines PER=1%. Using modulated wave instead of carrier wave (CW) defined in IEEE 802.15.4g as considering actual environment.

The desired signal level is fixed -100dBm. Finding the BER=0.1% point with changing the interference level.

Channel rejection characteristics is defined as the following equation;

D/U[dB] = Interference level – desired level (-100dBm)

ML7396 setting;

Enable DIO mode:	Set 0x01 to the [PLL_MON/DIO_SEL] register (Bank 0 0x69)
Enable BER mode:	Set 0x80 to the [DEMOD_SET] register (Bank 1 0x01)
Enable BER sync.:	Set 0x00 to the [SYNCE_MODE] register (Bank 2 0x12)
Set BER demod:	Set 0x10 to the Bank 2 0x0A register
Rate:	Set 100 kbps at [DATA_SET] register (Bank 0 0x47)
RF_Status:	Set 0x06 (RX_ON) to the [RF_STATUS] register (Bank 0 0x6C)

Signal generator setting (Desired);

Freq:	Operating Frequency	**Rate:**	100 kbps
Amplitude:	-100 dBm	**Fdev:**	50 kHz
Mod:	2-Lvl FSK	**Filter:**	Gaussian (BT=0.5)
Data:	PN9		

Signal generator setting (Undesired);

Freq:	Interference Frequency	**Rate:**	100 kbps
Mod:	2-Lvl FSK	**Fdev:**	50 kHz
Data:	PN9	**Filter:**	Gaussian (BT=0.5)

[Note] Interference Frequency = Operating Frequency ±1CH (Adjacent)
Operating Frequency ±2CH (Alternate)

1CH = 400 kHz at 100 kbps data rate

Bit error meter se tting;

Data: PN9 **Samples:** 1e+5

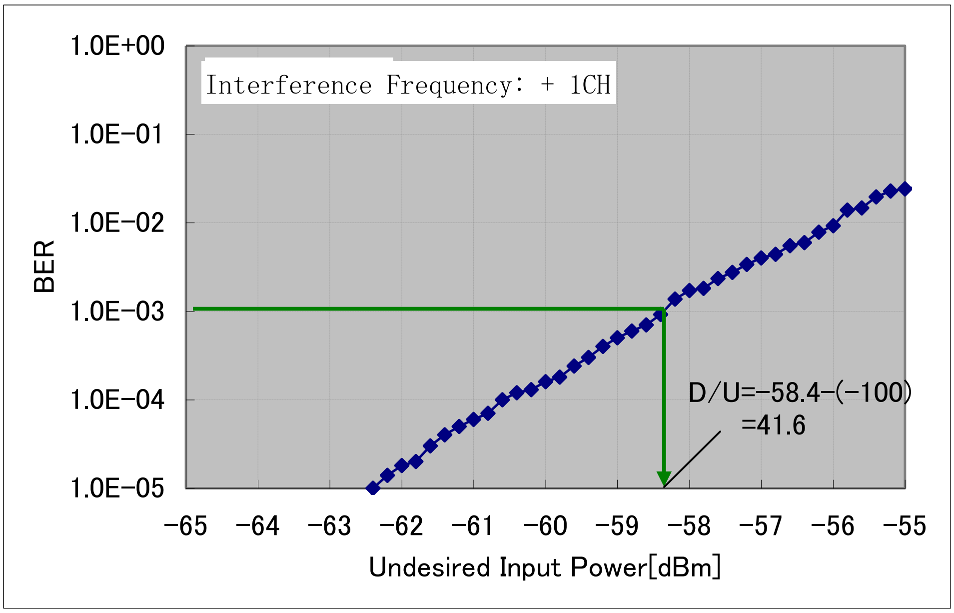


Figure 13.2.6 Example of adjacent channel rejection measurement

13.2.7. Blocking and Spurious Response

LAPIS semiconductor defines the Blocking and Spurious resuponse as follows;
The desired signal level is fixed -100dBm. Finding the BER=0.1% point with changing the interference level.
Blocking characteristics is defined as the following equation;
D/U[dB] = Interference level – desired level (-100dBm)
Spurious response is defined when the interference frequency is image frequency.

ML7396 setting;

Enable DIO mode:	Set 0x01 to the [PLL_MON/DIO_SEL] register (Bank 0 0x69)
Enable BER mode:	Set 0x80 to the [DEMOD_SET] register (Bank 1 0x01)
Enable BER sync.:	Set 0x00 to the [SYNCE_MODE] register (Bank 2 0x12)
Set BER demod:	Set 0x10 to the Bank 2 0x0A register
Rate:	Set 100 kbps at [DATA_SET] register (Bank 0 0x47)
RF_Status:	Set 0x06 (RX_ON) to the [RF_STATUS] register (Bank 0 0x6C)

Signal generator setting (Desired);

Freq:	Operating Frequency	**Rate:**	100 kbps
Amplitude:	-100 dBm	**Fdev:**	50 kHz
Mod:	2-Lvl FSK	**Filter:**	Gaussian (BT=0.5)
Data:	PN9		

Signal generator setting (Undesired);

Freq:	Interference Frequency
Mod:	Carrier Wasve (CW)

Bit error meter setting;

Data:	PN9	**Samples:**	1e+5

13.2.8. Receiving Energy Detection Range

Reading the [ED_RSLT] register (Bank 0 0x16) with sweeping the RF level of the signale generator or measureing some sample RF levels. Figure 13.2.8 shows the example of the result.
ML7396 should be set the gain free mode to follow the changes in the level of the signal generator.

ML7396 setting;

Set Gain Free:	Set 0x1E to the [GAIN_HtoM] register (Bank 0 0x1E)
Rate:	Set 100 kbps at [DATA_SET] register (Bank 0 0x47)
RF_Status:	Set 0x06 (RX_ON) to the [RF_STATUS] register (Bank 0 0x6C)

Signal generator setting (Desired);

Freq:	Operating Frequency	**Rate:**	100 kbps
Mod:	2-Lvl FSK	**Fdev:**	50 kHz
Data:	PN9	**Filter:**	Gaussian (BT=0.5)

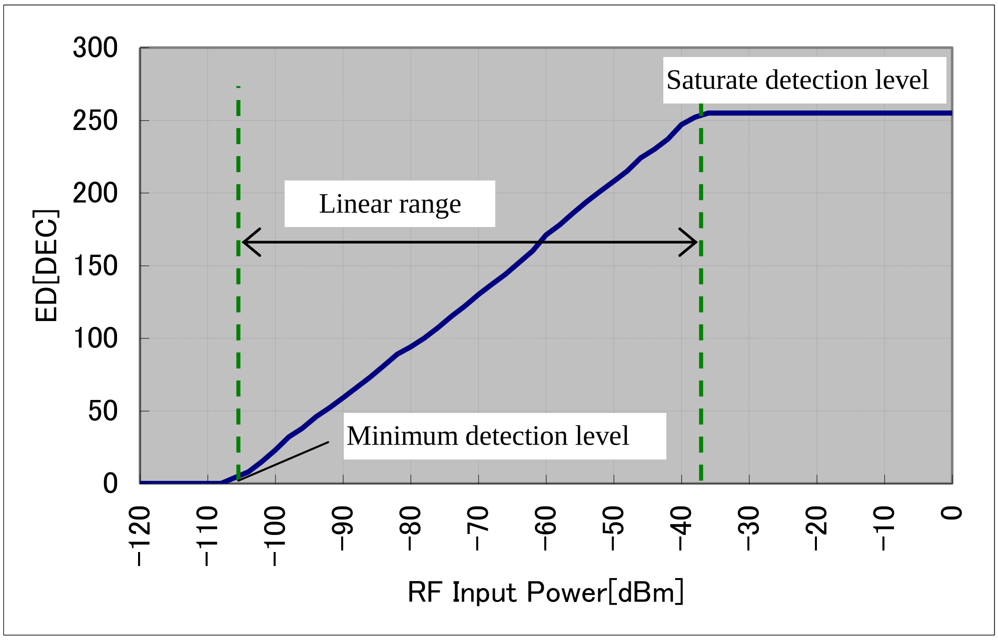


Figure 13.2.8 Example of receiving energy detection range measurement

13.2.9. Rx Spurious Emissions

ML7396 setting;

Rate:	Set 100 kbps at [DATA_SET] register (Bank 0 0x47)
RF_Status:	Set 0x06 (RX_ON) to the [RF_STATUS] register (Bank 0 0x6C)

Spectrum anlyzer setting;

CenterFreq:	Harmonics Frequency	**RBW:**	1 MHz
Mode:	BurstPower(Average)	**VBW:**	1 MHz
Detector:	Sampl	**Span:**	0 Hz
RefBW:	199 kHz	**Sweep:**	Single
RefLevel:	-20 dBm	**SweepTime:**	200 msec
Att:	5 dB	**Data Points:**	1001 pts

13.2.10. Operating Consumption Current

When on operating ML7396, measureing cunsumption current for the ML7396 RF board, not for the MCU board. (Exanple: the sum of the current at JP9, JP10 and JP19 on the ML7396 RF board.).

ML7396 setting;

Rate:	Set 100 kbps at [DATA_SET] register (Bank 0 0x47)
RF_Status:	Set 0x06 (RX_ON) or 0x09 (TX_ON) to the [RF_STATUS] register (Bank 0 0x6C)

13.2.11. Fading

The setting values of “100kbps setting1” and “100kbps setting2” are described at appendix "ML7396 Family Initial Register Setting” (v1.1.170922). The difference of setting1 and setting2 is the way of choose antenna. Setting1 choose either of two antenna which has higher received level The other hand, setting2 which is set “first search mode” is choosen, if first received level of antenna has higher than threshold, Therefore, setting2 requires more than 10 bytes preamble and setting1 requires more than 12 bytes as longer. For setting1, if the preamble is set as 10 bytes, the error is increased in the case of lower than -80dBm. For example, compareing receiving level at PER=1%, it is getting worse than 2dB. However, setting1 and setting2 have same characteristic if efficient level, higher than -80dBm, is received. Meanwhile, setting1 choose suitable antenna which has higher level. Also, both setting has same characteristic under setting preamble 12 bytes.

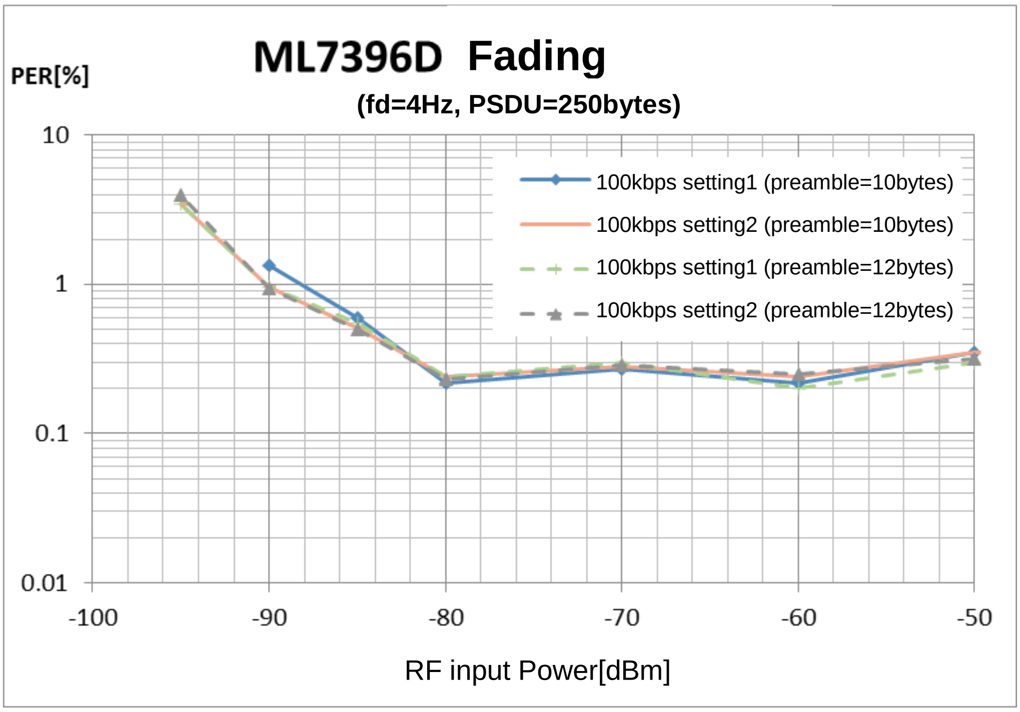
ML7396 setting;

Rate: Set 100 kbps at [DATA_SET] register (Bank 0 0x47)

Diversity: Set diversity ON at 2DIV_EN([2DIV_CNTRL] register (Bank 0 0x71(0)))=0b1

Fading simultor setting;

Rayleigh fading (doppler frequency=4Hz)



13.3. Temperature Characteristics

Mesurement results in this chapter are results of ML7396B.In case of other products, temperature characteristics are same, but absolute value is different.

13.3.1. Transmission Power

Measuring conditions: VDDIO = 3.3V, Frequency = 924.3 MHz, Data Rate = 100 kbps, PA mode = 13 dBm

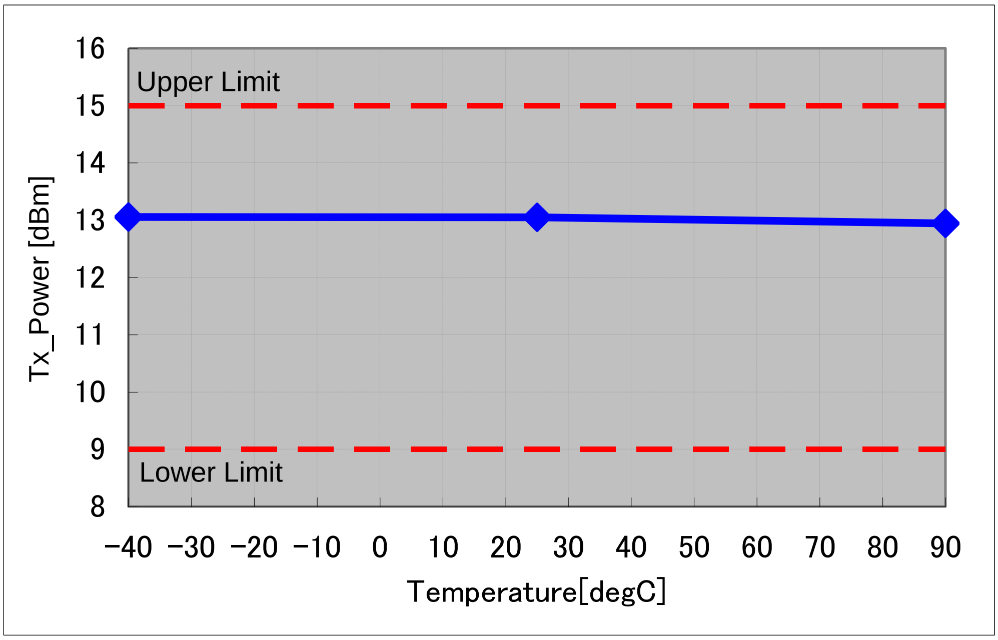


Figure 13.3.1 Representative temperature characteristics of transmission power

13.3.2. Occupied Band Width

Measuring conditions: VDDIO = 3.3V, Frequency = 924.3 MHz, Data Rate = 100 kbps, PA mode = 13 dBm

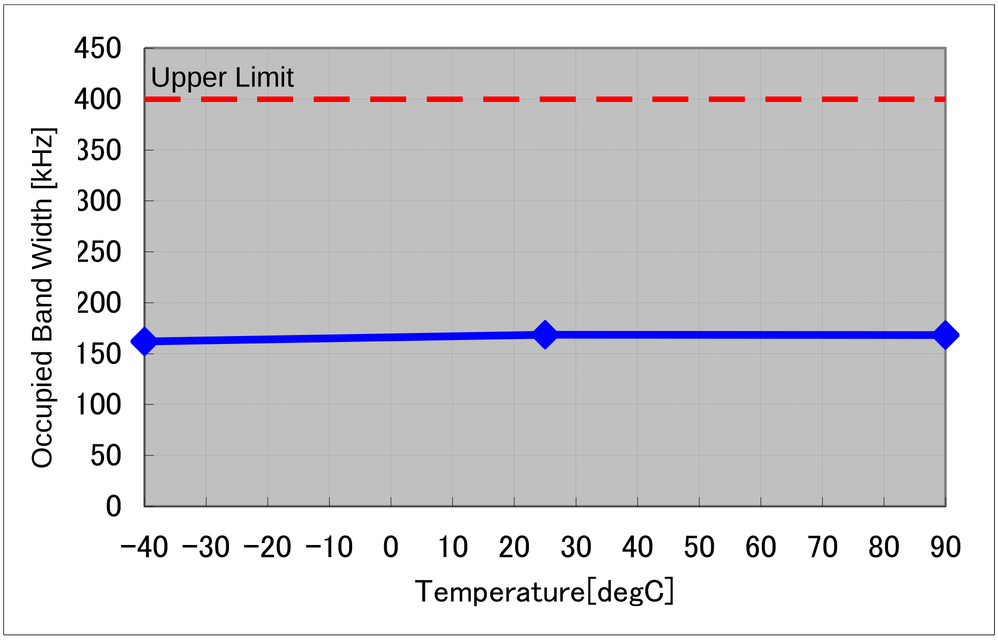


Figure 13.3.2 Representative temperature characteristics of occupied band width

13.3.3. Adjacent Leakage Power

Measuring conditions: VDDIO = 3.3V, Frequency = 924.3 MHz, Data Rate = 100 kbps, PA mode = 13 dBm

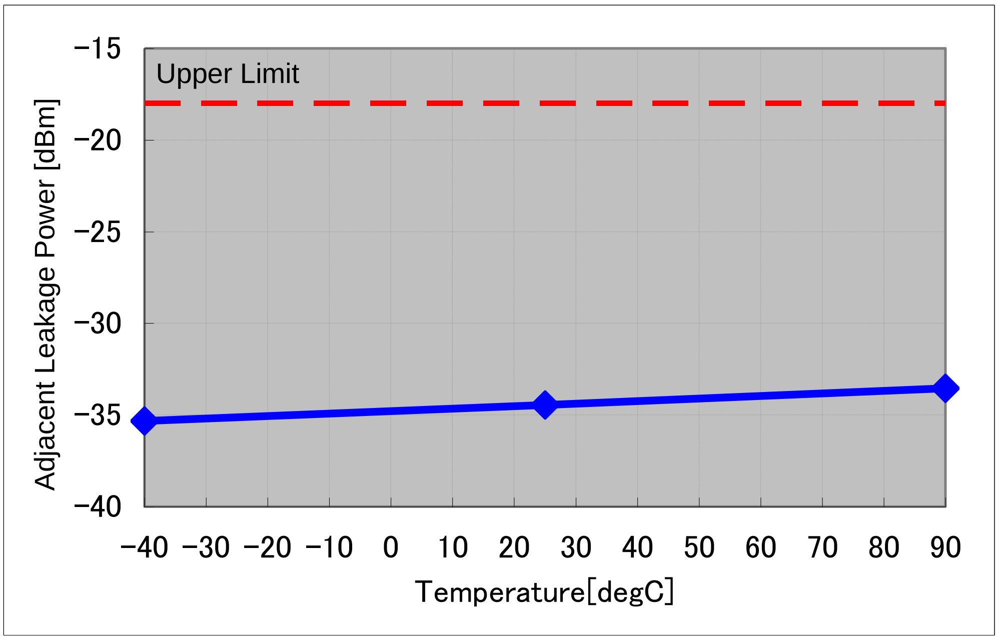


Figure 13.3.3 Representative temperature characteristics of adjacent leakage power

13.3.4. Spurious Emissions

Measuring conditions: VDDIO = 3.3V, Frequency = 924.3 MHz, Data Rate = 100 kbps, PA mode = 13 dBm

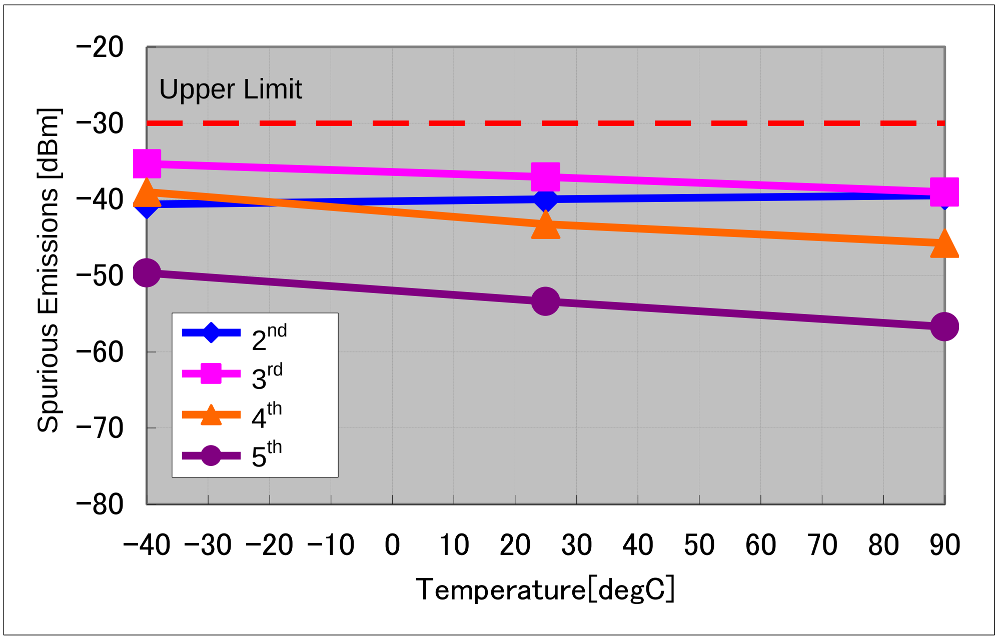


Figure 13.3.4 Representative temperature characteristics of spurious emissions

13.3.5. Receiver Sensitivity

Measuring conditions: VDDIO = 3.3V, Frequency = 924.3 MHz, Data Rate = 100 kbps

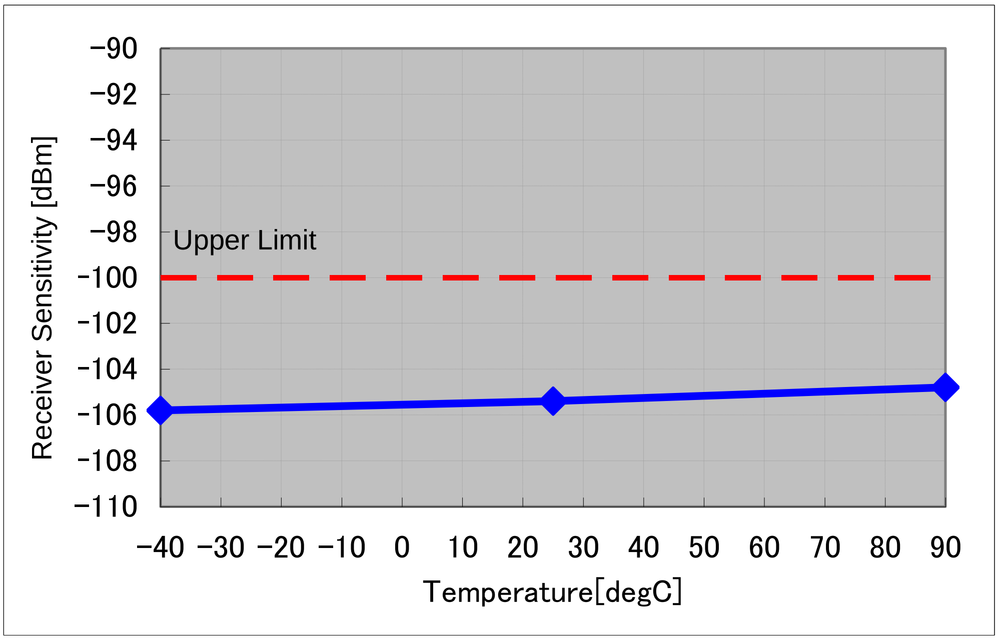


Figure 13.3.5 Representative temperature characteristics of receiver sensitivity

Receiver sensitivity of ML7396D better 2dB than ML7396B. Both temperature chractristics are same. The charactristics of ML7396A/E are same as ML7396B.

13.3.6. Adjacent/Alternate Channel Rejection

Measuring conditions: VDDIO = 3.3V, Frequency = 924.3 MHz, Data Rate = 100 kbps

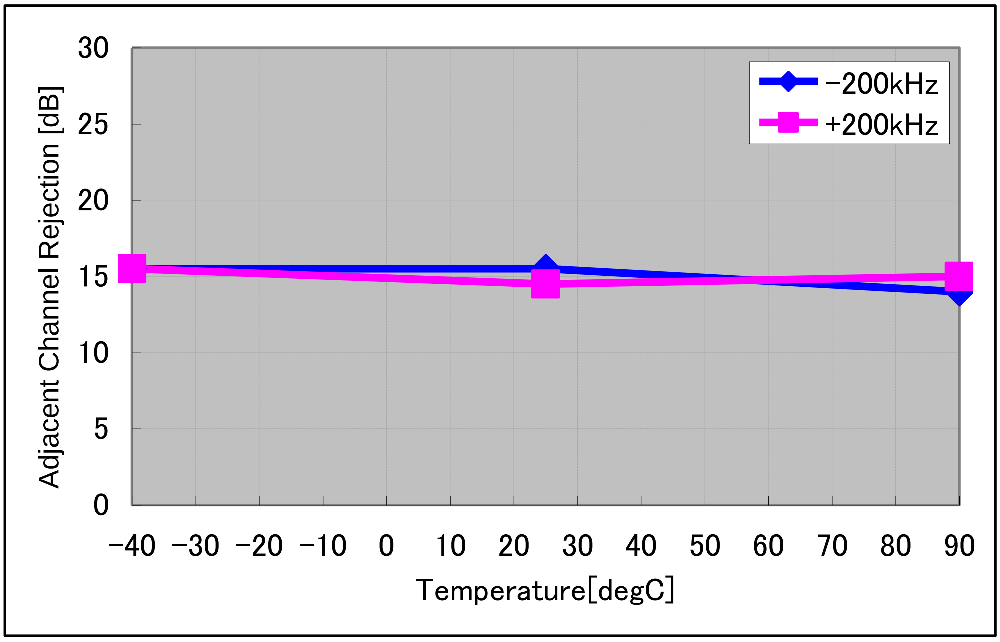


Figure 13.3.6.1 Representative temperature characteristics of adjacent channel rejection (±200kHz)

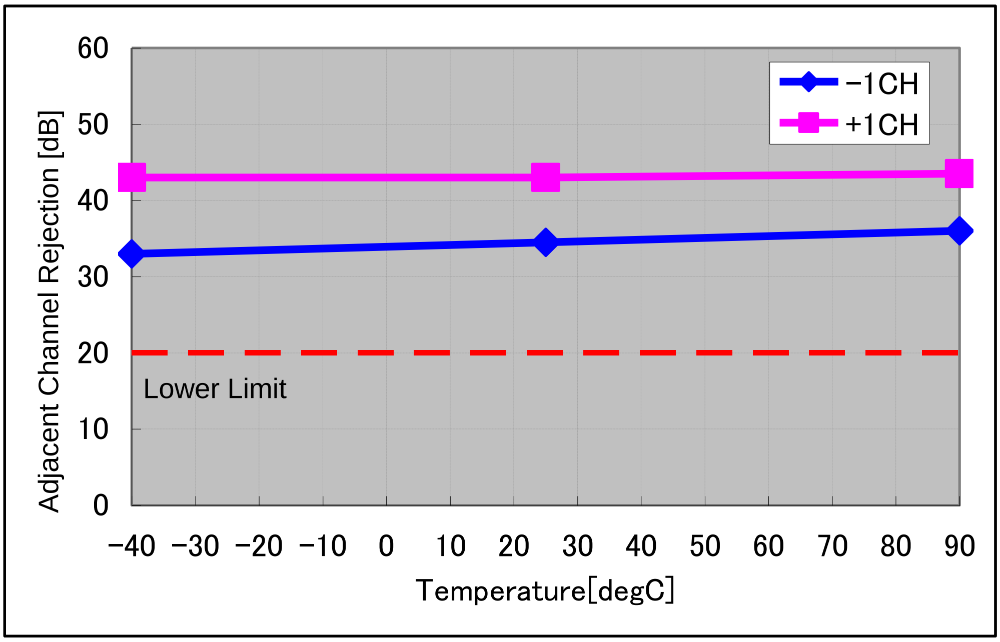


Figure 13.3.6.2 Representative temperature characteristics of adjacent channel rejection (±1CH = 400kHz)

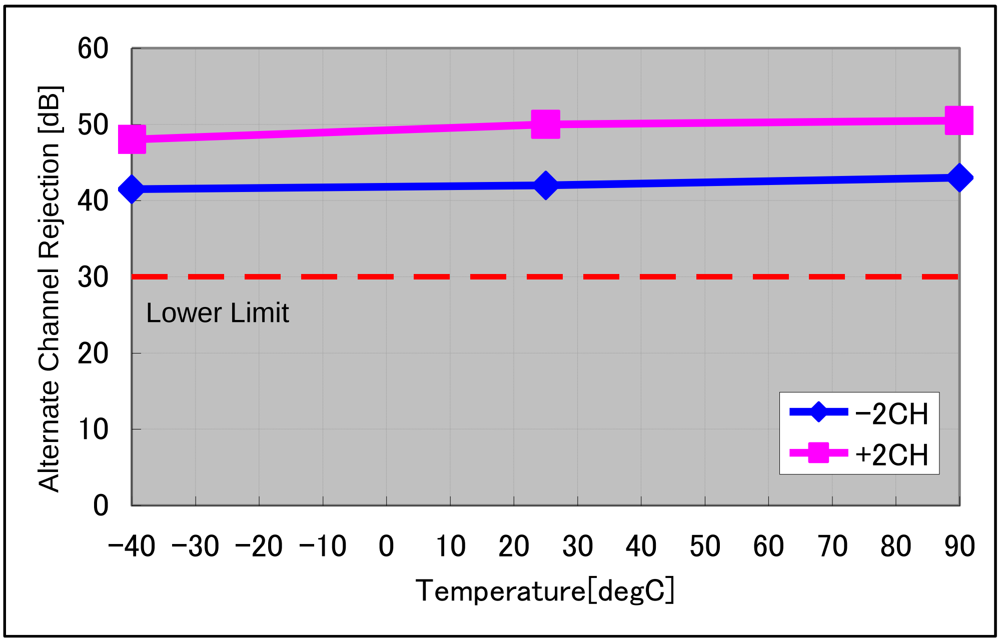


Figure 13.3.6.3 Representative temperature characteristics of alternate channel rejection (±2CH = 800kHz)

13.3.7. Blocking (Spurious Response)

Measuring conditions: VDDIO = 3.3V, Frequency = 924.3 MHz, Data Rate = 100 kbps

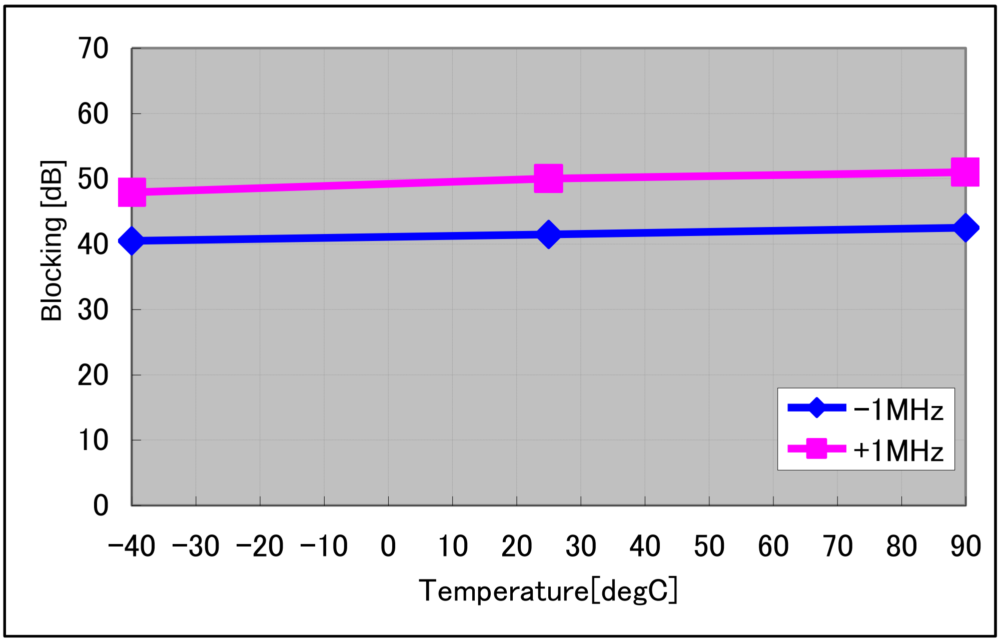


Figure 13.3.7.1 Representative temperature characteristics of blocking (±1MHz)

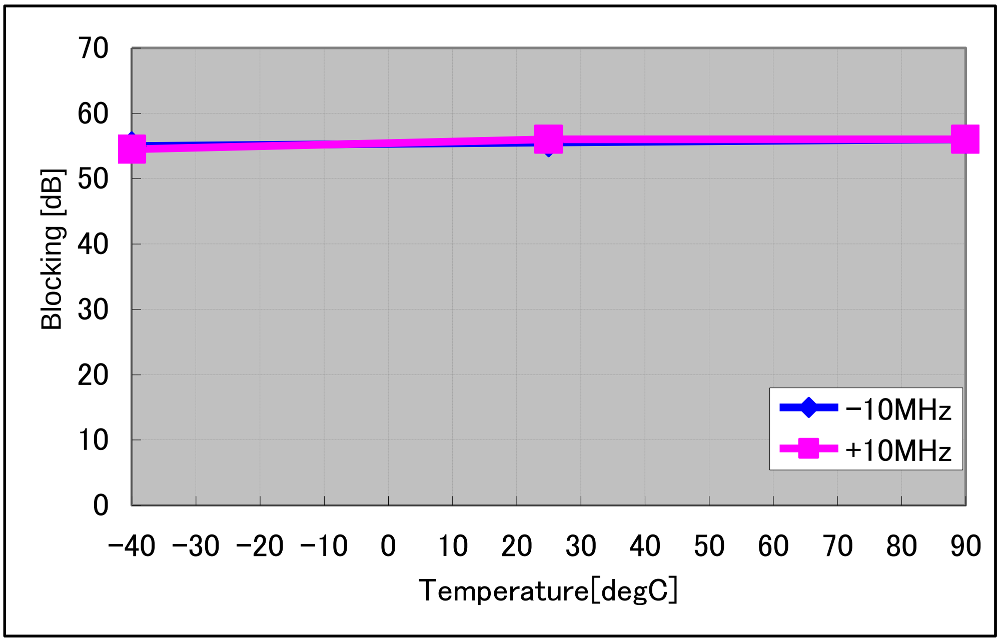


Figure 13.3.7.2 Representative temperature characteristics of blocking (±10MHz)

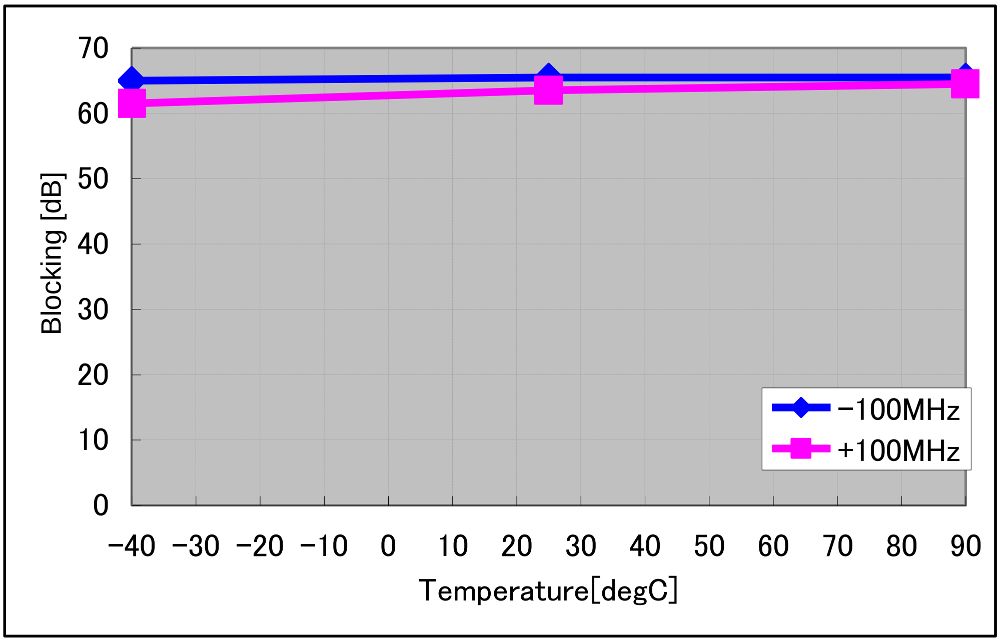


Figure 13.3.7.3 Representative temperature characteristics of blocking (±100MHz)

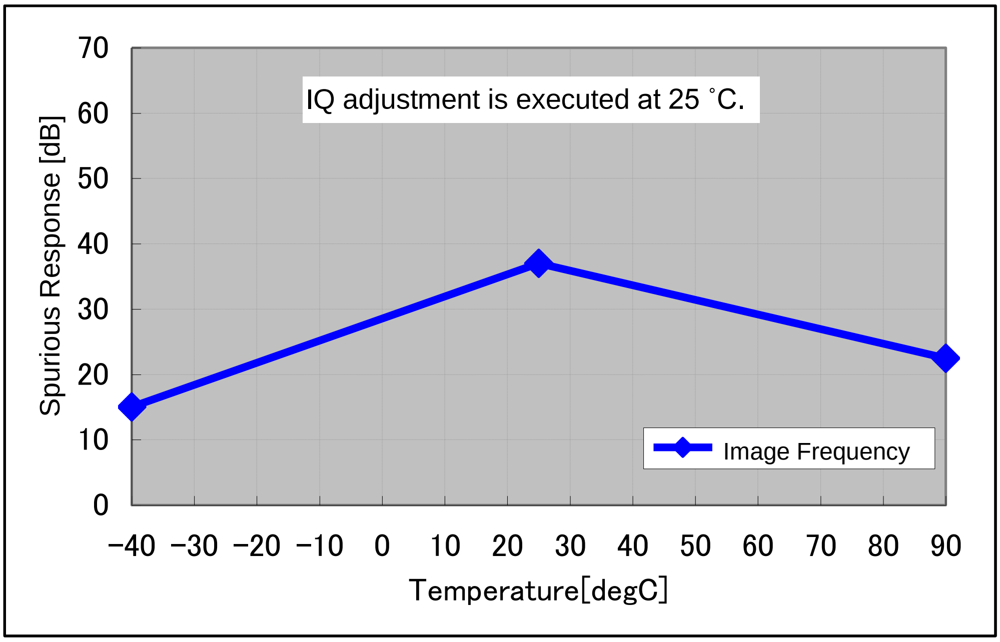


Figure 13.3.7.4 Representative temperature characteristics of spurious response

13.3.8. Receiving Energy Detection Range

Measuring conditions: VDDIO = 3.3V, Frequency = 924.3 MHz, Data Rate = 100 kbps

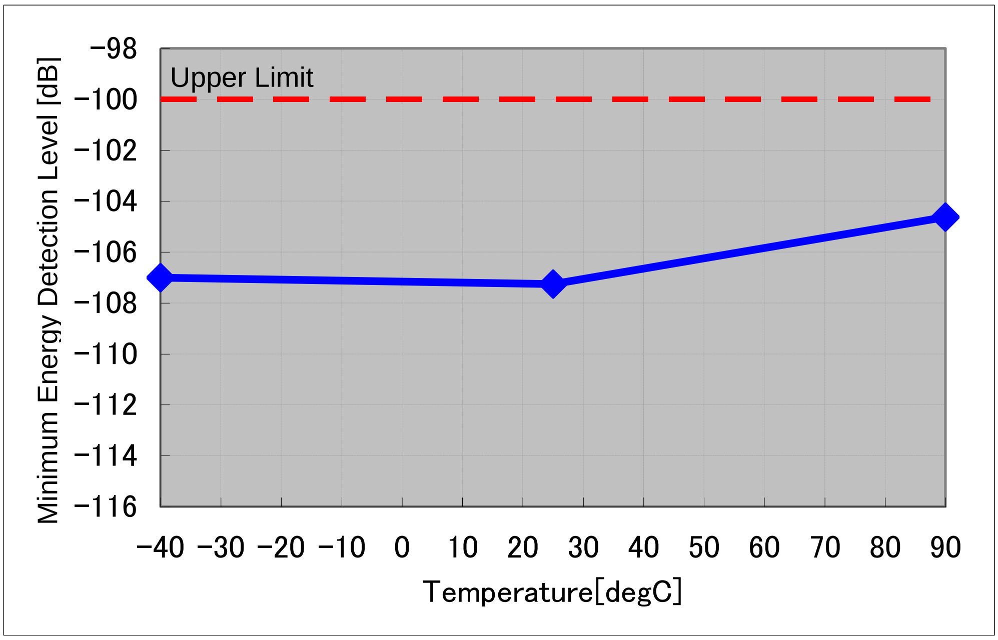


Figure 13.3.8.1 Representative temperature characteristics of minimum receiving energy detection level

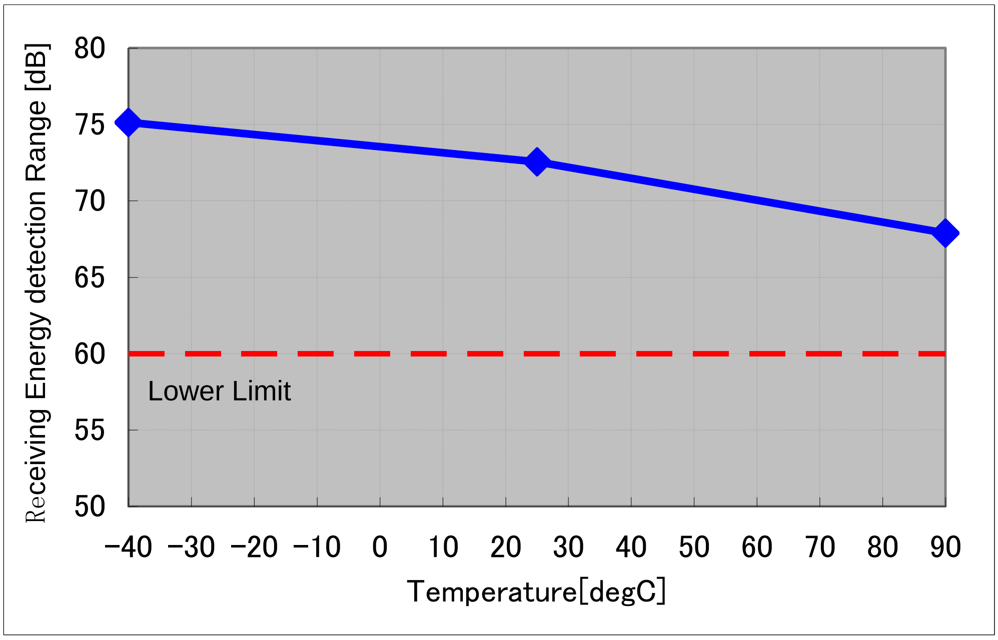


Figure 13.3.8.2 Representative temperature characteristics of receiving energy detection range

13.3.9. Rx Spurious Emissions

Measuring conditions: VDDIO = 3.3V, Frequency = 924.3 MHz, Data Rate = 100 kbps

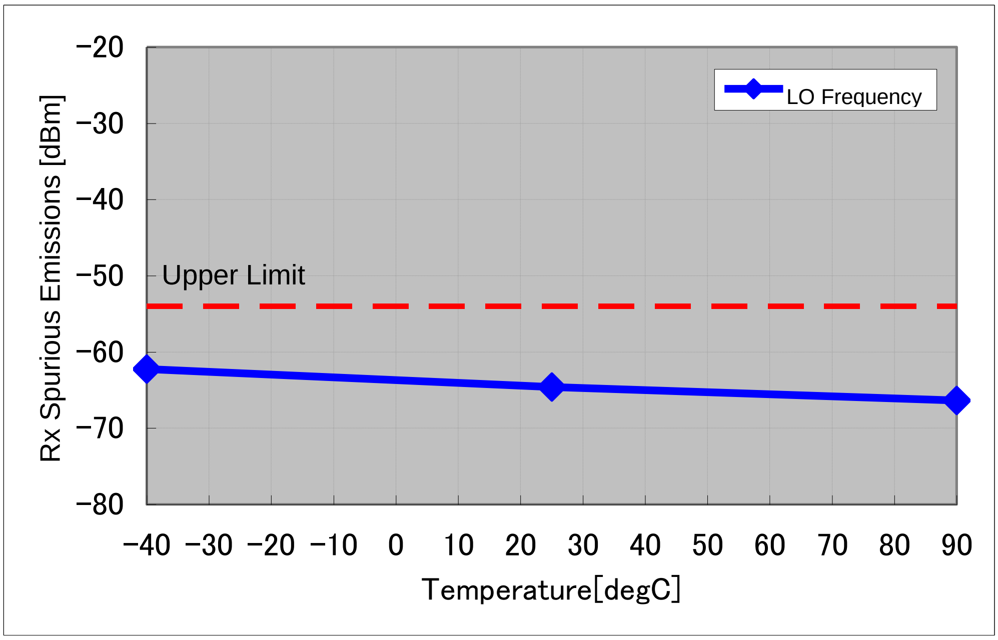


Figure 13.3.9 Representative temperature characteristics of Rx spurious emissions

13.3.10. Operating Consumption Current

Measuring conditions: VDDIO = 3.3V, Frequency = 924.3 MHz, Data Rate = 100 kbps, PA mode = 13 dBm

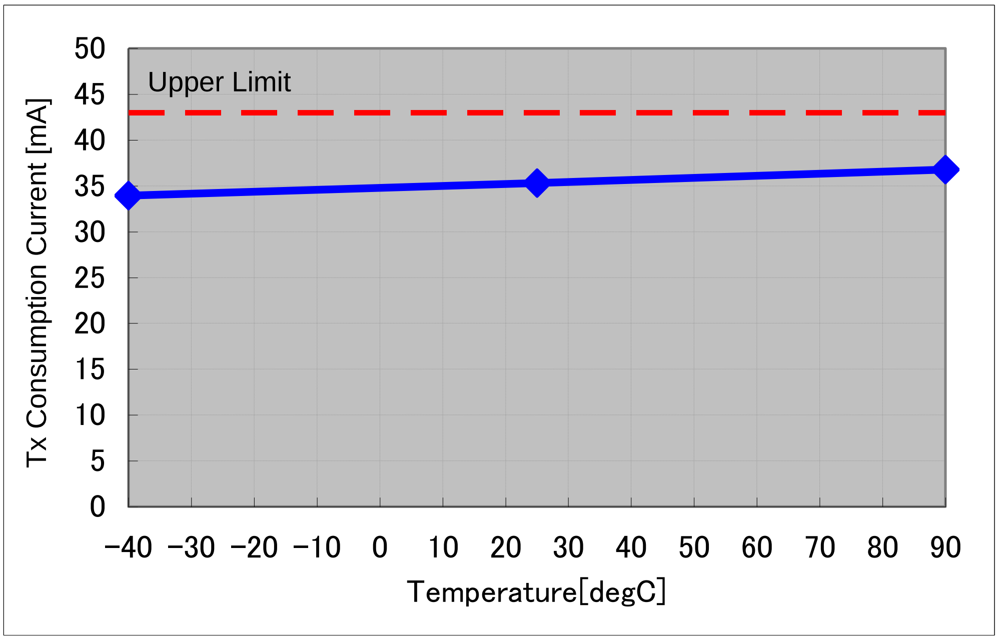


Figure 13.3.10.1 Representative temperature characteristics of Tx consumption current

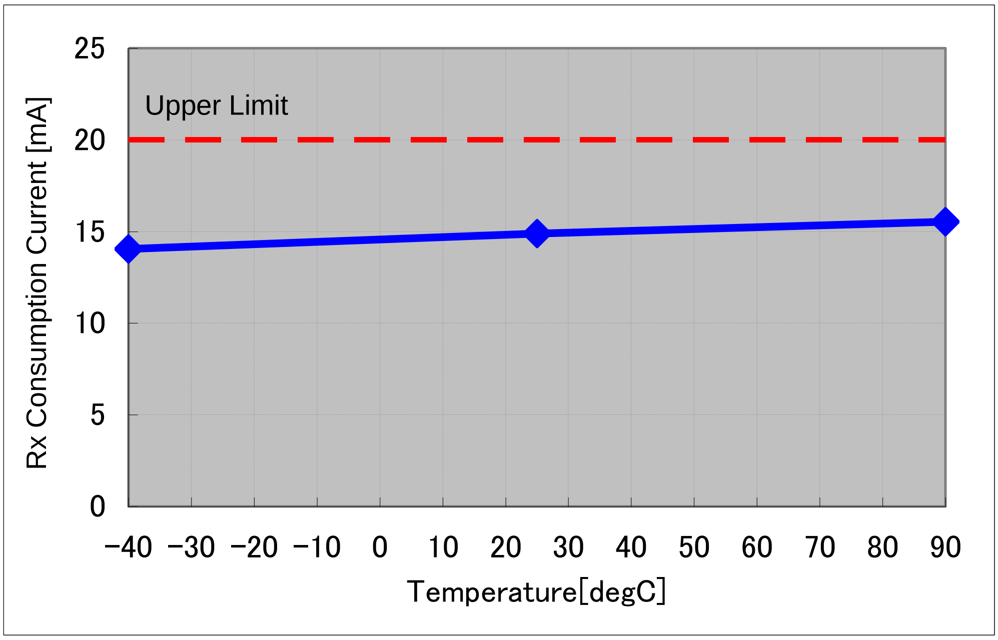


Figure 13.3.10.2 Representative temperature characteristics of Rx consumption current

14. Bit Error Rate (BER) measurement

14.1. Measuring configurations

Equipment to prepare: 1) ML7396x-EVB (ML7396 evaluation kit, x=A or B or E)
2) Signal Generator
3) Bit Error Rate Meter

Test macro to prepare: ML7396B_TRXtest_YYYYMMDD.ttl (YYYYMMDD : creation date)

[Note] The test macro is included in the ML7396 evaluation kit.

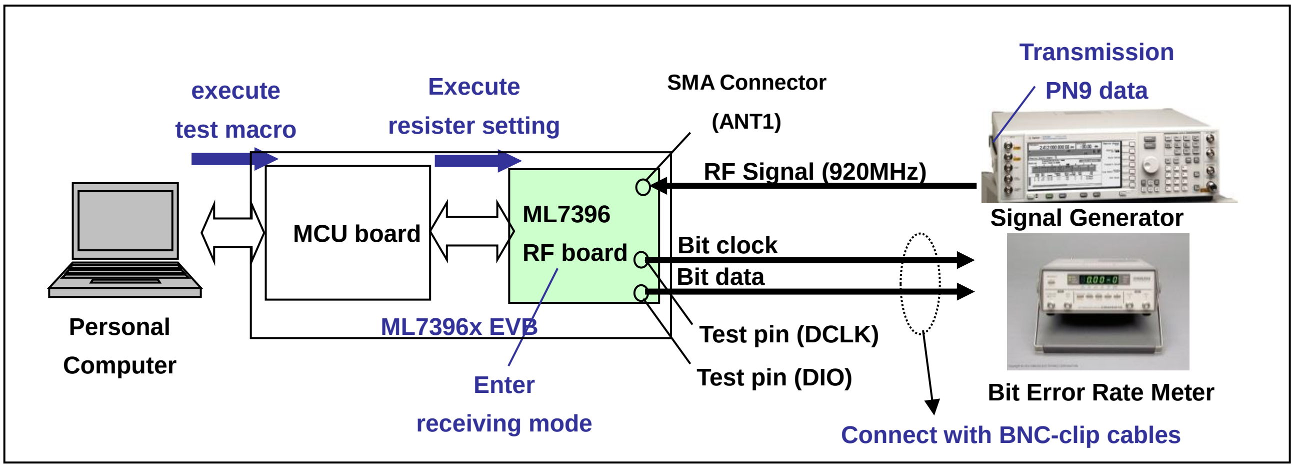


Figure 14.1.1 System configurations for BER measurement

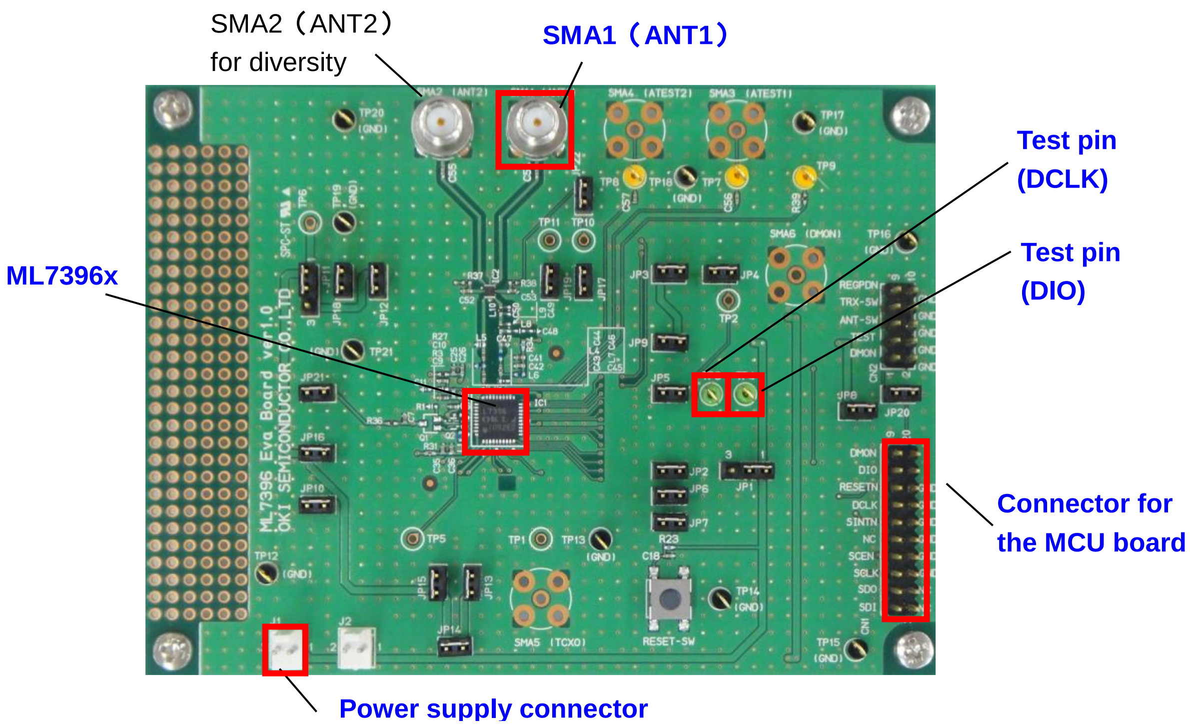


Figure 14.1.2 BER measurement relative parts position on the ML7396 RF board

14.2. Measuring step

Step 1: Execute the RF test macro of ML7396B_TRXtest_YYYYMMDD.ttl on the ML7396x-EVB. (Details are described in section 14.3)

Step 2: Start transmitting PN9 data from the signal generator.

Step 3: Measure BER with the bit error rate meter.

14.3. Executing RF test macro

Following shows dialog boxes when executing the RF test macro.

1) At first, “Data Rate” dialog box will appear. When push “OK ” button without input, “1: 100 kbps” is automatically selected

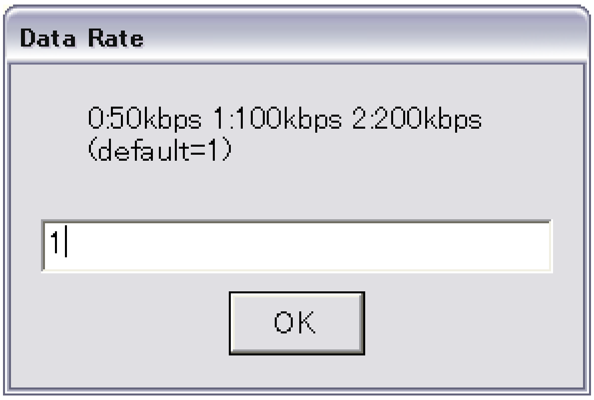


Figure 14.3.1 “Data Rate” dialog box

2) 2ndary, “Channel” dialog box will appear. When push “OK” button without input, “0: CH#0” is automatically selected

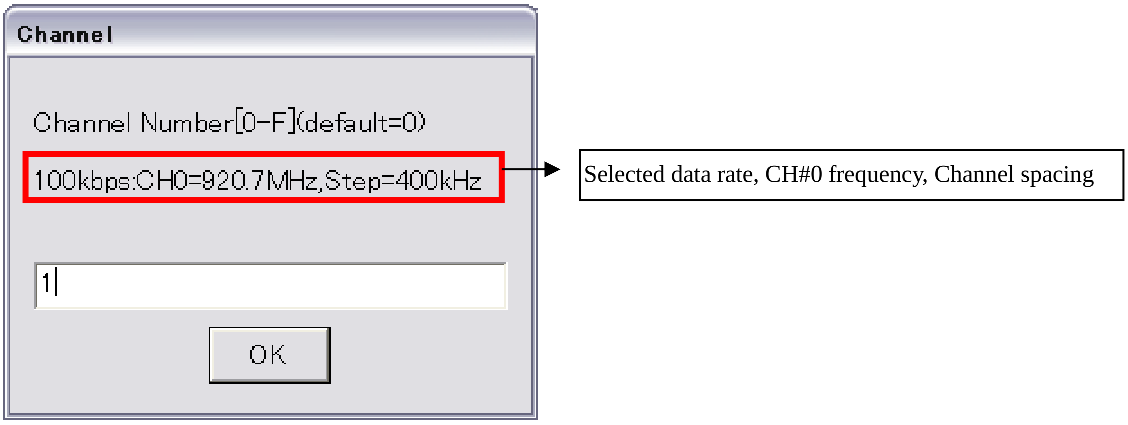


Figure 14.3.2 “Channel” dialog box

3) After that, “RF_Frequency” dialog box shows the selected RF frequency.

Figure 14.3.3 “RF Frequency” dialog box

4) Then ,“TX or RX” dialog box will appear. Input “2: RX” and push “OK” button

Figure 14.3.4 “TX or RX?” dialog box

5) Finaly, “BER MODE” dialog box will appear. Input “1: BER” and push “OK” button.

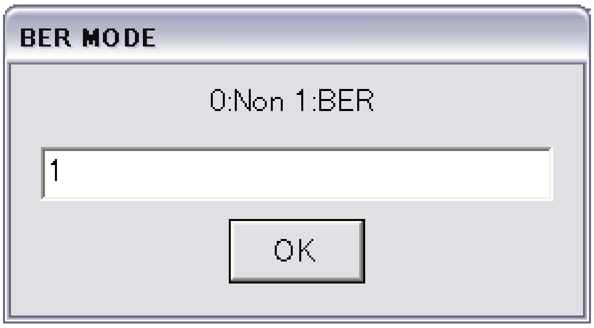


Figure 14.3.5 “BER MODE” dialog box

Revision history

Document No.	Date	Page		Content
		Previous	New	
FEXL7396DG-01	2012.4.12	–	–	The first edition
FEXL7396DG-02	2012.9.28	i	i	Add ML7396E to the target product list
		8	8	Table 5.1.1 Add component values for 868MHz and 915MHz band , delete component values for 950MHz
		11	11	Add LPF1 in Figure 6.1
		12	11	Table 6.1.1 and Table 6.2.1 Add component values for 868MHz and 915MHz band. Delete component values for 950MHz band.
		16	14	Delete the explanation of the external regulator
		17	–	Delete section 10 of “RESETN pin”
		19,20	16,17	Bill of Material Add component values for 868MHz and 915MHz band. Delete components value for 950MHz band.
		–	18	Add component value for 250mW transmission circuit.
		–	19-41	Add section “12. RF characteristics measurement”, Add section “13 Bit Error Rate measurement”
FEXL7396DG-03	–	–	–	–
FEXL7396DG-04	–	–	–	–
FEXL7396DG-05	–	–	–	–
FEXL7396DG-06	2013.2.28	12	12	Figure 6.3.1 Delete resistor R74
		18	18	The bill of materials for 250mW transmission circuit Delete resister R74
FEXL7396DG-07	2013.7.18	2	2	Add note of decoupling capacitor
		4	4	Add note of crystal oscillator
		10	10	Add description of impedance
FEXL7396DG-08	2017.4.28	ii	ii	Add ML7396D in target products
		14	14	Add notes on board artworks
FEXL7396DG-09	2017.10.3	-	21	Add fading measurement configuration
		-	31	Add fading characteristic data