AN12237

QN908x with External PA User Guide

Rev. 0 — August 2018 **Application note**

Document information

Info	Content
Keywords	QN9080, BLE, range extender, schematic, PCB layout
Abstract	This application note briefly describes the QN9080 range extender solution with different kinds of external PA/LNA modules, including introduction, hardware design, software application, and test results.

Revision history

Revision number	Date	Substantive changes
0	2018/08	Initial release

Contact information

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1. Introduction

The QN9080 has a maximum transmit power of 2 dBm and receiver sensitivity of -95 dBm. These values apply to most applications where the communication distance is not too long. For a long-distance communication application (such as smart home), the TX power and RX sensitivity must be improved to ensure that the communication distance is sufficient.

In such cases, the Front-End Module (FEM) must be placed before the QN908x RF port, which integrates the PA, LNA, and RF switches for the TX and RX channels. When combined with the QN908x, it can enhance the communication range and extend the scope of applications for long-distance communication.

The FEM IC solution is recommended in this document. The following sections describe the range extender solution reference design based on QN908x.

2. Hardware design

This section describes the QN9080 range extender solution hardware design. As an example, the hardware design contains parts of the FEM, reference schematic, PCB layout, BOM, and test results.

The QN9080 device contains a TX/RX switch. The RF port pins are matched to a 50-Ω single-ended port. The range extender FEM module has these features:

- The FEM module integrates the LNA, PA, and TX/RX switches.
- The input port must be single-ended with the impedance of 50 Ω.
- Logic control pin to switch the TX/RX channels.

2.1 Range extender solution with external PA SKY66114-11

SKY66114-11 is a high-performance and fully-integrated RF FEM designed for Bluetooth Low Energy (BLE) applications. The FEM device integrates the highly efficient saturated PA, high-gain LNA, T/R, and bypass RF switch. The power supply voltage ranges from 1.8 V to 3.6 V. The digital control interface is also compatible with the 1.6 V to 3.6 V COMS level. The block diagram of SKY66114-11 is shown in Fig 1.

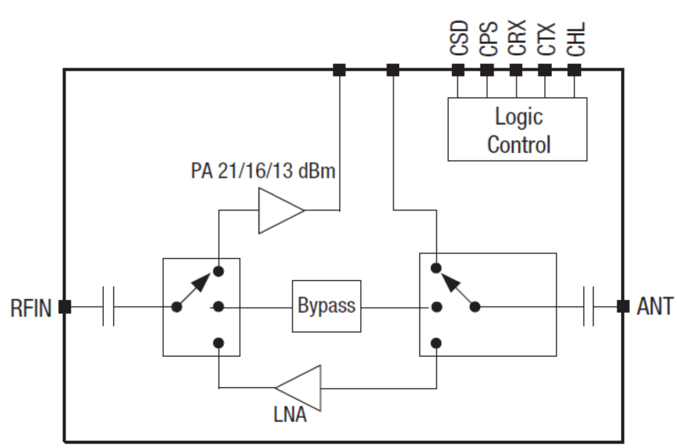


Fig 1. SKY66114-11 block diagram

2.2 Logic control

SKY66114-11 has five logic pins to control the IC operation mode. These five logic pins can be connected to the QN9080 GPIO pins. The reference design connection is shown in Fig 2.

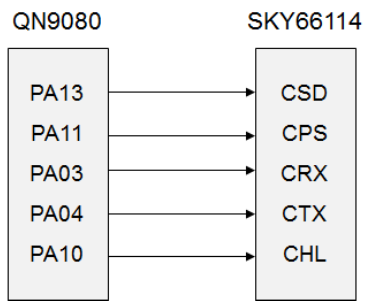


Fig 2. QN9080 logic control pins

The truth table of the logic control pins is shown in Table 1.

Table 1. Logic control truth table

CSD	CPS	CRX	CTX	CHL	Operation mode
0	x	x	x	x	Chip sleep mode
1	0	1	0	x	RX LNA mode
1	0	x	1	1	TX high-power mode
1	0	x	1	0	TX low-power mode
1	1	1	0	x	RX bypass mode
1	1	x	1	x	TX bypass mode
1	x	0	0	x	Chip sleep mode

Note: “1” denotes logic high state (voltage > 1.6 V).
“0” denotes logic low state (voltage < 0.3 V).
“x” denotes arbitrary state: either “1” or “0” can be applied.

2.3 Schematic diagram

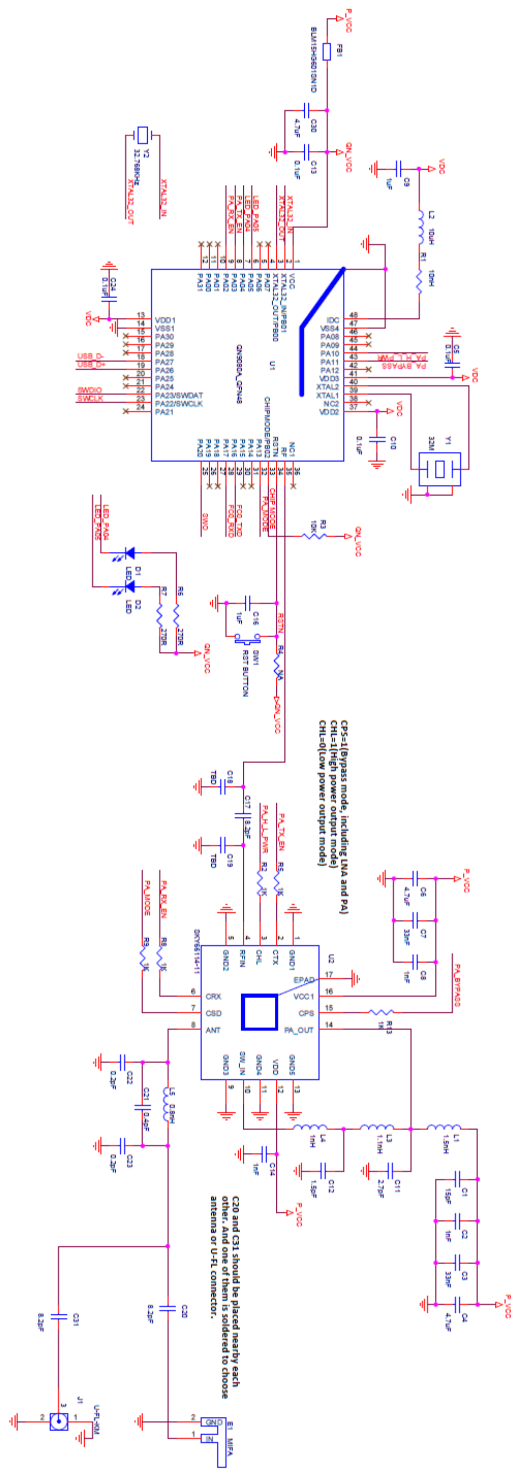
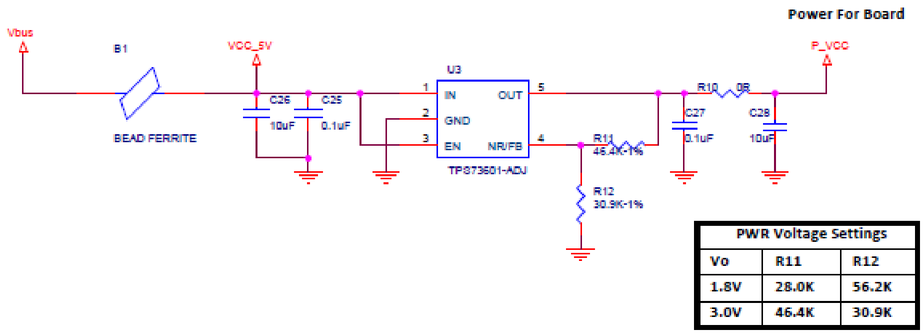


Fig 3. Range extender solution with SKY66114-11 schematic



PWR Voltage Settings		
Vo	R11	R12
1.8V	28.0K	56.2K
3.0V	46.4K	30.9K

Fig 4. QN9080 USB dongle board power supply

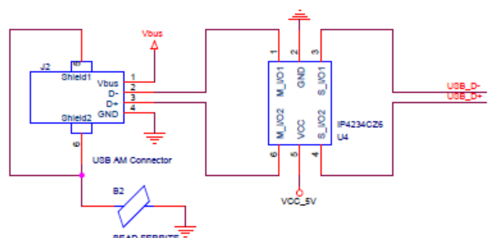


Fig 5. QN9080 USB dongle board USB interface

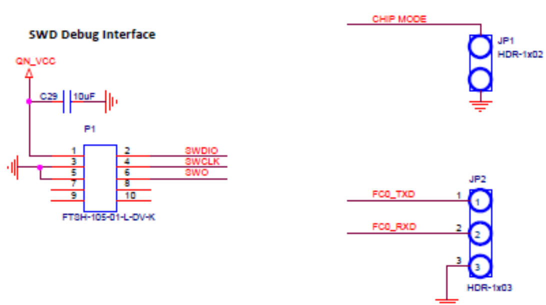


Fig 6. QN9080 USB dongle board debug interface

Notes:

1. It is recommended to add an A L-C "π" type harmonic filter after the PA output port for harmonic suppression (if necessary).
2. There are two RF paths which can be selected using a capacitor. One is connected to the U.FL connector which can be used for the conductive test. The other is connected to the on-board MIFA antenna which can work as the USB dongle.

2.4 PCB layout

The QN9080 USB dongle with the PA board of the range extender solution is a 4-layer stack PCB board. Here are some of its features:

- 4-layer stack, Top Etch/GND/PWR/Bottom Etch.
- The thickness of the PCB board is 1.0 mm.
- The dielectric material of the PCB is a standard FR-4 with $\varepsilon_r = 4.5$, $\tan\delta = 0.02$ (typ).

Table 2. PCB stack-up

Stack-up name	Material	Thickness (mm)	Stack-up figure
Top Etch	Copper	0.018	
Dielectric	FR-4	0.28	
GND	Copper	0.018	
Dielectric	FR-4	0.284	
PWR	Copper	0.018	
Dielectric	FR-4	0.28	
Bottom Etch	Copper	1.2	
Total thickness		0.916	Note: This is the thickness without the solder mask layer.

The PCB layout of the QN9080 USB dongle with the PA board is shown in the following figures.

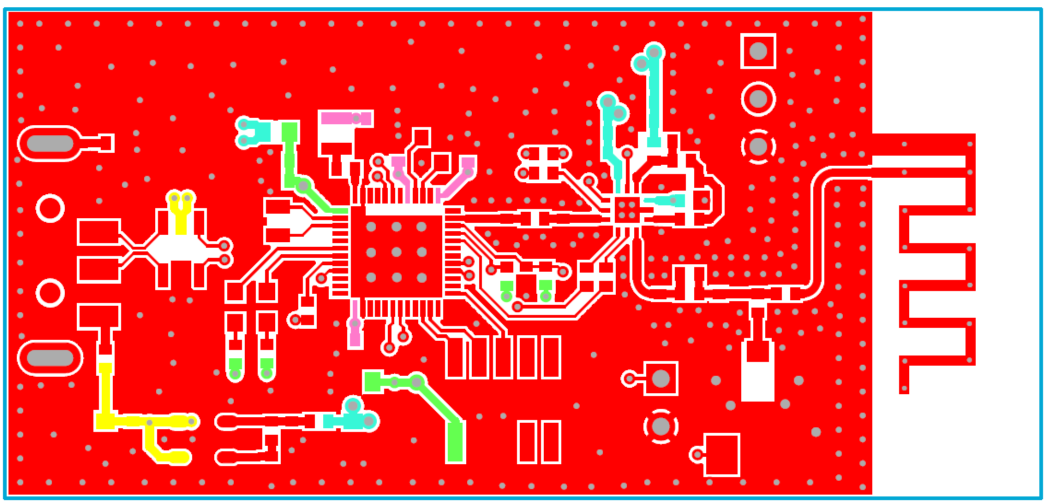


Fig 7. Range extender solution with SKY66114 top etch layer

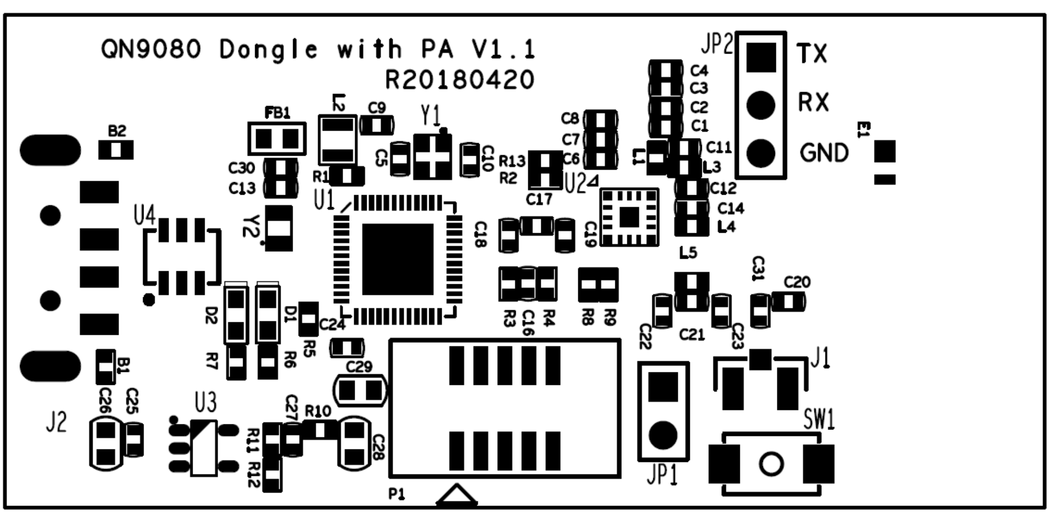


Fig 8. Range extender solution with SKY66114 top silkscreen layer

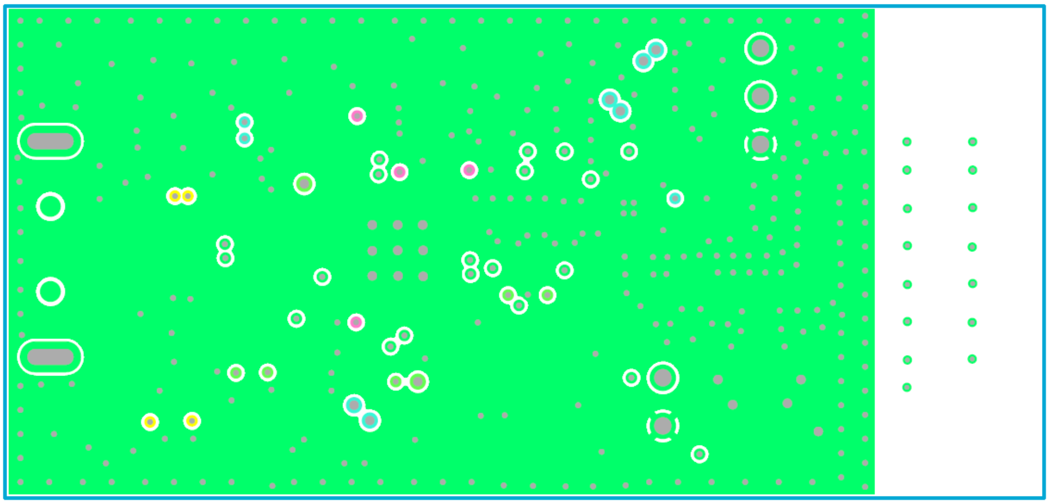


Fig 9. Range extender solution with SKY66114 GND layer

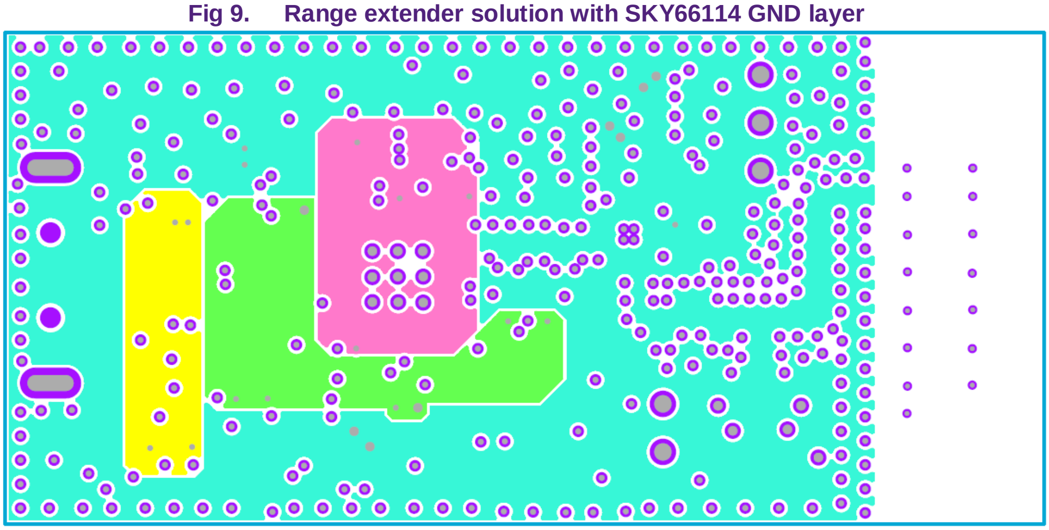


Fig 10. Range extender solution with SKY66114 PWR layer

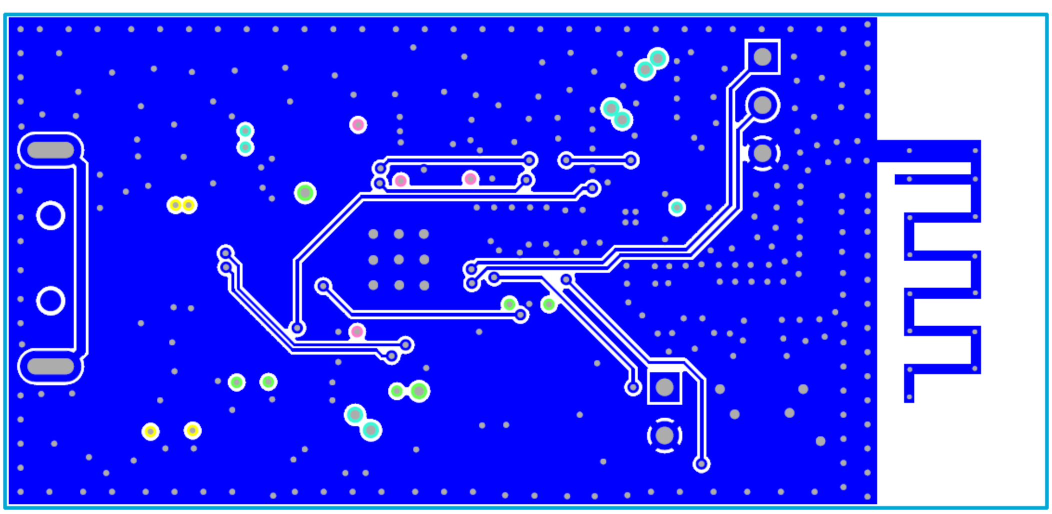


Fig 11. Range extender solution with SKY66114 bottom layer

2.5 BOM list

Table 3 shows the BOM of the QN9080 range-extender solution with SKY66114.

Table 3. Range extender solution with SKY66114 BOM

QN9080_USB Dongle with PA SKY66114 board_V1.1 EBOM						
Item	**Part Description**	**Footprint**	**Reference**	**Qty**	**Manufacturer**	**Mfg Part No.**
Capacitor						
1	C_SMD, 100nF, X7R, ±10%, 16V, 0402	0402	C5,C10,C13,C24,C25,C27	7	Murata	GRM155R71C104KA88
2	C_SMD, 33nF, X7R, ±10%, 16V, 0402	0402	C3,C7	2	Murata	GRM155R71C333KA01J
3	C_SMD, 1nF, X7R, ±10%, 16V, 0402	0402	C2,C8,C14	3	Murata	GRM155R71C102KA01D
4	C_SMD, 0.2pF, C0G, ±0.1pF, 50V, 0402	0402	C22,C23	2	Murata	GRM1554C1HR20BA01D
5	C_SMD, 0.4pF, C0G, ±0.1pF, 50V, 0402	0402	C21	1	Murata	GRM1554C1HR40BA01D
6	C_SMD, 1.5pF, C0G, ±0.1pF, 25V, 0402	0402	C12	1	Murata	GRM1555C1H1R5BA01D
7	C_SMD, 2.7pF, C0G, ±0.1pF, 25V, 0402	0402	C11	1	Murata	GRM1555C1H2R7BA01D
8	C_SMD, 8.2pF, C0G, ±0.1pF, 50V, 0402	0402	C17,C20	2	Murata	GRM1555C1H8R2BA01D
9	C_SMD, 15pF, C0G, ±5%, 50V, 0402	0402	C1	1	Murata	GRM1555C1H150JZ01D
10	C_SMD,1uF, X5R, ±10%, 6.3V, 0402	0402	C16	1	Murata	GRM155R60J105KE19J
11	C_SMD,4.7uF, X5R, ±10%, 6.3V, 0402	0402	C4,C6,C9,C30	4	Murata	GRM155R60J475ME87D
12	C_SMD,10uF, X5R, ±10%, 16V, 0603	0603	C26,C28,C29	3	Murata	GRM188R61C106MAALD
	C_SMD, NA	0402	C18,C19	2		
Resistor						
13	R_SMD, 0R, ±5%, 0402	0402	R10	1	Yageo	RC0402JR-070RL
14	R_SMD, 270R, ±1%, 0402	0402	R6,R7	2	Vishay	CRCW0402270RFKED
15	R_SMD, 1K, ±5%, 0402	0402	R2,R5,R8,R9,R13	5	Vishay	CRCW04021K00FKED
16	R_SMD, 10K, ±5%, 0402	0402	R3	1	Yageo	CRCW040210K0FKED
17	R_SMD, 30.9K, ±1%, 0402	0402	R12	1	TE Connectivity	CPF0402B30K9E1
18	R_SMD, 46.4K, ±1%, 0402	0402	R11	1	Vishay	CRCW040246K4FKED
	R_SMD, NA	0402	R4	1		
Inductors and Beads						
19	Bead, 300mA, 600 Ohm@100MHz	0402	B1,B2	2	Murata	BLM15HG601SN1D
20	Bead, 1000mA, 470 Ohm@100MHz	0603	FB1	1	Murata	BLM18PG471SH1D
21	Inductor, 1.2A, 0.9nH, 30mOhm	0402	L5	1	TDK	MHQ1005P0N9BT000
22	Inductor, 500mA, 1.0nH, 150mOhm	0402	L4	2	TDK	MHQ1005P1N0BT000
23	Inductor, 500mA, 1.1nH, 150mOhm	0402	L3	2	TDK	MHQ1005P1N1BT000
24	Inductor, 400mA, 1.5nH, 200mOhm	0402	L1	1	TDK	MHQ1005P1N5BT000
25	Inductor, 10uH, ±20%,200mA,0806	0806	L2	1	Murata	LQH2MCN100M52L

Table 3. Range extender solution with SKY66114 BOM

26	L_SMD,10nH, 0402	0402	R1	1	HONGYEX	HBLS1005-10NJ
Oscillator						
27	Crystal, 32MHz, ±10ppm, 8pF, 2.0x1.6x0.45 mm	SMD_2016	Y1	1	Murata	XRCGB32M000F2N13R0
28	Crystal, 32.768K, ±20ppm, 12.5pF, 2.0x1.2x0.6 mm	SMD_2012	Y2	1	YOKETAN	S2012
Diodes and LEDs						
29	LED, single color-Green led.	SMD0603	D1	1	Kingbright	KPT-1608SGC
30	LED, single color-Red led.	SMD0603	D2	1	Kingbright	KPH-1608SURCK
IC						
31	IC, Bluetooth Low Energy core IC,QFN48	QFN48	U1	1	NXP	QN9080D
32	IC, SKY66114-11: 2.4 GHz Bluetooth® Low Energy/802.15.4/Zigbee® Front-End Module	MCM-16	U2	1	SkyWorks	SKY66114-11
33	IC, 400-mA, Low-IQ, Low-Dropout Regulator, Voltage adjustable	SOT23-5	U3	1	TI	TPS73601DBVT
34	IC, ESD protection IC for USB interface	TDOP6	U4	1	Nexperia	IP4234CZ6
Connector						
35	Connector, dual row 2x5pin, pitch 1.27mm	SMT	P1	1	Samtec	FTSH-105-01-L-DV-K
36	Connector, U.FL connector	SMD	J1	1	Hirose	U.FL-R-SMT-1(10)
37	Connector, USB AM connector	DIP	J2	1	Molex	48037-1000
Others						
38	Switch, Ultra-small-sized Tactile Switch	SMT	SW1	1	E-SWITCH	TL1015AF160QG
39	Cable, U.FL test cable			1	Hirose	U.FL-2LP-088K1T-A-(150)

2.6 PCB layout comments for RF

Because the QN9080 and the range-extender solution PA are based on BLE 2.4 GHz and the parasitic parameters affect the RF performance, the PCB layout must be done carefully. Pay attention to the following:

- The RF traces must be routed on the top layer of the PCB board with a pure reference plane under the layer and they must be as short as possible. The characteristic impedance of a RF trace is 50 Ω.
- When routing RF traces, avoid right-angle corners and vias on the RF trace.
- The RF components must be on a RF trace, which reduces the length of a stub.
- If the RF trace on the top layer is a Coplanar Waveguide (CPW), there must be more than one row of vias along the RF trace. The pitch between vias must be lower than a quarter-wave of 2.4 GHz.
- When using an RF connector, the ground under the connector must be avoided.

3. Test results

3.1 Test setup

3.1.1 Test condition

The QN9080 USB dongle with the PA board were measured in these test conditions:

- Tc=25 °C and Vcc=3 V (Power supply for the PA).
- QN9080 was under the Direct Test Mode (DTM) and measured by CBT32.
- QN9080 worked in the internal DC-DC power supply mode.

3.1.2 Test connection

The RX sensitivity and TX output power tests were done using CBT32. There was an RS232-to-UART board which was used to transfer the UART voltage to the RS232 voltage and communicate with the CBT32. To reduce the space interference, the DUT boards were placed in a shielded box.

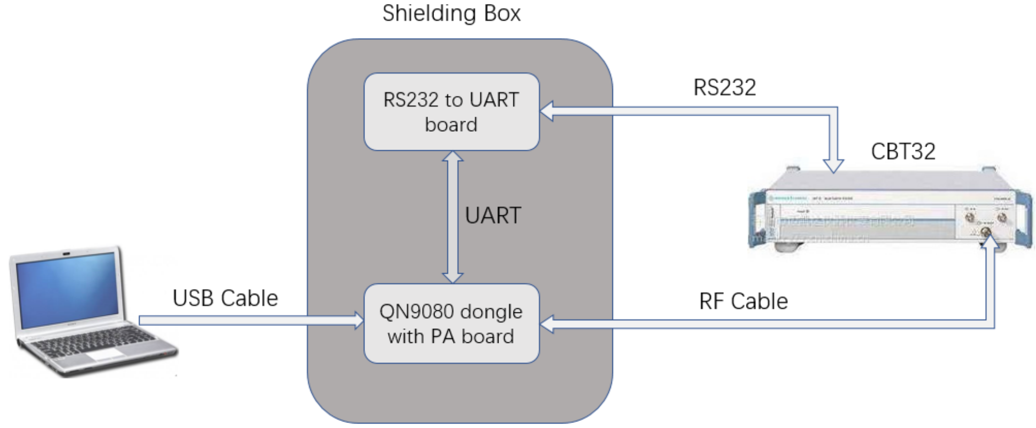


Fig 12. RX and TX test connection

3.2 RX sensitivity test

These data were tested with the SKY66114 device entering the RX LNA mode. The power supply voltage of the USB dongle was 5 V. Table 4 lists the sensitivity and current test values.

Table 4. SKY66114-11 RX sensitivity and current @ Vcc = 3 V

Channel (MHz)	Sensitivity (dBm)	QN9080 USB dongle current @ 5 V (mA)
2402	-102.0	11.54
2440	-101.0	11.55
2480	-101.8	11.68

Note: The test data are just a reference for your design.

3.3 TX power test

These data were tested on the SKY66114 entering the TX mode. There were two TX modes of the SKY66114 (the high-power mode and the low-power mode). The test results are shown in Fig 13 and Fig 14.

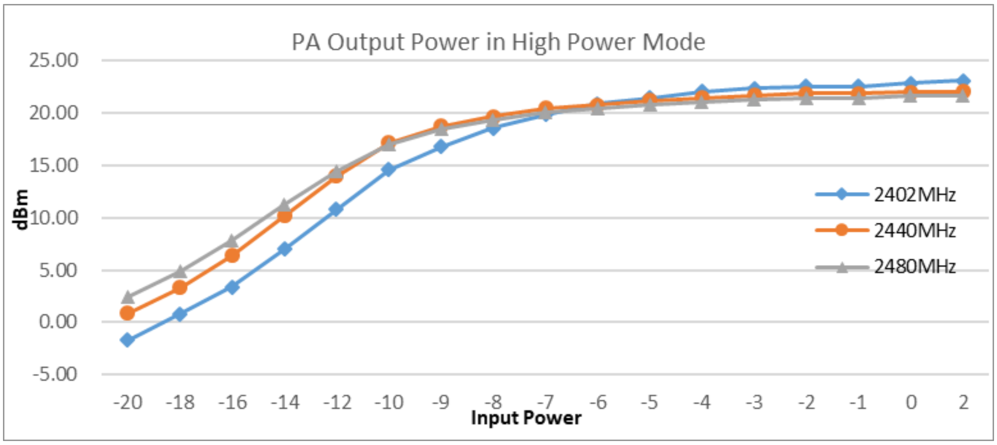


Fig 13. PA output power in high-power mode

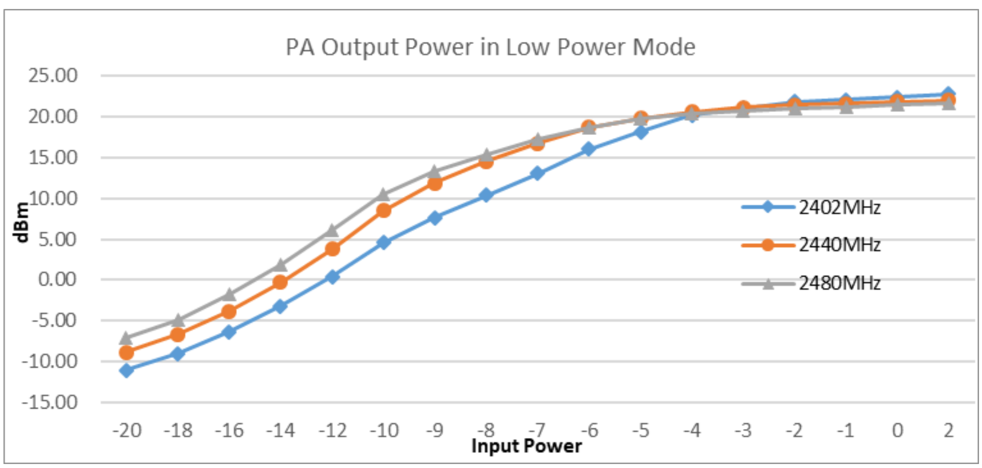


Fig 14. PA output power in low-power mode

4. Software design

According to the extender PA solution described above, there is a software example which must be added to the Bluetooth demo application.

4.1 GPIO pin setting

The QN9080 USB dongle with the PA board has two LEDs (LED1 and LED2) which need the GPIO control. There are five GPIOs which are used to control the PA chip SKY66114. The other pins are not occupied.

Add the GPIO pins defined in the *gpio_pin.c* file:

```
/* Declare Output GPIO pins */
gpioOutputPinConfig_t EXT_PAPins[] = {
                    {.gpioPort = gpioPort_A_c, /* EXT_PA_RXEN */
                     .gpioPin = 2U,
                     .outputLogic = 0,
                     .slewRate = pinSlewRate_Fast_c,
                     .driveStrength = pinDriveStrength_Low_c},

                    {.gpioPort = gpioPort_A_c, /* EXT_PA_TXEN */
                     .gpioPin = 3U,
                     .outputLogic = 0,
                     .slewRate = pinSlewRate_Fast_c,
                     .driveStrength = pinDriveStrength_Low_c},

                    {.gpioPort = gpioPort_A_c, /* LED1 */
                     .gpioPin = 4U,
                     .outputLogic = 0,
                     .slewRate = pinSlewRate_Slow_c,
                     .driveStrength = pinDriveStrength_Low_c},

                    {.gpioPort = gpioPort_A_c, /* LED2 */
                     .gpioPin = 5U,
                     .outputLogic = 0,
                     .slewRate = pinSlewRate_Slow_c,
                     .driveStrength = pinDriveStrength_Low_c},

                    {.gpioPort = gpioPort_A_c, /* EXT_PA_H_L_PWR */
                     .gpioPin = 10U,
                     .outputLogic = 0,
                     .slewRate = pinSlewRate_Fast_c,
                     .driveStrength = pinDriveStrength_Low_c},

                    {.gpioPort = gpioPort_A_c, /* EXT_PA_BYPASS */
                     .gpioPin = 11U,
                     .outputLogic = 0,
                     .slewRate = pinSlewRate_Fast_c,
                     .driveStrength = pinDriveStrength_Low_c},

                    {.gpioPort = gpioPort_A_c, /* EXT_PA_MODE */
                     .gpioPin = 13U,
                     .outputLogic = 0,
                     .slewRate = pinSlewRate_Fast_c,
```

```
                    .driveStrength = pinDriveStrength_Low_c}};
```

Add the GPIO pin-control macro defined in the *gpio_pin.h* file:

```
/*LED control define*/
#define  LED1_OFF()              GpioSetPinOutput(EXT_PAPins + 2)
#define  LED2_OFF()              GpioSetPinOutput(EXT_PAPins + 3)


#define  LED1_ON()               GpioClearPinOutput(EXT_PAPins + 2)
#define  LED2_ON()               GpioClearPinOutput(EXT_PAPins + 3)


/* SKY66114 control define*/
#define  EXT_PA_RX_EN()          GpioSetPinOutput(EXT_PAPins)
#define  EXT_PA_TX_EN()          GpioSetPinOutput(EXT_PAPins + 1)
#define  EXT_PA_PWR_EN()         GpioSetPinOutput(EXT_PAPins + 4)
#define  EXT_PA_BYPASS_EN()      GpioSetPinOutput(EXT_PAPins + 5)
#define  EXT_PA_MODE_EN()        GpioSetPinOutput(EXT_PAPins + 6)


#define  EXT_PA_RX_DIS()         GpioClearPinOutput(EXT_PAPins)
#define  EXT_PA_TX_DIS()         GpioClearPinOutput(EXT_PAPins + 1)
#define  EXT_PA_PWR_DIS()        GpioClearPinOutput(EXT_PAPins + 4)
#define  EXT_PA_BYPASS_DIS()     GpioClearPinOutput(EXT_PAPins + 5)
#define  EXT_PA_MODE_DIS()       GpioClearPinOutput(EXT_PAPins + 6)
```

4.2 Adding software initialization

After the software initialization is performed by the *main_task()* function, the *EXT_PA_User_Init()* function shall be added below the BLE host stack initialization. The *EXT_PA_User_Init()* function source code is:

```
void EXT_PA_User_Init(void)
{
        /* control pin init */
        (void)GpioOutputPinInit( EXT_PAPins , 7);

        /* set control pin output low */
        EXT_PA_MODE_DIS();          //disable PA mode
        EXT_PA_RX_DIS();            //disable RX
        EXT_PA_TX_DIS();            //disable TX
        EXT_PA_BYPASS_DIS();        //disable bypass mode
        EXT_PA_PWR_DIS();           //disable High power mode

        /* enable ble rx interrupt */
        NVIC_EnableIRQ(BLE_TX_IRQn);

        /* enable ble tx interrupt */
        NVIC_EnableIRQ(BLE_RX_IRQn);

        /* set tx power */
        RF_SetTxPowerLevel(SYSCON, kTxPower0dBm);
```

```
    /* 10ms for PA stable */
    volatile uint32_t delayX;
    for (delayX = 0; delayX < 80000; delayX++)
    {   ;   }
}
```

4.3 Adding BLE TX/RX interrupt handler

When the BLE starts the TX or RX, the BLE TX or RX interrupt is generated when the BLE TX and RX interrupts are enabled. Add this code into the interrupt handle to control the PA work status in the TX or RX modes.

```
/* BLE TX Interrupt */
void BLE_TX_IRQHandler(void)
{
   /* NXP: get ble status */
   uint32_t dbg_stat = *(volatile uint32_t*)0x40000080;

    if(dbg_stat & 0x0800)   //judge if ble is in transmit state
    {
        /* start of tx */
        EXT_PA_MODE_EN();     //enable PA mode
        EXT_PA_PWR_EN();      //enable High power mode
        EXT_PA_RX_DIS();      //disable RX
        EXT_PA_TX_EN();       //enable TX
        LED2_ON();            //LED2 ON
    }
    else
    {
        /* end of tx */
        EXT_PA_PWR_DIS();     //disable High power mode
        EXT_PA_TX_DIS();      //disable TX
        EXT_PA_RX_DIS();      //disable RX
        EXT_PA_MODE_DIS();    //disable PA mode
        LED2_OFF();           //LED2 OFF
    }
}

/* BLE RX Interrupt */
void BLE_RX_IRQHandler(void)
{
    /* NXP: get ble status */
   uint32_t dbg_stat = *(volatile uint32_t*)0x40000080;

    if(dbg_stat & 0x0400)   //judge if ble is in receive state
    {
        /* start of rx */
        EXT_PA_MODE_EN();     //enable PA mode
        EXT_PA_RX_EN();       //enable RX
        EXT_PA_TX_DIS();      //disable TX
        EXT_PA_PWR_DIS();     //disable High power mode
        LED1_ON();            //LED1 ON
```

```
    }
    else
    {
        /* end of rx */
        EXT_PA_PWR_DIS();      //disable High power mode
        EXT_PA_TX_DIS();       //disable TX
        EXT_PA_RX_DIS();       //disable RX
        EXT_PA_MODE_DIS();     //disable PA mode
        LED1_OFF();            //LED1 OFF
    }
}
```

5. Table of contents

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