SKYWORKS®

Skyworks FEMs for Smart Utility Metering and IoT

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Wireless metering applications for utilities, such as for smart cities, smart home, smart agriculture and asset management are growing in the industrial scientific and medical (ISM) bands. Wireless protocols such as Wireless Smart Utility Network (Wi-SUN®), Long Range (LoRa®) or wireless meter bus (WM-BUS), Bluetooth®, and wireless fidelity (Wi-Fi®) are commonly used for communication among nodes with mesh, star, or hybrid combination and their supported profiles extend the coverage up to 1000+ meters [1, 2, 3, 4]. As an example, the WM-BUS uses star topology while Wi-SUN uses multiple combinations of topologies. The various wireless smart metering protocols and their associated radio frequency of operation across multiple regions are given in Table-1.

#	Wireless protocol	Frequency range in MHz	ISM 169 MHz	ISM 450 MHz	ISM 900 MHz	ISM 2400 MHz	Notes
1	Wi-SUN®	450-527 779-787 863-869 902-928 2400-2485		✓	✓	✓	World-wide deployment; smart meters with regional variants for radio frequency (RF) power and frequency
2	LoRa® / WM-BUS	169, 433 (Asia) 868 (Europe) 915 (North America)	✓	✓	✓		169 MHz M-BUS for hard to reach places such as with water meters for range-reach up to 4 kms. LoRa for direct transportation of data from meter.
3	Bluetooth®	2400-2483.5				✓	Bluetooth® low energy applications.
4	Wi-Fi®	2400-2485				✓	Global support with multiple applications; re-uses existing wide area network (WAN) infrastructure.
5	LTE-M / NB-IoT, Cat-1/4	Ultra Low: 410-700 Low: 700-960 Mid: 1400-2200 High: 2300-2700		Non-ISM bands with Cellular networks			To transport data on long-term evolution (LTE) WAN directly from smart meters.
6	Anterix bands (LTE and others)	896-901 935-940			Non-ISM, adjacent to ISM-900		Private LTE and other narrow band channels, suitable for industrial and localized clusters.
7	GNSS L5/L1	1164-1189 (L5) 1559-1606 (L1)			Non-ISM bands as per GNSS constellations		Global navigation satellite system (GNSS) for smart city location services.

Table-1 Smart utility application protocols and frequencies

As illustrated in Figure-1 and the Skyworks whitepaper [5], "Enhancing Wi-SUN® Alliance Product Range with Skyworks RF Front End Modules," the Wi-SUN topology uses nodes (often called "motes") and are referred to as leaf, router and border-router nodes. Multiple personal area networks (PAN) form a Wi-SUN field area networks (FAN).

- The border-router node is the concentrator for WAN connectivity through Internet backhauls.
- The router nodes are flexible to operate in any mode.
- The leaf nodes are the Reduced Function Devices (RFD) or end nodes and participate in star topology with router and border-router nodes.

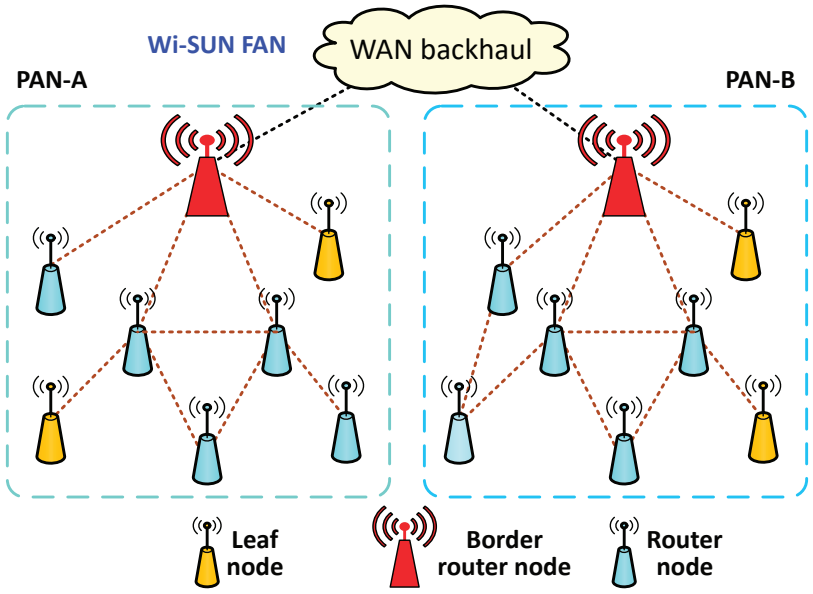


Figure-1 Wi-SUN network topology

Functionally, the border-router node will have WAN capability to communicate with the central service data centers. Such WAN would be any established Internet connection or through radio-links such as with cellular long-term evolution (LTE) or variants, LoRa, and in industrial settings in North America with Anterix bands. For remote location and for quick uninterrupted service, wireless WAN becomes necessity with longer reach. The need for dual mode such as with ISM and LTE in border node will be essential to re-use the nodes for flexible WAN connectivity without sending service personnel for rework and with new boxes. For easy identification of the location and tampering identification, GNSS location services as given in the Skyworks whitepaper [6] "Enhancing GNSS RF Signal Quality with Skyworks LNAs and FEMs" are also included with the nodes and the location may be activated remotely based on the service needs.

Under the Internet of Things (IoT) umbrella, Skyworks supplies high-performance, small footprint front end modules (FEM) operating in the ISM and licensed bands covering 169 to 2700 MHz for multiple wireless protocols and regions of the world for the emerging IoT and smart utility products. FEMs are composed of transmit (TX) and receive (RX) basic blocks such as power amplifier (PA), low noise amplifier (LNA), input/output matching networks, internal/external filters, switches/multiplexers, couplers and power detectors, and multiple antenna outputs offering many choices for engineers and developers.

Smart Utility Applications with FEM

Figure-2 illustrates high-level blocks of a smart meter that uses a system on chip (SoC) and FEM. The illustration includes a generic micro-controller unit (MCU) and a wireless processor. It is also common to see wireless and RF systems in separate functional modules. The MCU interfaces with the wireless modules using serial interfaces such as a universal asynchronous receiver-transmitter (UART).

Based on the protocols and scalability of the product for multiple protocols, such as in border routers, there could be an application-processor that performs multiple management functions. In Figure-2, the MCU manages the interfaces, power management, clocks, and low power modes. The wireless processor works with wireless protocols and manages the low-power RF sections.

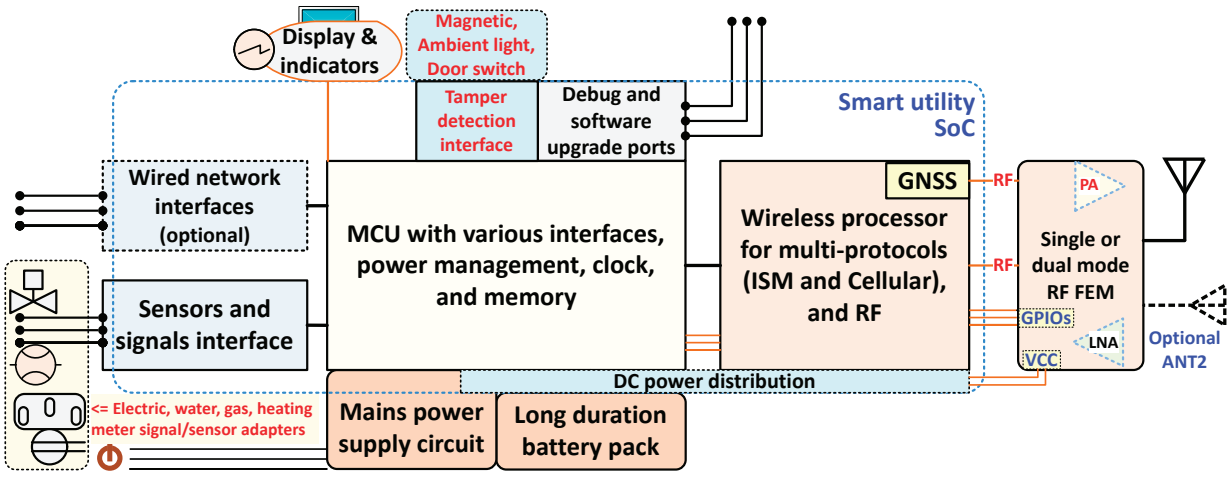


Figure-2 Application of FEM with SoC

RF power from the wireless section of the SoC is efficient up to -10 dBm to 4 dBm, and may require an efficient external RF FEM to extend the RF range. Some SoCs support up to 16 dBm but the efficiency of these SoC generated RF power is lower than a direct RF FEM.

Skyworks RF FEMs support up to 30 dBm to 33 dBm with power added efficiency (PAE) of 40% to 50%, suitable for efficient, extended range. Examples of range and FEM efficiency benefits are given in Skyworks whitepaper [7] "RF Front-End Modules Boost Wireless Performance" for Bluetooth® signal applications. There is greater savings in using a FEMs for smart meters, as wireless meters use up to 30 dBm transmit power to account for various deployment environments that may be hidden behind concrete walls or in metal enclosures.

The MCU will interface with multiple wired and wireless interfaces. Among wireless interfaces, multiple protocols may be provisioned for re-use of the device with various configurations. For various benefits stated in the previous sections, the FEM would interface with RF sections of the SoC and gets controlled through general purpose input/output (GPIOs), and inter-integrated circuit (I2C) interface.

Some Skyworks FEMs are provisioned with a dual antenna. When space is available, two antennae, preferably oriented 90 degrees to each other, will maximize performance. Based on the smart utility box mounting, one or both antennae will get a good signal.

The SoC received signal strength indicator (RSSI) function decides which antenna port to use. This operation could be automated or set with remote configurations. With dual mode FEMs, dual antenna usage may be time multiplexed between smart utility and WAN link.

Skyworks ISM FEM Key Features (860-960, 400-500, 169-170 MHz)

Among the ISM bands, ISM-900 is widely used for metering and utilities. The key features and benefits of the Skyworks ISM-900 FEMs are as follows.

- Frequency channels that support from 860-960 MHz
- Miniature devices with options consisting of TX power amplifier, RX low noise amplifier, bypass, internal and external filters, switches, and TX forward and reverse power detectors
- Support of multiple modes TX, RX, bypass, and sleep/shutdown
- TX power from 20 dBm to 33 dBm and TX gain from 16 dB to 36 dB to keep flexible SoC interface
- LNA gain combinations in the range of 12 dB to 18 dB
- Low RX system noise figure (NF) 1.5 dB
- Linearity across wide input ranges, as specified through the third order input intercept point (IIP3), out of band IIP3 (OOB IIP3), and 1 dB compression point (IP1dB)
- Supply voltage range capability from 2 V to 5 V
- Very low leakage current in sleep/shutdown mode that extends battery life
- Dual antenna for extended range coverage through antenna switching
- Simpler digital control to manage FEMs using 2 to 4 digital control lines

The Skyworks FEMs in 169-170 MHz, and 400-500 MHz also support higher power up to 30 dBm with many features commonly shared with ISM-900 FEMs. Table-2 provides a list of the part numbers and key specifications for multiple ISM family FEMs. Refer to the individual data sheets parametric information such as linearity characteristics.

#	Data-sheet	Skyworks Part number	PA	LNA	Ant1, Ant2	Package (mm x mm)	Frequency (MHz)	Tx Pout (dBm)	Tx Gain (dB), Icc (mA) @Pout (dBm)	Tx bypass loss (dB)	LNA gain/NF(dB), Icc (mA)	Rx bypass loss (dB)	Sleep Icc (µA)	Mode switching time (µs)	VDD/VCC (volts)
1		RFX1010	✓	✓	Ant 1	3 x 3	780-960	27	28, 350@27	NA	14/3, 16 12/3.5, 10	NA	1	1	2.7-3.6
2		SE2435L-R	✓	✓	Ant 1 Ant 2	4 x 4	860-930	30	26, 550@30 26, 275@24	NA	16/2, 6	2	< 1	< 1	2.0-4.8
3		SKY65111-348LF	✓		RF OUT	3 x 3	600-1100	33	36, 700@29.5	NA	NA	NA	< 10	NA	2.5-5.0
4		SKY65362-11	✓	✓	Ant 1 Ant 2	6 x 6	900-930	30.5	33, 515@30.5	NA	16/2.5, 6	3	0.05	< 11	3.0-5.25
5		SKY65364-11	✓	✓	Ant 1	6 x 6	890-960	30.5	21.9, 730@30	NA	16/1.7, 20	0.9/3	0.03	0.5	Tx: 3.4-3.8 Rx: 3.0-3.45
6		SKY65364-21	✓	✓	Ant 1	6 x 6	890-960	30	16, 680@30	NA	15/1.5, 12	0.5/3	0.50	0.5	Tx: 3.4-3.8 Rx: 3.0-3.45
7		SKY66101-11	✓	✓	Ant 1 Ant 2	6 x 6	902-928	30	33, 670@30	NA	16/2.5, 6	3	< 1	< 1	2.0-4.8
8		SKY66105-11	✓		Ant 1 Ant 2	6 x 8	902-931	30	29, 450@29	NA	NA	0.7	< 10	1-2	2.0-4.8
9		SKY66122-11	✓	✓	Ant 1	6 x 6	863-928	30	30, 640@30	NA	16/2.5, 6.5	NA	< 1	1-3	3.0-5.0
10		SKY66420-11	✓	✓	Ant 1	3 x 3	860-930	27	16, 280@27	< 1.5	18/1.5, 5	NA	< 1	Tx: < 2 Rx: < 4	2.0-4.8
11		SKY66421-11	✓		Ant 1	3 x 3	860-930	27	16, 280@27	NA	NA	0.6	< 1	< 1	2.0-4.8
12		SKY66422-11	✓	✓	Ant 1	3 x 3	860-930	22	20, 80@20	2.2	17/1.7, 4	NA	0.40	Tx: 20/0.2 Rx: 10/4	2.5-3.6
13		SKY66423-11	✓	✓	Ant 1	3 x 3	860-930	27	29, 280@27	< 1.5	18/1.5, 5	NA	< 1	Tx: 2 Rx: 4	2.0-4.8
14		SKY66100-11	✓		Ant 1	4 x 4	169-170	27	32, 325@27	0.9	NA	0.4	< 1	< 1	2.0-3.6
15		SKY66121-11	✓		Ant 1	4 x 4	169-170	30	39, 600@30	NA	NA	w/ filter 0.9	< 1	1	2.0-4.0
16		SKY65366-21	✓	✓	Ant 1	6 x 6	400-500	30.2	20, 780@30	2	21/1.8, 12	2	0.30	0.5	Tx: 3.7-4.0 Rx: 3.0-3.45
17		SKY66119-11	✓	✓	Ant 1	6 x 6	450-470	30.5	25, 740@30	1.8	15.5/1.3, 5	2.3	0.03	0.5	Tx: 3.4-3.8 Rx: 3.0-3.8

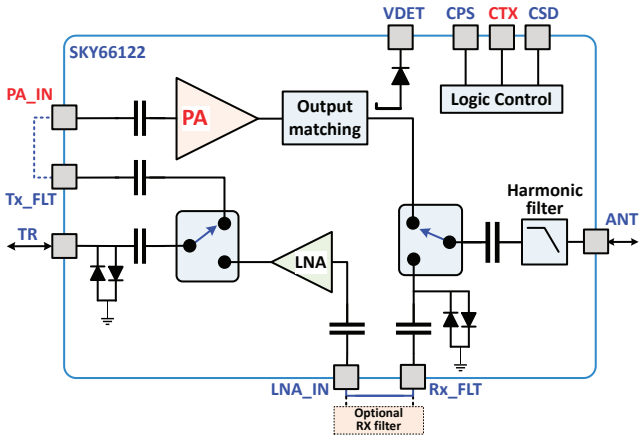
Table 2. ISM-900 family FEMs for Wi-SUN (NA indicates not applicable)

Functional hardware block diagrams grouped by hardware configuration for the devices listed in Table-2 are shown as follows.

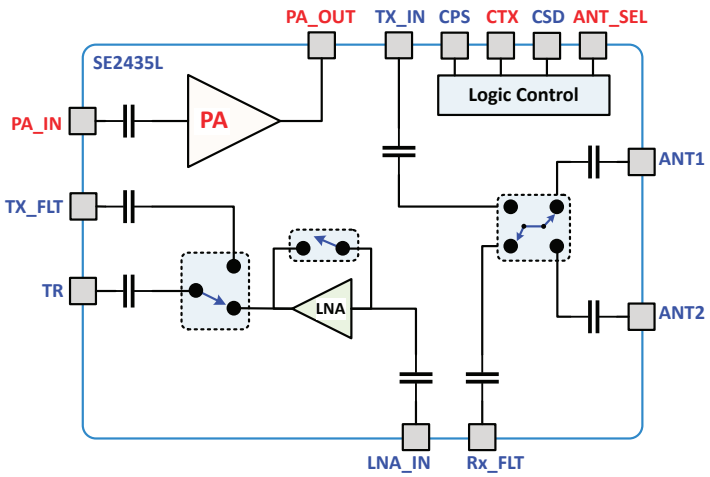
ISM-900 (860-930/960 MHz) FEM Architecture

Efficient FEMs optimize communication within the network, and across multiple networks for longer distances, saving communication time, and increasing network throughput. Popular ISM-900 FEM architectures are illustrated below. Refer to the individual data sheets for more details. Contact Skyworks for custom FEMs covering specific applications/protocols and frequency bands.

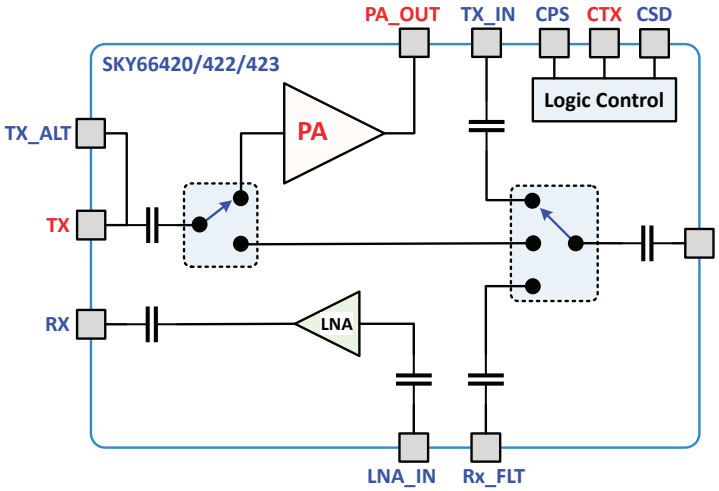
SKY66122



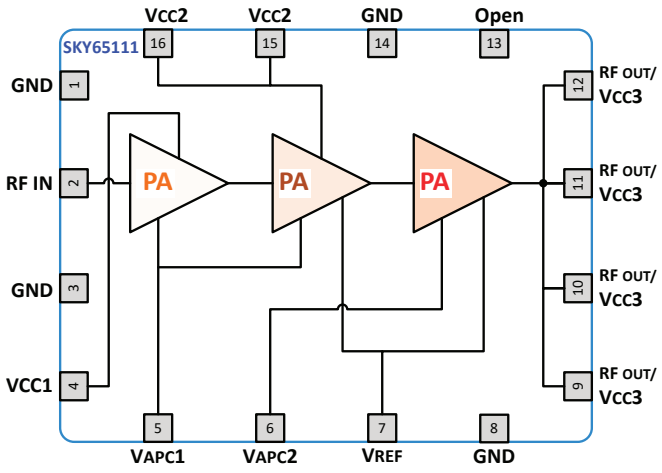
SE2435L



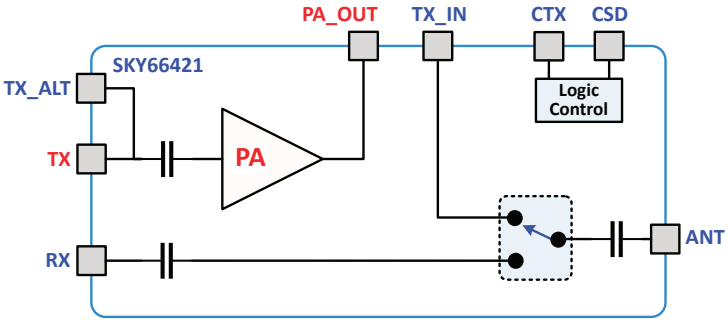
SKY66420, SKY66422, SKY66423



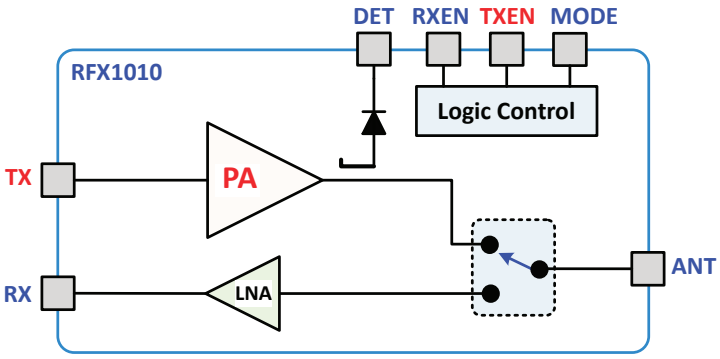
SKY65111



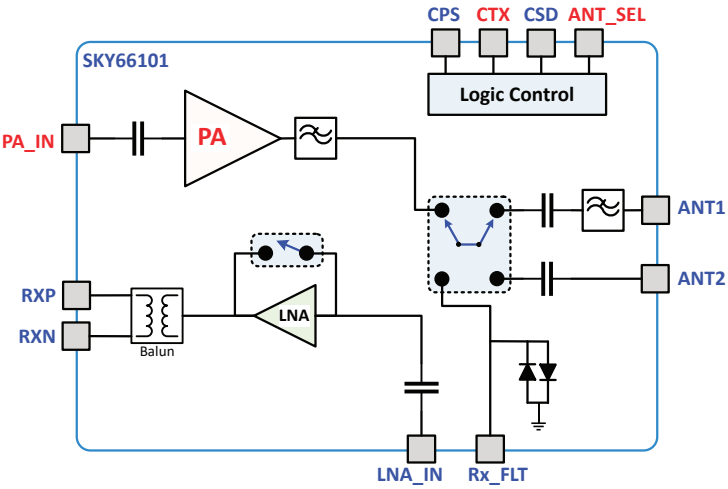
SKY66421



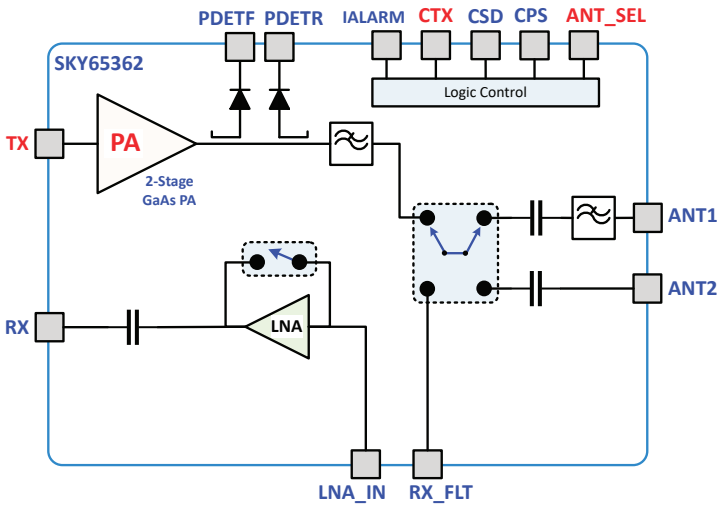
RFX1010



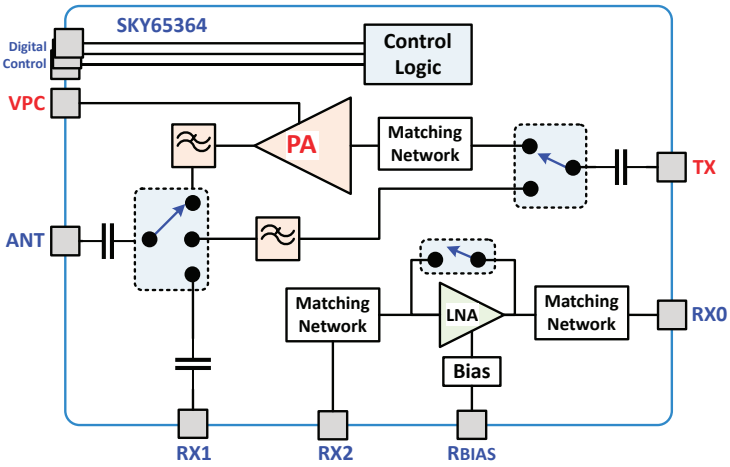
SKY66101



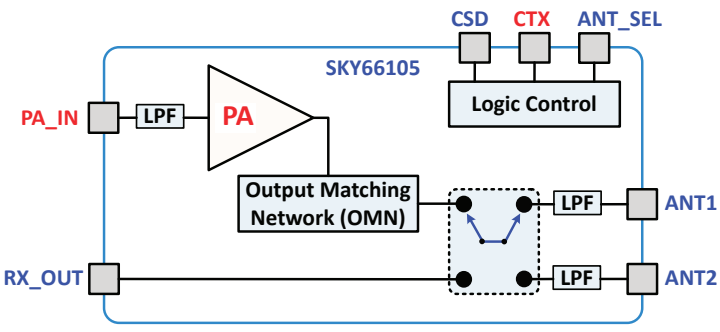
SKY65362



SKY65364-11, SKY65364-21

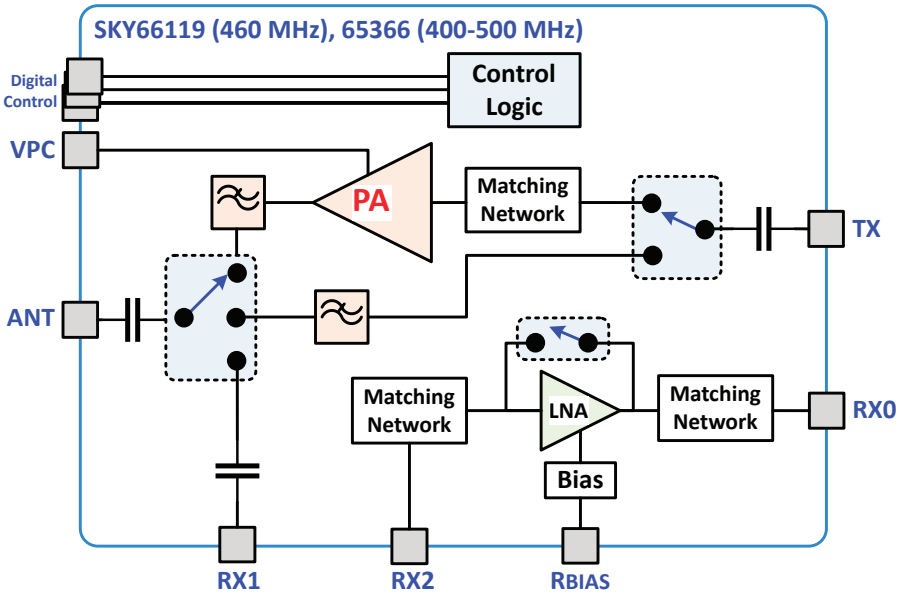


SKY66105

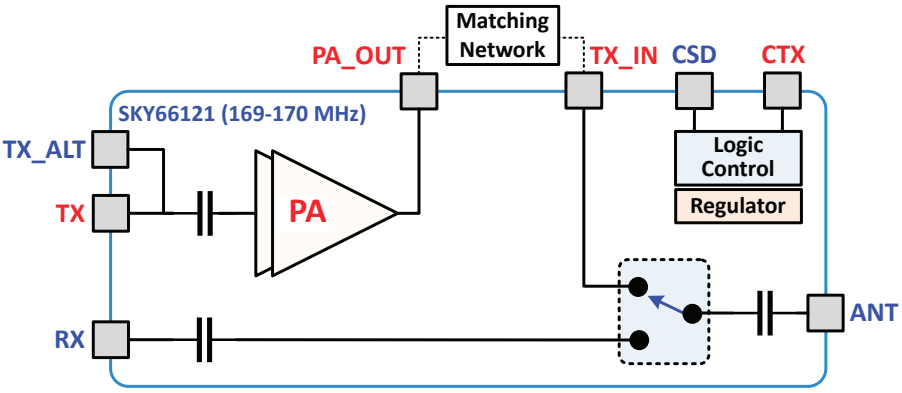


400–500, 169–170 MHz FEM Architecture

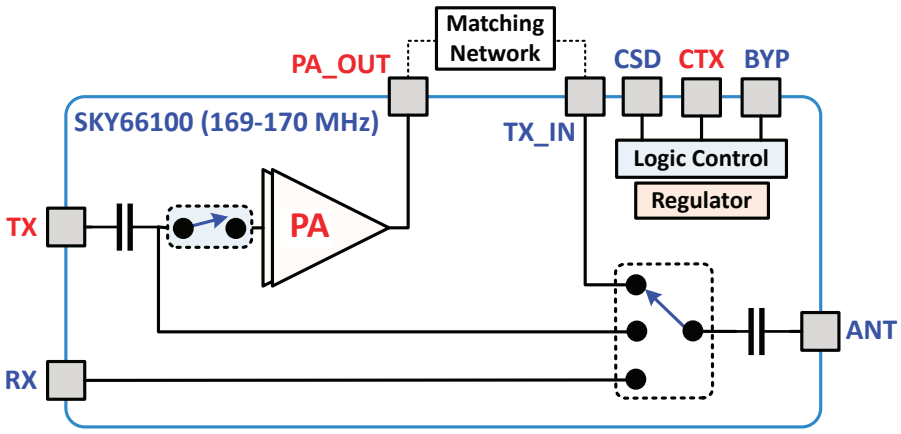
SKY66119 (450–470 MHz), SKY65366 (400–500 MHz)



SKY66121 (169–170 MHz)



SKY66100 (169–170 MHz)



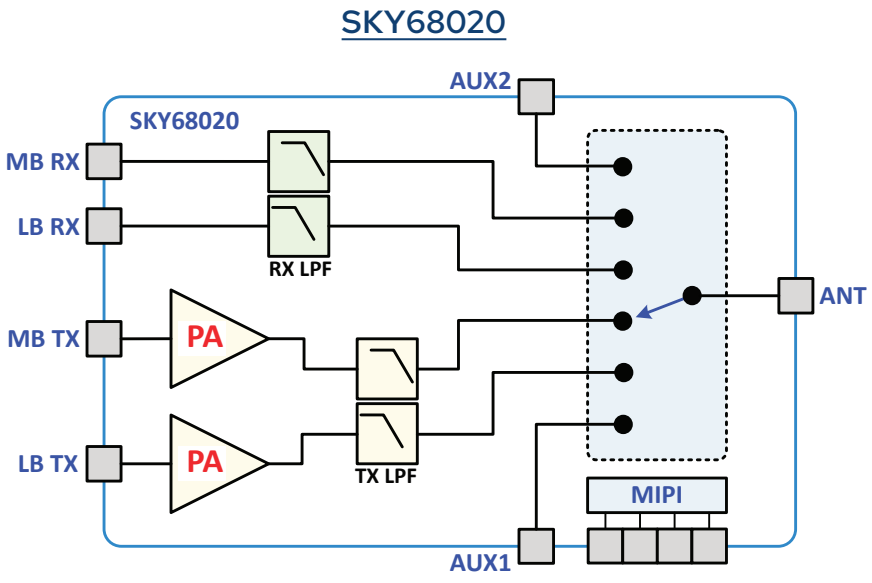
LTE-M FEMs and LTE Modules

Below are the commonly used FEMs for LTE-M and LTE modules used in IoT and metering applications. Refer data sheets for multiple cellular Skyworks FEMs.

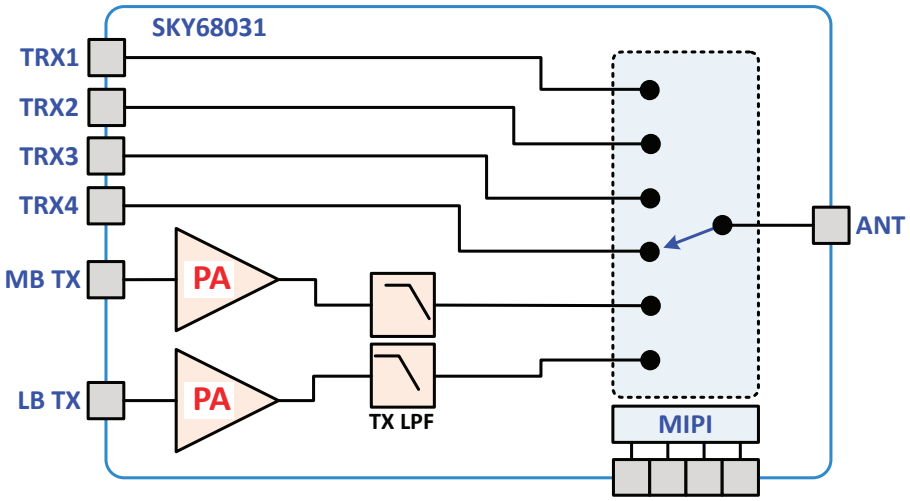
#	Data-sheet	Skyworks Part number	PA	LNA	Ant1, Ant2	Package (mm x mm)	Frequency (MHz)	Tx Pout (dBm)	Tx Gain (dB), Icc (mA) @Pout (dBm)	Tx bypass loss (dB)	LNA gain/NF(dB), Icc (mA)	Rx bypass loss (dB)	Sleep Icc (µA)	Mode switching time (µs)	VDD/VCC (volts)
1		SKY68020-11	✓		Ant 1	4 x 5	Tx: 663-915 / 1695-1980	24	25.5, 300@24	0.4-0.6	NA	w / filter: 2	0.40	5	2.85-4.5 VIO: 1.65+
2		SKY68031-11	✓		Ant 1	3 x 3	Tx: 699-915 / 1695-1980	23.5	25.5, 325@23.5	0.4-0.6	NA	0.4-0.6	0.40	5	2.85-4.5 VIO: 1.65+
3		SKY68040-11 MMPA	✓		RFO_LB RFO_HB	3 x 4.2	663-915 / 1626-2020	26.5	29.5, 300@26.5	NA	NA	NA	few µA	NA	2.8-4.2
4		SKY66431	✓		Ant 1	8.8 x 11.3	698-2200	23	NA	NA	NA	0.4-0.6	1	LTE complaint	< 5.5
5		SKY66425-11 Dual mode (ISM + LTE/ Anterix)	✓	✓	Ant1 Ant2	6 x 7	863-940 / 699-2170	29	30, 360@27	0.6-0.7	18/1.6, 4.8	1.4	< 1	1-2	2.5-4.8

Table-3 Skyworks LTE-M FEMs, and LTE fully integrated modules

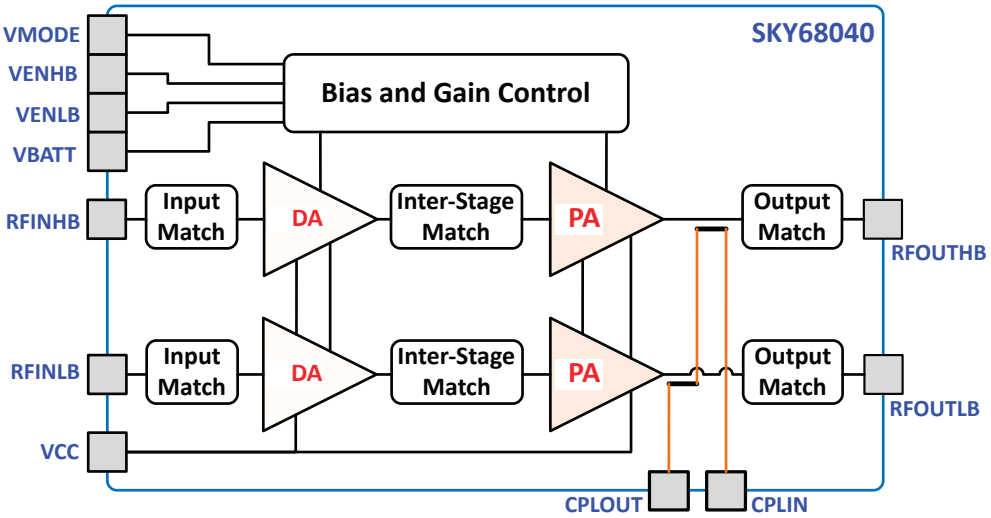
Functional hardware block diagrams grouped by hardware configuration for the devices listed in Table-3 are given here.



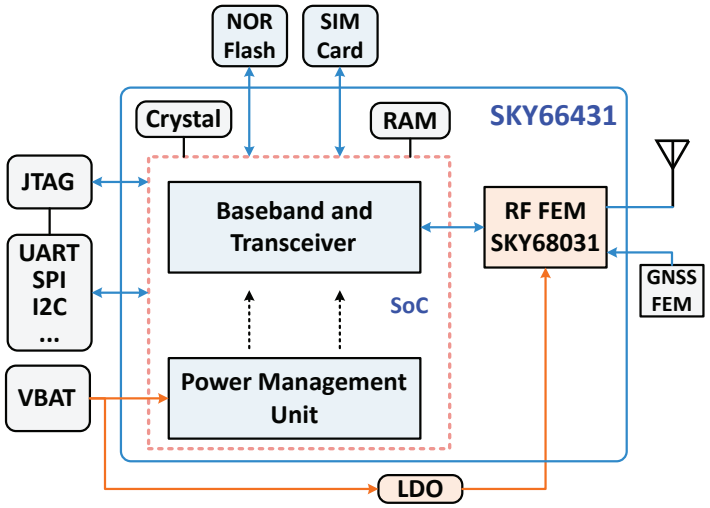
SKY68031



SKY68040



SKY66431 (SiP with SKY68031 iFEM)



Dual (ISM + LTE) Mode FEM

The SKY66425 dual mode FEM will support multiple modes for ISM band, Anterix [8], LTE low- and mid-band.

- Anterix bands: [896-901], [935-940] MHz.
- ISM + Anterix band: 863-940 MHz (includes Anterix band on both band edges of ISM band).
- LTE/LTE-M on transmit-receive (TRX): [699-2170] MHz, and TRX port can also be used for LTE band-71.

The top-level modes of operations are given here.

- Low power RF signal for ISM, and Anterix would be fed from ISM-900 SoC or LTE SoC. The low-band PA. supports up to 27 dBm. Anterix band uses higher power than regular LTE applications of 23 dBm.
- ISM RX operation through LNA or LNA bypass.
- Anterix RX, LTE_TRX would use TRX bypass path.
- ANT1/ANT2 with 2-pole 3-throw (2P3T) switch provides maximum flexibility to use ISM-900, LTE (low-mid- bands), and Anterix.

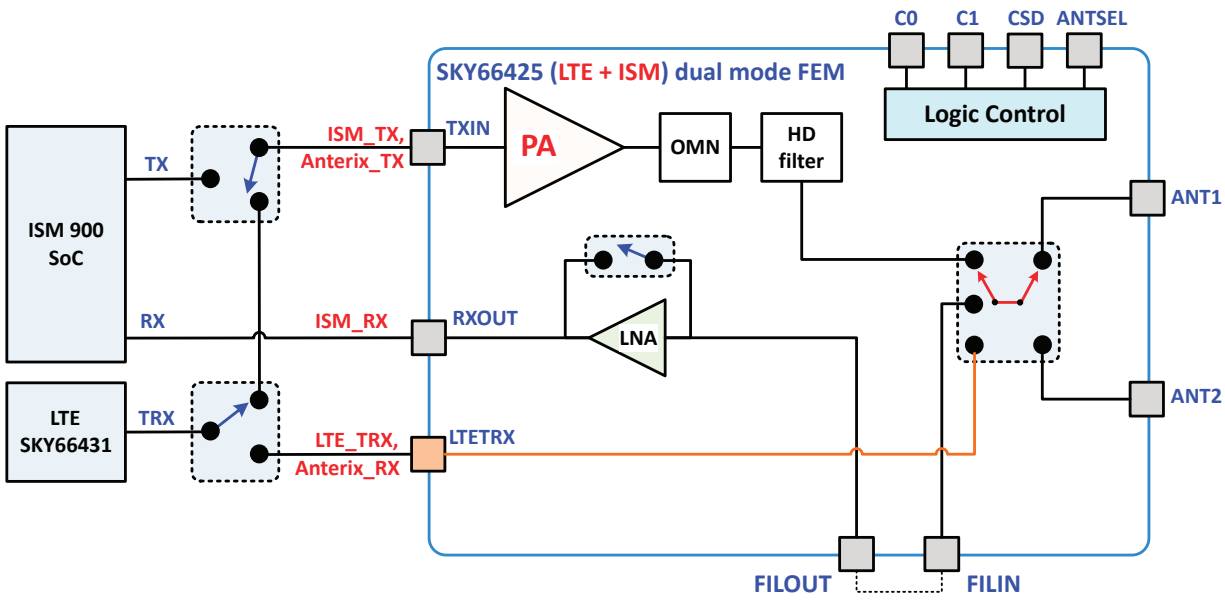


Figure-3 Typical SKY66425 application diagram used for ISM, LTE, and Anterix bands.

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2. What is the Wi-SUN Alliance? https://wi-sun.org/
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6. Enhancing GNSS RF Signal Quality with Skyworks LNAs and FEMs. https://www.skyworksinc.com/-/media/SkyWorks/Documents/Whitepapers/Skyworks_GNSS_Whitepaper.pdf
7. RF Front-End Modules Boost Wireless Performance. https://www.skyworksinc.com/-/media/SkyWorks/Documents/Whitepapers/Skyworks_Bluetooth_whitepaper.pdf
8. Anterix is modernizing industrial communications through Private LTE. https://anterix.com/the-key-to-private-lte/

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