APPLICATION NOTE

PART AN95021
433MHz front-end with the SA601 or
SA620

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ABSTRACT

Although designed for 1GHz, the SA601 and SA620 can also be used in the 433MHz ISM band. The SA601 performs amplification of the antenna signal and down conversion to a first IF. The SA620 has the same functionality, but also has a VCO on-chip. This VCO drives the mixer, so no external LO signal is required.

Applying the SA601 or SA620 means that a receiver with high sensitivity and wide dynamic range can be built without a lot of external components. The design will be easier compared with discrete Front Ends.

Combined with an IF system like the SA676, a high performance dual conversion receiver can be built. This receiver can operate from 2.7 to 5.5V allowing the use of a 3-cell battery. IF frequencies can be chosen according to one's needs with a maximum first IF of 100MHz and a maximum second IF frequency of 2MHz.

This application note explains how to use the SA601 or SA620 at 433MHz. The performance at 433MHz is discussed. The application circuit diagrams that are used to obtain the measurement results are shown.

CONTENTS

1. INTRODUCTION

The SA601 and SA620 address high performance applications at 1GHz like cellular and cordless phones. The SA601 comprises a Low Noise Amplifier (LNA) and a Mixer. The SA620 comprises, besides an LNA and Mixer, a VCO (Voltage Controlled Oscillator). Although intended for 1GHz, it is possible to apply these Front-Ends at lower frequencies.

This paper describes the performance of these devices at 433MHz. This band is being used for remote control systems, car alarms, telemetry, wireless audio links, etc.

By using the SA601 or SA620 followed by, for example an SA676 FM IF, a low voltage, high performance receiver for FM, AM, FSK, ASK demodulation can be built. The Front-Ends require only a few passive components for decoupling and signal handling. No extra circuitry is required for compensation for temperature and power supply variations. This will ease your 433MHz receiver design without trading off performance, and give you fast time to market.

2. SA601

The SA601 comprises a 1.2GHz LNA and Mixer. The block diagram is shown in Figure 1. In a receiver it performs the amplification of the antenna signal and the down conversion to the first IF frequency. This signal can then be handled by an IF system like the SA676 which takes care of AM and FM demodulation.
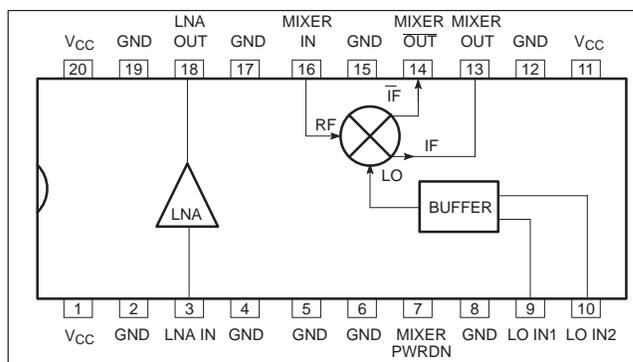

Figure 1. SA601 Block Diagram

Using the SA601 at 433MHz will show the following differences compared to the performance at 900MHz:

- The LNA will show a higher gain while having the same Noise Figure (NF)

- Because of this higher gain, the Intercept point (IP3) becomes less

The higher gain increases the sensitivity of the receiver. It also offers the possibility to allow some mismatch at the LNA input and hence, some gain loss. This means that a 50Ω source can be connected directly to the LNA input without matching. In case you do want to calculate the matching circuits for the LNA and mixer input, Table 1 shows the S-parameters of the LNA and mixer input at 433MHz.

The IP3 performance of the SA601 at 433MHz is worse than at 1GHz. However, it is still more than sufficient for applications in the 433MHz band.

Table 1. SA601 and SA620 S-parameters

	LNA				Mixer
	S_{11}	S_{22}	S_{21}	S_{12}	S_{11}
	R + j X	R + j X			R + j X
433MHz	34.0Ω - 62.8Ω	55.1Ω - 47.4Ω	5.4U ∠ 128°	62mU ∠ 68°	9.9Ω + 5.4Ω

433MHz front-end with the SA601 or SA620

AN95021

2.1 Application circuit

The application circuit diagram is shown in Figure 2.
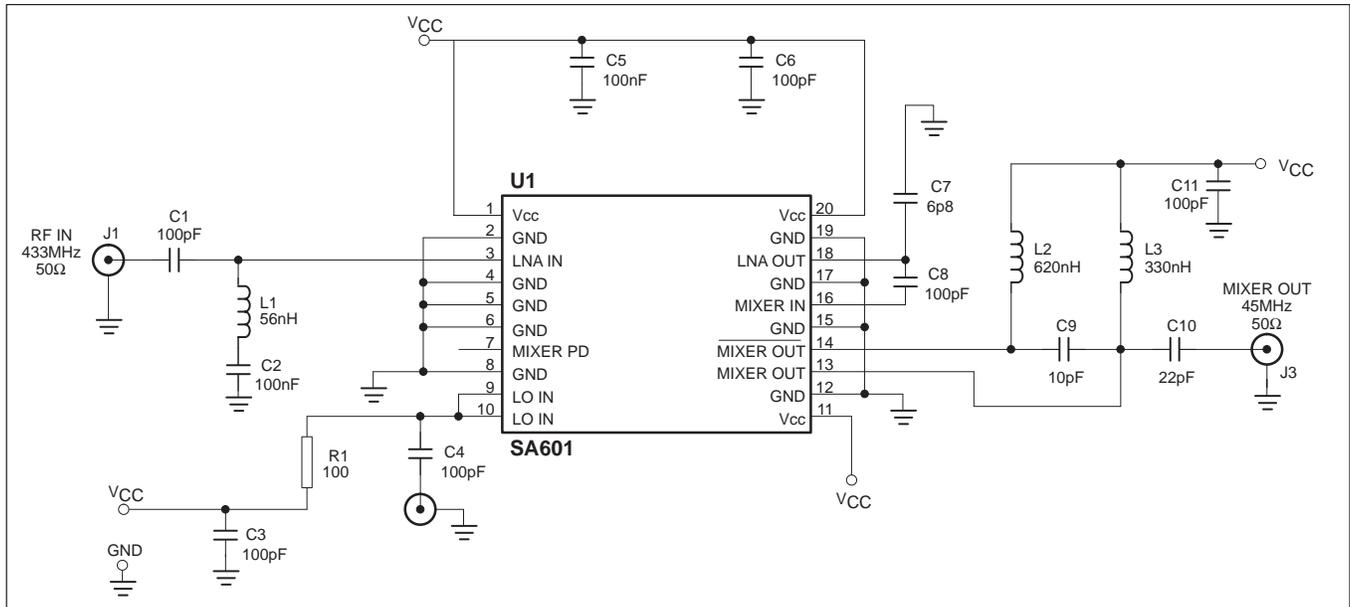
Figure 2. Application Circuit Diagram

Table 2. SA601 Application Components

C1	DC blocking	C9	Mixer output current combiner
C2	Time constant for LNA compensation loop	C10	Mixer output match to 50Ω load
C3	V_{CC} decoupling	C11	V_{CC} decoupling
C4	DC blocking	R1	LO input match
C5	Vcc decoupling	L1	AC blocking
C6	Vcc decoupling	L2	Mixer output current combiner
C7	LNA to Mixer input match	L3	Mixer output current combiner
C8	DC blocking		

Table 2 shows that most of the external components are for blocking DC at the in- and outputs and decoupling of the power supply. In your actual receiver the DC-blocking capacitors for RF IN, LO IN and MIXER OUT can be removed if there is no DC path present.

Capacitor C2 determines the bandwidth of the compensation loop of the LNA. The LNA is stabilized for temperature and power supply variations. To achieve a compensation loop which controls the LNA gain, the bandwidth of this control loop must be low compared to the actual input frequency. Otherwise the compensation loop and, thus, the LNA gain would be affected by the RF input signal.

To isolate C2 from the LNA input for 433MHz signals an inductor L1 is included. This forms a short for the compensation loop frequencies and an open for the 433MHz frequencies.

If there is already a DC path at the LNA input (J1) to ground, then L1 and C2 can be omitted. In that case C1 must be increased to

100nF. C1 has two functions then: block DC from the LNA input, and determine the bandwidth of the compensation loop.

The LNA output is matched to the Mixer input with a 6.8pF capacitor (C7) to ground and a series inductor of 9nH. This inductor is realized by the traces between LNA out and Mixer and the inductance of C8.

The SA601 mixer has differential outputs. This means that a direct interface with a symmetrical filter or symmetrical gain stage is possible. However, most filters are asymmetrical, therefore, a transformation from differential to single-ended is required. With a current combiner circuit[1], the differential output currents are shifted such that they are in phase. These currents are then combined to create a single-ended output. L2, L3 and C9 form this current combiner circuit.

The inductor can be calculated as follows:

- Choose a value for C9: 10pF

- F is 45MHz

- Calculate L for appropriate current combining

$$F = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot 2 \cdot C}}$$

$$L = \frac{1}{(2 \cdot \pi \cdot F)^2 \cdot 2 \cdot C} = \frac{1}{(2 \cdot \pi \cdot 45\text{MHz}) \cdot 2 \cdot 10\text{pF}}$$

$$L = 625\text{nH}$$

1. A current combiner circuit for better mixer conversion gain, Sheng Lee, Alvin K. Wong, Michael G. Wong, Philips Semiconductors

433MHz front-end with the SA601 or SA620

AN95021

Figure 3 shows the implementation of the calculated component values.
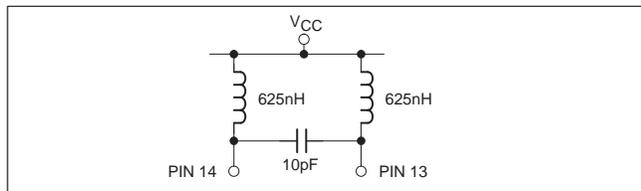

Figure 3. Current Combiner Circuit

After designing the current combiner circuit, the next step is to match the mixer output to the impedance of the load. In the application circuit the load is assumed to be 50 Ω. This is done to make evaluation more simple since most RF measurement equipment have 50 Ω inputs.

In addition to the impedance of the load (50 Ω), it is also important to know what the optimum load impedance is for the mixer output. For the SA601 mixer output this is 600 Ω. To create a matching from 600 to 50 Ω the circuit from Figure 4 is applied.
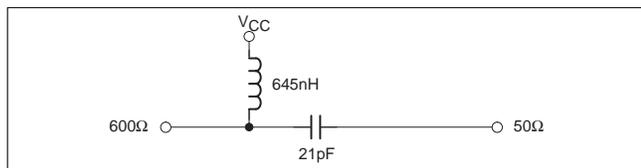

Figure 4. Mixer Output Match to 50Ω Load

The circuits from Figures 3 and 4 can be merged into one circuit as is shown in Figure 5. The values between brackets are the actual component values applied in the application circuit diagram.
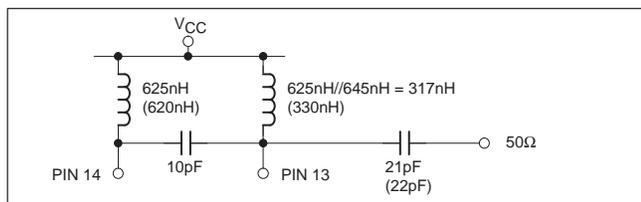

Figure 5. Mixer Output Circuitry With Current Combiner and 50Ω Matching

2.2 Measurement Results
For the measurements a power supply of 3V is applied. The RF frequency is 433MHz and the LO frequency is 478MHz with a level of -7dBm.

The current consumption of this application is 7.8mA.

2.2.1 Conversion gain, Noise Figure and IP3
In Table 3 the performance of the LNA and mixer is shown together with the overall performance.

Table 3. LNA, Mixer Measurement Results

	LNA	Mixer	LNA & Mixer	Units
Gain	15.4	9.2	24.7	dB
Noise Figure	1.5	12	2.5	dB
IIP3	-14.3	+1.7	-18.1	dBm

The results show that this Front-End offers 25dB of power gain with a noise figure contribution of only 2.5dB at 433MHz.

2.2.2 Isolation
Another important parameter for a Front-End receiver is the isolation between the Local Oscillator and the Antenna (LNA input). For 433MHz applications the requirement[2] is that spurious signals generated by the receiver have a maximum level of -57dBm for frequencies below 1GHz. The LO level measured at the LNA input is -53dBm. This means only 4dB extra suppression is required to meet the requirements. Because the Local Oscillator is offset 45MHz of the RF frequency, a simple bandpass filter, or the selectivity of the antenna, is already sufficient.

3. SA620
The SA620 comprises a 1.2GHz LNA, Mixer and VCO. The block diagram is shown in Figure 6. In a receiver the SA620 performs the amplification of the antenna signal and the down conversion to the first IF frequency. The VCO can be part of a phase-lock-loop or set to a fixed frequency by using a resonator. The output signal of the mixer can be handled by an IF system like the SA676 which takes care of AM and FM demodulation.

The S-parameters of the LNA and mixer input are the same as for the SA601. These parameters are shown in Table 1.

The LNA performance of the SA620 is the same as for the SA601. The mixer performance, however, is different. This is due to the output structure of the mixer. Figure 6 shows that there is one mixer output. Remember the SA601 has 2 mixer outputs which were combined using the current combiner circuit. Therefore, the mixer conversion gain is higher for the SA601 mixer. Furthermore, the SA620 incorporates a buffered VCO output (Pin 11) which can be used to drive the input of a frequency synthesizer.

3.1 Application circuit
Figure 7 shows the application circuit for a 433MHz receiver with a 478MHz VCO design.

2. ETSI I-ETS 300 220 Annex A.1.3.
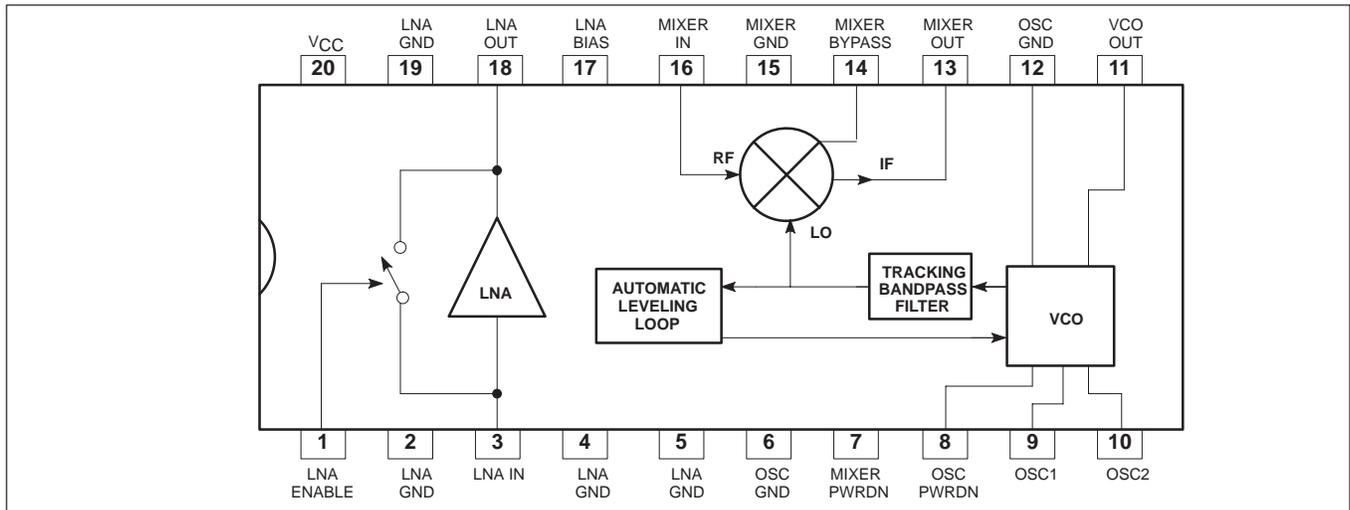
Figure 6. SA620 Block Diagram
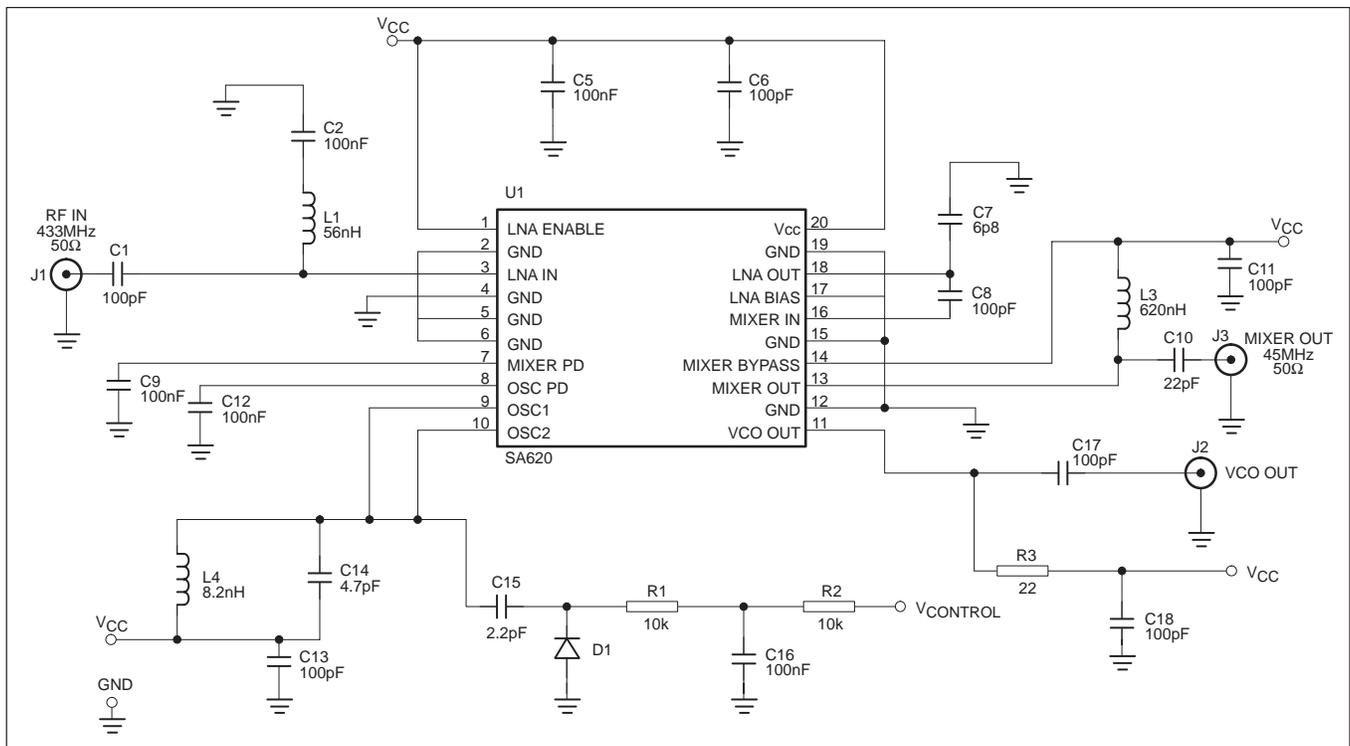
Figure 7. Application Circuit Diagram

Table 4 shows that most of the external components are for blocking DC at the in- and outputs and decoupling of the power supply. In your actual receiver the DC-blocking capacitors for RF IN, LO IN and MIXER OUT can be removed if there is no DC path present.

As with the SA601 capacitor, C2 determines the bandwidth of the compensation loop of the LNA. The LNA is stabilized for temperature and power supply variations. To achieve that a

compensation loop controls the LNA gain. The bandwidth of this control loop must be low compared to the actual input frequency. Otherwise the compensation loop and, thus, the LNA gain, would be affected by the RF input signal. To isolate C2 from the LNA input for 433MHz signals, an inductor L1 is included. This forms a short for the compensation loop frequencies and an open for the 433MHz frequencies.

Table 4. SA620 Application Components

C1	DC blocking
C2	Timeconstant for LNA compensation loop
C5	V_{CC} decoupling
C6	V_{CC} decoupling
C7	LNA to Mixer input match
C8	DC blocking
C9	Mixer Bias decoupling
C10	Mixer output match to 50 Ω load
C11	V_{CC} decoupling
C12	VCO Bias decoupling
C13	V_{CC} decoupling
C14	Tuning capacitor
C15	Limits tuning range of VCO
C16	Filters noise at $V_{control\ line}$
C17	DC blocking
C18	V_{CC} decoupling
L1	AC blocking
L3	Mixer output match to 50 Ω load
L4	Tuning inductor
R1	Prevents loading of Tank circuit by the $V_{control\ line}$
R2	Filters noise at $V_{control\ line}$
D1	Varactor SMV 1204-099 Alpha Industries

If there is already a DC path at the LNA input (J1) to ground, then L1 and C2 can be omitted. In that case, C1 must be increased to 100nF. C1 has two functions then: block DC from the LNA input, and determine the bandwidth of the compensation loop.

The LNA output is matched to the Mixer input with a 6.8pF capacitor (C7) to ground and a series inductor of 9nH. This inductor can be realized by the traces between LNA Out and Mixer In and the parasitic inductance of C8.

The mixer output is matched to 50 Ω at 45MHz with L3 and C10.

The VCO output, Pin 11, delivers -20dBm into a 50 Ω load. The output level is set with R3. A lower output level can be achieved by reducing the value of this resistor. A higher value for R3 is not recommended because this will affect the VCO performance.

The components that determine the actual frequency of the VCO are L4, C14, C15 and D1 according to:

$$F = \frac{1}{2 \cdot \pi \cdot \sqrt{L4 \cdot \left(C14 + \left(\frac{C15 \cdot CD1}{C15 + CD1}\right)\right)}}$$

Figure 8.

The formula shows that the influence of the varactor D1 on the VCO frequency depends on the value of C15. That means that, if the

tuning range of the VCO is too wide, it can be scaled back by reducing the value of C15.

The SA620 VCO can easily oscillate from 300 to 1.2GHz, so it is important to have only one resonance circuit at Pins 9 and 10. Also, parasitic resonances must be prevented, which can be accomplished by putting the components close to Pins 9 and 10, and by decoupling the power supply close to L4 and C14.

3.2 Measurement Results
For the measurements a power supply of 3V is applied. The RF frequency is 433MHz and the VCO frequency is tuned to 478MHz.

The current consumption of this application is 11.3mA.

3.2.1 Conversion gain, Noise Figure and IP3
In Table 5 the performance of the LNA and mixer is shown together with the overall performance.

Table 5. Measurement Results

	LNA	Mixer	LNA & Mixer	Units
Gain	15.5	4.5	19.5	dB
Noise Figure	1.5	8.5	2.6	dB
IIP3	-14.2	0.0	-18.5	dBm

The results show that this Front-End offers 19.5dB of power gain with a noise figure contribution of 2.6dB at 433MHz.

3.2.2 Isolation
The isolation between the LO signal and antenna input is -59dBm. The requirement[3] for 433MHz ISM band is -57dBm at the antenna input for signals outside the 433MHz band and below 1GHz. This means that, without any selectivity at the antenna input, this requirement is already met. In practice there will be selectivity from the antenna filter or the antenna itself, meaning the LO signal is further suppressed.

4. CONCLUSION
The advantages of using the SA601 or SA620 as a 433MHz Front End are:

- Ease of design

- Good performance

- Minimum amount of external components

- Power supply operation from 2.7 to 5.5V

When there is an external Local Oscillator available, the SA601 is the best choice because it has higher overall gain than the SA620. This is because the SA601 mixer has a differential mixer output. The SA620 has the benefit of having a VCO on-chip. With this VCO the LO frequency is generated, so no extra VCO module is required.

Both the SA601 and SA620 come in an SSOP20 and are in full volume production.

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3.   ETSI I-ETS 300 220 Annex A.1.3.