

Frequency Downscaling of an ISM Band Superhet Receiver IC

A low-cost, effective approach to extend the operating frequency range of an existing double-conversion superhet receiver IC down to lower RF bands

By **Andreas Laute, Jeff Peter and Matthias Lange**
Melexis GmbH Haarbergstrasse

Today, users of wireless systems can take advantage of a broad range of worldwide license-exempt industrial/scientific/medical (ISM) and short-range-device (SRD) bands. Many applications cover the frequency range of a few kilohertz to 930 MHz, including telemetry, telecommand, alarms, model control, immobilizers, animal identification, wireless voice, personal identification and general data transmission. Even new technologies, such as Bluetooth and HomeRF, will not easily compete with most of these well-established, very low cost approaches.

Naturally, it is the goal of a manufacturer of radio frequency integrated circuits (RFICs) to offer a product spectrum that covers as much as possible of the available frequency allocation for such ISM and SRD applications. The current RFIC standard product line of Melexis contains six different receiver versions. These receiver chips have been originally designed to deal with the frequency range of 310 to 950 MHz [1, 2, 3]. A variety of frequency-compatible RF transmitter ICs is also available from Melexis [3, 4]. One member of the receiver family is the TH71102, a fully integrated double-conversion superhet receiver designed in an advanced RF-dedicated 0.6 μm BiCMOS process.

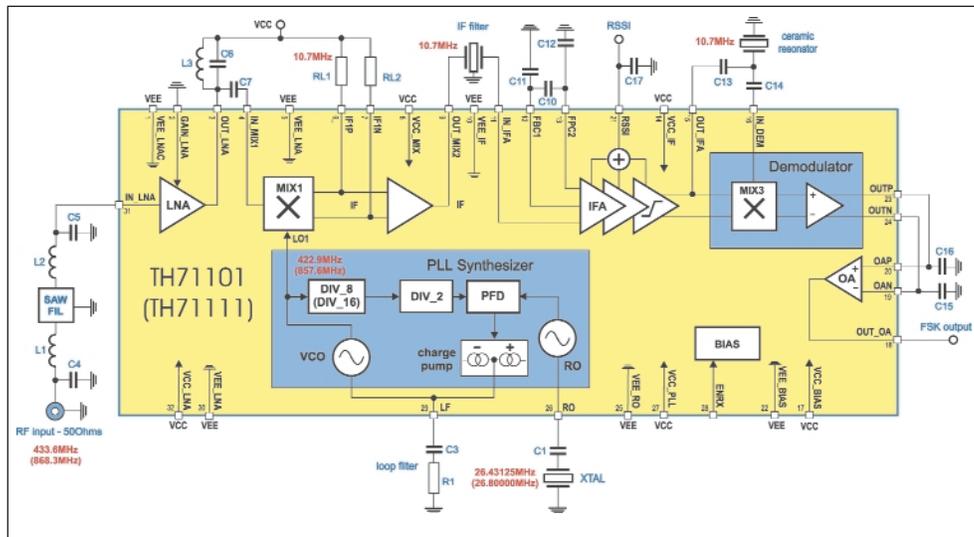
This article shows how the TH71102 may be used to extend its operating frequency range from 310 to 480 MHz down to the lower ISM and SRD bands located between 26.9 and 47 MHz. The range extension can be easily achieved without adding any external circuitry. A brief description of the RFIC's original receiver architecture, which is double-conversion superhet, is also provided, and the functionality of some building blocks of the TH71102

FSK/FM/ASK receiver chip is explained. A theoretical approach to modify the existing double-conversion receiver in order to derive a single-conversion system is outlined. By doing so, a downward operating frequency extension by more than one decade is possible. The basic idea behind this concept is to bypass the first mixer of the superhet receiver IC. Then, the LNA directly drives the second mixer and the second mixer is actually the only mixer in the receiver. The first mixer input has to be terminated in order to prevent undesired signal pick-up. Applying a capacitor to ground can do this very easily. Finally, measured results are presented. System performance measures as for example input sensitivity, image suppression or spurious responses are reported.

The TH711xx family of superhet receivers

Table 1 shows some of the system parameters of the 32-pin low-cost variants of the Melexis TH711xx receiver family. Some functional blocks, common to all of these receiver ICs, are the LNA with selectable gain (in order to assure a high dynamic range), as well the first and second down-conversion mixers in case of double conversion reception, or just one mixer in case of the single superhet. A high-gain limiting IF amplifier (IFA) with RSSI signal generation and a phase-coincidence demodulator (DEMOM) create the IF gain strip and demodulator part. A PLL synthesizer (PLL SYNTH) featuring a fully on-chip RF VCO (VCO) and some additional circuits are implemented for frequency generation, data slicing, filtering and biasing.

Figure 1 shows the block diagram of the single-conversion superhet receivers TH71101 and TH71111, respectively. The user has the choice



▲ **Figure 1. Single-conversion superhet block diagram with external components.**

to configure an ASK, FM or FSK receiver by arranging the external components appropriately. An RF front-end filter should be used to achieve both a high degree of image rejection and good blocking immunity. For high frequencies (greater than 100 MHz), the best trade-off with respect to cost, performance and repeatability usually comes with a surface acoustic wave filter (SAWFIL). After pre-amplification by the LNA, the mixer (MIX1) downconverts the RF signal to the IF range, where a ceramic filter sets the desired receiver bandwidth and, hence, defines its selectivity. A phase-coincidence

demodulator, formed by an internal mixer (MIX3) and an external ceramic resonator with two capacitors, performs both FSK and FM modulation.

The operational amplifier (OA) acts as a comparator that delivers a rail-to-rail output signal. In case of ASK reception, where the external FSK/FM components are not needed, the RSSI signal can be directly taken to feed the OA, in this case constituting an adaptive threshold data slicer, in order to set up an ASK demodulator.

The single-conversion superhet allows a reasonably high degree of image suppression by selecting a high IF, in addition to good front-end filtering [5]. A typically used IF is 10.7 MHz. In this case, the RF front-end filter's attenuation at 21.4 MHz off the center frequency determines the image suppression, which is about 50 dB (measured value derived with TH71101 and TH71111).

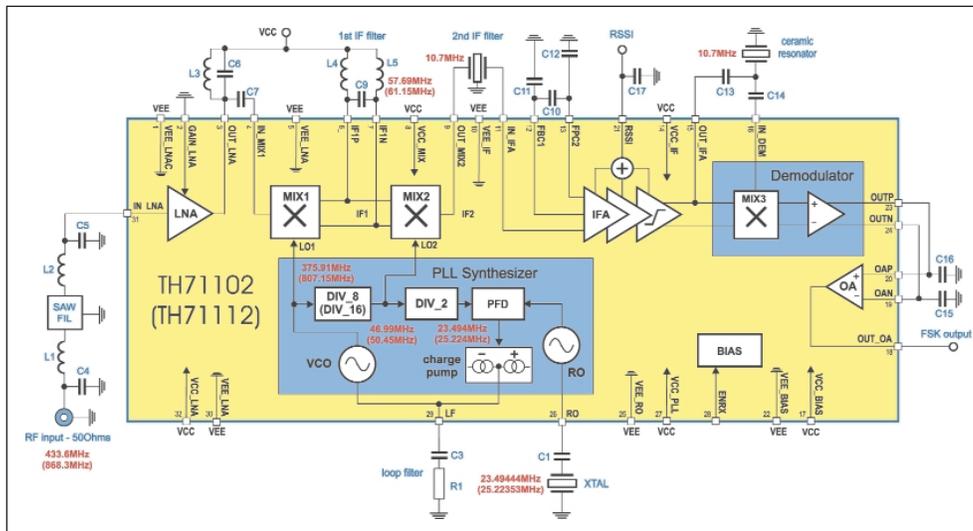
The double-conversion approach can be treated as the next step in the evolution of the superhet receiver. It should be used if higher values of image rejection are needed. Of course, other receiver concepts can be employed toward the same goal; some of them are direct-conversion and low-IF receivers. Direct-conversion

receivers have an inherently high degree of image rejection (theoretically up to infinity), but they suffer from other problems, such as DC offsets and LO signal spurious emission [6]. Low-IF receivers do image rejection electronically, but practical values are poor (around 30 dB) [7]. With the Melexis receiver chips, the system designer has the choice to do a simple upgrade from the single to the double superhet, just by replacing either TH71101 with TH71102 (310 to 480 MHz) or TH71111 with TH71112 (800 to 950 MHz). A corresponding double superhet application diagram is depicted in Figure 2.

Here, a second mixer (MIX2) is needed to convert the first IF (IF1) to the second (IF2). Additionally, the PLL synthesizer has been modified slightly to

Receiver IC	TH71101	TH71102	TH71111	TH71112
Frequency Range	310 to 480 MHz	310 to 480 MHz	800 to 950 MHz	800 to 950 MHz
Supply Range	2.5 to 5.5V, FSK 2.2 to 5.5V, ASK			
Supply Current	6.5 to 7.8 mA	6.5 to 7.8 mA	7.6 to 9.2 mA	7.6 to 9.2 mA
Standby Current	< 50 nA	< 50 nA	< 50 nA	< 50 nA
Demodulation	FSK, FM, ASK	FSK, FM, ASK	FSK, FM, ASK	FSK, FM, ASK
Frequency Conversion	single superhet	double superhet	single superhet	double superhet
Input Sensitivity, narrow band (including RF front-end filter loss)	-111 dBm, FSK -109 dBm, ASK @ 40 kHz IFBW	-111 dBm, FSK -109 dBm, ASK @ 40 kHz IFBW	-109 dBm, FSK -108 dBm, ASK @ 40 kHz IFBW	-109 dBm, FSK -108 dBm, ASK @ 40 kHz IFBW
Input Sensitivity, wide band (including RF front-end filter loss)	-104 dBm, FSK -106 dBm, ASK @ 150 kHz IFBW	-104 dBm, FSK -106 dBm, ASK @ 150 kHz IFBW	-102 dBm, FSK -104 dBm, ASK @ 150 kHz IFBW	-102 dBm, FSK -104 dBm, ASK @ 150 kHz IFBW
Maximum Input Signal	-10 dBm, FSK -20 dBm, ASK			
Image Rejection (including RF front-end filter loss)	> 50 dB	> 65 dB	> 50 dB	> 65 dB
Spurious Emission	< -65 dBm	< -65 dBm	< -65 dBm	< -65 dBm
Package	LQFP32	LQFP32	LQFP32	LQFP32

▲ **Table 1. Parameters of the Melexis 32-pin TH711xx receiver family.**

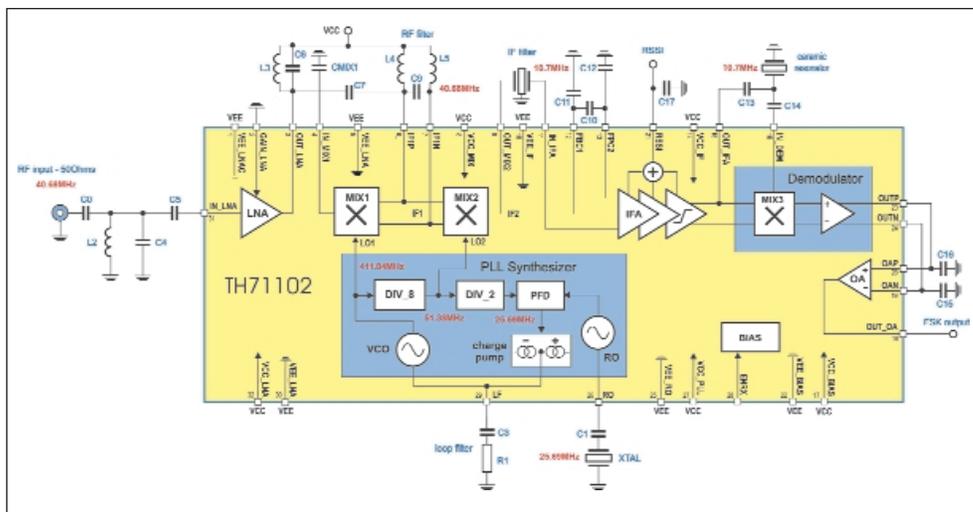


▲ **Figure 2. Double-conversion FSK superhet block diagram with external components.**

deliver two LO signals (LO1 and LO2) that drive the mixers. A simple external LC network between MIX1 and MIX2 acts as a band-pass filter for the IF1 signal. Considering the same frequency of 10.7 MHz, as for the single-conversion case, now as IF2, the values for the first IF may be in the order of 60 MHz (depending on the exact RF needed). This leads to a substantially higher degree of image rejection (65 dB measured) because the attenuation of the SAW front-end filter, taken approximately 120 MHz away from its pass-band frequency, is now much higher than at 21.4 MHz.

Transformation to a low-RF SCSH receiver

Receiver ICs with fully integrated VCOs are very welcome to the system designer because there is no need for external VCO components, such as varactor diodes or inductors. On the other hand, a fully integrated VCO typically has a limited LO frequency range that restricts the



▲ **Figure 3. Low-RF FSK superhet derived by DCSH-to-SCSH transformation.**

receiver's operating frequency range. The frequency translation scheme of a standard double-conversion superhet (DCSH) receiver follows the rule that the highest frequency of operation (high-RF) is down-converted by the first mixer to a lower frequency of operation (low-RF) that constitutes the first IF. A second mixer handles the next step of downconversion to derive the second IF. It follows logically that the operating frequency range of a DCSH should be down-scalable, if the first mixer could be bypassed to make the second mixer's input to be the terminal of the desired signal frequency

(now the low-RF). Then, the DCSH is transformed to a single-conversion superhet (SCSH) receiver.

The TH71102 block diagram, shown in Figure 2, reveals that MIX1 ports IN_MIX1 and IF1 are fully accessible. This gives the chance to connect the LNA output not to the input of MIX1 but to the input of MIX2. In this situation, MIX2 is the one and only mixer in the system, able to receive low-RF signals. Figure 3 outlines how the transformation from DCSH to SCSH can be realized by using the TH71102. As can be seen from this application circuit, port LO1 of MIX1 cannot be disconnected because it is internal to the IC. Furthermore, the internal signal path from MIX1 to MIX2 is fixed. This affects two issues:

1. The input of MIX1 must be AC-grounded to prevent from picking up unwanted high-RF signals that could be down-converted and interfere with the desired low-RF,
2. The output of MIX2 must be matched to the desired low-RF signal to keep parasitic LO1 feed-through as low as possible.

Both demands can be easily met — the first by applying a capacitor to pin IN_MIX1 that is well connected to ground, and the second because the LC tank at pins IF1P and IF1N is trimmed to the desired low-RF.

The specified LO1 frequency range of the TH71102 is 300 to 450 MHz [8]. This translates to an LO2 range of 37.5 to 56.25, which is the new LO frequency range of the receiver that has

been derived by DCSH-to-SCSH transformation. Table 2 summarizes the new operating frequency range of the SCSH. According to CEPT/ERC recommendation 70-03 [9], the low-frequency services shown in Table 3 can be covered by the modified TH71102 application circuit.

Experimental data of the low-RF SCSH receiver

A test board has been fabricated to validate the theoretical approach of the DCSH-to-SCSH transformation. The board's circuit schematic corresponds to Figure 3, with a receiving frequency of 40.68 MHz, the center frequency of one of the non-specific SRD bands. The receiver's front-end RF filter characteristic is constituted by three separated LC band-pass filters (L2 and C4; L3 and C6; L4, L5 and C9).

A frequency sweep measurement can be performed to check the system's RF response without disturbing the LC filters' impedances — a common RF test problem caused by the coupling effect of the measurement system.

The test configuration consists of a swept frequency signal generator to input the RF signal over the desired measurement frequency range, and a spectrum analyzer operating in max hold mode to display the output signal at the IF port. In this case, the superhet receiver's re-sponse is taken indirectly through its RF-to-IF conversion. Figure 4 shows the corresponding front-end filter characteristic, measured at pin OUT_MIX2, down-converted to the IF of 10.7 MHz.

	LO high-side injection	LO low-side injection
possible RFs	LO – IF	LO + IF
range of RFs	(37.5 to 56.25)MHz – RF	(37.5 to 56.25)MHz + IF
range of RFs at IF = 10.7 MHz	26.8 to 45.55 MHz	48.2 to 66.95 MHz

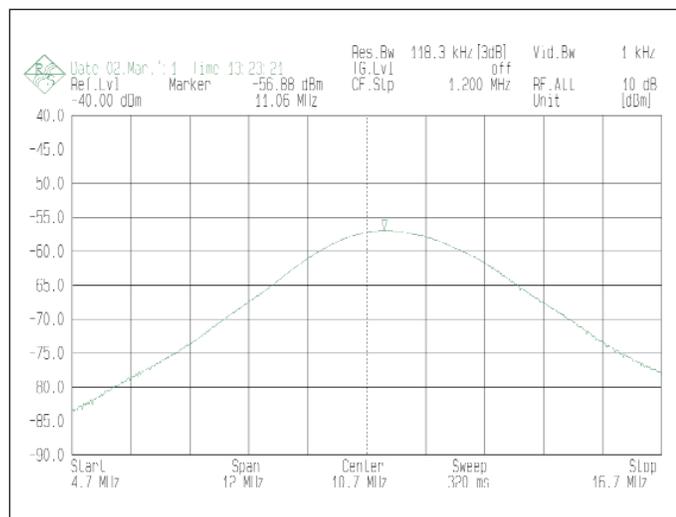
▲ **Table 2. Summary of the new operating frequency range of the SCSH.**

While Figure 4 gives some insight in front-end selectivity, blocking and image rejection capability of the receiver, the same measurement should be made with the spectrum analyzer picking up the signal behind the IF filter, in order to visualize the channel selectivity. The result is depicted in Figure 5, showing the ceramic IF filter response with a 3 dB bandwidth of 150 kHz.

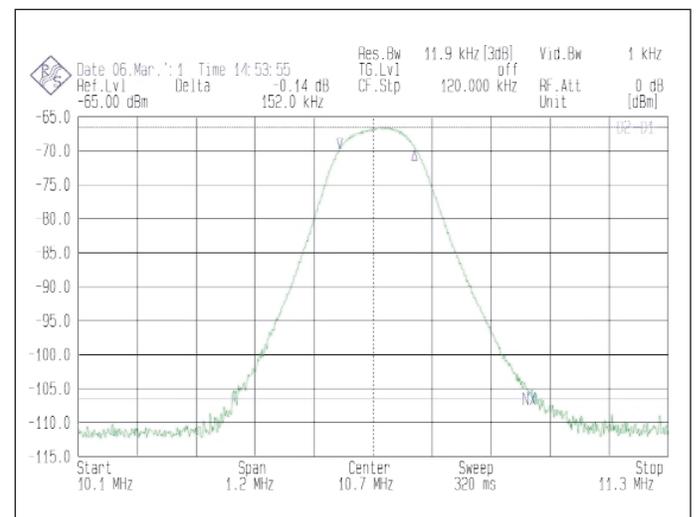
Table 4 summarizes the most important parameters in order to quantify the receiver's performance.

Service	Frequency Range	Channel Spacing	Typical Applications
Non-specific SRDs	26.957 to 27.238 MHz 40.660 to 40.700 MHz	No channels specified	Telemetry, telecommand alarms, data in general and other similar applications
Model Control	26.995 to 27.195 MHz 34.995 to 35.223 MHz 40.665 to 40.695 MHz	10 kHz	Controlling the movement of a model
Inductive Applications	26.957 to 27.283 MHz	No channels specified	Car immobilizers, animal identification, alarm systems personal identification, proximity sensors, anti-theft systems, automatic article identification
Narrow-band audio	29.7 to 47.0 MHz	50 kHz	Audio signal transmission

▲ **Table 3. Low-frequency services covered by the modified TH71102 application circuit.**



▲ **Figure 4. Receiver RF front-end response, downconverted to IF.**



▲ **Figure 5. Receiver IF response behind the 150-kHz-wide ceramic filter.**

Parameter	Condition	Value	Unit
Stand-by current	ENRX at 0 V	<1	nA
Current consumption at LNA high gain	GAIN_LNA at 0 V	7.7	mA
Current consumption at LNA low gain	GAIN_LNA open	6.3	mA
FSK input sensitivity at LNA high gain	GAIN_LNA at 0 V	-108	dBm
FSK input sensitivity at LNA low gain	GAIN_LNA open	-70	dBm
FSK maximum input signal at LNA high gain	GAIN_LNA at 0 V	-10	dBm
FSK maximum input signal at LNA low gain	GAIN_LNA open	0	dBm
ASK input sensitivity at LNA high gain	GAIN_LNA at 0 V	-110	dBm
ASK input sensitivity at LNA low gain	GAIN_LNA open	-72	dBm
ASK maximum input signal at LNA high gain	GAIN_LNA at 0 V	-24	dBm
ASK maximum input signal at LNA low gain	GAIN_LNA open	-5	dBm
Image rejection	GAIN_LNA at 0 V	36	dB
Rejection of undesired double-conversion RF at 451.72 MHz	GAIN_LNA at 0 V	77	dB
Rejection of undesired double-conversion RF at 370.36 MHz	GAIN_LNA at 0 V	65	dB
Spurious emission	GAIN_LNA at 0 V	< -104	dBm

▲ **Table 4. Summary of important parameters quantifying the receiver's performance.**

Conclusion

This article has described how a frequency range extension of a commercially available integrated receiver IC can be realized. A very effective frequency down-scaling can be arranged by applying the DCSH-to-SCSH transformation to the double-conversion receiver chip TH71102. This leads to a shift in frequency from the 310 to 480 MHz range to approximately 27 to 67 MHz, without the need for any extra components.

A reasonable amount of image suppression can be achieved even without a SAW front-end filter. A cascade of three simple LC band-pass filters yields a value of 36 dB. This is good news for the system designer because the cost of expensive SAW filters can be saved. All other system parameters, such as input sensitivity or spurious emission, are in very good shape. ■

References

1. A. Laute and J. Peter, "A Fully Integrated 900 MHz Double Superhet Receiver Chip," *Microwave Engineering Europe*, August/September 2000: 41-48.
2. "RF Receivers Support Many Applications," *Electronic Products*, December 2000: 87.
3. Jack Brown, "Transmitter and Receiver ICs Run on ISM and SRD Bands," *Microwaves & RF*, December 2000: 196-198.
4. A. Laute and J. Peter, "A Fully Silicon Monolithic Integrated 868/915 MHz FSK/FM/ASK Transmitter Chip," *Proceedings of the IEEE MTT-S Workshop on Silicon Monolithic Integrated Circuits in RF Systems*, Garmisch-Partenkirchen, Germany, April 26-28, 2000.
5. U. Rohde, J. Whitaker and T.T.N. Bucher,

Communications Receivers, Second Edition, New York: McGraw-Hill, 1997.

6. C.D. Hull, J.L. Tham and R.R. Chu, "A Direct-Conversion Receiver for 900 MHz (ISM Band) Spread-Spectrum Digital Cordless Telephone," *IEEE Journal on SSC*, 12/1996: 1955-1963.

7. J. Crols and M.S.J. Steyaert, "Low-IF Topologies for High-Performance Analog Front Ends of Fully Integrated Receivers," *IEEE Trans. on Circuits and Systems — II*, 3/1998: 269-282.

8. http://www.melexis.com/home_products.htm

9. CEPT/ERC/REC 70-03 relating to the use of short range devices (SRD), March 1, 1999.

Author information

Dr. Andreas Laute joined German IC manufacturer Thesys in 1994, where he worked as the manager of the application laboratory dealing with RF device test and characteriza-

tion, parameter extraction, system design and application support. Melexis, a Belgium microelectronics company, acquired Thesys in 1999. Since that time, Laute has been manager of the business unit BiCMOS. He holds four patents in the fields of RF receiver and demodulator circuits, and his research interests include bipolar transistor modeling, wireless transmitter, receiver, transceiver and VCO circuit design, as well as RF system architectures. He may be reached by e-mail at andreas.laute@melexis.com.

Jeff Peter received a Dipl.-Ing. degree in electrical engineering from the Technical University of Dresden, Germany, in 1996. He joined Thesys that year and began working in the area of BiCMOS and bipolar technologies. From 1998 to 1999, he was with Austria Mikro Systeme in Unterprenstatten, Austria, where he has been involved in the design of frequency synthesizers. He is now working at Melexis as a project engineer in the BiCMOS business unit, where he designs RF transmitter and receiver chips for ISM bands. His research interests include high-performance analog integrated circuits for telecommunications.

Matthias Lange received a Dipl.-Ing. degree in electrical engineering from the Technical University of Dresden, Germany, in 1996. In the same year, he joined the Institute of Microelectronic and Mechatronic Systems (IMMS) in Erfurt, where he has been engaged in the development of integrated wireless RF systems for ISM/SRD applications. He joined Melexis in 2000 and is now focused on receiver and transmitter designs in the business unit BiCMOS. His research interests include analog integrated circuit design for RF applications.