Upgrading a 434-MHz Transmitter IC to 868 MHz

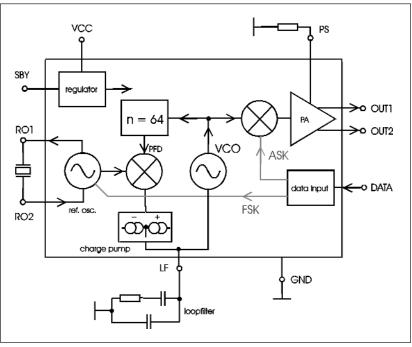
Frequency doubling allows an existing IC to be used as a transmitter in the European ISM band

By Dr. Andreas Laute Thesys GmbH

he new industrial-science-medical band for the frequency range of 868 to 870 MHz [1] offers numerous applications for wireless data transmission. The use of short range devices (SRDs) within this new ISM band requires appropriate transmitter (TX) and receiver (RX) components that fulfill the recommendations according to the known ETSI standard I-ETS 300 220 [2]. A cost-efficient method for the construction of an 868-MHz TX circuit is to use a well-established TX IC for 434 MHz in conjunction with a frequency doubler in the form of a diode pair. The presented technique makes use of the differential amplifier output, which can easily be connected to a Schottky diode pair in order

to constitute a frequency doubler. The additional circuitry does not require any other active components, and hence does not increase power consumption.

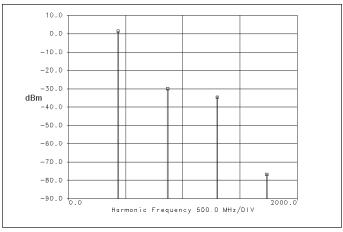
The TH7101 and TH7106 ICs from Thesys are developed for data transmission of amplitude shift keying (ASK) and frequency shift keying (FSK) signals, respectively [3, 4, 5]. Both ICs cover the frequency range of approximately 300 to 440 MHz and can be used for power supplies ranging from 2.6 to 4.8 V. The ASK type TH7101 has a mixer in front of the power amplifier (PA) that acts as an on/off switch driven by the data



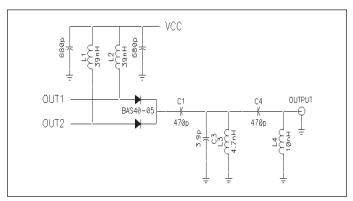
■ Figure 1. Block diagram of TH7101/7106 ASK/FSK transmitter.

in order to generate ASK-modulated signals. The TH7106 makes use of the pullability of the reference oscillator's crystal. Integrated pulling capacitors are switched by the data for FSK generation at the reference frequency. The small frequency deviation of the crystal is then upconverted (multiplied by 64 through the on-chip PLL synthesizer) to obtain the required FSK deviation of the RF carrier. The fully integrated VCO is a ring oscillator, and the PA is a differential cascode open-collector configuration that delivers about 1 dBm output power. Figure 1 shows the block diagram of both transmitters.

ISM-Band Transmitter



■ Figure 2. Transmitter spectrum at 434 MHz, harmonic balance simulation result.



■ Figure 3. Circuit schematic of the frequency doubler.

Frequency doubler approach

A frequency doubler can easily be constituted if the differential output of the TX IC (with signal frequency f1) is directly connected to the anodes of a Schottky diode pair. Then the circuit principally acts as an RF full-wave rectifier where the common-cathode pin of the diode pair draws a signal that is double the frequency of the differential input signal ($f_2 = 2 \times f_1$). A tuned circuit for $f_2 = 868$ MHz, DC blocked to the diode pair, ensures optimum response to the desired signal and suppresses the unwanted signal at frequency f_1 and other harmonically related signals. An impedance matching network placed after the tuned circuit transforms the circuit impedance to the desired load impedance, e.g. 50 ohms of the spectrum analyzer.

Not only the RF carrier is affected by the frequency doubler circuit. By using the FSK-modulated TX, twice the frequency deviation is achieved as well. The original FSK signal s(t) with carrier frequency $f = \omega/2\pi$ and peak deviation $\Delta f = \Delta \omega/2\pi$ denoted by:

$$s(t) = \cos\left(\omega t \pm \Delta \omega t\right) \tag{1}$$

which leads to the squaring product:

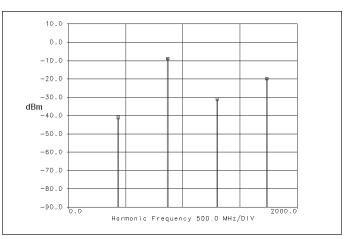


Figure 4. Transmitter spectrum at 868 MHz, harmonic balance simulation result.

$$s^{2}(t) = \frac{1}{2} + \frac{1}{2}\cos(2\omega t \pm 2\Delta\omega t)$$
 (2)

In most cases this doubling in frequency deviation is very welcome to the system designer because it yields a higher performance margin (and a higher detection voltage after the receiver's demodulator). The DC component of the new signal can be easily removed by a blocking capacitor.

Simulation results

Output power and harmonic content of the TX IC have been checked by means of a harmonic balance simulator. We have used the HP EEsof Series IV J-Omega nonlinear engine for this purpose [6]. In order to save simulation time and memory, only the IC's PA stage was included during the harmonic balance run. Operation at 434 MHz was evaluated first. In this situation, the differential output is connected to a balanced-to-unbalanced (balun) transformer to drive a single-ended 50-ohm load. Package and board parasitics have been taken into account. Figure 2 shows the simulation result indicating a signal power of 1 dBm at the fundamental wave. The second and third harmonics are at -30 dBm and -35 dBm, respectively.

The design of the PA output for operation at 868 MHz is shown in Figure 3. It has been changed by replacing the balun with a Schottky diode pair (BAS40-05W from Siemens), a tuned circuit and an impedance transforming network. Each open-collector output of the IC must be biased through an inductor against positive supply. The diode pair is DC-blocked to the tuned circuit and therefore zero-biased (which gives highest conversion gain). Figure 4 illustrates the corresponding simulation result. The desired signal at 868 MHz appears at -9 dBm. Spurious signals are present at 434 MHz (-41 dBm, the input signal), at 1302 MHz (-31 dBm, the second harmonic of the input signal) and at 1736 MHz (-20 dBm, third harmonic of the input and second harmonic of the desired signal).

Measurement results

A hardware setup was constructed to verify the circuit's performance. The FSK transmitter TH7106, housed in a SSOP16 package, was used on an RF board for this test. Again the circuit at the original frequency of 434 MHz was evaluated first. Figure 5 shows the spectrum analyzer plot for the same frequencv range as used for the simulation (DC to 2 GHz). We can measure an output power of 1.1 dBm at the fundamental wave, while the spurious signals are at –31 dBm for the second and –39 dBm for the third harmonic, respectively. These results are in very close agreement with the harmonic balance simulation.

A second RF board was designed for populating the FSK TX IC together with the components required for the frequency doubling circuit. Measurement results, taken under the same conditions as before, are depicted in Figure 6. The signal power at 868 MHz measures -9.3 dBm, while the input signal appears at -40 dBm. These values correlate well with simulation. Higher-order harmonic products are further reduced to -52 dBm (1302 MHz) and -34 dBm (1736 MHz), respectively. The discrepancy between simulated and measured results at frequencies above 1 GHz is very likely to be due to poor modeling of the Schottky diode pair and the inductors of the frequency doubling circuit.

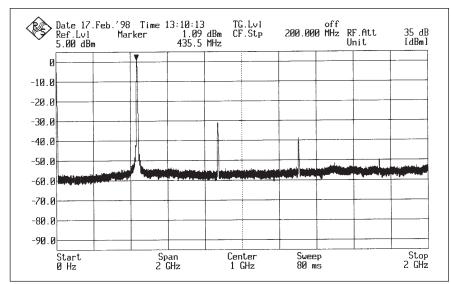
The transmitter's phase noise $L(f_m)$, a criterion which is especially important in the case of FSK signal transmission, is theoretically degraded by 6 dB due to the nature of frequency doubling. This can be expressed by the simple formula (which is known from PLL synthesizer noise theory [7])

$$\Delta L(f_m) = 20 \log(N) \text{ in dB}$$
 (3)

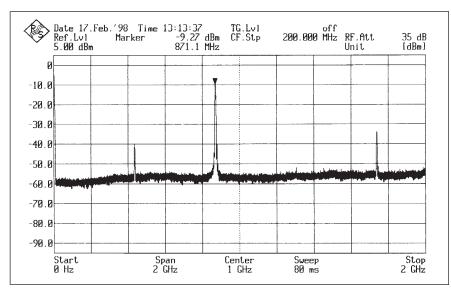
where N is the ratio of the frequency conversion. Phase noise measurements exactly reveal this expectation. Single-sideband phase noise at 10 kHz carrier offset changes from $-85~\mathrm{dBc/Hz}$ (at 434 MHz) to $-79~\mathrm{dBc}$ (at 868 MHz). Figure 7 shows the phase noise measurement at 868 MHz.

Conclusions

A relatively simple approach to upgrade an existing 434-MHz transmitter to the new ISM band at 868 MHz has been presented. The used TX IC has a differential output stage and hence allows the construction of a frequency doubler in a very efficient way by driving a common-cathode Schottky diode pair. The diodes are zero-



■ Figure 5. The measured transmitter output spectrum at 434 MHz.



■ Figure 6. The measured transmitter output spectrum at 868 MHz.

biased, therefore no additional power consumption occurs. The frequency doubler's conversion loss is about 10 dB, which is better than for commercially available passive frequency doublers. All spurious signals are already low enough in order to fulfill the requirements of the ETSI standard I-ETS 300 220. The amount of FSK frequency deviation is doubled as well, which is in most situations desirable due to improved FSK system performance. Phase noise is reasonable low to allow for reliable FSK data transmission.

Optionally the circuit can be very attractively changed to a dual-frequency transmitter. This can be arranged by adding either a pair of 3-dB/0-degree couplers (which gives two TX outputs at different carrier frequencies at the same time) or single-pole/double-throw switches (that gives either the 434 MHz or the 868 MHz to the output) onto the circuit board.

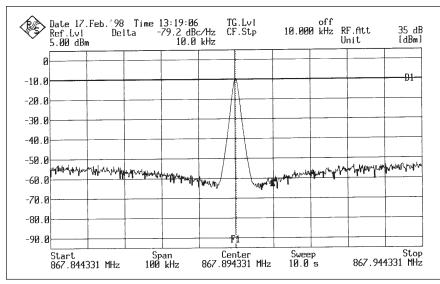


Figure 7. The transmitter phase noise. measured at 868 MHz.

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Andreas Laute received the Dipl.-Ing. and Dr.-Ing. degrees in electrical engineering from the Technical University of Ilmenau, Germany, in 1991 and 1996, respectively. From 1991 to 1993 he was a research assistant in the Department of RF and Microwave Techniques, TU Ilmenau, where he has done research in the areas of microwave radiometry and digital demodulation techniques. His Ph.D. thesis (Dr.-Ing.) dealt with two novel techniques for coherent and differential demodulation of QPSK signals.

Since 1994 he has been employed at Thesys Microelectronics, where he runs the device characterization laboratory, working in the fields of RF device test and characterization, parameter extraction, system design and application support. Dr. Laute holds three patents in the fields of RF receiver and demodulator circuits. His research interests include bipolar transistor modeling, wireless transmitter/receiver and VCO design.

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