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Two 868MHz Transmitter Concepts – A Comparison between SAWs and PLLs

Introduction

Applications in the new European short-range devices (SRD) band at 868 to 870 MHz are demanding for appropriate solutions for low power transmitters and receivers to build up economic wireless communication links. Transmitter systems for SRDs can be distinguished either from their type of modulation or from the kind the RF carrier is practically generated. In the first category, we can mainly differentiate between amplitude and frequency modulation, while the second category can be essentially divided into SAW-based and PLL-based solutions. The later comparison shall be the content of this paper. For 868MHz SRDs, FM or FSK transmission should be preferred because to the receiver a strong interfering 900MHz GSM signal appears as an AM blocker (due to the GSM burst mode).

Both transmitter concepts are compared with respect to some important parameters such as power consumption, RF output power, frequency tolerance, FSK/FM feasibility, temperature characteristics, reliability and price. Finally the pros and cons of each type of transmitter are judged in order to give the potential user a guideline whether he may use the PLL-based or SAW-based version.

Today the most economic way to design a PLL-TX is to use only one fully integrated circuit (IC) that contains all components for frequency synthesis and modulation generation (because costumers want high-quality, reliable and cheap solutions). For the SAW-TX there are mainly two circuit configurations: a Colpitts oscillator employing a one-port SAW resonator, or a Pierce oscillator that uses a two-port SAW device. A number of different 868MHz transmitter designs have been developed by the author, therefore the presented performance comparisons are strongly based on practical design experiences. Among them are, for example, that for the SAW-TX the two-port resonator Pierce is the better choice if high efficiency and good frequency stability are essential.

A PLL Transmitter using an RFIC

Circuit Description

The PLL-TX circuit is based on the RFIC TH7108 [1]. It is manufactured in a 0.8µm BiCMOS process featuring a transition frequency of f_t = 15 GHz. This RFIC is housed in a SSOP16 and can be used at power supply voltages ranging from V_{cc} = 2.1 to 5.5 V and operates at a temperature range from –40 to +85 °C. Some blocks of the PLL-TX are: a PLL synthesizer with reference oscillator, a fully integrated VCO, a power amplifier, a standby and biasing circuitry and a mode-control logic. The RFIC allows four different modes of operation:

the whole TX active, the whole TX shut down, external clock only and TX only. The external-clock feature can be used to drive a micro controller with a 3.4MHz clock signal.

The PLL feedback divider ratio is 32, which means that the RF carrier frequency f_c can be set by choosing a crystal with a reference frequency $f_{ref} = f_c / 32$. For f_c = 868.3 MHz (the center frequency of the first 868MHz SRD sub-band) we need f_{ref} = 27.1344 MHz. For this frequency, fundamental-wave quartz crystals can still be easily manufactured. FSK modulation is achieved by pulling the series resonant frequency of the crystal through the data. The Colpitts reference oscillator requires two external capacitors that can be selected by the user to set the exact center frequency f_c and frequency deviation Δf. Optionally an external varactor diode can be added in series to the crystal to generate analog FM. Other PLL components are a phase/frequency detector, a charge pump and a loop filter. Only the later requires three passive off-chip components to optimize the loop bandwidth for lowest phase noise. The VCO is a ring oscillator that can be used for the frequency range of 700 to 1000 MHz. So, operation at other RFs, as for example in the US 915MHz ISM band, is no problem. RF output power can be selected either by applying a resistor (between 15k and 68k) or a voltage (of 0.3V to V_{cc}) to the power-select (PS) pin. ASK modulation can be achieved via output power modulation at the same pin. An open-collector differential output is ideally suited to match a high-impedance loop antenna. Our test board contains a balun impedance transformation network for single-ended drive of a 50Ω spectrum analyzer or for direct connection of a λ/4 monopole antenna. **Fig. 1** shows the schematic of the complete PLL transmitter for FSK operation.

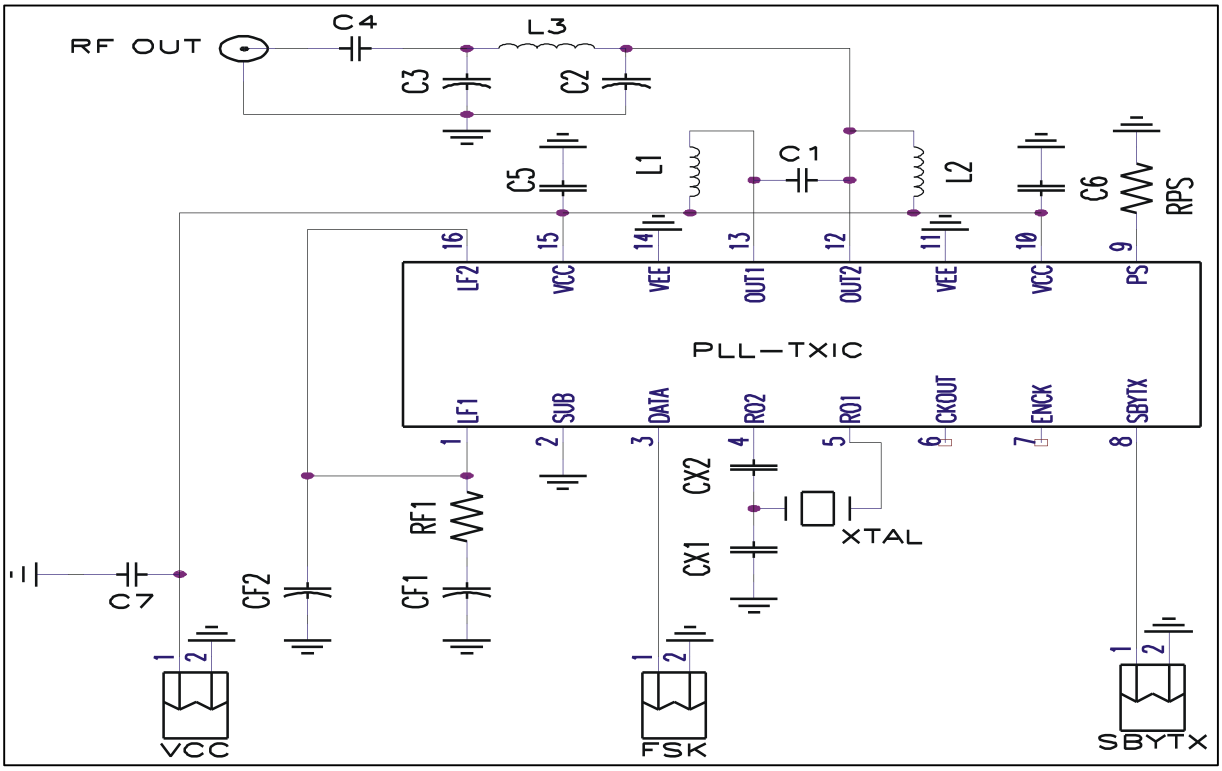

Fig. 1: 868MHz FSK transmitter utilizing the TH7108 PLL-TXIC

Parameters

The following table gives a parameter variation overview but is restricted to some fundamental performance issues as there are: current consumption I_{cc}, output power P_o, 2^{nd} and 4^{th} harmonics P_2 and P_4, respectively, center frequency f_c and FSK deviation Δf. All parameters have been measured over full power supply (V_{cc}) and temperature range (T_a).

V_{cc} / V	I_{cc} / mA	P_o / dBm	P_2 / dBm	P_4 / dBm	f_c / MHz	Df / kHz
T_a = -40 °C						
2.1	8.2	-1.0	-44	-54	868.336	± 49
3.0	9.1	-0.4	-41	-49	868.335	± 50
5.5	9.8	0.5	-40	-41	868.334	± 51
T_a = 23 °C						
2.1	9.4	-0.2	-42	-46	868.347	± 50
3.0	10.0	0.4	-39	-42	868.346	± 50
5.5	10.8	1.4	-39	-36	868.346	± 51
T_a = 85 °C						
2.1	10.1	-1.2	-47	-43	868.353	± 50
3.0	10.6	-0.8	-48	-40	868.352	± 51
5.5	11.2	0.0	-49	-42	868.352	± 52

Table 1: Some parameters of the PLL-TX vs. V_{cc} and T_a

In order to visualize the performance of the transmitter, some spectrum plots are shown below under nominal conditions (3 V, 23 °C).

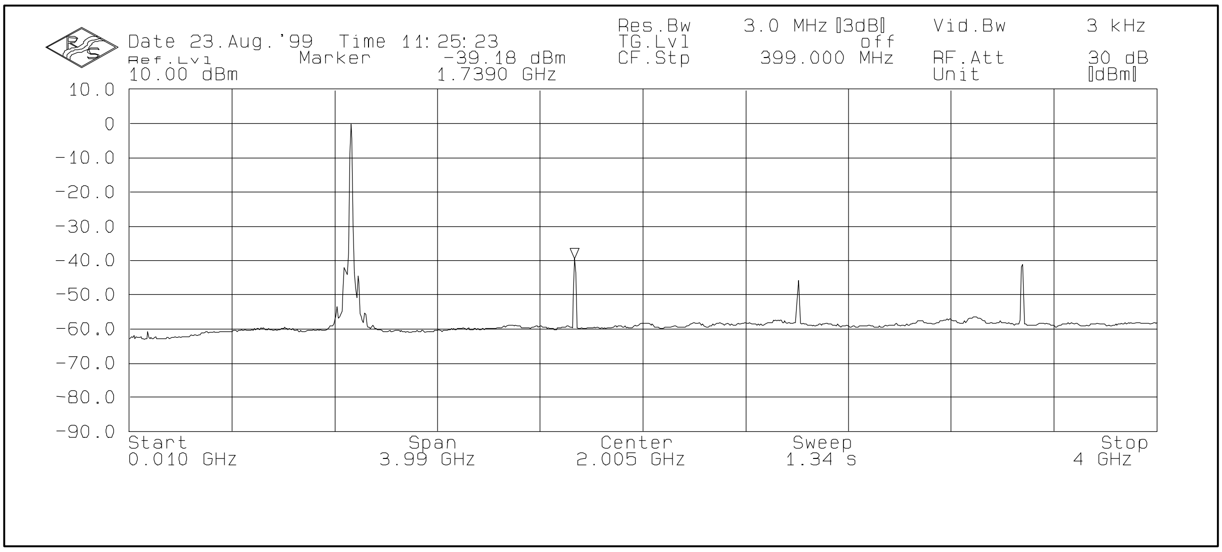

Fig. 2: Output signal and harmonics

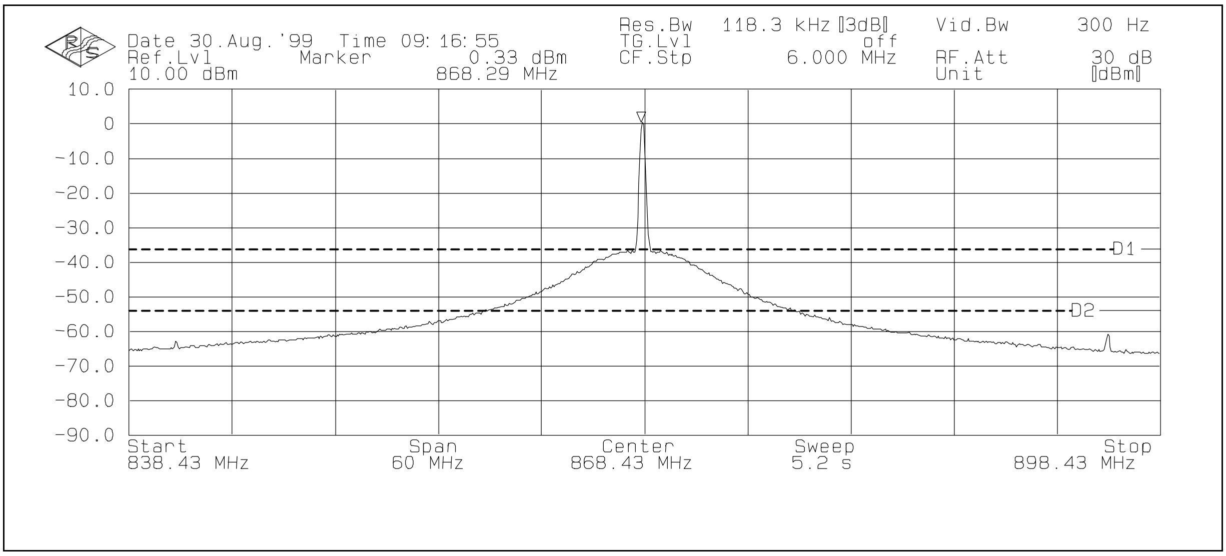

Fig. 3: Output power, phase noise and reference spurs (display lines indicate EN 300 220 limits)

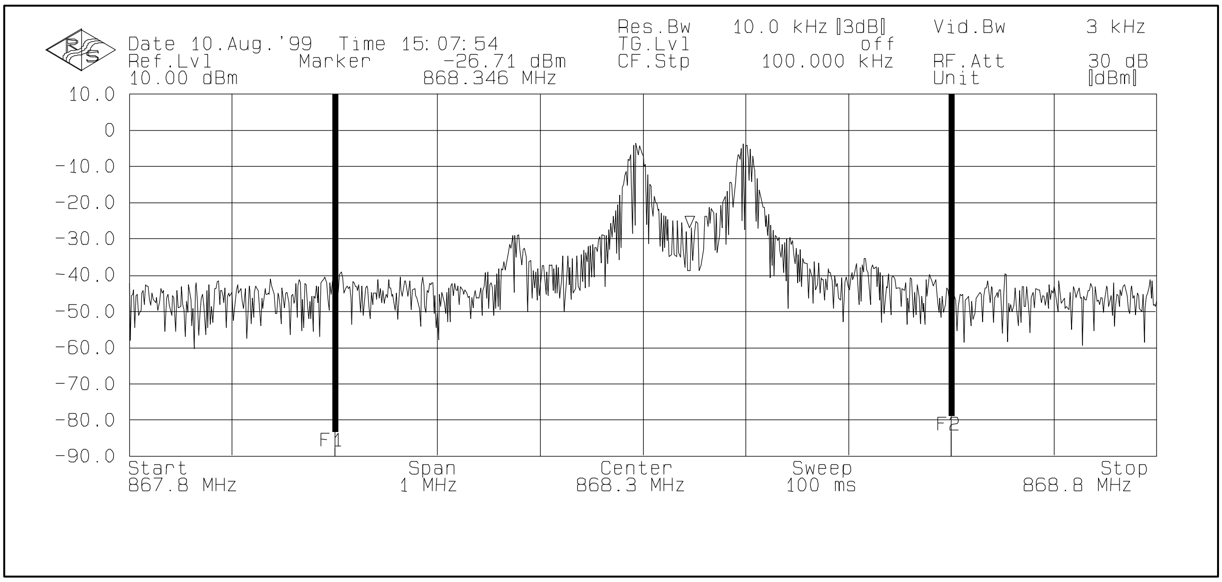

Fig. 4: FSK modulation (frequency lines indicate first 868MHz sub-band)

A SAW-based Transmitter

Circuit Description

Designing a SAW-based TX means to start with the selection of a circuit topology and then to chose an appropriate SAW resonator. One-port SAWs have two terminals and can therefore be compared to crystals; and indeed well-known crystal oscillator topologies, as for example the Colpitts, can be used, but with much more difficulties in getting the oscillator to work well (because of the much higher frequency). The author's first 868MHz SAW-TX designs utilized such one-port resonators; they worked, but frequency stability versus power supply and temperature variations was unacceptable for SRD production parts. Therefore, a two-port SAW has been used for the final design.

The SAW resonator R2709 can be well modeled using the equivalent circuit given by the manufacturer [2]. First, the design started with harmonic balance simulations on a single-bipolar Pierce. Then the circuit was optimized for maximum power output and minimum current consumption by adding a second bipolar as a booster. **Fig. 5** depicts the circuit diagram of the final SAW-TX with FM/FSK ability, which has been further optimized by hand tuning.

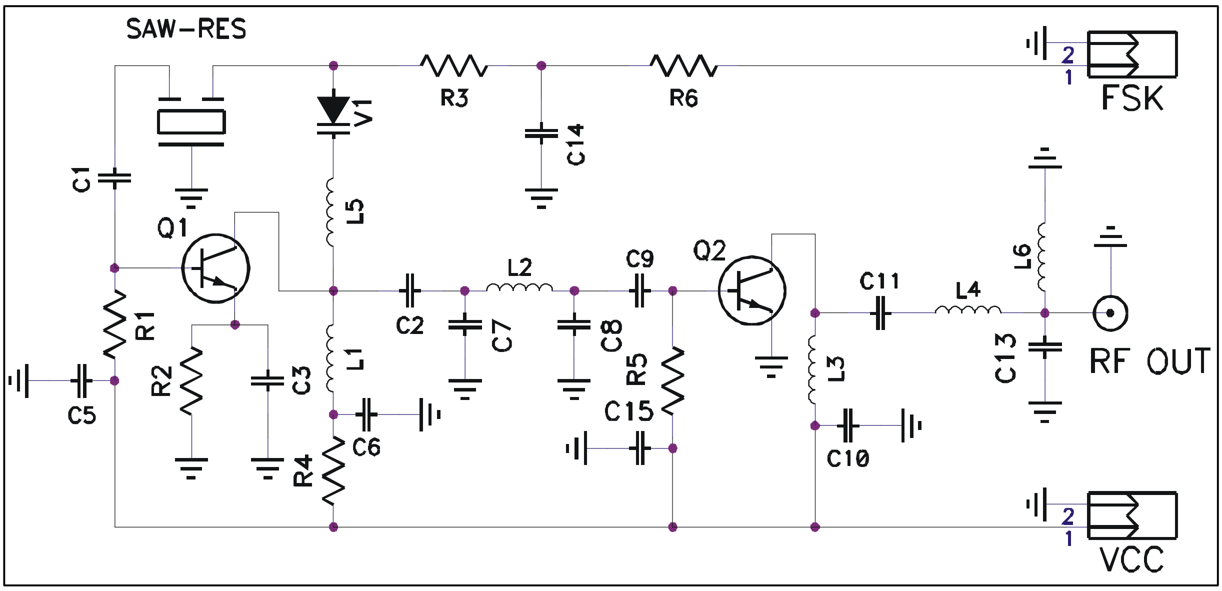

Fig. 5: 868MHz SAW-TX with two-port SAW resonator and two bipolars

Parameters

Unlike the PLL-TX, the SAW-TX has been characterized only within the temperature range of T_a = -20 °C to 55 °C; this is the general extreme temperature range specified in EN 300 220-1 [3]. Using the SAW-TX outside this temperature range is possible but degrades center frequency stability and usable modulation range (frequency deviation drops). Also the upper power supply limit must be restricted to 3.8 V (or 3.3 V at –20 °C), but the lower limit can be 2.0 V (instead of 2.1 V at the PLL-TX). Under nominal conditions, the SAW-TX can operate at 10 mA while delivering approx. 10 dBm into a 50Ω load. Harmonics stay below –30 dBm, but with very small headroom at maximum supply voltage. This might be a problem when using the SAW-TX with an antenna (discussed later). The following table shows the parameter variations of current consumption I_{cc}, output power P_o, 2nd and 3rd harmonics P_2 and P_3, respectively, center frequency f_c and FSK deviation Δf.

V_{cc} / V	I_{cc} / mA	P_o / dBm	P_2 / dBm	P_3 / dBm	f_c / MHz	Df / kHz
T_a = -20 °C						
2.0	5.3	4.8	-37	-41	868.392	± 46
3.0	9.5	9.9	-36	-33	868.413	± 61
3.3	10.8	10.9	-35	-32	868.432	± 53
T_a = 23 °C						
2.0	5.8	4.5	-36	-42	868.355	± 14
3.0	10.1	9.8	-34	-35	868.372	± 29
3.8	13.8	12.1	-32	-31	868.402	± 56
T_a = 55 °C						
2.0	6.1	4.3	-38	-42	868.284	± 8.5
3.0	10.6	9.3	-36	-36	868.294	± 15
3.8	14.3	12.0	-32	-32	868.303	± 25

Table 2: Some parameters of the SAW-TX vs. V_{cc} and T_a

Spectrum plots under nominal conditions (3V, 23°C) are listed below.

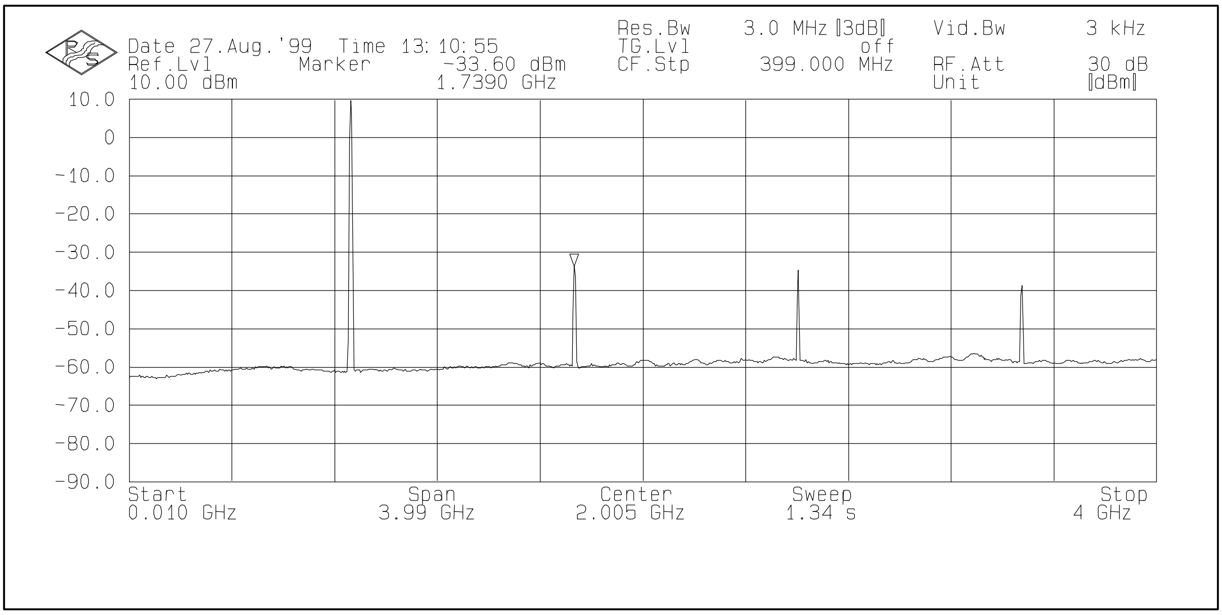

Fig. 6: Output signal and harmonics

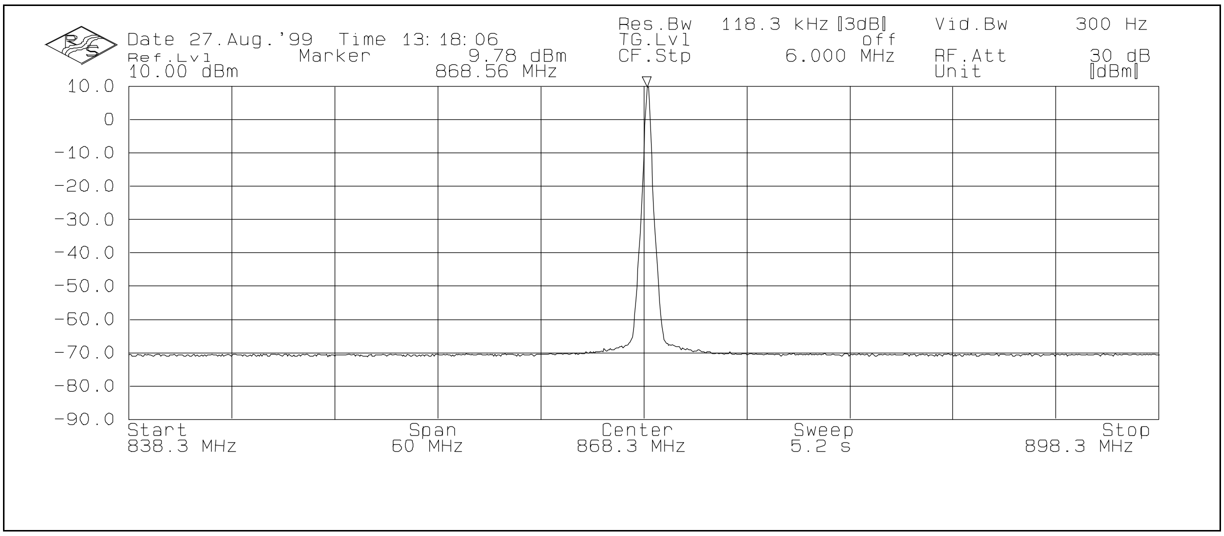

Fig. 7: Output power and phase noise (same span used as with PLL-TX in Fig. 3)

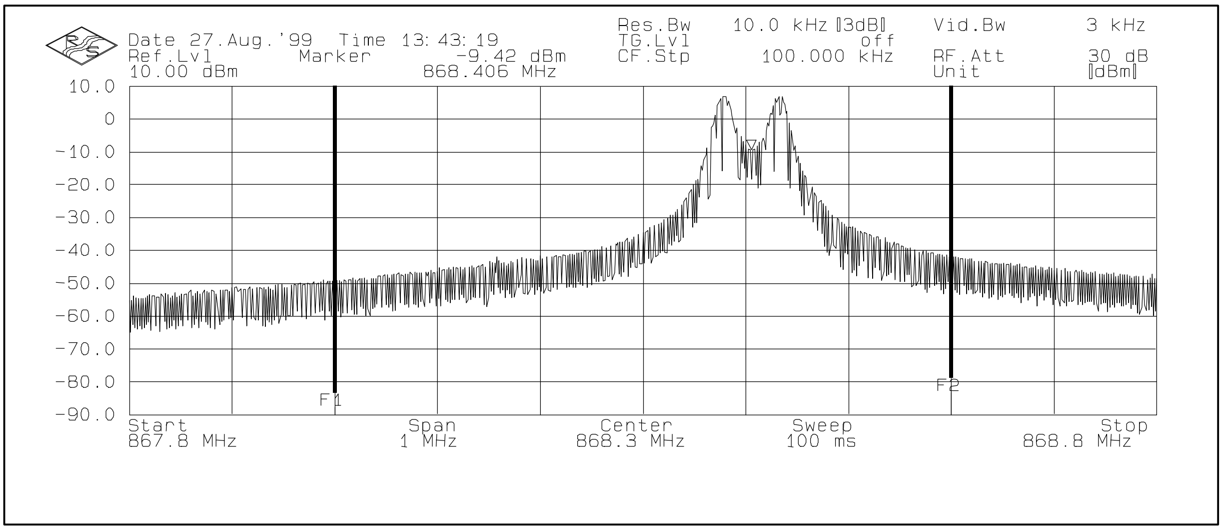

Fig. 8: FSK modulation (frequency lines indicate first 868MHz sub-band)

Performance Comparison

The two 868MHz transmitters are presented with respect to some design issues and have been compared to their most important parameters. Both can be used for FSK or FM applications in the first SRD sub-band that ranges from 868.0 to 868.6 MHz. Here signals can be transmitted with a power level of up to 25 mW (14 dBm).

The PLL-TX has been used at 1 mW (0 dBm) only. The RFIC TH7108 can be used at power levels of up to approx. 2 mW (3 dBm). The main constraint that must be considered here is that the current consumption should be less than (or equal to) 10 mA to allow the cos-tumer to use a Lithium cell battery; these cells typically should not be used at higher currents to prevent them from early discharge. Therefore, the power-select resistor has been chosen to deliver 0dBm output power at 10mA DC current. Choosing the desired carrier frequency for any 868MHz sub-band means to select a crystal with appropriate reference frequency. This is not a big deal because inexpensive crystals can be ordered at numerous manufacturers with typical lead times of a few weeks. Therefore, the PLL-TX offers great frequency flexibility. Using the PCB of the PLL-TX with an antenna causes no problem. All radiated harmonics are at the same relative level below the fundamental output signal as with a 50Ω termination (spectrum analyzer). This is because all active parts of the transmitter are on-chip, so there is no chance for distributed spurious emissions anywhere on the PCB.

The SAW-TX delivers 10 mW (10 dBm) under nominal conditions but can also be used up to 16 mW (12 dBm), at V_{cc} = 3.8 V. Due to the high efficiency, current consumption is only 10 mA nominal (same as PLL-TX). Unfortunately, there are only a few 868MHz SAW resonators currently available at some fixed resonant frequencies (e.g. for 868.3, 868.35 or 868.95 MHz). This means that the SRD developer has to accept the given frequencies for his applications, or has to spend a lot of money for a costumized SAW. Generally we can say that, at least with today's technology, SAWs cannot be taken for the designated narrow-band alarm channels at 868MHz. This is because of their inherently poor frequency stability. Antenna measurements showed that effective radiated power at the 4th harmonic is up to 5 dB higher than –30 dBm, and hence not within the EN 300 220-1 requirements (note that this is not the case at the 50Ω conductive measurement). This implies that the PCB radiates. A solution would be to put the PCB into a grounded metal box. But this is a cost factor which might not be acceptable.

Conclusions

Finally a fair comparison of both transmitter technologies based on the presented design examples is summarized in the following table. This may help the user of 868MHz SRDs to find "his" choice of transmitter architecture. Of course, the reported designs are exemplary, so the author does not claim to show the absolute best features reachable with a PLL nor with a SAW transmitter. But even with some variations at any parameter on either circuit (which might be achieved with other transmitters), the reported data serve as a comparative guideline.

Issue	PLL-TX	SAW-TX
efficiency = $P_o/(I_{cc}*V_{cc})$	3.7 %	34 %
frequency stability vs V_{cc} and T_a	+7 / -9 kHz +8 / -10 ppm	+60 / -88 kHz +69 / -101 ppm
FSK deviation stability vs V_{cc} and T_a	+2 / -1 kHz	+32 / -20 kHz
reliability or ease of production	- high - fully integrated chip with only few passive components	- medium - manufacturing tolerances are critical due to lot of Ls and Cs
type approval	no problem with harmonics phase noise limits max. output	no problem with phase noise harmonics are critical
price	- low - net component costs are approx. 5.5 to 6.5 DM at 10k units	- medium - net component costs are approx. 7.5 to 9.5 DM at 10k units

Table 3: Comparison of several SRD issues

References

[1] TH7108 – 868/915MHz FSK/ASK/FM Transmitter, Preliminary Data Sheet, Rev. 1.2, August 1999, Thesys GmbH.

[2] R2709 – SAW Resonator, Preliminary Data, June 25 1998, Siemens Matsushita Components.

[3] EN 300 220-1 – European Standard (Telecommunications Series), V1.2.1 (1997-11), European Telecommunications Standard Institute (ETSI).