AN5599

Application note

The ST1PS0x synchronous step-down converter: output Pi filter

Introduction

This application note provides some information on how to manage the ST1PS0x device family, in an RF communication system. The considerations present in this application note are valid both for the ST1PS01 and ST1PS02 part numbers.

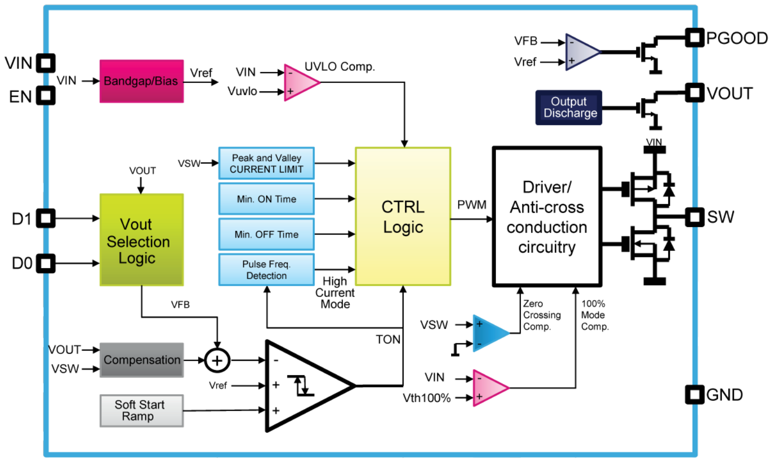
The ST1PS0x is a nano-quiescent miniaturized synchronous step-down converter. The device can provide up to 400 mA output current with an input voltage ranging from 1.8 V to 5.5 V. This converter is specifically designed for applications where high efficiency, PCB size and thickness are the key factors. The output voltage, that can be dynamically selected, can be set using digital control inputs. Thanks to the enhanced hysteretic architecture the ST1PS0x reaches a very high efficiency conversion using just a 2.2 µH (typ.) inductor and two small capacitors. Based on the application requirement, the inductor can be changed thanks to the hysteretic architecture implemented.

1 How the ST1PS0x works

1.1 Hysteretic buck architecture

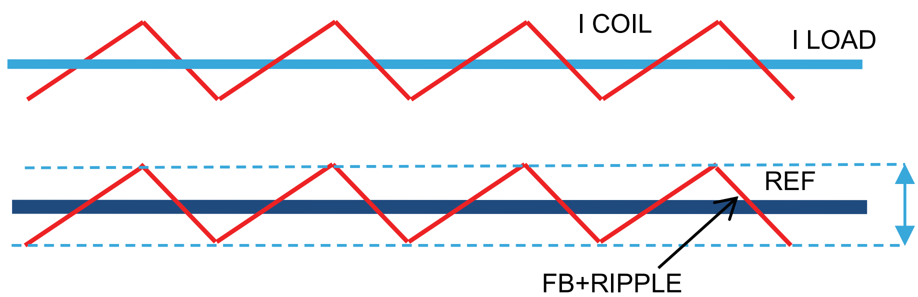
The ST1PS0x is a hysteretic buck converter. Figure 1. Block diagram of the ST1PS01 shows its architecture.

Figure 1. **Block diagram of the ST1PS01**



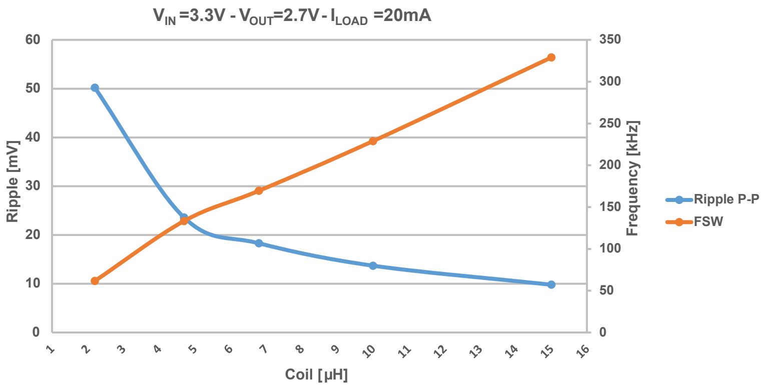
The output ripple is a combination of the hysteresis window and the internal feedthrough compensation, based on sensing of the coil current.

Figure 2. **ST1PS0x behavior**



For a fixed coil, the peak-to-peak current is almost invariant with VIN and VOUT. The higher the coil inductance, the lower the peak-to-peak current. Thanks to the hysteretic control based on the threshold of the internal comparator, the coil value can be changed to increase the DC-DC switching frequency and reduce the output ripple, as shown in the following graph Figure 3. Switching frequency vs. coil value.

Figure 3. **Switching frequency vs. coil value**



Due to the high di/dt current loop, switching noise appears on the SW node as ringing at each commutation edge and, when used in an RF communication system, unwanted spurious emissions can appear above and below the center frequency used for the transmission as shown in Figure 7. RF spectrum degradation.

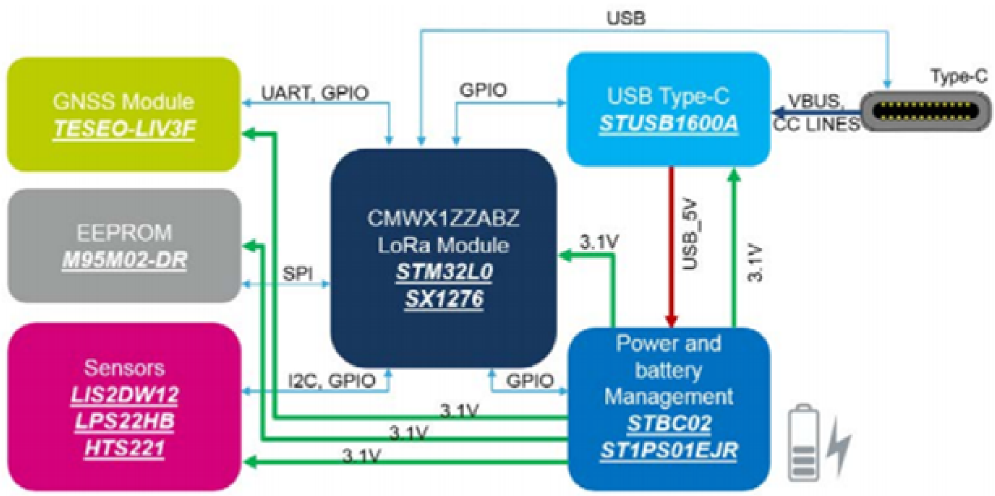
1.2 Typical applications

Switching regulators are used in portable devices to prolong battery life, thanks to their high power conversion efficiency. The ST1PS0x step-down regulators, are specifically designed to achieve small size, low quiescent current and high efficiency for all IoT devices, asset trackers, smart sensors, wearable devices, and smart meters.

Using the synchronous rectification architecture, the efficiency reaches 92% at 400 mA at full load and 95% when only 1 mA is supplied. The internal circuit characteristics, focused on energy saving, maintain the quiescent current at 500 nA and include a low power voltage reference. There is also a pulse frequency counter to control the converter current with light loads extending battery life. A wide range of input voltages from 1.8 V to 5.5 V, adds flexibility, allowing the use of various battery types or simple configurations, such as a single lithium battery.

1.2.1 Example of IoT applications

Figure 4. **Block diagram of the STEVAL-STRKT01**



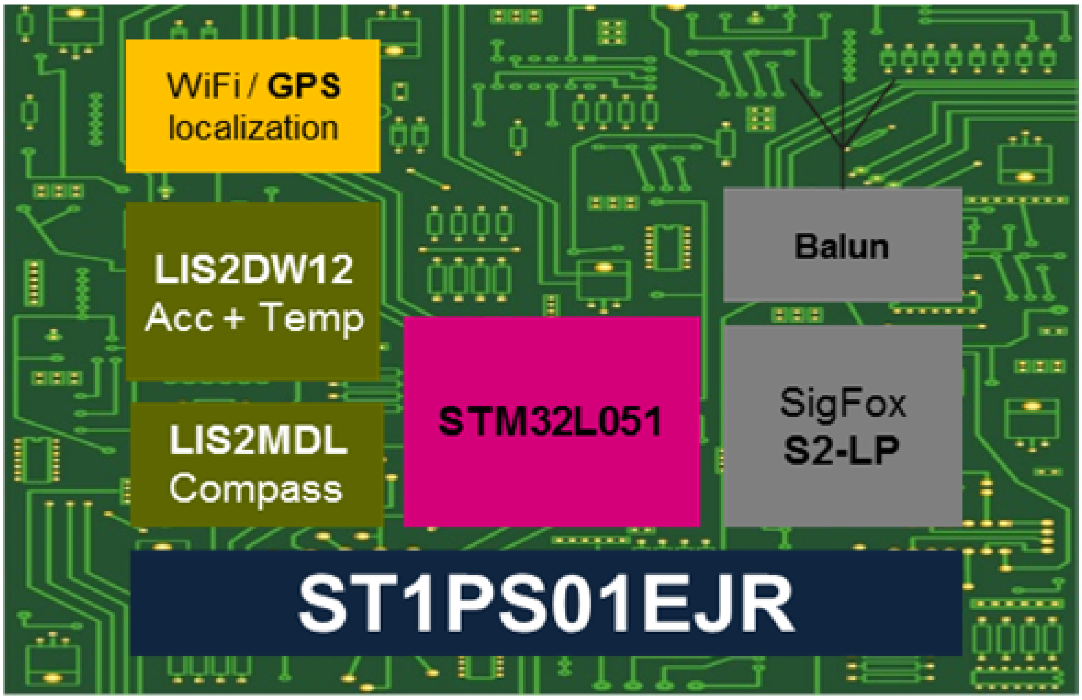
The STEVAL-STRKT01 is supplied by LiPo battery and implements low power strategies thanks to an enhanced power/battery management design using the ST1PS01 step-down converter that ensures long battery autonomy. In Figure 4. Block diagram of the STEVAL-STRKT01, the ST1PS01 device supplies all the blocks. Some system architectures supplied by switching controllers can be noise sensitive. Power supply noise can therefore generate an undesired worsening performance of those systems.

1.2.2 Noise sensitive applications

A radio frequency (RF) system, where the S2-LP is implemented, can be taken into consideration as a case study. In fact, it requires a good filtering of power supply to achieve optimum performance during radio frequency power transmission.

Here below a simplified block diagram of a SigFox S2-LP RF transceiver supplied by the ST1PS01 buck converter.

Figure 5. Block diagram RF transceiver



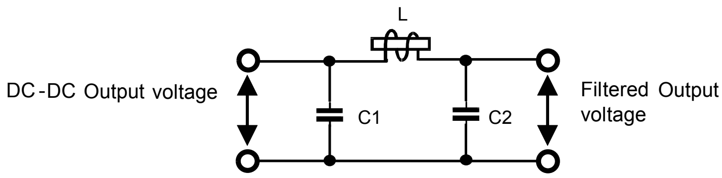
SigFox is a low power wide area network (LPWAN) used to connect IoT infrastructure, in which a lot of sensors can be integrated, and real-time data can be transmitted. The volume of data sent is low, the operating range is long, and the current consumption is in the range of few mA or tens of mA per transmission. D-BPSK (differential binary phase-shift keying) modulation is used for the transmission with a fixed bandwidth of 100 Hz within an unlicensed frequency spectrum that is below 1 GHz; for the Europe region 868 MHz and 915 MHz for the U.S. region. The power level for the Europe region is limited to 14 dBm and the power consumption is in the range of 20 mA.

The SigFox IoT modules are battery-powered so low power consumption of the ST1PS0x buck converters plays an important role in the battery duration.

2 Filtering effective method

An effective method for filtering high frequency power supply noise and providing a clean supply voltage for the S2-LP RF transceiver is the use of a Pi filter. The Pi filter circuit design is shown below. Switching regulators are used in portable devices to prolong battery life, thanks to high power conversion efficiency.

Figure 6. Pi filter schematic



The passive components used are two capacitors and a coil, connected as shown above. These three components are arranged in the form of the Greek number pi. This is the reason that the circuit is called a Pi filter.

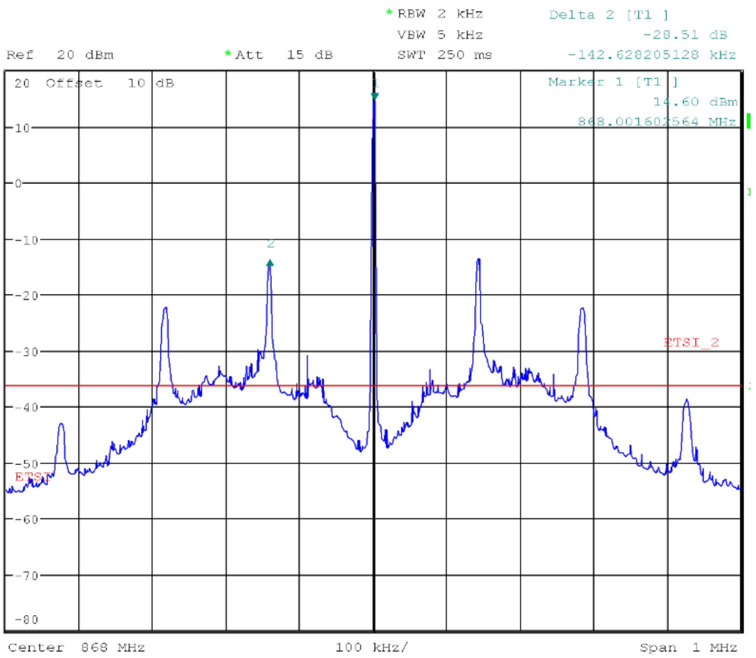
The values of the L and C elements determine the cut-off frequencies for these circuits. When the capacitors are placed as shunt elements, they bypass high frequency components in the input signal to ground, further reducing the high frequency power supply noise.

In the first instance the output resistance of the source can be considered negligible and cut-off frequency can be calculated using the formula below:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

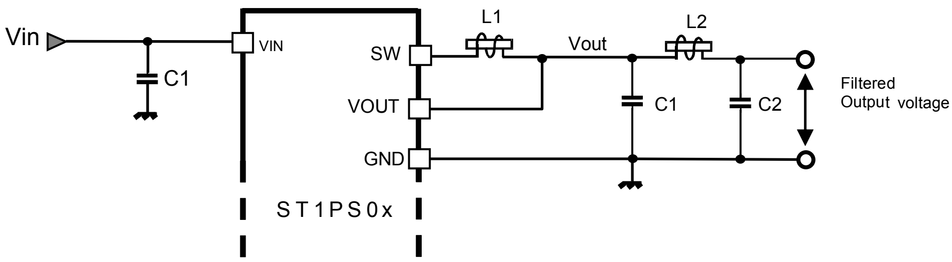
Here below an example of degradation of the RF spectrum, due to the spurious emissions generated by switching buck converter @Vin 3.6 V and Vout 2.7 V.

Figure 7. RF spectrum degradation



Adopting the Pi filter shown in Figure 8. Output Pi filter, it is possible to strongly reduce the generated spurious emissions and improve RF transmission performance with an RF spectrum devoid of degradation.

Figure 8. Output Pi filter



According to Eq. (1), it is possible to calculate the cut-off frequency using values below for the passive components:

L2 = 10 uH

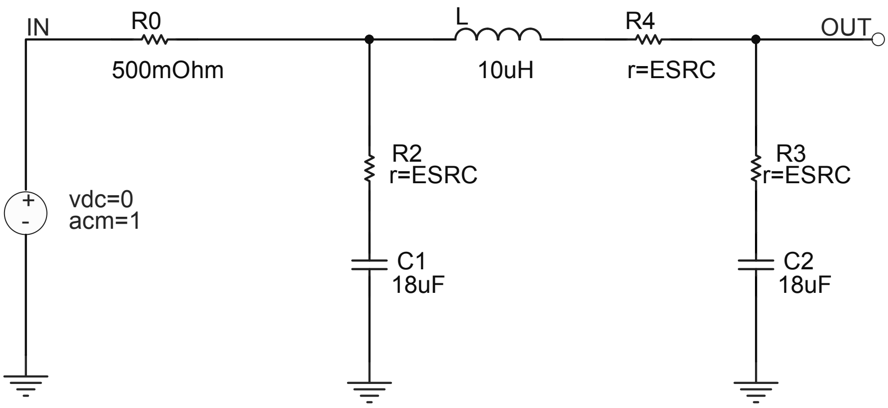
C = C1 = C2 = 47 uF (nominal capacitance)

So, the cut-off frequency is in the range of:

$$f_0 = 7344Hz \quad (2)$$

Taking into consideration the ESR and the real capacitance of capacitors, the DCR of the coil and assuming that the output resistance of the source is 0.5 Ω, the frequency response of the circuit below is shown in Figure 10. Frequency response of Pi filter.

Figure 9. ESR and ESL of passive components



C1 and C2 characteristics:

- Nominal capacitance: 47 uF
- Real capacitance @ 2.7 V: 18 uF
- ESR @ 100 kHz: 1.5 mOhm

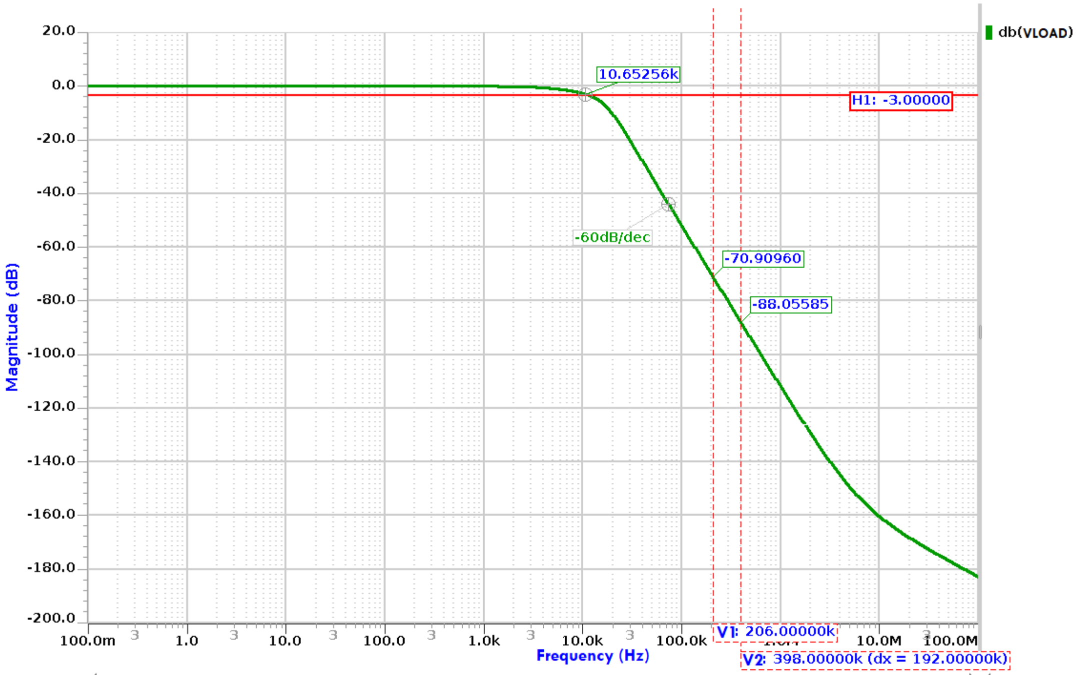
L characteristics:

- Inductance: 10 uH
- RDC: 560 mOhm typ.
- Isat: 300 mA

For the selection of the coil of the Pi filter, it is important to choose a saturation current rating greater than the current required by the application and a DCR as low as possible, in order to reduce the voltage drop across the coil.

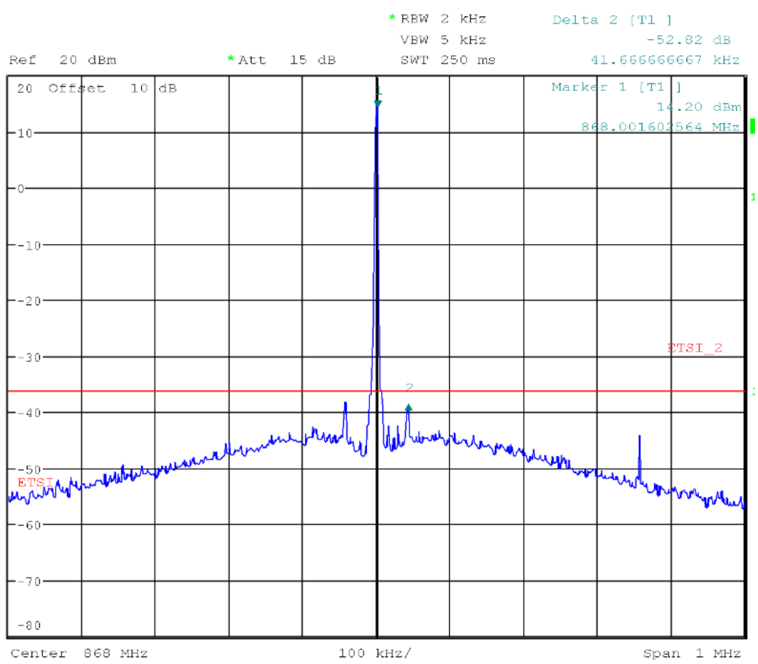
The frequency response shows the attenuation of spurious emissions on Vout 2.8 V @Vin 3 V (V1 cursor) and Vin 3.6 V (V2 cursor).

Figure 10. **Frequency response of Pi filter**



The effective attenuation results in a very clean spectrum that complies with the specifications as shown in Figure 11. Clean RF spectrum. So, with a low-cost solution, it is possible to achieve excellent results in terms of optimization of sensitive RF applications.

Figure 11. **Clean RF spectrum**



Revision history

Table 1. Document revision history

Date	Version	Changes
03-Mar-2021	1	Initial release.

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