Using the SY1007 in the UHF Band (405MHz)

1 Summary

The SY1007 is an RF front-end ASIC meant to implement the RF section of GNSS receivers in the L-band. Since this device – apart from low-pass filtering at the near base-band quadrature outputs – does not contain any frequency-selective circuit (band-pass filters) it can be used also at frequencies different from the L-band, provided the various external components are re-tuned to the desired operating frequency.

This application note explains how to proceed on the basis of an application centered at 405MHz. The most critical part that needs to be re-tuned correctly is the RF VCO. When operated at frequencies below its nominal 1.3-1.5GHz frequency range in fact there is the risk of either degrading VCO phase noise or reducing its tuning range excessively. LNA and IF-strip on the other hand are rather straightforward to re-tune by adjusting matching networks and IF-filter to the desired frequency range and bandwidth.

2 SY1007 RF ASIC Block Diagram

The block diagram of the SY1007 is shown in Figure 1. It is a programmable dual conversion super-heterodyne receiver. Apart from the 15MHz low-pass filters on the I/Q outputs, the device does not contain any frequency selective circuit that could limit its operating frequency. Matching networks and filters are implemented externally to the chip as LC-networks. Both the RF and the IF local oscillators can be independently programmed to accommodate various frequency plans by selecting the proper external components. Please see the SY1007 data sheet for more detail.

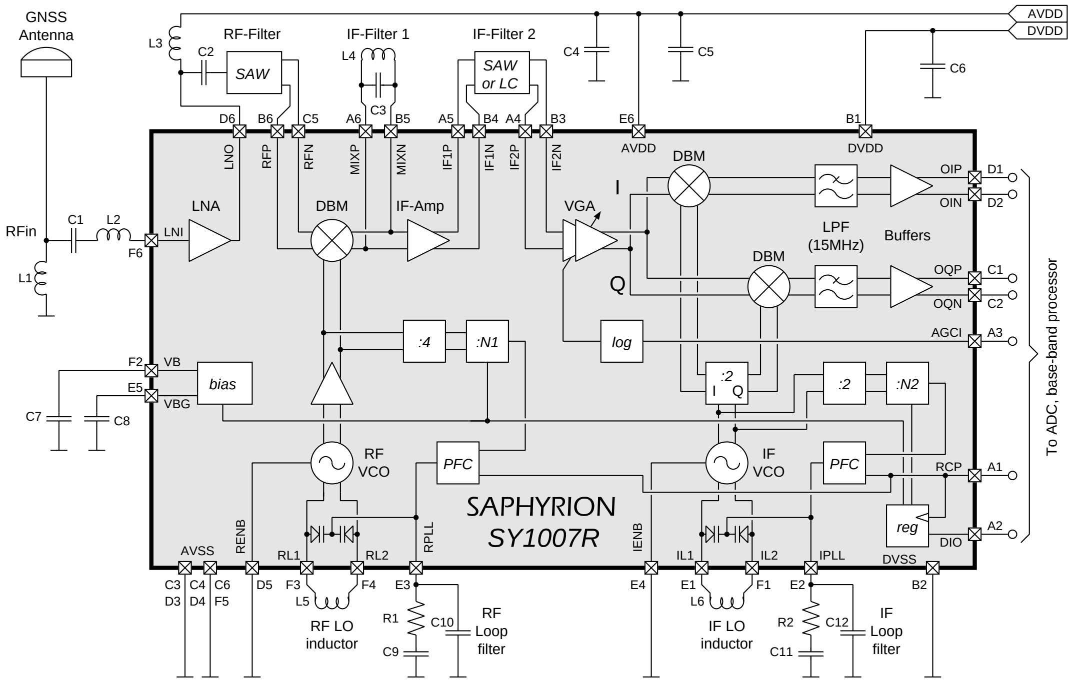

Figure 1: Block diagram of the SY1007.

When the SY1007 is used at frequencies in the UHF range (below 1GHz) the following shall be considered:

- The minimum divider ratio for the RF PLL is 256 (RF PLL register set to 64). The reference frequency of the PLL shall therefore be set accordingly.
- The RF VCO core has been configured for 1.3-1.5GHz operation. If the RF VCO is operated at a frequency much lower than its design frequency range, the tank-circuit must be reconfigured as parallel LC tank-circuit.
- LNA and RF mixer are wide-band circuits that operate without problems in the UHF range. The LNA simply needs the proper matching networks to set its I/O impedances while the mixer already provides a 50Ω wide-band termination with no external components.

3 Specification and Frequency Plan

The UHF application considered in this application note is a satellite communications system with the following parameters:

- Center frequency: 405MHz,
- Signal bandwidth: 10MHz,
- IF output center frequency: 5MHz.

The first thing to do is to find a suitable frequency plan for this application. It is assumed that a 405MHz SAW filter is used at RF, while a 4th or 6th order LC band-pass filter is used at IF. To select a frequency plan the following considerations can be followed:

- In order to simplify IF filter design (as 4th or 6th order LC-filter) the center frequency should be around 8-10 times the required bandwidth. If the IF-filter bandwidth is much narrower than about 10% of its center frequency a careful alignment will become necessary while sensitivity to temperature may become excessive.
- Good image rejection is generally easy to achieve when a SAW filter is used at RF. If the image is placed more than 10-15% apart from the desired channel good image rejection ($>$40-50dB) is generally achieved. Some attention to SAW filter side lobes is however needed. A side lobe at frequencies just above the pass-band is rather common in most SAW filters.
- The reference frequency of the PLL should be selected as high as possible to reduce spurious signals and to obtain good phase noise. Since the minimum division ratio of the RF PLL is 256 there is however a limit on the maximum usable reference frequency.

A good frequency plan that complies with these considerations can be achieved using a reference frequency of 2MHz and setting the minimum possible division ratio to the RF PLL. The resulting frequency plan is shown in Table 1.

Parameter	Value	Parameter	Value
Reference frequency	2.0MHz	Image frequency	619MHz
RF LO frequency	512MHz	IF LO frequency	112MHz
RF division ratio	256	IF division ratio	56
1st IF	107MHz	2nd IF (output)	5.0MHz

Table 1: Frequency plan for the UHF receiver example.

Other frequency plans are however possible. The 2nd IF can be adjusted in steps of 2MHz by adjusting the IF PLL divider as long as it fits within the 15MHz bandwidth of the base-band filters (on-chip), while by using a 1MHz reference finer frequency plan adjustments are possible, however at the expense of higher PLL spurious signals.

4 Configuration of the SY1007

As previously said in order to operate the SY1007 in the UHF range only requires a proper selection of the external components since the device does not band-limit the signals by itself. All recommendations given in the SY1007 data sheet – especially in the applications information (Section 13) – shall be adhered to, no matter in which band the SY1007 is operated.

4.1 LNA and Mixer

The equivalent circuits of LNA and mixer are shown in Section 9 of the SY1007 data sheet. The LNA is a cascoded single-stage amplifier, basically able to operate from $\approx$DC to $>$2GHz. It is configured to operate at a specific frequency by properly selecting its matching networks. At UHF the same matching network topologies shown in the data sheet can be used, only the component values need to be adapted. As usual with RF designs, these values will need to be fine-tuned experimentally on the actual PCB of the application.

The RF mixer is a double-balanced (Gilbert cell) mixer. This design is intrinsically wide-band and provides a fairly constant gain from $\approx$DC to $>$2GHz. Its input is matched to 50Ω (balanced) using a common-base input stage (1/gm) and thus requires no external matching network. A balun is necessary to couple a single-ended SAW filter to the balanced input of the mixer. The same LC design shown in the SY1007 data sheet (Figure 21) can be used also in the UHF band. For 405MHz operation the calculated values are (Table 2):

Component	Value
C	7.5pF
L	20nH

Table 2: Balun component values.

As usual in RF design, also in this case the calculated components need to be adjusted experimentally on the PCB of the application in order to fit the actual parasitics of the PCB.

4.2 107MHz IF-Filter

The 107MHz IF-Filter is a rather straightforward design. It can be implemented and calculated as explained in the SY1007 data sheet. Referring to the data sheet, Figure 22, a 107MHz 4th order coupled resonators LC-filter can be implemented with the following values:

Component	Value
C1	39pF+4.3pF
L1	56nH
C2	36pF+3.3pF
L2	51nH

Table 3: 107MHz IF-filter component values.

Capacitors C4 and C5 can be set to 100pF, while C3-L3-R3 shall be omitted. All values were rounded to the nearest E24 value, while PCB stray capacitances were ignored (about 1pF can be estimated). To obtain a sufficient repeatability and temperature stability 5% (or better) wire-wound inductors and 2% (or better) COG ceramic capacitors shall be used. A simulated frequency response of the 4th order 107MHz IF-filter using the components shown in Table 3 is shown in Figure 2.

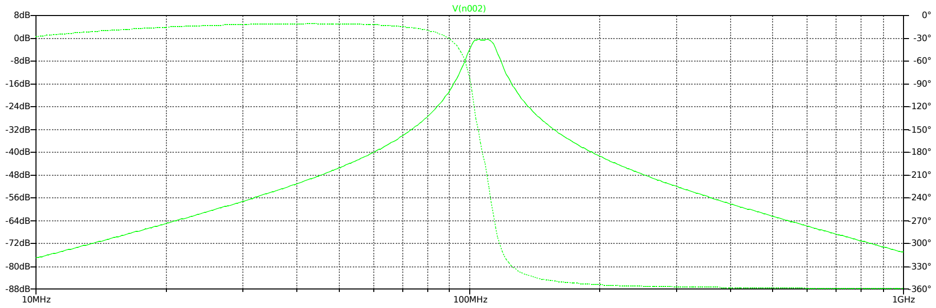

Figure 2: Simulated frequency response of the 107MHz IF-filter.

Also the IF filter will need to be aligned experimentally on the PCB of the application in order to compensate its stray capacitances. By implementing C1 and C2 as parallel capacitors this task is simplified while a fine alignment can be obtained by replacing only the capacitors with the smaller value (4.3pF and 3.3pF).

4.3 RF Local Oscillator and PLL

The RF oscillator of the SY1007 is originally designed for operation between about 1.3GHz to 1.5GHz. When it is centered within this frequency range all it is needed is an external inductor with the proper value (typically about 4.7nH to 6.8nH). Since this inductor is part of the VCO tank-circuit – the capacitance is on-chip – increasing its value will reduce VCO frequency.

In order to use the RF oscillator at 512MHz however it is no longer sufficient to increase the value of the external inductor, as this would lead to severe signal clipping within the oscillator, which in turn leads to very poor VCO phase noise performances. The proper way of reducing the VCO frequency to 512MHz is to use a *parallel LC tank-circuit* instead of the inductor. This parallel tank-circuit needs however to be dimensioned carefully, mainly by experiment, otherwise the VCO may not operate properly. If the inductor value is too large severe signal clipping will still occur, while if the inductor is too small the tuning range of the VCO will be insufficient to cover even the normal spread due to component tolerances.

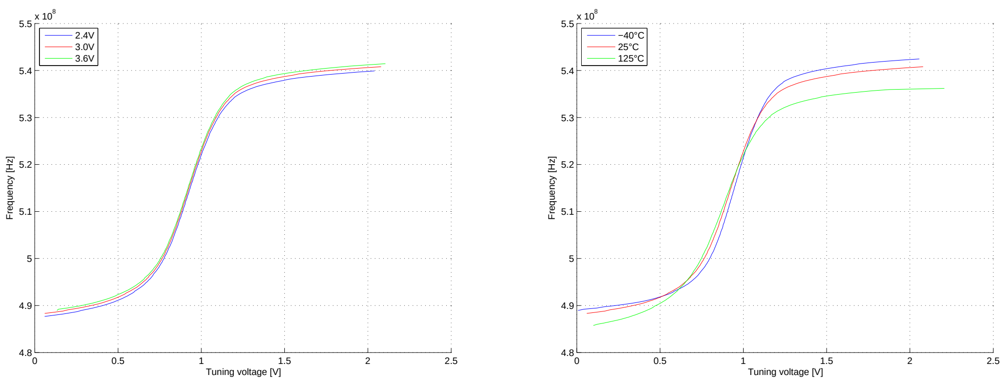

Figure 3: Measured tuning curves vs. temperature and supply voltage of the RF PLL.

By using a 22nH inductor in parallel with a 2.2pF capacitor instead of L5 (see Figure 1 of the SY1007 data sheet) proper VCO performances can be obtained. The RF VCO was constructed using the components shown in Table 4 and verified with a measurement.

Component	Value	Size	Type
Inductor	22nH	0603	muRata LQP11A22NG00
Capacitor	2.2pF	0603	DLI C06CF 2R2C 9L

Table 4: RF VCO tank-circuit component values and types.

The measured tuning curves are shown in Figure 3, while the phase noise measurement is shown in Figure 4. Two different measurement systems – a base-band analyzer below 20kHz offset and a spectrum analyzer above 20kHz offset – were used to obtain this measurement. The 2 measurements – merged in a single graph – are shown in different colors.

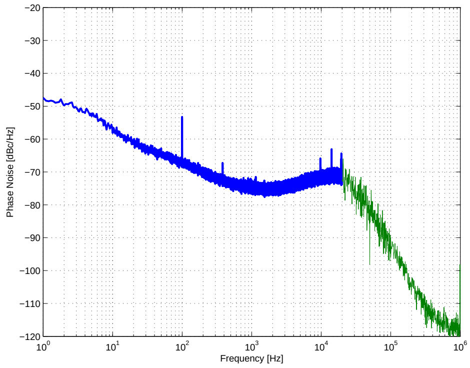

Figure 4: Measured phase noise of the RF PLL.

4.4 IF Local Oscillator and PLL

The IF VCO is designed for operation at center frequencies within a range of about 200MHz to 400MHz, i.e. a local oscillator frequency of 100MHz to 200MHz. To obtain a VCO center frequency of 224MHz (IF local oscillator of 112MHz) it is therefore sufficient to select the suitable inductor value, i.e. 150nH (found experimentally on the SY1007 test PCB). The IF VCO was constructed using the inductor shown in Table 5 and verified with a measurement.

Component	Value	Size	Type
Inductor	150nH	0805	ATC 0805 WL

Table 5: RF VCO tank-circuit component values and types.

The measured tuning curves are shown in Figure 5. The frequency shown is the actual local oscillator frequency (after the divider by 2, see Figure 1 of the SY1007 data sheet).

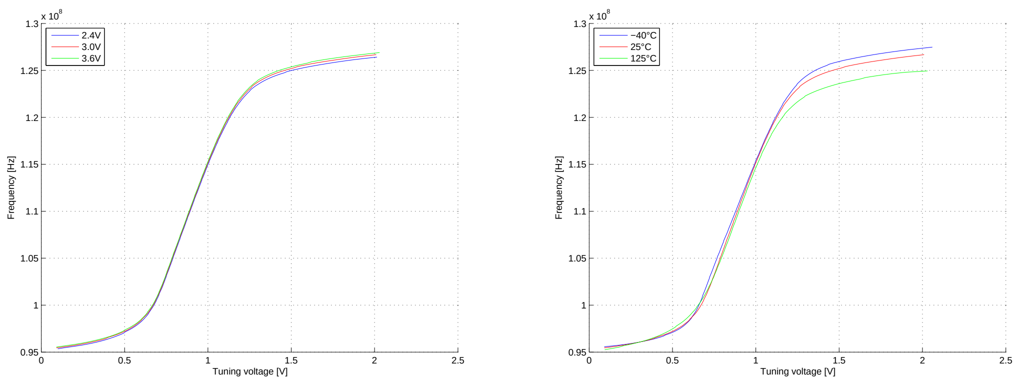

Figure 5: Measured tuning curves vs. temperature and supply voltage of the IF PLL.

A phase noise measurement for this IF local oscillator configuration was not done. Figure 6 shows the phase noise measurement for the IF local oscillator configured for 185MHz operation (IF VCO frequency = 370MHz). The phase noise at 112MHz (IF VCO frequency = 224MHz) is expected to improve by about 2dB.

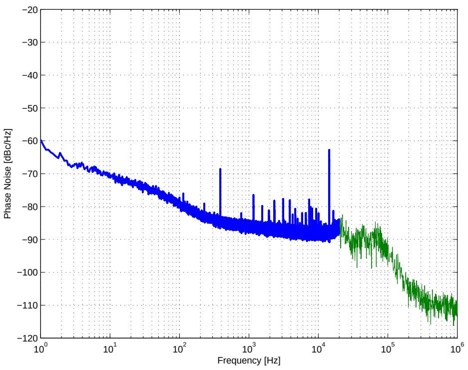

Figure 6: Measured phase noise of the IF PLL (185MHz).

The same measurement method used for the RF VCO was used also here, i.e. two different measurement systems – a base-band analyzer below 20kHz offset and a spectrum analyzer above 20kHz offset – were used. The 2 measurements – merged in a single graph – are shown in different colors.

5 Conclusions

The SY1007 device was originally designed as an L-band RF front-end for GNSS applications. Flexibility and configurability to support various GNSS signals and receiver frequency plans was a design requirement of this chip. Since the design of the SY1007 is basically wide-band and all band-pass filters are external to the chip, it is possible to configure it for operation also at different frequencies not in the L-band.

This application note shows how to configure the SY1007 for an example 405MHz UHF application. The most critical part in this respect is the RF VCO, since it is required to operate at a frequency well below its designed range. By selecting the appropriate external components however good operation can be achieved, as the measurements done on a prototype have shown. The lower operating frequency actually results in somewhat improved performances, in particular for the VCOs that will show a phase noise improvement of about 5dB and 2dB for the RF and IF VCOs with respect to the performances achieved by a corresponding L-band prototype.

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