RF360 Europe GmbH

A Qualcomm – TDK Joint Venture

Application Note
SAW-Components

GPS low noise front-end amplifier with SAW filter B3520

App. Note #16

GPS is rapidly growing in Automotive and in consumer market as well. GPS navigation for cars and motor trucks becomes more and more standard. A GPS front-end, consisting of an amplifier - filter combination is discussed. System comparison based on noise figure and gain is performed.

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GPS-Receiver topologies:

To receive the encoded right hand circular polarised GPS signal (1575.42MHz) special antennas and receivers are necessary.
At this point a differentiation has to be performed because there are mainly two types of receiver systems we are talking about.

For the first type, the GPS antenna and the Rf receiver are located separately. These types are often found in navigation systems which are part of the optional equipment of the car manufacturers.
Here the GPS antenna is mounted in a certain radome on the roof of a car or on the car boot. The receiver is placed in the navigation system, usually in the dash board. The whole antenna consists of a flat patch antenna, a SAW - or a microwave ceramic front-end filter and a LNA (Low Noise Amplifier) which gets is supply voltage via the RF cable.

For the second system, the GPS antenna and the receiver are putted together in one unit. The Antenna is a kind of helix shaped slot antenna, designed on thin PCB material. Antenna-receiver unit is connected to a PDA or a notebook via USB – or a certain interface cable. Here the front-end (antenna, filter and LNA) is similar to the first system.

On the following pages two different front-end topologies are compared and an example of a GPS front-end is described.

Front-end:

As mentioned above, the GPS antenna itself consists of a Patch antenna (see fig.1), a SAW – or a microwave ceramic filter and a LNA.

Fig. 1: EPCOS patch antennas of different sizes (from left to right 25x25mm, 18x18mm 13x13mm)

For the automotive market especially two main circuit topologies have been established. The first one can be seen in Fig. 2.
After the patch antenna there is a RF filter followed by a LNA. The antenna system is connected to the receiver via RF cable. Power supply is provided by this RF cable as well.

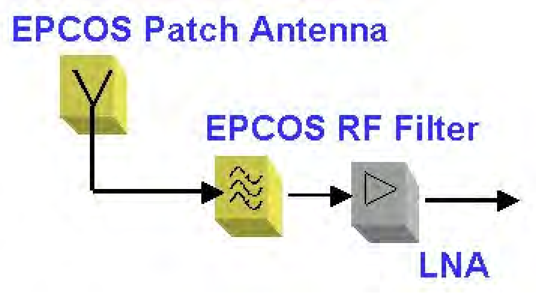

Fig. 2: GPS antenna system with patch - RF filter - LNA

For the second system the signal is detected by the patch antenna, passes a first LNA , a RF filter and a further second LNA. A RF cable provides the connection between the antenna system and the „in car" receiver unit. Fig.3 shows the block diagram of this topology.

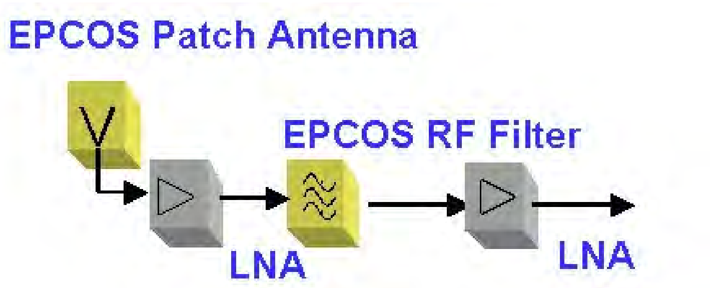

Fig.3: GPS antenna system with patch – LNA – RF filter - LNA

Both systems have certain advantages. This makes it necessary to have a close look at some characteristic parameters.
Sensitivity, selectivity, noise, gain and sensitivity against blocking due to GSM or AMPS signals for instance, are points where both systems have to be compared with each other.

Noise / Sensitivity

Following calculations show the difference in noise figure between topology 1 and 2.

Filter – LNA
Assuming an insertion loss of the SAW filter to 1.3dB would result in a „gain“ of about –1.3dB and a noise figure of 1.3dB.
The gain and noise of the amplifier shall be 27dB and 1.15dB
For further calculation noise figure and gain / IL has to be considered as linear values, not in logarithmic scaling. Remark: F (dB) => F (linear) => 10E(F/10)]

With equation 1 the total noise figure is calculated to:

$$F_G = F_1 + \frac{F_2 - 1}{v_1} + \frac{F_3 - 1}{v_1 * v_2} + ... \qquad [1]$$

Equation 1: Total noise figure of added single elements

$$F_G = F_{Filter} + \frac{F_{LNA} - 1}{v_{Filter}} \quad => \quad F_G = 1.35 + \frac{1.3 - 1}{0.74} = 1.76 \Rightarrow 2.46dB \qquad [2]$$

LNA – Filter – LNA
The following relevant parameters are assumed to:

Gain of both amplifiers 15dB each and noise figure 1.2dB each.
For the filter the same values, taken from point 1 are valid.
Inserting all values in equation 1 results in a total noise figure of:

$$F_G = F_{LNA1} + \frac{F_{Filter} - 1}{v_{LNA1}} + \frac{F_{LNA2} - 1}{v_{LNA1} * v_{Filter}}$$

$$F_G = 1.32 + \frac{1.35 - 1}{31.6} + \frac{1.32 - 1}{31.6 * 0.74} = 1.35 \Rightarrow 1.30dB \qquad [3]$$

Noise figure is about 1.2dB lower in the structure with the filter in front of the LNA. In practice this results in a better sensitivity of the system with the filter between the two LNAs.
As the GPS signal field strength is very low, a high sensitivity of the receiver system is mandatory. This can be achieved by choosing the proper front-end topology and a suitable front-end filter with low insertion loss.

Using a filter with the double insertion loss (2.6 dB instead of 1.3 dB), the noise figure of topology 1 increases up to 3.74dB (compare with [2]). Whereby with the second circuit topology the noise figure increases only by 0.1dB, to 1.40dB (compare with [3]).
This shows that the „LNA – Filter – LNA“ structure is more robust in point of IL min. (minimum insertion loss) of the SAW filter and provides better sensitivity.
Using the „Filter – LNA“ structure, it is important to use a filter with an IL min. as low as possible to get a reasonable low noise figure.

Selectivity / receiver blocking

As already mentioned GPS signals are very weak. So bad receiving conditions may cause the system to loose lock.
But also strong jamming signals generated by GSM, AMPS base stations or mobile phones for instance, can prevent detection of the satellite signal by blocking the receiver.
Therefore it is indispensable to ensure a high selectivity at certain frequencies to suspend the jammer. This can be done by using selective low noise amplifiers in conjunction with SAW – or microwave ceramic filters as shown with our both examples.
With both topologies a good attenuation is ensured. The selectivity of the patch itself, of the SAW filter and of the amplifiers is sufficient to avoid disturbances. With topology 2, however, a little disadvantage could appear. Since the LNA is the first stage after the patch very strong injected jamming signals can drive the amplifier into non-linear behaviour. Due to this high input power, the LNA is going into compression and therefore the gain will be reduced. This drops down the sensitivity of the system. The so called „input P_{1dB} point“ therefore is an important measure. This P_{1dB} point is reached when the input power level is so high that the gain of the amplifier is reduced by 1dB. A further increasing of the input power decreases the gain even more.
The application environment of the GPS antenna determines the danger of blocking. Using the GPS antenna close to a GSM antenna where the maximum output power is +33dBm @ 900MHz the probability of compression is higher than with a stand alone GPS antenna. The “input P_{1dB} “ point of common LNAs is in a range of –15....-22dBm at GPS Frequency (1575.42MHz). Of more interest is the P_{1dB} point in presence of a GSM interferer. Rejection of first amplifier’s input matching improves the P_{1dB} (GSM) point significant by typical 10...15dB. For the whole system the microwave patch antenna provides a certain selectivity for linear polarised signals.

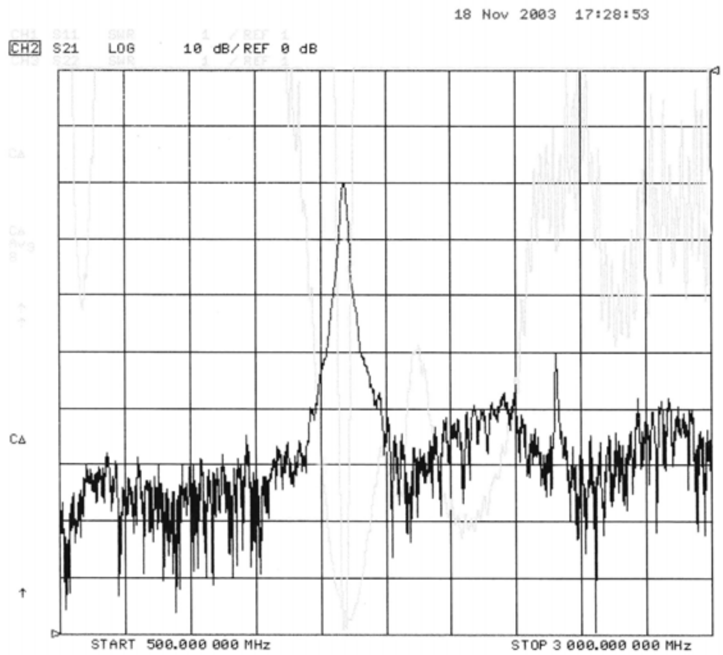

Fig. 4: Selectivity of an EPCOS microwave patch antenna for linear polarised signals, f_C:1575.42MHz

Figure 4 shows the selectivity of an EPCOS patch antenna with a size of 25mm*25mm. Attenuation of the patch itself is minimum 50dB over a frequency range which covers all possible jamming frequencies.

In conclusion both systems provide enough selectivity to suspend disturbing frequencies. Using the second circuit topology with a first LNA it should be checked whether there are spurious injections (GSM, AMPS etc.) due to the PCB layout structure. This could cause blocking and non-linear operation in the first amplifier.

GPS front-end with SAW filter B3520

To document all the above explanations, a GPS front-end with an EPCOS GPS filter B3520 has been designed. Here only the amplifier/ filter section without patch antenna has been realised. The patch would be placed in front of the „RF in“ connection (see Figure 5).For this sample the second circuit topology (LNA-filter-LNA) was used. Because of the higher sensitivity this circuit structure has been preferred.

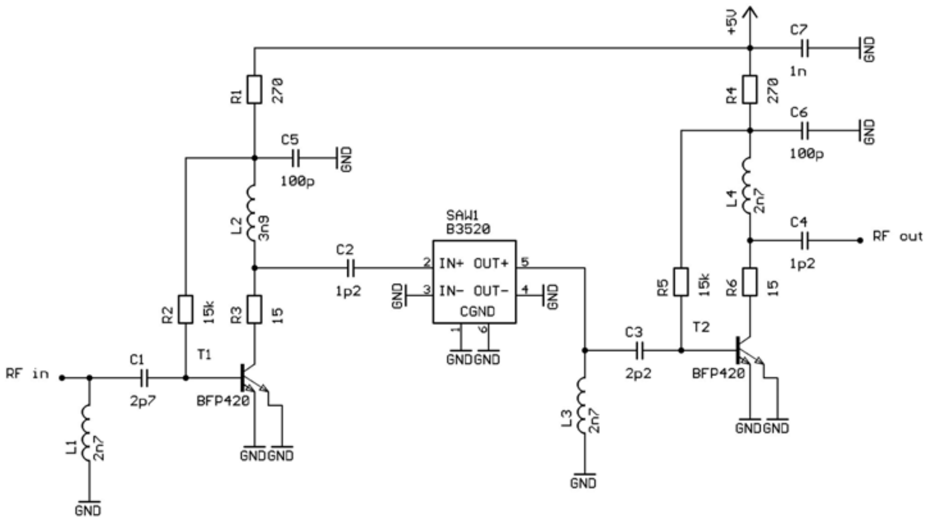

Fig. 5: Schematic of GPS front-end with B3520

Since the impedance of a patch is 50 Ohm the input of the first LNA (RF in) is matched to 50 Ohm also, in order to get optimum S_{11} and S_{21} performance. The gain of both LNAs is approximately 16dB, so that the total gain of the front-end is about 32dB. The output of the second LNA (Rf out) is also matched to 50 Ohm.

For biasing the transistors T1/T2 the resistors R1/R2 and R4/R5 are implemented. Both transistors are realised with a BFP420 from Infineon. This transistor has a low noise figure of 1.1dB and a f_T (transition frequency) of 25GHz, therefore it is well suited for this application. To keep the noise figure of the whole circuit low, the emitters of the transistors are connected to ground directly. L1/C1 and L3/C3 provide the matching to the RF input and the filter output.

To achieve a certain selectivity of the amplifiers and to ensure a proper matching to the filter input and to the RF output, L2/C2 and L4/C4 are used. The 15 Ohm resistors are inserted to improve S_{11} a little bit. The blocking capacitors are realised with C5/C6/C7 to keep the V_{CC} path free from RF.
Figure 6 shows the respective layout of the front-end.
Matching inductors L1/L2 and L3/L4 are discrete components, but PCB printed version are possible too.

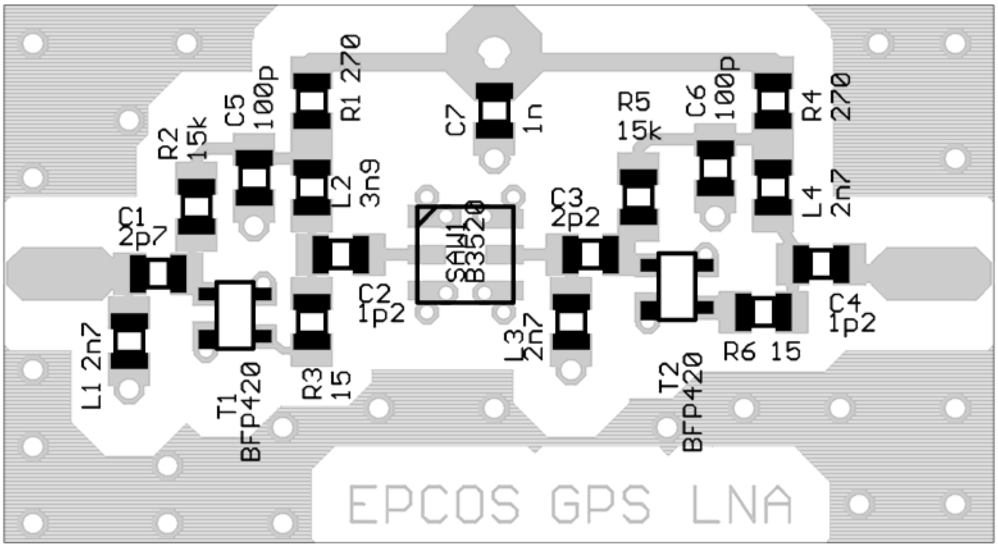

Fig. 6: Layout of the GPS front-end with B3520: Scale 4:1

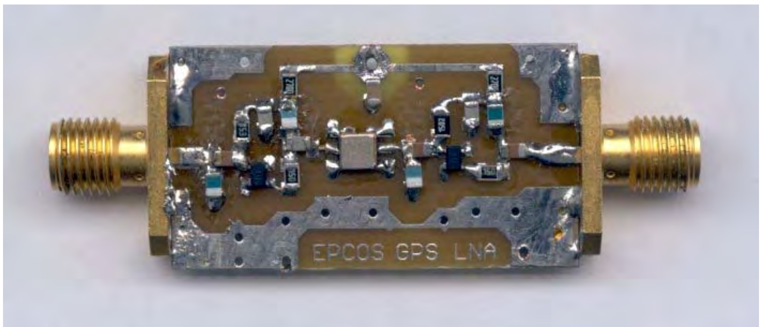

Fig. 7: Original PCB of the GPS front-end

The dimensions of the PCB is 32mm x 18mm. Designing a complete active GPS antenna (including patch) the PCB would be more squarish. On top layer the antenna would be placed and on the bottom layer, the LNAs together with the filter would be assembled.

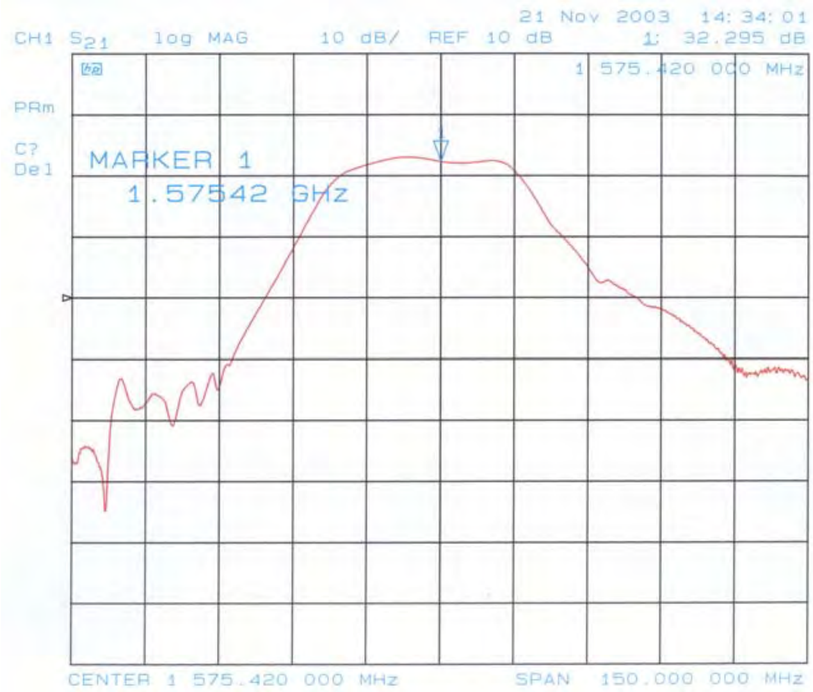

Fig. 8: S_{21} behaviour of the GPS front-end, Span 150MHz, P_{IN}=-40dBm

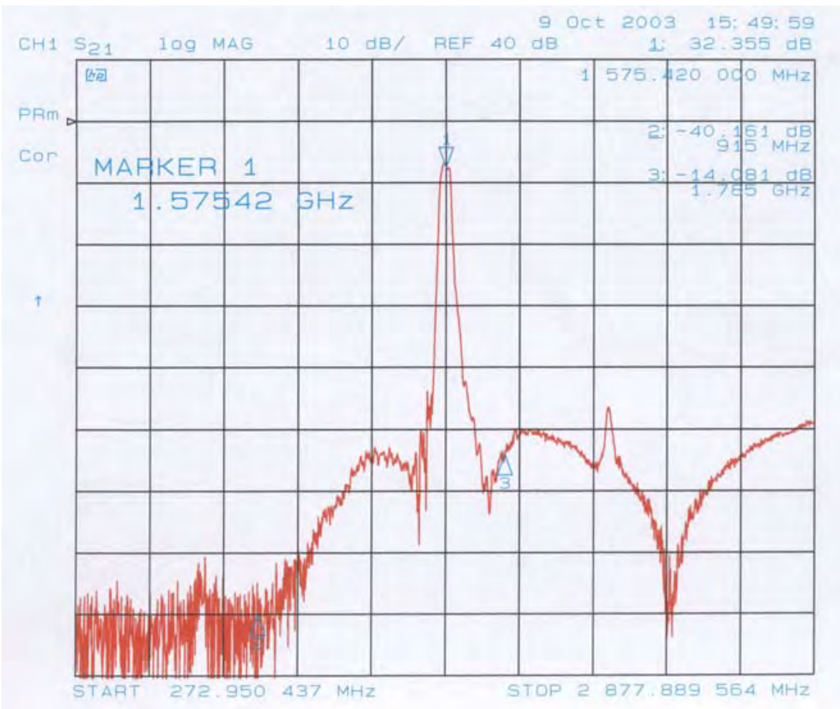

Fig. 9: S_{21} curve, selectivity performance, P_{IN}= -40dBm

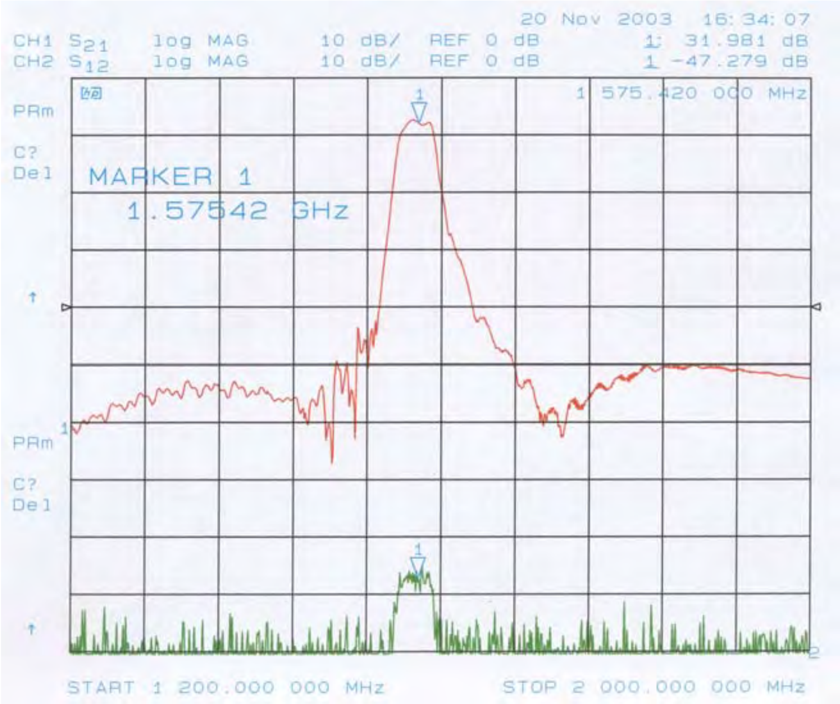

Fig. 10: S_{12} in comparison to S_{21}, P_{IN}= -25dBm

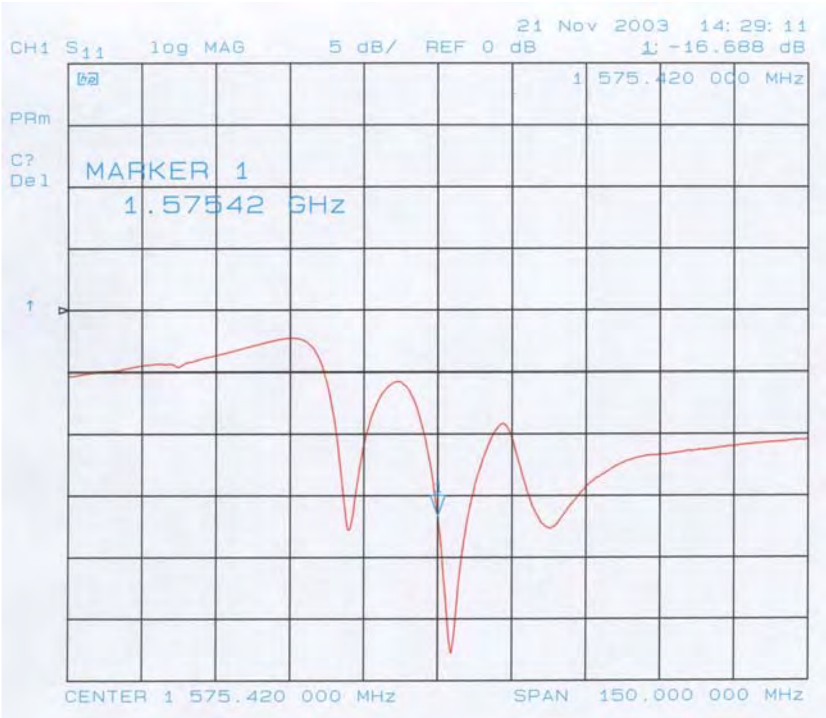

Fig. 11: S_{11} reflection behaviour, P_{IN}=-40dBm

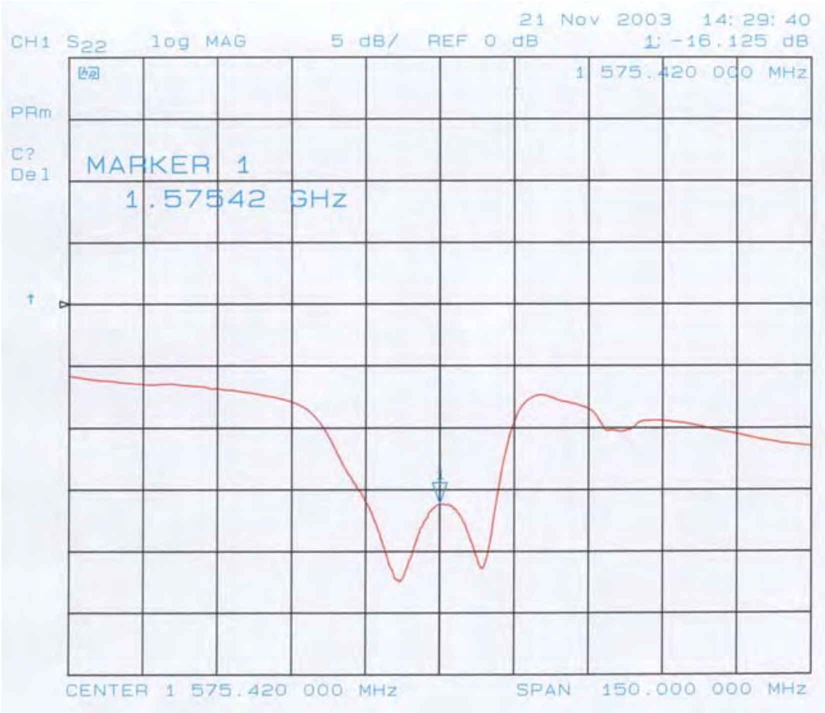

Fig. 12: S_{22} reflection behaviour, P_{IN}=-40dBm

Supply voltage:	+5V	
Current consumption:	20mA	
Operating temperature range:	-40°C...+85°C	
P1dB in (interfere:GPS)	-22dBm	@1575.42MHz
P1dB in (interfere:GSM)	-7dBm	@915MHz
Noise figure:	1.4 simulated	@1574.42MHz
VSWR input:	1.3 : 1	@1575.42MHz
VSWR output:	1.4 : 1	@1575.42MHz

Table 1: Electrical characteristics at ambient temperature (25°C)

The circuit has been tested from –40°C up to +85°C. The measurements have shown, that the circuit is stable over the whole temperature range. The gain of the front-end (measured at 1575.42MHz, the amplitude ripple over the total passband of B3520 is approximately 1dB) varies from 34dB (@ -40°C) to 30dB (@ +85°C). The input (S_{11}) and output (S_{22}) reflection coefficients are always better than –12dB in the passband of 1575.42MHz ± 1MHz.

Conclusion:

The discussion of different GPS low noise front-end architectures shows significant differences in point of noise figure and selectivity.

Filter - LNA:
To achieve a high sensitivity it is mandatory to use front-end filters with low insertion loss. Filters with low insertion loss have a worse selectivity than those with low insertion loss.
Blocking is less critical because of the filter in front of the LNA.
The LNA often is realised with an integrated Amplifier with high gain.

LNA – filter – LNA
The sensitivity is determined by the first LNA, whose noise figure usually is in a range of 1.1dB to 1.2dB
The filter and the second LNA do not have significant influence on the sensitivity. So sensitivity is better than with the Filter-LNA topology.
The selectivity is better because filters with higher insertion loss (1.3dB instead of 0.8dB) can be used. To further improve selectivity of this system, filters with much better selectivity and still higher insertion loss (approximately up to 3dB) can be used. The sensitivity thereby will not be worsened drastically.

Commercial point of view
Comparing the costs of both systems also a difference is detectable.
The “filter-LNA” structure usually is built with one integrated amplifier after the filter. Due to this circuit structure the gain of this amplifier has to be very high, because it is normally not splitted into two seperate sections. For a standard GPS front-end it has to be about 30dB. These amplifiers are usually more expensive than two amplifiers made of discrete components.
With the “LNA-filter-LNA” topology the gain of the two amplifiers is about 15dB each and can be built with standard RF transistors and passive components. These components are low in price and the availability also is ensured because of the possibility of multi sourcing.

Table 2 shows a short comparison of both systems

	Filter - LNA	LNA - Filter - LNA
noise figure	high	low
gain	high	high
sensitivity	medium	high
price	medium	discrete sol. - low
design effort	medium	more complex

Table 2: Comparison of both systems