Global Position System
Low Noise Amplifier

GPS, LNA, Sensitivity, Jamming, Cohabitation, TTFF

This White Paper explains why an external low noise amplifier results in a better performance.
Next generation mobile handsets will be equipped with GSM, WLAN, Bluetooth and GPS.
Integrating all these functionality onto one printed circuit board gives housing problems or
cohabitation challenges. Some of them can be solved easily at low cost but others cannot.
In this paper the GPS and its cohabitation with GSM and WCDMA will be explained.

1   GPS Integration Challenge

Currently people are using Personal Navigation Devices (PND) to finding a location around the globe. Likewise for wireless LAN, wherever you are, you want to have the Internet available. Downside of this multi functionality is that you have to carry many devices with you. For this reason mobile handset makers start to integrate the GPS WLAN etc. into one device.

Referring to GPS, the received signal strength is very weak. The satellites have an orbit altitude of 20200 km (90 degrees elevation) from earth. It's transmit power is 44.8 Watt at 1575.43 MHz and the antenna gain is 12 dBi. Assume that the PND device has an antenna gain of 4 dBi. Then the received signal power is -120 dBm using the free space loss model. Including additional losses (atmospherically, antenna) the received power is -125 dBm. While the noise power in the

system bandwidth (2.046 MHz) is -110 dBm! But due to the modulation scheme, which is direct spread-spectrum there is a processing gain of 43 dB. In fact signals can be recovered theoretically till -110-43=-153 dBm. In order to improve quality of services the received power strength requirement will be several dB above the theoretical level. For instance, during acquisition the received power required is -135 dBm and for tracking -147 dBm.

For cohabitation it is important to cope with the low signals level at the GPS frequency. Unfortunately, this integration is not straightforward. Putting different wireless functionality into one housing is called cohabitation. Compare this with interpersonal relationship you have to put in effort in to make it happen.

founded by Philips

Figure 1 depicts an example of GSM and GPS cohabitation. Suppose that the GSM transmitter transmits at 1800 MHz at a power level of +36 dBm (4 Watt). The GPS receiver receives GPS signals at 1575.42 MHz (L1 frequency) at a power level of -125 dBm (about 0.1 fWatt). The isolation between the GSM output and the GPS's receiver input is approx. 15 dB. Leaving 21 dBm of GSM power at the GPS receive input.

Filtering will help to reduce the GSM power level at the GPS receiver's input, see Fig 2, but will increase the noise level, which reduces the GPS receiver sensitivity. High attenuation filters have high insertion losses. Next to this the wideband noise emission from the power amplifier of the GSM cannot be filtered out, because it is present directly in the GPS band.

Finally, the GPS antenna might be separated far away from the GPS receiver IC. Long PCB tracks results in an increased noise level, which reduces the GPS receiver sensitivity as well. Note that integrated GPS antennas have often low antenna gains (-6 dBi).

Cohabitation gives four problems to solve:

▸ Reduced GPS receiver sensitivity due to high filter losses to attenuate out of band jamming signals (GSM, DCS, WCDMA) to avoid overdriving the Low Noise Amplifier (LNA) and improve out of band O-IIP3

▸ Cross modulation that corrupts GPS reception

▸ Wideband noise power generate by jamming PA

▸ Antenna GPS receiver separation

What will the end user experience when using an external LNA? Improved sensitivity results in a shorter time to first fix (TTFF). TTFF definition is the specification detailing the time required for a GPS receiver to acquire satellite signals and navigation data, and calculate a position solution. The latter is called a fix. Long TTFF results in an increased frustration level of the users. This long TTFF can be improved by using an external LNA.

Resume, GPS receivers suffer a lot from receiver desensitization if a neighbor jamming signal(s) is (are) present. This white paper concentrates mostly on problem one and two. Problem three can be solved by applying GPS blanking during Tx burst. Problem four is solved by placing the LNA as close as possible to the GPS receive antenna or use an active antenna with a high gain LNA.

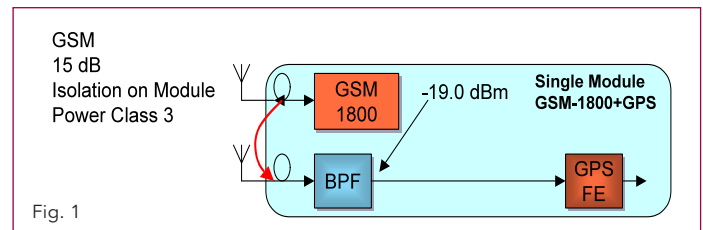### Block diagram of GSM and GPS integrated on one PCB

Fig. 1

GSM transmits at class 3 (+36 dBm). At the GPS antenna input the received GSM power is 21 dBm. The band pass filter attenuates the GSM signal with 40 dB. Leaving –19 dBm at the input of the GPS front-end IC

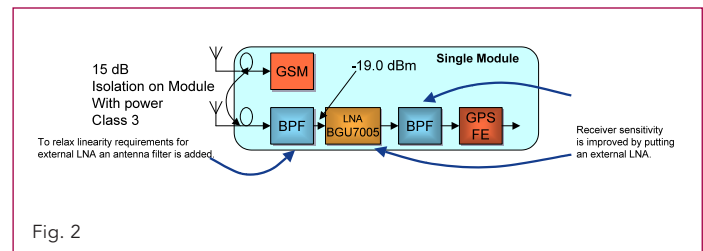### External LNA with BPF filters and GPS front end receiver

Fig. 2

2 GPS and GSM-1800 Cohabitation

GSM-1800 uses 1710–1785 MHz to send information from the mobile station to the base transceiver station (uplink) and 1805–1880 MHz for the other direction (downlink), providing 374 channels (channel numbers 512 to 885). Duplex spacing is 95 MHz.

GSM-1800 is also called DCS (Digital Cellular Service) in the United Kingdom, while being called PCS in Hong Kong (not to mix up with GSM-1900 which is commonly called PCS in the rest of the world.)

According to the 3GPP TS 45.005 V8.3.0 (2008-11) there are three power classes defined for GSM-1800.
These power classes are:

    Class 1: 1 Watt or (+30 dBm),

    Class 2: 0.25 Watt or (+24 dBm) and

    Class 3: 4 Watt or (+36 dBm).

In case of GSM-1800 cohabitation, proper filtering and proper amplifier design can solve problems 1 and 2. The NXP BGU7005 LNA has special properties to improve the GPS receiver sensitivity.

2.1 Cross modulation that corrupts GPS reception

The NXP BGU7005 can cope with strong GSM jamming signals while maintaining its low noise figure of 1.1 dB. In fact the BGU7005 improves its immunity at the GSM-1800 frequency, this results in an improved out of band input third order intercept point (IIP3) linearity, +10 dBm. Poor out of band IIP3 performance of an external LNA gives cross-modulation (xmod) that corrupts GPS reception.

Fig 3 shows the BGU7005 in a front-end module with pre- and post filtering. Pre-filtering is required to reduce the GSM 1800 transmit power to avoid that the LNA will go into compression. Post-filtering is needed to protect the integrated LNA in the GPS IC.

Suppose that the PCS-1900 jammer is at one meter distance of the GPS receive antenna. In this case the received power at the GPS receive antenna is -19.8 dBm where the antenna gain for PCS-1900 is 0 dBi and for GPS receiver -6 dBi. This PCS-1900 signal together with GSM-1800 signal will give cross modulation at the GPS frequency due to third order intermodulation.

Suppose that the GSM-1800 transmit frequency f1=1713 MHz and PCS-1900 transmit frequency f2=1851 MHz. GSM-1800 is transmitting at +36 dBm and the PCS is transmitting at +24 dBm. The out of band third order intercept point frequency can be found to be f3rd =2*f1-f2=1575 MHz. This is exactly the GPS frequency band. But the amplitude of this component depends heavily on the linearity of the LNA.

The powers at the input of the first BPF are +21 dBm for GSM, and -19.8 dBm for PCS, respectively at one meter distance. Suppose that the filter attenuates the signals with 40 dB. Then at the input of the LNA the signal powers are -19 dBm and -59.8 dBm, respectively. The LNA has an out of band IIP3 of +10 dBm, which gives an intermodulation level at the input of the LNA (at the GPS frequency) of -117.8 dBm. If the GPS signal is at -125 dBm then the Jamming to Signal ratio J/S can be maximum 35.3 dB! This is at the edge of the GPS requirement regarding narrow band jamming signals.

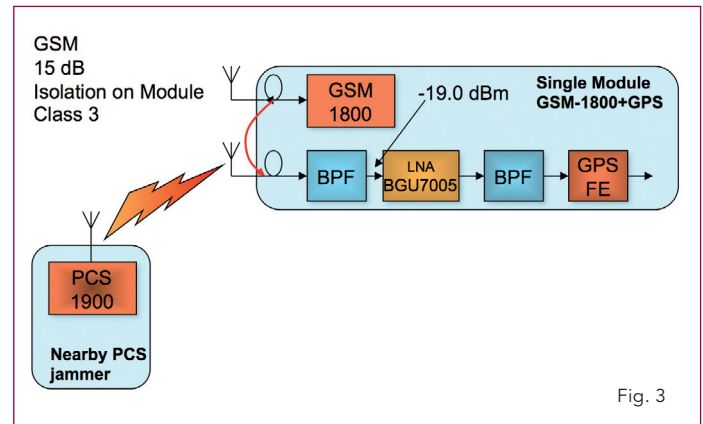**Block diagram of GSM cohabitation with NXP's BGU7005**

Fig. 3

GSM-1800 mobile transmit frequency range is 1710 – 1785 MHz power class 3 (+36 dBm) and PCS-1900 (UMTS-FDD) mobile transmit frequency range 1850 -1910 MHz jammer power class 3 (+24 dBm) (3GPP TS 25.101).

2.2 Wideband noise power generate by jamming PA

Problem 3 cannot be solved by simply filtering because the wide band noise resulting from the GSM PA falls directly in the GPS band. Fortunately the GSM radio interface has a time division duplex (TDD) mechanism. Implying that the transmit burst and the receive burst are shifted in time. During receive the GSM cannot transmit and vice versa. This feature of the TDD behavior is used in the cohabitation problem 3.

The wide noise of the GSM is specified to be -79 dBm in 30kHz bandwidth from 6 MHz onwards or -124 dBm/Hz. The frequency difference between GSM 1800 and GPS is 135 MHz. This translates to a total wide band noise power in the GPS band of -61 dBm!

During transmit mode of the GSM the GPS receiver is switched off. In the measurement engine of the GPS receiver an extrapolation algorithm is used for location calculation. It is assumed that the GPS user's location change is small. For better position accuracy it is desired that the GPS receiver is always on and reduce the number of blanking intervals. Therefore blanking is not used in case of cross modulation.

The BGU7005 is equipped with a shutdown pin where the LNA can be switched on or off also called blanking (software blanking is possible as well). Blanking speed of the BGU7005 is 1 MHz.

3 GPS and UMTS-FDD Cohabitation

In contrast with GSM, UMTS-FDD (WCDMA) has a frequency division duplex (FDD) operation, which implies that both the transmitter and receiver are active simultaneously. Therefore blanking of the GPS receiver does not make sense.
In the WCDMA case the GPS receiver relies on the pre- and post filtering. Insufficient attenuation of the WCDMA signals results in a saturated LNAv

3.1 Cross modulation that corrupts GPS reception

A saturated LNA (or often called LNA is in compression) gives distortion in the GPS frequency band. Fig 6 shows the worldwide frequency spectrum allocation. In North America, Europe, Africa, China and Australia the 1710 MHz band and the 1810 MHz band are occupied with UMTS-FDD and GSM communication systems. Both having high transmit powers. The out of band inter modulation of the third order of the LNA given the 1710 MHz frequency and 1810 MHz frequency gives distortion components in the GPS bands.

Suppose f1=1713 MHz (UMTS-FDD 1800) and f2=1851 MHz (UMTS-FDD 1900) then the third order component can be found to be f3rd =2*f1-f2=1575 MHz. This is exactly the GPS frequency band. But the amplitude of this component depends heavily on the linearity of the LNA. See also Fig 4.

The typical power level of the GPS signal is -125 dBm. It is allowed that the out of band intermodulation product of order 3 (IM3) power level coming from a two tone is to be 11.7 dB higher than the GPS signal level therefore the out of band linearity of the LNA should be about 100 dBm without filtering and including 10 dB antenna isolation. Of course this is not feasible. But in case of selectivity in front of the LNA the linearity requirement will relax. The input 1 dB compression point is of the LNA -9 dBm at 1.8 V. The max transmit mode of GSM is +36 dBm and the antenna isolation is 15 dB. The minimal attenuation required by the filter to prevent that the LNA is going into compression at UMTS frequency is (36-15)-(-9) =30 dB.

Consequently, the out of band input IP3 measured for the BGU7005 is +9 dBm. But the GPS specification requires that the out of band linearity should be better than +9 dBm. Suppose that the UMTS 1800 jammer is 3 meters away from the GPS receive antenna and that the UMTS 1900 transmitter transmits at +30 dBm. The received power level at the GPS antenna from the UMTS 1800 jammer transmitting at +24 dBm is -29.3 dBm. The antenna gain for the UMTS 1800 is -10 dBi giving -39.3 at the input of the LNA. In this case the IM3 level is -24.3 dBm at GPS L1 frequency. A GPS signal at -125 dBm will be heavily distorted.

In order to solve this out of band linearity a band pass filter with sufficient attenuation is placed in front of the external LNA. Suppose that a band pass filter has an attenuation of 40 dB for the out of band signals. Then by using the previous input powers, this results in an IM3 level of −140 dBm.

The continuous wave (CW) jammer to (GPS) signal ratio J/S can be maximum +30 dB. This implies that for a typical power level of GPS signal of -125 dBm the maximum jamming signal is -95 dBm. This results in a minimum out of band IIP3 requirement of +57 dBm having the above mentioned power levels. Often a margin of 3 dB is used, resulting in an out of band IIP3 of +60 dBm.

Fig 5 shows the NXP's front end module with the BGU7005. It can clearly been seen that the cumulative out of band IIP3 is above 60 dBm. The minimum out of band requirement of 57 dBm is easily met. Moreover the cumulative noise is 2.3 dB. As extra feature the BGU7005 can be implemented in the application as low external component count or as low current consumption.

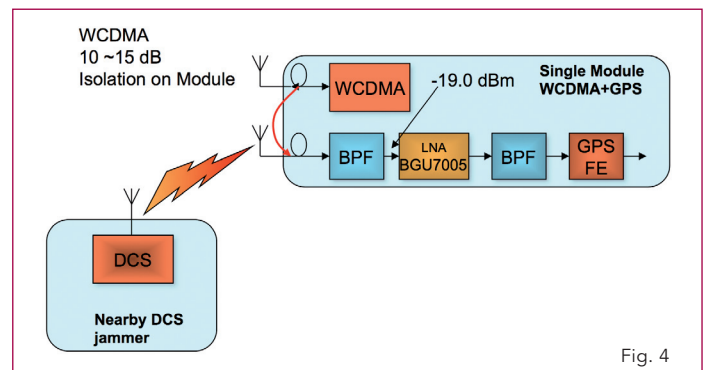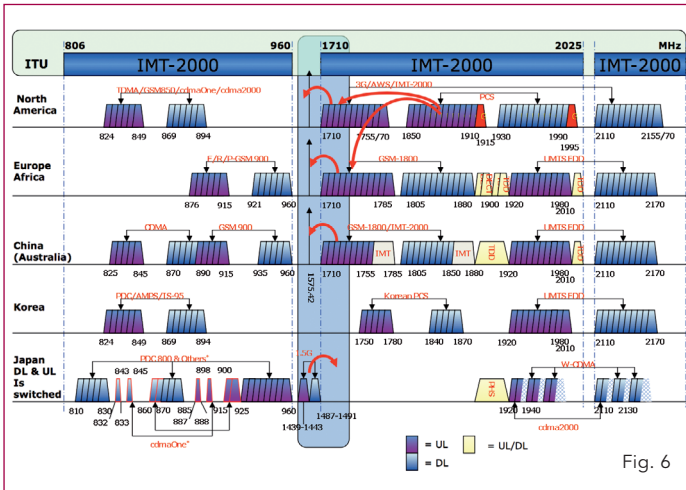**Interference into GPS receiver for UMTS-FDD 1800 and UMTS-FDD 1900**

Fig. 4

NXP's front-end module linearity performance at the antenna input

Parameter	BPF1	BGU7005	BPF2	GPS IC
Gain [dB] @ GPS L1	-1.2	16.5	-1.2	0
Gain [dB] @1713 MHz	-	15.6	-	-
Gain [dB] @ 1851 MHz	-	14.7	-	-
Noise Figure [dB] @GPS L1	1.2	1.1	1.2	0
IIP3 [dBm] out of band	100	10	100	100
Selectivity out of band [dB] @ 1713 MHz	53	0	45	0
Selectivity out of band [dB] @ 1851 MHz	53	0	45	0
Cumulative out of band IIP3 [dBm]	62.00	10.00	141.46	100
Cumulative NF [dB] @ GPS L1	2.30	1.12	1.20	0.00
Cumulative Gain [dB] @ GPS L1	14.1	15.3	-1.2	0

Fig. 5

Worldwide frequency spectrum allocation between 800 and 2000 MHz.

Fig. 6

3.2 Wideband noise power generated by jamming PA

Problem 3 cannot be solved by simply filtering, because the wide band noise resulting from the WCDMA PA is directly in the GPS band. The WCDMA radio interface has a frequency division duplex (FDD) mechanism. Implying that the transmit burst and the receive burst are in frequency shifted. Transmitting and receiving happens at the same time. Blanking is not possible in this case and cannot solve problem 3.

During the transmit mode of the GSM, the GPS receiver is switched off. In the measurement engine of the GPS receiver an extrapolation algorithm is used for location calculation. It is assumed that the GPS user's location change is small.

The spurious level is defined in 3GPP TS 25.101 version 8.4.0 Release 8 and is specified to be -79dBm in 100 kHz measurement bandwidth (absolute requirement) or -129 dBm/Hz. Resulting in -66 dBm noise power in GPS band! Fortunately the user equipment is transmitting at a lower power compared to GSM. In fact wideband noise is not really a problem and therefore blanking is not required.

4 Conclusions

Why buy LNA at all?

A lot of GPS measurement engine ICs have an integrated CMOS LNA, which has a moderate RF performance. NF is relatively high and linearity is poor (out of band IIP3 < -16 dBm). To improve the GPS receiver sensitivity and cohabitation (is mainly linearity) issues often an external filter is applied. To compensate for GPS receiver sensitivity loss an external LNA is placed after the filter.

Why buy LNAs from NXP?

NXP has a high performance BICMOS SiGe:C process having Ft/Fmax of 180 GHz and having many, many years of experience of small low cost package development.
The BGU7005 has:

▸ Fast switching shutdown function.

▸ Small form factor, BGU7005 uses only 2 external components (1x Coil and 1x decoupling capacitor)

▸ Total Front–End requires only 4 components (2x BPF, 1x Coil and 1x decoupling capacitor

▸ Front-End end reference evaluation module which has ~3x3 mm² with a total of 5 components

▸ Lowest cost (cost effective package and low cost SiGe:C process)

▸ Re-configurable application lowest current vs. out of band linearity

▸ Knowledgeable application support.

Common misunderstandings of GPS external LNA

▸ In band input IP3 not important since GPS signal is very weak (-130 dBm)

▸ High gain is not important for integration into a mobile phone. Internal LNA of GPS IC will be overdriven

▸ BGU7005 is not aimed as active antenna LNA

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