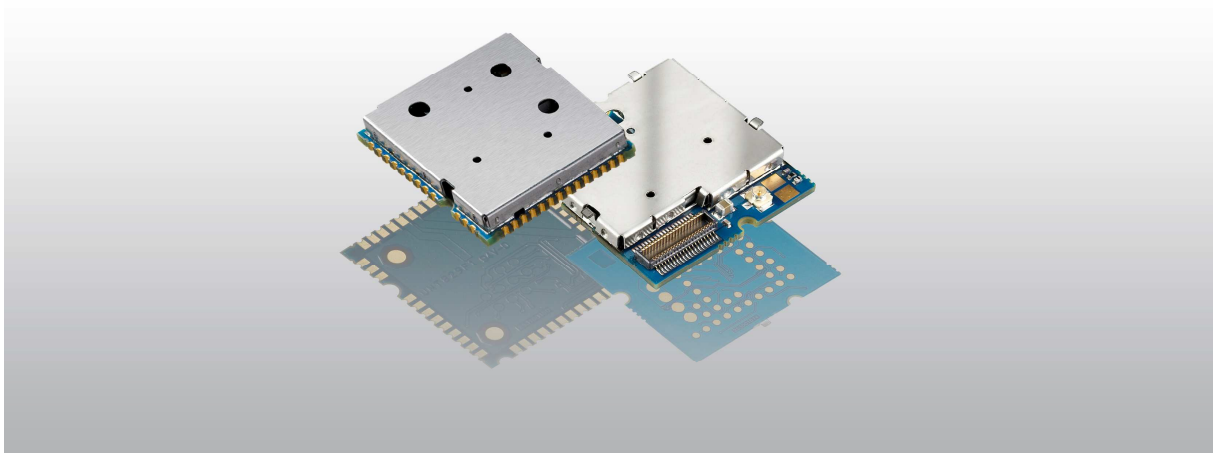


# RADIO APPLICATION NOTE FOR HILO HILO<sup>NC</sup> MODULES



~ Freedom of speech  
for smart machines ~

**SAGEMCOM**

**NOTE D'ETUDE / TECHNICAL DOCUMENT**

**FICHE RECAPITULATIVE / SUMMARY SHEET**

<b>Ed</b>	<b>Date</b> <i>Date</i>	<b>Référence</b> <i>Reference</i>	<b>Pages modifiées / Changed pages</b>	<b>Observations</b>  <i>Comments</i>
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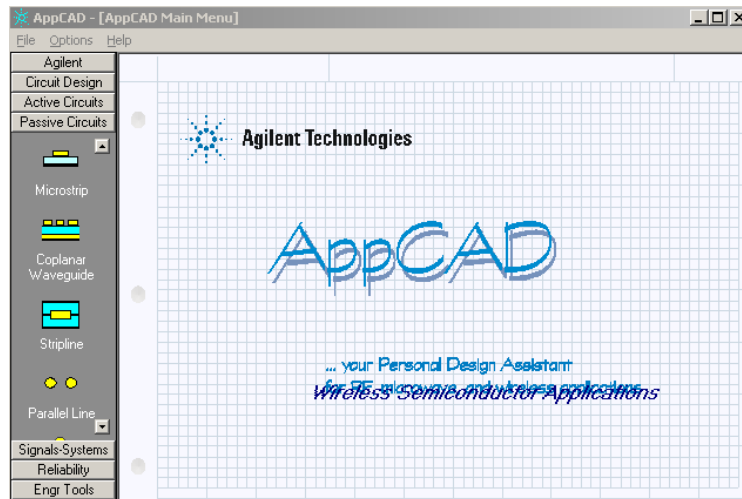
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# 1 Document purpose

This application notes reminds basics design rules and their applications around Sagemcom Hilo module. Some calculations and length effects can understand with Agilent Appcad tools:



We remind some basics RF principles.

We describe also a method to implement Hilo modules on PCB.

We describe the main issue that designer of electronics system must solved during the design process with Hilo modules.

## 2 RF basis

### 2.1 Wavelength

If we suppose a perfect wire in DC condition: after the first turn on, the current is established. If this wire is not resistive, we don't have any voltage drift resulting of ohm low: Everywhere on this line, and referred to the ground, the voltage is the same.

If we applied an RF signal, instead of DC, the input voltage is continuously changing. This potential can not be instantly the same everywhere on this line: we are limited to the celerity of the signal, which is close to the celerity light. Where you are on this line, it is necessary to wait a few times that the potential arrives to you. The potential over the line can't be the same everywhere. Thus in RF conditions, any length of wire will introduce some voltage change and not only due to ohms low. This effect, when it is wanted, is responsible of antenna radiating properties.

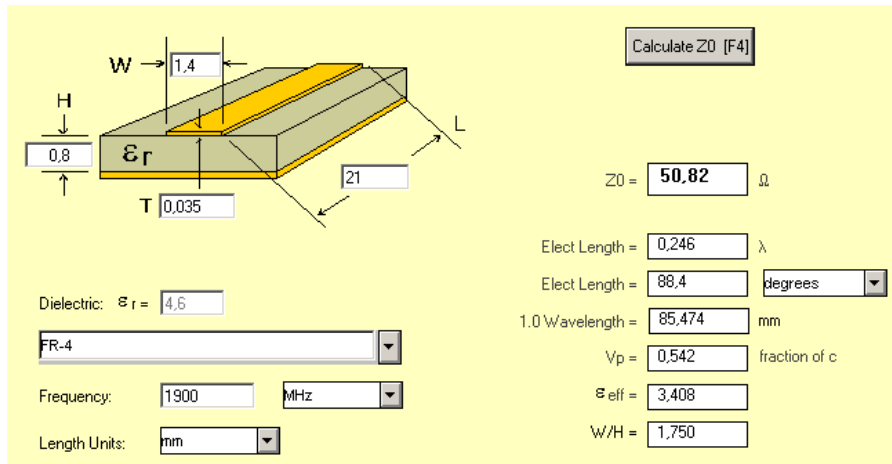
Any length will introduce phase effects. That's why it is necessary to minimize the connection to ground for all the components connected to 0 V signal. Otherwise, Hilo PIN physically connected to ground, won't be electrically at 0V. Depending of amplitude of this issue, it can produce unwanted effects: degradations of transmitting and receiving performances, reset..

We must compared frequencies used and usual electrics length. Consider the Hilo modules frequency band:

band	Frequencies for RX and TX in Mhz	Wavelength in the air (cm)
EGSM	890-960	32
DCS1800	1710-1880	17

and PCS1900		
UMTS band 1	1922-2167	16

At 1900 Mhz, the wavelength is about 16 cm in the air. These wave lengths will be reduced in the FR4 PCB. Let's consider a micro strip line on FR4 PCB with 0,8 mm space between ground and track:



Thus, the quarter wave equal only 22mm for an incoming signal at 1900 Mhz. We recall that in a quarter wave section, when one side is at 0V, the other side is at the maximum voltage. Thus, few millimeters of conductors can have electrical drift effect.

**Minimize conductor's length in RF design**  
**Minimize connections length to ground layer**  
**Classics ohm law doesn't applied to RF design**

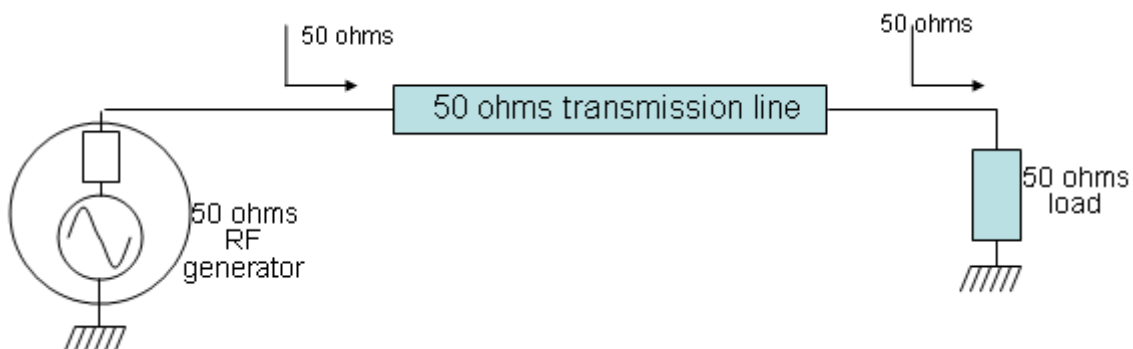
## 2.2 Matched load at 50 ohms

In first linear approach, and for best reliability, a generator must be loaded by its conjugate complexes impedance. In case of internal real impedance, the generator must be loaded by the same impedance value. In RF design we used the 50ohms value. Hilo modules are designed to work on 50 ohms load. Thus, filters, transmissions lines, coaxial connectors and antenna must be designed for this value.

**For antenna, coaxial connectors and transmission line, used only 50 ohms impedance**

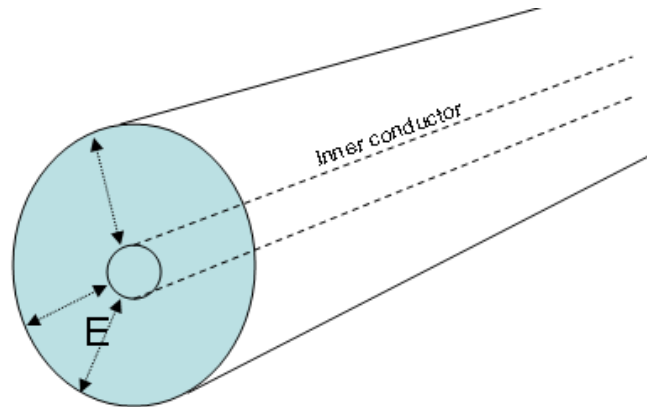
## 2.3 50 ohms line principle

We have seen that any length of conductor will introduce some voltage phase shift. The module must see a 50 ohms load. But we can not put the antenna directly on the output PIN module. The solution is the matched transmission line. If this line is loaded with 50 ohms load, the module will see also 50 ohms load at the input line



This is an other example to explain that 50 ohms value in transmission line doesn't refer to ohms low, but to the characteristic impedance of line : We look at ratio  $Z=U/I$  and distributions of currents and voltage in conductors.

A perfect transmission line mustn't radiate: electric fields and current are locked into the transmission line if source, load and transmission line are the same impedance. The coaxial cable offers the best results:

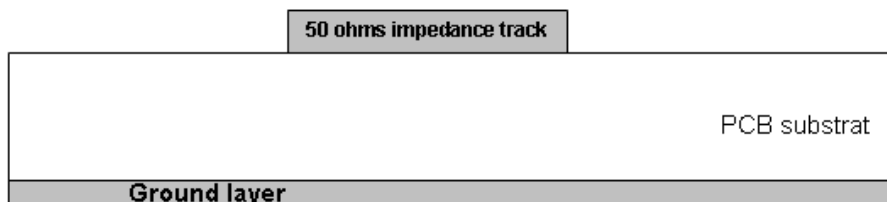


Electric field is totally locked into the cylinder. If the line is matched: the input generator impedance, the output load and the characteristic impedance are equal. Thus, currents on inner and outer conductors, have the same amplitude, but are opposite in sign: they cancelled themselves.

**For antenna output track respect 50 ohms impedance line design rules**

## 2.4 Microstrip line

Coaxial connector is not the best choice for SMT components assembly. It is not possible to add components in series or in parallel on this line. The PCB design process is not compatible with this circular structure. For radio frequency design on PCB, we prefer planar structures. The microstrip line is well designed for PCB design:



**As it is mentioned, a ground plan is absolutely needed below all the radio microstrip tracks!** This ground plan will be on the first board layer below the radio layer (top or bottom), excepted in case of a 50 Ω pad (*look spring contact pad, see §3.4.1*).

**Respect carefully micro strip design rules and dimensions  
Be sure that resulting dimensions are compatible with PCB manufacturer tolerance**

Calculation example:

You must choose your own thickness, and substrate material (FR4 here). Adjust W to target Z0=50 ohms.

**Microstrip**

Calculate Z0 [F4]

Z0 = **50,01** Ω

Elect Length = **0,062** λ

Elect Length = **22,2** degrees

1.0 Wavelength = **162,398** mm

Vp = **0,542** fraction of c

ε<sub>eff</sub> = **3,408**

W/H = **1,800**

Dielectric: ε<sub>r</sub> = **4,6**

FR-4

Frequency: **1** GHz

Length Units: **mm**

## 2.5 Stripline design

If the 50 ohms output line doesn't need any components, you can use the stripline structure:

AppCAD - [Stripline]

File Calculate Select Parameters Options Help

Main Menu [F8]

**Stripline**

Calculate Z0 [F4]

Z0 = **50,2** Ω

Elect Length = **0,136** λ

Elect Length = **48,9** degrees

1.0 Wavelength = **73,568** mm

Vp = **0,466** fraction of c

ε<sub>eff</sub> = **4,60**

W/H = **0,406**

Dielectric: ε<sub>r</sub> = **4,6**

FR-4

Frequency: **1,9** GHz

Length Units: **mm**

Normal [Click for Web: APPLICATION NOTES - MODELS - DESIGN TIPS - DATA SHEETS - S-PARAMETERS](#)

Anyway the, module antenna port is on the top or bottom side. You need to use via hole to go from external layer to the internal 50 ohms track.

## 2.6 Coplanar grounded design

A ground plan should be placed on each side of the radio micro strip, on same layer. The distance between the ground plan and the microstrip (this distance is called G) is important, and we recommend to have a typical value that can be used is  $G = 0.8 * W$ .

**Coplanar Waveguide**  With Groundplane  No Groundplane

Calculate Z0 [F4]

Z0 = **49.9**  $\Omega$

Elect Length = **0.059**  $\lambda$

Elect Length = **21.3** degrees

1.0 Wavelength = **169.360** mm

Vp = **0.565** fraction of c

$\epsilon_{eff}$  = **3.13**

Shape factor = **0.397**

Dielectric:  $\epsilon_r =$  **4.6**

**FR-4**

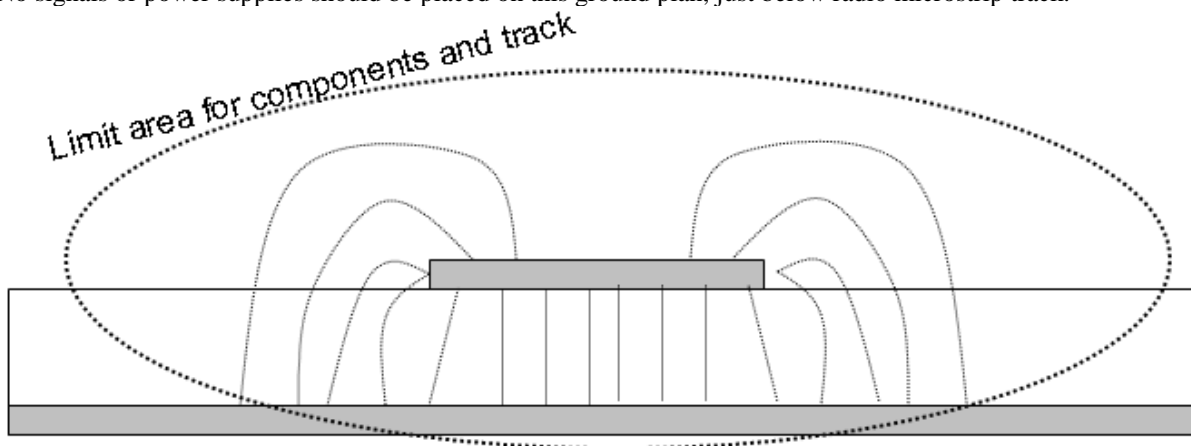
Frequency: **1** GHz

Length Units: **mm**

If G is too low, there will be important power losses in the microstrip due to high coupling between RF signal and ground. Be sure that width and space dimensions are compatible with your PCB manufacturer.

## 2.7 Space around PCB line

Resulting from planar geometry, the electric field in a strip line is not perfectly closed into the substrate. No signals or power supplies should be placed on this ground plan, just below radio microstrip track.



To avoid any coupling effect and transmission mismatch: Don't place components case, shield or track around transmission line.

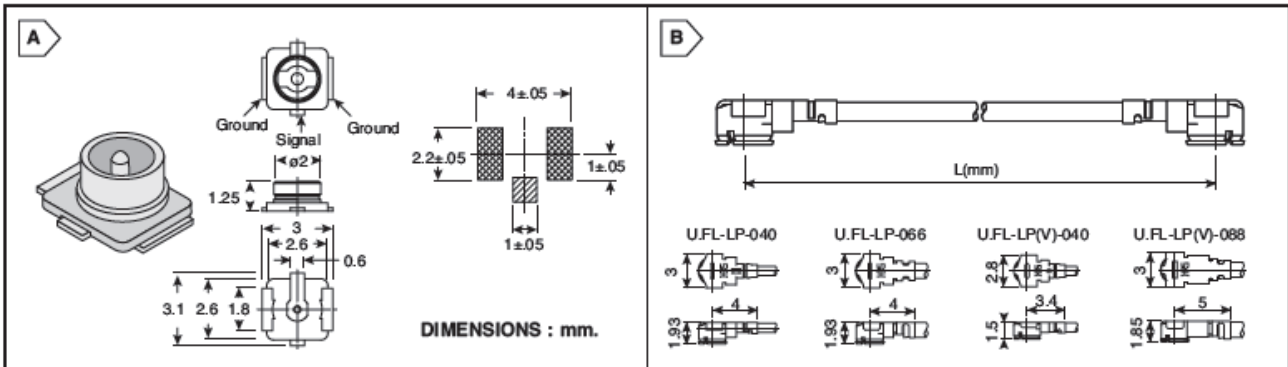
Keep some space around micro strip line

## 2.8 U.FL coaxial connector

If you are not using the HiloNC version, you can connect a micro-coaxial cable to the module, through the U.FL connector on Hilo module.

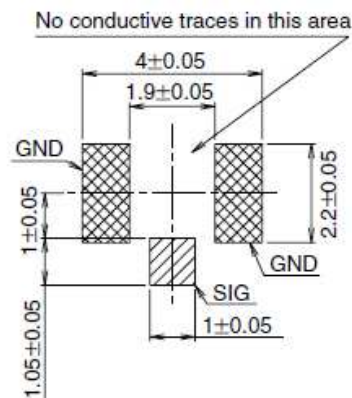
Be careful !! U.FL connector is not designed for a lot of matting-demating operation. You have to take account of this, during radiated qualification test. A bad connection on “U.FL” type connector can have bad results on radiated emission during certification process.

For more information about U.FL connectors, look at: <http://www.hirose.com/>



For the layout, read carefully U.FL the recommended Pattern (here is an example: don't use values for your design):

### Recommended PCB Mounting Pattern



Don't use any conductive trace under the central pin!!

**Follow carefully recommendation for SMT layout**  
**Limits mounting and dismounting operation with U.FL connector**  
**Use new connectors for certification process**

## 3 PCB layout

In RF design, the PCB layout is a part of the design. Due to high integration level, Hilo Module minimize layout issues and RF knowledge required. But minimal rules must be respected.

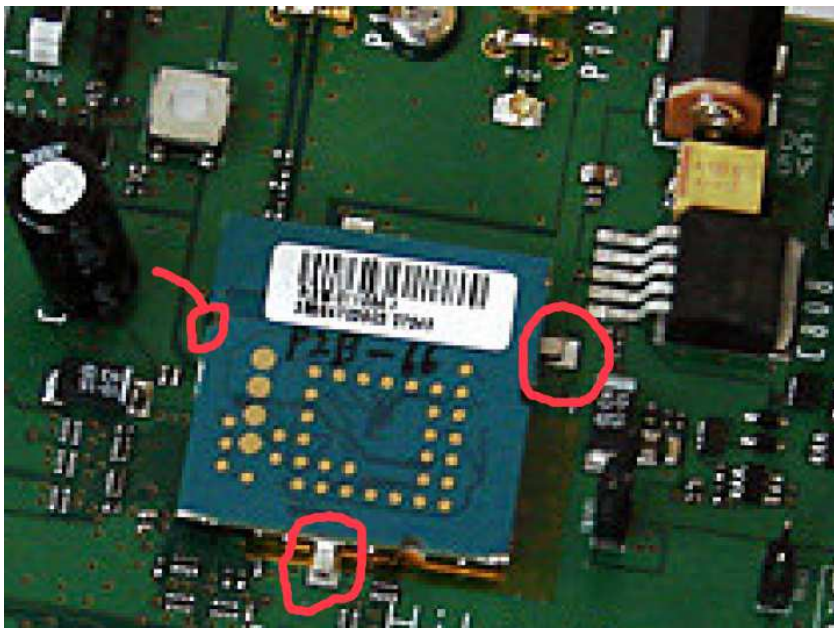
### 3.1 Power supply and via to ground

The layout of supply can contribute to final communication behavior. The layout of supply tracks must follow next rules:

- For VBAT Hilo PIN, it is mandatory to use a track width compatible with burst current in EGSM mode: 1,7A. Remember that any resistive track will introduce a voltage drift.
- Decoupling capacitor positive side must be closed to the VBAT pin. The negative side must be connected to the ground layer with many via holes.
- It is recommended to use a plain copper under module case connected to ground.
- Via holes must be used for connection between Hilo ground pin and ground layer.

### 3.2 Hilo case PIN connection

When using Hilo version, you have some pin connections on package. Like demoboard example, it is mandatory to connect these pins directly to ground.



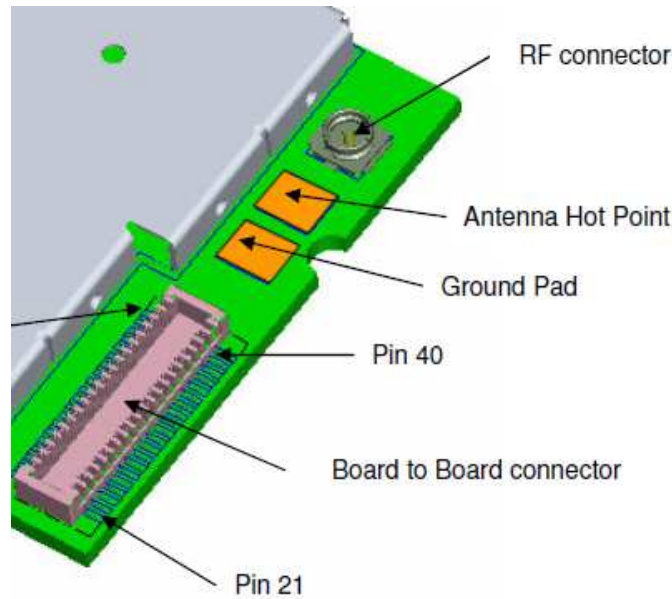
Use many via hole to connect this pad to the internal ground layer.

### 3.3 Decoupling capacitors

A perfect decoupling capacitor must be seen as a short circuit for RF signal. To minimize length of tracks, and inductive effects, they must be closed to the package and connector. Lower is the capacitor value, closer to the PIN module it must be.

### 3.4 Hilo springs connector

On Hilo modules, connectorized versions, you can use springs contacts for antenna connection : “Antenna hot point” and “ground pad “on next figure:



### 3.4.1 If springs are used

The pad should be  $50 \Omega$ , as the RF line connected to it. But since the width of the pad is higher than the width of the RF line, it means that the distance from the pad to the ground plan below should be higher than the distance from the RF line to the ground plan below in order to keep the  $50 \Omega$  impedance on both.

If we consider the example of RF line given in § 2.4

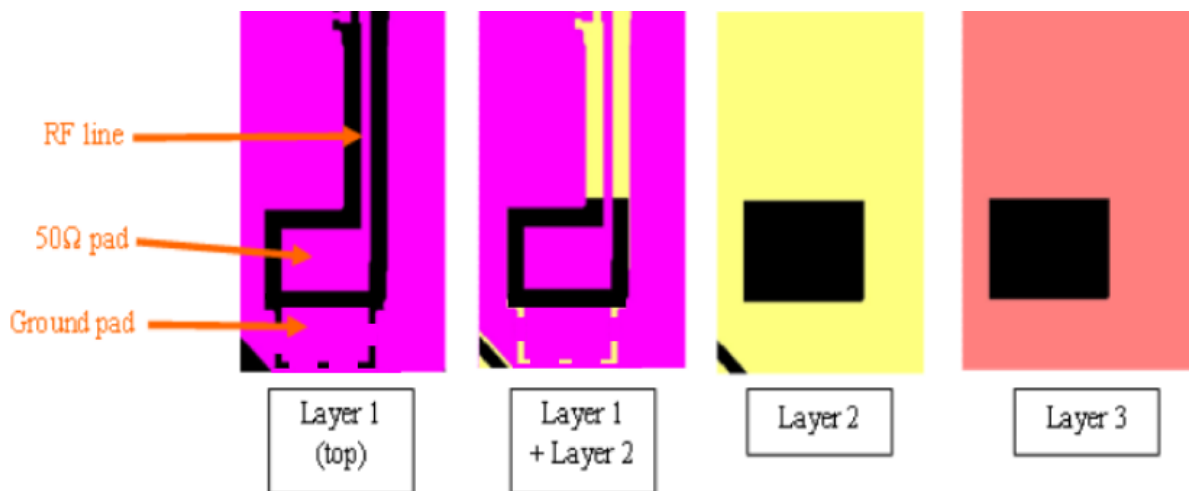
Dielectric material = FR-4

Microstrip thickness:  $T = 0.035 \text{ mm}$

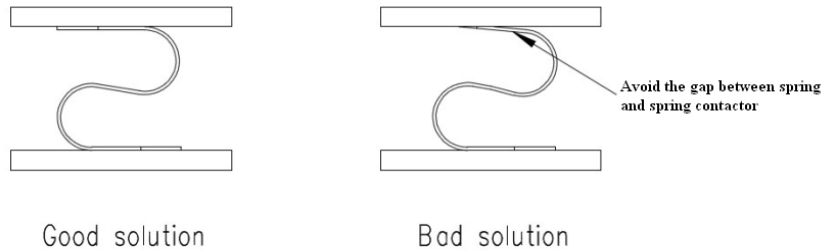
Microstrip width:  $W = 1,44 \text{ mm}$

Distance from the microstrip to the ground plan:  $H = 0.8\text{mm}$

Then, when calculating the RF line impedance with these values we obtain  $50 \Omega$ . Now, if we consider that the RF pad has a width of  $2.5\text{mm}$ , if we keep  $H=0.8\text{mm}$  then the impedance of the pad is  $33 \Omega$ ! To have a  $50 \Omega$  pad,  $H$  should become  $1.4\text{mm}$  approximately. This explains why we have to remove the ground plan below RF pads on all layers, until we reach the new  $H$  value calculated for the pad only. An example can be seen here:



It is recommended to solder the spring contact on the whole surface instead of only 2 points



### 3.4.2 If springs are unused

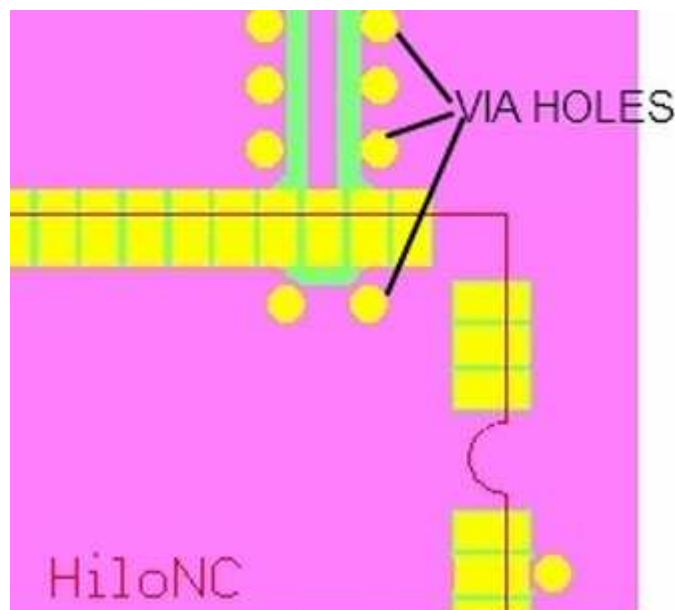
You can use the U.FL coaxial connector for antenna connection. In this case you need to keep springs unused. It is mandatory to keep isolation space under springs pads: avoid any component in proximity of RF pads.

### 3.5 Ground connection

Many pin are connected to ground. Uses many via hole to connect ground pins to the ground layer. This applied for all Hilo modules.

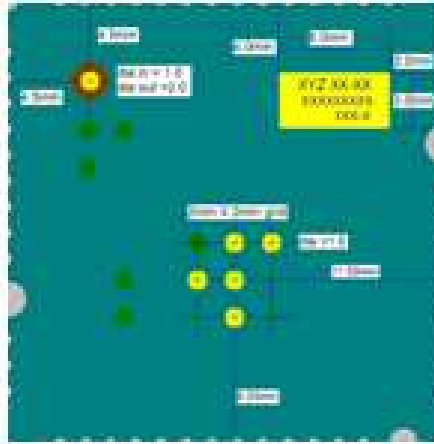
### 3.6 Hilo NC antenna port

On the HiloNC module, we don't have spring contact or U.FL coaxial connector. The track width will be calculated following microstrip structure design. It is mandatory to use via holes for ground PIN antenna. They need to be directly connected to internal ground layer.



### 3.7 Hilo NC prohibited area

The HiloNC module is directly soldered on the PCB. Some pin test and tracks are used under the module case. We recommend using a plain copper layer under any RF device. But to prevent short circuit with ground, we define prohibited area for copper layer under the module. Look at HiloNC and Hilo NC V2 applications note for details.

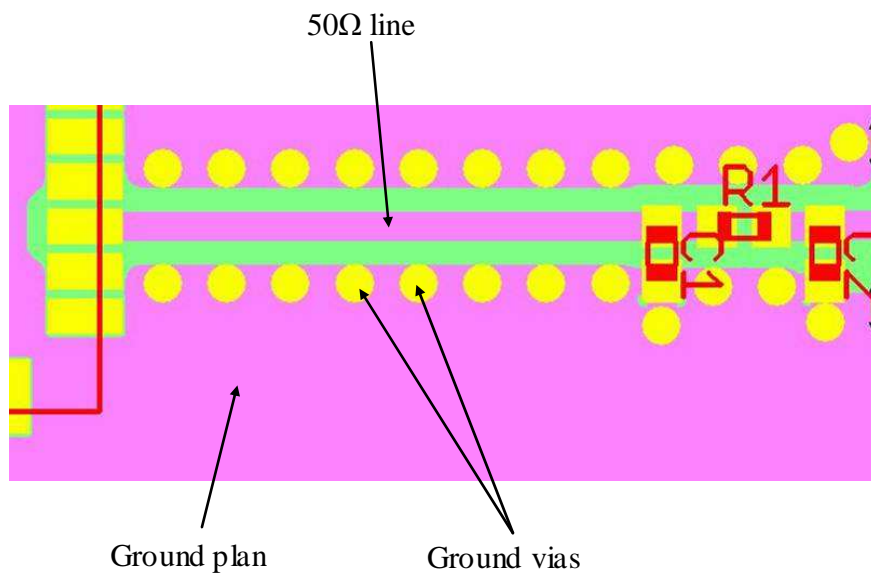


### 3.8 50 ohms micro strip output line example

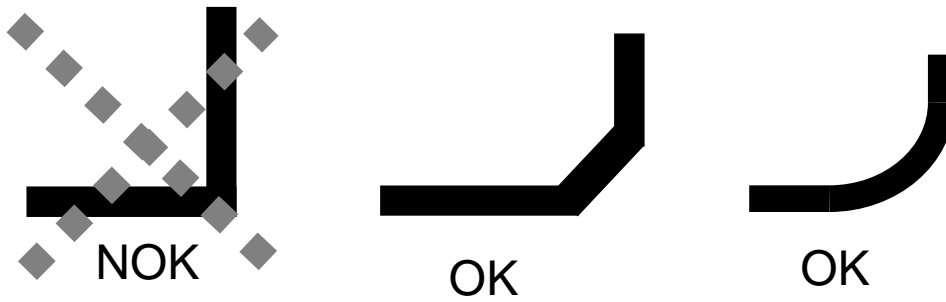
- RF signal lines should be kept as short as possible.

We remind that even if it is well design, a microstrip line radiated a few part of electrical field: it is not perfectly closed on the line.

- Do not use components or cover close to this strip.
- RF signal line should not be routed over or under any other components or other signal paths.
- RF signal line should not be routed near noise sources such as digital signals, oscillators, switching power supplies, or any other RF transmitters.
- RF lines bends should be avoided. If it's absolutely needed, it's better to use 45° bend or radius bend, instead of 90° bend.
- Ground vias are recommended to be placed on the whole radio path, as it's designed on the following example:



If you need to change the direction of the track, don't use a right angle:



If you need to pass from one layer to another, use via holes. Use diameter compatible with PCB track width. Don't use a small diameter via holes: it is like a series inductor which introduces some mismatch.

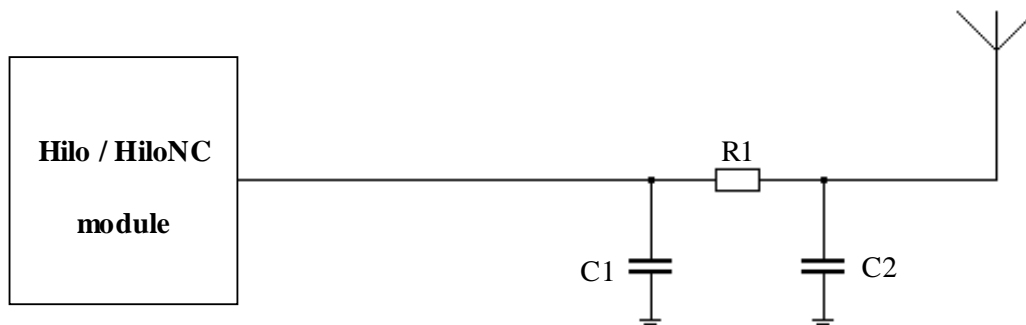
It is recommended to use a width compatible with you components size. See some examples.



Remember that first criteria for track width in the line impedance (50ohms). See § 2.4. Higher will be the thickness between track and ground plane, higher will be the width of the track. Thus, in multilayer PCB, you have to select carefully your layer for 50 track output.

### 3.9 Matching network

The Hilo module is design for 50 ohms system. If the antenna is not matched to 50 ohms, it is recommended to add a matching network. This matching network can be a classic  $\Pi$ -type network. The best placed is close to the antenna.



- The 3 components R1, C1 and C2 can be 0402 or 0603.
- When no matching is needed, the following values must be used:  $R1=0\Omega$ ;  $C1=C2=unused$ .
- When matching is needed, the values depend of the RF line and antenna impedances.

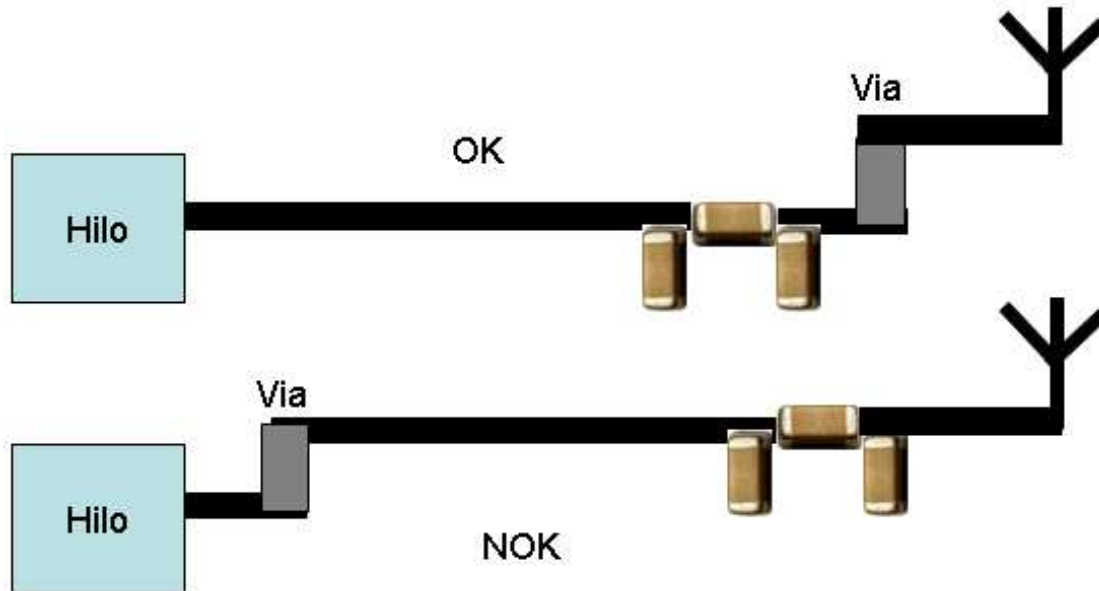
A layout example of this matching network is given in previous §.

Here is short view:



On the left view, the shunt components will let an open track if they are not soldered. This stub will have some un-matching effect. We recommend the center layout view.

Any via, hole or other mismatching effect must “behind” the matching network, seen from Hilo module. The aim is to show 50 ohms to the Hilo module output.



### 3.10 Coaxial output connector

The 50 ohms line can be ending by the feeding point of an internal antenna, or a coaxial connector. Here are some connectors type often used in RF design:

name	advantage	disadvantage	
U.FL (Hirose)	Low cost	Not designed for a lot of matting unmatting operation	
W.FL (Hirose)	Very small	Not designed for a lot of matting unmatting operation	
SMA	Very use in RF laboratories	Cost and size. It can be loosen in vibrating system	

**For U.FL connector:** Respect the manufacturer recommendation for footprint and input line. Check dimension value of your connector manufacturer! See previous § 2.8 on U.FL connector. Don't use conductive trace under center pin. It is recommended to use via hole around the connector for ground connection to the ground layer.

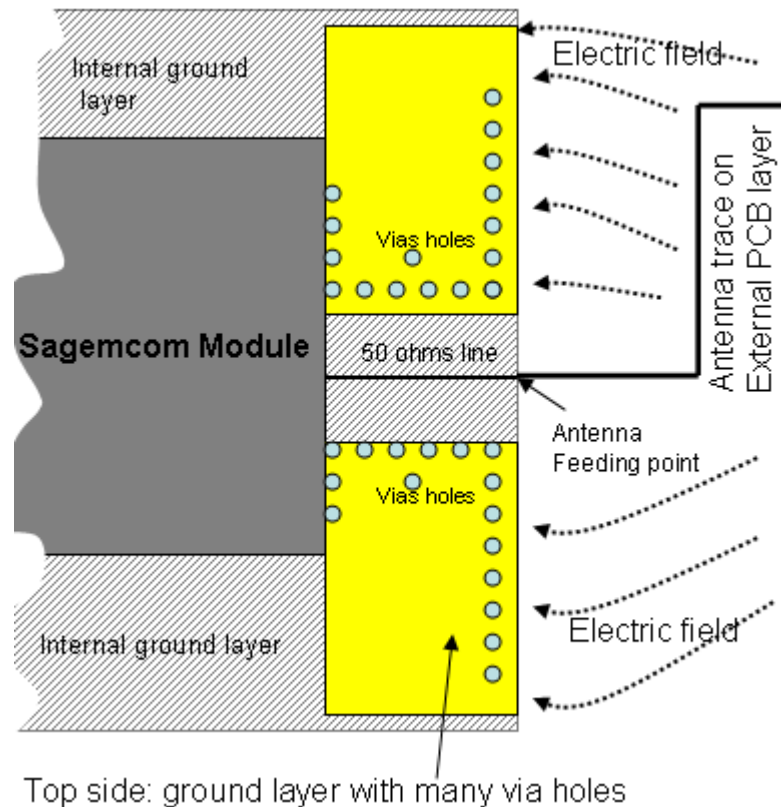
**For SMA connector:** Keep some space between 50 ohms lines and grounds pads. The design rule is about 4 times, or more the thickness of substrate. Thickness is the value between 50 ohms track and ground layer. See §2.7. Here is the layout view, opposite to the SMA connector.



The 4 external ground PIN must be connected to the internals and external ground layers. You need also to keep some space around the center PIN. The ground must be routed to the Hilo ground output antenna.

### 3.11 Antenna and module on the same PCB

This chapter takes account of basics RF requirements for antenna and module integration on the same PCB. Previous HF layout requirements suggest having tracks shorter as possible between module output and antenna feeding port. But: Most of printed antenna needs a ground plane. This ground area must be defined with antenna designer. In every case, it is recommended to keep some space between Hilo modules and input antenna feeding point. A short 50 ohms line is used to connect the module antenna port to the 50 ohms antenna feeding point. Ground plane must be routed in every layer. They must be connected with many via holes.



It is not necessary to have a straight line from module to the antenna feeding point, if transmission line is designed for 50 ohm impedance.

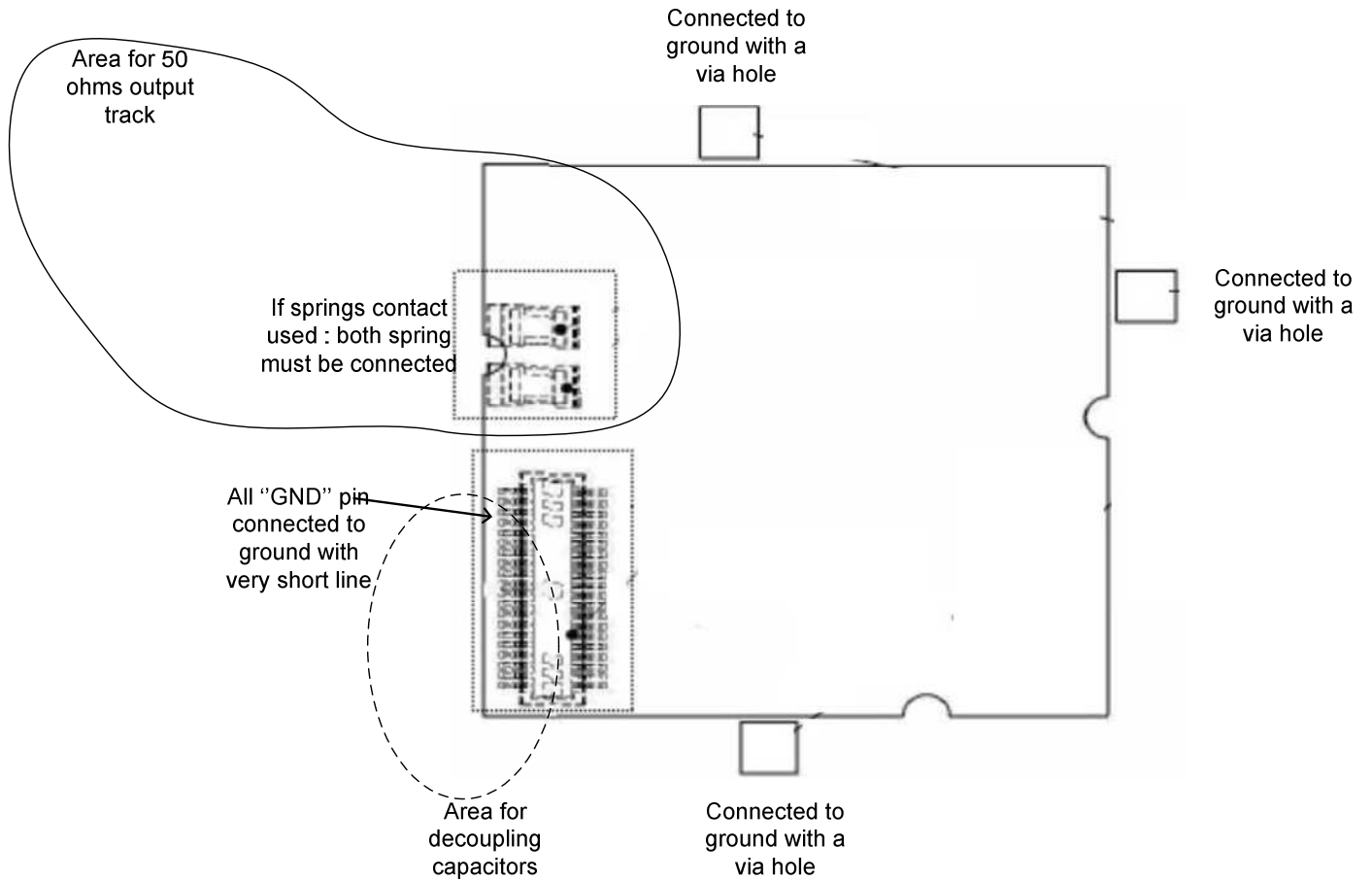
A space must be used between the antenna and the Hilo module. It permits the well establishment of the electric field between the radiative part of the antenna and the ground.

Any electronics part placed close to the antenna, can degrade harmonics certification results.

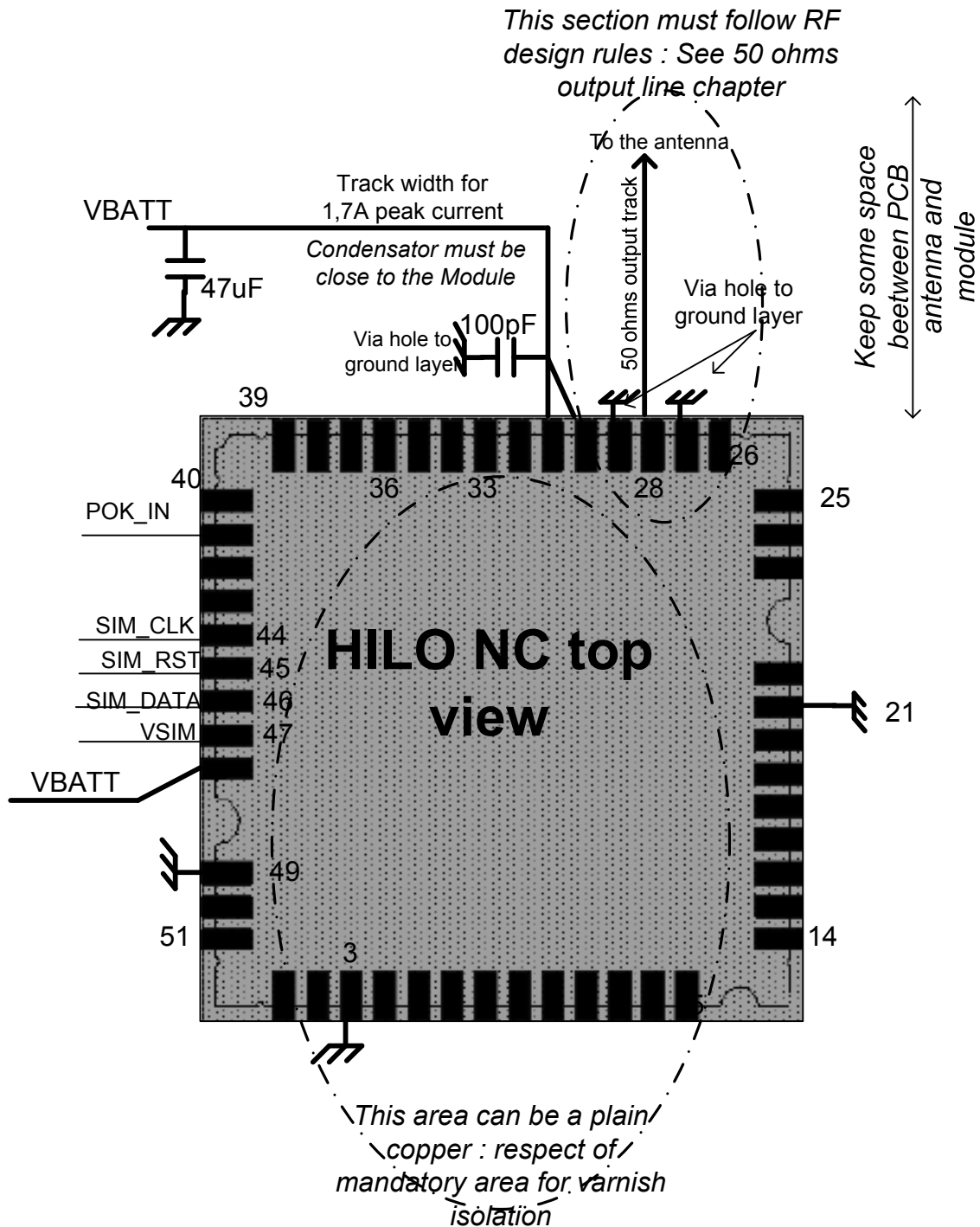
**Used Integrated antenna implied some knowledge about radiated effect  
Antenna designer must provide some layout and ground plane recommendations  
Keep some space between antenna, Hilo module and electronics parts**

### 3.12 Hilo layout overview

Decoupling capacitor must be close to de decoupled PIN: minimize track length.  
 You need to provide some space around the 50 ohms transmission line.  
 It is better to use via hole for ground connection to the internal ground layer.

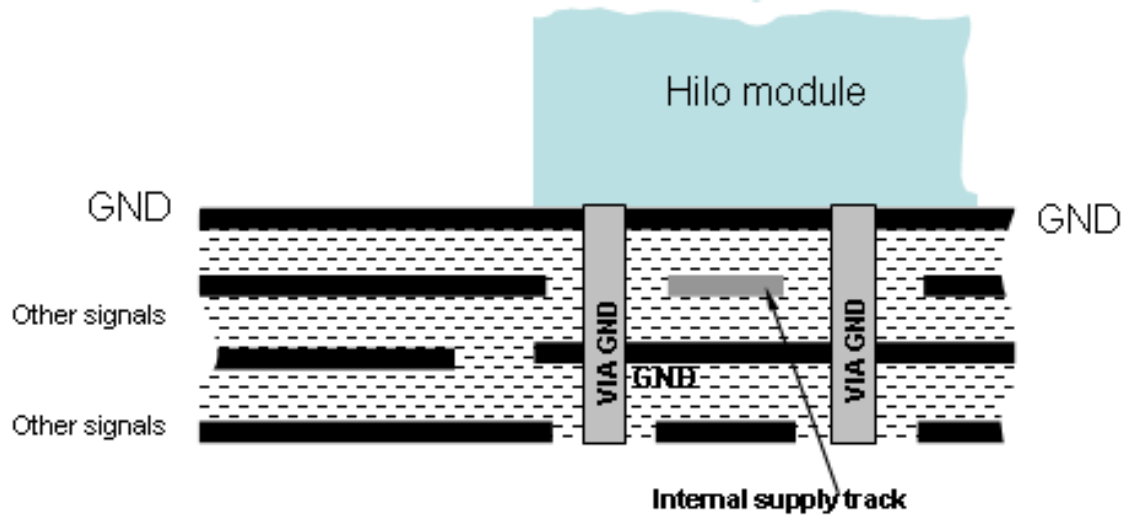


### 3.13 HiloNC layout overview



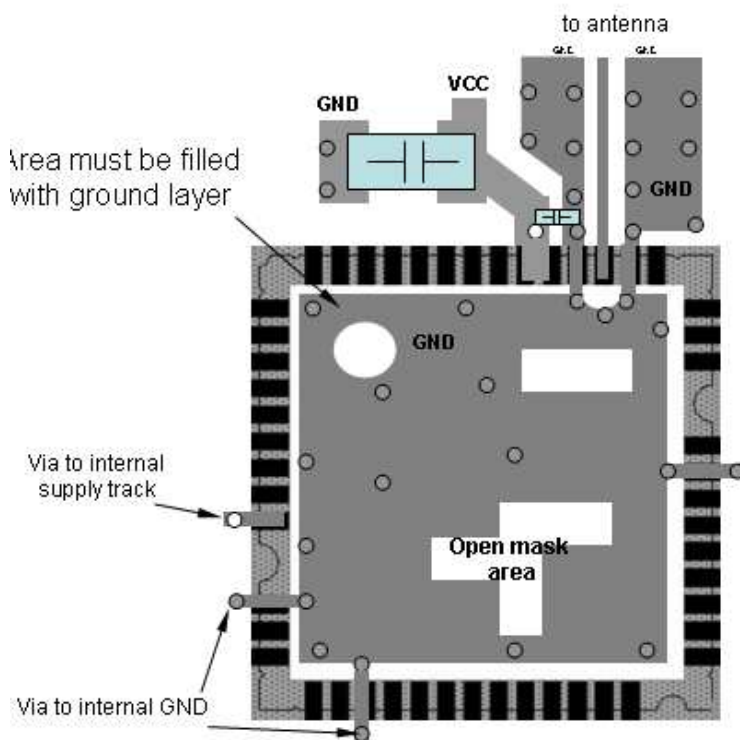
Due to the 1,7 A peak current, it is no recommended to use a VBAT line, just under the module. This rule should be also follow by any signal. It is better to buried internal track between two ground layers.

### Simplified PCB profile view around internal supply track "VCC"

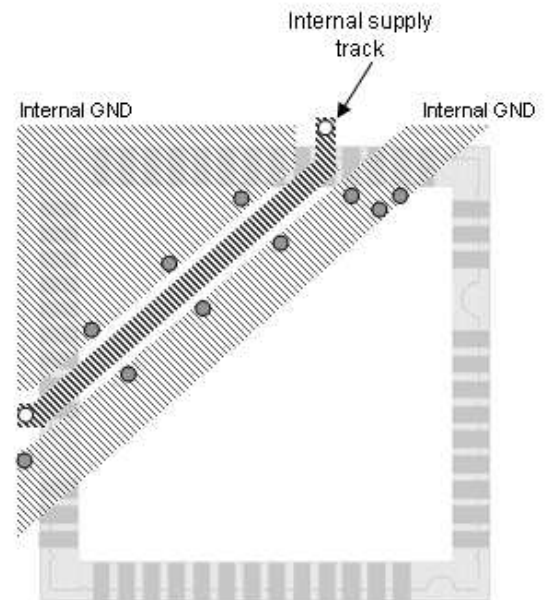


Internal supply track must be locked into ground layer and via holes

Only VCC, GND and antenna output are represented in this simplified layout view



Hilo solder layer



Internal supply signal layer

VIA HOLES : 0,8 mm is recommended for via diameter. Many via holes can be used in parallel instead of only one small via hole diameter. Supply via holes must be chosen to be able to provide 1,7 A during the 2G TX burst.

## 4 Hilo module Integration

### 4.1 Keep the receiver sensitivity

In parallel with PCB design rules, the designer must take account of Hilo receiver sensitivity. See 5.4.1 for the level of demodulated signals. A recurrent issue is coming from the harmonics signal of other electronics systems falling down the GSM receiver band.

Relation between communication channel and the received frequency can be calculated with § 7. The main effect is a loss of sensitivity on some communication channels.

We have many major sources of harmonics:

- Power supply with switching regulators (DC-DC or AC-DC converter)
- Any logical signal with high data rate : bus memories, I2C , SPI...
- Any external data connection on your board
- Any telecommunication system ( Wifi, Zigbee, RFID..) close to your design

During the design:

- Respect PCB design rules.
- With switching regulators :
  - Choose the frequency of switching
  - Respect layout and design recommendation from switching regulator manufacturer.
  - Keep space between switching regulators and module and antenna.
  - Keep the possibility to shutdown some regulators section and telecommunication subsystem.
  - Use shielding inductors for switching regulators.
- Respect of high data rate bus design rules :
  - Adjust the IC internal impedance
  - Use buried tracks for the BUS.
  - Choose a small slope for logical signals ( few V per time)
  - Lower the operation frequency.
- Don't place inductors close to the module and the antenna input.
- Choose the best behavior of your product: minimize data rate activities during a telecommunication or registering process on 2G or 3G network.

For investigation:

- First, sensitivity must be performed in conducted. See §5.2
- Shut down all the data rates activities.
- Use external DC power supply instead of on board switching regulators.
- When the source is found, confirm the solution in radiated condition. See §5.3.2

Any design improvement to keep Hilo performance, will also improve the EMC effects in conducted and radiated conditions.

Let's see a common example of integration issue:

25 MHz quartz oscillator is commonly used on Ethernet transceiver: the frequency of 38<sup>th</sup> harmonics is:  $25 \times 38 = 950$  Mhz. And 950 Mhz is the receive channel number 75 in GSM band (see §7) . It explains how your design can be susceptible to the high harmonic range of a clock oscillator or any signal, even if it is far from frequency used in the receiver.

**Pay attention to switching regulator, high data rate bus, sub system activities, layout and placement.  
Design improvement will also improve EMC results**

## 4.2 Transmission issue

Hilo power supply must be "clean" in any case, even if the supply current is high. Let's see the burst issue in 2G mode: This effect is not a purely RF issue. It happened during a communication in 2G mode, when module is transmitting to the network. In GSM and DCS communication principle, the transmission is done during a short time: about 300 $\mu$ S. During this burst transmission, at max output power, consumption is about 1,7 Ampere, depending also of DCS or GSM bands. Thus, power supply must be able to provide this peak current. See application notes for design help. If supply decreases during the burst, the communication can failed. The layout must also take account of this peak current. The width of supply track must be choosing to minimize the voltage drift between supply and Hilo input. And high current can cause some magnetic effect on sensitive device like high gain audio amplifier and microphone input.

**Take account of burst peak current that occurs in 2G mode for your layout and power supply choice and layout**

## 5 Final product Investigations

### 5.1 Initial test

This part supposes that you have solved all the issues about software and classical electronics issues: Respect of Specification:

- Power supply range.
- Compatibility current between power supply and Hilo module.
- Level, threshold values and push pull or open collector output configuration for microcontroller.
- Respect of application notes.

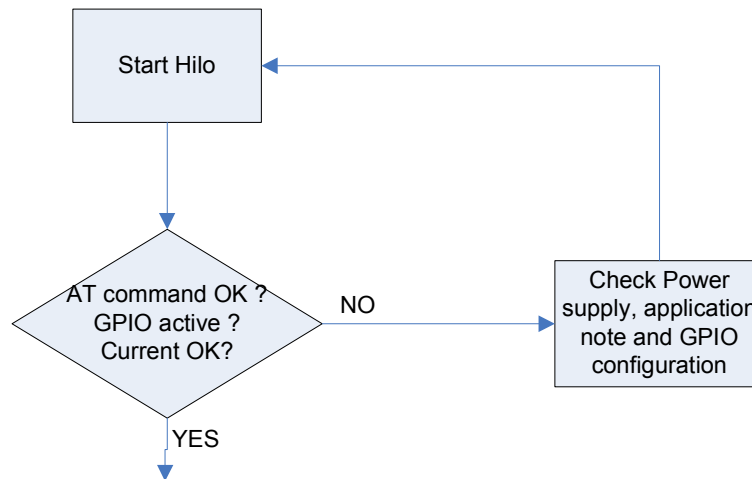
During this initial test you can send some AT command to check the behavior of Hilo module. You can check GPIO value and other static electrical value.

**Basics electrical behavior must be check before any RF test  
Any electrical issue must be solved before RF test**

If Hilo Module is not started, check:

- Schematic application note : GND pin , supply pin
- Supply current capabilities
- POK\_IN value change before and after start up
- VGPIO output before and after start-up

If Hilo module is started (VGPIO high level), use the AT command to check level of TX and RX signals.



We can now perform radio test

## 5.2 Conducted RF test

### 5.2.1 Aim

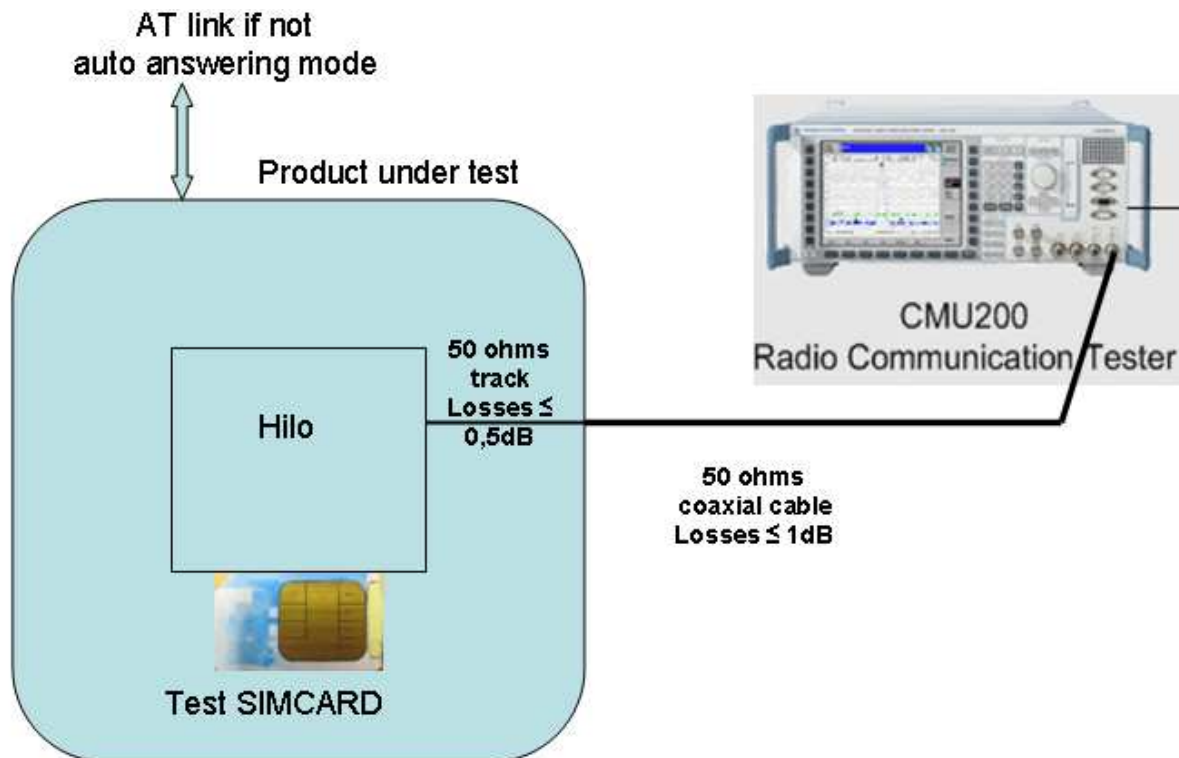
During design process, before any measurements with antenna it is recommended to check the design in conducted conditions:

- Antenna is not used: RF link is done through a coaxial cable directly connected to the module antenna output.
- Communication must be established with a communication tester, like the CMU200 from Rohde Schwartz instead of real network.
- You will be able to check both transmit and receiving properties of the Hilo module when it is integrated in your design.
- This take account the integration issues: conducted spurious generated by supply, microcontroller or logical circuits effect.
- It is recommended to performed many test on many channel and many bands.

**Any RF issue in conducted condition must be solved before investigations in radiated conditions**

### 5.2.2 Setup

Use a communication tester like CMU200 from R&S. If you configure the Hilo module in auto answering (“AST0=1” follow by “AT&W”) you do not need the AT link for hang up the call. The sim card is a specific test sim card.



## Conducted RF test

Communication tester can report RF parameters dependant with your design integration:

- Conducted transmitted power
- Receiver sensitivity
- Consumption and behavior on a controlled 2G or 3G network

The coaxial cable makes a link between the DUT and the communication tester.

To follow the rules of conductive RF measurement:

- The antenna must not be connected to the module during this measurement.
- All connectors, tracks, and cable must be 50 ohms impedance.
- Take care of connection between coaxial cable and product track.
- The losses (in dB) must be know and used in communication tester configuration.
- Theses losses are frequency dependent and must be adjusted for every communication band.

### 5.2.3 Transmit power investigation

During the communication, the DUT must be able to transmit at max output power. On 2G network, power requirement is transmitted to the mobile, through "PCL" parameter. It can be changed on communication tester. Following 3GPP norma:

EGSM, GSM850 : Max power, PCL = 5 ; output power = 33dBm +2,5 at 25°C  
 DCS1800, PCS1900 : Max power, PCL = 0 ; output power = 30dBm +2,5 at 25°C

You must subtract the losses of your transmission line (microstrip or coaxial) between antenna feeding point and Hilo module antenna port. If your design is not able to transmit at max output power check:

- Supply voltage on VBAT Hilo pads during the transmission.
- Losses of your transmission line: should be lower than 0.5dB
- Ground connection : via hole to the ground layer for all ground connections

## 5.2.4 Receiver sensitivity investigations

If your design is not able to received with level complaints with Hilo module specification, check :

- Supply voltage and noise on Vbat Hilo pads
- Level on logical signals
- Losses of your transmission line: should be lower than 0.5dB
- Ground connection: via hole to the ground layer.

Blocked channel:

Embedded clock signal and theirs harmonics can block a receiving channel. See § 5.4.1 to understand the weakness of received signals. If the channel used to received the network signal is totally blocked by the on board harmonic signal, you have many ways of improvements:

- Lowering harmonics clocks: lowering rising and falling time or lowering voltage of clock signal.
- Choose a fundamental frequency which can push the harmonics outside the receiving band.
- Improve the layout.

For investigation you must be able to know the relation between channel number (ARFCN ) and the frequency of the signals used for communication. See § 7

## 5.3 Radiated RF test

Many tests can be performed in radiated conditions on the final product.

- It is very difficult to repeat radiated test outside specific radio anechoïde chamber.
- A design not able to work in conducted conditions, wont be able to work in radiated conditions.
- A design able to work in conducted conditions can be unable to work in radiated conditions.

### 5.3.1 Real network operator

It is the easiest way to see if the final product is able to communicate in radiated condition.

Advantage:

- We don't need any specific RF tools
- We can test the product in its final environment

Disadvantage:

- Diagnosis is very subjective. We are not able to performed investigations.
- Repetitive test are not reproducible.
- We are dependent of operator coverage
- We are depend of operator network management strategy: channel and band.

**Connection on real network gives some subjective and un-reproducible criteria for RF radiated diagnosis**

### 5.3.2 Anechoïde chamber

The disadvantages of test on operator networks can be overpassed with radiated measurements in a radio anechoïde chamber. This kind of chamber will make a high isolation between environment and product under test. We can add a network simulator for behavior investigation under radiated conditions.

**Anechoïde chamber can be used for investigation on transmit and receive mode and for radiative certifications process**

### 5.3.3 TIS and TRP

Total Isotropic Sensitivity (TIS) is industry standard methods for sensitivity measurement. Total Radiated Power (TRP) used the same principle for power transmit measurement.

Measurement is done all around the product, over a sphere, determining the RF performance of wireless devices. They take account of both product and antenna contribution on final transmit and receiving characteristics.

**TIS and TRP measurement are very representative of final products performances under radiated conditions**

## 5.4 Unity explanation

In Hilo specification, certification reports and norma, we use unity used only in RF environment.

### 5.4.1 dBm

It is a power measurement unity, referred to 1mW. Thus conversion from Watt to dBm is done by this formula:

$$\text{Power(dBm)} = 10 * \log (\text{power (mW)})$$

Example: For 2 watts, which equal to 2000 mW. In dBm:  $10 * \log (2000) = 33\text{dBm}$ .

It is the maximum output power for a mobile phone in transmit mode in GSM and EGSM bands.

For the reverse conversion, used :  $P(\text{mW}) = 10^{( P(\text{dBm}) / 10 )}$

Thus for 30dBm, we have, in watts:  $10^{( 30 / 10 )} = 10^3 = 1000 \text{ mW} = 1 \text{ Watt}$ .

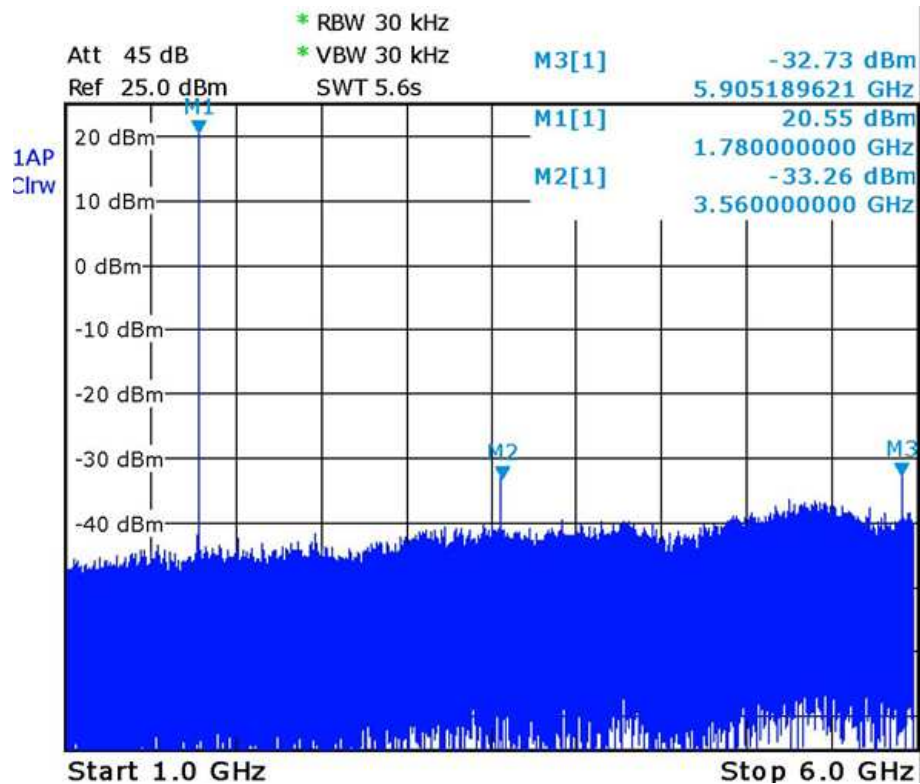
We can used this formula to illustrate the weak signal used in a receiver: the standard use in GSM, impose that receiver must be able to demodulate signal at -102dBm, with a bit error rate of 2,44%.

$-102 \text{ dBm} = 10^{( -102 / 10 )} = 10^{(-10,2)} = 63 \text{ pW}$ . Pico watts is a  $10^{-12}$  factor of multiplication. It is easy to understand that a receiver must be sensitive to a very weak signal.

**The signal received by a Hilo module receiver sections is very weak  
It can be overpass by on board clock signal harmonics**

### 5.4.2 dBc

During harmonic measurements of output spectrum, we can use the “dBc” unity. It is a dB measurement relative to a reference. Often the reference is the power of the carrier: “c”. Let’s consider a RF generator and the spectrum analyzer view:



We see than fundamental (1780 MHz) signal power value is: 20,6 dBm , the second harmonics is at -33,3 dBm. It is easy to calculate the dBc value :  $20,6 \text{ dBm} - (-33,3 \text{ dBm}) = 53,9 \text{ dBc}$ . The third harmonic level is at:  $20,6 \text{ dBm} - (-32,7 \text{ dBm}) = 53,3 \text{ dBc}$ .

### 5.4.3 EIRP and dBm

During the final qualification process, product is used with his antenna. The power radiated by the product is a combination of conducted output power at the module output (on 50 ohms load), and the radiated properties of the antenna in the product environment.

To be able to make some power radiated measurement we introduce the EIRP unit: Effective Isotropic Radiated Power.  $\text{EIRP (dBm)} = \text{Forward transmit power (dBm)} + \text{Antenna Gain (dB)}$ .

Lets consider 2 transmitters :

A high power transmitter of 10 watts on conducted load, with a bad antenna of -10dB gain.

First, power must be translated in dBm: 10 watts = 40dBm. Thus  $\text{EIRP(dBm)} = 40 \text{ dBm} - 10 \text{ dB} = 30 \text{ dBm EIRP}$

Lets see a second transmitter with 1 watt (30dBm) output, connect to a better antenna of 0dB gain. Thus  $\text{EIRP(dBm)} = 30 \text{ dBm} + 0 \text{ dB} = 30 \text{ dBm EIRP}$

Seen from a receiver, theses both transmitters have the same effect over the air. We have take account of transmitter and associated antenna. We also take account of all the radiated effect that can change transmitter behavior. We are in the same conditions than in final use. We can compare two different systems from a radiated power point of view.

The EIRP take account of antenna gain which changes around the antenna. The EIRP is related to a given position. To take account of all the position around the DUT, we use the TRP measurements.

#### 5.4.4 Return loss, SWR and S11

When the transmission line, power source and load are well matched, there is no power reflected: All the power outgoing from transmitter is going to the load. If the load is a perfect antenna (50 ohms impedance at the working frequency), all the power will be radiated. See § 2.3

When the impedance differs, there is some reflected power “Pr”: Even if Hilo module is respecting the specification (33 dBm max output power in GSM band) it can not transmit all these power on a mismatched load. Return loss measurement is relative to transmission line theory. There are many formulas to define the return loss.

“Pin” in watt, is the output power from the transmitter. “Pr” in watts, is the output reflected by the unmatched load. Thus:  $RL(dB)=10*\log (Pr/Pin)$ .

If your transmitter in sending 2watts, and if the power reflected by the antenna, equal 250 mW, Thus  $RL = -9dB$

Return loss in dB is also named: S11, referred to S-parameters.

Range of S11: 0dB to -XXdB. At 0dB we have a totally unmatched load (all the power is reflected). It can be a short circuit or an open circuit. Only the phase differ and we don't see this in the dB calculation.

In the telecommunication range S11 of -20dB is a very good matching value. Commonly, we target -10dB or better. S11= -3dB is a poor quality load. In this particular case, half of the power in not transmitted to the load: It return to the power source an can have some unwanted effects.

#### VSWR:

An other unit for return loss is the VSWR: Voltage Standing Wave Ratio. With the reflected power effect, it appears some voltage standing wave. We express VSWR with maximum and minimum amplitude value.

$VSWR = V_{max} / V_{min}$ . VSWR range is 1 (no reflection) to infinite (total reflection).

Relation between RL and VSWR:

$$| RL | dB = 20\log((VSWR+1) / (VSWR-1))$$

$$VSWR = (1+(10^{(|RLdB|/20)}) / ((10^{(|RLdB|/20)})-1))$$

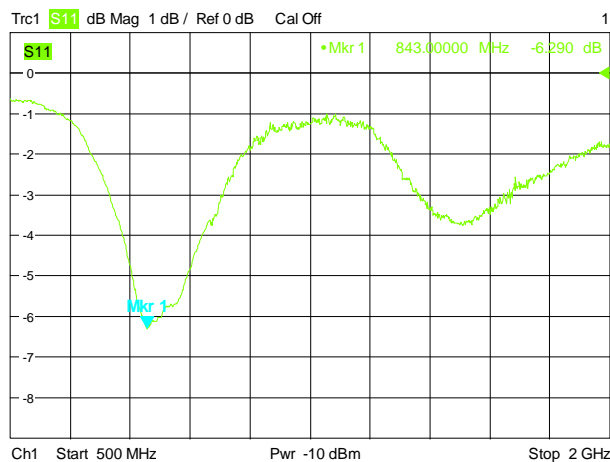
If,  $RL = -9 dB$ , thus  $VSWR = 2,099$

Return loss and SWR are defined over a band of interests. A part designed to work at a given frequency can not have a good return loss over all the RF range, from DC to 250 Ghz. The return loss must be optimized for a band of interest.

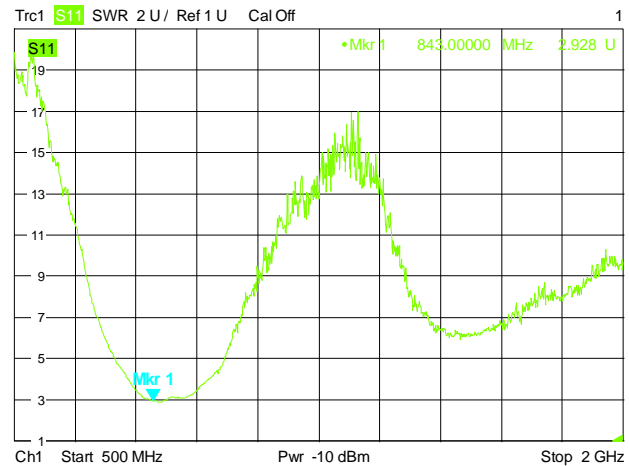
**Transmission line:** if a transmission line is well designed for communication band, we can consider that response ripple is negligible: Return loss is “flat “ and can be considered as the same value over all the operating communication band.

**Antenna:** The return loss of an antenna is very dependant of frequency.

Lets see some real measurements: S11 and SWR of the same antenna. You can see that return loss is not flat over the 500 Mhz to 2 Ghz band. The best frequency is around marker Mkr”1”: the S11 is low and SWR also. For frequencies higher or lower, we don't have so good results: the return loss is growing.



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**Return loss is used to quantify the ability of a RF part to work at a given frequency**  
**Return loss can change over the band of interest**  
**Return loss must be optimized over the band of interest**

## 5.5 Antenna

Hilo modules are designed to be used on real communication networks. Antenna is the radiating element and must be well designed. You can keep all the design on your side (printed PCB), you can use intermediate solution with other manufacturer or you can use totally external antennas.

**Antenna can be shortly summarized with next parameters:**

- Frequency band of used
- Radiation pattern with direction and polarization
- Efficiency
- Return loss or VSWR
- Integration rules: Some volume must be free of any components and ground layers around the antenna.
- Minimum PCB dimension: It is also influenced by the kind of antenna: monopole or dipole.

**You can use an external antenna connected to the 50ohms coaxial Hilo output**

- Antenna behavior is less influenced by your design.
- Only one disadvantage: more space used for your final product.

Stubby antenna with 50 ohm coaxial connector:



External antenna with a coaxial cable:

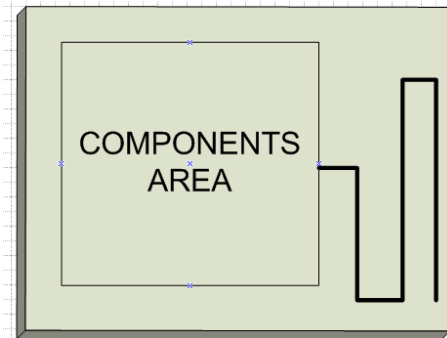


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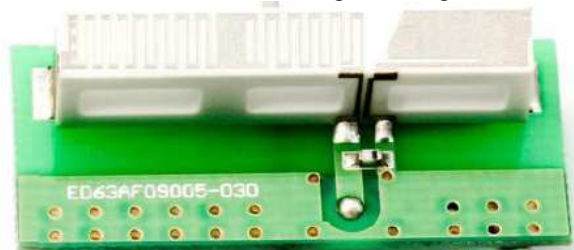
**You can design you product with on board antenna**

- You can totally design antenna with printed antenna on the same PCB
- You can use ceramic SMD and stamped ceramic antenna over plastic carrier.
- Most important difficulties: Antenna radiation pattern, efficiency and tuning will be influenced by all your design: components, shield and copper layer.

Antenna trace on the same PCB:



Ceramic antenna with PCB guard for ground :



FR4 PCB with short coaxial cable and connector:



Metal stamped on plastic carrier:



Type of antenna	Cost study	Price per unit	Connector on the product	Time to market	Risk	Number of Iteration design	Influence from no radiated part of the design on the final radiation pattern
Printed track on the same PCB	High and long	Very low	no	long	high	many	high
Flex antenna	High and long	low	Yes/no	long	high	many	high
Components : ceramic or plastic	Medium : take account of product environment and antenna manufacturer requirements	medium	no	medium	medium	few	medium
Connectorized with short coaxial near the PCB product	Null : reported to the antenna manufacturer	High	yes	short	low	low	low
Connectorized with coaxial cable far from the PCB product	Null : reported to the antenna manufacturer	High	yes	short	low	low	null

Some basics antenna principles:

- Better is the matching (low return loss), narrower will be the usable band. Outside it, the return loss can be high.
- Like any transmitter, the Hilo module can suffer from antenna with high return loss: sensitivity decrease and some issue appears in transmit mode.
- To keep the full performances of the GSM module over the air, it is strongly recommended to choice an antenna which offers a VSWR parameters value lower than 2.
- The VSWR is used to evaluate the ability of an antenna to receive the conductive power from the hilo module.
- Don't make confusion between antenna efficiency and VSWR. Even if the VSWR is equal to 1 (perfect 50 ohm matched), you can have a bad efficiency. This is exactly what happened with a perfect 50 ohms resistor used as a load.
- Efficiency is an intrinsic parameter of the antenna. It's only depends of the topology or mechanical drawing of the radiated parts.

**Used an antenna matched for 50 ohms and your frequency band of interest**  
**Don't confuse efficiency and return loss**  
**Antenna can be un-tuned by environment: components, case and PCB**  
**Take account of antenna designer recommendation for mounting antenna on your product**  
**An un-matched antenna decrease Hilo modules performances in real network**  
**An un-matched antenna and reflected RF power can have some unpredictable effect on your product and certification process**

## 5.6 Certification test

### 5.6.1 Aim

The Hilo module is pre-certified for communication network. Thus, the final product, witch used Hilo module is compliant with 3GPP standards. You don't need to pass all the tests used for mobile qualification in 3GPP range.

The Hilo module uses a 50 ohms output connection to an external antenna. Your final product is the association of Hilo module, an antenna, and your PCB. The result, in radiated conditions, is influenced by this association. The aim of certification process is to check that your product is following the regulation limitation in radiated condition. We look the spurious and harmonics radiated by your product.

### 5.6.2 Description

#### Environment:

- Test are performed in anechoïde chamber
- Product is connected to a communication tester
- Communication is done trough the product antenna.
- Calibrated receiving antenna and receiver are used to measure the absolute radiated spurious and harmonics power

#### Polarization:

- Measurements are done over many frequencies, in both polarizations: Horizontal and Vertical. Product must not overpass the limits in both polarization

#### Position:

- The measurement is done over 360°. Usually the product is placed on a rotating table.
- The measurement is repeated for all the product position: "stand" " flat" "side"..

### 5.6.3 Investigation after certification

To improve the result, we must be able to repeat the measurements before product modifications. In radiated conditions every detailed has some effect on absolute radiated value seen by the certification receiver. For investigation process and measurement repeatability, **we must know all the next parameters:**

- Package: use the same. Influence of any materials for the case: metal and plastic.
- PCB layout and components values: result can change with or without unmounted components and with few change in layout.
- Angular position: Test is performed over 360 °. The issue can occur only at a defined angle.
- Polarization of receiving antenna : test is performed over two polarizations
- If product use external antennas : relative position of antenna and coaxial cable must be considered
- Position of supply line if no battery in product : supply wire can radiating
- Supply value: can change on board product with regulator behavior.
- Take account of battery technology and case.
- Configuration of module output power: defined by the communication tester.
- Channel and band used for the test: defined by the communication tester.
- Absolute value (in dBm) and frequency reported by the certification receiver

## 6 RF exposure limitation

In some application we must be able to declare the minimal distance of operation with respect of power density limitation. Two steps:

- Define the limit
- Calculation of minimal distance to respect this limit

Following EN62311:2008 we must respect the next limitations seen in table 2 of Official Journal of the European Communities 30.7.1999:

Table 2

Reference levels for electric, magnetic and electromagnetic fields  
(0 Hz to 300 GHz, unperturbed rms values)

Frequency range	E-field strength (V/m)	H-field strength (A/m)	B-field ( $\mu$ T)	Equivalent plane wave power density $S_{eq}$ (W/m <sup>2</sup> )
0-1 Hz	—	$3,2 \times 10^4$	$4 \times 10^4$	—
1-8 Hz	10 000	$3,2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8-25 Hz	10 000	$4\,000/f$	$5\,000/f$	—
0,025-0,8 kHz	$250/f$	$4/f$	$5/f$	—
0,8-3 kHz	$250/f$	5	6,25	—
3-150 kHz	87	5	6,25	—
0,15-1 MHz	87	$0,73/f$	$0,92/f$	—
1-10 MHz	$87/f^{1/2}$	$0,73/f$	$0,92/f$	—
10-400 MHz	28	0,073	0,092	2
400-2 000 MHz	$1,375 f^{1/2}$	$0,0037 f^{1/2}$	$0,0046 f^{1/2}$	$f/200$
2-300 GHz	61	0,16	0,20	10

**Power density:**

The power is divided by the surface of the equivalent sphere. We use the W/m<sup>2</sup> value. The relation between distance, power in watt and watt power density is given by:  $\text{Power density} = P / (4 \cdot \pi \cdot d^2)$  with P in watt and d in meter. Thus  $d = (P / 4 \cdot \pi \cdot \text{Power density})^{1/2}$

**Limit:**

For Hilo3G module we must consider 400 to 2000 MHz range: Limitation = F/200 in average watt. Limitation change with exact operating frequency.

**Average value:** we must take account of the module transmit mode:

In 2G mode (GSM, GPRS or EDGE data) Transmission is bursted and must be averaging. If one time slot is used the ratio between peak power and average power is 1/8. In dB =  $10 \log(1/8) = -9 \text{ dB}$

In 3G mode we don't have any average effect: average = peak power. Thus, 0dB ratio for average effect.

**Peak power:**

In 2G mode: 33dBm = 2W for EGSM900 and GSM850 and 30dBm = 1W for DCS1800 / PCS1900.

In 3G mode (UMTS, WCDMA) : Classe 3, 24dBm = 0,25W

**Other gain and losses**

We add the antenna gain in dBi. We subtract the cable losses.

**Example:**

2G mode band GSM850, channel 128, with antenna of 2dBi gain and a coaxial cable of 1dB losses.

The frequency of transmission (UL channel 128) is 824 MHz. Thus limit =  $824 / 200 = 4,12 \text{ W/m}^2$  average = 36,1 dBm/m<sup>2</sup> average limit.

Power average must take account of cable losses, averaging factor, antenna gain, and module.

$$P_{avg} = P_{peak\_module} + \text{average factor} - |\text{cable losses}| + \text{antenna gain} = 33 - 9 - 1 + 2 = 25 \text{ dBm} = 0,316 \text{ W}$$

Relation between power density limit,  $P_{avg}$  and distance:

$$d = (P_{avg} / (4\pi \cdot P_{limit}))^{1/2} = (0,316 / (4 \cdot \pi \cdot 4,12))^{1/2} = 7,8 \text{ cm.}$$

Thus, to not exceed the exposure recommendation limits, we must be far more than 7,8 cm of the antenna.

## 7 Frequencies for 2G and 3G band

For investigation on a specific channel you must be able to know the frequency used by the module.

**ARFCN:** See 3GPP TS45005

Band	ARFCN range	Module transmit frequency (MHz) calculation	Module receive frequency (Mhz)	Frequency receiving range (MHz)
GSM 850	$128 \leq n \leq 251$	$F_I(n) = 824.2 + 0.2 \cdot (n-128)$	$F_U(n) = F_I(n) + 45$	869,2 to 893,8
E-GSM 900	$0 \leq n \leq 124$	$F_I(n) = 890 + 0.2 \cdot n$	$F_U(n) = F_I(n) + 45$	935 to 959,8
	$975 \leq n \leq 1023$	$F_I(n) = 890 + 0.2 \cdot (n-1024)$		925,2 to 934,8
DCS 1 800	$512 \leq n \leq 885$	$F_I(n) = 1710.2 + 0.2 \cdot (n-512)$	$F_U(n) = F_I(n) + 95$	1805,2 to 1879,8
PCS 1 900	$512 \leq n \leq 810$	$F_I(n) = 1850.2 + 0.2 \cdot (n-512)$	$F_U(n) = F_I(n) + 80$	1930,2 to 1989,8

**UARFCN:** See 5.4.4 and annexe E in 3GPP TS 25.101

UMTS BAND	UARFCN range	Transmit frequency			Received frequency		
		calculation	Fmin TX	Fmax TX	calculation	Fmin TX	Fmax TX
BAND1	9612 ≤ N ≤ 9888	Ftx= N/5	1922,4 Mhz	1977,6 Mhz	Frx= N/5+190	2112 Mhz	2167,6 Mhz
BAND2	9262 ≤ N ≤ 9538	Ftx= N/5	1852,4 Mhz	1907,6 Mhz	Frx= N/5+80	1932 Mhz	1987,6 Mhz
BAND5	4132 ≤ N ≤ 4233	Ftx= N/5	826,4 Mhz	846,6 Mhz	Frx= N/5+45	871,4 Mhz	891,6 Mhz
BAND8	2712 ≤ N ≤ 2863	Ftx= N/5+340	882,4 Mhz	912,6 Mhz	Frx= N/5+385	927,4 Mhz	957,6 Mhz

## 8 References



see <http://www.hp.woodshot.com/>



<http://www.3gpp.org/>

Spurious emission test: 3GPP TS 51.010-1 § 12.2 Radiated spurious emission.

Frequencies and channel number :

2G: 3GPP TS45005

3G: 3GPP TS25.101 §5.4 channel arrangement

Hilo module applications notes: [www.sagemcom.com](http://www.sagemcom.com) /support/module

## 9 Glossary

**ARFCN:** Absolute Radio Frequency Channel Number. Channel number used in 2G mode.

**DUT:** design under test

**dBm:** unity power , referred to 1mW See § 5.4.4

**Hilo:** name of Sagemcom product line dedicated to M2M communication

**Harmonics :** Particular case of spurious signal. It is an integer multiple frequency of main radiated signal used by the module during communication on the network.

**S11:** Scattering parameter for reflected power evaluation. See § 5.4.4

**Spurious :** Any unwanted radiated signal by the product

**SWR:** standing wave ratio see § 5.4.4

**UARFCN:** Absolute Radio Frequency Channel Number: Channel number used in 3G mode.

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