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Power Supply for Wireless Applications

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Application Note 26

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Content

Tables

Figures

1   Introduction

Efficient power supply design is a key issue for any wireless application - be it GSM, GPRS or UMTS. The purpose of this application note is to support system integrators in developing an application layout that minimizes current consumption, reduces the effects of voltage drops and ripples and ensures a reliable product performance.

This document covers the entire range of Cinterion wireless modules. All examples have been chosen to be generally applicable to most product types. Yet, the diversity of the products implies that, due to hardware or software specific properties, functional differences occur regarding the implementation of features, AT commands and parameters. Therefore, please consult the documents supplied with your module, especially [1] and [2], to make sure whether or not a described feature is supported.

1.1   Related Documents

[1]   AT Command Set for your module
[2]   Hardware Interface Description of your module
[3]   Application Note 07: Li-Ion Batteries in GSM Applications

The latest product information and technical documents are ready for download on the Cinterion Wireless Modules Website or may be obtained from your local dealer or the Cinterion Wireless Modules Sales department.

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http://www.cinterion.com

1.2   Terms and Abbreviations

Abbreviation	Meaning
GSM	Global System for Mobile Communication
GPRS	General Packet Radio Service
IC	Integrated Circuit
PCB	Printed Circuit Board
RF	Radio Frequency
USB	Universal Serial Bus
Vbat	Battery Voltage

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2 Power Supply Issues

Because of its high current consumption during transmission, power supply design for wireless modules should be focused on the transmitting mode (dedicated mode). With this in mind, the following sections sketch the main issues in designing power supply solutions. Please refer to the Hardware Interface Description [2] of your wireless module for the respective module specific current values.

2.1 Power Consumption for GSM/GPRS/EDGE

Due to the maximum RF power levels of approx. 2W the power supply current is modulated with 2A (approx.) pulses of 0.577ms every 4.6ms. During the receive only time period, current GSM call consumption is approx. 100mA. An example current profile is illustrated in Figure 1.

The measured values refer to the GSM 900MHz band at maximum power level with a real 50Ohm load. These values may increase up to 2...3A with an antenna connected depending on its mismatch.
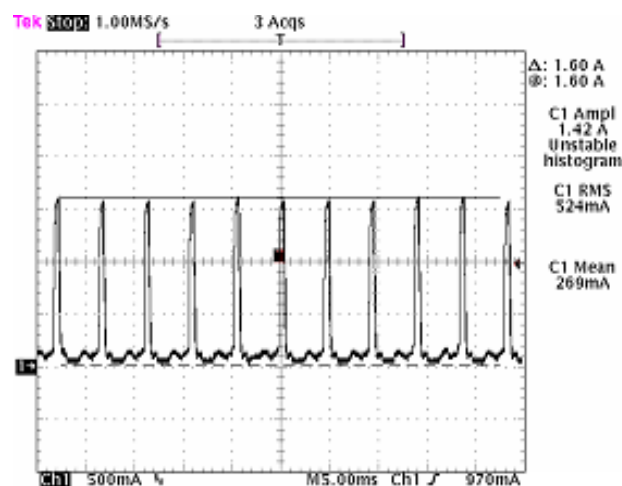

Figure 1: Current peaks in GSM talk mode (example)

During a GSM call the module transmits in one timeslot, receives in one timeslot and is idle for 6 timeslots. Eight timeslots make up a frame. Within such a frame the module therefore transmits for 577 μs and is idle or receiving for 4.03ms.

AN26: Power Supply for Wireless Applications
2.2 GSM/GPRS vs. UMTS/HSDPA Power Supply Requirements

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To give you an idea Table 1 lists current consumption values for the module MC75i.

Table 1: Typical and maximum current consumption for MC75i

Parameter	Description	Conditions	Min	Typ	Max	Unit
I$_{BATT+}$	Average supply current	TALK mode: EGSM 900/GSM 850 GSM 1800/1900		315 230	460 275	mA
		DATA mode: GPRS Class 8, (4 Rx, 1 Tx) EGSM 900/GSM 850 GSM 1800/1900		325 255	495 300	mA
		DATA mode: GPRS Class 10, (3 Rx, 2 Tx) EGSM 900/GSM 850 GSM 1800/1900		560 400	680 500	mA
		DATA mode: GPRS Class 12, MC75i only, with reduced power out (1 Rx, 4 Tx) EGSM 900/GSM 850 GSM 1800/1900		625 445	730 530	mA
	Peak supply current (during transmission slot every 4.6ms)	Power control level PCL 5		1.9	3.0	A

Typical values in the above table apply at an optimal 50Ohm antenna match. Maximum values were measured at total antenna mismatch. A power supply design for a GSM/GPRS module should be able to deliver 495mA for 1Tx timeslot in average, while also being able to deliver up to 3.0A during GSM bursts.

2.2 GSM/GPRS vs. UMTS/HSDPA Power Supply Requirements

Some modules support GSM/GPRS as well as HSDPA and UMTS. The power supply requirements for HSDPA and UMTS differ from the GSM/GPRS requirements.

As mentioned in Section 2.1 the supply current for GSM/GPRS transmissions includes maximum current bursts of up to 3.0A every 4.6ms. Because of a different transmission and modulation technology, this is not the case for HSDPA/UMTS transmissions. The supply current for HSDPA/UMTS is an averaged constant current. It depends on the output power level with no peak current pulses included. The maximum supply current for HSDPA/UMTS is less than 1A.

Therefore, a power supply circuit for a combined GSM/GPRS/UMTS/HSDPA module must be able to supply up to 3.0A peak current (GSM/GPRS) and an averaged current of less than 1A (HSDPA/UMTS). This combination makes circuit design somewhat more complex and these issues should be taken into account.

2.3   Power Losses and Voltage Drops for GSM/GPRS

The modules are specified to operate with specific voltage supplies. Voltage supplies may for instance range from 3.2V to 4.5V as measured on the module's power connector.

When consuming as much as 2…3A peak current, voltage losses due to stray resistances occur. Resistances occur in various parts, but there are three main areas to take into account.

* Impedance/resistance in the power source
* Resistance on connectors
* Resistance in signal tracks and lines

Assuming that the total resistance in the power supply line is 50mOhm and that the resistance in the ground line is the same, this amounts to a total resistance of 100mOhm (0.1 Ohm). Calculating the voltage drop over the power supply line results in 200mV. To be on the safe side, it should be assumed that the voltage drop during the Tx burst does not exceed 400mV. This means that if the data sheet states a minimum voltage supply of 3.2V for a wireless module, the power supply solution should provide at least 3.6V.
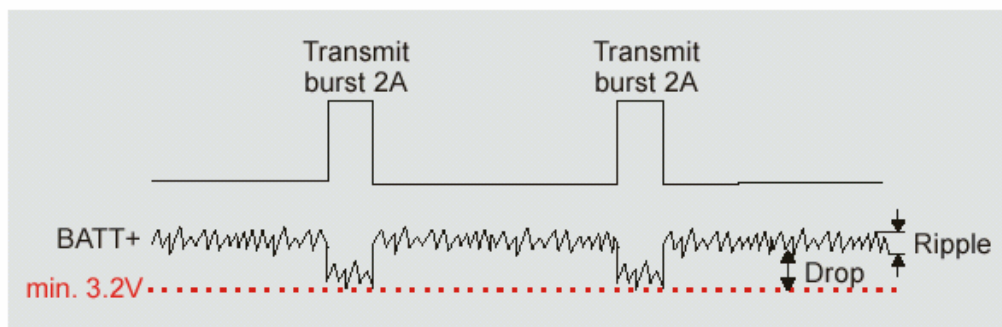
Figure 2: Voltage drop and ripple

2.4   Ripple

Another issue for power supply solutions is supply voltage ripple. Ripple can develop as a result of using a switched power supply circuit or as a result of disturbances caused by bad immunity to what is radiated from the own RF antenna. Please note that requirements here are far beyond those required to pass standard EMC tests.

A U_{ripple} requirement during a transmit burst should not exceed the following values (see [2] for module-specific voltage ripple conditions):

* V_{eff} = 50mV @ f<200kHz
* V_{eff} = 2mV @ f>200kHz

3   Power Supply Solutions

There is a great variety of possible power supply solutions for wireless modules. The most common ones are described in the following sections:

•   Linear regulation (see Section 3.1)
•   Capacitor supply (see Section 3.2)
•   Mix between linear and capacitor supply (see Section 3.3)
•   Battery (see Section 3.3.1)
•   Switched DC/DC converter (see Section 3.3.2)

NOTE: The values used in the following sections are sample values. These values will have to be recalculated for any customer-specific power supply solution.

3.1   Linear Regulation

Power supply with linear regulators is straightforward to design, and the total cost for the components can be quite low. As seen in Section 3.2 the power supply solution must be able to deliver at least 3A. If the module's desired supply voltage is for example 4V and the regulator input voltage is 12V, the efficiency is (only) 33%. The rest is transformed into heat.
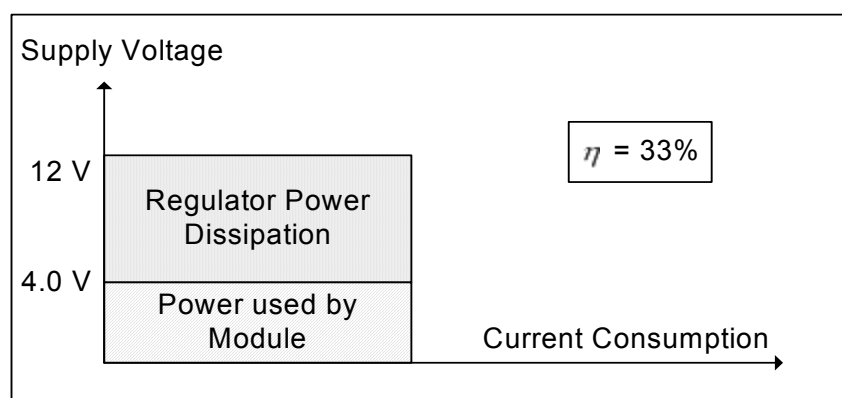
Figure 3: Linear regulation

The advantage of this solution is that there is no big requirement on the input power supply and on the input capacitor. Also, big voltage drops can be filtered by the regulator.
The requirements for the sample circuit are:

	GSM	GPRS 10
Input voltage	12V	12V
Average current	0.5A	0.9A
Peak current	3A	3A
Avg. Power dissipation at regulator IC	4W	7.2W

The peak power dissipation of the circuit is 3A x 8V = $24W_{peak}$, while the heat power is based on the average power consumption. In this case $3.5W_{avg}$ shall dissipate as heat.

For low dissipations the IC surface alone may be sufficient for cooling. For medium power dissipations the thermal issues can be resolved by having a big copper area on the PCB for cooling purposes. For higher power dissipations extra cooling is necessary. A cooling element as heat sink is often required. The below formula is useful when working with cooling elements.

$$PDmax = \frac{Tjmax - TA}{JC + CS + SA}$$

PDmax= Maximum power dissipation
Tjmax= Maximum IC temperature
TA= Ambient temperature
JC= Junction/case thermal resistance
CS= Case/sink thermal resistance
SA= Sink/ambient thermal resistance

NOTE: Modules are sensitive to heat. If cooling for the either module or its housing is insufficient, the module will warm up. If the module gets too hot, it will shut down! This may happen during a long call (long warm up period), if the cooling is not sufficient.

3.2   Capacitor Supply

If the module is integrated on a board with a power supply component that delivers 5V and sufficient current, it is possible to design a basic power supply solution for the module.

The appropriate voltage can be achieved by adding one or two diodes in series with the power supply line. The voltage drop over the diodes will create a suitable voltage for the module.

A big capacitor has to be added, able to supply the module during transmission bursts. The capacitor must be able to deliver up to 3A during 1 burst and must have low ESR values. These requirements translate to the following values:

*   ESR values less than 50mOhm
*   Ripple current more than 3A
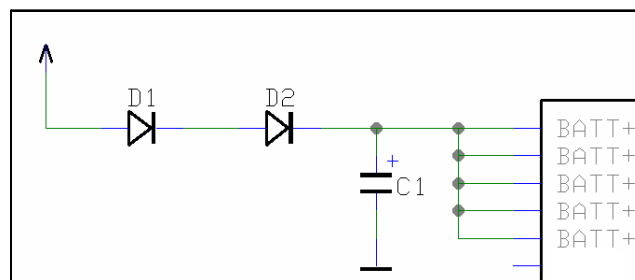*   4700 – 10 000 µF

Figure 4: Capacitor supply

3.3 Linear and Capacitor Supply

In a mixed power supply solution there are two components that can supply the current for the module if operated in parallel. These components are usually a big capacitor and a power supply circuit. Such a combination is the most easy and cheapest to realize. Most power supply circuits require a capacitor at the output side in any case.
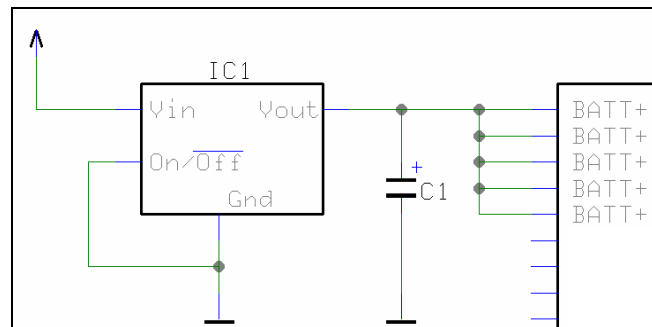
Figure 5: Mixed supply

With this solution power is supplied from both the capacitor and the IC.

3.3.1 Example with Low Current Regulator IC

The average power consumption of a wireless module is 440mA, while the peak consumption is max. 3A during the Tx burst, which can be 1 x or 2 x 577μs.

In this example the IC delivers 500mA and covers the average power supply needs. However, it is not able to handle current peaks. Current peaks must instead be handled by the capacitor. The capacitor should be able to deliver 2.5A (3A – 500mA) for 1 x or 2 x 577μs. It should also have low ESR and high ripple current. The higher the rated voltage is the better are - as a rule - ESR and ripple current.

The resistance in the power supply feeding line together with the ESR resistance of the capacitor is 50mOhm. 50mOhm @3A mean a 150mV voltage drop of the module. The IC is a zero resistance current source. The power supply IC delivers 0.5A, the capacitor the remaining 2.5A. The maximum voltage drop is 400mV.

Since the Tx burst frequency is 217Hz, it can be considered as ripple current. The required capacitance can be calculated using the formula:

$$C = Q/U = (I \times \Delta t)/(\Delta U)$$

C= capacitance (Farad)
Δt= discharge time (here: 577μs)
Q= charge
ΔU= voltage change (here: max. 250mV)
I= current (here: 2.5A)

With the sample values this results in:

$$C = 2.5A \times 577\mu s / 250mV = 5770\mu F$$

The above example is a worst case scenario with bad antenna matching and strict power restriction by the regulator chip. In practice 4700…7200 µF are enough for GSM; for GPRS class 10 the values will have to be doubled.

NOTE: A capacitor loses its capacity through ageing or low temperatures. If the product is likely to operate at low temperatures, check the datasheet for remaining capacitance at low temperatures. It is also a good idea to compensate for ageing and low temperatures by choosing a capacitor with higher values than required. Often it is easier to meet the requirements by adding two or more capacitors in parallel.

These capacitors will dissipate power depending on ripple current and ESR; power that will additionally heat up the capacitor:

$$P = I^2 \times R / 8 = 39mW \ (R_{ESR} = 50mOhm, I = 2.5A, 1Tx)$$

3.3.2   Example with High Current Regulator IC

In the previous example there was a need for a large capacitor. To be able to use a smaller capacitor, the IC must deliver higher currents.

In this example the IC can deliver 2.5A. It means that the ripple current over the capacitor is 0.5A.

Assuming the IC is a zero resistance current source the capacitor delivers 0.5A. Even with an ESR of 300mOhm a maximum voltage drop of 150mV occurs. The required capacitance can be calculated as follows:

$$C = Q / U = (I \times \Delta t) / (\Delta U)$$

C= capacitance (Farad)
Δt= discharge time (here: 577µs)
Q= charge
ΔU= voltage change (here: max. 400mV-150mV=250mV)
I= current (here: 3A-2.5A=0.5A)

With the sample values this results in:

$$C = 0.5A \times 577µs / 250mV = 1154µF$$

In practice 470…1000 µF are enough for GSM, for GPRS class 10 at least 2200µF are recommended.

3.4   Battery

Using a Li-Ion battery, the battery must be able to deliver all necessary power peaks to the module. Therefore, the battery should be connected directly to the module.

For charging and choosing the correct battery see the separate application note on Li-Ion batteries in GSM applications [3]. Please note however, that the charging feature is not available for every module.

3.5   Switched DC/DC Converter

A switched DC/DC converter is very often used when there are requirements for a small footprint, high efficiency and little heat dissipation. Linear regulation often leads to undesirable heat dissipation that needs to be dispersed by a heat sink. This problem can be solved by using a switched DC/DC converter that creates (almost) no heat at all.

However, there are a number of issues to take into account when working with switched DC/DC converters: Shall the DC/DC converter be isolated, which design typology is the best to use (boost, buck, fly back, or other), which operation modes is best employed (PWM, hysteretic, other), switching frequency, required efficiency, cost/size, post filtering as well as layout.

Not all of these issues can be covered in an application note, but some guidelines are given here.

There are DC/DC controllers available on the market with an integrated switch (like the simple switch series from National), and they are often easier to design than DC/DC controllers with external switch.

When working with switched regulation the switching frequency is very important as it decides how fast the switcher reacts on voltage drops (together with the filter in the error amplifier) at the load (in this case, the wireless module). The switching frequency is also important for the choice of components around the switcher circuit. Higher frequency means smaller (and cheaper) components.

Integrated switch circuits typically work with frequencies from 50kHz to 1MHz. There are disadvantages operating with high frequencies. A switch creates ripple on the supply voltage. This ripple **must** be minimized on the power supply line to the wireless module. Otherwise, there may be the risk of violating the transmitter modulation spectrum and therefore application approval, especially at higher DC/DC switch frequencies.

Normally there are no EMC tests for frequencies below 150kHz. This means that with a switcher frequency of 48kHz, even the third overtone is below the limit. But this third overtone can cause a violation of the modulation of the signal (see also Chapter 4), if the ripple value is too high. This point should be considered, even if the risk of a spectrum violation is much smaller than at high switching frequencies.

If a small, inexpensive design is required, it should be realized with higher frequencies, but the mentioned issues need to be taken into account.

NOTE: Keep in mind that around a DC/DC switch (specially the coil) there are magnetic fields, which can create disturbances to other electronic circuits. This might be the case if the coil is placed close or under / over the RF part of the wireless module.

4 Design Considerations

As already mentioned above the switch frequency from a switched DC/DC converter might cause violation on the transmitter's modulation spectrum.

If the unit has to be able to work with input voltages such 30…40V it may be inconvenient to work with linear regulation.

If you are not sure how to design a switched DC/DC converter that does not cause any trouble for the wireless module, and linear regulation is not suitable for your design, the following ideas might be helpful.

4.1 Post Filtering

With post filtering an extra inductor and an extra capacitor are added after the components included in the DC/DC design.

The dimensions of these extra components depend on how well filtered the output power from the DC/DC switch is. It might be enough to use a small inductor of 1uH. The inductor must of course be able to handle the current (2…3A) and it should not have too much resistance so as not to create too big a voltage drop.

A switched DC/DC regulator has a feedback line from the output side that is used by the circuit to regulate the output voltage. It would be nice, if the feedback line could be taken from the output of the extra LC filter. The regulator could then compensate for the voltage drop over the second inductor as well. In most cases this is not possible. An LC filter creates a phase shift. The regulation IC expects this phase shift from the ordinary output filter. By adding an extra phase shift in the feedback line, it's likely to add malfunction of the regulation IC.

However, the output capacitor in the extra LC filter can be calculated according to what was previously mentioned in this application note.

4.2 Double Regulation

A second way of solving the problem is to use double regulation. A switched DC/DC converter can be used to convert input voltage >6V to for instance 5V. As a second step a linear regulator can be used to convert 5V to 4V, which can be a suitable voltage level for a GSM module. A linear regulator with a drop out voltage less then 1V must be chosen.

The advantage with this design is a post filtering effect that lowers the DC/DC converter's typical output ripple. The disadvantage is the cost and size for having two regulators on board.

4.3 Reduced Resistance between Battery and Module

Generally, the power lines of the PCB tracks connecting the module with the battery should be as short and low resistant as possible.

To minimize the effect of voltage drops (max. 400mV), you can decrease the GND resistance by using additional ground connections from the wireless module to the customer application. This can be done by using a screw or spring contact.

5 Layout Guidelines

5.1 General Guidelines

The PCB layout is very critical in a power supply design, and should be considered as one of the most important design issues. A PCB strip line has to be viewed as a resistance as well as an inductance. The resistance for a strip line can be calculated with the formula:

Resistivity x Length / Area

Resistivity The resistance for copper, which is 0,017μOhm x m @ 20 degrees
Length   The length of the lead
Area   Width x copper thickness

Examples:
In this first example the strip line on the PCB is 0,5mm wide, 100mm long and has a 0,035mm copper thickness. The resistance can be calculated as:

$R = 0,017 \times 0,1m / (0,5 \times 0,035)mm^2$
R = 0,0017 / 0,0175 = 0,097 Ohm

The resistance in this lead is almost 100mOhm; more than enough to have an influence on the power supply line.

In the second example the strip line on the PCB is 2mm wide, and 20mm long. The resistance can be is calculated as:

$R = 0,017 \times 0,02 m / (2 \times 0,035) mm^2$
R = 0,00034 / 0,07 = 0,005 Ohm

The resistance is 5mOhm, which is almost neglectable.
The conclusion from these examples is obvious. The lead from the power supply IC and/or capacitor shall be as short and wide as possible.

NOTE: In the examples above it is assumed that the copper thickness on the PCB is 35μm. Normal values of copper thickness can be from 15μm to 50μm. If the copper thickness had been 15μm instead of 35μm in the examples above, the resistance had been 2,3 times higher.

The figure below shows a power supply line on the PCB. It is a wide line, but with short narrow lines to each soldering pad to a module's connector. A wide line across all power supply lines will decrease the solderability.
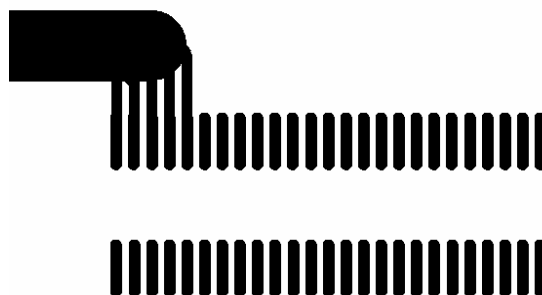

Figure 6: Power feeding line

As previous mentioned a strip line could also be seen as an inductor. In the figure below the power supply-feeding line is placed in parallel with a microphone line. If those lines are seen as inductors they can be viewed as a transformer. The efficiency of the transformer depends on the frequency, distance and length of the line. So, if the small line were a data line, it might not have any impact. But since it is a microphone line, some problems can arise from this kind of design.
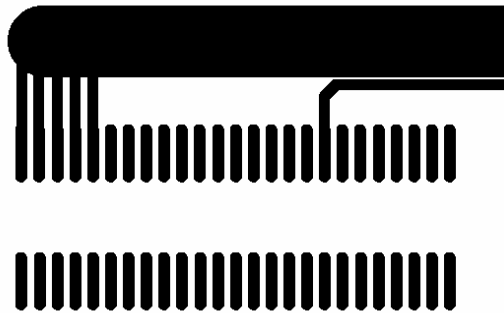

**Figure 7:** Inductance of power feeding line

5.2   Guidelines for DC/DC Converters

When working with switched DC/DC converters there are some special issues to consider for PCB layouts. Guidelines can very often be found in the data sheet for the IC, but here are some general hints:

- Place the inductor as close as possible to the switch.
- Place the freewheeling diode (or second switch) on the line between the switch and the inductor.
- Place the output capacitor as close as possible to the inductor.
- Place the input capacitor as close as possible to the switch.
- Keep all lines to the components mentioned above as short and thick as possible.
- Consider the block consisting of switch, inductor, free-wheeling diode, and input and output capacitors as a source of disturbance signals, and keep it as far away from micro controller, audio blocks and other parts that can easily be interfered.
- the RF part should not be placed too close to the converter

It is sometimes recommended to run the ground lines to the power section separately from other ground lines. This is to prevent the high current in the output circuit to influence the regulating circuit. However, both ground lines must be connected in one single point to ensure that the potentials for the two grounds cannot differ.

Figure 8 shows an approved example for a DC/DC converter with fixed 150kHz switching frequency. The circuit has a low pass prefilter (C4-L2) to suppress the 150kHz switching ripple feeded to the input supply cable. The output capacitors C1 and C2 are doubled to reduce the ESR value as well as the input capacitor C3 must be a low ESR capacitor. An additional output L-C low pass post filter (L3-C7) should be added during the first design phase as it decreases the high frequency spectrum which may violate the GSM modulation spectrum. This post filter can be skipped if not needed after design validation.

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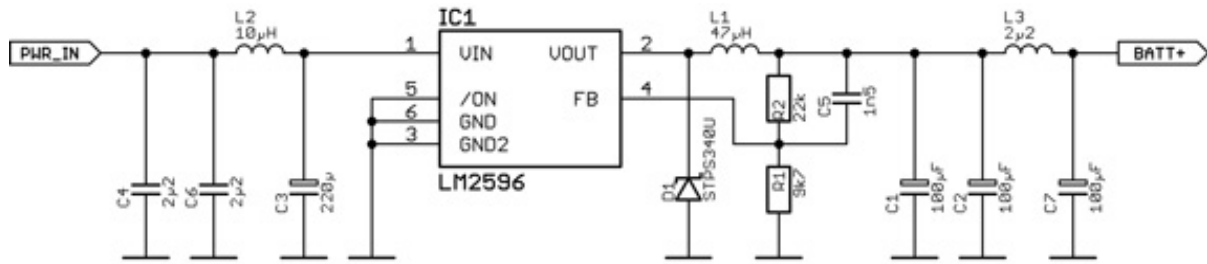
Figure 8: DC&DC converter (example with 150kHz switching frequency)

Table 2: Item list for DC/DC converter (example with 150kHz switching frequency)

Item	Description	Ordering code / Value	Manufacturer
C1, C2, C7	Tantal capacitor	100µF 6V3	
C3	Aluminium capacitor	220µF 35V	
C4, C6	Ceramic capacitor	2µ2 35V	
C5	Ceramic capacitor	1n5	
D1	3A, 40V power schottky rectifier	STPS340U	STM
IC1	3A fixed 150kHz switching converter	LM2596	National Semicunductor
L1	Inductor closed housing	CDRH125NP-470M / 47µH	Sumida
L2	Inductor	74477310 / 10µH	Würth Elektronik
L3	Inductor	744773022 / 2µ2	Würth Elektronik

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6   Current Limitation by AT Command

Some modules provide the possibility to reduce the maximum RF output power and hence the maximum required peak supply current. This can be achieved using the AT^SCFG command. Please refer to the AT Command specification of your module for more information [1].

7 USB Design

This reference design is aimed at USB equipment, but can be used for all cases with similar requirements. According to USB specification (revision 2.0 Chapter 7.3.2) power supply from a high power port is:

Table 3: USB Host / powered Hub voltage specification

Parameter	Min	Max
Supply Voltage at USB port [V]	4.75	5.25
Supply Voltage at end of USB cable [V]	4.625	5.125
Current limitation [mA]	500	

A power supply of 500mA is enough for GSM modules, but not enough for GPRS class 10 or HSDPA/UMTS modules. This reference design is therefore only suitable for GSM and GPRS class 8 modules. For designs with GPRS class 10 or UMTS a battery supply with battery charging current from USB or another additional power supply is recommended.

NOTE: According to the USB specification there is also a low power port. A low power port does not deliver enough power for a GSM/GPRS/HSDPA/UMTS application. Also, there is a voltage loss on the USB connection cable under maximum load. It is defined as 250mV (125mV each in Vusb and Vgnd). The user should include this fact in a calculation.

When a USB unit is plugged into the network, it has a certain amount of capacitance between VBUS and ground (C1). In addition, the regulator supplies current to it's output capacitor (C3)as soon as power is applied. Consequently there could be a surge of current into the device, which might pull the VBUS below its minimum operating level. This problem must be solved by limiting the inrush current during the power up phase.

According to the USB specification the maximum load that can be placed at the downstream end of a USB cable is 10µF in parallel with 44Ohm resistance.
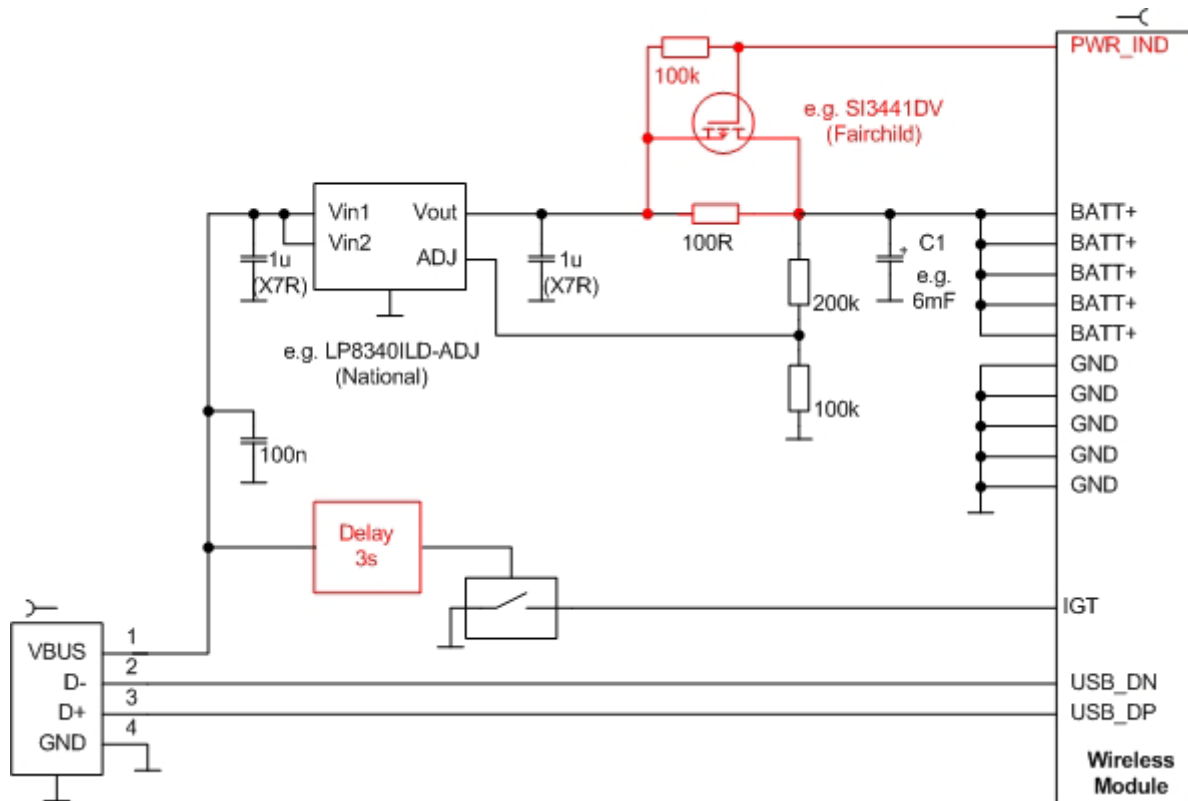
Figure 10: USB power supply

In the design above the red circuit limits the inrush current of the 6mF capacitor C1 at 40mA. Make sure that the module is being turned on after C1 is full charged. The delay has to be approximately 3s.