A new approach to the challenge of powering modern cellular M2M modems
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Industrial applications for machine-to-machine (M2M) data exchange are becoming ever more common, supported by the wide availability of easy-to-use cellular modem modules.

Modem modules from suppliers such as Sierra Wireless and Cinterion handle all the RF and protocol functions required for an embedded device to operate on a 2G, 3G or 4G cellular telephone network. This still leaves the system designer, however, to implement a power circuit that ensures the modem operates in accordance with its specifications across the entire operating temperature range and under any load.

This article describes the challenges facing the power circuit designer, and describes why a hybrid component type is particularly well suited to the combination of requirements found in M2M modem applications.

Basic requirements of the modem's power circuit
A successful power circuit design will provide for the specified RF operation, and will support peak Transmit power specifications, while dissipating little energy.

- **RF operation** – the modem’s sensitivity can be badly impaired by power supply noise (output voltage ripple), reducing range and data rate, and threatening the modem’s compliance with emissions regulations and its conformance to the 3GPP (cellular network) and other standards.

- **Transmit power** – in M2M designs, the antenna is commonly a poor fit for the application. If space is constrained, the antenna might be too small or poorly positioned. While the modem module manufacturer will tend to specify the device’s power requirement under ideal conditions using an efficient narrowband antenna, in real applications it is more common for a single, inefficient wideband antenna to be used to transmit and receive signals at multiple frequencies (in dual-, tri- and quad-band modems). This means that the maximum Transmit power will commonly be higher than the figure specified in the module’s datasheet.

- **Power dissipation** – industrial and automotive applications often have to be capable of dissipating power losses at high ambient temperature (typically 85°C). Where the power supply’s voltage regulation is provided by a low-dropout regulator (LDO) – as is often the case – the high losses in the device tend to necessitate the use of a large heatsink and space for cooling air flows. The result: the end product becomes larger than it might otherwise be, costs more and wastes more power.

The power circuit, then, has a strong impact on the module’s performance. Despite this, the design guidelines and good practices that the circuit designer should follow are frequently poorly documented by module manufacturers. Most M2M module datasheets provide little information on the correct way to design the power rail, and provide performance ratings only for a perfect antenna set-up, which is hardly ever found in the real world.

**Supplying peak power in Transmit mode**
One of the key specifications of every cellular telephone standard is the peak power of transmissions. Each flavor of cellular telephone standard specifies a different value for peak Transmit power, but the highest value is for the oldest protocol, GSM (a 2G technology), which specifies $+33\text{dBm}$ at the antenna (see Figure 1). Since modules are always backwards-compatible with every legacy network standard still in operation, every module will offer compatibility with GSM. This, then, determines the peak Transmit power capability of every cellular module on the market.

This output power requirement can be expressed thus:

Equation 1: \[
10 \log \left( \frac{P_{\text{OUT}}}{1\text{mW}} \right) = +33\text{dBm}
\]

The energy requirement is therefore:

Equation 2: \[
P_{\text{OUT}} = \frac{33\text{dBm}}{10} / 1000 \approx 2\text{W}
\]

In practice, however, an approximately 2W power supply to the module’s integrated power amplifier (PA) will not achieve the specified $+33\text{dBm}$ peak output. This is because OEMs normally use modules that do not include an integrated antenna or antenna connector – OEMs need the flexibility to design their own antenna system.

Power efficiency varies markedly from one antenna implementation to another. Moreover, the antenna-to-module connection needs to be matched in impedance at the operating frequency. A matching network is never perfect, and induces some power loss in its own right (see Figure 2). As a consequence, the PA output usually calls for some headroom to ensure the delivery of $+33\text{dBm}$ power at the antenna. A useful rule-of-thumb for the guard band is -1.5dB, which raises the required output power at the PA to $+34.5\text{dBm}$. Using equation 1, this requires a 2.8W power supply.
Fig. 2: the power supply to the module must take account of system losses as well as the required input to the module’s power amplifier.

Of course, the power supply must also allow for losses inside the PA – integrated PAs typically offer between 45% and 60% efficiency. Since the input voltage to the PA can also vary, normally from 3.2V to 4.2V (4.2V being the peak output voltage of a lithium-ion battery), it follows that a module must be capable of handling a wide range of input currents.

Module manufacturers typically specify their products’ peak current requirement at 2A or lower. But as stated above, this is under ideal conditions, assuming the use of an efficient narrowband antenna. In practice, this will be insufficient for most real-world designs: a safe guideline is to specify a peak current on the power rail of 2.5A. This allows for power losses due to the PCB, the matching circuit and the antenna. Figure 3 shows that it is actually possible to make a case for setting the peak current capability at a level higher than 2.5A.

Fig. 3: peak current capability on the power rail is normally far above the 2A typically specified in a module manufacturer’s datasheet.

In practice, however, the PA normally applies internal current limitation to avoid damage to the circuit, and to ensure Transmit power will not exceed the limits imposed by the cellular telephone standards. In most PAs, this peak current limit is set to 2.5A.

Finally, the design of the power rail must also take into account the requirements of functional blocks other than the PA: these include the RF transceiver and the baseband processor. This typically adds an overhead of 500mA.

The module’s power supply rail therefore must be capable of delivering a 3A peak current without any output voltage degradation.
As well as peak power capability, the power circuit designer must also support average current levels while providing for appropriate thermal dissipation capability. A good guideline is to assume a 1A maximum average current requirement.

**Timing and transient response**

With the provisioning of an appropriate current output settled, the designer must then turn to the timing of power delivery. 2G technologies, which use time-domain multiplexing, produce a power profile consisting of recurring episodes in which power must be ramped up and ramped down in a short space of time. In a multi-slot time mask, the modem might require two power steps, with each step having to be completed in approximately 18µs (see Figure 4).

![Fig. 4: the power circuit must respond extremely fast in order for the modem to stay within the power output bands specified by cellular network standards](image)

If the power supply is not to degrade RF performance, the output voltage transient response must be very fast and stable. Power system designers have commonly tried to work around a circuit with inherently slow transient response by using large output capacitors to provide energy to the modem during transients. This approach, however, has severe drawbacks:

- Large capacitors are expensive and occupy a large area on the board
- Large capacitors struggle to operate fast enough at high frequencies
- A large capacitor usually features a high ESR value, adding a low-frequency pole to the open loop response. The open loop gain margin is impaired by this additional pole, and this makes the system much slower to react to load transients.

The better approach is to adopt a power supply design that offers inherently fast transient response but that does not require a large output capacitor. Power supply designers have achieved this in the past by using:

- A high-speed LDO with good phase margin, offering higher stability and fewer under/overshoots
- A DC-DC step-down (buck) converter with a high switching frequency
The use of a high-frequency switching power supply will inevitably make the designer nervous: in wireless applications, EMI and noise generated by the power supply can all too easily impair RF signals, leading to reduced range and data rate, and increased error rates, as well as endangering compliance with network standards and EMC requirements.

And while noise counter-measures can be taken (such as the use of shielded inductors, and careful board layout to limit the length of noisy traces), the use of an ordinary switching DC-DC converter is a risky approach, and can involve the designer in long, painful fine-tuning and many revisions of the board design.

For many, these drawbacks outweigh the advantages of high efficiency and fast transient response offered by a DC-DC converter. The converse is true of designs using an LDO: noise from output voltage ripple is so low as to be negligible, but this is balanced by the low efficiency and high power dissipation that are characteristic of the LDO.

A combination of the attributes of both devices would, therefore, seem to be desirable in M2M modem power supplies – and this is the promise of a new hybrid type of device called HELDO® (High Efficiency LDO) from Micrel. This is a single monolithic device which consists of a switching DC-DC converter that feeds an LDO (see Figure 5). The MIC38300HYHL, a 3A HELDO device, is well suited to the M2M module applications discussed above.

Fig. 5: the MIC38300 HELDO® from Micrel is a hybrid DC-DC converter/LDO device

The DC-DC converter regulates the input voltage to the required output plus the LDO’s minimum dropout value of 1.2V. The LDO then steps the input from the DC-DC converter down to the voltage required by the system.

The LDO’s low-noise output cleans up the input from the DC-DC converter (see Figure 6), while dissipating the smallest possible amount of energy because its input is as close as possible to its output. Clever control circuitry inside the chip ensures that the DC-DC converter’s output is maintained at the appropriate level above the LDO’s output, while still providing a fast response to load transients. Housed in a 4mm x 6mm MLF™ package offering 24°C/W thermal resistance, the MIC38300HYHL can sustain a 1A average current at an ambient temperature of up to 105°C.
This hybrid device thus provides an answer to the combination of problems involved in designing a power circuit for an M2M modem module: offering the best of both worlds, it is efficient and generates little noise, so RF performance is not impaired by switching noise, while high efficiency and ample thermal dissipation capability enable operation even in industrial applications operating in harsh and hot conditions.

Fig. 6: the integrated LDO in the MIC38300 provides a very low-noise output suitable for use in sensitive RF applications.