ON Semiconductor

Design Note – DN05130/D

NCP171- LDO Regulator, Dual Mode Ultra Low Iq

Device	Application	Input Voltage	Output Power		Topology	I/O Isolation
NCP171	Consumer	1.7 V – 5.5 V	0 - 150 mW		Linear regulator	No

Other Specification

	Output 1 (Low Power Mode)	Output 1 (Active Mode)
Output Voltage	1.15 V	1.2 V
Ripple	N/A	N/A
Nominal Current	1.5 mA	30 mA
Max Current	5 mA	80 mA
Min Current	0	0

Others	

Introduction:

The fast growth of battery powered wireless IoT devices has created a major design challenge for designers in achieving the 10-year battery life objective.

A common approach to extending battery life has been to take advantage of the dual mode operation of such IoT nodes, namely Active and Low Power Modes, Figure 1. combined with deep duty cycling, to minimize time spent in Active Mode, Figure 2. Considering Low Power Mode is where the system operates most of the time with typical loads in the uA level, Quiescent current (Iq) of the Voltage Regulator can dominate the battery life. This means a LDO with Iq in the Nano Amp range can be a more efficient solution that a Buck regulator when it comes to extending battery life.

The NCP170 offering 500nA of Iq and the new NCP171 offering 50nA with Dual Mode functionality offer efficient solutions for the battery powered wireless IoT node.

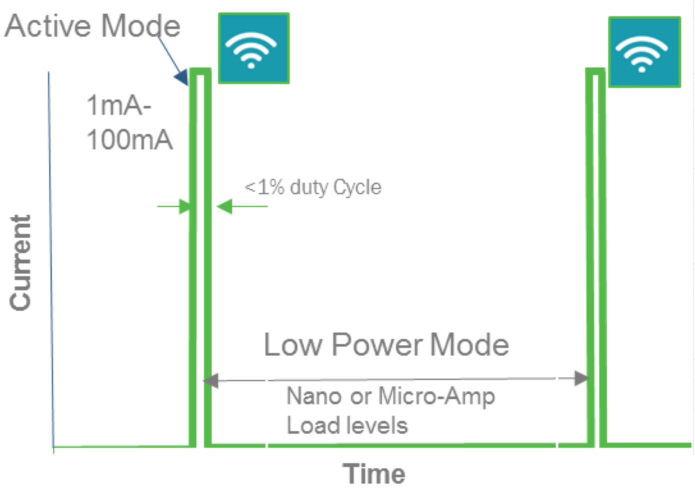

Figure 1: Typical Battery Powered IoT Power Profile with Active and Low Power modes

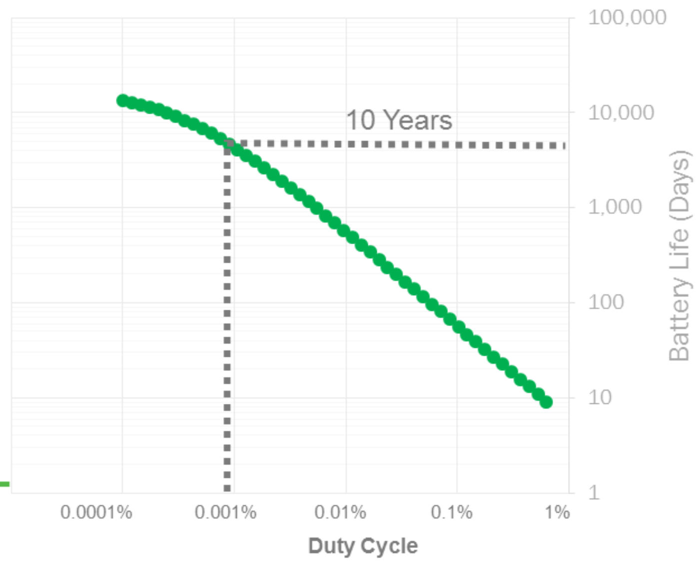

Figure 2: Battery Life vs Duty Cycle

Table 1: Battery life calculation, Buck vs Low Iq LDO

	I Act	T Act	Active Mode Energy Use Efficiency adjusted	I Low Power	T Low Power	Low Power Mode Energy Use	Regulator Efficiency	On Time Duty Cycle	Battery Life (270mA.Hr)
Low Iq Buck Regulator	10 mA	4 Sec	43 mA.Sec	Load= 2uA + Iq= 2uA	86,396 Sec	346 mA.Sec	94%	0.000463%	5 Years
LDO NCP170	10 mA	4 Sec	78 mA.Sec	Load= 2 uA + Iq=500nA	86,396 Sec	86 mA.Sec	51%	0.000463%	8 Years
SLIQ LDO NCP171	10 mA	4 Sec	78 mA.Sec	Load= 2 uA + Iq=50nA	86,396 Sec	47 mA.Sec	51%	0.000463%	10 Years

Circuit Description

The NCP171 is a Dual mode linear regulator, offering an Output current up to 80 mA in Active Mode while offering no load consumption of as low as 50 nA in Low Power Mode. The Dual Mode function is selectable by the ECO pin. The input Voltage range from 1.7 V to 5.5 V is suitable for battery operated equipment like IoT applications, Portable Communication Equipment and Customer applications. The new concept of the Dual Mode Super - Low IQ (SLIQ) Linear Regulator employed in the NCP171 is one way to fulfill 50 nA Quiescent Current and excellent Transient Response and Low Noise, both on the same piece of silicon. The NCP171 follows ON Semi's previous Ultra Low power LDO, The NCP170 at 500nA Iq, offering 50nA, a 10X reduction in Quiescent current without compromising the Dynamic performance of the regulator.

NCP170 linear regulator achieves very good dynamic performance thanks to the so-called Adaptive Bias technique, which rapidly increases the circuit's ground current with increasing output current. Thus, when the load changes from a few mA to maximum current, the circuit is in a relatively large ground current band and the load transient response in this area is satisfactory. But for a modern "green" application mainly powered by coin cell which operates 99% of the time with a microcontroller in Sleep mode with a total application consumption of a few micro amps range, the 500 nA quiescent current within this regulator is unacceptable. On the other hand, these applications often require good load transient response and PSRR at load variations from a few tens µA to several tens of mA for proper operation of RF equipment to communicate with the environment. Applying adaptive bias technique in such a wide range of loads from tens of nA to tens of mA brings a compromise. Namely average dynamic behavior is sacrificed to low quiescent current or high quiescent current is trade-off for better dynamic behavior. Finding a suitable equilibrium for different applications is then very challenging, because the Adaptive bias curve is suitable for specific application and every compromise results in not so perfect of a solution.

We assume that in a microcontroller operated application it is known when the system needs to go to Sleep mode and when it needs to wake up for RF Transmission or high current Sensing. The microcontroller can therefore control the ECO pin of the NCP171 regulator by one output pin with two-state logic and switch this regulator into the optimal operation mode as needed. The simplified operating block diagram is shown in Figure 3. Simplified Operating Schematic.

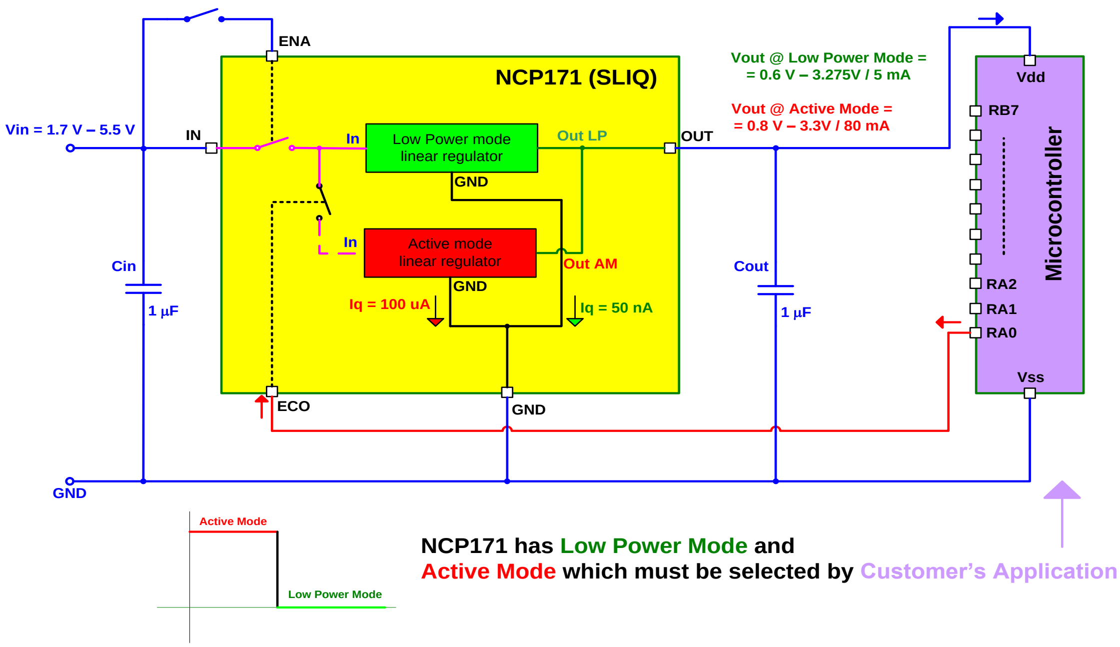

Figure 3: Simplified Operating Schematic

This means we can put the NCP171 controller into the Low Power mode with Quiescent Current below 50 nA during sleep of the microcontroller (usually up to 99% of the operating time) or switch to so called Active mode with excellent dynamic behavior so that the higher current demands of the operation will be met. . The higher ground current associated with short period of Active time is easily justified by excellent dynamic behavior. Once complete with Active mode tasks, RF communication and/or any High current Sensing required, the microcontroller will bring the NCP171 regulator back to Low Power mode offering more than 1000X reduction in its quiescent current. This will significantly extend the battery life.

In addition, the output voltage of the NCP171 regulator in Low Power mode can be offset, via a factory programmable value of 50 mV and up to 200mV at 50mV increments. This Voltage Scaling can bring additional energy savings and help extend the battery life even further. The Output Voltage in Low Power Mode can be factory programmed within a range from 0.6V to 3.275V at 25mV increments. The short current limit in the Low Power Mode is internally set to approximately 10 mA and does not allow an overheating during short circuit.

The output voltage of the Active Mode part could be factory programmed within a range of 0.8 V to 3.3 V with output current capability of 80 mA. The output voltage of this regulator must be higher by internally factory programmed offset of 50 mV, 100 mV, 150 mV or 200 mV. In order to improve the output noise the error amplifier compares the output voltage with the desired voltage created by resistor divider in reference path with internal noise filter. The high power dissipation during short output current occurrence is limited by internally factory programmed Current limit at approximately 160 mA and subsequently by Thermal Shutdown Circuitry dedicated only for this Active Mode part. The internal structure of mentioned NCP171 dual mode linear regulator is depicted in the Figure 4. Simplified Block Diagram

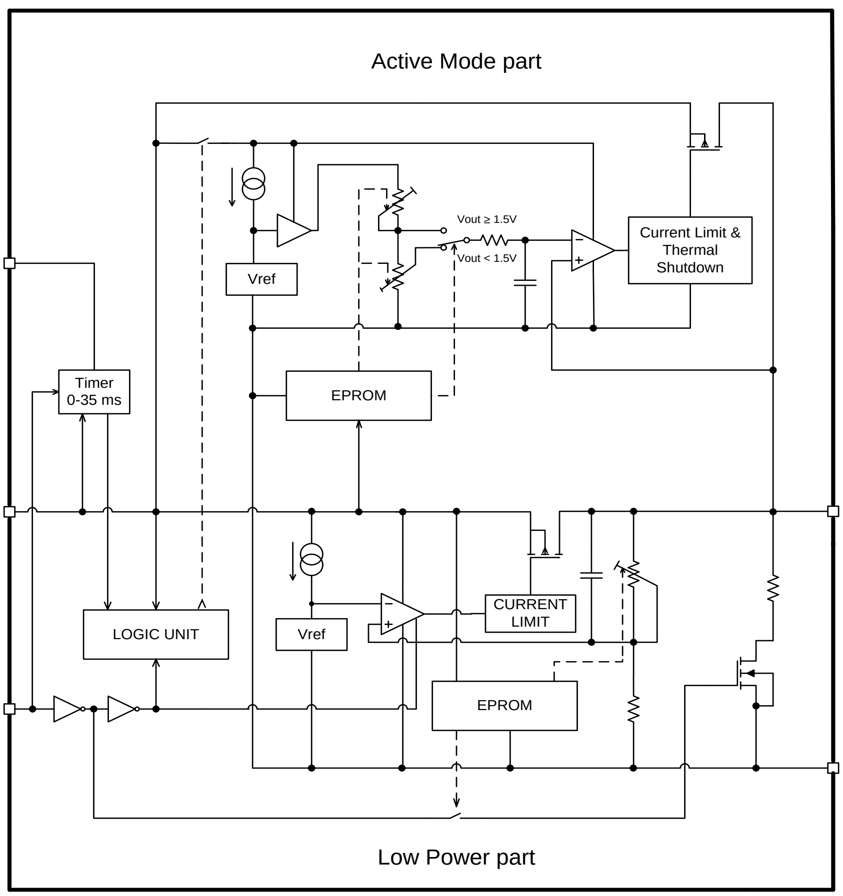

Figure 4. Simplified Block Diagram

Ground current & Load Transient Response

The following Figures show typical measured performance of the NCP171 in the evaluation board mentioned below. The demoboard 50 mm x 50 mm double layer PCB is depicted in the Figure 5. The demoboard in Figure 6, Schematic, shows the wiring of aforementioned demoboard. A comparison of Ground Currents versus Output Current is depicted in the Figure 7. for the NCP170 and the NCP171 in both Low Power and Active Modes. This chart shows ten times lower ground current for the NCP171 in Low Power Mode (green curve) compared to Ground Current for the NCP170 device (red curve). This kind of comparison are commonly presented in order to showcase the lowest possible quiescent current but without offering it's trade off against the dynamic performance of the LDO. One very important parameters which describes the dynamic behavior is the Load Transient Response. We present, in Figure 8, The transient response behavior for again the NCP170 and the NCP171 in Low Power Mode and Active Mode.

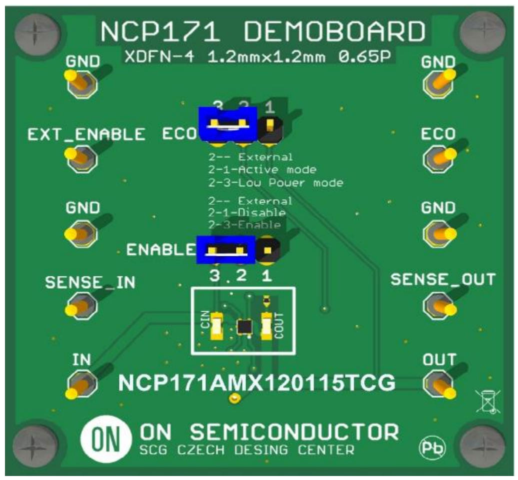

Figure 5. Demoboard

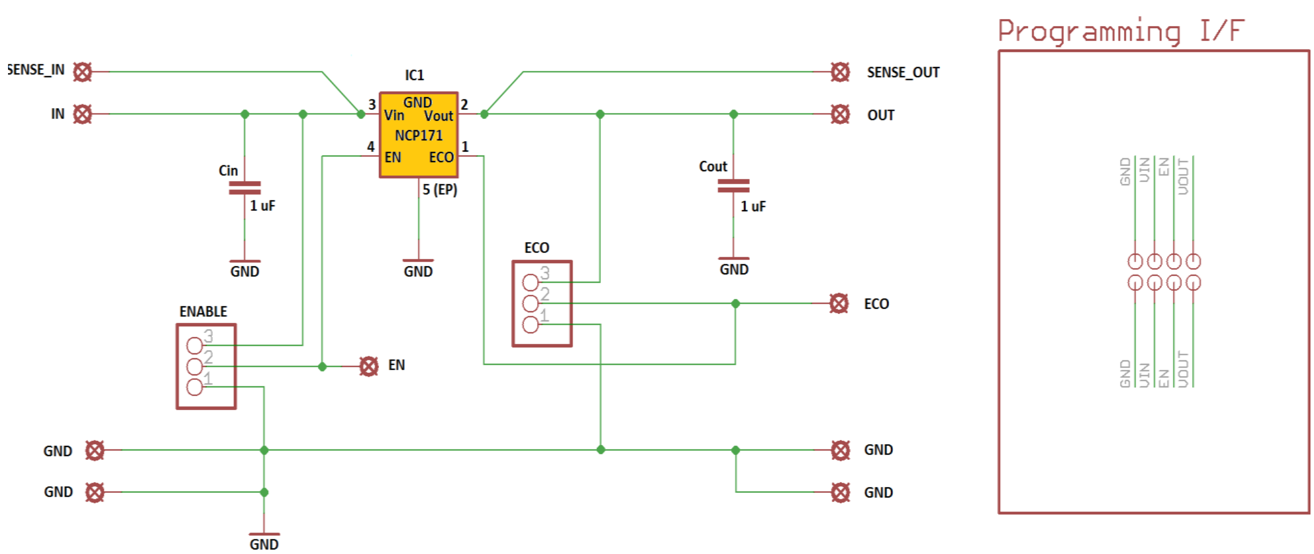

Figure 6. Schematic

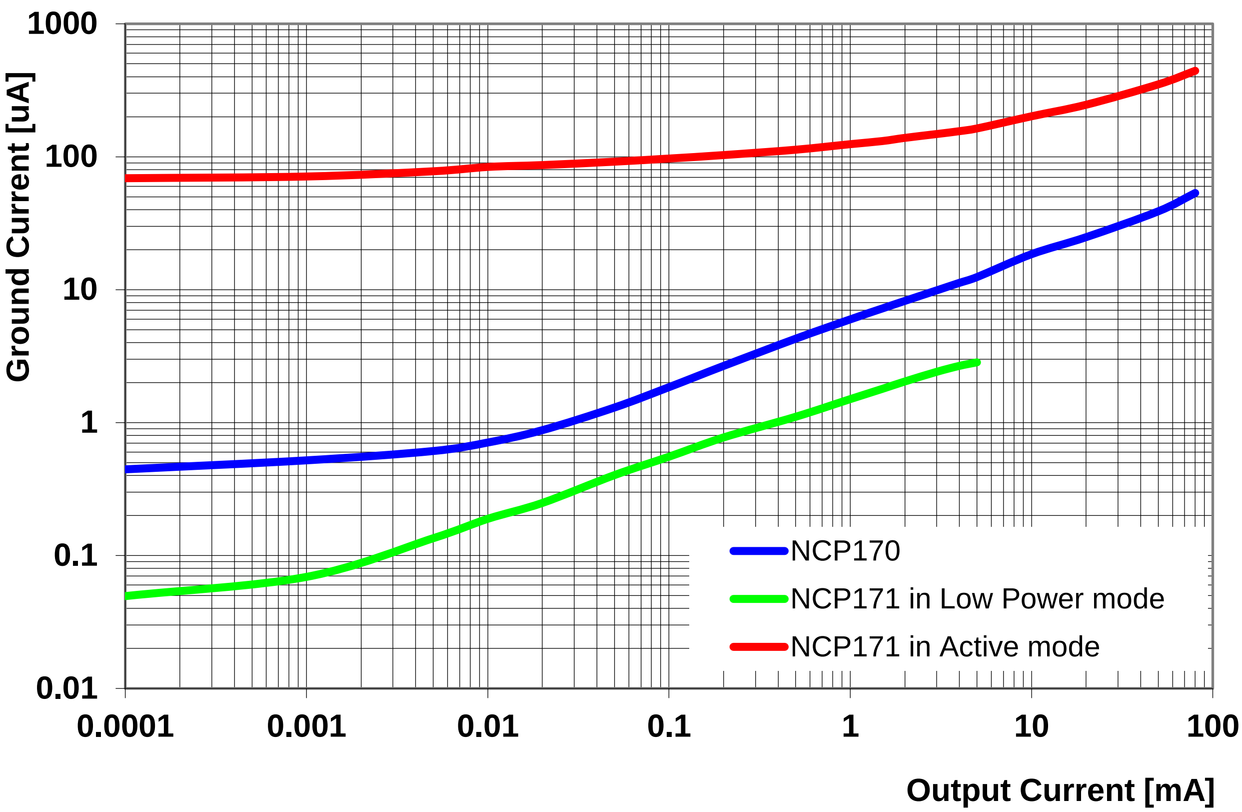

Figure 7. Ground Current vs. Output Current

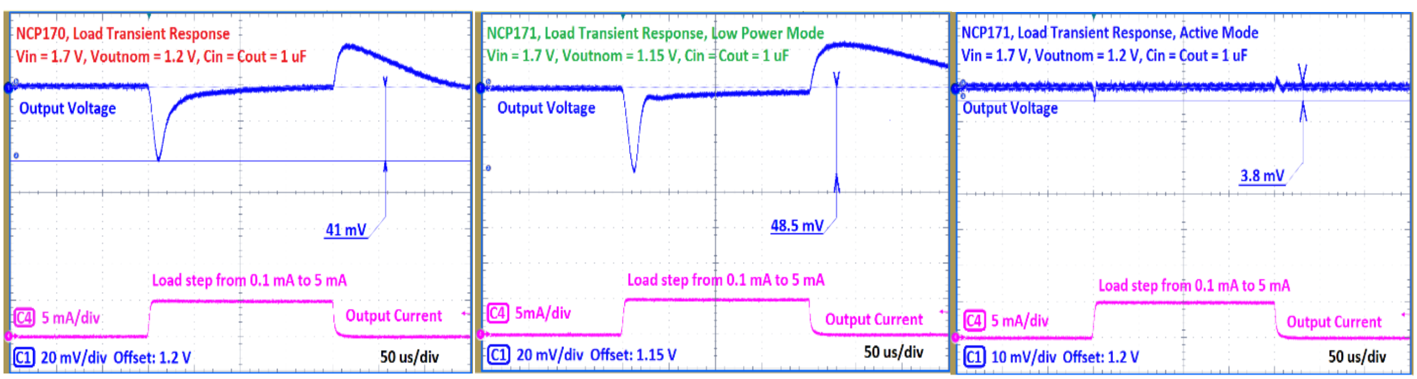

Figure 8. Load Transient responses

The load current transition from zero or minimal output current to its maximum rated value and vice versa invokes undershoot and overshoot at Output Voltage line. The most important part of mentioned output voltage variation is the undershoot. The worst case occurs in load step from no load to rated maximum current but this is not typical for most applications. A more reasonable minimum current for the transient response was chosen at 100 uA. Moreover the mentioned undershoot depends on maximum current of the load step, because the maximum rated current is usually not used. This maximum current of load step is the X axis parameter in Figure 9 Undershoot at Load Transient

Responses. In this chart we can see almost similar undershoot for NCP170 and NCP171 in Low Power Mode in a range of 0 to 5 mA, but significantly lower undershoot for the NCP171 in Active Mode

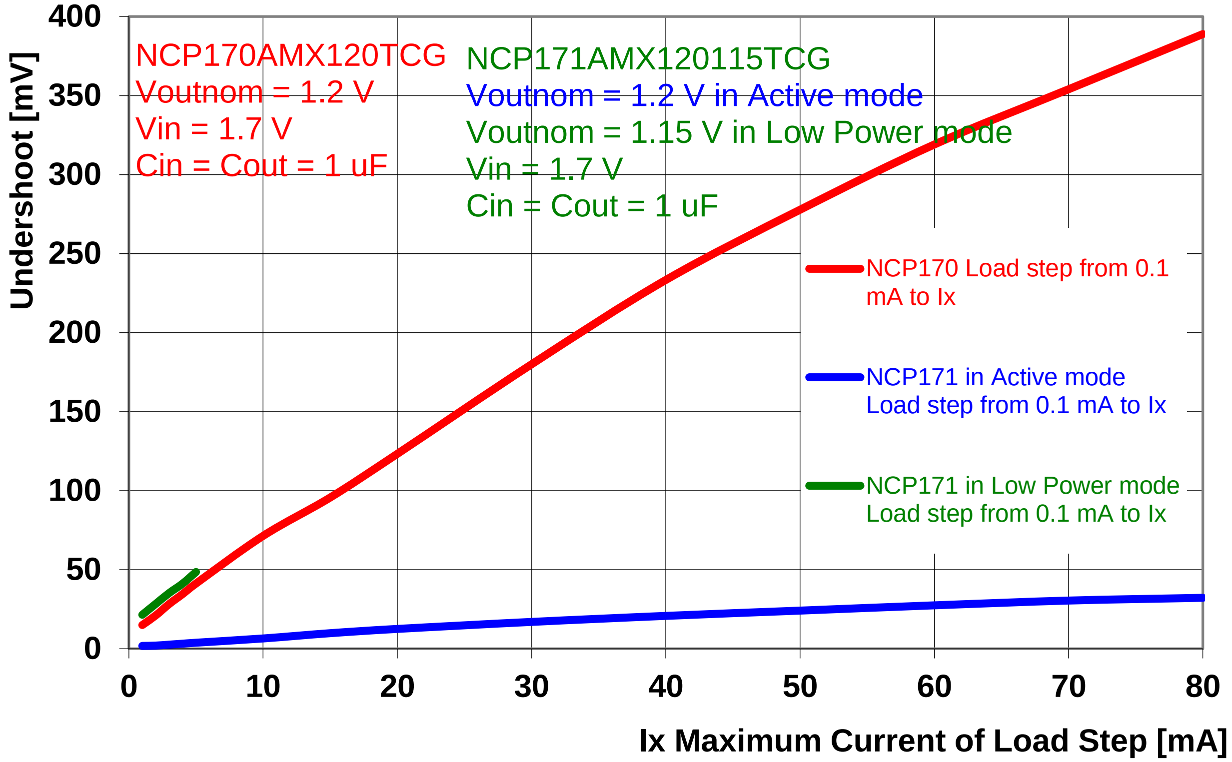

Figure 9. Undershot at Load Transient Responses.

Low Power to Active Mode and vice versa transition.

The oscillogram Figure 10. Active Mode to Low Power Mode and vice versa transition shows the output voltage behavior during these transitions. The transition from Low Power Mode does not depend on the Output Current, but slightly depends on Input Voltage. The typical duration of this transition takes from 95 us to 105 us. The detailed transition is depicted in Figure 11. Low Power to Active Mode transition. Output Current needs to be taken care of before the transition from Active Mode to Low Power in order to avoid current limit activation at Low Power part. It is not recommended to hold the output current higher than Ioutmax = 5 mA before this transition. The transition from Active mode to Low Power Mode is accompanied by small undershoot at Output Voltage line. This undershoot depends on the Output current and slightly depends on Input Voltage and Output Voltage offset. The transition behavior is depicted in Figure 12. Active Mode to Low Power Mode transition.

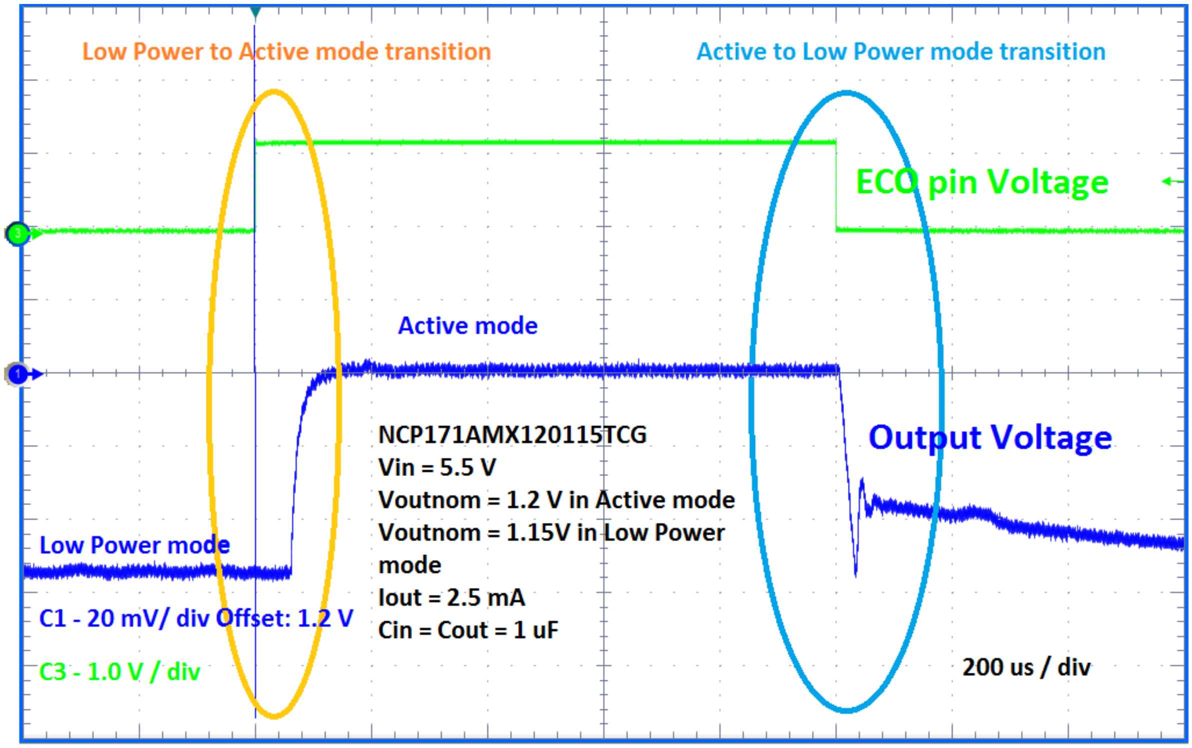

Figure 10. Active Mode to low Power Mode and vice versa transition

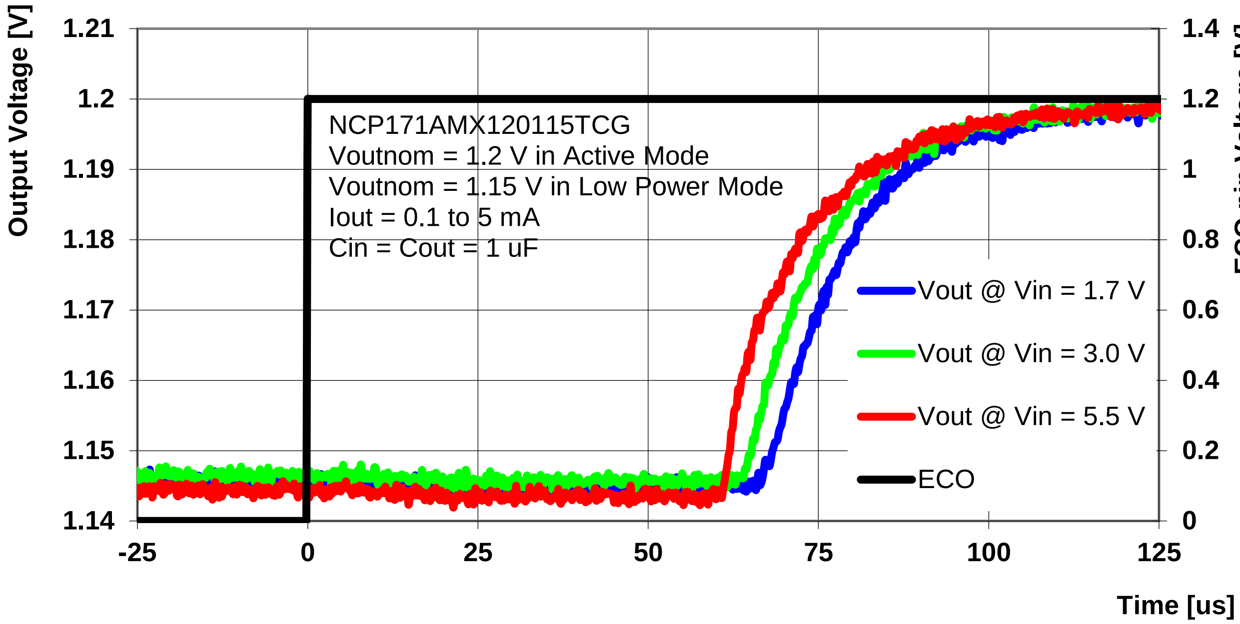

Figure 11. Low Power to Active Mode transition

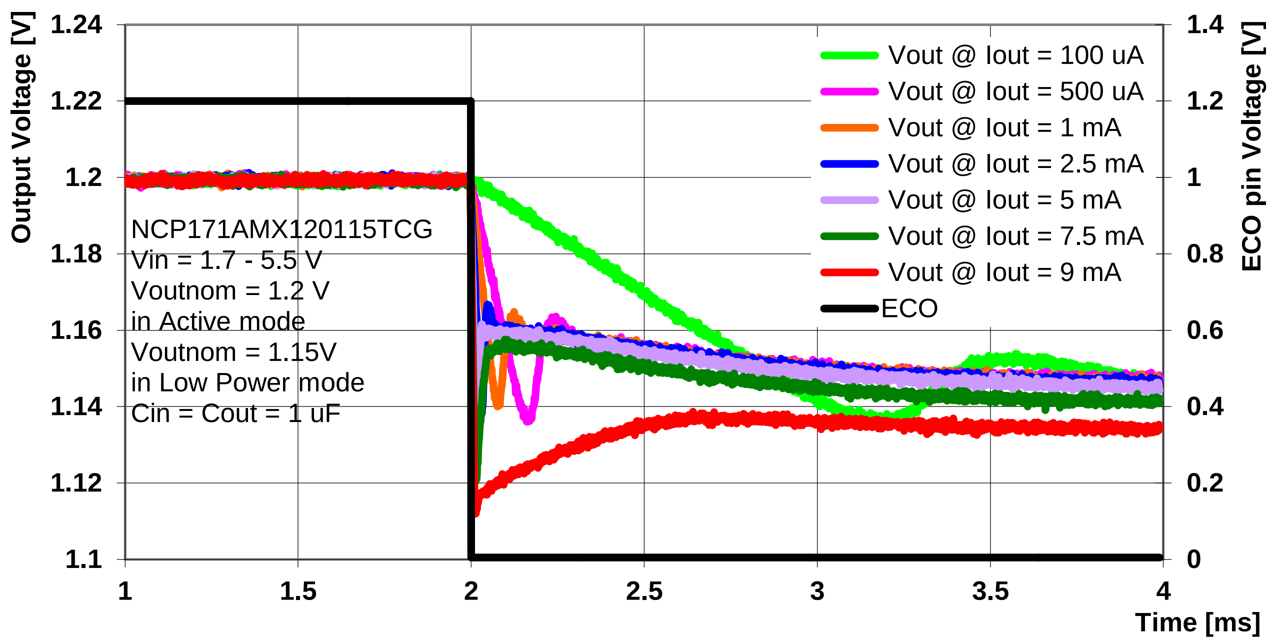

Figure 12. Active Mode to Low Power Mode transition

Enforced Active Mode.

In order to achieve smooth and stable startup and fast reaching of the desired output voltage after turning on the Input Voltage or starting by Enable signal, The NCP171 employs an internally enforced Active Mode for factory set duration time of approximately 35 ms. The Active mode part is therefore enforced despite being set to Low Power part by ECO pin during this period. This feature helps to significantly reduce the current spikes invoked by output capacitor charging and customer's application startup current. This is depicted in Figure 13, Startup by Enable shows the startup behavior. The accuracy of the 35mS built in timer slightly depends on temperature and on the Input Voltage.

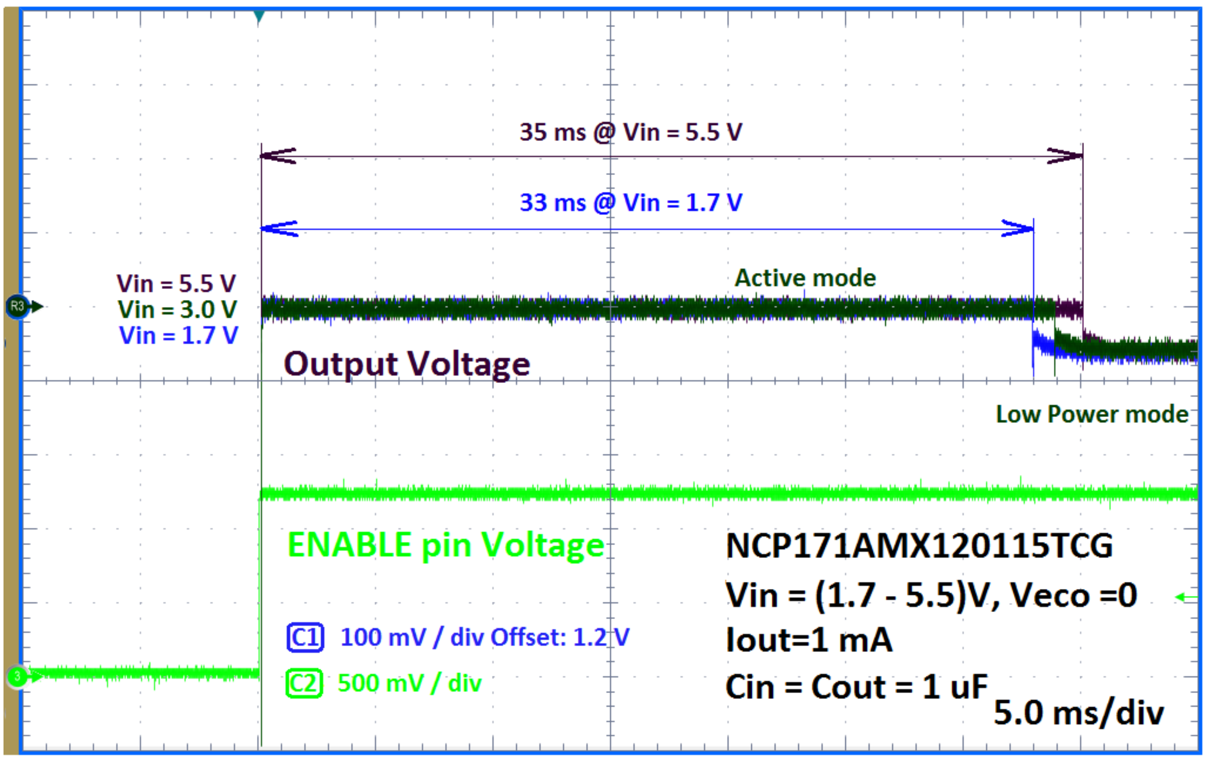

Figure 13. Startup by Enable

Upon completion of the enforced Active mode the NCP171 will switch to the already set mode, via ECO pin, either the Low Power or Active Mode. The typical startup time is about 100 us.

It is possible to override this enforced Active mode during the final test procedure in production by setting the in-factory programmable timer to zero. The comparison of the startups at devices with and w/o enforced Active mode is showed in the Figure 14. Startup comparison. This picture shows much longer startup with significant dependence on Output Current within device in case when the timer is set to zero. The typical startup time in this case is about 1.5 ms. However the device assures proper startup up to declared maximum current in Low Power Mode (5 mA) for all conditions, some customer's applications could require higher startup current which could result in higher current spikes. In this case the startup behavior especially the Output Voltage curve could be unacceptable.

The enforced Active mode is not utilized in Thermal Shutdown protection. In this case the device starts into mode given by ECO pin level.

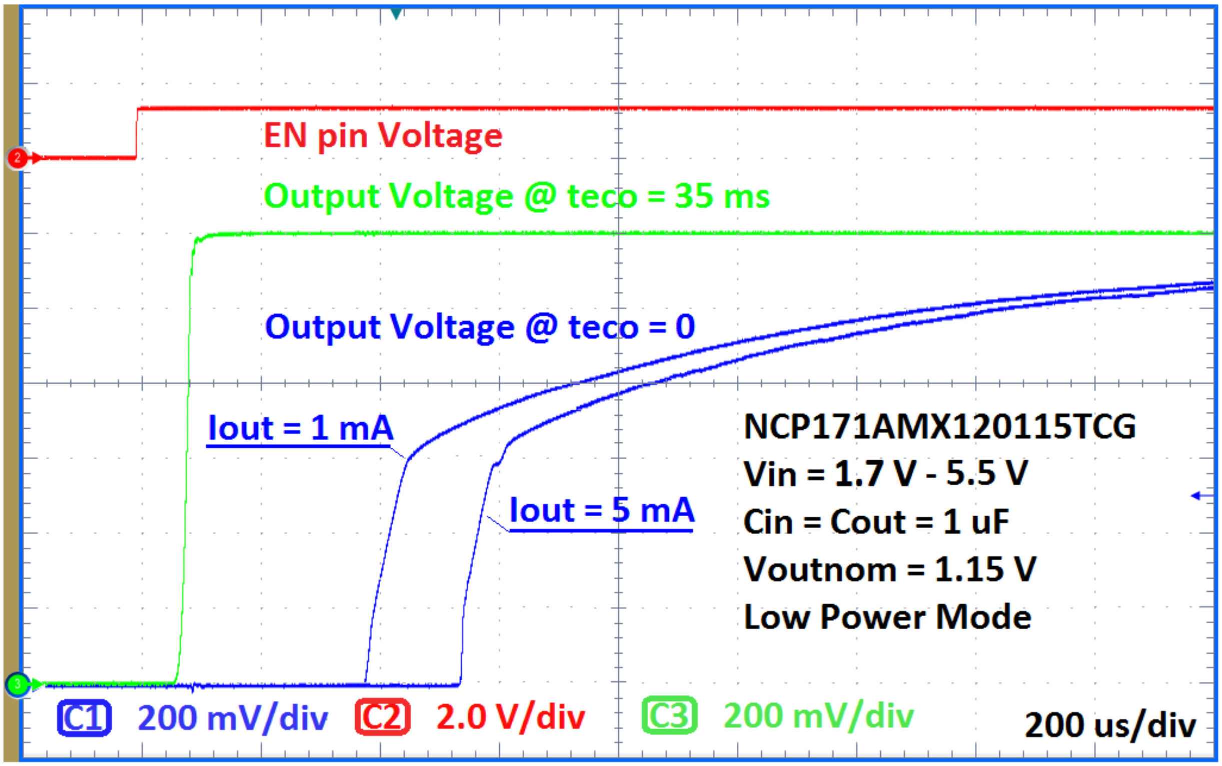

Figure 14. Startup comparison

Conclusion.

The NCP171 is the ideal solution for battery powered applications where maximizing efficiency is the highest priority. This device allows significantly extended battery life in applications with very low consumption for a very long time, and short-term power consumption of up to 80mA with very good dynamic performance. The need to control the working mode with an external wire is usually not a big obstacle because most devices are controlled by a microcontroller. In addition the NCP171 offers further power reduction by lowering the voltage in Low power mode via a factory programmed voltage offset.

Bill of Materials

Designator	Quantity	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed	Lead Free
CIN	1	Capacitor	1.0 uF	10%	0805	SAMSUNG	CL21B105KOF NNN	Yes	Yes
COUT	1	Capacitor	1.0 uF	10%	0805	SAMSUNG	CL21B105KOF NNN	Yes	Yes
LDO1	1	LDO regulator	1.2 V	2 %	XDFN-4	ON Semiconductor	NCP171AMX12 0115TCG	No	Yes
Pin	2	RM 2.54 mm,	Jumper	-	2.54mm	Harwin	M20-9990305	Yes	Yes
Jumper	2	Jumper,	Jumper	-	2.54mm	Harwin	M7686-05	Yes	Yes
Pin	10	Pin 1.3.mm	-	-	1.3mm	Various	Various	Yes	Yes

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