Team Discover

Table of Contents

Problem

Anyone who is driving regularly in the city knows how much pain it can be to find an empty parking spot. The city center offers only a limited number of parking spaces and only a few of them are part of a daily fluctuation. Actually, according to studies, drivers in Hungary spend on average 30 hours a year looking for parking spaces.
Besides frustration, the fight for parking spots is also a major contributor to congestion and leads ultimately to more emission and pollution. Another study conducted by Donald Shoup analyzed drivers in a 15-block district of LA. It turned out that the drivers notched up 1.5 million kilometers in a year looking for parking spaces, wasted 178.000 liters of gasoline and produced 662 tons of carbon dioxide needlessly.

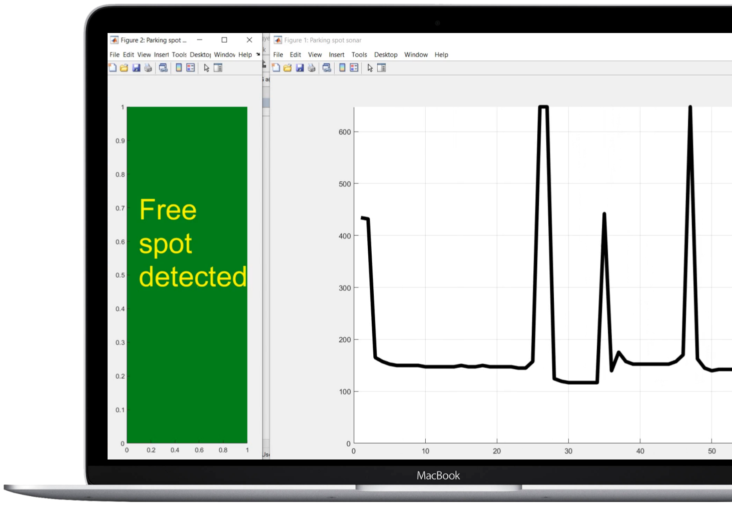
But what if we knew where the nearest free spaces are?

Solution overview

Just under 26 hours, we have prototyped a parking spot scanner, which can be mounted to the side of any car, even ones that don't have a modern sensor technology built in. Our scanner is equipped with an ultrasonic sensor and a camera, this way we are able to detect empty parking spaces when we pass by them. By uploading the free parking spaces to a central database, the system can let other drivers know where they can park efficiently and optimize the parking traffic.

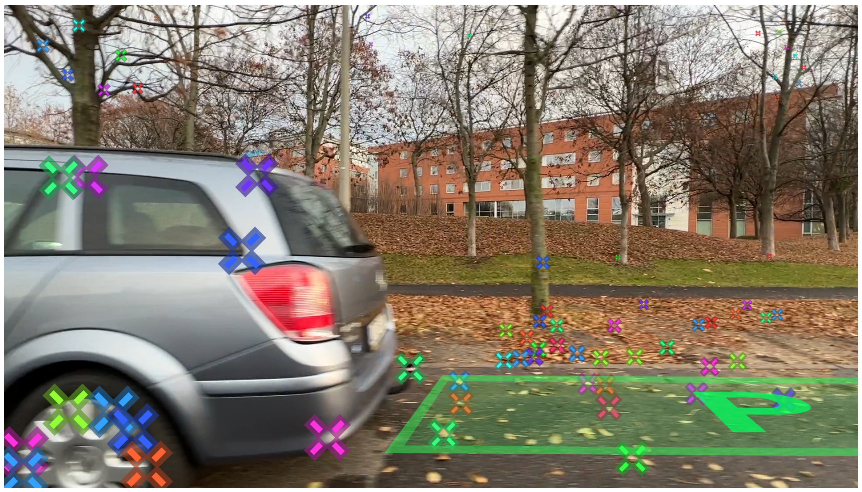
Ultrasonic sensor

During the weekend, we have done real-life testing with our prototype on the streets of Budapest. Our ultrasonic sensor measures the distances on the right side of the car and estimates occupancy on a threshold based logic. If the signal level is low that means that an object is close to the car, also indicated by a red flag. If the signal level is high, then there are no obstacles in the line of the sensor, hence a green flag. The spikes are the small spaces between cars, but if the space is empty long enough, then it could be a parking spot.



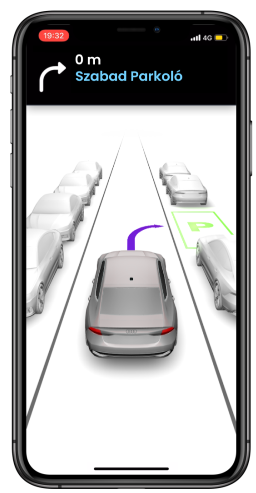
Camera image

As a second layer of information we have a video feed as well, tracking the environment, so that we can double-check whether a free space is in reality a parking spot or not. The final decision for the availability of the parking spots is based on the probability values calculated by the ultrasonic sensor and the camera measurements fused together with a parking spot database stored in the cloud.

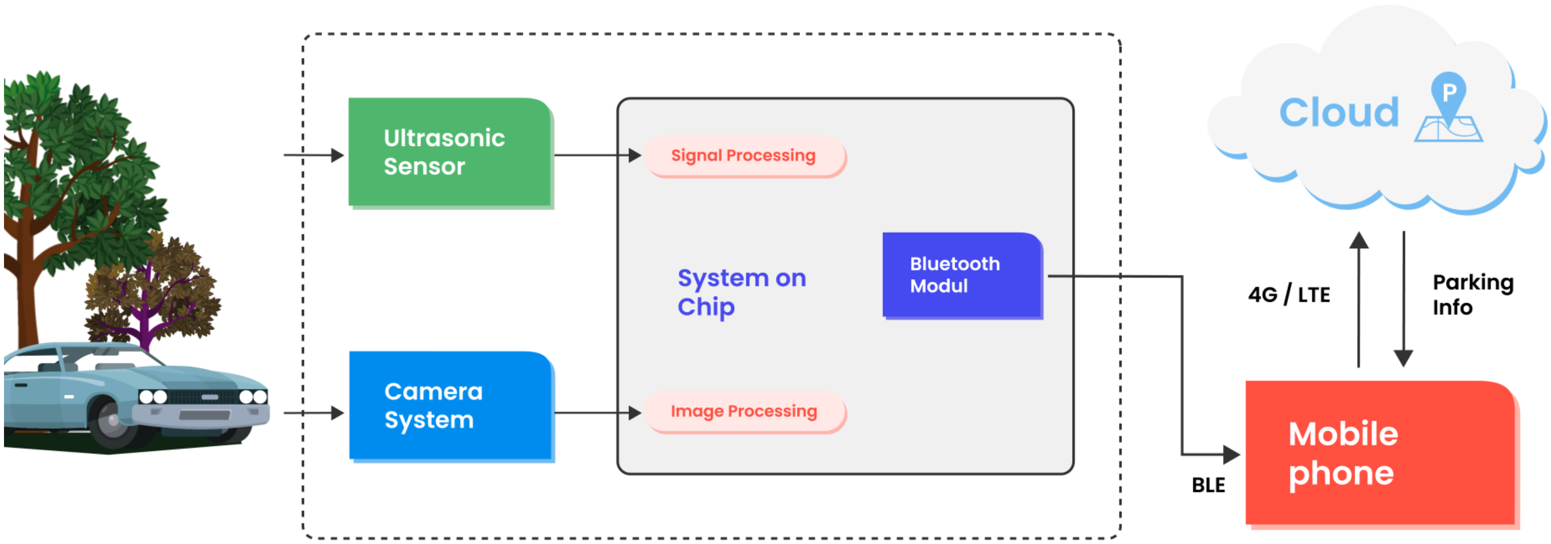


Mobile navigation

The system of scanners roaming the city will help the entire driving community to optimize their routes. Each connected mobile device uploads the measured data to a cloud based server where further processing is done. The measurements together with the GPS information of the phone are fused with a parking spot database to estimate whether a parking spot might be available on the spot. Meanwhile, other drivers who are looking for parking spots and are using waze, will be navigated to the available parking spaces efficiently.



Block diagram of the system

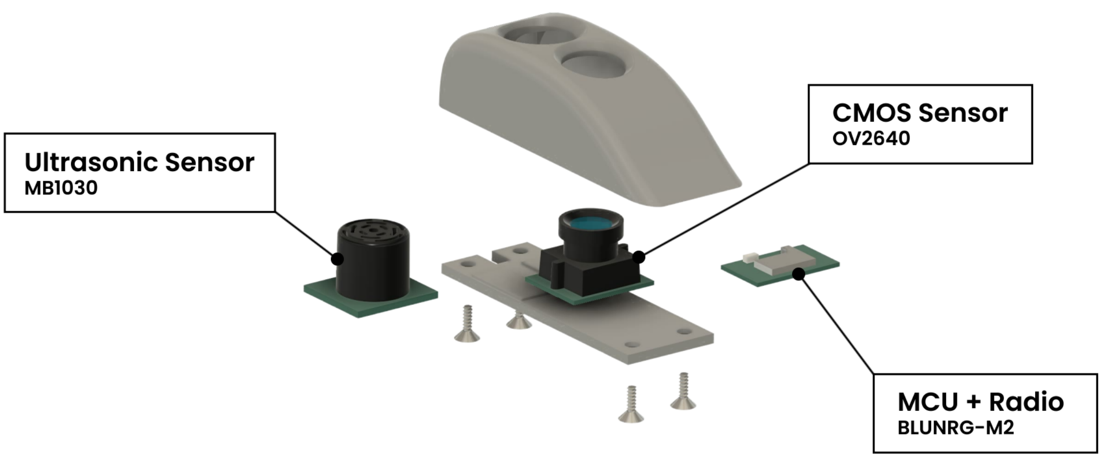


Our end-to-end community parking solution is based on the data collected by a multi-sensor hardware element. The environment, especially the surrounding parking cars on the side of the road are observed by an LV-MaxSonar EZ3 ultrasonic distance sensor and a CMOS OV2640 camera.
The raw measurement signals of the ultrasonic sensors that are going through the Signal Processing Unit are first filtered with a moving average method and then further processed so that an adaptive peak finder can analyze the distances. Meanwhile, the images collected by the camera are processed by the Image Processing Unit and estimate the availability of parking spots with semantic segmentation.
Our hardware uses a BlueNRG-M2, a Bluetooth-Low-Energy (BLE) system-on-chip application processor certified module, that is compliant with BT specifications v5.2 and BQE qualified. Switch mode power supply, 2.4GHz radio, embedded antenna and crystal high frequency oscillators are integrated to offer a certified solution to optimize the time-to-market of the final applications. The processor communicates with the driver's mobile phone using the BLE communication protocol, to optimize and save battery usage. Our BLE communication is using the State-Of-The-Art AES-128 ECB encryption method. The BLE package that contains the processed measurement information is the following:

```
typedef struct {
    uint32_t unix_timestamp; //Seconds since Epoch
    uint8_t ultrasonic_probability; //0-255 mapped to 0.0f - 100.0f [%]
    uint8_t camera_probability; //0-255 mapped to 0.0f - 100.0f [%]
    uint8_t ultra_pulse_length; //0-255 mapped to 0.0f - 10.0f [s]
    uint8_t cam_estimated_length; //0-255 mapped to 0.0f - 50.0f [m]
} MeasurementType;
```

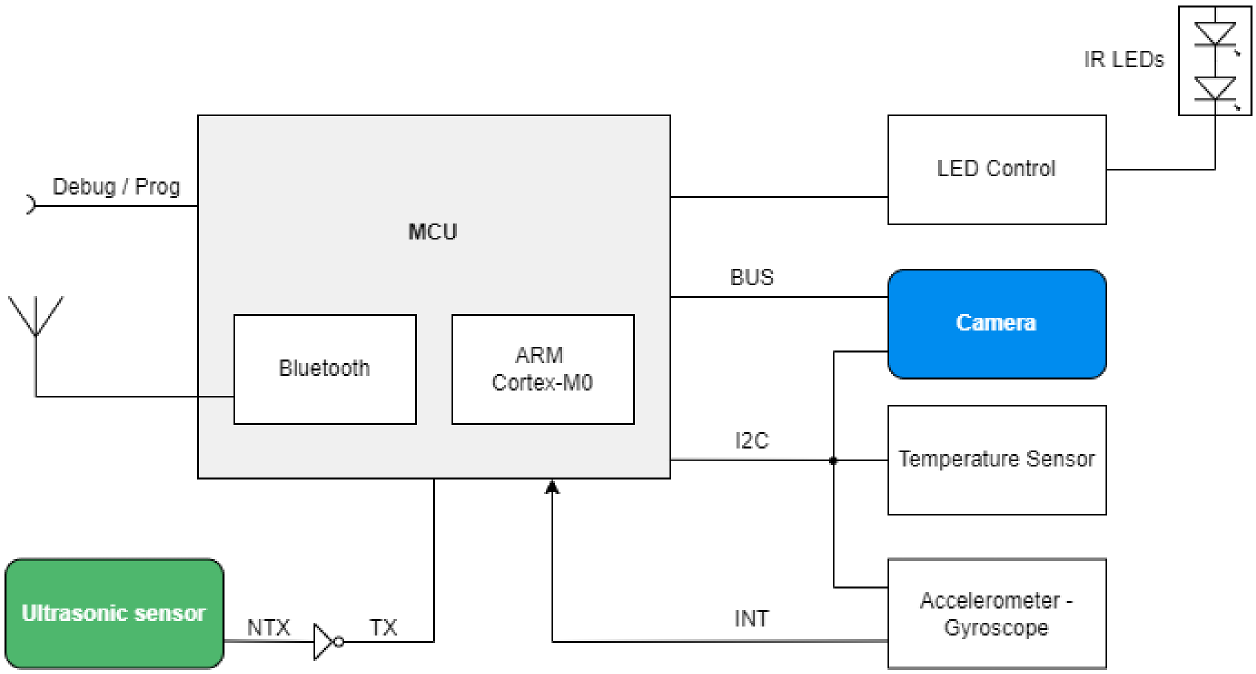
The information characterizing the parking spots are further complemented with GPS information derived from the mobile phone of the driver. Once the driver's phone collects all the necessary measurement information, it uploads them via a secured 4G/LTE protocol to a Cloud based server.
The cloud-based server is the primary logic module determining the availability and distribution of parking spots. The server uses the GPS information of predefined parking spots in the city and fuses them together with the measurement information collected by the cruising cars. In case a driver is looking for a parking spot in the city center, the system automatically reveals the available spots in real-time so that users can park their car efficiently and hassle free.

Exploded view of our hardware prototype

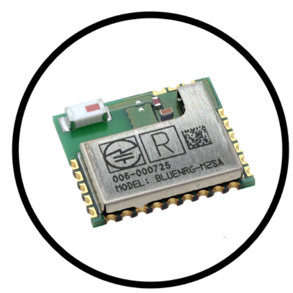


The enclosure was designed to fit all the components snugly, while providing a visually aesthetic and aerodynamic design. It can be easily assembled and serviced due to its simple, yet efficient two-piece design. The material used in the prototype is PLA, as is easily printable, therefore excellent for rapid prototyping, however it lacks the durability for long-term outside use. Therefore, the next generation of the prototype would be printed from ASA, which is resistant to UV light, and performs well in various temperatures and humidity levels.
The ultrasonic sensor and the camera are mounted side-by side and fixed by their circuit boards.
To secure the two parts of the housing, four self-tapping screws are used, that are purposefully made to be used with plastic parts. To secure the housing to the side of the vehicle, 3M VHB double-sided tape is used. This ensures easy installation and removal without any special tools or modifications to the vehicle.

Hardware Architecture



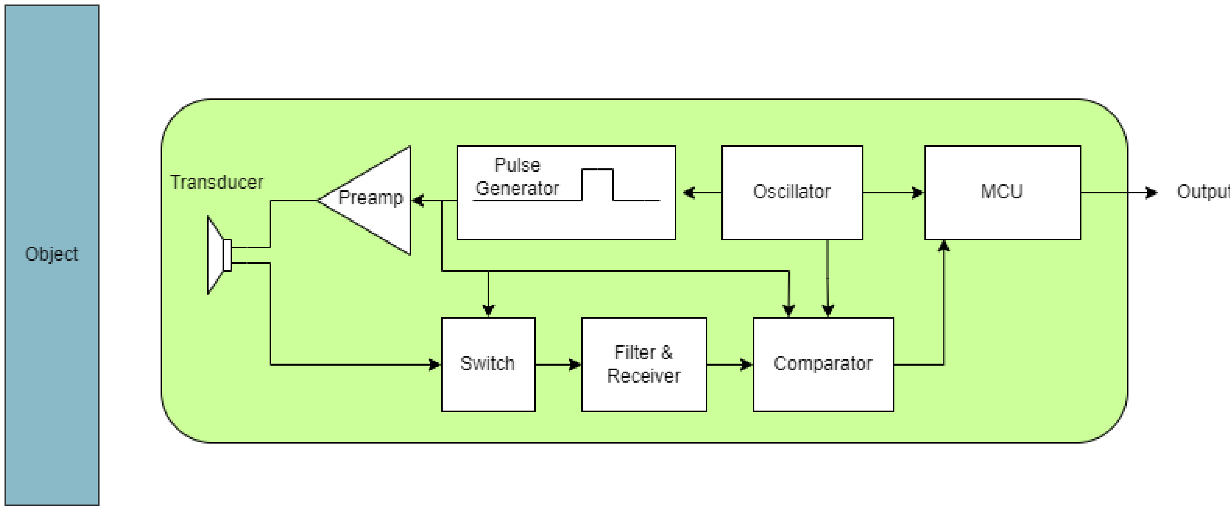
Main controller



The BlueNRG-M2 main controller is a combined application processor and Bluetooth radio with a very low power consumption. It has an ARM Cortex M0 core, Bluetooth stack, many peripherals, and sleep mode with RAM retention. The purpose of the main controller is to acquire sensory data, sensor calibration and configuration. The same controller also manages the communication interface. The BlueNRG module has an internal, but independent watchdog which may be used to recover from software crashes.

Ultrasound unit

The LV-MaxSonar MB1030 ultrasonic ranging sensor includes all analogue and digital circuitry for measuring the pulse return time. From this information and the speed of sound it calculates the distance between itself and an object reflecting the waves. The internal sensor architecture is the following:

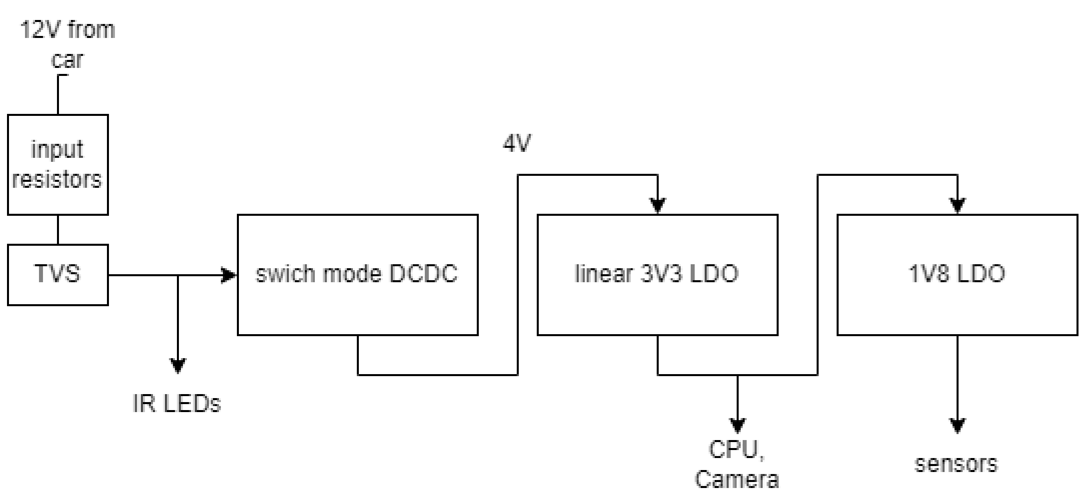


Camera module

The CMOS OV2640 camera module has required voltage level regulators for its analogue circuitry to provide 3.0 and 2.5 V rails. This camera includes hardware for efficient compression of the frames.

Power

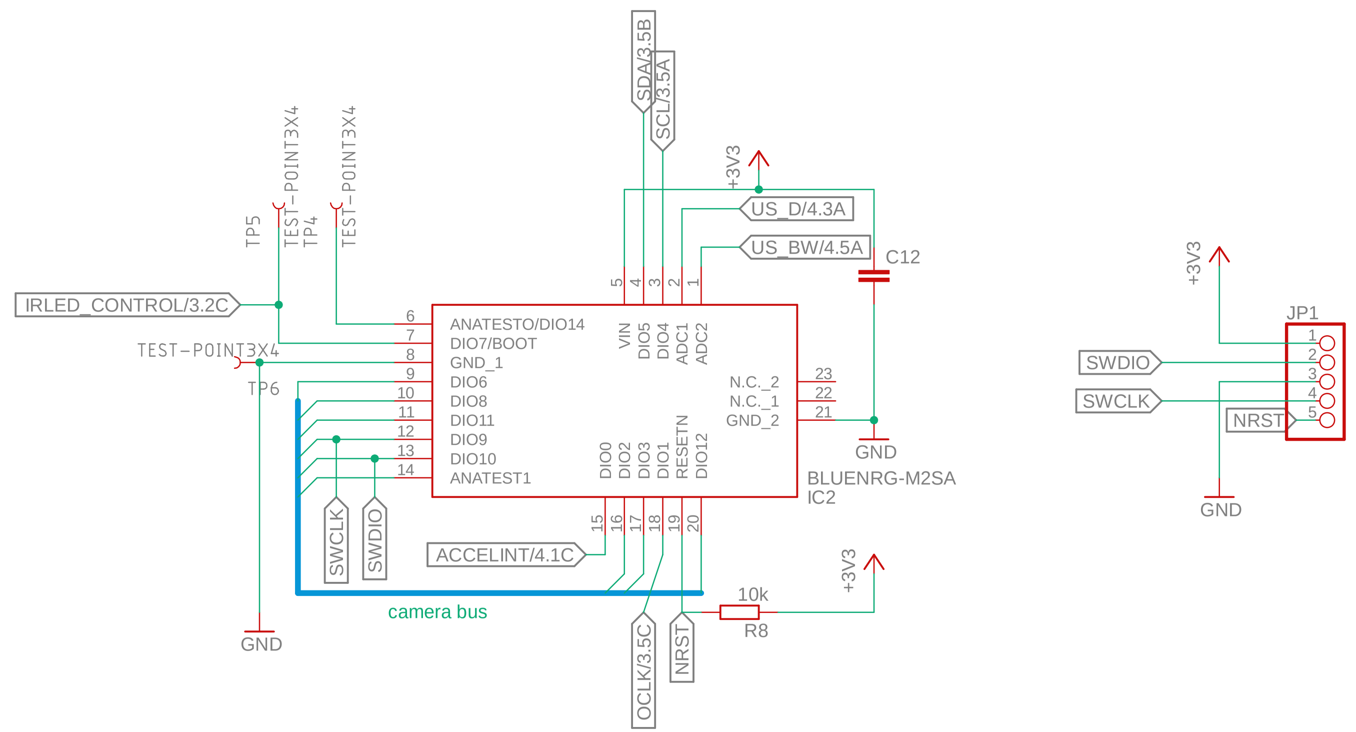
The device is powered from the ignition or always-on 12V circuit (maximum input voltage is 30V). The input is protected from transient voltages with a diode compliant to IEC 61000-4-2 and IEC 61000-4-4.



The components require either 3.3V or 1.8V volts to operate. These voltage levels are provided by a chain of linear low drop voltage regulators. For efficiency, reducing linear regulator losses, the input voltage (12V) is fed into a switch mode regulator that outputs 4V. Using linear regulators for the lower voltages are cheaper, require fewer components and also provide better noise levels. However the energy efficiency is reduced.

Circuit schematic drawings

We designed our schematic in Autodesk Eagle which presents all the components and connections. Component values, tolerances are also given when applicable. The particular circuit schematic drawings can be found in the next chapter, while a detailed Bill of Materials (BOM list) is included in the Appendix.



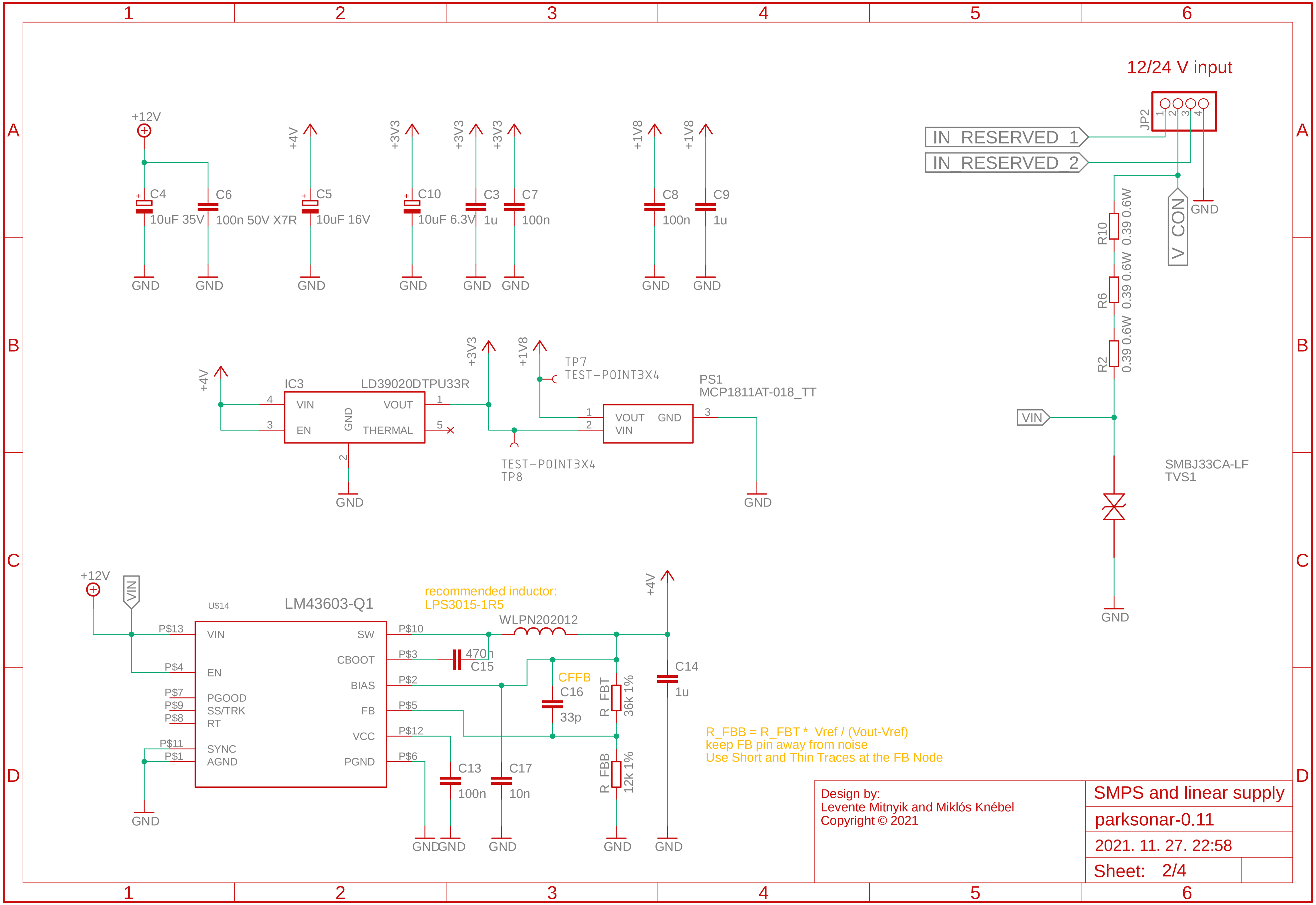
Design by:
Levente Mitnyik and Miklós Knébel

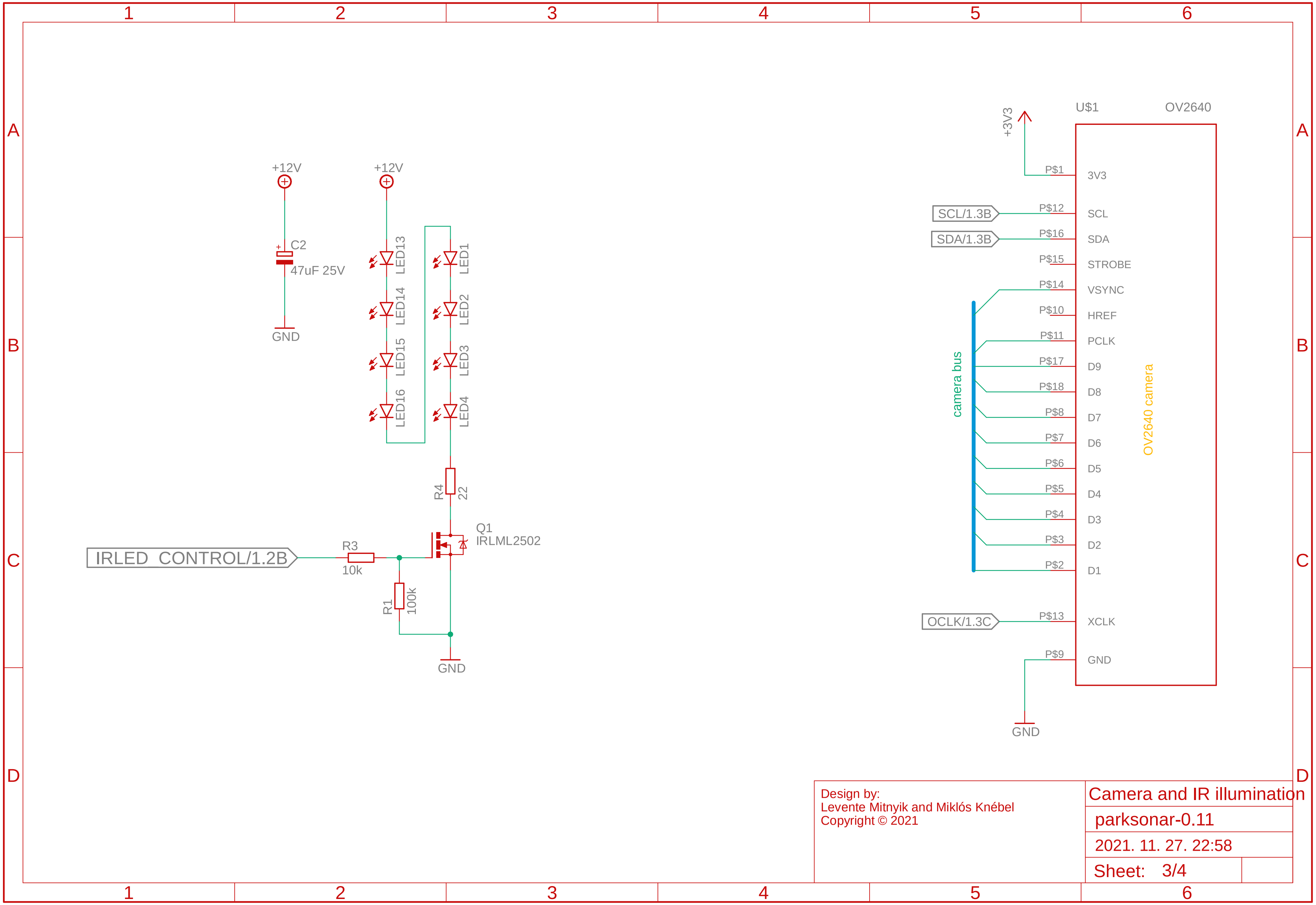
CPU, radio

parksonar-0.11

2021. 11. 27. 22:58

Sheet: 1/4


12/24 V input
JP2
IN_RESERVED_1
IN_RESERVED_2
V_CON
GND
R10 0.39 0.6W
R6 0.39 0.6W
R2 0.39 0.6W
VIN
SMBJ33CA-LF
TVS1
+12V
C4 10uF 35V
C6 100n 50V X7R
+4V
C5 10uF 16V
+3V3
C10 10uF 6.3V
C3 1u
C7 100n
+1V8
C8 100n
C9 1u
IC3 LD39020DTPU33R
VIN EN GND VOUT THERMAL
TP7 TEST-POINT3X4
TP8 TEST-POINT3X4
PS1 MCP1811AT-018_TT
VOUT VIN GND
U$14 LM43603-Q1
VIN EN PGOOD SS/TRK RT SYNC AGND
SW CBOOT BIAS FB VCC PGND
P$13 P$4 P$7 P$9 P$8 P$11 P$1
P$10 P$3 P$2 P$5 P$12 P$6
recommended inductor:
LPS3015-1R5
WLPN202012
470n C15
CFFB C16 33p
C13 100n
C17 10n
R_FBT 36k 1%
R_FBB 12k 1%
C14 1u
R_FBB = R_FBT * Vref / (Vout-Vref)
keep FB pin away from noise
Use Short and Thin Traces at the FB Node
Design by:
Levente Mitnyik and Miklós Knébel
Copyright © 2021
SMPS and linear supply
parksonar-0.11
2021. 11. 27. 22:58
Sheet: 2/4



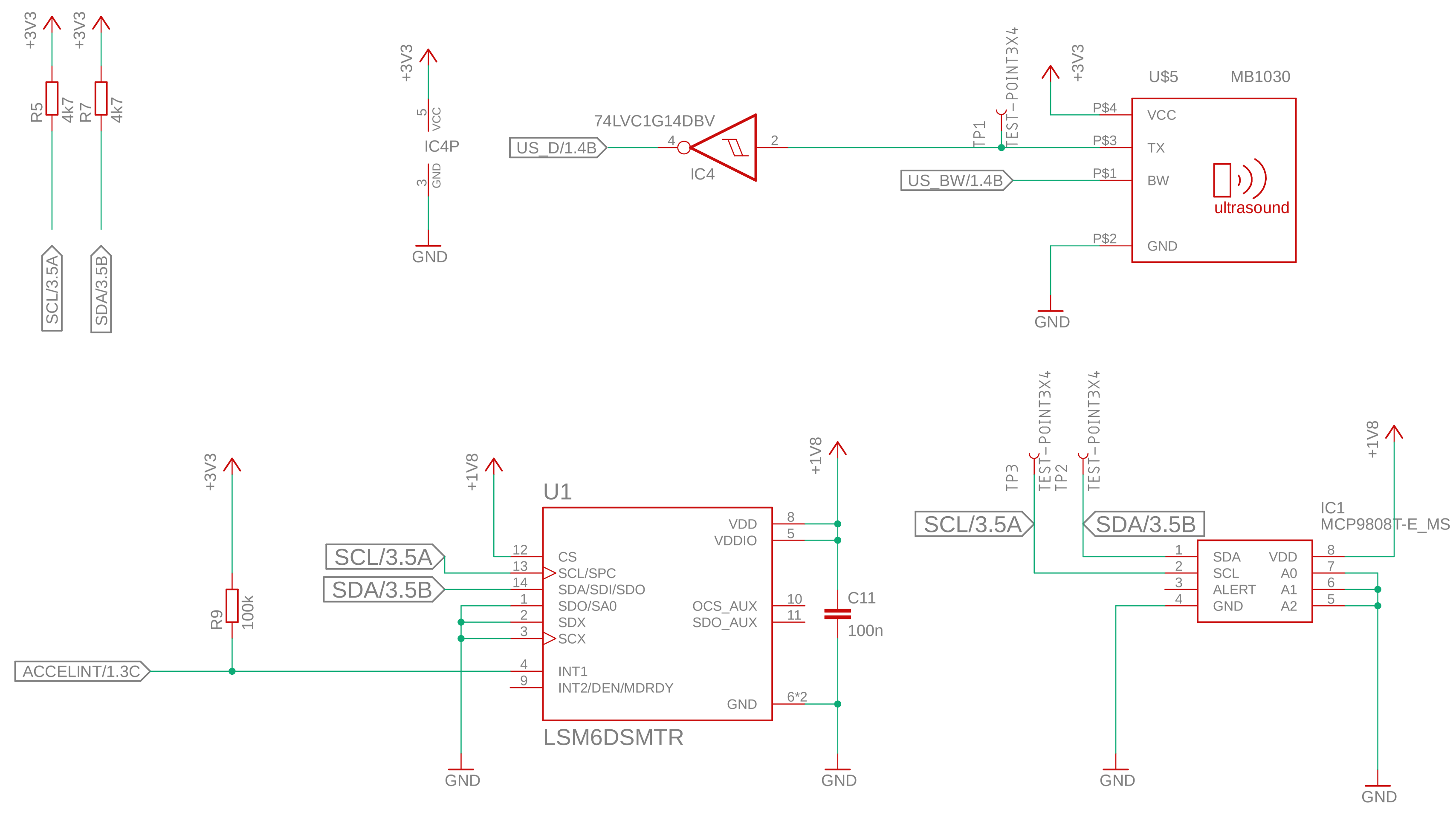
Design by:
Levente Mitnyik and Miklós Knébel

Camera and IR illumination

parksonar-0.11

2021. 11. 27. 22:58

Sheet: 3/4



Design by:
Levente Mitnyik and Miklós Knébel

Sensors

parksonar-0.11

2021. 11. 27. 22:58

Sheet: 4/4

Technical Characteristics and Design Considerations

General product attributes and requirements

Operating Temperature	between -30°C and +65°C
Detection Range	0.1 m - 6.45 m
Ultrasound Reading Frequency	20 Hz max.
Safety level	QM
Operating Voltage	12 - 24 V DC
Power consumption	1.8W max
ESD withstand voltage acc. to ANSI/ESDA/JEDEC JS-001 (HBM, Class 2)	2kV
Camera Lense	High Quality F1.8 / 6mm
Camera Image Transfer Rate	10 FPS
Camera Resolution	352 x 288 CIF
Radio Frequency	2402-2480 MHz
Unit dimensions	80mm x 29mm x 21mm

Component characteristics

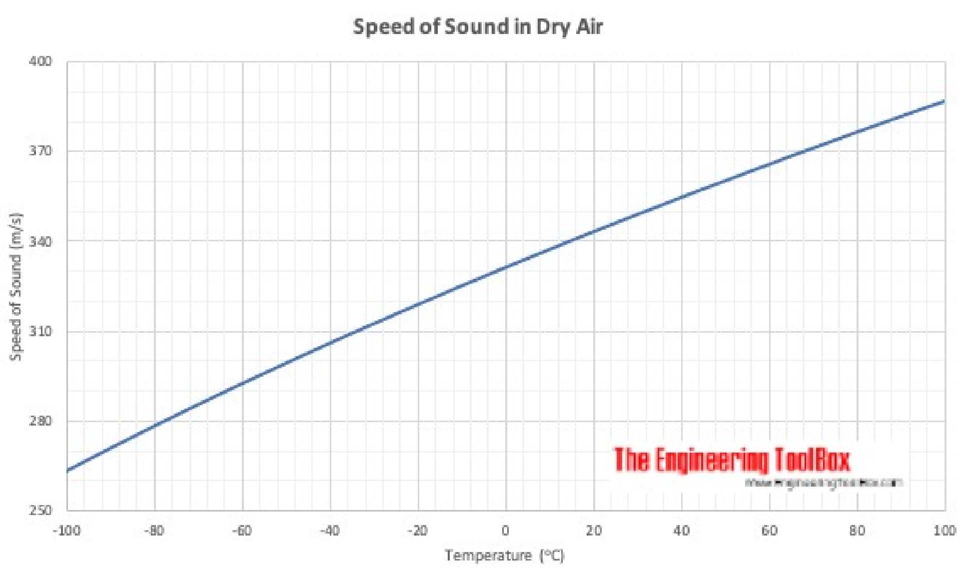
In general, the component selection decisions were made in favor of items that are well integrated and modular, so they do not require many external components to operate. In addition, all our components were designed to work sufficiently within their electrical boundaries, with keeping in mind to resist both harsh weather conditions and mechanical stress. For our electrical design, we have only selected solid state capacitors (tantalum and MLCC) ensuring the longest possible lifetime for the hardware.

In the case of the BlueNRG-M2 main processor, both the chip and an integrated module are available from distributors. We chose the module, where the antenna and power supply are on board together with the processor and some passive components below a metal sheet shielding. This eliminates the need for complicated design procedures (e.g. for antenna and shielding) that altogether makes development much cheaper and faster. The module with the antenna and shielding has much better EMC/EMI properties than what we could have designed in a few days during the hackathon.

The SoC has brown out detection and reset, and can detect insufficient supply voltage to the chip. But the device can also fail if there is no 12V (e.g. just 10 V) which the main processor can not detect, since the voltage regulators are there. To address this an voltage divider to analog digital channel is used to monitor the input voltage and halt operation below a threshold.

Ultrasound sensor

We have selected the MB1030 ultrasonic sensor that offers a decent signal to noise ratio (SNR) and has only one transducer that has additional benefits such as space efficiency. This sensor processes the time of the sound echo but does not take into account other parameters affecting the time of flight. The speed of sound is dependent on the temperature of the medium, so in order to compensate for this effect we built in a MCP9808 digital temperature sensor. The relation between speed of sound and temperature is depicted below.



Internal and external Communication

We are using BLE communication for data transmission, since the receiver (smartphone) is always in the vicinity of the vehicle (<2.5 m) and therefore a very low transmission power is sufficient. Moreover we can assume that the direction of the receiver is inside the car, meaning that the signal can be directed directly towards the side of the device that has the adhesive.
For internal communications only a low traffic is expected on the I2C bus, namely the configuration of the sensors, infrequent temperature and accelerometer

readings. Therefore we can slow down the bus thus reducing unwanted HF radiation. Although our selected sensors are operating at 1.8V the I2C bus is pulled up to 3.3 volts to match the level of the main controller. The same principle is applied to the interrupt line from the accelerometer.

Power

We are combining switch mode and linear regulators (LD39020DTPU33R and MCP1811AT-018) to improve power efficiency. The switch mode produces 4V which is with a good margin above the recommended input of the 3V3 regulator. For our hardware design, we have selected the adjustable output voltage version of the LM43603-Q1 which is an automotive grade synchronous step-down voltage converter. This has an outstanding waterfall test response, that is almost zero overshoot, which means correctness of voltage levels at startup. The device offers very good quiescent current consumption. For that the feedback resistors should be in the range of 10-100 kOhms. To set the output to 4V, the following values should be used: R_{FBB} = 12 kOhm and R_{FBT} = 36 kOhm.

$$V_{out} = 1.011 * (\frac{R_{FBT}}{R_{FBB}} + 1)$$

Since the Bluetooth module may produce high current peaks for transmission, output capacitors have to be designed large enough. For this purpose, additionally a 33 pF feed-forward capacitor is also included in the converter's design to increase stability. Its value might need to be adjusted depending on the final hardware layout and manufacturing process. One of the main design challenges of an automotive power supply is passing the CISPR 25 Class 5 conducted and radiated EMI standards. Noise through parasitic capacitance can be treated. An EMI filter at the front end of the power supply in order to attenuate these emissions. But a better option is to design a good supply. In every, but especially in automotive power supplies, a regulator's switching frequency, pinout, PCB layout, and package must be optimized to minimize noise coupling to the board or the environment, and consequently reduce conducted and radiated emissions.

Linear and switch mode regulators are both accompanied by the required bypass capacitors for smooth voltage rails and stability. The total power required for the active system is **225mW** (daylight conditions). When the device is idle, it shuts down to a low power state, when the power consumption is just around **30 uW**.
The standby state exits upon an accelerometer interrupt and/or on a timer. The losses of linear regulators were included in the wattage calculations. The per-component and per-mode power consumption metrics can be found below:

Bluetooth		
RX:	7.55 mA (25mW)	
TX:	+4 dBm +2 dBm -2 dBm -5 dBm	10.73 mA (35mW) 9.27 mA (30mW) 8.46 mA (28mW) 7.89 mA (26mW)
CPU core		
Active mode 1.89 mA (6.2mW) Standby, Sleep (RAM retention): <1uA		
Ultrasound sensor		
Active: <3mA, typical, 1mA (3.3mW)		
Camera		
Acquiring image: 50 mA (165mW) Standby: <20uA		
Accelerometer		
Active: <85uA (28uW) Power down: <3uA Sleep with alert: <9uA		
Temperature sensor		
Active: 200uA typical (66uW) Sleep: 0.1 uA typical		
IR led illumination		
Off: effective 0 mA On: typical 129 mA (1.5W)		

Prototyping

During our prototyping in the last 26 hours, we used the additive manufacturing process called Fused Deposition Modelling. We created several revisions to our design, improving the sensor location, ease of assembly, and aesthetics in each one. We used a lower layer height and thus increased resolution for the model showcased in the video, which took slightly longer to print, but resulted in improved fit and finish.
For the final prototype, we used a different 3D printing process, Masked Stereolithography. This process yields much higher quality prototypes, which in our case gave us a glimpse into how our product would look like injection moulded.

During the weekend we have created our functional electrical circuits with soldering and breadboards, made signal processing and tested our solution in a real street environment. Although we are still at a prototype level, it was astonishing to see how well the majority of the parking spots were already detected correctly. Based on the schematic designs we created, we would be able to improve our MVP to the next level and implement our solution on custom PCBs.

References

- Texas Instruments, IR LED Illumination and ICR Control Reference Design for IP Network Cameras With Day/Night Vision
- STMicroelectronics: DT00142, Design tip, BLE module integration design guidelines by Sergio Rossi
- STMicroelectronics: BLUENRG-2 AND BLUENRG-2N, IoT-ready Bluetooth® Low Energy processors, https://www.st.com/en/wireless-connectivity/bluenrg-2.html
- Texas Instruments, SNVA780 - Designing High-Performance, Low-EMI Automotive Power Supplies
- https://www.st.com/resource/en/datasheet/ld39020.pdf
- Teledyne SP Devices, The art of pulse detection, 2018
- APPLICATION NOTE 3229, SELECTING TEMPERATURE SENSORS FOR SYSTEM MEASUREMENT AND PROTECTION
- OV7670 datasheet
- OV2640 datasheet, Color UXGA Camera, with OmniPixel2™ Technology
- MB1030 datasheet

Appendix

BOM list

Part	Value	Device	Package	Description
C2	47uF 25V	CPOL-EU153CLV-0810	153CLV-0810	POLARIZED CAPACITOR, European symbol
C3	1u	C-EUC0402	C0402	CAPACITOR, European symbol
C4	10uF 35V	CPOL-EU153CLV-0810	153CLV-0810	POLARIZED CAPACITOR, European symbol
C5	10uF 16V	CPOL-EU153CLV-0810	153CLV-0810	POLARIZED CAPACITOR, European symbol
C6	100n 50V X7R	C-EUC0402	C0402	CAPACITOR, European symbol
C7	100n	C-EUC0402	C0402	CAPACITOR, European symbol
C8	100n	C-EUC0402	C0402	CAPACITOR, European symbol
C9	1u	C-EUC0402	C0402	CAPACITOR, European symbol
C10	10uF 6.3V	CPOL-EU153CLV-0810	153CLV-0810	POLARIZED CAPACITOR, European symbol
C11	100n	C-EUC0402	C0402	CAPACITOR, European symbol
C12		C-EUC0402	C0402	CAPACITOR, European symbol
C13	100n	C-EUC0402	C0402	CAPACITOR, European symbol

C14	1u	C-EUC0402	C0402	CAPACITOR, European symbol
C15	470n	C-EUC0402	C0402	CAPACITOR, European symbol
C16	33p	C-EUC0402	C0402	CAPACITOR, European symbol
C17	10n	C-EUC0402	C0402	CAPACITOR, European symbol
IC1	MCP9808T-E_MS	MCP9808T-E_MS	SOP65P490X110-8N	Microchip Temperature Converter -40+125 C +/-1C Serial-I2C, SMBus, 8-Pin MSOP
IC2	BLUENRG-M2SA	BLUENRG-M2SA	BLUENRGM2SA	STMicroelectronics
IC3	LD39020DTPU33R	LD39020DTPU33R	DFN4	
IC4	74LVC1G14DBV	74LVC1G14DBV	SOT23-5	Single Schmitt-Trigger Inverter Gate
JP1		PINHD-1X5	1X05	PIN HEADER
JP2		PINHD-1X4	1X04	PIN HEADER
LED1		LEDCHIPLED_0805	CHIPLED_0805	IR LED
LED2		LEDCHIPLED_0805	CHIPLED_0805	IR LED
LED3		LEDCHIPLED_0805	CHIPLED_0805	IR LED
LED4		LEDCHIPLED_0805	CHIPLED_0805	IR LED
LED13		LEDCHIPLED_0805	CHIPLED_0805	IR LED
LED14		LEDCHIPLED_0805	CHIPLED_0805	IR LED
LED15		LEDCHIPLED_0805	CHIPLED_0805	IR LED
LED16		LEDCHIPLED_0805	CHIPLED_0805	IR LED
PS1	MCP1811AT-018_TT	MCP1811AT-018_TT	SOT95P237X112-3N	MICROCHIP - Fixed LDO Voltage Regulator, 2V to 5.5V, 400mV drop, 1.8V/150mA out
Q1	IRLML2502	IRLML2502	SOT23	N-Channel HEXFET® Power MOSFET Logic Level
R1	100k	R-EU_R0402	R0402	RESISTOR, European symbol
R2	0.39 0.6W	R-EU_R0402	R0402	RESISTOR, European symbol
R3	10k	R-EU_R0402	R0402	RESISTOR, European symbol
R4	22	R-EU_R0402	R0402	RESISTOR, European symbol
R5	4k7	R-EU_R0402	R0402	RESISTOR, European symbol
R6	0.39 0.6W	R-EU_R0402	R0402	RESISTOR, European symbol
R7	4k7	R-EU_R0402	R0402	RESISTOR, European symbol
R8	10k	R-EU_R0402	R0402	RESISTOR, European symbol
R9	100k	R-EU_R0402	R0402	RESISTOR, European symbol
R10	0.39 0.6W	R-EU_R0402	R0402	RESISTOR, European symbol
R_FBB	12k 1%	R-EU_R0402	R0402	RESISTOR, European symbol
R_FBT	36k 1%	R-EU_R0402	R0402	RESISTOR, European symbol

SMB J33C	TVS1	TVS1	DO214AA	
TP1	TEST-POINT3X4	TEST-POINT3X4	PAD.03X.04	SparkFun Test Points
TP2	TEST-POINT3X4	TEST-POINT3X4	PAD.03X.04	SparkFun Test Points
TP3	TEST-POINT3X4	TEST-POINT3X4	PAD.03X.04	SparkFun Test Points
TP4	TEST-POINT3X4	TEST-POINT3X4	PAD.03X.04	SparkFun Test Points
TP5	TEST-POINT3X4	TEST-POINT3X4	PAD.03X.04	SparkFun Test Points
TP6	TEST-POINT3X4	TEST-POINT3X4	PAD.03X.04	SparkFun Test Points
TP7	TEST-POINT3X4	TEST-POINT3X4	PAD.03X.04	SparkFun Test Points
TP8	TEST-POINT3X4	TEST-POINT3X4	PAD.03X.04	SparkFun Test Points
U$1	OV2640	OV2640	OV2640	Camera module
U$5	MB1030	MB1030	MB1030	LV-MaxSonar-EZ3, ultrasonic range finder
U$12	WLPN202012	WLPN202012	WLPN202012	SMD inductor, 1500 mOhm
U$14	LM43603-Q1	LM43603	LM43603	3.5-V to 36-V, 3A Synchronous Step-Down Voltage Converter, Automotive - Q100
U1	LSM6DSMTR	LSM6DSMTR	PQFN50P300X250X86	iNEMO inertial module: 3D accelerometer and 3D gyroscope Check prices