January 14, 2021

Compact Feature Description for sensor integrated applications

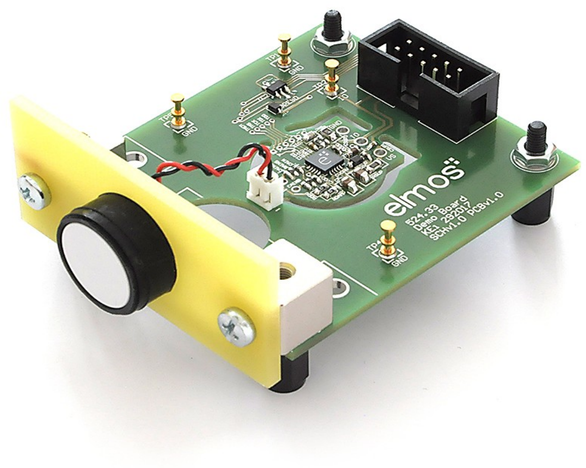


Figure 1: Evaluation Boards E524.33

1 Introduction

In some applications the ultrasonic sensor IC E524.33 can be integrated into a complete sensor module. The IO interface of the IC is the available communication interface of the sensor module. This document shall introduce the basic functionality and configuration features and the communication commands of the integrated IC E524.33. It shall support customers of sensor modules to design the IO master interface for a stable communication and data transfer.

The timing of the IO interface signal is dependent on the external circuitry applied to the IC by the sensor producer. Please use the sensor documentation as reference for timings at the IO port of the sensor.

This document is only referring to the IC related behavior regarding the specified IO timings and voltage levels.

All referenced parameter settings in this document are extracted from the general E524.33 data sheet. The only valid origin of the IC parameter values is the data sheet.

Features

- Supports directly driven transducers
- Best measurement performance
  - Advanced analog & digital signal processing
  - Configurable measurement profiles
  - Two static and one automatic thresholds
  - Echo peak detection / All peak detection
  - Near field detection
- High robustness and diagnostics
  - Ringing time and ringing frequency measurement
  - Noise suppression / Fast time constant algorithm
  - Integrated temperature sensor
  - Supply voltage monitoring
- Advanced IO communication interface
  - 2-wire and 3-wire versions
  - Envelope readout via IO or testmode

Applications

- Ultrasonic park assist systems (USPA, PAS, ...)
- Advanced driver assistance systems (ADAS)
- Distance and level metering

General Description

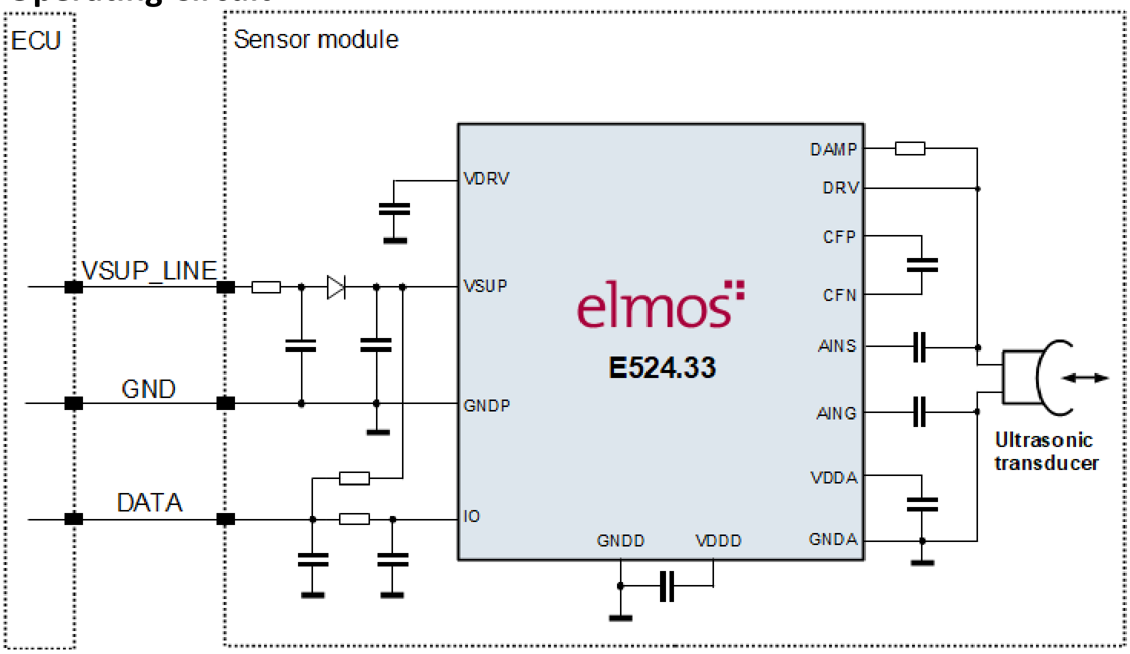
This device provides best performance in ultrasonic applications. It builds the core for a robust and easy-to-handle distance measurement system, while offering flexibility for customer applications.

The integrated driver stage drives the connected ultrasound transducer directly and provides significant reduction of system costs and size by removing the transformer and other external components.

Digital signal processing (automatic thresholds, sensitivity time control,...) optimizes short and long range detection performance. The optimized smart damping algorithm reduces the blind zone to a minimum and the new near field detection identifies objects directly in front of the sensor.

To ensure flexibility for customer applications, the optimized I/O interface offers 3 configurable measurement profiles that can for example be set up for a near, medium and far range. Numerous diagnosis possibilities, such as monitoring the supply voltages and temperature sensor, the detection of communication errors or the measurement of the decay time and frequency deviation, enable reliable sensor operation.

Typical Operating Circuit



2 Absolute Maximum Ratings

- Stresses beyond these absolute maximum ratings listed below may cause permanent damage to the device. **These are stress ratings only; operation of the device at these or any other conditions beyond those listed in the operational sections of this document is not implied.**
- Exposure to absolute maximum rated conditions for extended periods may affect device reliability.
- All voltages referred to ground (GNDA) unless otherwise specified.
- Currents flowing into terminals are positive, those drawn out of a terminal are negative.

Table 1: Absolute Maximum Ratings Table

No.	Description	Condition	Symbol	Min	Max	Unit
1	Supply voltage		VSUP	-0.3	36	V
2	Supply voltage	t < 500 ms	VSUP	-0.3	40	V
3	Voltage at pin IO		V_{IO}	-0.3	36	V
4	Voltage at pin IO	t < 500 ms	V_{IO}	-0.3	40	V

3 Recommended Operating Conditions

Table 2: Recommended Operating Conditions

No.	Description	Condition	Symbol	Min	Typ	Max	Unit
1	Supply voltage		VSUP	6	-	18	V
2	Ambient temperature		T_{AMB}	-40	-	105	°C

4 Electrical Characteristics

- VSUP = +6V to +18V,
- T_{AMB} = -40°C to +105°C, unless otherwise noted.
- Typical values are at VSUP = 12V and T_{AMB} = +25°C.
- Positive currents flow into the device pins.
- All time values are based on the typical oscillator frequency $f_{OSC,typ}$.

4.1 Supply Voltages and Power-on Reset

Table 3: Supply and POR - Electrical Parameters

No.	Description	Condition	Symbol	Min	Typ	Max	Unit
1	Current consumption at VSUP	t>t_{SU_VDRV}	I_{VSUP}	-	5.4	8	mA
2	Current consumption at VSUP in standby mode		I_{VSUP_STBY}	-	0.8	1	mA
3	Current consumption at VSUP during reload phase of VDRV*)	Default external circuitry	I_{VSUP_RELOAD}	-	14	20	mA
4	Threshold at VSUP from operation mode to reset state		$VSUP_{PORL}$	-	-	4.0	V
5	VSUP undervoltage detection threshold		$VSUP_{UV,L}$	4.7	5.0	5.3	V
6	VSUP undervoltage detection hysteresis		$VSUP_{UV,HYST}$	0.1	0.3	0.5	V
7	Start-up time until communication via IO is possible*)	Default external circuitry	t_{D_IO}	-	260	800	µs

*) Not tested in production

4.2 Temperature sensor

Table 4: Temperature sensor - Electrical Parameters

No.	Description	Condition	Symbol	Min	Typ	Max	Unit
1	Temperature sensor code at 25°C	@ T_{AMB}=25°C	$TSENS_{C\_RT}$	430	442	454	LSB
2	Accuracy of temperature sensor output at 25°C	@ T_{AMB}=25°C	$TSENS_{ACC25}$	-6	-	6	°C
3	Slope of temperature sensor*)		$TSENS_{SLOPE}$	0.488	0.513	0.541	°C/ LSB
4	Integration time of ADC*)		$TSENS_{T\_DEL}$	-	5.5	-	ms

*) Not tested in production

4.3 IO Interface

Table 5: IO Interface (DC) - Electrical Parameters

No.	Description	Condition	Symbol	Min	Typ	Max	Unit
1	Voltage threshold for pin IO to detect low input signal	only 524.33	V_{IO12_IL}	0.29	0.33	0.36	VSUP
2	Voltage threshold for pin IO to detect high input signal	only 524.33	V_{IO12_IH}	0.62	0.67	0.70	VSUP
3	Voltage at pin IO to output low level	I_{IO} = 4mA	$V_{IO\_OL\_4}$	-	-	0.5	V
4	Current limitation for pin IO	V_{IO} < 18V	I_{IO_LIMIT}	30	-	60	mA
5	Resolution of current DAC for envelope via IO*)		N_{IDAC}	-	6	-	Bit
6	Current per LSB for envelope via IO		I_{IDAC_STEP}	-	16.6	-	µA/ LSB
7	Maximum IDAC output current for envelope via IO		I_{IDAC_max}	900	1060	1250	µA

*) Not tested in production

Table 6: IO Interface (AC) - Electrical Parameters

No.	Description	Condition	Symbol	Min	Typ	Max	Unit
1	Slew Rate		SR_{VIO}	-	1.7	-	V/µs
2	Input debouncer		T_{DEB}	0	-	20	µs
3	IO high phase after T_{CMD} or IO high phase after an echo reporting (measurement)		T_D	21	50	71.2	µs
4	IO low phase for send request		T_{SND}	78.8	100	118.7	µs
5	IO low phase for receive request		T_{REC}	131.3	150	166.2	µs
6	IO low phase beginning of measurement command		T_{MEAS}	183.8	200	213.7	µs
7	IO low phase to enter command mode		T_{CMD}	236.3	250	261.3	µs
8	Setup time for V_{PROG}		T_{VPROG}	-	-	5	ms
9	Programming time		T_{PROG}	22	25	-	ms
10	Bit length, ECU to sensor module		T_{BIT_WR}	131.3	150	166.2	µs
11	IO low phase for a logical '0', ECU to sensor module		T_{BIT0_WR}	78.8	100	118.7	µs
12	IO low phase for a logical '1', ECU to sensor module		T_{BIT1_WR}	21	50	71.2	µs
13	Bit length, sensor module to ECU		T_{BIT}	142.5	150	157.5	µs
14	IO low phase for a logical '0', sensor module to ECU		T_{BIT0}	92.5	100	107.5	µs
15	IO low phase for a logical '1', sensor module to ECU		T_{BIT1}	42.5	50	57.5	µs
16	Debouncing of echo signal		T_{DEB_ECHO}	-	3	-	$1/f_{DRV}$

No.	Description	Condition	Symbol	Min	Typ	Max	Unit
17	Debouncing after an echo signal		T_{ECHO_DEB}	-	16	-	$1/f_{DRV}$
18	Pulse width low frequency calibration pulse		T_{CAL}	-	496	-	$1/f_{DRV}$
19	Pulse width of calibration pulses		T_{CALS}	-	8	-	$1/f_{DRV}$

5 Functional Description

5.1 Overview

5.1.1 Ultrasonic distance measurement

The principle of ultrasonic distance measuring is based on transmitting a pulse and measuring the reflection time of the received pulse as shown in 1. The relationship between the distance from the transducer to the object L and the time T it takes to receive the echo is L = c * T/2, where c is the velocity of sound (c = 343 m/s at 20°C). The IC requires only one transducer, which acts as a transmitter and receives the reflected pulse with a time delay. The time delay is proportional to the distance to measure.

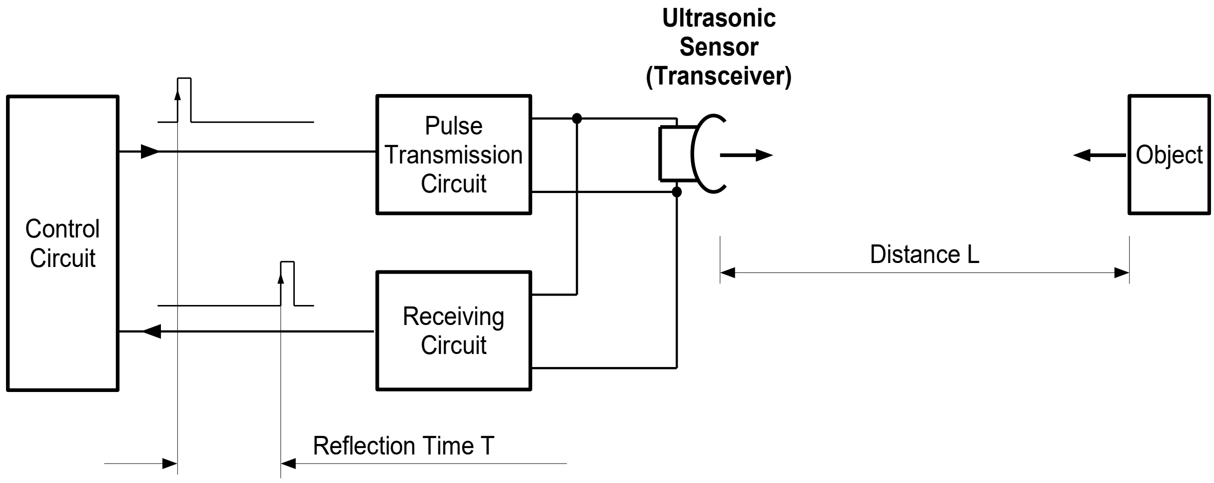


Figure 1: Principle: Ultrasonic distance measurement

5.1.2 Measurement cycle

An ultrasonic measurement cycle is defined as the time period, where the IC performs actions with the aim to gather an associated set of data for further processing in the control unit (ECU). A cycle may contain:

- Noise measurement
- Bursting
- Envelope data sampling
- Obstacle detection
- Collecting diagnostic information

The measurement cycle is started by a 'SEND' or 'RECEIVE' request by the control unit. Internal logic generates a burst signal for the transducer first. Incoming reflected pulses are amplified, digitally filtered and compared to customer programmable threshold levels or to the automatically generated threshold. If the echo pulse exceeds the set threshold level, the IC triggers the IO line. The time elapsed from sending out a burst signal to receiving an echo signal from an object is proportional to the distance of the object.

Once a cycle is initiated by the control unit, it cannot be interrupted during the programmable measurement time. If no measurement is performed the device is in Idle state.

5.1.3 Measurement modes

The device supports the following modes of operation:

- SEND mode (Direct mode): Bursting and measuring
- RECEIVE mode (Indirect mode): No bursting, only measuring

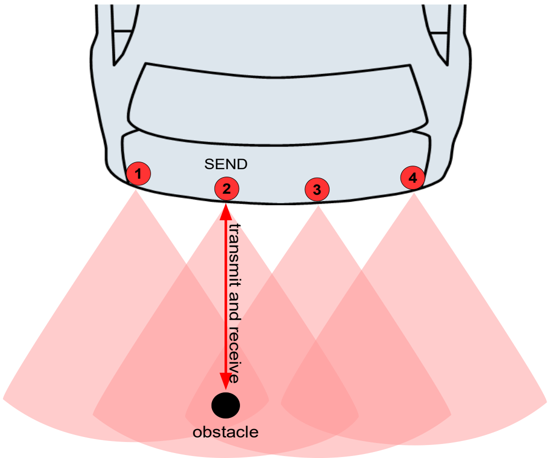


Figure 2: Direct Measurement

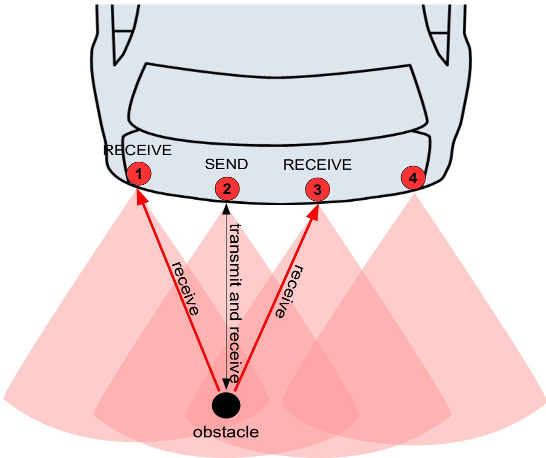


Figure 3: Indirect Measurement

In **SEND mode** (direct measurement) the sensor transmits and receives its own ultrasonic signal.

In **RECEIVE mode** (indirect measurement) the sensor does not send any ultrasonic signal. It only receives a signal sent out by another sensor.

5.1.4 Interface

The communication between the control unit and the sensor IC is possible via 3-wire interface. The E524.33 support a dedicated IO-line for data transfer on different voltage levels.

The three wires are ground (GND), supply (VSUP) and one signal line (DATA).

5.2 Supply Voltages and Power-on Reset

The E524.33 provides two internal regulators (VDDA and VDDD) as supplies for the internal circuits. Additionally a configurable driver supply voltage (VDRV) is generated for burst generation at the transducer.

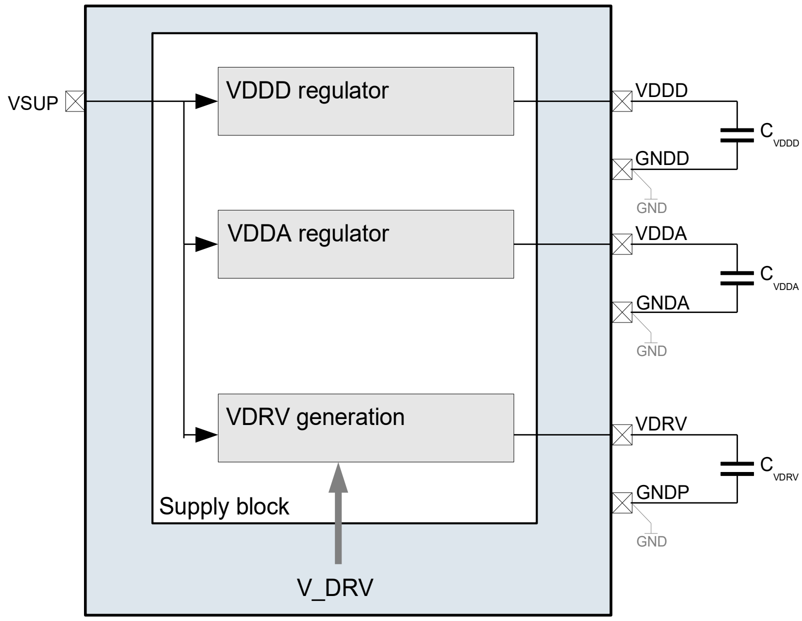


Figure 4: Supply block

The VDRV output voltage is configurable. It is defined at end of line sensor calibration and stored in non volatile memory area of the IC.

5.2.1 IC functionality based on VSUP and VDRV

Comparators monitor the voltages VSUP and VDRV to detect undervoltage and overvoltage.

- If VDRV rises above $VDRV_{OV}$, no further pulses will be sent to protect the driver structure and the VDRV overvoltage flag is set.
- If VDRV decreases below $VDRV_{UV\_L}$, the VDRV undervoltage flag is set.
- If VSUP decreases below $VSUP_{UV\_L}$, the VDRV voltage generation is stopped and no further pulses will be sent to prevent data loss due to reset below $VSUP_{POR}$. The VSUP undervoltage flag is set.

With 'READ_STATUS' the undervoltage and overvoltage information can be read out.

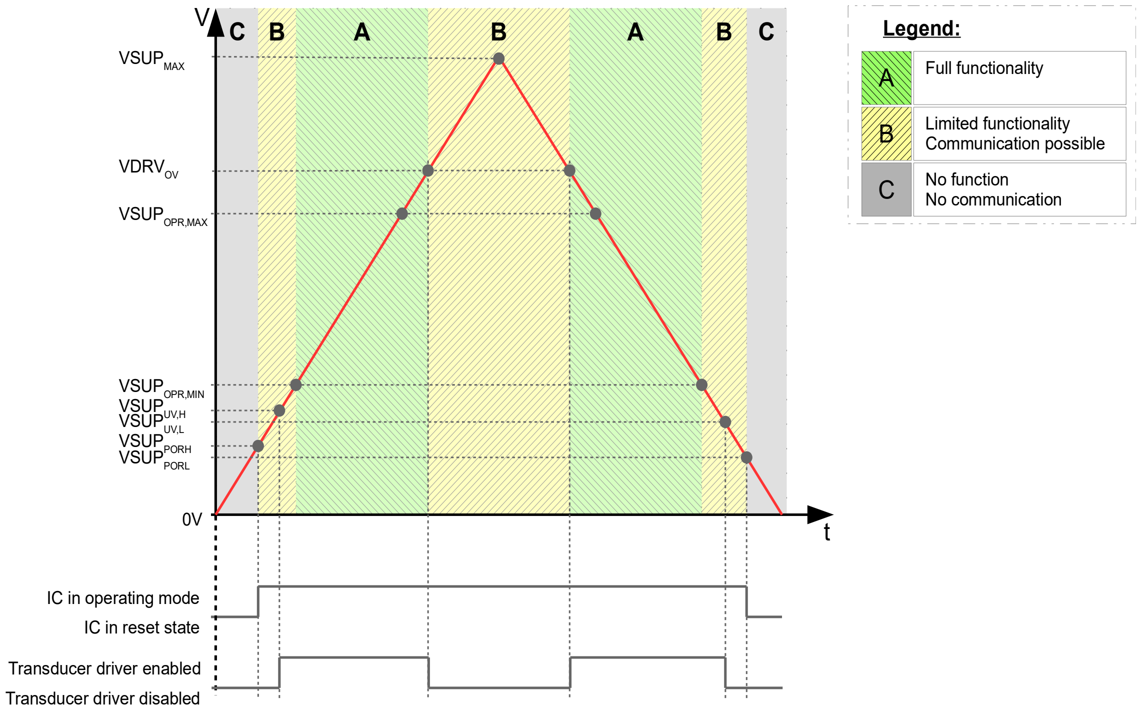


Figure 5: IC functionality

The digital part is running, when the power-on-reset is high. When the power-on-reset goes from high to low state, the digital part is in reset state. This results in full functionality down to $VSUP_{OPR,min}$ and a still working digital part down to $VSUP_{POR}$. Between $VSUP_{OPR,min}$ and $VSUP_{POR}$ the performance is limited, but communication with the control unit is possible without restrictions and data retention is guaranteed.

5.2.2 Power up sequence

The IC begins to power up once an external voltage is supplied to the pin VSUP. A power-up diagram is shown in 6. The sequence can be described as follows:

1. An external supply voltage is supplied to pin VSUP.
2. After the Power-on-reset (POR) signal to the digital part is released, the digital part is running and communication via the interface is possible. The receiver path is enabled to receive signals.
3. The VDRV generation has reached its configured voltage level and the transducer driver can be switched on. The start-up time t_{SU_DRV} depends on the supply voltage VSUP, the VDRV voltage (set by V_DRV) and on the external capacitor CDRV.

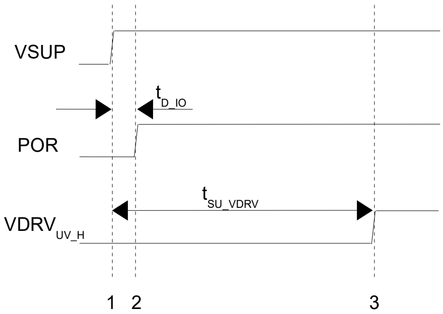


Figure 6: Power up sequence

5.2.3 Standby mode

This IC supports a standby mode to reduce current consumption.

- The standby mode is entered with the 'STANDBY' command.
- The command 'WAKE_UP' initiates a wake up from standby mode. Also any other valid command leaves the standby mode. Full functionality is available after all capacitances are charged.

For minimum current consumption in standby mode the IO has to be at VSUP level.

5.3 Signal Processing

The signal processing unit of the IC contains anlog filter and amplifier stages and digital filter, signal enhancement and gain stages. A dynamic gain feature (STC) is implemented based on digital gain stage. The sensitivity time control (STC) improves the long distance detection range by keeping a good short distance detection performance.

5.3.1 Echo Detection

The echo detection is performed by comparing the echo envelope signal of the digital filter output with a threshold value. The result appears at pin IO in SEND / RECEIVE mode. If the current envelope of the echo signal goes above the chosen threshold (A or B) for a time $t > t_{DEB\_ECHO}$, pin IO is pulled to GND.

The kind of threshold generation as well as the echo detection type (standard, peak detection, all-peak detection) has impact on the accuracy of IO-line output.

The IC offers two different possibilities of threshold generation:

- static threshold generation (two independent programmable thresholds)
- automatic threshold generation (combination of static and dynamic threshold generation)

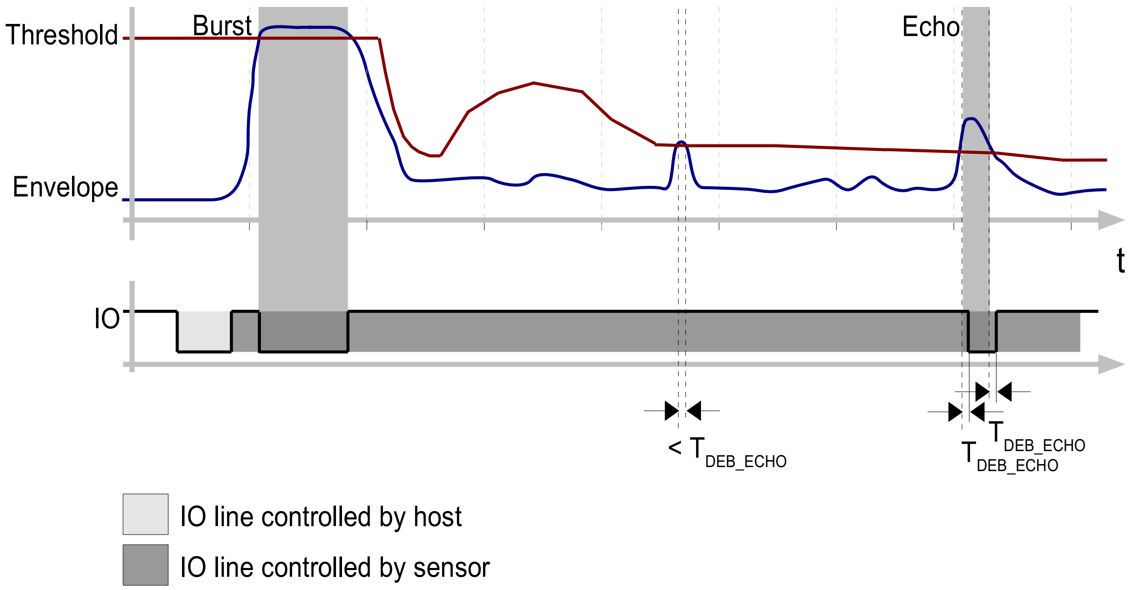


Figure 7: Echo Detection based on a static threshold curve

5.3.2 Noise measurements

Ambient noise before measurement cycle

As increased ambient noise might disturb the measurement in SEND or RECEIVE mode, the IC measures the ambient supersonic noise directly before entering SEND or RECEIVE mode. The ambient noise measurement is performed during the low phase of all 'SEND' or 'RECEIVE' commands. The output of the digital filter is compared to a threshold value which can be selected by bits NOISE_CFG according to 7. This noise measurement is performed with the sum of analog and digital amplification $G_{ANA} + G_{DIG} + G_{STC}$.

Table 7: Threshold value for noise measurement depending on bits NOISE_CFG

NOISE_CFG[1]	*NOISE_CFG[0]*	*Threshold value*
0	0	16
0	1	32
1	0	64
1	1	128

Ambient noise during measurement cycle

If ambient noise occurs within a 'SEND' or 'RECEIVE' measurement, the ATG calculation adapts to the higher noise level. If the ambient noise increases and the ATG rises to a level of 128, noise during the measurement is indicated.

The results of the noise measurements is stored after each 'SEND' or 'RECEIVE' command and can either be read out with the IO command 'READ_STATUS' or within the status information after each 'SEND' or 'RECEIVE' command.

5.3.3 Echo detection type

The IC offers 3 different types of echo detection during the measurement cycle, which are all shown in the following figure.

- Echo width detection
- Echo peak detection (EPD)
- All-peak detection (APD)

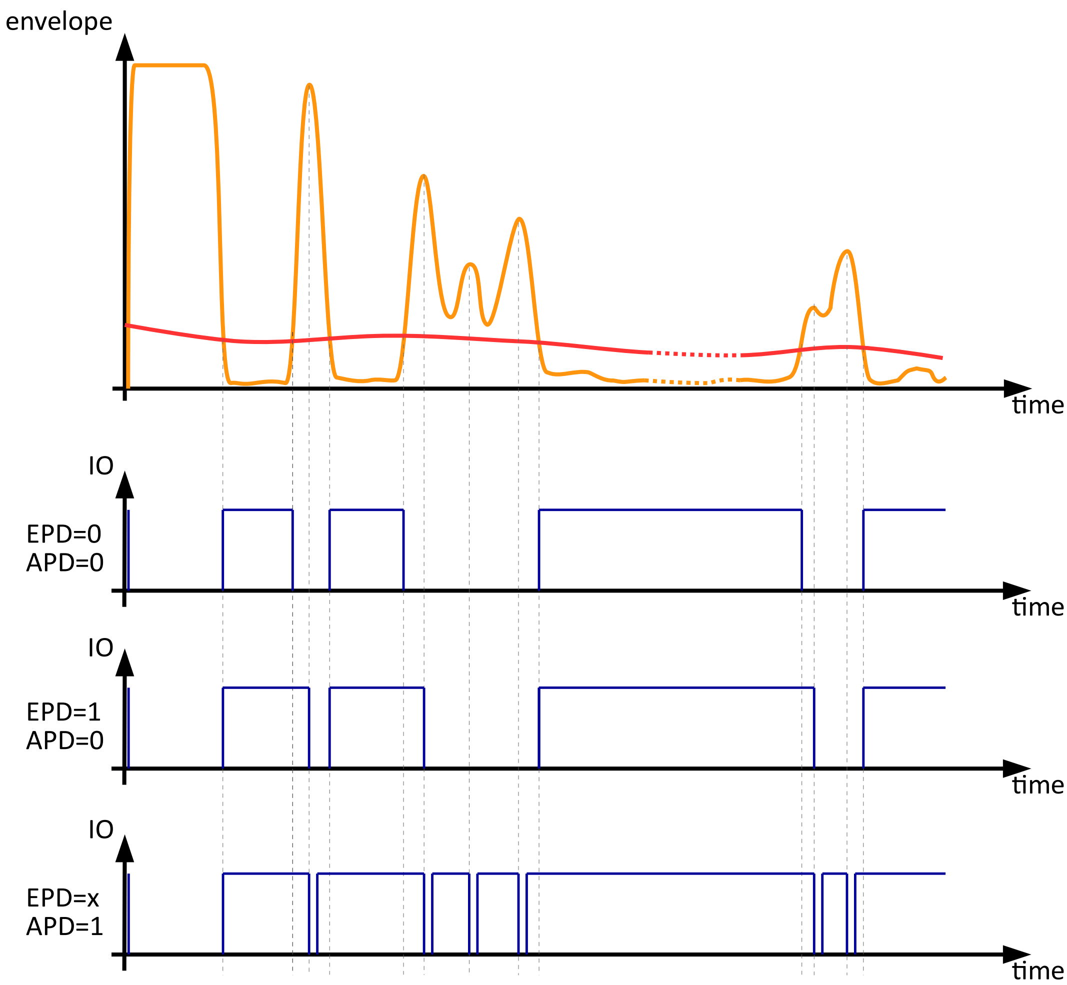


Figure 8: Different types of echo detection

In case, the echo detection uses the crossing points between envelope and threshold (EPD='0' or APD='0'), a change on the IO gets valid after T_{DEB_ECHO}. Due to clearness this is not shown in the figure.

In case, the echo detection uses the peak detection (EPD='1' or APD='1'), a change on the IO line gets valid immediately, if the current envelope sample is equal or below the previous one.

Additionally to the detection types a near-field detection (NFD) has been implemented for the short range.

Echo Peak Detection (EPD)

In case of EPD='0' echo peak detection is inactive, which means: echo width detection is active. The IO-line is pulled down when the envelope signal crosses the threshold curve. The detected position of an obstacle depends on the ratio between the echo maximum and the crossing point of threshold curve with envelope signal.

In case of EPD='1' echo peak detection (EPD) is active. This means the IO-line is pulled down at the first maximum after the envelope signal crossed the threshold curve. The detected position of an obstacle nearly stays constant even with varied gain or threshold crossing.

The behavior of echo width and echo peak detection are depicted in the following figures. Two different obstacles were placed at the same distance to the sensor.

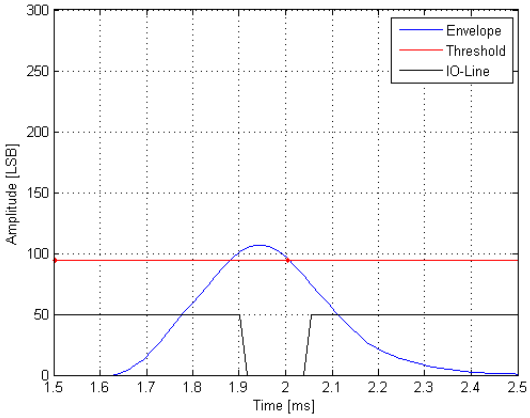


Figure 9: EPD='0' with low echo height

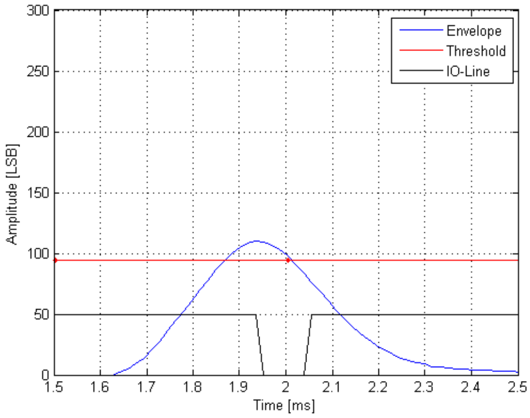


Figure 10: EPD='1' with low echo height

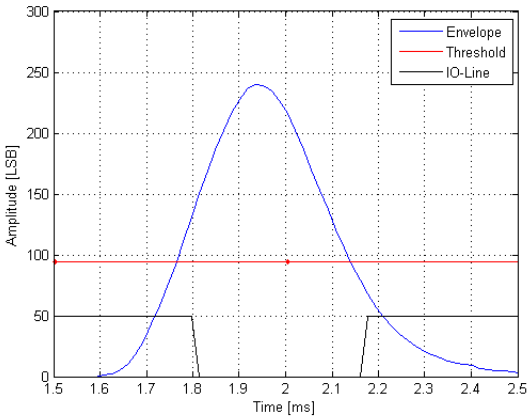


Figure 11: EPD='0' with high echo height

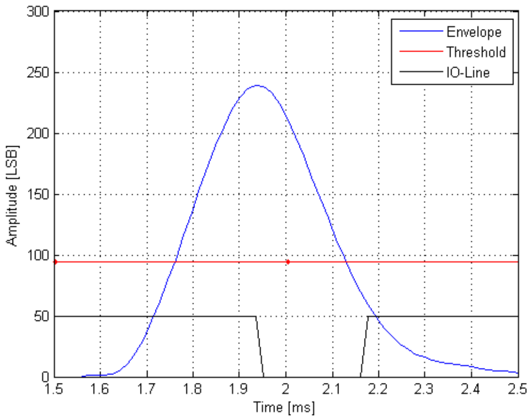


Figure 12: EPD='1' with high echo height

Echo peak detection during overdrive

Even if an echo signal overdrives within the 8 Bit range, the correct maximum position can be detected with EPD='1'. Echo height is calculated before digital gain and limitation is applied.

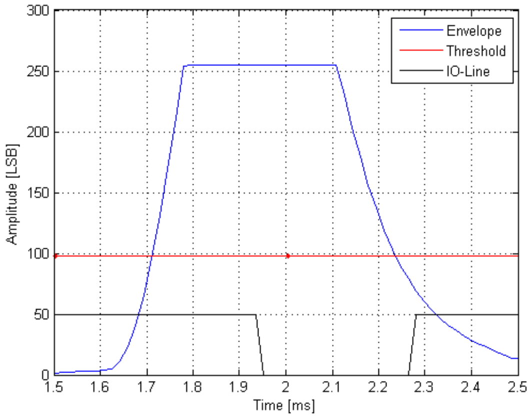


Figure 13: Echo peak detection with overdrive

All-peak detection (APD)

The All-peak detection detects all maxima when the envelope signal is above the threshold curve. Each detected maximum will pull the IO line to GND. In order to detect all following maxima, the length of the low signal on the IO line is reduced to $T_{ECHO2WIRE}$.

This function can be switched on / off in the MEAS_SETUP register. The default setting is Echo Peak Detection.

5.3.4 Near-field detection (NFD)

The near field detection analyses the energy within a specified time window. The higher the energy in this window, the more probable a near-field object is in the analyzed region.

The IO command 'READ_NFD_STATUS' returns the energy level and Tcomp.

The result of the measurement can either be read out with the IO command 'READ_STATUS' or within the status information after each 'SEND' command.

5.3.5 Signal enhancement

Ringing time (RT)

The end of ringing time can be indicated by the envelope function after digital processing (RT_CFG='0'-default) or by a comparator using the analog input signal. When the IO line behavior during ringing is controlled by a comparator (RT_CFG='1') the ringing time is independent from G_ANA, G_DIG and the digital filter.

The configuration can be chosen with the RT_CFG bit, which is stored in the volatile memory.

The following figure shows the ringing time behavior of the IO-line:

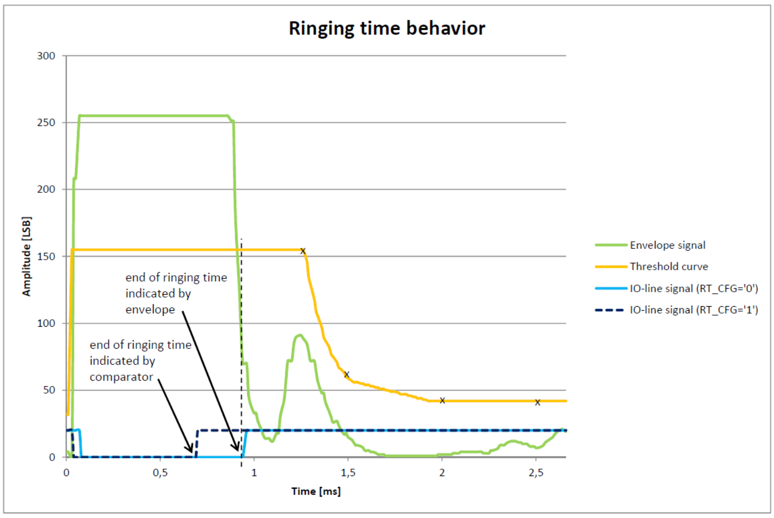


Figure 14: Ringing time behavior example

5.4 Temperature sensor

The integrated temperature sensor may be used for an adjustment of the transducer frequency or to monitor the temperature of the IC.

- The 'READ_TEMP' command returns the current temperature value.
- The first valid value after power-on or wake-up is available after $TSENS_{T\_DEL}$.
- The detected temperature is a junction temperature of the integrated circuit and not of the IC ambient.

The command 'READ_TEMP' returns a 10 bit value corresponding to the IC temperature. A higher ADC value $TSENS_C$ represents a higher temperature T. To calculate the temperature from the read value $TSENS_C$ the following formula can be used:

$$T(TSENS_C) = 25^\circ C + (TSENS_C - TSENS_{C\_RT}) \cdot TSENS_{SLOPE}$$

To get an exact temperature, use the measured $TSENS_{C\_RT}$ value at 25°C.

5.5 Memory and device configuration

The E524.33 support two kinds of memory:

- Registers (volatile memory)
- EEPROM cells (non-volatile memory)

The 4 registers "Measurement Setup", "Threshold Setup A", "Threshold Setup B" and "Calibration Setup" are used to configure the device.

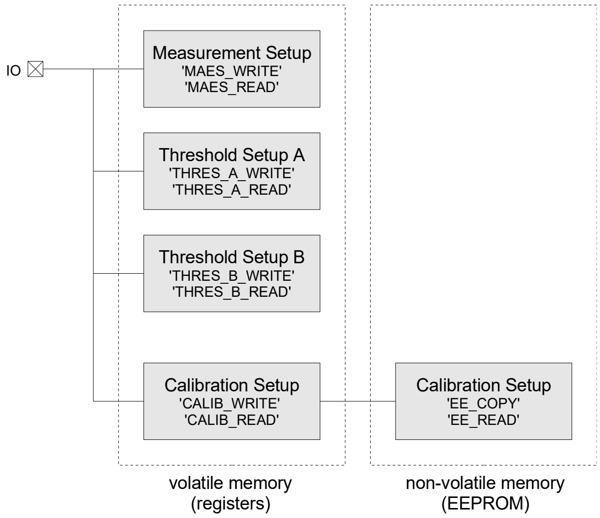


Figure 15: Memory and configuration overview

5.5.1 "Measurement Setup" and "Threshold Setup A/B"

The registers "Measurement Setup" and "Threshold Setup A/B" contain the settings for different measurement setups and parameters for the echo detection. Both are set to their default values after power up and can be changed by sending new data by 'MEAS_WRITE', 'THRES_A_WRITE' and 'THRES_B_WRITE' commands via the IO line. The communication protocols are secured with parity bits and a successful data transmission can be verified with the 'READ_STATUS' command. Due to the fact that the settings depend on the complete (parking) application, they are normally known and written by the master ECU.

5.5.2 "Calibration Setup"

Tolerances of the transducer membrane result in different sound pressure level and the sensitivity. Therefore the behavior of a single ultrasonic sensor may differ from others. Thus, the "Calibration Setup" contains values like transducer frequency, transmitting power of the driver stage and amplifier gain and must be adjusted by a customer end-of-line calibration to allow the same performance over all ultrasonic sensor modules.

After power up the register "Calibration Setup" is loaded from the EEPROM cells.

The calibration of an ultrasound sensor is done in the end of line calibration step of the sensor module production. The calibration ensures that the sensor is configured correctly for good send and receive performance. This settings are individual for each transducer.

5.6 IO Interface

The IO interface is used to communicate between the IC and the hosting ECU. The most common 'SEND_A' and 'RECEIVE_A' commands are initiated by an ECU pulling the IO pin low for T_{SND} or T_{REC}. For the additionally available 'SEND_B', 'SEND_C' and 'RECEIVE_B', 'RECEIVE_C' commands the ECU pulls the IO line low for T_{MEAS} and issues a 2 bit command sequence. For all other commands, the ECU pulls the IO line low for T_{CMD} and issues a 5 bit command sequence. A logic '0' is signalized with pulling the line low for T_{BIT0} and a logic '1' with T_{BIT1} as shown in 16. The bit length and all other timing parameters are temperature dependent and depend on f_{OSC}.

The ECU side has to ensure the correct timing and number of data bits during communication. Incorrect timing or data transfer result in discarding the command as invalid communication.

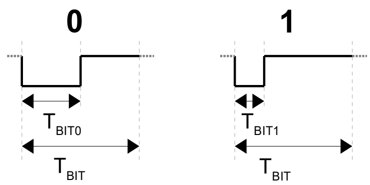


Figure 16: IO Pin bit encoding

E524.33

Data is sent between the E524.33 and ECU by pulling the single line DATA low for defined periods of time. The application circuitry needs to take care of the location and size of the external components to ensure secure communication via DATA.

Incoming data to the E524.33 is recognized as a low if V_{IO} is below V_{IO_IL} of the voltage at VSUP. A debouncing circuit suppresses interference shorter than T_{DEB}. Outgoing data transmission to the ECU is accomplished by pulling the IO line low overcoming the pull-up resistor $R_{IO\_PU\_ECU}$. To reduce EMI, the slew rate pulling low is limited to SR_{VIO}. The slew rate of the rising edge is defined by external circuitry.

5.6.1 Exchange of commands

The E524.33 supports following 'SEND' and 'RECEIVE' commands from the hosting ECU.

Table 8: 'SEND' and 'RECEIVE' command structure summary

Command	***Coding***	***Command Description***
SEND_A	T_{SND}	Initiates a burst signal via the internal drivers followed by a measurement sequence and a status sequence. Measurement parameters of profile A from measurement setup register are used.
RECEIVE_A	T_{REC}	Initiates a measurement sequence without preceding burst, useful for triangulation in systems with multiple transducers. The measurement sequence is followed by a status sequence. Measurement parameters of profile A from measurement setup register are used.
SEND_B	T_{MEAS} + 10	Initiates a burst signal via the internal drivers followed by a measurement sequence and a status sequence. Measurement parameters of profile B from measurement setup register are used.
RECEIVE_B	T_{MEAS} + 00	Initiates a measurement sequence without preceding burst, useful for triangulation in systems with multiple transducers. The measurement sequence is followed by a status sequence. Measurement parameters of profile B from measurement setup register are used.
SEND_C	T_{MEAS} + 11	Initiates a burst signal via the internal drivers followed by a measurement sequence and a status sequence. Measurement parameters of profile C from measurement setup register are used.
RECEIVE_C	T_{MEAS} + 01	Initiates a measurement sequence without preceding burst, useful for triangulation in systems with multiple transducers. The measurement sequence is followed by a status sequence. Measurement parameters of profile C from measurement setup register are used.

The E524.33 supports following commands from the hosting ECU besides the 'SEND' and 'RECEIVE' commands.

Table 9: Command structure summary

Command	***Coding***	***Command Description***
READ_STATUS	T_{CMD} + 01100	Verifies previous transmission of threshold setups A and B and the measurement setup, reads current noise status, reads frequency deviation between driver and resonance frequency, reads overvoltage, undervoltage and reset state.
READ_NFD_STATUS	T_{CMD} + 10101	Returns the near-field energy level and the Tcomp value for adaption of the near-field parameters to the transducer type.
READ_TEMP	T_{CMD} + 01111	Returns the ADC value of the temperature sensor.
ENVELOPE_SEND_A	T_{CMD} + 10001	Initiates a burst signal via the internal drivers followed by a measurement sequence of profile A. Instead of the echo detection the envelope signal is shown on the IO line. (useful in 3-wire configuration)

Command	Coding	Command Description
ENVELOPE_REC_A	T_{CMD} + 10010	Initiates a measurement sequence of profile A without preceding burst. Instead of the echo detection the envelope signal is shown on the IO line. (useful in 3-wire configuration)
READ_ID	T_{CMD} + 01110	A 24 bit chip ID is transferred on the IO line.
STANDBY	T_{CMD} + 11101	Initiates standby mode to decrease current consumption.
WAKE_UP	T_{CMD} + 11110	Initiates a wake up from standby mode.
THRES_A_WRITE	-	Writes individual values for threshold A to replace the defaults
THRES_B_WRITE	-	Writes individual values for threshold B to replace the defaults
MEAS_WRITE	-	Writes individual values for profile A/B/C and further configuration settings to replace the defaults

5.6.2 'SEND' and 'RECEIVE' Commands

The IC can store 3 individual profiles, called profile A, profile B and profile C, which are used by the 3 SEND commands and the 3 RECEIVE commands. In each profile the number of pulses (NPULSES), the length of measurement time (TMEAS) and a threshold curve selection (THSEL) can be stored in the volatile memory to configure the different profiles.

These profiles are intended to provide a short range and a long range measurement besides a normal range measurement. Alternatively they could be used to configure the profiles for different temperatures or for diagnosis purpose.

Table 10: Available Profiles

Profile	NPULSES	TMEAS	THSEL	'SEND' and 'RECEIVE' commands
Profile A	NPULSES_A	TMEAS_A	THSEL_A	'SEND_A', 'RECEIVE_A'
Profile B	NPULSES_B	TMEAS_B	THSEL_B	'SEND_B', 'RECEIVE_B'
Profile C	NPULSES_C	TMEAS_C	THSEL_C	'SEND_C', 'RECEIVE_C'

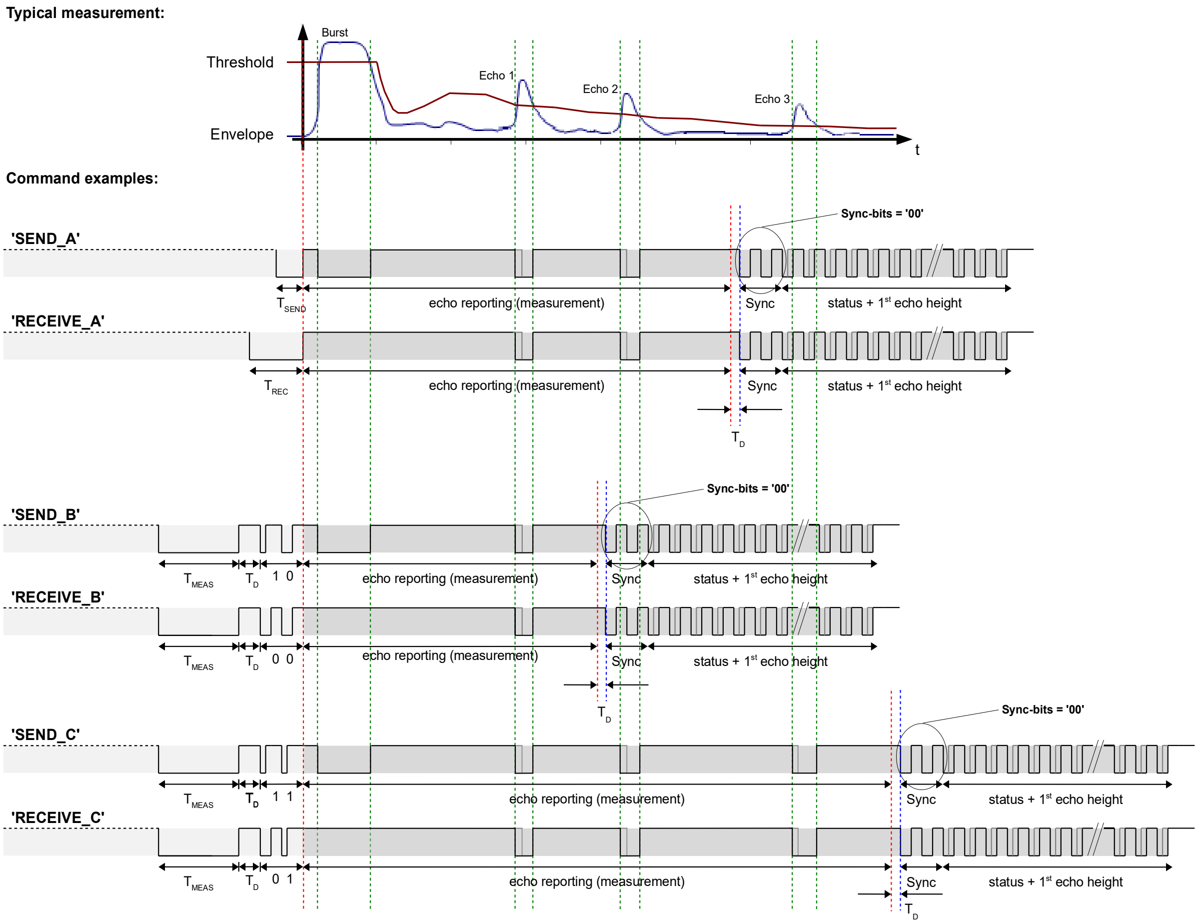


Figure 17: 'SEND' and 'RECEIVE' commands for typical measurements with 524.33

'SEND_A' command

The 'SEND_A' command initiates a burst followed by a measurement sequence. The SEND mode is requested from the ECU by holding the IO pin low for T_{SND} and is entered with the rising edge of the corresponding command.

As long as the E524.33 operates in SEND mode, no instructions coming over the IO-Interface are accepted. The interface is ready to receive new instructions when a high level remains at the IO pin for at least T_{DEB} to debounce after the SEND mode has ended.

The E524.33 can diagnose the proper operation of the transducer. After the 'SEND_A' command, the transducer driver is activated and sends out a burst for the length T_{TX}. This also causes high signal levels at the receiving amplifier and changes the level on the IO-line.

E524.33

For the E524.33, the duration of the low phase after T_{TX} can be used for diagnosis purposes. Figure 18 illustrates the 'SEND_A' command timing for the E524.33 with an example of correct operation.

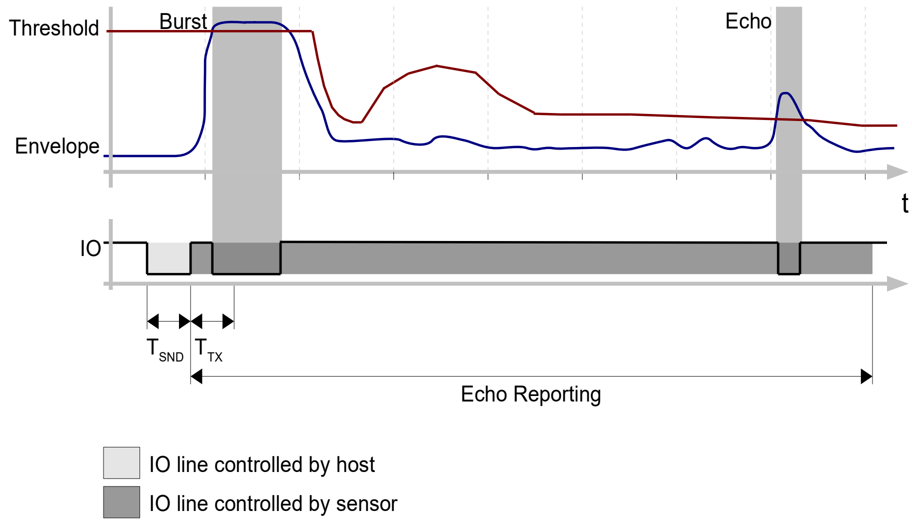


Figure 18: E524.33 'SEND_A' command timing

The example above shows a typical envelope curve with one echo and a possible threshold curve. An echo is detected, when the signal line crosses the threshold line, which means that the comparator is triggered.

The figure below shows that a crossing between threshold line and envelope will only be recognized on the IO_line if a debounce time of T_{DEB_ECHO} is maintained.

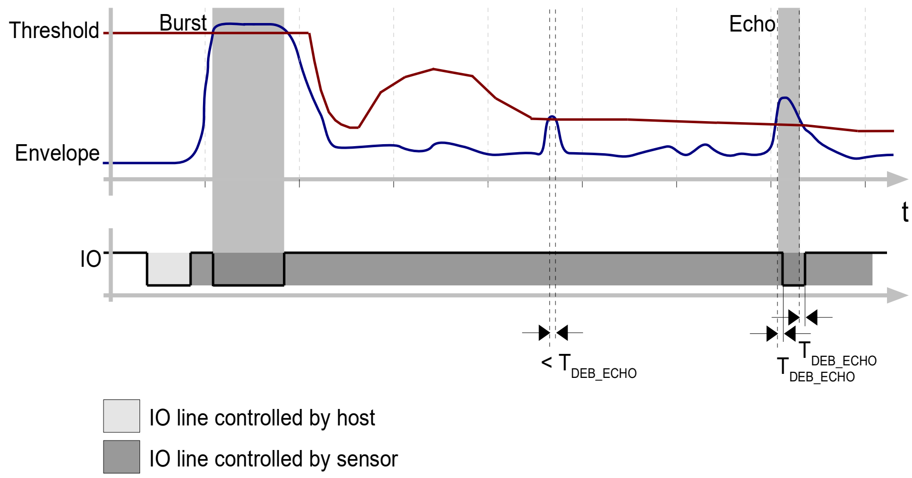


Figure 19: E524.33 'SEND_A' command timing with T_{DEB_ECHO}

'SEND_B' and 'SEND_C' command

'SEND_B' and 'SEND_C' commands are similar to 'SEND_A' command except:

1. The profile setups (NPULSES, TMEAS, THSEL) are individually set using the 'MEAS_WRITE' command.
2. Each command has a different coding.

Please refer to figure 17 for an overview and chapter 5.6.2 for detailed information.

'RECEIVE_A' command

A 'RECEIVE_A' command is identical to the 'SEND_A' command but skips the burst. The RECEIVE mode is requested from the ECU by holding the IO pin low for T_{REC} and is entered with the rising edge of the corresponding command. A filter output signal exceeding the comparator threshold indicates a received echo. In RECEIVE mode the threshold sensitivity can be increased by a scaling factor set by THRESSCALE_REC.

As long as the E524.33 operates in RECEIVE mode, no instructions coming over the IO-Interface are accepted. The interface is ready to receive new instructions when a high level remains at the IO pin for at least T_{DEB} to debounce after RECEIVE mode has ended.

E524.33

20 shows the timing for a E524.33 'RECEIVE_A' command.

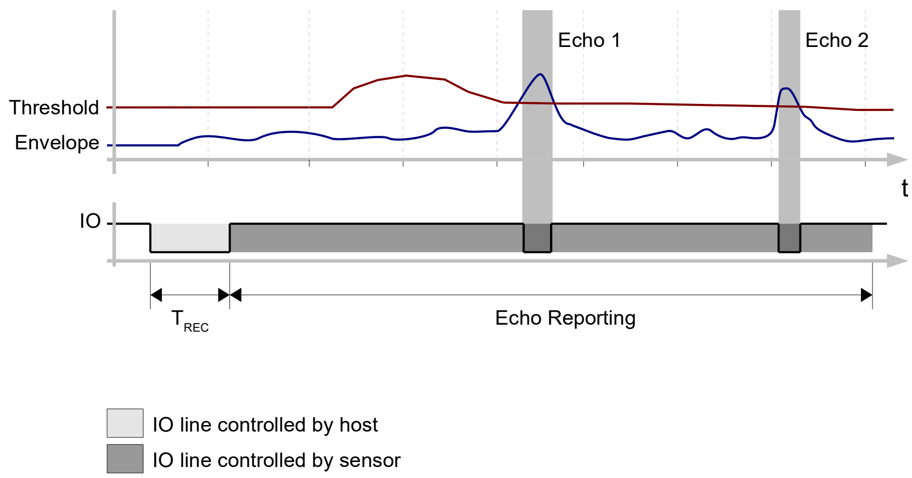


Figure 20: E524.33 'RECEIVE_A' command timing

The E524.33 operates purely in receiving mode for the entire sequence. In the example, two echoes are received and pull pin IO low. The thresholds are scalable with the selected scaling factor THRESSCALE_REC as part of the measurement setup.

'RECEIVE_B' and 'RECEIVE_C' command

'RECEIVE_B' and 'RECEIVE_C' commands are similar to 'RECEIVE_A' command except:

1. The profile setups (NPULSES, TMEAS, THSEL) are individually set using the 'MEAS_WRITE' command.
2. Each command has a different coding.

Please refer to figure 17 for an overview and chapter 5.6.2 for detailed information.

Status information after 'SEND' and 'RECEIVE' commands

Each measurement (SEND or RECEIVE) is followed by IO high phase with duration T_D, two synchronisation-bits '00' and selectable status information, which can be configured with STATUS_CFG.

It can be chosen, if:

- no status
- diagnosis flags for hardware functionality, noise level and the ringing frequency deviation
- the diagnosis flags and the height of the first detected echo
- the diagnosis flags, the height of the first and the second detected echo

are transmitted.

This status information is intended to provide an overview of the status without sending additional commands. It can be used as a first diagnosis if the system is working properly.

The configuration of STATUS_CFG is stored in the volatile memory of the measurement setup register.

The meaning of the status bits and the assignment to STATUS_CFG is as follows:

Table 11: Status wrap up bits assigned to STATUS_CFG

Bit	Meaning	STATUS _CFG=0	STATUS _CFG=1	STATUS _CFG=2	STATUS _CFG=3
17:12	6 Bit value of the echo height of the second detected echo. Upper 6 Bit of 8 Bit value are used. The returned value is the maximum of the region when the signal line is above the threshold. No second echo during the measurement cycle results in '000000'.				x
11:6	6 Bit value of the echo height of the first detected echo. Upper 6 Bit of 8 Bit value are used. The returned value is the maximum of the region when the signal line is above the threshold. No echo during the measurement cycle results in '000000'.			x	x
5	'0': Criterion for near-field object not fulfilled during last measurement. '1': Warning: There might be a near-field object detected during last measurement.		x	x	x
4	reserved		x	x	x
3	'0': No noise detected neither before nor during last measurement. '1': Noise detected either before or during last measurement.		x	x	x
2	'0': no undervoltage, no overvoltage. '1': Indication that a supply/driver voltage outside spec occurred.		x	x	x
1:0	'00': |freq_dev| ≤ 3.12% '01': |freq_dev| ≤ 6.24% '10': |freq_dev| ≤ 9.36% '11': |freq_dev| > 9.36% or invalid measurement (default in RECEIVE mode)		x	x	x

More detailed status information is available by using the 'READ_STATUS' command.

5.6.3 'READ_STATUS' command

The command 'READ_STATUS' can be used to get a more detailed information than the indication within the status flags after each measurement. It can help to detect hardware problems.

The meaning of these bits is as follows:

Table 12: Read Status: Bits 0-4

Bit 4:0	***Meaning***
01111	+11.7% frequency deviation between the transducer driver and its resonance frequency
01110	+10.92% frequency deviation between the transducer driver and its resonance frequency
...	
00001	+0.78% frequency deviation between the transducer driver and its resonance frequency
00000	0.0% frequency deviation between the transducer driver and its resonance frequency
11111	-0.78% frequency deviation between the transducer driver and its resonance frequency
...	
10001	-11.7% frequency deviation between the transducer driver and its resonance frequency
10000	-12.48% frequency deviation between the transducer driver and its resonance frequency

The frequency deviation between driver frequency and transducer resonance frequency is transmitted as a complement on two. Each digit equals 0.78% frequency deviation. The value is valid after the 'SEND' commands.

Table 13: Read Status: Bits 5-16

Bit	***value***	***Meaning***	***Reaction***
Bit 5	'0'	Result of frequency measurement is invalid (default after RECEIVE mode).	
	'1'	Result of frequency measurement is valid.	
Bit 6	'0'	Not used	
Bit 7	'0'	Not used	
Bit 8	'0'	Not used	
Bit 9	'0'	No undervoltage at VSUP detected.	
	'1'	Undervoltage at VSUP detected during last measurement cycle.	• Charge pump is switched off • No further burst pulses are sent (Except at V_DRV='0000')
Bit 10	'0'	No undervoltage at VDRV detected.	
	'1'	Undervoltage at VDRV detected during the last measurement cycle.	
Bit 11	'0'	No overvoltage at VDRV detected.	

Bit	value	Meaning	Reaction
	'1'	Overvoltage at VDRV detected during last measurement cycle.	No further burst pulses are sent
Bit 12	'0'	Transducer driving voltage during burst ok.	
	'1'	Transducer driving voltage during burst not ok.	No further burst pulses are sent
Bit 13	'0'	No noise during last measurement detected.	
	'1'	Noise during last measurement detected.	
Bit 14	'0'	No noise before last measurement detected.	
	'1'	Noise before last measurement detected.	
Bit 15	'0'	No near-field object detected.	
	'1'	Warning: There might be a near-field object.	
Bit 16		reserved	

The 'READ_STATUS' command timing diagram is shown in figure 21. The transmission starts with the MSB.

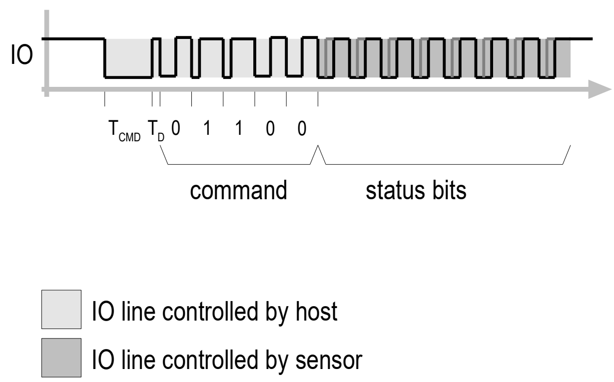


Figure 21: 'READ_STATUS' command

5.6.4 'READ_TEMP' Command

The 'READ_TEMP' command timing diagram is shown in figure 21. The transmission starts with the MSB.

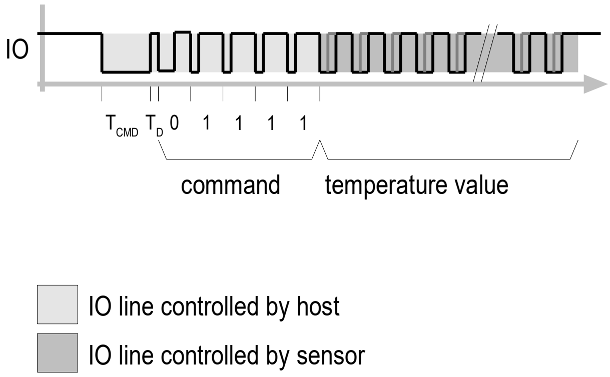


Figure 22: 'READ_TEMP' command

5.6.5 'READ_NFD_STATUS' command

The 'READ_NFD_STATUS' command timing diagram is shown in figure 23. The transmission returns near-field detection values to support adapting the near-field detection algorithm to the transducer type. The first bit transmitted is the MSB of 13Bit for the energy level and 11 Bit for the T_{COMP} value.

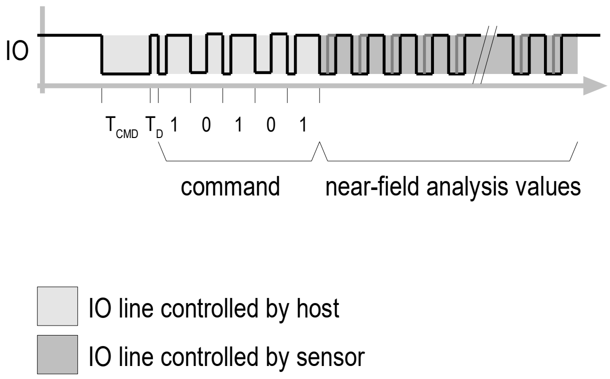


Figure 23: 'READ_NFD_STATUS' command

5.6.6 'ENVELOPE_SEND_A' and 'ENVELOPE_REC_A' commands

Instead of the echo detection in 'SEND' or 'RECEIVE' mode the envelope signal for 'SEND_A' or 'RECEIVE_A' (only profile A is possible) can be read out via IO line. This might be useful during evaluation or analysis of a moulded 3-wire system, where JTAG access is not possible.

The 'ENVELOPE_SEND_A' command initiates a burst signal via the internal drivers followed by a measurement sequence of profile A. Then the envelope signal is shown on the IO line.

The 'ENVELOPE_RECEIVE_A' command initiates a measurement sequence without preceding burst. After the measurement sequence of profile A the envelope signal is shown on the IO line.

The current output of the DAC with the external pull-up resistor results in a curve, that depicts the envelope function.

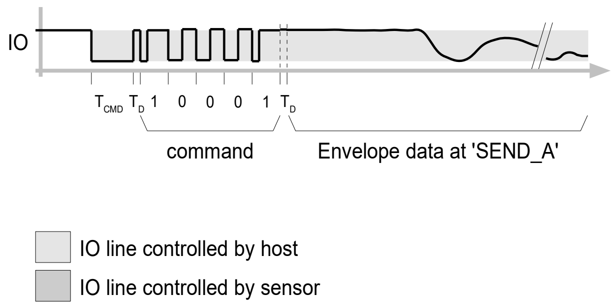


Figure 24: 'ENVELOPE_SEND_A' command

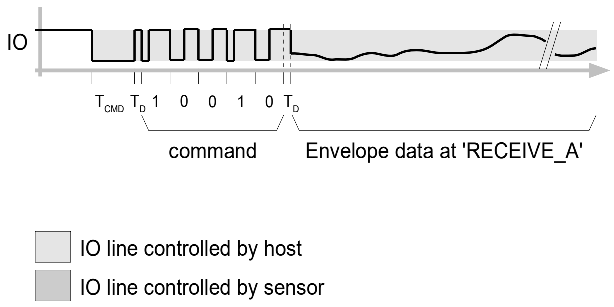


Figure 25: 'ENVELOPE_RECEIVE_A' command

5.6.7 'READ_ID' command

A 24 bit chip ID is transferred on the IO line with the command 'READ_ID'. The MSB of the ID is transmitted first.

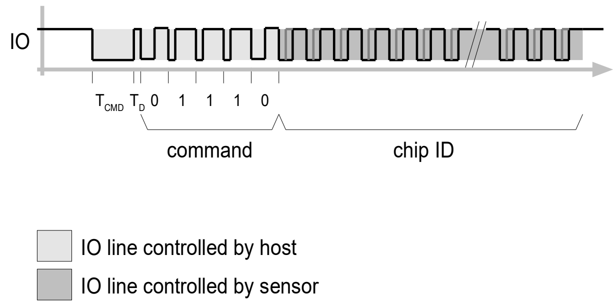


Figure 26: 'READ_ID' command

5.6.8 'STANDBY' and 'WAKE_UP' command

Besides normal operation E524.33 offers a current saving standby mode. All settings and status information keep their content.

- To enter standby mode send the 'STANDBY' command.
- To return to normal operation send the 'WAKE_UP' command.

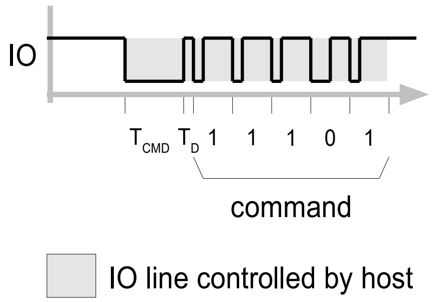


Figure 27: 'STANDBY' command

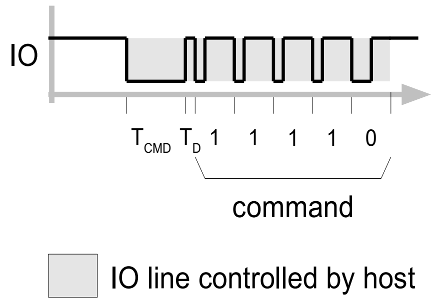


Figure 28: 'WAKE_UP' command

5.7 Diagnosis

The following table shows a brief overview of the available diagnosis possibilities.

Table 14: Diagnosis overview

Diagnosis type	*Detection of:*	*Diagnosis possibility*	*IC realization*	*Further IC action*
Transducer	• Sensor short • Sensor open • Sensor blockage (ice, mud, ...) • Temperature	• Measurement of ringing time • Measurement of frequency deviation • Measurement of temperature	• 'READ_STATUS' command / Wrap up bits • Interpretation of IO line behavior • 'READ_TEMP' command	
Supply	• Undervoltage at VSUP • Driver voltage VDRV • IC Reset	• Supply watchdog • Driver voltage monitoring	• 'READ_STATUS' command / Wrap up bits	• Transducer driver will be disabled in case of over-/undervoltage
Noise	• External disturbance	• Noise measurement before each distance measurement • Noise measurement during each measurement • Observation of the IO line during the measurement	• 'SEND'/'RECEIVE' commands • 'READ_STATUS' command / Wrap up bits • Interpretation of the IO line behavior (ECU)	
Communication	• Data transmission errors	• Evaluation of parity bits • Read back of transmitted data	• 'READ_STATUS' command / Wrap up bits • Write and Read of configuration data	• Command is ignored in case of wrong parity and register set to default
Temperature	• Temperature	• Measurement of temperature	• 'READ_TEMP' command • Indirect via oscillator frequency	
Driver + external circuitry	• CF malfunction • driver switch check • C_VDRV malfunction	• Driver voltage monitoring	• 'READ_STATUS' command / Wrap up bits	

6 Abbreviations

Table 15: Abbreviations

Abbreviation	*Explanation*
ADC	Analog to Digital Converter
APD	All Peak Detection
ASIC	Application Specific Integrated Circuit
ASSP	Application Specific Standard Product
ATG	Automatic Threshold Generation
CFG	Configuration
DAC	Digital to Analog Converter
DEB	Debouncing
EEPROM	Electrically Erasable Programmable Read-Only Memory
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPD	Echo Peak Detection
ESD	Electrostatic Discharge
ESR	Equivalent Serial Resistance
FTC	Fast Time Constant
IC	Integrated Circuit
IO-IF	Input/Output Interface
JTAG	Joint Test Action Group
LSB	Least Significant Bit
MSB	Most Significant Bit
NFD	Near Field Detection
NFTG	Near Field Threshold Generation
OV	Overvoltage
POR	Power-on Reset
RT	Ringing Time
STC	Sensitivity Time Control (also called dynamic gain control)
UV	Undervoltage

Table of Content

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