



**BMD101 Product Brief  
(Preliminary)**

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## Features and Benefits

### High Performance Bio-Signal System-on-Chip (SoC)

- Single Chip Solution for accurate Bio-Signal Detection and Processing
- Mixed Signal SoC with Integrated Analog Front End (AFE) and DSP
- Accurate ECG raw signals output

### Advanced Analog Signal Processing

- High Performance AFE for Bio-Signal Detection Ranging from  $\mu\text{V}$  Level to  $\text{mV}$  Level
- Advanced Low-Noise Amplifier (LNA) and Anti-alias Filtering
- High Resolution (16-bit) ADC
- Low Input-Referred Noise
- Automatic Sensor-Off Detection
- Fully integrated high pass filter with DC drifts removal

### Powerful Digital Processing Capability

- Reliable detection and real time heart rate ( $\pm 1\text{bpm}$ )
- Strong notch filter with at least  $-60\text{dB}$  rejection for both  $50\text{Hz}$  and  $60\text{Hz}$  power supply
- Built-in low pass filter with stable passband to the cutoff frequencies and  $-40\text{dB}$  at the stop frequency

### Flexible Interface

- UART (57600 Baud Rate) with 64 Byte TX FIFO

### Low Power Consumption

- Single  $3.3\text{V}$  ( $3.3\pm 10\%$ ) Power Supply with On-Chip  $1.2\text{V}$  Regulator
- Low Current Consumption –  $0.8\text{mA}$

### ESD Protection with External Diodes

- $8\text{kV}$  Air Discharge
- $4\text{kV}$  Contact Discharge

### Clocking Scheme

- Built-In RC Oscillator

## Small Form Factor

- SON8

## Target Applications

### Medical Equipment

- Health care center/Clinic ECG monitor and analysis
- HRV monitor
- Mobile ECG monitor and expert system

### Portable Heart Rate Monitor

- Regular usage
- Long term care
- Sleep study
- Potential irregular heart rhythm detection

### Sports and Training

- Heart rate monitor for recreation
- Heart rate guidance and alarm device for athlete training

## Sensor Electrode requirements

### Sensor Materials

- Stainless Steel
- Silver-Silver Chloride (Ag-AgCl)

### Sensor Dimensions

- Recommended Diameter of Sensor is ~10mm

## Device Overview

### System Function

BMD101 is NeuroSky's 3<sup>rd</sup> generation bio-signal detection and processing SoC device. BMD101 is designed with an advanced analog front-end circuitry and a flexible, powerful digital signal processing structure. It targets bio-signal inputs ranging from  $\mu\text{V}$  to  $\text{mV}$  level and deployed passes the raw signal through with NeuroSky proprietary algorithms.

The Low-Noise-Amplifier and ADC are the main components of the BMD101 analog front end. Because of the BMD101's extremely low system noise and programmable gain, it can detect bio-signals and convert them into digital words using a 16-bit high resolution ADC. The AFE also contains a sensor-off detection circuit.

The heart of the BMD101 digital circuit is a powerful system management unit. It is in charge of overall system configuration, operation management, internal/external communication, proprietary algorithm computation, and power management. BMD101 also comes with hardwired DSP blocks to accelerate calculations, such as various digital filtering, under the supervision of the system management unit.

### Analog Front End

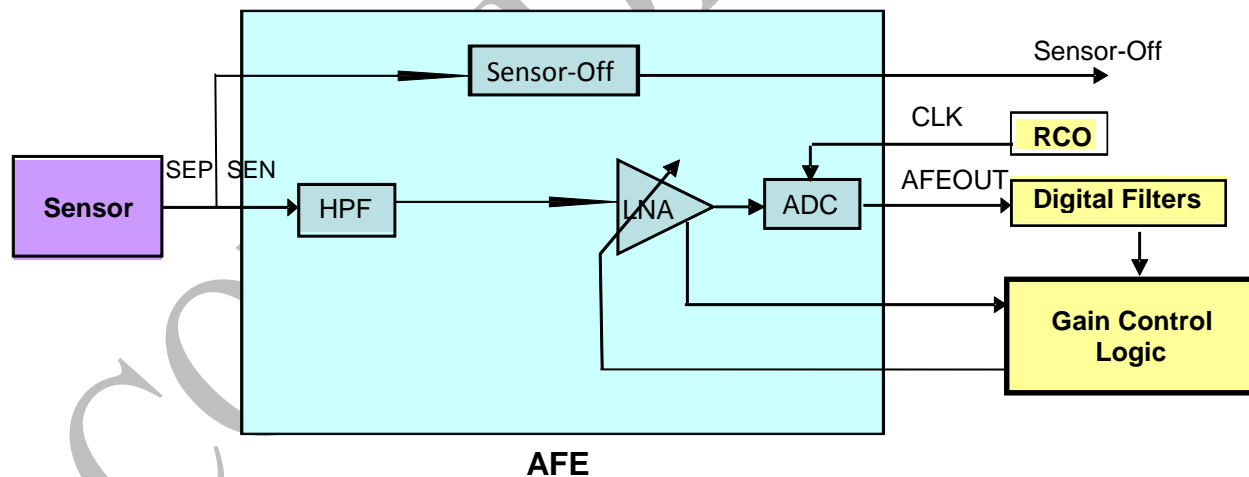


Figure 1. Block Diagram of AFE and its Interfaces to Sensor and ASIC Digital Section

The AFE receives low amplitude differential analog input signals. In case this signal contains large, slowly varying DC components, the DC is removed by a fully integrated high pass filter (HPF). The signal is then amplified by a programmable-gain low noise amplifier (LNA). The LNA output is converted to a digital bit stream by the 16-bit ADC.

BMD101 has built-in sensor-off detection capability. Any resistance between two sensor input pins that exceeds typically 19-25 Meg Ohms will trigger the sensor-off status.

Also, the BMD101 contains an internal LDO which consists of a bandgap cell to generate a 1.2V reference followed by two separate unity gain buffers, for the analog and digital supplies.

A digitally controlled oscillator (DCO) is included in the BMD101 as well, which provides a fully integrated 22.1MHz clock reference signal.

The majority of the filtering of the bio-signal in this system will be done in the digital domain. It is expected that the main interferers is due to pick-up of the local power-supply frequency, i.e. 50Hz or 60Hz, depending on the geographical region.

The BMD101 has low DC offset levels as referred to the input of the ASIC, very low input referred noise and a low noise floor. It has good SNR and very good ENOB for the ECG application ranges. BMD101 CMRR levels are also very low.

## Digital Signal Processing

After data leaves the ADC it goes through the digital filters per Figure 2.

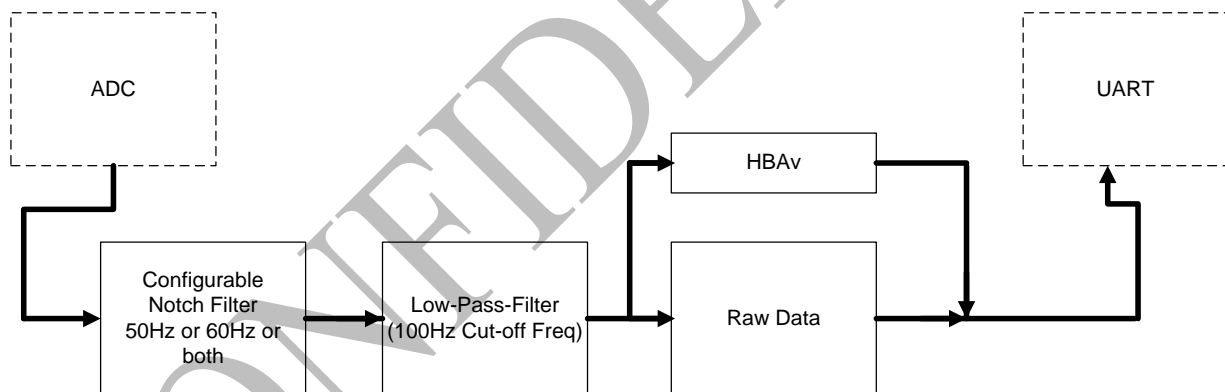


Figure 2. Digital Signal Processing Data Path

## Notch Filter

The Notch Filter is typically customized to be a 50Hz or 60Hz or both notch through configuration. The notch rejection is usually -63dB for both 60Hz and 50Hz.

## Low Pass Filter

The Low Pass Filter has 100Hz cutoff frequency. It provides a stable passband to the cutoff frequency, and -40dB at the stop frequency.

## Electrical Characteristics

### Absolute Maximum Ratings <sup>(1), (2), (3)</sup>

Symbol	Parameter	Min	Max	Units
VDD	Input Voltage	-0.1	3.6	V
V <sub>sense</sub>	Analog Input Voltage , Differential Mode	-1.0	1.0	V
T <sub>op</sub>	Operating Temperature <sup>(4)</sup>	0	70	deg. C

<sup>(1)</sup> The Absolute Maximum Ratings listed are the limits above which permanent damage to the device may, or will, occur. Continued normal operating performance is not guaranteed if the Absolute Maximum levels are exceeded.

<sup>(2)</sup> Unless otherwise noted, all Absolute Maximum Ratings listed apply within the normal BMD101 operating temperature.

<sup>(3)</sup> The Absolute Maximum Ratings listed include only the BMD101. No external circuitry is included.

<sup>(4)</sup> Entire ASIC

Table 1. BMD101 Absolute Maximum Ratings

**BMD101 Specifications, (Preliminary)**BMD101 Specifications under normal operating conditions <sup>(1),(2),(3)</sup>

Symbol	Parameter	Min	Typical	Max	Units
VDD	Input Operating Power Voltage	2.5	3.3	3.6	V
IDD	Input Operating Power Current	700	870	900	uA
V <sub>OH</sub>	Digital Output Voltage	2.4		3.6	V
V <sub>OL</sub>	Digital Output Voltage	-0.1		0.4	V
V <sub>IH</sub>	Digital "1" Input Voltage	1.6		3.6	V
V <sub>IL</sub>	Digital "0" Input Voltage	0		0.8	V
N/A	UART Baud Rate		57600		bits/sec.
V <sub>sense</sub>	Analog Input Operating Voltage	-8		8	mV
G <sub>Notch</sub>	Notch Filter Gain (50 Hz and 60 Hz)	-62 <sup>(4)</sup>	-69.6	N/A	dB
F <sub>LCO</sub>	Low Cutoff Frequency		0.5		Hz
F <sub>HCO</sub>	High Cutoff Frequency		103		Hz
CMRR	Common Mode Rejection Ratio		82	N/A	dB
SNR	Signal to Noise Ratio		68.2	N/A	dB
PSRR	Power Supply Rejection Ratio		82	N/A	dB
T <sub>op</sub>	Operating Temperature <sup>(5)</sup>	0	25	70	deg. C
HBM	Analog Input ESD Voltage <sup>(6)</sup>	-2000		2000	V

<sup>(1)</sup> Unless otherwise indicated, all parameter limits listed apply within the normal BMD101 operating temperature range.

<sup>(2)</sup> The limits listed include only the BMD101. No external circuitry is included.

<sup>(3)</sup> Gain = 128 linear for all cases.

<sup>(4)</sup> With respect to Mid Band Gain, (Mid Band is 20 Hz)

<sup>(5)</sup> Entire ASIC

<sup>(6)</sup> (Human Body Model) per ANSI/ESDA/JEDEC JS-001-2010

Table 2. BMD101 Specifications, (Preliminary)



## Digital Output Packets Format

BMD101 communicates through UART interfaces.

The main digital interface of BMD101 is the UART interface (TX/RX). It is a standard UART interface that deploys a 1 start bit, 8 data bits, and 1 stop bit format. Applications of UART can be built, based on this UART interface.

The digital output packet of the UART/TX interface follows the following scheme:

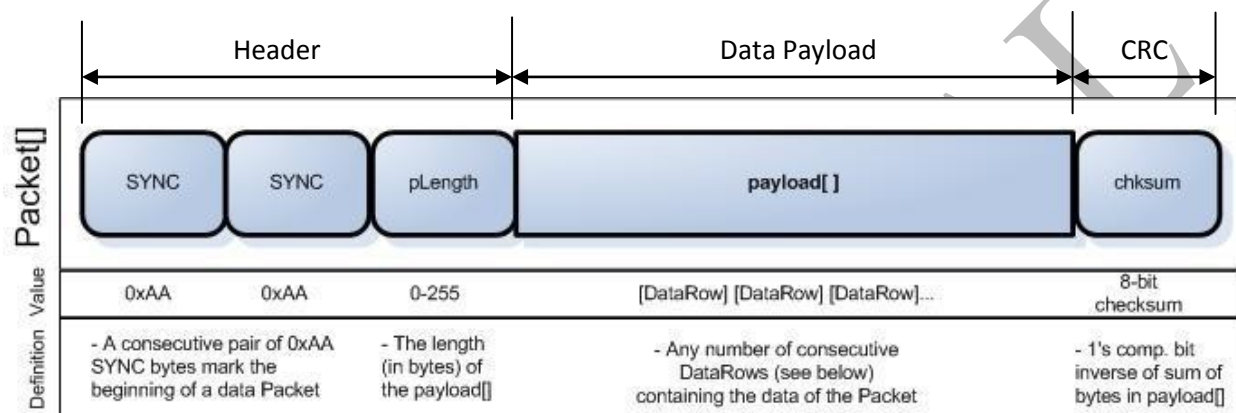


Figure 3. Digital Output Packet Format

Packets are sent as an asynchronous serial stream of bytes. Each packet begins with its Header, followed by its Data Payload, and ends with its CRC checksum byte.

The Header of a Packet consists of 3 bytes: two synchronization [SYNC] bytes (0xAA 0xAA), followed by a payload length [PLENGTH] byte. The two [SYNC] bytes are used to signal the beginning of a new arriving Packet. The [PLENGTH] byte indicates the length, in bytes, of the Packet's Data Payload.

The Data Payload of a Packet is simply a series of bytes. The number of Data Payload bytes in the Packet is given by the [PLENGTH] byte from the Packet Header. The interpretation of the Data Payload bytes is defined in detail in the "Data Payload Format" section below. Note that the Data Payload should NOT be parsed until AFTER the [CRC] Checksum is verified.

The CRC Checksum of a Packet must be used to verify the integrity of the Packet's Data Payload. The CRC Checksum is defined as:

- 1) Summing all the bytes of the Packet's Data Payload
- 2) Taking the lowest 8 bits of the sum
- 3) Performing the bit inverse (one's compliment inverse) on those lowest 8 bits

A receiver receiving a Packet must calculate the CRC Checksum of the Data Payload they received, and then compare it to the [CRC] Checksum byte received with the Packet. If calculated and received CRC values do not match, the entire Packet should be discarded as invalid. If they do match, then the Data Payload can then be parsed.

### Data Payload Format

The Data Payload itself consists of a continuous series of DataRows. Parsing a Data Payload involves parsing each DataRow until all the bytes of the Data Payload have been parsed.

A DataRow consists of bytes in the following format:

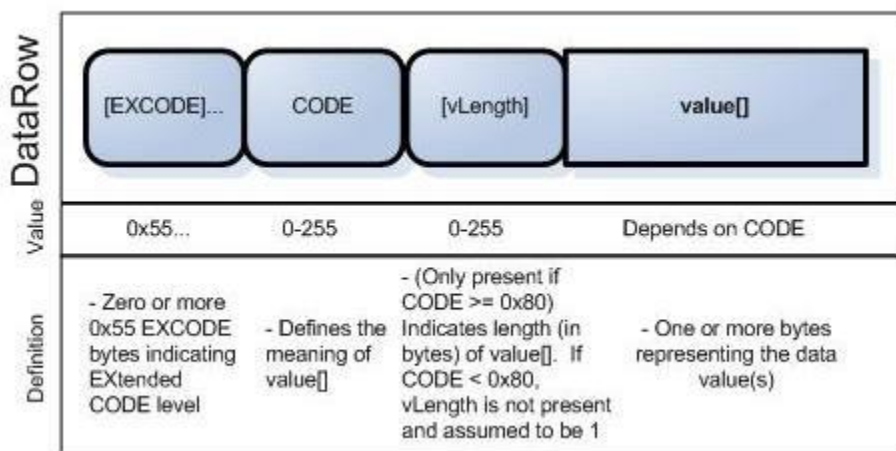


Figure 4. DataRow Format

The DataRow may begin with zero or more [EXCODE] (extended code) bytes, which are bytes with the value 0x55. The number of EXCODE bytes indicates the Extended Code Level. The Extended Code Level, in turn, is used in conjunction with the [CODE] byte to determine what type of data this DataRow contains.

The [CODE] byte indicates the type of data encoded in the DataRow. For example, a [CODE] of 0x03 indicates that the DataRow contains a heart rate value. For a list of defined [CODE] meanings, see the "[CODE] Definitions Table" below. Note that the meaning of the [CODE] is dependent on the Extended Code Level. Also note that the [EXCODE] byte of 0x55 will never be used as a [CODE] (nor will the [SYNC] byte of 0xAA).

If the [CODE] byte is between 0x00 and 0x7F, then there is no [LENGTH] byte, and the [DATA] byte immediately after the [CODE] is the 1-byte [DATA] value and the end of the DataRow.

If, however, the [CODE] byte is between 0x80 and 0xFF, then it is followed by a [LENGTH] byte indicating the number of bytes of [DATA...]. These higher [CODE]s are used for returning arrays of values, values that cannot fit in a single byte, or values that need a varying number of bytes to represent.

The format is defined in this way so that any properly implemented parser will not break in the future if new [CODE]s representing arbitrarily long [DATA...] values are added (they simply ignore unrecognized [CODE]s, but do not break in parsing), the order of [CODE]s is rearranged in the Packet, or if some [CODE]s are not always transmitted in every Packet.

[CODE] Definitions Table

Extended Code Level	[CODE]	(Byte) [LENGTH]	Data Value Meaning
0	0x02	N/A	Signal Quality (0—sensor off, 200—sensor on)
0	0x03	N/A	Real-time Heart Rate (Beats Per Minute)
0	0x08	N/A	Don't Care
0	0x80	2	16-bit Raw Data (2's Complement)
0	0x84	5	Don't Care
0	0x85	3	Don't Care

### Step-By-Step Guide to Parsing a Packet

1. Keep reading bytes from the stream until a [SYNC] byte (0xAA) is encountered.
2. Read the next byte and ensure it is also a [SYNC] byte (if not, return to step 1.)
3. Read the [PLENGTH] byte.
4. Read the next PLENGTH bytes of the [PAYLOAD...], saving them into a storage area (such as an unsigned char payload [256] array). Sum up each byte as it is read by incrementing a checksum accumulator.
5. Take the lowest 8 bits of the checksum accumulator and invert them. Here is the C code:

```
checksum &= 0xFF;
checksum = ~checksum & 0xFF;
```
6. Read the [CRC] byte and verify that it matches your calculated checksum (if not, return to step 1).
7. Loop until all bytes (and hence, DataRow's) have been parsed from the data payload[] array:
  - a) Parse and count the number of [EXCODE] bytes (0x55) that may be at the beginning of the current DataRow.
  - b) Parse the [CODE] byte for the current DataRow.
  - c) If applicable, parse the [LENGTH] byte for the current DataRow.
  - d) Parse and handle the [DATA...] byte(s) of the current DataRow, based on the DataRow's [EXCODE] level, [CODE], and [LENGTH].
  - e) If not all bytes have been parsed from the payload[] array, return to 7a. to parse the next DataRow.

## Application Block Diagram

BMD101 is a total single chip solution with very small form factor and low power consumption, suitable for portable applications. It requires almost zero effort to integrate with target systems.

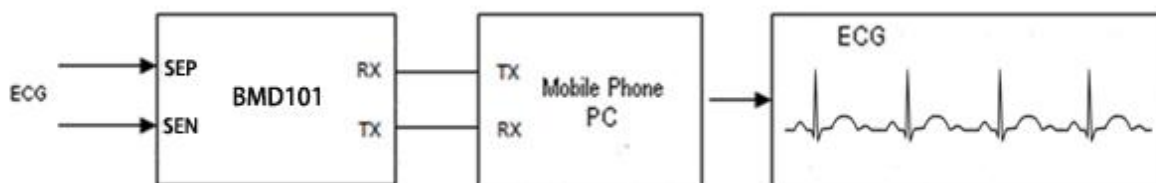


Figure 5. BMD101 Application Example

## Document Conventions

### Acronyms Definition

AFE	Analog Front End
ASIC	Application Specific Integrated Circuit
CMRR	Common Mode Rejection Ratio
CRC	Cyclic Redundancy Check
ECG	Electrocardiography
IP	Intellectual Property
LDO	Low Drop Out
POR	Power-On-Reset
SNR	Signal to Noise Ratio
TX/RX	Transmit/Receive
UART	Universal asynchronous receiver/transmitter

### Packaging Information

Orderable Device	Status	Package Type	Pins	Eco Plan <sup>(1)</sup>	MSL, Peak Temp <sup>(2)</sup>	Storage Temp <sup>(3)</sup>
NS BMD101	ACTIVE	SON	8	Pb-Free (RoHS)	Level-3-260C-168 HR	5°C - 30°C

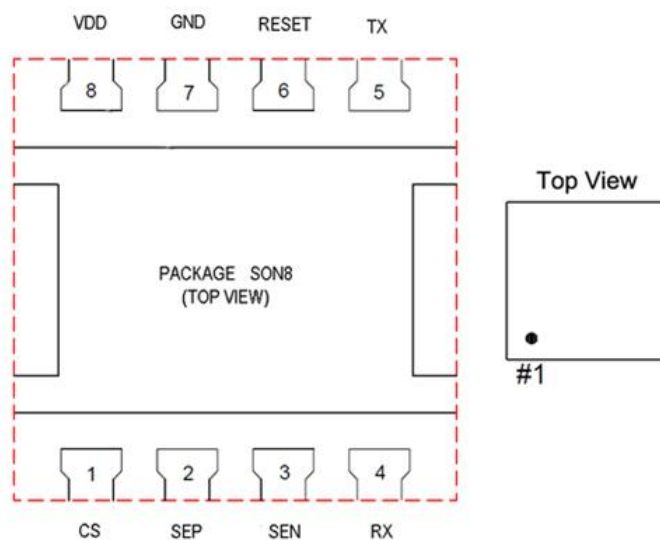


Figure 6. BMD101 Pinout

### Package Pin Assignments

Terminal	Name	Function	Direction	Comment
1	CS	Power up or down control of LDO	Input	Active high
2	SEP	Positive ECG analog input	Input	
3	SEN	Negative ECG analog input	Input	
4	RX	UART RX	Input	
5	TX	UART TX	Output	
6	RESET	System reset pin	Input	Active low
7	GND	Ground	Supply	
8	VDD	3.3V power supply	Supply	

<sup>(1)</sup> Pb-Free (RoHS) -- The term "Lead-Free" or "Pb-Free" means semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials.

<sup>(2)</sup> MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications and peak solder temperature.

<sup>(3)</sup> Recommended Temperature: room condition around 5 °C to 30 °C (can be stored for 1 year).