

1 Physical Connections and Interfaces

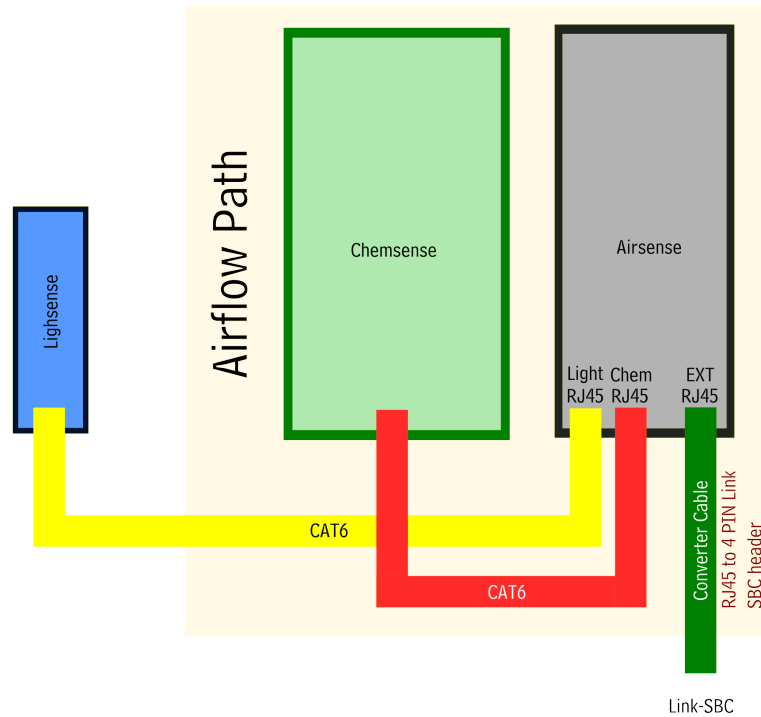


Figure 1: Connections between the sensor boards and interface to Link SBC

2 Data Transmission

The data from the sensor boards is sent as a formatted unit of data — a transmission packet. A transmission packet is composed of several data sub-packets, each of which carries information pertaining to the parameter listed in the sub-packet. The transmission packet format and the data sub-packets are described here.

2.1 Transmission Packet

A transmission packet can be broken down into 6 segments. The structure of the transmission packet (and the data sub-packet) relies on byte positions and predefined values for some segments. The first segment is the start byte or the preamble. The preamble is followed by the packet sequence number and protocol version, each of which are 4 bits long and are together packed into a single byte. Next, a one byte field that reports the length of the data which follows it immediately. The data segment is followed by a single CRC byte, and finally the packet ends with a one byte postscript. The table below lists the packet and the static values, if any, for each of the segments.

Field	Value	Segment	Length
Preamble	0xAA	1	1 Byte
Packet Sequence Number	Variable	2	1 Nibble
Protocol version	0x00	2	1 Nibble
Length of data (not whole packet)	0x9D	3	1 Byte
Data	...	4	157 Bytes
CRC of data (not whole packet)	Variable	5	1 Byte
Postscript	0x55	6	1 Byte

Table 1: Transmission Packet Segments

The table below illustrates how the segments are organized in a transmission packet.

Preamble	Seq. Number Prot. Ver.	Data Length	Data	CRC	Postscript
Byte 0	Byte 1	Byte 2	up to 255 Bytes	Penultimate Byte	Final Byte

Table 2: Transmission Packet structure

2.2 Data Packer CRC

To validate the data transmitted from the sensor board, a CRC value for the data is calculated and transmitted as part of the data packet. The Maxim 1-Wire CRC polynomial is used for calculating the CRC. On receiving the data packet, the CRC of the data packet is recalculated and compared with the value transmitted as part of the packet. If the two CRC values match, the transmission is error-free. The equivalent polynomial function of the CRC is:

$$CRC = x^8 + x^5 + x^4 + 1.$$

Further description of the Maxim 1-Wire CRC is available in Maxim Application Note 27. Below are the Python and C implementations of the CRC calculator. The CRC implementations below take a data byte and the previous CRC as inputs, and return the new CRC as return value.

Python Code:

```
def calc_crc (data_byte,CRC_Value)
    CRC_Value = ord(data_byte) ^ CRC_Value
    for j in range(8):
        if (CRC_Value & 0x01):
            CRC_Value = (CRC_Value >> 0x01) ^ 0x8C
        else:
            CRC_Value = CRC_Value >> 0x01
    return CRC_Value
```

C Code:

```
unsigned char CRC_CALC (unsigned char data, unsigned char crc)
{
    unsigned char i;
    crc ^= data;
    for (i=0x00; i < 0x08; i++)
```

```

    {
        if (crc & 0x01)
            crc = (crc >> 0x01) ^ 0x8C;
        else
            crc =  crc >> 0x01;
    }

    return(crc);
}

```

2.3 Data Sub-packets

The data segment of the transmission packet is further broken down into many sub-packets. The sub-packet starts with a source identifier. A one bit validity field and seven bits “length of the sub-packet” field are packed together as the next byte. The length field counts the number of bytes following it which make up the sub-packet. The table below shows the organization of a sub-packet. The validity bit is set to 0 if the sensor represented in the sub-packet is dead, disabled, unconnected, unresponsive or if data could not be collected from the sensor in the time window. Instead of recreating the full packet in the buffer, sans the particular sub-packet, the sensor segment is marked as invalid. If the field is set to 1, it indicates a valid measurement/reading. The seven bits length field restricts the size of the sub-packet to 127 bytes.

Source ID	1-bit Validity [0: invalid, 1: valid] 7-bits Length	Data
Byte 0	Byte 1	up to 127 Bytes

3 Data Formats

The data sent in each sub-packet is encoded in one or more formats. Currently we define eight formats for various types of data including integers, bytes, and floating point numbers. The numerical range of these representations is restricted to within the bounds of values that we expect from the various sensors and other sources. Thus the encoding schemes are specifically designed to effectively and efficiently encode the values expected in the sensor streams. The eight formats, and the encoding schemes are listed below.

Format	Number of Bytes Used	Value Represented	Value Range
1	2	unsigned int_16 input	0 – 65535
2	2	int_16 input	$\pm\{0 - 32767\}$
3	6	byte input[6]	0x00 – 0xffffffff
4	3	unsigned long_24 input	0 – 16777215
5	3	long_24 input	$\pm\{0 - 8388607\}$
6	2	float input	$\pm\{0 - 127.99\}$
7	4	byte input[4]	0x00 – 0xffffffff
8	2	float input	$\pm\{0 - 31.999\}$

Table 3: Data formats

3.1 Format 1

This 2 byte format is used to transmit an integer between 0 and 65535. The number is split and serialized as follows –

8 Most Significant Bits	8 Least Significant Bits
Byte 0	Byte 1

3.2 Format 2

This 2 byte format is used to transmit an integer between -32767 and 32767. The number is split and serialized as follows –

Sign Bit 7 Most Significant Bits	8 Least Significant Bits
Byte 0	Byte 1

The Sign Bit which is the most significant bit in Byte 0 is set as follows —

Positive Integer	0
Negative Integer	1

3.3 Format 3

This 6 byte format is used to transmit an array of 6 bytes. The array is serialized as follows –

Array[0]	Array[1]	Array[2]	Array[3]	Array[4]	Array[5]
Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5

3.4 Format 4

This 3 byte format is used to transmit an integer between 0 and 16777215. The number is split and serialized as follows –

8 Most Significant Bits	Bits 15 – 8	8 Least Significant Bits
Byte 0	Byte 1	Byte 2

3.5 Format 5

This 3 byte format is used to transmit an integer between -8388607 and 8388607. The number is split and serialized as follows –

Sign Bit 7 Most Significant Bits	Bits 15 – 8	8 Least Significant Bits
Byte 0	Byte 1	Byte 2

The Sign Bit which is the most significant bit in Byte 0 is set as follows —

Positive Integer	0
Negative Integer	1

3.6 Format 6

This 2 byte format is used to transmit a floating point number between -127.99 and 127.99. Only 2 fractional places are allowed in this format and the number is serialized as follows –

Sign Bit 7 bit representation of Integer part	0 7 bit representation of the Fractional part
Byte 0	Byte 1

As shown above, the leading bit of the Byte 1 is always set to 0, and the Sign Bit which is the most significant bit of Byte 0 is set as follows —

Positive Number	0
Negative Number	1

3.7 Format 7

This 4 byte format is used to transmit an array of 4 bytes. The array is serialized as follows –

Array[0]	Array[1]	Array[2]	Array[3]
Byte 0	Byte 1	Byte 2	Byte 3

3.8 Format 8

This 2 byte format is used to transmit a floating point number between -31.999 and 31.99. Only 3 fractional places are allowed in this format and the number is serialized as follows –

Sign Bit 5 bit representation of Integer 2 most significant bits of fraction	8 least significant bits of the fraction
Byte 0	Byte 1

As shown above, the format uses 5 bits for representing the integer part and 10 bits to represent the fractional part. The Sign Bit which is the most significant bit of Byte 0 is set as follows —

Positive Number	0
Negative Number	1

4 Parameters

The sensor boards output a set of parameters which are identified by a unique ID. Each parameter has a set of values associated with it which are encoded in an appropriate data format. The table below lists the various parameters produced by the sensor boards, the unique source ID used to identify them, the values produced by them and the format in which the value is encoded.

Parameter	Source ID	Values and Formats
Airsense MAC address	0x00	MAC Address – Format 3
TMP112	0x01	Temperature – Format 6
HTU21D	0x02	Temperature and Humidity – Format 6
HIH4030	0x03	Humidity – Format 1
BMP180	0x04	Temperature – Format 6 & Pressure – Format 4
PR103J2	0x05	Temperature – Format 1
TSL250RD	0x06	Visible Light – Format 1
MMA8452Q	0x07	3 Accelerations and Vibration – Format 6
SPV1840LR5H-B	0x08	RMS Sound Level – Format 1
TSYS01	0x09	Temperature – Format 6
HMC5883L	0x0A	3 Magnetic Fields – Format 8
HIH6130	0x0B	Temperature and Humidity – Format 6
APDS-9006-020	0x0C	Visible Light – Format 1
TSL260RD	0x0D	IR Light – Format 1
TSL250RD	0x0E	Visible Light – Format 1
MLX75305	0x0F	Light – Format 1
ML8511	0x10	Light – Format 1
MLX90614	0x12	Temperature – Format 6
TMP421	0x13	Temperature – Format 6
Total reducing gases	0x15	Raw Concentration – Format 5
Nitrogen dioxide	0x17	Raw Concentration – Format 5
Ozone	0x18	Raw Concentration – Format 5
Hydrogen sulphide	0x19	Raw Concentration – Format 5
Total oxidizing gases	0x1A	Raw Concentration – Format 5
Carbon monoxide	0x1B	Raw Concentration – Format 5
Sulfur dioxide	0x1C	Raw Concentration – Format 5
SHT25	0x1D	Temperature & Humidity – Format 2
LPS25H	0x1E	Temperature – Format 2 & Pressure – Format 4
Si1145	0x1F	UV intensity – Format 1
Chemsense MAC address	0x20	MAC Address - Format 3

Table 4: Data sub-packet structure (each row is a "chunk")

Each parameter and its values are composed into a sub-packet based on the format described in document section 2.3. In the

case of parameters with 2 or more values, the encoded values are arranged in the sub-packets sequentially. The context of each parameter, its utility and the arrangement of its values is described below. In all the tables below, the validity bit is set to 1. The parameter descriptions below are aggregated based on the sensor-board they are situated on - Airtense, Lightsense and Chemsense.

4.1 Airtense:

4.1.1 Airtense MAC address

This is a six byte ID that uniquely identifies each Airtense board. The ID is provided by a DS2401 1-Wire DSN chip. The 1-byte family ID and CRC provided by the DSN chip are omitted, and the rest six bytes are used as the Unique ID. The Unique ID uses Format 3 for encoding and the arrangement is listed below.

0x00	0x86	ID in Format 3
Byte 0	Byte 1	Bytes 2 — 7

4.1.2 TMP112

TMP112 is a digital temperature sensor, which provides the temperature values in centigrade.

0x01	0x82	Temperature in Format 6
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	°C	None	None

4.1.3 HTU21D

HTU21D is a digital temperature and humidity sensor, which provides relative humidity value (%RH) and temperature value in centigrade.

0x02	0x84	Temperature in Format 6	%RH in Format 6
Byte 0	Byte 1	Bytes 2 & 3	Bytes 4 & 5

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	°C	None	None
Relative Humidity	%RH	None	None

4.1.4 HIH4030

HIH4030 is an analog humidity sensor, which provides an analog voltage representative of the relative humidity. The analog voltage is converted and packed into Format 1 using a 10-bit ADC.

0x03	0x82	RH in Format 1
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Relative Humidity	raw integer	Bulk Curve Fitting	%RH

4.1.5 BMP180

BMP180 is an digital temperature and barometric pressure sensor, which provides temperature in centigrade and pressure in hectopascals.

0x04	0x85	Temperature in Format 6	Pressure in Format 4
Byte 0	Byte 1	Bytes 2 & 3	Bytes 4 — 6

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	°C	None	None
Atmospheric Pressure	hPa	None	None

4.1.6 PR103J2

PR103J2 is an analog temperature sensor whose resistance changes with change in temperature. The sensor is implemented in a voltage divider circuit, and the center-tap voltage is converted and packed into Format 1 using a 10-bit ADC.

0x05	0x82	Temperature in Format 1
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	raw integer	Bulk Curve Fitting	°C

4.1.7 TSL250RD

TSL250RD is an analog visible light sensor that produces an analog voltage that is representative of the irradiance measured in $\mu\text{W}/\text{cm}^2$. The output voltage of the sensor is converted and packed into Format 1 using a 10-bit ADC.

0x06	0x82	Light intensity in Format 1
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Light Intensity	raw integer	Bulk Curve Fitting	$\mu\text{W}/\text{cm}^2$

4.1.8 MMA8452Q

MMA8452Q is a digital 3-axis accelerometer. The accelerations in 3 orthogonal directions, x, y and z, as a multiple of acceleration due to gravity (g) are obtained from the sensor, and a vibration value (represented as multiple of g) is calculated using high-frequency time series data from the three axis.

0x07	0x88	Acc. X in Format 6	Acc. Y in Format 6	Acc. Z in Format 6	Vibration in Format 6
Byte 0	Byte 1	Bytes 2 & 3	Bytes 4 & 5	Bytes 6 & 7	Bytes 8 & 9

Value	Board Output	Post-Processing Mode	Post-processed Output
Acc. X	g	none	none
Acc. Y	g	none	none
Acc. Z	g	none	none
Vibration	g	none	none

4.1.9 SPV1840LR5H-B

SPV1840LR5H is a MEMS microphone that is sampled at high frequency to obtain the peaks and calculate the sound intensity for a time window. The raw calculated intensity is represented as a 16-bit integer value using Format 1.

0x08	0x82	Sound Intensity in Format 1
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Sound Intensity	raw integer	Bulk Curve Fitting	dB

4.1.10 TSYS01

TSYS01 is a digital temperature sensor, which provides the temperature values in centigrade.

0x09	0x82	Temperature in Format 6
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	°C	None	None

4.2 Lightsense:

4.2.1 HMC5883L

HMC5883L is a digital 3-axis magnetometer. The magnetic field strengths in 3 orthogonal directions, x, y and z are obtained from the sensor.

0x07	0x88	Field strength X in Format 8	Field strength Y in Format 8	Field strength Z in Format 8
Byte 0	Byte 1	Bytes 2 & 3	Bytes 4 & 5	Bytes 6 & 7

Value	Board Output	Post-Processing Mode	Post-processed Output
Mag. Field X	Gauss	none	none
Mag. Field Y	Gauss	none	none
Mag. Field Z	Gauss	none	none

4.2.2 HIH6130

HIH6130 is a digital temperature and humidity sensor, which provides relative humidity value (%RH) and temperature value in centigrade.

0x0b	0x84	Temperature in Format 6	%RH in Format 6
Byte 0	Byte 1	Bytes 2 & 3	Bytes 4 & 5

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	°C	None	None
Relative Humidity	%RH	None	None

4.2.3 APDS-9006-020

APDS-9006-020 is an analog visible light sensor that produces an analog voltage that is representative of the general luminance. The output voltage of the sensor is converted and packed into Format 1 using a 16-bit ADC.

0x0c	0x82	Raw luminance in Format 1
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Ambient Light Intensity	raw integer	Bulk Curve Fitting	$\mu\text{W}/\text{cm}^2$

4.2.4 TSL260RD

TSL260RD is an analog Near-infrared light sensor that produces an analog voltage that is representative of the irradiance measured in $\mu\text{W}/\text{cm}^2$. The output voltage of the sensor is converted and packed into Format 1 using a 16-bit ADC.

0x0d	0x82	Near-infrared intensity in Format 1
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Near-infrared Intensity	raw integer	Bulk Curve Fitting	$\mu\text{W}/\text{cm}^2$

4.2.5 TSL250RD

TSL250RD is an analog visible light sensor that produces an analog voltage that is representative of the irradiance measured in $\mu\text{W}/\text{cm}^2$. The output voltage of the sensor is converted and packed into Format 1 using a 16-bit ADC.

0x0e	0x82	Light intensity in Format 1
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Ambient Light Intensity	raw integer	Bulk Curve Fitting	$\mu\text{W}/\text{cm}^2$

4.2.6 MLX75305

MLX75305 is an visible light sensor that produces an analog output that is representative of the light intensity. The output voltage of the sensor is converted and packed into Format 1 using a 16-bit ADC.

0x0f	0x82	Light intensity in Format 1
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Ambient Light Intensity	raw integer	Bulk Curve Fitting	$\mu\text{W}/\text{cm}^2$

4.2.7 ML8511

ML8511 is an ultra-violet light sensor that produces an analog output that is representative of the ultra-violet light intensity. The output voltage of the sensor is converted and packed into Format 1 using a 16-bit ADC.

0x10	0x82	UV intensity in Format 1
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
UV Light Intensity	raw integer	Bulk Curve Fitting	$\mu\text{W}/\text{cm}^2$

4.2.8 MLX90614

MLX90614 is an IR digital temperature sensor, which provides the temperature values in centigrade.

0x12	0x82	Temperature in Format 6
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	$^{\circ}\text{C}$	None	None

4.2.9 TMP421

TMP421 is a digital temperature sensor, which provides the temperature values in centigrade.

0x13	0x82	Temperature in Format 6
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	$^{\circ}\text{C}$	None	None

4.3 Chemsense:

4.3.1 Total reducing gases

This parameter provides the current output of the electrochemical ToR sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x13	0x82	Raw current value in Format 5
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.3.2 Nitrogen dioxide

This parameter provides the current output of the electrochemical NO₂ sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x13	0x82	Raw current value in Format 5
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.3.3 Ozone

This parameter provides the current output of the electrochemical O₃ sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x13	0x82	Raw current value in Format 5
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.3.4 Hydrogen sulphide

This parameter provides the current output of the electrochemical H₂S sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x13	0x82	Raw current value in Format 5
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.3.5 Total oxidizing gases

This parameter provides the current output of the electrochemical ToX sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x13	0x82	Raw current value in Format 5
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.3.6 Carbon monoxide

This parameter provides the current output of the electrochemical CO sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x13	0x82	Raw current value in Format 5
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.3.7 Sulfur dioxide

This parameter provides the current output of the electrochemical SO₂ sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x13	0x82	Raw current value in Format 5
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.3.8 SHT25

SHT25 is a temperature and humidity sensor. The temperature and humidity raw values are encoded in Format 2.

0x13	0x84	Raw temperature value in Format 2	Raw humidity value in Format 2
Byte 0	Byte 1	Bytes 2 & 3	Bytes 4 & 5

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	raw integer	Bulk Curve Fitting	°C
Humidity	raw integer	Bulk Curve Fitting	%RH

4.3.9 LPS25H

LPS25H is a temperature and pressure sensor. The temperature and pressure raw values are encoded in Format 2 and Format 4 respectively.

0x13	0x85	Raw temperature value in Format 2	Raw pressure value in Format 4
Byte 0	Byte 1	Bytes 2 & 3	Bytes 4 — 6

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	raw integer	Bulk Curve Fitting	°C
Atmospheric Pressure	raw integer	Bulk Curve Fitting	hPa

4.3.10 Si1145

Si1145 is an Ultra-violet sensor. The raw output from the sensor is encoded Format 1.

0x13	0x83	Raw UV intensity in Format 1
Byte 0	Byte 1	Bytes 2 & 3

Value	Board Output	Post-Processing Mode	Post-processed Output
UV Intensity	raw integer	Bulk Curve Fitting	$\mu\text{W}/\text{cm}^2$

4.3.11 Chemsense MAC address

This is a six byte ID that uniquely identifies each Chemsense board. The Unique ID uses Format 3 for encoding and the arrangement is listed below.

0x00	0x86	ID in Format 3
Byte 0	Byte 1	Bytes 2 — 7