5. Theory of Operation/Technical Description

Wireless Link Digital Telemetry Systems are accomplished with an optimum mix of analog and digital circuitry in order to provide a low-cost, flexible system capable of handling a wide variety of telemetry requirements. Utilization of state-of-the-art design technology combined with a latest generation micro-controller allows the design to meet requirements of a high performance, high reliability communications link for transferring measurement data while still maintaining a highly cost-effective price.

Transmitter Details

The following figure presents a more detailed overview of a Digital Telemetry Transmitter.

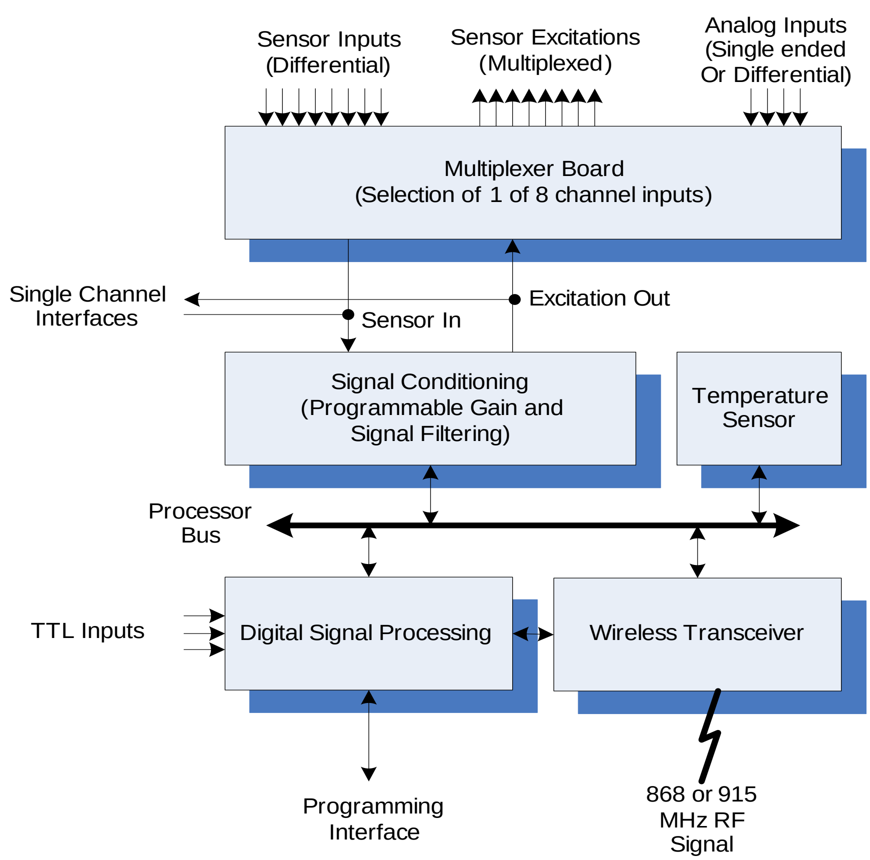

FIGURE 2-1 Transmitter Block Diagram

At the heart of the transmitter design is a high-speed processor with analog to digital conversion capabilities. Execution processing of the processing logic is determined via configuration data stored within electronically erasable programmable read-only-memory (EEPROM). The

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configuration tables contained within this memory dictates operational characteristics such as the number of input sensor channels, the type of each input, output RF frequency selection, and so forth.

EEPROM memory space within the transmitter, including both configuration tables and executable program space, can be reprogrammed via the external programming interface to the Digital Telemetry Receiver. As such, all significant operational characteristics of the Transmitter can be readily modified or customized, even for fielded units.

For transmitters limited to a single input sensor channel, onboard circuitry is available to process the input measurement data through signal conditioning circuitry. When the number of input sensor channels exceeds one (1), an optional multiplexer card is provided. This card includes up to an eight (8) to one (1) multiplexer to support connecting multiple sensor channels to the single input of the main board. All sensor-input logic also includes associated excitation voltage output circuitry that may be utilized to drive sensors requiring an input voltage, such as balanced bridges.

Operation of the signal conditioning logic is controlled via the processor to establish appropriate gain settings. This powerful feature of the design allows the same circuitry to be reprogrammed to support a wide variety of potential input sensor types. Furthermore, because the sensor type information is also included in the EEPROM configuration tables, these settings can be changed for various user requirements on a sensor by sensor basis.

Series 500e systems also include programmable filtering. This allows for configurable settings of the sensor input filtering based on sample rates through the ADC as well as signal multiplexing requirements for multiple channel systems.

In addition to sensor inputs, multiple channel systems also include analog channel inputs. These four (4) inputs are typically pre-conditioned signals ranging up to 0-5 VDC for single ended inputs. Alternatively, the analog inputs can be paired to provide two (2) differential inputs with ranges up to $\pm$2.5 VDC. When activated, these channels replace the corresponding channels of sensor inputs.

Data transmission across the wireless link is accomplished with dual data channels known as the primary and the background channels respectively. The primary data channel is allocated in excess of 90% of the transmit bandwidth and includes the input sensor data measurement information. The background channel is relatively low rate and contains information required for receive side frame synchronization and error detection.

Another key feature to the design is that the background channel is also utilized to transmit data pertaining to the current transmitter operating temperature. This information is utilized to support real-time temperature based compensation of sensor data samples through the receive chain. The background channel also includes lower rate sampling of discrete TTL inputs.

Series 500e systems support transmit frame formats compatible with either 16-bit, 12-bit or 8-bit ADC sensor sampling. This programmable feature provides for higher sampling rates when in 8-

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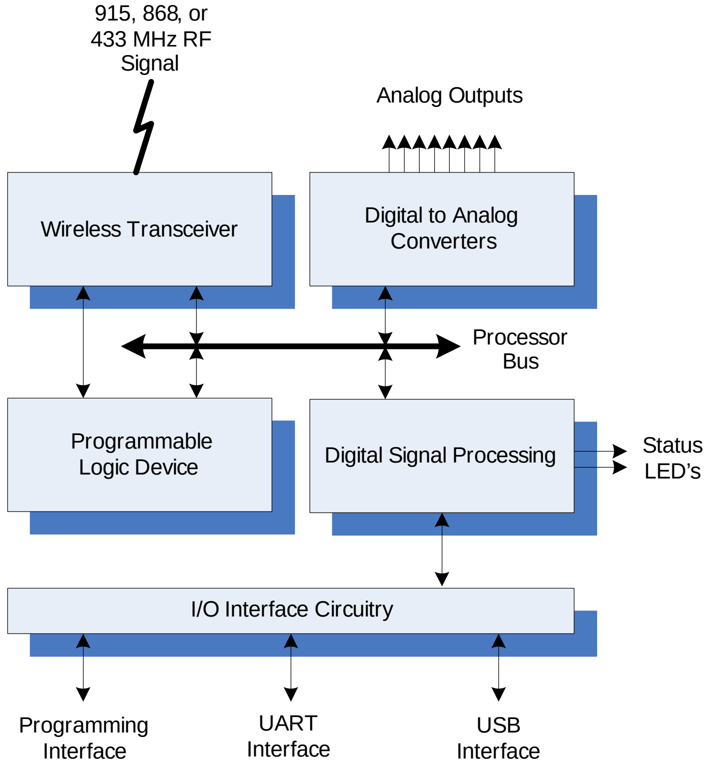
bit mode, while supporting enhanced measurement resolution at slightly lower sampling rates when in 12 bit or 16 bit modes.

Receiver Details

Figure 2-2 presents a more detailed overview of the Series 500e Digital Telemetry Receivers.



Receiver Block Diagram

The receiver incorporates a high-speed digital signal processor to provide for full real time processing of incoming measurement samples. Logic within the processor interfaces with the Wireless Link receiver via a high speed programmable logic device (PLD) to recover bit, byte, word, and frame synchronization with the incoming data stream. The process of achieving this level of synchronization is known as the acquisition process and is in-turn reflected on the front panel "SYNC" indicator. Once frame synchronization has been achieved, the "SYNC" indicator is illuminated.

After proper acquisition, the processor begins performing error detection functions via embedded checksums within the incoming data. All received data samples during a frame detected to have an error within it are flagged as error samples.

The data samples are processed through configurable data processing prior to outputting the data to analog and digital output channels. Data processing, in this case, may include standard gain adjustment multiplication, offset addition, transmitter temperature dependent data compensation, as well as alternate data averaging and or filtering functions.

Program execution of the processor is directed via code and configuration tables stored in EEPROM memory space resident within the device. The contents of this memory space can be loaded via the remote control RS-232 interface to a standard personal computer. This feature allows fielded Digital Telemetry Receiver systems to be upgraded to new releases of executable firmware, or modified to support new transmitters or alter the processing characteristics of existing transmitters.

The minimum configuration of a Digital Telemetry Receiver supports eight (8) analog output channels. These onboard channels, designated as Analog Channels 1 through 8, support 16 bits of data resolution and can be programmed to cover an entire output voltage range of -10 to +10 VDC.

System Data Processing Overview

The Series 500e products can be configured to process input sensor measurements anywhere within the range of 0 to 5VDC. Typically, instrumentation sensors do not utilize this entire measurement range. For instance, a single active arm, 350Ω strain gage with 5V excitation will only produce a ±1.25 millivolt DC (mVDC) signal for strain levels of ±500 microstrain (uE). Obviously, these signal levels are not overly useful to most end-user processing equipment.

To create a useful signal, the product line provides programmable gain, offset, and data filtering functions on the input sensor signals. The following sections describe this processing in more detail.

Gain and Offset Processing

The Digital Telemetry process applies various stages of gain to the input signal such that the configured measurement input levels of the sensor end up corresponding to a specified output analog voltage range (e.g., -10 to +10VDC). For the strain gage example, this implies a gain of x 8000 in order to translate -1.25 mVDC to -10 VDC and +1.25 mVDC to +10 VDC.

A gain of this magnitude is never 100% accurate. Furthermore, small errors introduced by the exact mechanical installation of the sensor, ground differentials, cabling losses, or transmitter sensor input to digital measurement processing circuitry end up causing additional errors. These errors are reflected as incorrect gain or variations in offset (i.e., where a 0 reading does not correspond to a 0 output).

In order to compensate for these factors, the Digital Telemetry System provides programmable gain and offset controls that are invoked at various stages within the system. The following figure provides a very simplistic overview of this process.

(**Sensor Input** × **System Gain**) + **System Offset** = **Output Value**

<u>VDC Voltage</u>
Unipolar Range limited from 0 to +5 VDC or Bipolar Range limited from -2.5 to +2.5 VDC. Installation, connection, or sensor interface circuitry characteristics contribute to gain and offset errors.

<u>Multiplier Value</u>
Accomplished via Programmable Gain Amplification in Digital Telemetry Transmitter combined with Digital Multiplier in Receiver

<u>Adder Value</u>
Accomplished via Digital Adder in Receiver (limited to -10.00 to +20.00).

<u>Analog or Digital Representation of Output VDC Voltage</u>
Programmable for output range from -10 to +10 VDC.

Data Processing Overview

The system gain and offset values are set to not only translate the input measurement signal range to the desired analog output voltage range, but are also utilized to account for the gain and offset errors discussed above.

The following figure presents a more detailed view of the entire signal processing of the Digital Telemetry System.

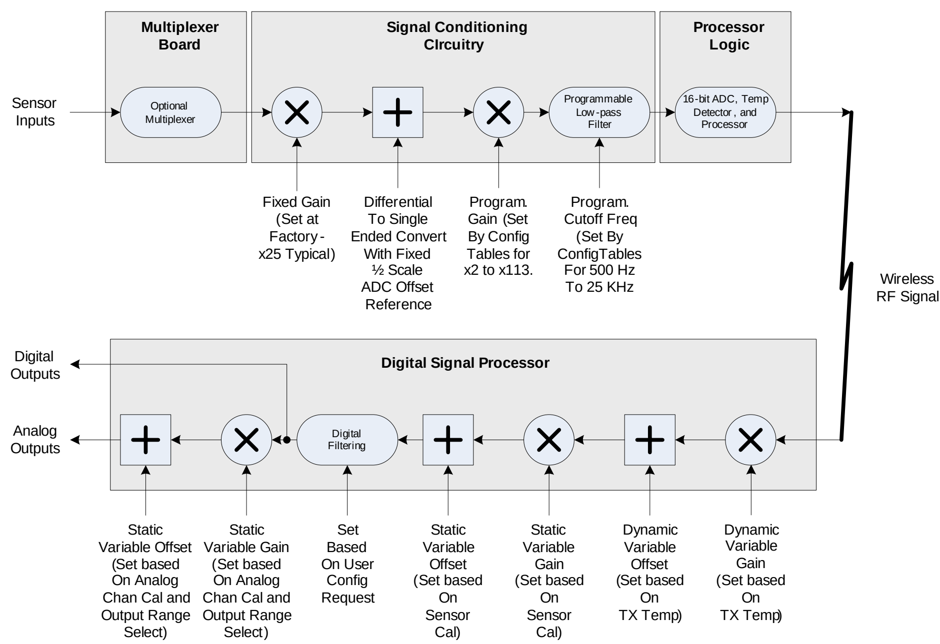


FIGURE 2-4 Data Processing Details

Normal sensor inputs are processed through three (3) stages of conditioning prior to digitization. All input signals through this path are treated as differential inputs. As such, for sensor inputs with a grounded negative lead, the sensor ground must be left floating with respect to the transmitter ground.

The first stage applies a fixed gain, typically set for x25. On a custom basis, this fixed gain may range anywhere from x1 to x50 based on end user requirements. The fixed gain is accomplished with a low noise, differential instrumentation amplifier, thus providing enhanced conditioning performance through the transmit system, including high common mode rejection.

The next stage establishes the offset to the input signal, bringing it to the center point of the analog to digital converter (ADC) range. This process also converts the differential signal to its single ended equivalent.

The next process provides a programmable gain stage. With a gain varying from x2 to x113, this stage provides the final amplification to the required input range for the ADC. Typically, transmit side gain is limited to cover 90% of the ADC range, which precludes sensor gain and offset errors from saturating the ADC.

All programmable logic on the transmit side may change on a per channel basis for multi-sensor channel systems. This allows for freely mixing sensor types or measurement ranges with the same transmitter product. However, these settings are classified as static in that they are established by the PC control software and downloaded into the transmitters EEPROM space. While the transmit logic will change these settings for each channel, they are not changed in response to any other dynamic conditions, such as transmitter temperature.

The receive side provides the final gain and offset processing of the system. This gain/offset is not only utilized to convert the signal to the selected output range of the digital to analog conversion (DAC) for analog channels (0-5, 0-10, ±5, or ±10 VDC), but also accounts for gain/offset errors of the input sensor signal, as well as dynamic characteristics of the transmitter system.

The first part of the processing through the receive side is dependent upon the transmitter operational temperature at the time of the measurement. The transmitter logic monitors its own temperature and periodically reports this value across the wireless link. This allows the receive side to dynamically compensate for gain/offset variations of the transmitter due to temperature. A highly accurate factory calibration of each transmitter product across temperature provides the means for precise measurements in the field.

For sensor data which varies with temperature (e.g., thermocouples), the dynamic gain/offset compensation feature is utilized to modify the receiver gain multiplier and offset adder to compensate for these real time variations. Thus, the system automatically provides the 0 reference junction for these types of devices.

This dynamic gain/offset processing is followed by additional static logic which is controlled by PC software sensor calibration processing logic. This feature is utilized to correct installation specific errors of the individual sensors. For example, an offset error in the installation of a strain gage would be compensated for by this level of static gain/offset corrections.

Digital samples output from the receiver via either the RS-232 serial or the USB port are limited to these corrections only. Digital samples are always represented as 16 bit signed outputs and thus range from -32768 to +32767. The -32768 will always correlate to the minimum configured measurement value for the sensor, while +32767 will correlate to the maximum configured measurement value.

A final stage of static corrections is applied to account for analog channel output errors. This process is controlled by analog channel calibration logic of the PC control software combined with the operator selected output range of the channel (i.e. 0-5V, ±5 V, 0-10 V, or ±10 V). This mechanism provides for highly accurate outputs for either digital or analog sample formats.

Analog input signals to the transmitter (i.e., 0-5 VDC single ended or ±2.5 VDC differential signals as opposed to <±45 mV sensor inputs) are processed directly into the ADC through a voltage divider, bypassing the entire discrete signal conditioning circuitry. Since these signals are not buffered, they exhibit high source impedance and typically require an external driver. The analog input signals can be grouped to form a pair of differential input analog inputs through the ADC. After digitization, all remaining gain/offset logic through the receive logic is identical to normal sensor inputs.

Data Filtering

In addition to offset and gain processing, the transmit logic supports low pass filtering which typically provides anti-aliasing protection through the digital sampling process. However, for multiplexed sensor system, the cutoff frequency through the filter must be increased to provide for the required switching speed of the multiplexer, thus allowing some minimal amount of aliasing be passed. The PC support software automatically sets the cut-off frequency of this filter based on the requested data rate and channel configuration of the transmitter.

The receive side processing supports digital data filtering of the measurement samples. Filtering may be utilized to eliminate high frequency noise from the sensor inputs which may be present due to power supply noise or other equipment operating near the telemetry system.

The first type of filter which may be applied is known as an “Infinite Impulse Response” (or IIR) filter, since any given input sample affects all future outputs. The formula for this filter is:

```
OUT(n) = (K x IN(n)) + ((1-K) x OUT(n-1))
```

In this formula, OUT(n) implies the output value to the analog channel for time period “n”, while IN(n) implies the new measurement sample for the analog channel during time period “n”. K is a simple constant that may be programmed to be equal to 1/2 to 1/256 in denominator multiples of 2.

The second type of filter which may be applied is known as an averaging filter. In this case, multiple samples are accumulated and then the average of the accumulation is output after a fixed sample period. The sample period may be set to 2 to 256 samples in multiples of 2.

Sample Rate and Throughput Delays

The sampling rate of the sensor channels inputs is dependent upon:

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a) Wireless Link Transmit Data Rate
b) Configured Resolution of ADC Samples (i.e., 8, 12, or 16)
c) Number of Active Sensor Channels

These same factors affect the fixed system throughput delay (i.e. time from sensor sampling through corresponding output on the receivers digital or analog ports. The following table summarizes these timing characteristics of the Digital Telemetry System.

Table 2-1 Sample Rate and Throughput Delay Characteristics

TX Data Rate (bps)	ADC Resolution (bits)	# of Active Sensor Channels	Sensor Sample Rate (Hz)	Throughput Delay (approx. msec)
152300	8	1	16922	3.90
152300	8	2	8461	4.02
152300	8	4	4231	4.25
152300	8	8	2115	4.73
152300	12	1	9519	3.57
152300	12	2	4759	3.78
152300	12	4	2380	4.20
152300	12	8	1190	5.04
152300	16	1	8461	4.02
152300	16	2	4231	4.25
152300	16	4	2115	4.73
152300	16	8	1058	5.67
76150	8	1	8461	7.80
76150	8	2	4231	8.04
76150	8	4	2115	8.51
76150	8	8	1058	9.46
76150	12	1	4759	7.14
76150	12	2	2380	7.56
76150	12	4	1190	8.40
76150	12	8	595	10.09
76150	16	1	4231	8.04
76150	16	2	2115	8.51
76150	16	4	1058	9.46
76150	16	8	529	11.35
38075	8	1	4231	15.60
38075	8	2	2115	16.07
38075	8	4	1058	17.02
38075	8	8	529	18.91
38075	12	1	2380	14.29
38075	12	2	1190	15.13
38075	12	4	595	16.81
38075	12	8	297	20.17
38075	16	1	2115	16.07
38075	16	2	1058	17.02
38075	16	4	529	18.91
38075	16	8	264	22.69
19037.5	8	1	2115	31.20
19037.5	8	2	1058	32.15

TX Data Rate (bps)	ADC Resolution (bits)	# of Active Sensor Channels	Sensor Sample Rate (Hz)	Throughput Delay (approx. msec)
19037.5	8	4	529	34.04
19037.5	8	8	264	37.82
19037.5	12	1	1190	28.58
19037.5	12	2	595	30.26
19037.5	12	4	297	33.62
19037.5	12	8	149	40.34
19037.5	16	1	1058	32.15
19037.5	16	2	529	34.04
19037.5	16	4	264	37.82
19037.5	16	8	132	45.38

Digital Telemetry Control Software

Each Digital Telemetry System is delivered with Control Software compatible with running on a standard Personal Computer (PC) operating under the Windows operating system. This software provides a number of critical functions for the system, including the following:

- Communications Analysis Functions
  - On-line monitoring of communications performance
  - Analysis of communications frequencies

- System Calibration
  - Modifications to system gain and offset settings
  - Calibration of output analog channels

- Table Control Functions
  - Edit functions of currently defined Digital Telemetry Systems
  - Download functions to update or restore EEPROM memory space

Transmit Antenna

Each ST-540e Transmitter is supplied with an antenna, Antenna Factor, Inc. Model ANT-916-CW-RH or equivalent. The antenna specification sheet is below.