

An Embedded Data System with Free-Space Optical Data Transmissions and a Magnetic Power Coupling

Hiroyuki Kumagai[†]
AerospaceComputing, Inc.
Los Altos, California

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ABSTRACT

A small data acquisition system based on an embedded system has been developed. The system can be mounted on a stationary frame as well as a rotating frame. The data can be transmitted via a semi-diffused infrared beam without any special media such as fiber optics. A magnetic power coupling was also developed to transfer power to the system when it is mounted on a rotating frame. This combination of the optical data transmission and magnetic power transmission completely eliminates the need for the traditional electro-mechanical slip rings when the data acquisition system is mounted on a rotating frame.

1.0 Introduction

In a typical wind tunnel test environment at NASA/Ames Research Center, the wind tunnel model and the facility instrumentation often require a few thousand data channels. In such a complex system, wiring an individual sensor to a dedicated rack-mount amplifier can present difficulties in cabling. In the National Full Scale Aerodynamics Complex (NFAC) with test sections as large as 80- by 120-ft, cables used to connect the sensors to the amplifiers are typically over 100 ft long. Transmission of low level signals over such long cables degrades the Signal-to-Noise (S/N) ratio. Models, such as helicopter rotors, require data to be transmitted from a rotating frame, such as rotor blades. This has traditionally been accomplished by electro-mechanical slip rings. Electro-mechanical slip rings have a high initial cost and high maintenance costs. They also contribute to S/N ratio degradation. Furthermore, the signal degradation is not constant, and therefore, frequent calibrations of the remote sensing system are required. Electro-mechanical slip rings also require precise mechanical alignment during installation, which is labor intensive.

To minimize the S/N ratio degradation, it is desirable to keep the cable length between sensors, amplifiers and filter as short as possible. Ideally, the analog signal from the sensors is digitized locally near the sensors and the digital signal is transmitted to a remote location for data processing.

[†]Research Associate
NASA/Ames Research Center
Moffett Field, CA 94035-1000

Digital data transmission between a rotating frame and a stationary frame, via electro-mechanical slip rings, can improve the data quality; however, the other drawbacks associated with electro-mechanical slip rings still remain. It is therefore desirable to eliminate the mechanical slip rings completely.

2.0 Proof-of-Concept Data Acquisition / Transmission System Architecture

The objective of the present proof-of-concept system is to demonstrate capabilities to amplify, filter, digitize, and multiplex sixteen (16) analog data channels into a single optical data stream near the sensors, then transmit the data stream via free-space infrared transmission to a remote site. The second goal is to keep the size of the system as small as possible. Since there are no wires or fiber optics required, the system can be mounted on a rotating frame without any additional devices. The block diagram of the data acquisition and transmission system is shown in Figure 1. In Figure 2 the system is shown with a typical packaging. In this particular packaging, the analog and digital sections of the system are on a single stack, divided by a shielded partition. The analog section consists of two printed circuit boards (PCB's), which are instrumentation amplifiers and anti-aliasing filters. The digital section consists of three PCB's, which are the core processor, analog signal interface and high speed communication boards.

Figure 3 shows an example of the system on a rotating frame. The digital section of the system, identical to that in Figure 2, is mounted in the center of the rotating platform. The optical transmitter also resides in the center of rotation above the digital system. The analog section is mounted on one of the side walls of the structural frame. This system also includes a signal generator to simulate sensor outputs, an RF modem for remote console, and a visual LASER for alignment. They are also mounted on the vertical wall of the structural frame.

2.1 The Core Processor

The core processor for this system is an AMPRO® CoreModule™/486 or LittleBoard™/486. AMPRO has been a pioneer in the field of small form factor computers which are fully compatible with desktop PC's. AMPRO's form factor is defined as PC/104, which has become a pseudo industry standard. It has also become a proposed extension to IEEE-P996. The PC/104 has a size of 96.5 mm by 91.4 mm by 15.2 mm. In spite of its size, it is fully compatible with a desktop PC. The CoreModule/486 has a Cyrix 486™ processor running at 25 MHz with 4 M bytes of memory. The LittleBoard/486 is based on an Intel i486DX running at 25 MHz with 16 M bytes of memory.

The embedded data system does not have a local console device; however, the system can be controlled by a remote console. An RS-232 serial communication port on the CPU board is configured as a console emulator so that the system console I/O (screen display output and keyboard input) are redirected to the serial port. In this manner, an ASCII terminal at a remote location can be used as a system control console. In order to eliminate the hard wiring requirement, an RF modem is used to transmit and receive the console I/O. Since the data traffic for the control console is low, relatively low speed communication (1.2 to 19.2 K bits/sec) is sufficient. A 900 MHz digital spread spectrum modem is used to minimize the RF interference.

2.2 Analog signal interface

A Real Time Devices DM406 is used as an analog signal interface. It has a 100 kHz, 12-bit Analog-to-Digital Converter (ADC) with an analog multiplexer. The multiplexer can be configured for 8 channel differential or 16 channel single-ended signals. It also has a 2 channel, 12-bit Digital-to-Analog Converter (DAC) and 16 channel digital I/O (DIO) capabilities.

In order to maximize the number of data channels, the DM406 is configured for 16 channel single-ended input. Sixteen instrumentation amplifiers are added in the front-end to accommodate small differential signals from the sensors. A more detailed discussion of these instrumentation amplifiers is given in section 2.5.

The output from the DAC is used to create reference voltages to calibrate the front-end amplifiers.

The DIO is currently programmed as 8-bit input and 8-bit output. Two of the input channels are used to read an optical shaft encoder (1 per revolution and N per revolution). The N per revolution signals can also be used to trigger the DM406 so that the data acquisition will occur at known azimuthal locations. One of the outputs is used to switch a visual alignment LASER which shows the location of the infrared data beam, aiding in locating the receiver optics. The second output channel controls the multiplexers on the front-end instrumentation amplifier board. The third output is used for sensor bridge resistance equivalence calibration (R-CAL). When this output is high, it will switch a set of multiplexers or electro-mechanical relays, which may exist on the wind tunnel model, to switch-in an R-CAL equivalence across the sensor bridge. This set of multiplexers, relays and the R-CAL equivalence is not a part of the data acquisition system. Six input channels and 5 output channels are currently unused.

2.3 Communication Module

An RS-422 serial communication module, Sealevel System's ACB-104™ is used for data transmission. It is based on a Zilog® 85230 running at 20 MHz local clock. The Zilog 85230 is a versatile Enhanced Serial Communication Controller (ESCC) which can be configured for various synchronous and asynchronous communication protocols. It also has Cyclic Redundancy Check (CRC) and Digital Phase Lock Loop (DPLL) hardware on the chip. The DPLL can be used to encode and decode the synchronous clock in the data stream.

The current system uses an ACB-104 as a simplex synchronous transmitter with Synchronous Data Link Control (SDLC) / High level Data Link Control (HDLC) with bi-phase space clock encoding. The SDLC-16 CRC word is automatically appended to each data packet. Although the ESCC is running at the 20 MHz clock and is capable of transmitting the synchronous data at 5 M bits/sec when a dedicated data path and clock path are used, the clock encoding scheme limits the actual data rate to 307 K bits/sec since the DPLL must run at the 16-times-clock-mode for pulse edge capturing. The resulting data stream in differential RS-422 can drive the optical transmitter. If optical transmission is not necessary, a pair of wires can connect the embedded system and the receiver workstation directly.

2.4 Receiver Workstation

The current receiver workstation is an IBM PC/AT compatible desktop computer based on an Intel® i486 processor. A Sealevel System's ACB-IV serial communication module is connected to the ISA bus. The ACB-IV is also based on a Zilog 85230 ESCC running at 20 MHz. It is configured as a simplex receiver with protocol identical to the transmitter ESCC. The CRC computation is automatically executed for each packet, and if an error is found, a flag is raised. The flag values are recorded along with the data. Once the optical signal is converted to a differential RS-422 signal, any workstation with a high speed RS-422 can be used as a data receiver.

2.5 Front-End Analog Signal Processor

The analog signal processor consists of two printed circuit boards (PCBs). Sixteen (16) channels of instrumentation amplifiers reside on one PCB and sixteen (16) channels of anti-aliasing filters on the other PCB. The differential output from sensors can be connected directly to the instrumentation amplifiers. The amplified signal is then filtered for anti-aliasing, and its output is connected to the ADC input. Each board is a custom designed 4-layer PCB with a small size (120.5 mm by 84.5 mm by 15.0 mm), taking full advantage of the small size offered by the Surface Mount Devices (SMD's).

The instrumentation amplifier board can use either Burr-Brown® INA118 or INA128 or Analog Devices® AD620 instrumentation amplifiers in the SOIC-8 package. These amplifiers are pin compatible, and direct replacement is possible without any modifications to the board or the peripheral components. The amplifier board has a switch selectable gain feature with gains of 1, 10, 100 and 1000. The amplifiers have a wide bandwidth, up to 200 kHz (INA128 with -3 dB knee point at gain of 100), and are suitable

for wide range of sensor applications. Each channel of the amplifier also has a two-to-one analog multiplexer in front of the amplifier input. This multiplexer can be used either to multiplex two independent data channels or to use the Voltage Calibration (V-CAL) feature of the data acquisition / transmission software. A number of reference voltages can be generated from the DAC to calibrate the amplifier / filter system. The switch control is connected to one of the DIO output ports of the DM406 so that the software has full control over the multiplexers. The switch control and two sets of input channels for all multiplexers are available individually at the amplifier board connector so that the re-configuration (V-CAL or multiple data) can be performed by changing the wiring harness. The system is currently configured so that the DAC output is connected to one side of the multiplexer and the data to the other, and all sixteen multiplexers are switched together by a single DIO output.

The anti-aliasing filter consists of two Burr-Brown UAF-42 filter chips per channel, configured as a 4-pole Butterworth Low Pass Filter. The cut-off frequency is resistor / capacitor programmable.

3.0 Optical Transmitter and Receiver

The optical transmitter converts the RS-422 signal generated by the Sealevel System's ACB-104 to a TTL pulse train which drives a Hamamatsu infrared (IR) communication Light Emitting Diode (LED). Its peak wave length is at 890 nm. The IR LED is housed in a optical collimator, originally designed for a LASER diode, which emits a semi-diffused beam. A semi-diffused beam was selected over a highly collimated beam in order to accommodate a larger alignment tolerance. This large alignment tolerance not only eliminates a lengthy receiver / transmitter alignment procedure but also accommodates wind tunnel model motion during the wind tunnel test.

The optical receiver has very simple collecting optics consisting of a single Fresnel lens. The Fresnel lens was selected because it makes a large aperture collector at an extremely low cost, and image quality is not an issue for this particular application. An optical quality infrared filter is placed just in front of the focal point of the collector optics. A PIN photodiode is used as an IR detector. A high speed, high gain amplifier, combined with an Automatic Gain Control (AGC), stabilizes the signals before the RS-422 conversion.

Although the Sealevel System's ACB-104 has a data rate of 307 Kbits/sec, its actual bit rate is approximately 1 Mbits/sec due to the clock encoding. The transmitter and receiver circuits are custom designed and tested for bandwidths up to 6 Mbits/sec.

The AGC with its time constant selected to account for beam meandering due to transmitter motion / rotation is essential in a wind tunnel environment. The receiver circuit also features an auto-shut-off to prevent generation of erroneous digital signals when the transmitter is inactive. The final stage of the receiver circuit converts the digital pulse train to RS-422, then sends it over conventional twisted pair wires to a receiver workstation which houses a Sealevel System's ACB-IV communication card on the ISA bus.

4.0 Proof-of-Concept System Software

The operating systems currently in use on the transmitter and receiver are DR-DOS and MS-DOS, respectively, due to their low cost. The data acquisition / transmitter software and the receiver software have been developed under MS-DOS with the Borland® C++ compiler. The operating system and the application software on the transmitter system reside on an EPROM which acts as a read-only solid-state disk. The EPROM image was developed using the AMPRO Solid State Storage utility. The 4 Mbit EPROM currently used leaves ample free storage space.

The SDLC/HDLC protocol was selected for the communication protocol. Although the transmission speed is limited by a single optical path to the equivalent speed of the asynchronous communication, the bit-oriented synchronous protocol allows maximum utilization of the hardware functions, such as the built-in Cyclic Redundancy Check with the SDLC CRC-16 error detection polynomial. The clock encoding / decoding algorithm is also performed at the hardware level.

The current transmitter software runs in three modes: data acquisition, amplifier voltage calibration (V-CAL) and resistance equivalent calibration (R-CAL). Each mode operates in an infinite data acquisition and transmission loop until an interruption is made by the user via remote console. In the data acquisition mode, the front-end multiplexer input is switched to the sensor output. In the V-CAL mode, a reference voltage is generated by the DAC on the DM406; then the front-end multiplexer input is switched to the DAC output. The R-CAL mode is identical to the data acquisition mode except the R-CAL switch line, which is one of the DM406 DIO output ports, is switched on high.

The receiver software resides on a hard disk on a conventional desktop PC workstation. The current receiver software includes a real time alpha-numeric data display, automatic and manual recording, an amplifier / filter calibration routine used in conjunction with the data acquisition / transmission system V-CAL function, off-line data retrieval, and basic statistical computation routines. The real time and off-line display also accommodates engineering unit computations and display.

5.0 Magnetic Power Coupling

Significant power is required to operate the embedded data acquisition and transmission system, as well as the sensor system, on the rotating frame. Traditionally, power transmission is also performed through electro-mechanical slip rings. However, the disadvantage of electro-mechanical slip rings becomes even more obvious when a large amount of electrical power passes through mechanical contacts in the form of arcing or accelerated oxidization.

A new method of transferring electrical power between rotating and stationary frames has been developed to overcome such problems. The device known as the Contactless Magnetic Slip Ring (MSR) is essentially an A.C. transformer with a rotatable secondary coil. Unlike loosely coupled inductor devices, it has a high efficiency magnetic core. The inner and outer cores are arranged much like a conventional A.C. transformer. Layered silicon steel is used as the core material. The use of layered a core is important in reducing the eddy current losses. The primary and secondary coils are encased in an epoxy cast for mechanical and thermal stability.

In the current system, a torque source (electric motor) is located at the bottom, and the data acquisition / transmission system is mounted on a platform on the top (Figure 3). With this geometrical arrangement, a torque must be transmitted through the inner core of the MSR. The secondary coil is mechanically connected to the torque transmission shaft via a torque transmission pin (Figure 4). The air gaps for the torque transmission shaft and the torque transmission pin reduce the electrical efficiency.

The current proof-of-concept system is designed for 7 V, 7 A at the secondary coil output with an estimated efficiency of 53 %. This low efficiency is due mainly to large air gaps which resulted from a large machining tolerance required to accommodate inaccurate machining, namely, hand-crafted parts. The efficiency, therefore, can be improved with tighter tolerances and smaller air gaps. The D.C. conversion and voltage regulation are performed on the rotating frame.

A U.S. Patent is pending.

6.0 Current Performance and Future Upgrade

The current system with CoreModule/486 CPU can acquire and transmit data up to 600 Hz per channel with continuous data acquisition and transmission for 16 channels. The data rate can be improved to 1 kHz per channel when the LittleBoard/486 is used. Items that restrict the system performance are inefficiency in the prototype software, limitations of the PC/104 bus bandwidth, CPU performance, and ESCC speed.

The current software only utilizes word-by-word transfers across the bus. More streamlined software with DMA transfer could increase the data acquisition and transmission efficiency. The PC/104 bus supports 8- or 16-bit wide ISA devices. Both DM406 and ACB-104 are on the 8-bit bus. The wider bus devices available today will expedite data transfers across the bus. Although the ESCC on the ACB-104 and ACB-IV are locally running at 20 MHz, the clock encoding / decoding forces the ESCC to run at 16-times-clock mode for edge capturing. Providing two independent transmission paths, one for the clock stream, the other for the data, will improve the transmission performance up to 5 Mbits/sec. The second optical path can be added using frequency domain multiplexing. The free-space optical transmission has been demonstrated up to 120 ft. This demonstrated distance is limited by the building size, not by the system performance. A longer transmission distance can be achieved by a use of LASER diode and / or a diode array (LED or LASER) on the transmitter, and a larger collecting optics on the receiver.

New, emerging pseudo industry standards in embedded systems which utilize wider and faster buses, such as CompactPCI, or PC/104 Plus, are currently under investigation for a new system design. These bus standards are electrically identical to the PCI bus widely used for desktop PC's. The PCI bus is 32 bits wide, runs at 33 MHz, which provides more than a 10-fold performance increase over the current PC/104. Faster CPU's such as an Intel® Pentium® CPU running at 166 MHz or PowerPC running at 200 MHz, are available in a small form factor. Faster ADC's with speeds up to 300 K samples / sec with 16-bit resolution are also available. New standards in serial communications, such as 100-BASE-T or IEEE 1394, will meet the communication bandwidth required by a large amount of data collected by faster ADC's and CPU's.

7.0 Concluding Remarks

A proof-of-concept embedded data system with free space optical data transmission has been constructed and demonstrated for a rotating frame. The power transmission to the rotating frame was accomplished by a magnetic slip ring. Together, they eliminated the need for traditional electro-mechanical slip rings. Even in an application which does not involve rotation, a small, remote data acquisition system with a optical transmission is useful from a noise immunity and cabling standpoint.

Faster processors and ADC's, combined with the faster serial transmission devices currently available, will make it possible to construct a system capable of meeting current data acquisition requirements in various applications.

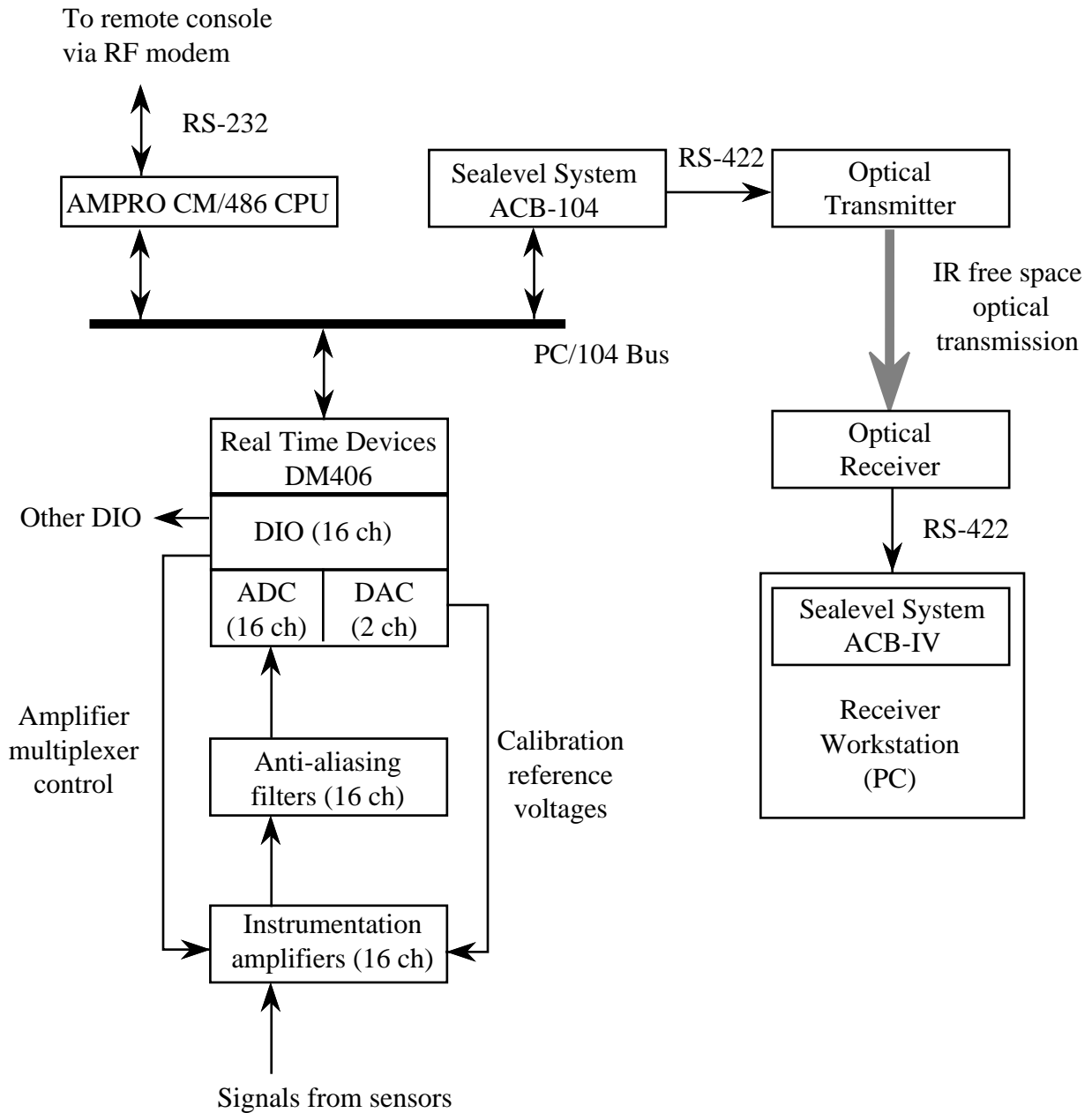


Figure 1 Embedded Data System Schematics

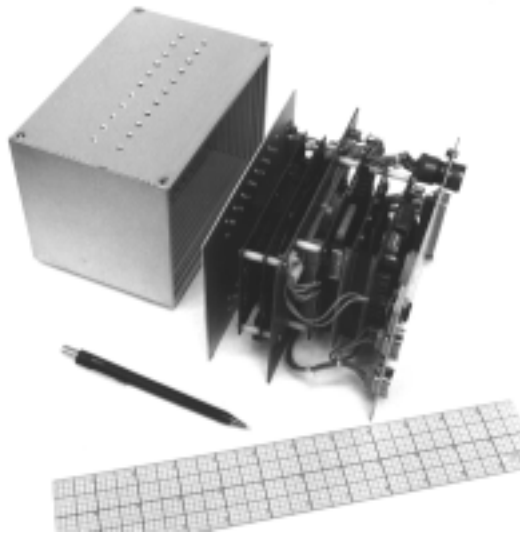


Figure 2 Embedded Data System

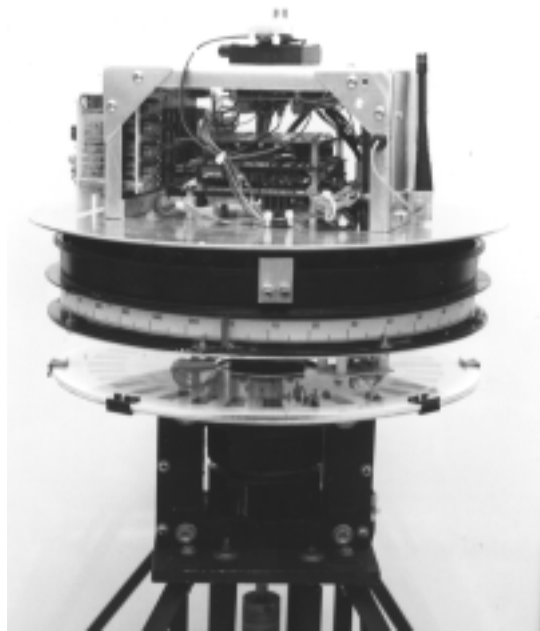


Figure 3 Embedded Data System on a Rotating Platform

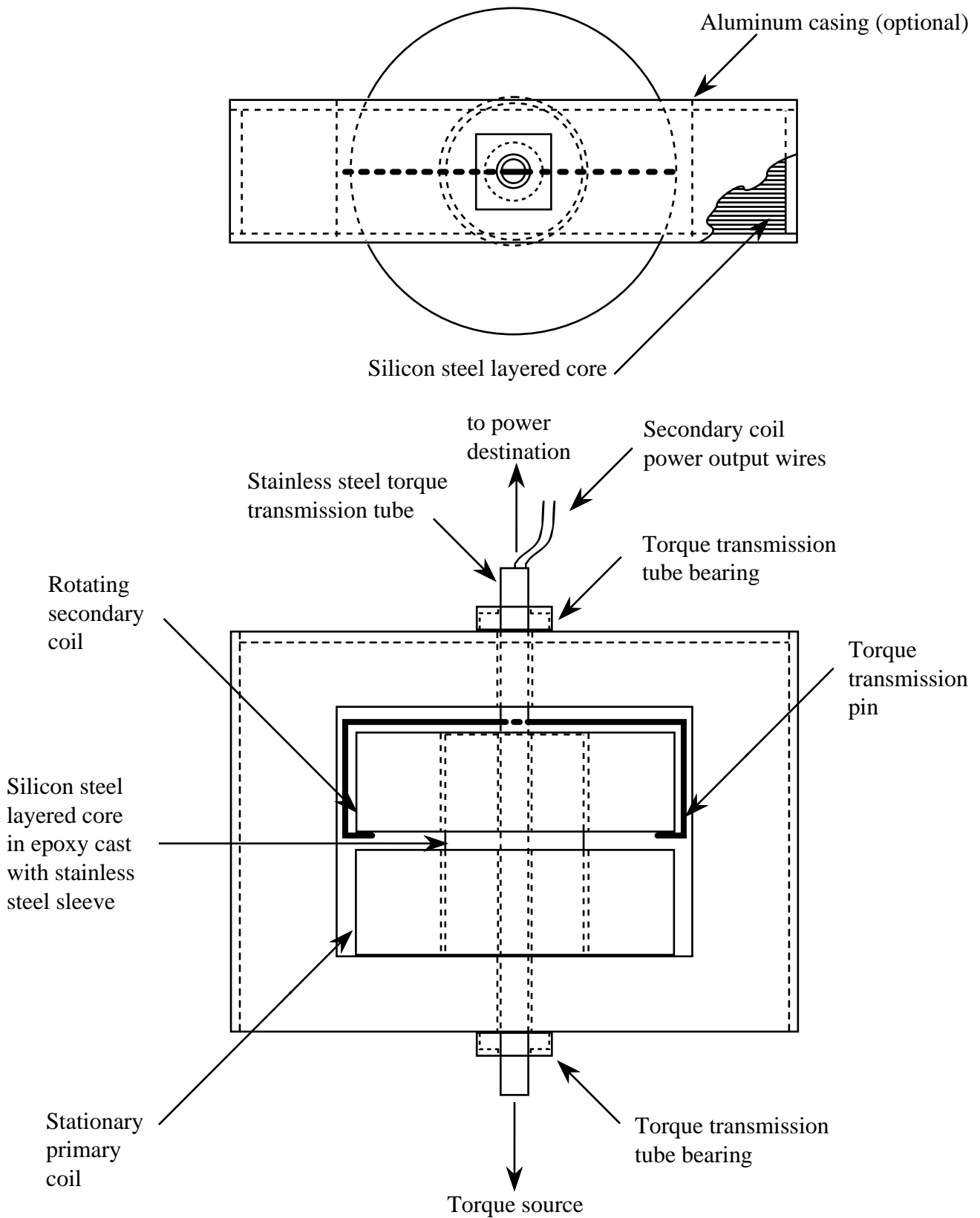


Figure 4 Contactless Magnetic Slip Ring