Applying fiberoptic data links to instrumentation

by Michael Steven Beer

A thesis sumitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Electrical Engineering
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Abstract:
The subject of this thesis is the application of a fiber optic data link for use in instrumentation applications where conventional information transmission techniques cannot be used due to excessive electrical noise. A technique was developed for converting a direct current voltage to a pulse string whose frequency was proportional to the voltage and transmitting this pulse string over the data link.

This technique also allowed recovery of the information at the receiving end in digital form using a microprocessor-based data acquisition system. As a demonstration of the validity of this technique, sensors were constructed to enable use of the data link to measure alternating currents, direct currents, and temperature. Mathematical transfer functions were developed for each of these sensors to aid the microprocessor-based system in providing accurate measurements.

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Signature Michael Beer

Date July 11, 1980

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Michael S. Beer

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ABSTRACT

The subject of this thesis is the application of a fiber optic data link for use in instrumentation applications where conventional information transmission techniques cannot be used due to excessive electrical noise. A technique was developed for converting a direct current voltage to a pulse string whose frequency was proportional to the voltage and transmitting this pulse string over the data link. This technique also allowed recovery of the information at the receiving end in digital form using a microprocessor-based data acquisition system. As a demonstration of the validity of this technique, sensors were constructed to enable use of the data link to measure alternating currents, direct currents, and temperature. Mathematical transfer functions were developed for each of these sensors to aid the microprocessor-based system in providing accurate measurements.

CHAPTER I

INTRODUCTION

This thesis describes a research activity directed towards applying fiberoptic data links to instrumentation. The intent of this thesis is to describe the equipment necessary to achieve this, and verify that the instrumentation/data link combination operates properly. There will be no attempt to compare this method with other instrumentation techniques, and no efforts will be made to optimize the results presented here with respect to a certain set of conditions. The techniques advanced in this thesis have application in areas where high voltages and electromagnetic interference make electrical methods of information transmission impossible or impractical.

Fiberoptic data links have been much publicized by Bell Laboratories because of the large quantity of information that they can carry. Fiberoptics have useful properties other than large bandwidth. The properties of fiberoptics that this research exploits involve electrical noise immunity and electrical isolation. Another benefit that the methods developed have is that they digitally encode the information that is to be transmitted. As a consequence, these methods work particularly well in, but are not limited to, systems that employ microprocessors and other digital equipment.

Fiberoptics involves the transmission of signals using visible and near-visible light in transparent waveguides. Due to the short wave-length of light relative to the other forms of electromagnetic radiation, these waveguides are much smaller than conventional waveguides. Typical fiberoptic fibers have cross-sections approaching that of a human hair. Because of this, the cables encasing the fibers are small diameter (1/4") and very flexible. The fiberoptics fibers themselves are constructed of either glasses or plastics, with glasses being preferred over plastics due to their lower attenuation. The fibers themselves are usually encased in several layers of plastic to form the fiberoptic cable. Since both glass and plastic are excellent insulators, the resulting fiberoptic cable provides excellent electrical isolation between transmitter and receiver. Since light waves are used rather than electric waves, the signals in the fiberoptics are immune to those type of interference that degrade electrical signals.

Information can be sent through fiberoptics in either analog or digital form. It was decided to use digital encoding in this project. The form of digital encoding chosen was pulse modulation, in which the frequency of the pulse string coming out of the analog-to-digital (A-to-D) converter is nearly a linear function of the input voltage. This type of A-to-D conversion will be referred to as voltage-to frequency conversion and the A-to-D converter will be referred to as a voltage-to-frequency converter throughout the rest of this thesis.

The instrumentation technique advanced in this thesis involves converting the quantity to be measured to a voltage. This voltage is then applied to a voltage-to-frequency converter and the pulse string from this converter is used to turn a light emitting diode (LED) on and off. The light from this LED is then launched down the fiberoptic cable. At the receiving end of the cable, the light signal is transformed into an electrical signal that conforms to the voltage levels established for Transistor Transistor Logic (TTL) circuits. This signal's frequency is then proportional to the quantity initially measured, the exact proportionality coefficient(s) being dependent on the transfer function of the system as a whole. This type of system is diagrammed in Figure 1.

Two types of sensors were developed to interface with the fiberoptics data link. One type of sensor measures temperature and the other type measures electrical current. The temperature sensor is an integrated circuit that produces a current proportional to the temperature of the device. Additional circuitry changes this current into a voltage and allows amplification and offset to be set so that the temperature range of interest can correspond to the voltage range of the voltage-to-frequency converter.

The current sensors developed for the data link evolved along two lines of thought. One line was aimed at measuring current levels in conventional A.C. lines and the other line was aimed at measuring currents that could be either D.C. or A.C. The first sensor was developed to measure these A.C. and D.C. currents. It is based on a Hall effect device and generates an output voltage proportional to the in-

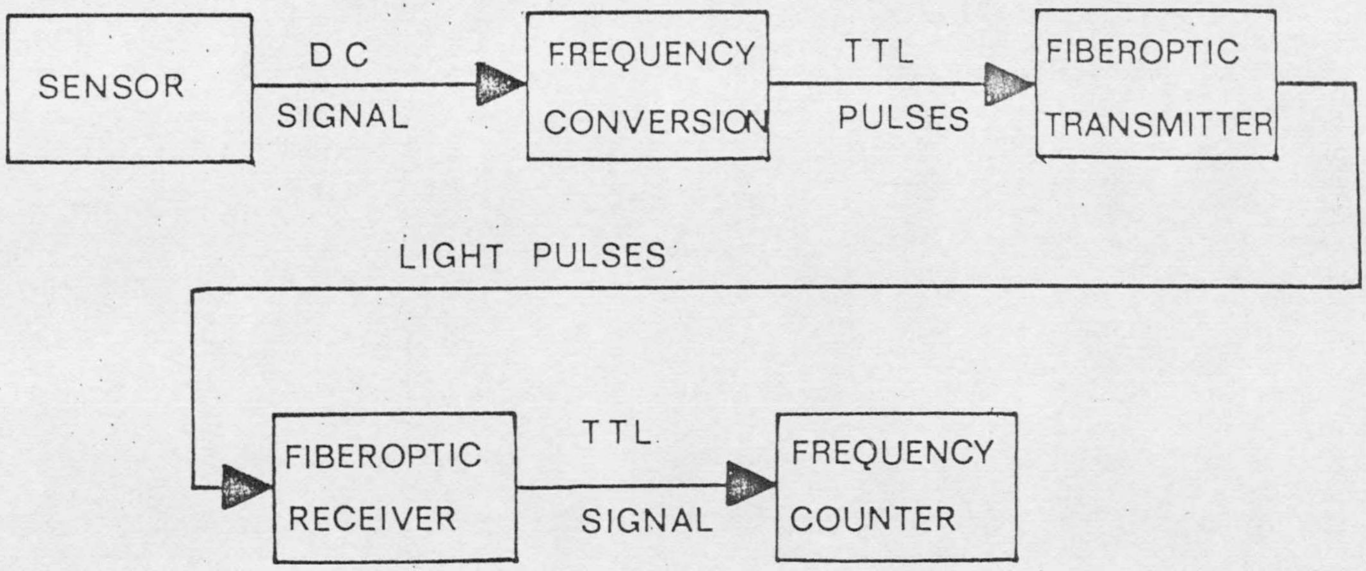

Figure 1 System Signal Flow

stantaneous intensity of the magnetic field surrounding the conductor and the excitation current supplied to the Hall effect device. The second current sensor is based around a conventional current transformer similar to those used in most power applications. This sensor is, of course, limited to A.C. currents with frequencies near 60 Hz. The current transformer outputs a current proportional to the A.C. current being measured. This A.C. current is passed through a resistor whose size was chosen so that the voltage drop generated corresponds to the voltage produced by the Hall effect device under similar conditions. The signal from either current sensor is processed by circuitry that rectifies and amplifies the signal producing an output that is compatible with the voltage-to-frequency converter.

No matter which sensor is used, the frequency of the voltage-to-frequency converter has to be determined. A microprocessor based data acquisition system (DAS) was used to determine the frequency of the pulse string generated by the fiberoptics data link receiver. The method used involved counting the number of pulses from the receiver over a known period of time. This method is generally referred to as a gated counter. The gated counter is controlled by a program that the DAS microprocessor executes. The program can direct the results to be printed on an output device or saved in memory.

This thesis describes the construction of the fiberoptic data link, the construction of the voltage-to-frequency converter, the construction of temperature and current transducers compatible with this equipment, and it describes the software used to control and calibrate the system.

CHAPTER II

THE FIBEROPTIC DATA LINK

The fiberoptic data link consists of a transmitter and receiver separated by 100 meters of Valtec PC10 FIBERdata single-fiber fiberoptic cable. This data link is not a high speed data link, although the speed limitation is in the electronics and not the fiberoptics. It was decided to design the link to handle a square wave at a maximum frequency of 100 kHz. The link had to also be able to perform down to D.C. conditions. These specifications were arrived at after considering the frequency ranges available in hybrid and monolithic voltage-to-frequency converters. Since these specifications were set, several commercially available data links have come on the market with virtually identical specifications. This frequency range appears to be the industry standard for low data rate fiberoptic links.

The specification that the link be capable of operating down to D.C. completely precludes the use of capacitively coupled amplifiers at any point in the transmitter or receiver. It was also decided from a point of size, power consumption and operating environment that semiconductor sources and detectors would be used in the data link.

The light sources chosen were conventional LEDs. These sources are by far the easiest sources to bias, operate and align. Another factor in this selection was the large amount of work that has gone into improving LED reliability and operating life. LEDs are also much easier to obtain than other types of solid emitters. The main disadvantage is that the devices require large amounts of power relative to the amount of power coupled into the optical fiber. This is a function of the broad area over which the light is emitted from the LED package and the small area that the terminated fiber optic has. This inefficiency is a trade-off that must be accepted to keep the ease of alignment attribute. The sources used in this data link nominally consume 100 milliwatts of power and the author has calculated that the amount coupled into the fiber is on the order of a few microwatts. Both red and infrared sources were used in the data link.

The detectors chosen were Positive Intrinsic Negative (PIN) diodes. These devices are readily available and operate at much lower bias voltages than avalanche type detectors. This is due to their internal construction which more effectively utilizes the voltages generated in the space-charge layer (11). The amount of current developed by one of these diodes in its reverse operating mode is linearly dependent on the incident light. This is true over the voltage range that extends from the reverse breakdown voltage of the diode to the point at which the generated current and the input resistance of the first amplifier produce enough voltage to remove the diode's reverse bias.

There was also the choice between single fiber light guides and multiple fiber light guides. The multiple fiber light guides are undoubtedly easier to use in a data link since they carry more light than single fiber guides, but they are more costly and also more difficult to properly terminate. Because of this, single fiber cable was chosen for this project. Again, it appears from advertising in electronics magazines that the choice of single fiber cables over multifiber cables has been made by nearly every data link manufacturer.

The Fiberoptic Transmitter

The schematic for the transmitter for the visible LED was provided by Valtec, the fiberoptic cable manufacturer. This was modified slightly for the infrared LED which required a different drive current from the red LED. These circuits are shown in Figure 2. The NAND gate provides hysteresis and drive current for the transistor, which can supply the higher current required by the light emitting diode. The different LED's used are shown along with the required current limiting resistors. The transmitter has worked well from the beginning of the evaluation, and this circuit has not been changed.

The Fiberoptic Receiver

This circuit was the most difficult of all of the circuits to design. The chief reason for this was the very small signal produced by the PIN diodes. The fiberoptics cable manufacturer had provided a schematic for a receiver with the cable that was used in the project. This receiver was constructed and it did work, but it was very sensitive to just about any change in operating conditions. Most of these pro-