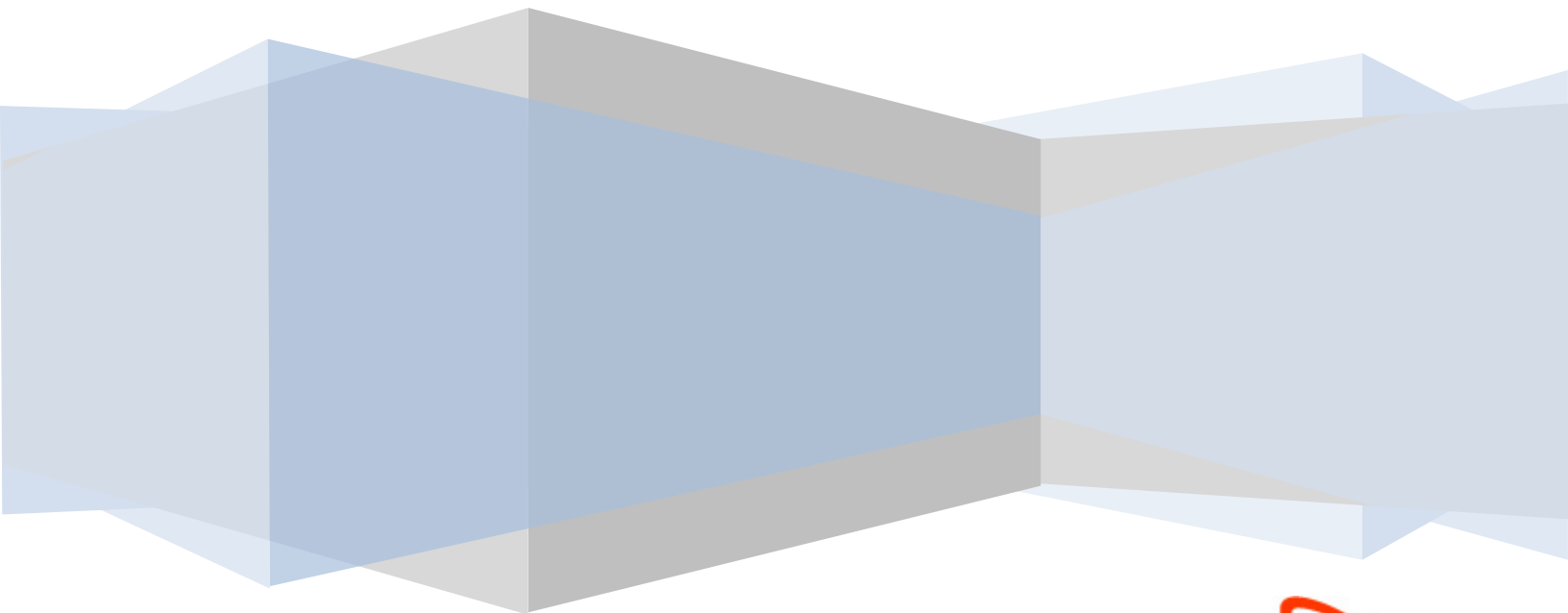


MSU College of Electrical and Computer Engineering

Load Metering and Transmission

ECE 480 Design Team 5

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Project Sponsored by ArcelorMittal



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I. Introduction

ArcelorMittal is a company in Burns Harbor, IN that produces steel from its raw components. There facility requires the power of several small cities and it is crucial that the processes are continued so that revenue is not lost. Damage can also occur to some of the mills used in the steel making process, if operations were to cease for a long period of time.

Michigan State University's design team five was charged with the task of working with ArcelorMittal to monitor the plants power consumption. The plant produces around sixty percent of the power that they require through steam turbine generation. The rest must be bought from the local power company NIPSCO. It is important to know at any time how much power is being used by the plant so that ArcelorMittal can buy the right amount of power from NIPSCO. Any power that is bought in excess of ninety-four megawatts is very expensive.

The existing power monitoring system is an old system and ArcelorMittal is worried about its reliability. Design team five's task is to develop and implement a redundant transmission system that can act as a backup to the existing system. The new system would run in parallel and cannot affect the existing system in anyway.

Several Ideas were put forth to transmit the data including pulse width modulation, frequency hopping spread spectrum, DSL transmission protocol, wireless FM transmission, and optical fiber. After weighing the pros and cons of each system it was decided that pulse width modulation was the optimal solution for the problem. Using the budget and time constraints that were provided by Michigan State University a plan set to be completed by design day.

II. Background

ArcelorMittal's steel operations in Burns Harbor, IN routinely require up to approximately 100 MW of total facility power usage. Due to the cost of electrical power and the company's limited generating capabilities it is vital to have immediate and uninterrupted knowledge of the current total electrical load throughout the facility. To monitor the total facility electrical load, ArcelorMittal needs to have the ability to transmit a signal, containing information on the electrical loads at each plant, to the central control room which could be located up to one mile away.

At each plant there are a series of transducers that convert the plant's total electrical load to a 0 to 100 mV analog signal. A voltage of 0 mV represents 0 MW of power usage and a voltage of 100 mV represents a known ceiling value of power usage for a particular plant. Any linear variation between 0 to 100 mV from the transducers represents a linear variation in power usage of the plant between 0 MW and the ceiling value. The voltage signal from the transducers is then converted into a frequency modulated (FM) signal which varies 10-30 Hz about a 1020 Hz carrier. The signal is sent to the control room over a two strand, twisted pair, shielded cable. At the control room the FM signal is converted to a 1 to 5 V analog variation which is read by a Programmable Logic Controller (PLC). This information is then stored in the company's computer system.

The system of signal transmission currently in use is the same system which was originally implemented when the facility was built about fifty years ago. ArcelorMittal would like to have a redundant way to transmit the electrical load signal from the plant to the control room due to the age of the current signal transmission system, the system's unknown level of future reliability, and the critical nature of the electrical load information being transmitted.

ArcelorMittal has asked ECE480 Design Team 5 to create a new, reliable and robust system of electrical load signal transmission specifically for the company's hot rolling plant. The new system must begin with using the existing 0 to 100 mV analog signal from the load transducers at the plant, specifically within the 138kV switchyard, and end with a 1 to 5 V or 4 to 20 mA signal at the PLC, in the Central Dispatch control room.

III. Design Restrictions

ArcelorMittal is very open to new design ideas from the team, but did provide a few restrictions. The design chosen by the Team must use the already existing 0 to 100 mV electrical load analog signal provided by the load transducers at the hot mill. The design must also provide a 1 to 5 V or 4 to 20 mA analog signal at the control room PLC. The designed solution must be capable of fitting inside the cabinet which houses the transducers in the switchyard and the cabinet which houses the PLC at the control room. The chosen design must also be capable of running in parallel with the current electrical load signal transmission system from the hot mill and must be implemented with zero down time of the hot mill or the current signal transmission system. The chosen design must be able to transmit the electrical load signal potentially one mile. The team may also choose to run a second cable from the hot mill to the control room to transmit the electrical load signal, if desired.

IV. Conceptual Design Descriptions

A. Pulse Width Modulation Transmission

One design solution is the use of Pulse Width Modulation (PWM) as a means of transmission of the analog signal. PWM will encode the analog signal value from a finite magnitude into a function of time. By designating the voltage level from the transducers as the modulating signal, a circuit would be used to control the duty cycle, or instantaneous pulse width, of a pulse train at any given instant in time. This duty cycle will be proportional to the original amplitude. The amplitude of the pulses are either full “on” or full “off”, analogous to a logic “1” or logic “0”, therefore transmission can be constituted as a digital one. Attenuation from the channel, therefore, is minimized due to the fact that the information is encrypted not in the magnitude but in the pulse duration. Demodulation will be performed at the receiver to extract the original analog signal¹.

Several methods can be used to employ this concept. The two main transmitter designs could be considered. The first design would have the analog input from the transducer summation (0 to 100mV) be converted into PWM function by a microprocessor. The second design requires the same input signal be referenced to a sawtooth generator as a carrier frequency to create the PWM waveform. For the application, given the length of the channel, a power amplifier is necessary to boost the pulse height. The receiver demodulates the waveform, typically, using an RC or LC low-pass filter². The resultant demodulated signal can then be adjusted to fit within the load constraints 1 to 5V and 4 to 20mA.

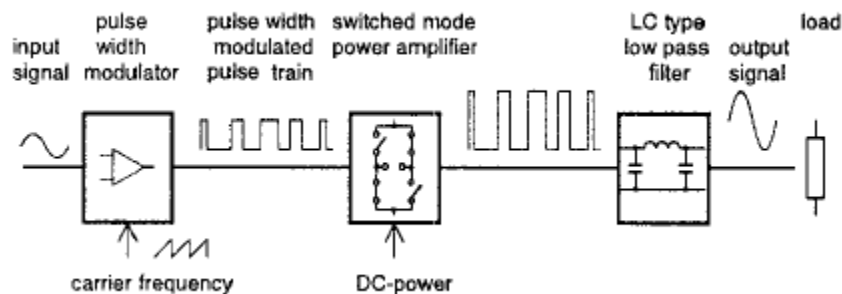


FIGURE 1

B. Frequency Hopping Spread Spectrum Transmission

Frequency Hopping Spread Spectrum (FHSS) transmission is a concept that consists of wireless transmitter and receiver units. Specific wireless transmitters and receivers manufactured by Weldmuller were found to fit in to the design specification. The transmitter and receiver pair features an output of the industry standard 4-20mA analog signal. FHSS is a technology that switches a carrier frequency rapidly among many channels within a spectrum. The sequence of the rapid changing frequency

channels are only known by the transmitter and receiver. This means the data that is transmitted will be highly secured. The transmitter and receiver use 902MHz to 928MHz frequency range as its spread spectrum. The transmitter is capable of sending a signal in a range up to 15km³. The conceptual design is divided into two parts. The first part is a circuit which can convert the load signal into a 1 to 5V and 4 to 20mA industry standard analog signal. Since the original load signal is a linear signal on the 0 to 100mV range, the converted signal will keep its linearity of 1 to 5V variation range. The second part is the transmitter and receiver set. The transmitter will be located with the conversion circuit and take the standard analog input and send it to the receiver located in central dispatch. In central dispatch the receiver will output the standard analog signal directly into the PLC.

C. DSL Transmission

DSL (Digital subscriber line or Digital subscriber loop) is a family of technologies that provides internet access by transmitting digital data over the wires of a local telephone network⁴. For this project, the DSL modem can be used as a transmission medium. The DSL modem can be used as both transmitter and receiver and can be used on either side of a telephone wire. The first part of the process would be to pick up the 0 to 100mV analog signal and convert it to digital signal. When the receiver gets the message, it will convert it back to analog signal, and send it to the PLC. Two DSL modems and two digital to analog converters are required. An existing phone line could be used and this would lower the cost further.

There could be errors in the system because more than one signal is being transmitted over this line. Line conditions also play a role in the signal integrity. The first goal of the project is reliability and if the telephone line is old or damaged, it will cause a lot of loss of crucial data and error messages.

D. Frequency Modulated Transmission

Frequency modulation is a way of transmitting a signal without have to worry about attenuation corrupting the signal being sent. A signal that is sent over a great distance without any type of modulation will experience attenuation due to the impedance of the medium and impedance matching across different mediums. Frequency modulation (FM) is a process that shifts the frequency of a carrier signal to encode the amplitude of the signal being sent. The frequency of a signal is maintained throughout transmission so attenuation is not a factor if the FM signal is powerful enough to reach its destination. The signal is then demodulated on the receiving end⁵.

The plant already uses wired FM modulation to transmit the total power usage of the plant. Since the goal of the project is to develop a redundancy to the current system it seemed that FM was a viable option. The team did not however, want to copy the existing system due to reliability purposes. If an event were to occur that would disrupt the wired FM communication it may also disrupt a system that is identical.

Using wireless FM would provide a redundant system that would not be identical to the existing method. Wireless FM is a line of sight transmission method, and since transmission of the signal is approximately a mile, it would be possible to use.

This design would include an FM transmitter that would take a 0 to 100mV signal and send it over a desired frequency band to a receiver. The receiver would decode the signal back into a 0 to 100mV signal and then an amplifier would boost the signal to a 1 to 5V, 4 to 20mA signal to be read by the programmable logic controller or PLC.

E. Optical Fiber Transmission

Optical fiber is a waveguide that can transmit light between two ends. Optical fiber can achieve longer distance and higher bandwidth communication than others kinds of communication. In an optical fiber, there is a higher refractive index core and a lower refractive index cladding surrounding the core. The combination of the core and cladding can achieve a waveguide of light due to total internal reflection⁶. To use optical fiber in the transmission of a load signal, the design will need to be split into three parts. The first part is the analog to digital (A/D) conversion. There will be two A/D converters on the two ends of the system. The A/D converter on the load side of the system will convert the analog load signal into a digital signal. Due to the high bandwidth of the optical fiber, the limitation on the resolution of the conversion is not a concern. Thus, the load signal can be converted with a higher resolution than necessary. On the central dispatch side of the system, a digital to analog (D/A) converter will be used to convert the digital signal back into a 1 to 5V, 4 to 20mA standard analog signal. The second part of the system is the transmitter and receiver of the light signal through the fiber. The transmitter and receiver also modulate the signal into a light signal and demodulate. The transmitter and receiver that will be used in this system will be a gigabit interface converter device (GBIC). GBIC devices are commonly used in fiber communication. The third part of the system is running the fiber. The company will need to purchase and install a new communication line of optical fiber. By setting a new line means there is no need to break current lines. It can be constructed without any distortion of the current systems.

V. Ranking of Conceptual Design

A. Pulse Width Modulation Transmission

Reliability - The implementation of PWM as a means of telemetry will require an original design and fabrication on the part of the team. This process comes at the greatest risk to reliability in comparison to the other proposals where most of the equipment used comes pre-fabricated and therefore certified and tested to an industry standard. However, the potential exists for the design team to develop a very rugged or comparably reliable prototype.

Expense - Since the PWM concept requires fabrication on the part of the design team, where virtually no pre-assembled equipment is used, the overall cost of the project is drastically reduced in comparison to the other proposals. Several of the components required are relatively inexpensive and widely available among parts suppliers.

Power Consumption - Most of the power consumed by the PWM design will be from the amplifier. A relatively higher power supply will be required to provide the necessary gain to overcome the channel impedance.

Feasibility and Simplicity of Design - Several design resources are available for the implementation of PWM as a means of telemetry. Knowing that the conceptual design will require an original design, the team will have a thorough and in-depth understanding of the overall project. If a potential problem were to occur with any of the other projects, schematics or essential application notes may not be as attainable as the PWM design. Also taking into account the knowledge background of the design team, its development is more conducive to the overall team's expertise.

B. Frequency Hopping Spread Spectrum Transmission

Reliability - FHSS consists mainly of two industry standard devices which are manufactured by an ISO 9001 certified company. Frequent periods of high reliability of the devices can be expected. However, due to the fact that wireless transmission which can be effected by bad weather and interference, the reliability performance is average.

Expense - The transmitter and receiver set is purchased from a company that produces high quality industry standard products. This means the cost of the system could be very expensive.

Power Consumption - Wireless transmission will consume a lot of power though the transmission side. Although the entire system uses very few components, the power consumption will still be much higher than a wired system.

Feasibility and Simplicity of Design - This transmitter and receiver set have an analog interface. Since there will be an analog input and output, the feasibility is very high in this system.

C. DSL Transmission

Reliability - The DSL system is susceptible to errors. If the sum of the errors is too high, the speed will be slow, and it will become disconnected. The reliability also depends on the condition of the medium.

Expense - Modems are inexpensive and an existing phone line can be used to transmit the signal. This option is very cost effective for these reasons.

Power Consumption - The power consumption of the two modems and converters will be very low giving this design an edge over some of the other designs.

Feasibility and Simplicity of Design - The telephone line is available, and DSL modems are easily available on the market.

D. Frequency Modulated Transmission

Reliability - The signal will be sent through the air and since wireless FM transmission is line-of-sight transmission the signal may be lost in a storm or if something passes through the signal line. The signal is reliable though and provides a way around attenuation.

Expense - FM transmitters and receivers are not incredibly expensive, but would be more expensive than a wired connection. Wireless FM is not a very common method of transmitting signals in industry so the availability of this kind of system may be limited.

Power Consumption - The power consumption of an FM transmitter is very high. To be able to get a clear signal a mile away could be difficult without using large amounts of power. The available power slots may not be able to provide the power needed and so this could do away with this type of design all together.

Feasibility and Simplicity of Design – The feasibility of this design is poor because the FM system is a complicated system. It would be hard to design a transmitter and receiver in the amount of time given for the project. These would most likely be bought from a vendor and this would increase the cost substantially.

E. Optical Fiber Transmission

Reliability - Optical fiber is very reliable. There is no electricity in the fiber which means there will be no concern about short circuit. Optical fiber can have the same high performance in any weather condition. The core and cladding are made out of silica or plastic which are free from corrosion and oxidation.

Expense - Optical fiber currently costs approximately one dollar per foot. In this project, there will be about 5000 feet of fiber used. In addition, the GBIC devices and converters will cost an extra hundred dollars. This is a very expensive option.

Power Consumption - Optical fiber has very little attenuation which means the transmitter use very little power to transmit a signal. However, the A/D and D/A converters will consume extra power, which raises the power consumption of the system.

Feasibility and Simplicity of Design - Due to the high expense of the optical fiber, the feasibility is relatively low. The technology is the most advanced and the most reliable, but with a very high cost, optical fiber is not very feasible.

	Reliability	Expense	Power Consumption	Feasibility and Simplicity of Design	Total
PWM	4	5	4	3	16
FHSS	3	2	1	5	11
DSL	2	4	3	4	13
FM	1	3	2	2	8
Optical Fiber	5	1	5	1	12

5 = Best Design; 1 = Worst Design

FIGURE 2

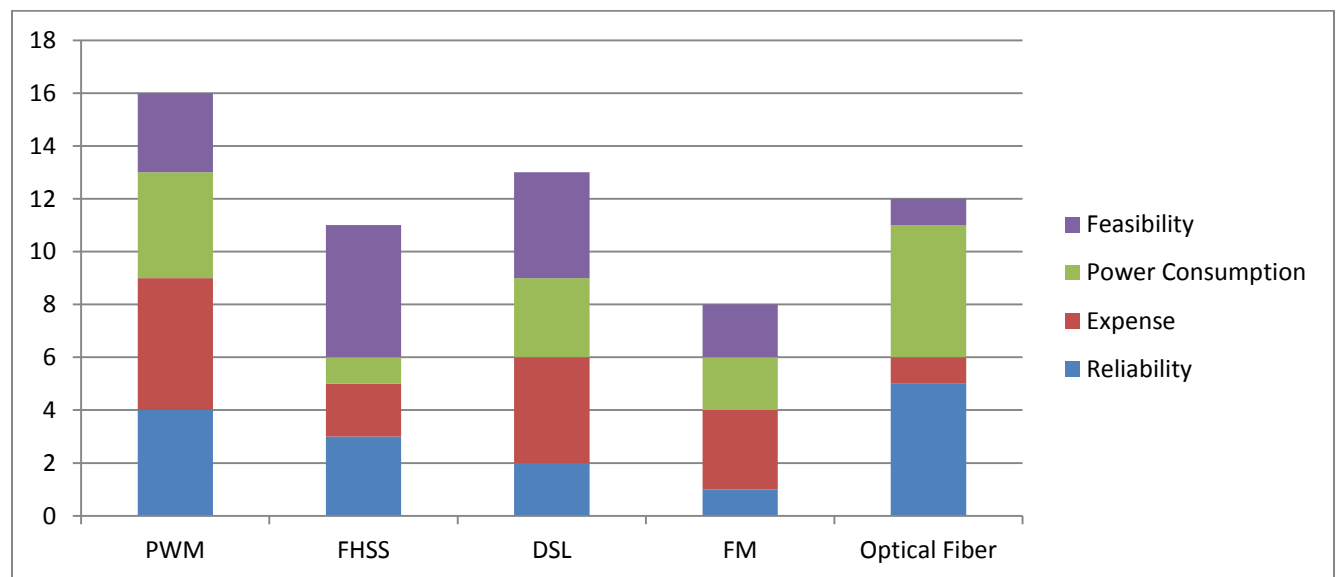
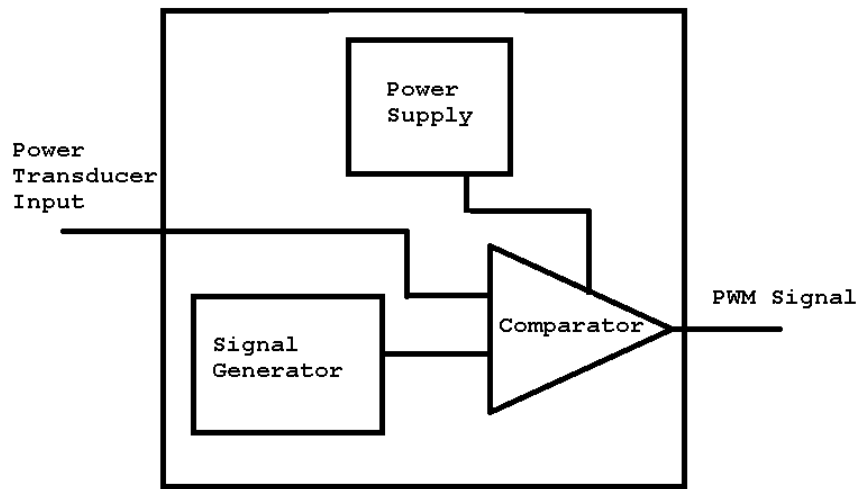


FIGURE 3

VI. Proposed Design Solution

Based upon the ranking evaluation, the use of PWM as a means of telemetry of the transducer voltages has several favorable attributes in comparison to the other design concepts. Consideration of the project's overall cost and feasibility were especially weighted in its support. Despite the noted reliability risks, the technology inherent to PWM transmission is that it has very high noise immunity. Also, the transmission of the input does not require any synchronization between the transmitter and receiver.

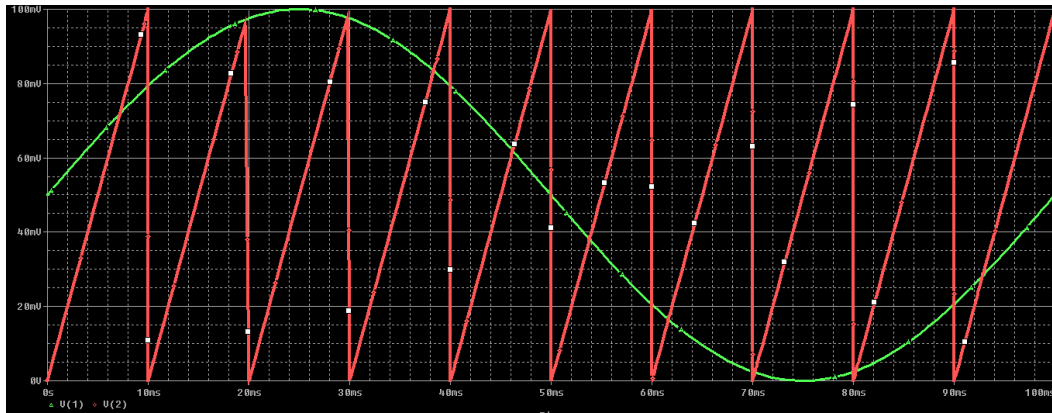
The new transmitter will be located in the same cabinet as the original transmitter. The input to the transmitter will be made from the same voltage dividing network of the power sensing transducers as the original design. In lieu of having to perform any program for a microcontroller, the comparator design could be used. As seen in the simplified block diagram below, the input from the transducers will be applied to a comparator that is being referenced to a sawtooth generator used as the carrier signal at a relatively higher frequency.



Simplified Block Diagram of Transmitter

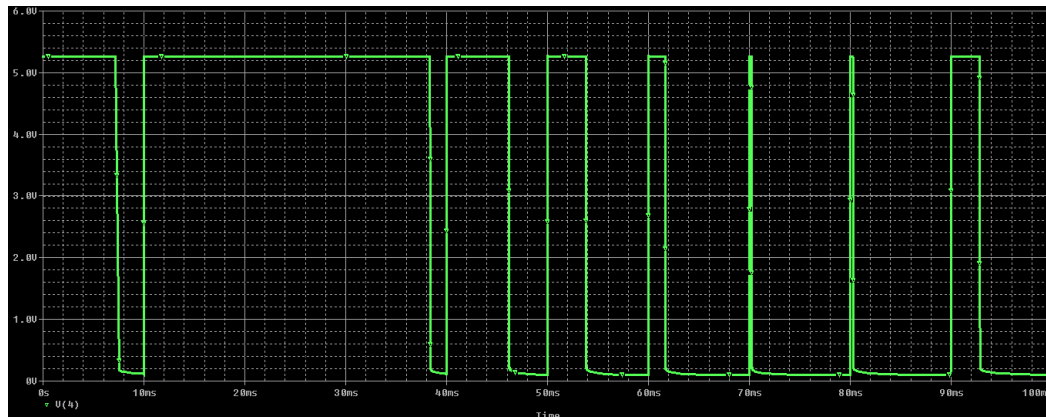
FIGURE 4

A sawtooth generator does not come standard and therefore will need to be constructed using a configured oscillator topology. The comparator will generate a pulse-width modulated output. The output will be transmitted down a standard twisted pair wire with overall shielding.



Reference Signal (Green) and Carrier Signal (Red)

FIGURE 5



PWM Output from the Comparator

FIGURE 6

The implementation of an amplifier may be necessary based on the impedance characteristics of the wire. The new receiver will be located at Central Dispatch near the original receiver. At the receiver, a passive low-pass filter will remove the higher frequency component of the carrier waveform and leave a low-frequency or corresponding scaled DC component of the transmission.

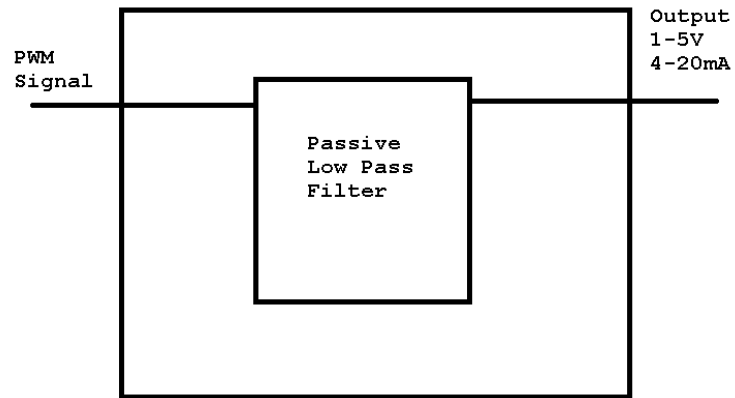


Figure: Simplified Block Diagram of Receiver

FIGURE 7

Based upon the specifications given by the sponsor, the output of the filter shall be within a range of 1 to 5 VDC and 4 to 20mA for totalization to be performed by a PLC.

VII. Risk Analysis

There are some risks associated with this design challenge. The most important risk is that any loss of existing metering capability in the process of creating a redundant system could cost the company millions of dollars. Power is bought from NIPSCO Power Company and they have a contract to buy up to ninety-four megawatts. Anything over this amount would result in prices that are ten times the normal amount of power. If central dispatch is blind to how much power they are using they could make an error and buy unnecessary power from the utility. This would put considerable loss of revenue for ArcelorMittal. Time is another foreseeable risk in that the project could take too long to implement, and in the process the existing system could cause the fore mentioned failure.

Risks with the proposed design solution are fairly low but there are potential risks. Noise in the line could result in an unwanted pulse trigger and false data could be transferred. There is no error checking included in the design. Some design solutions were proposed to limit this possibility including a filter and a dc offset.

VIII. Project Management Plan

Each of the five members of the team members have designated non-technical roles and will work on specific technical roles for the project once determined. The initial project plan consists of six weeks to completion of chosen design starting on September 24, 2012 with an additional five weeks until project delivery for unanticipated setbacks and preparation of the final project presentation. The initial project plan is detailed below.

September 24, 2012 – October 5, 2012

Gather data, experiment, research, prototype, and create the project design on paper

October 6, 2012 – October 19, 2012

Order parts for the chosen design and wait for delivery

October 20, 2012 – November 2, 2012

Build the chosen design and troubleshoot if necessary

November 3, 2012 – November 16, 2012

Extra time for unanticipated problems or need to rework chosen design

November 17, 2012 – December 6, 2012

Preparation for final project presentation and delivery

December 7, 2012

Project delivery

IX. Budget

The budget for the project consists of five-hundred dollars provided to the Team by the Michigan State University (MSU) Electrical and Computer Engineering (ECE) Department. The budget will be used to buy all supplies for the project which cannot be provided by the MSU ECE Shop or provided by the company.

X. References

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