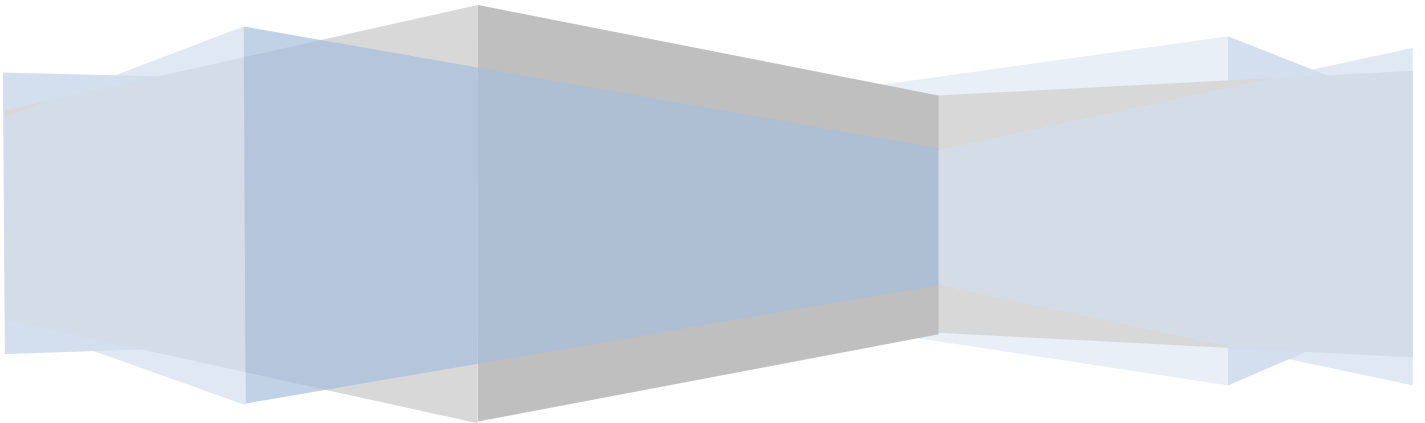


MSU College of Electrical and Computer Engineering

Load Metering and Transmission

ECE 480 Design Team 5

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The purpose of this project is to provide a redundant means of metering a totalized load sensed by transducers at a remote substation location and transmitting the signal to a central dispatch station for monitoring and decision-making.

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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 (PWM), Frequency Hopping Spread Spectrum (FHSS), Ethernet Remote I/O, wireless FM transmission, and Fiber Optic transmission. After weighing the pros and cons of each system it was decided that Pulse Width Modulation is the optimal solution for the problem. Using the budget and time constraints that were provided by Michigan State University a plan is established 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 has a deviation of 10-30 Hz with a 1020 Hz carrier. The signal is sent to the control room over a two conductor, 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 then provide a linear output within a range between 1 to 5 V and 4 to 20 mA at the output as a scaled representation of the input to be totalized by a PLC in the control room. 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", similar to a digital transmission. 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. PWM can be achieved by way of a monostable multivibrator, such as the LM555 timer, in conjunction with a free-running oscillator to provide triggering. A more common method is to create PWM by way of a comparator, employed via two main transmitter designs. The first design would have the analog input from the transducer summation (0 to 100mV) be converted into PWM function by a microcontroller where the comparison is embedded on

the microcontroller's hierarchy. The second design requires the same input signal be referenced to a sawtooth generator as a carrier frequency to create the PWM waveform. The PWM's waveform is then sent down a transmission line, typically coaxial or twisted-pair wire. At the receiver, the signal can be demodulated, typically, using an active or passive low-pass filter². Other methods are available for demodulation as well, such as the use of a microcontroller used to count the pulses. The resultant demodulated signal can then be adjusted to fit within the load constraints 1 to 5V and 4 to 20mA.

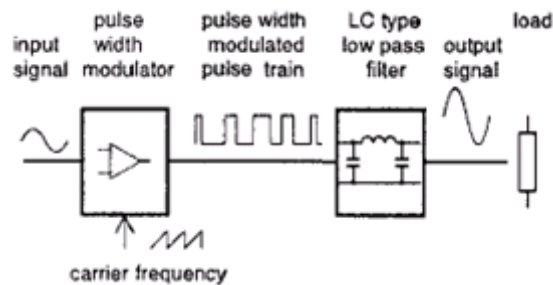


FIGURE 1

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. Ethernet Remote I/O

As an alternative design solution, Ethernet Remote I/O is a remote input and output device using Ethernet as the communication medium. The use of Ethernet I/O includes two Ethernet I/O devices that are connected using TCP/IP protocol through an Ethernet network. The Ethernet I/O device is capable of taking analog signal inputs and outputting peer to peer communication. In this design, there will be an Ethernet I/O device located in the substation to take the 0 to 100mV analog signal from the transducer, convert it to a digital signal, and transmit the signal through Ethernet. There will be another Ethernet I/O device located in central dispatch. It will receive the digital signal and convert it back to the 0 to 100mV analog signal. A circuit converting the 0 to 100mV signal to a 1 to 5V PLC signal will be designed and

fabricated to accomplish this task. Programming of the peer to peer communication is also needed to connect the two I/O devices.

Ethernet I/O devices are usually very reliable and robust. As a good example, the Ethernet I/O device that was manufactured by Advantech has a very wide operating temperature, which is from -10 to 50°C, and a sampling rate of 10 samples per second, which is more than enough for the design objective. The resolution is 16-bit which gives even higher resolution than needed. It comes with isolation protection, over voltage protection and even power reversal protection.⁴ Used in a typical industrial environment, this device is expected to be durable and long lasting.

D. Frequency Modulated Transmission

Frequency Modulation (FM) 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. 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, however, sought to develop an independent means of transmission that is not susceptible to a similar mode of failure. 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, posing a greater risk to reliability in comparison to the other proposals where most of the equipment used comes pre-fabricated and quality-controlled to an industry standard. However, the potential exists for the design team to develop a very rugged or comparably dependable prototype.

Cost - 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 as well as within the ECE Shop.

Power Consumption - Most of the power consumed by the PWM design will be based upon the required switching of the comparator. It is anticipated that transducer input shall have very slow rate of change, thus a low rate of pulse generation. At steady-state, the overall design is expected to draw power on the order of around 100mW.

Feasibility - Several design resources, such as PSPICE models, and other open-source layouts 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.

Size / Weight - Given that the PWM design is being constructed by the team, there is a lot of flexibility in regard to adapting the layout to fit any spatial constraints provided by the sponsor. The necessary components required for the construction are, individually, of negligent size or weight. The cumulative size of the overall project is anticipated to occupy no more than a cubic foot and the weight to be on the order of a few hundred grams if mounted in an enclosure.

Maturity of Technology - PWM is widely used in power electronic applications as a drive mechanism, but is not as widely used as a means of communication or transmission. Modern communication requires larger amounts of bandwidth, multiplexing and very data rates that is not offered through its use. For

the given application as a means of telemetry, it often implemented in lieu of standard current-loop transmitters due to its noise-immunity characteristics and ease of design.

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.

Cost -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 -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.

Size / Weight - The size of FHSS devices are no larger than a router. It can be mounted easily. The weight of these particular devices will be more than 500g, which is quite heavy and could cause extra stress to the mounting devices.

Maturity of Technology -Frequency Hopping Spread Spectrum is a highly advanced technology for transmitting signals securely. This technology is preferred by the military because of the high security of transmission. It is not very widely applied in civilian use. The devices available on the market are very limited.

C. Ethernet Remote I/O

Reliability -The Ethernet I/O devices are manufactured with industrial grade quality. High reliability of the devices can be expected. However, the reliability of the entire project relies not only on the devices but also on the Ethernet. The project could achieve a high reliability only when the Ethernet is reliable.

Cost -The expense of purchasing two Ethernet I/O devices is relatively high. This kind of product usually costs between two hundred and six hundred dollars. Two devices alone could consume our entire budget.

Power Consumption -The power consumption of Ethernet I/O devices is several watts. This power consumption is not significant but could make an impact because the devices need to operate continually.

Feasibility -The design of Ethernet I/O is very feasible. The peer to peer communication should be configurable using the software provided by the manufacturer of the devices. The devices will be plugged into a local Ethernet line and will transfer data through standard protocol.

Size / Weight - The size of Ethernet I/O devices are relatively small. The sum of three dimensions should be less than 10in. The devices are very light weight. The total weight of a single device should be no more than 200g which makes it very easy to install.

Maturity of Technology - Ethernet I/O is a very well developed technology. In the past Remote I/O was accomplished using RS485 as the communication protocol. Ethernet I/O is based on RS485 technology uses TCP/IP as its protocol and Ethernet as its communication medium. Ethernet I/O is a well-developed technology.

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.

Cost - 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 - 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.

Size / Weight - An FM system of signal transmission would require approximately the same space to implement as ArcelorMittal's current system of FM load signal transmission. The signal wire for transmitting the FM signal is already laid and bundled with many other signal wires. The transmitter would be a small box mounted in a switchyard instrumentation cabinet and the receiver would be about an identical size mounted in an instrumentation cabinet in the Control Room.

Maturity of Technology - FM signal transmission has been used for more than half a decade. The system of load signal transmission currently used by ArcelorMittal uses FM technology. The current FM system of load signal transmission has been proven reliable over a span of fifty years of use in ArcelorMittal's facility.

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.

Cost-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 -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.

Size / Weight - A fiber optic cable design implementation will require the use of an existing fiber optic cable along with a transmitter and receiver. The Transmitter must be able to be mounted inside an instrumentation cabinet in the switchyard which contains the load transducers. The receiver must be capable of being mounted inside the instrumentation cabinet in the Control Room which contains the load PLC.

Maturity of Technology - Fiber Optic cable is used throughout industry as a means of communicating over long distances. ArcelorMittal already uses fiber optic cable for signal transmission throughout its facility. Fiber optics are robust and proven reliable through years of use.

Solution Selection Matrix

Engineering Criteria	Importance	Possible Solutions					
		Pulse Width Modulation	Ethernet I/O	Optical Fiber	Frequency Hopping Spread Spectrum Transmission	Frequency Modulation Transmission (Wired)	Frequency Modulation Transmission (Wireless)
Reliability	5	9	9	9	3	9	3
Cost	4	9	3	1	3	1	1
Feasibility	3	9	9	3	3	3	3
Size/Weight	2	9	9	9	3	3	3
Power Consumption	2	9	3	3	9	1	1
Maturity of Technology	1	9	9	9	1	9	1
Totals		153	117	91	61	75	45

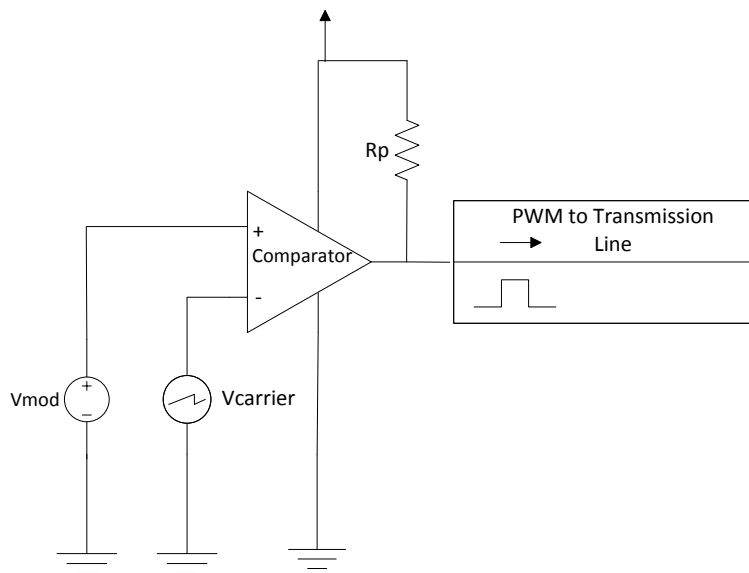
Importance Rating: 1 - 5 Scale, Strong = 9 points, Moderate = 3 points, Weak = 1 point
Total Calculation = (S1)(ImpC1) + (S1)(ImpC2) + ... +(S1)(ImpCn)

FIGURE 2

VI. Proposed Design Solution

Based upon the solution selection matrix, 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. The technology inherent to PWM transmission and similar modulation schemes is that it has very high noise immunity. This characteristic also makes PWM desirable in that if the transducer input were simply attempted to be amplified along the transmission line, any noise along the channel would also be amplified and sent to the receiver. By encoding the input as a small signal, the original amplitude becomes proportional to the duty cycle. The transmission of the input to the output does not require any synchronization between the transmitter and receiver.

The proposed plan will place the transmitter in the same cabinet as the original transmitter. The power required for our application will tap into the low-voltage DC bus available within the cabinet, ranging up to +24Vdc. 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 programming for a microcontroller and simplicity of design, the comparator in conjunction with a sawtooth generator design shall be used. As seen in the figure below, the input from the transducers will be applied to a comparator as the modulating signal that is being referenced to the higher frequency carrier from the sawtooth generator.

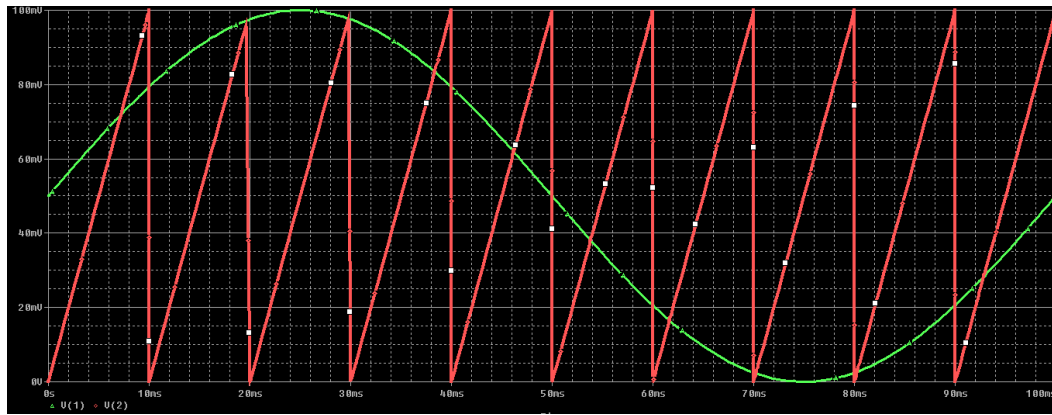


Simplified Diagram of Transmitter

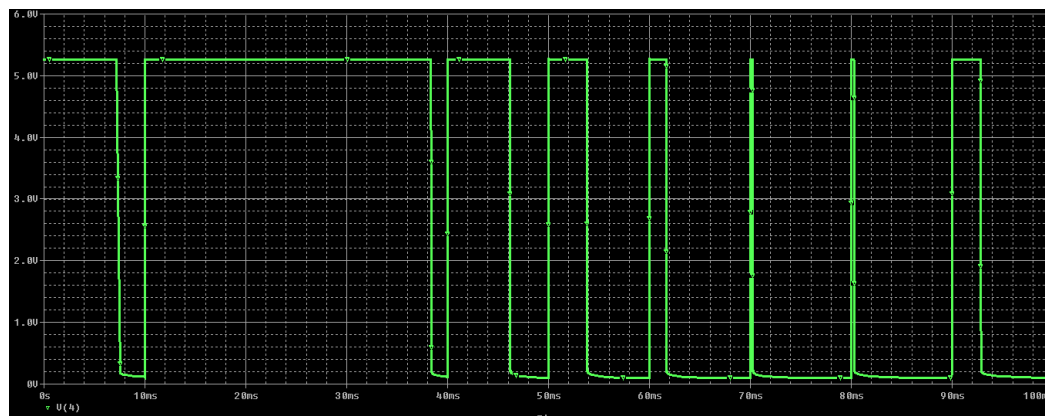
FIGURE 3

The high input impedance of the comparator will provide the necessary isolation from the already existing FM telemetry setup; therefore any consideration into a short circuit analysis need not be performed. A free-running sawtooth generator is not available as a stand-alone IC, but several ICs, such as the LM566, are available with applications where a precision triangle wave or sawtooth can be

constructed. The comparator will generate a pulse-width modulated output as seen in the subsequent figures. When the modulating signal amplitude is greater than that of the carrier signal amplitude, a positive pulse is generated. When the modulating signal is less, the comparator is driven to a value near zero.



Reference Signal (Green) and Carrier Signal (Red)



PWM Output from the Comparator

FIGURE 4

The output will be transmitted down a standard twisted pair wire, ideally with overall shielding. The twists within the wire minimize the cross-talk within the channel, and the shielding helps preclude any obstructive EMI. It is of significance to characterize the transmission line as a filter, itself. There are inherent resistive, capacitive and inductive components per unit length of the line. There is a bandwidth to the wire, and as long as the transmitting frequency is kept low enough and within the passband of the wire, the inductance will act as a short and the capacitance as an open.

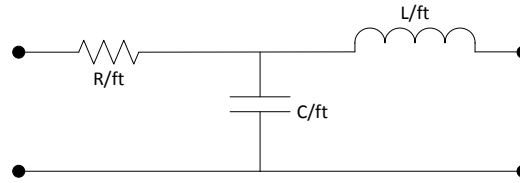


Figure 5: Transmission Line Distributed Components

FIGURE 5

The implementation of another comparator, such as a Schmitt trigger, may be necessary based on the impedance characteristics of the wire in order to reconstruct the pulses at the receiver. The new receiver will be located at Central Dispatch near the original receiver. Similar low-voltage DC shall be available in order to power our application. For the receiver, a low-pass filter will remove the higher frequency component of the carrier waveform and leave a low-frequency or corresponding scaled direct current (DC) component of the transmission. In order to minimize the added noise to the design; the use of inductors will be avoided. However, higher ordering of the filter is necessary to provide adequate higher frequency and noise rejection. The proposed receiver will be constructed using a Butterworth low-pass filter, such as the one exhibited below.

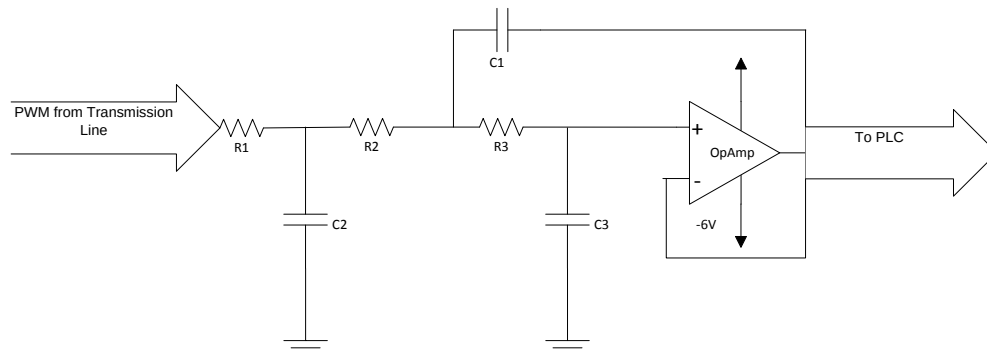


Figure: Simplified Diagram of Receiver using a 3rd Order Butterworth Filter

FIGURE 6

Based upon the specifications given by the sponsor, the output of the filter shall be within an approximate 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.

PROJECT TIMELINE

9/24 – 10/5	Gather data, experiment, research, prototype, and create the project design
10/6 – 10/19	Order parts for the chosen design and wait for delivery
10/20 – 11/2	Build the chosen design and troubleshoot if necessary
11/3 – 11/16	Extra time for unanticipated problems or need to rework chosen design
11/17 – 12/6	Preparation for final project presentation and delivery
12/7	Project delivery

FIGURE 7

IX. Budget

The proposed design has a big advantage over the other proposed designs because of the low cost. The parts including all the electronic components and chips can be found in the ECE shop with no cost. Parts may be ordered once the design is finalized. Low noise and low power consumption ICs will increase the signal integrity and overall power consumption of the design. The entire circuit needs to be fabricated on a printed circuit board. There are several options for fabrication. The ECE shop is capable of doing a simple Printed Circuit Board (PCB) fabrication. Since the design circuit is not complicated this may be a possibility. If the designed circuit board needs to be fabricated by a PCB fabrication company, it is estimated that the cost of fabrication will be one hundred dollars.

Besides the circuit, cases and mounting devices are also needed for mounting and installing the devices in the plant. It is estimated that the cost of the cases will be around thirty dollars and the cost of mounting devices will be fifty dollars. All the cost at this moment is estimated. However, with no more elements to be purchased, the cost of the entire project should be controlled at about two-hundred dollars.

PROPOSED BUDGET TABLE

Electronic components	\$10*
ICs	\$10*
PCB Fabrication	\$100*
Enclosure	\$30*
Mounting device	\$50*
Total	\$200*

*ESTIMATED COST

FIGURE 8

X. References

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