# Fiat Lux: A Fluorescent Lamp Transceiver

Tiffany K. Buffaloe  Deron K. Jackson  Steven B. Leeb
Martin F. Schlecht  Rebecca A. Leeb

*Abstract*—**The prevalence of electric discharge illumination has led us to consider ways to use discharge lamps for communication. This paper describes an optical transceiver system which transmits by modulating the lamp arc. The prototype power electronic lamp ballast uses a pulse frequency modulation scheme which ensures no perceptible flicker.**

## I. Introduction

OVER half of the artificial light produced in the United States comes from lamps in which an electric discharge through a gas is used to produce illumination [1]. The prevalence of electric discharge illumination has led us to consider ways to inexpensively use discharge lamps for communication. This paper describes an optical transceiver system which transmits information by modulating the arc in a fluorescent lamp. The prototype transmitter is a switching power electronic ballast that uses a pulse frequency modulation scheme [2] to ensure that the lamp exhibits no flicker perceptible to the human eye. A portable receiver decodes the information coded in the lamp light.

The received digital data stream could be used to deliver a visual (text) or audio message, or could be processed directly by a computer or other information handling system. We envision, for example, that the transceiver system could be used to provide a continuous, personal audio signal to the visually impaired. This signal could change with different lighting zones in a building to provide a kind of audio map or positioning system. With the addition of a power line carrier modem or other real-time information delivery scheme, the transceiver could also be used as a paging or broadcast system. The lamp-based transceiver system could be advantageous in comparison to other communication schemes (e.g., custom infra-red or radio-frequency transceiver installations) because it can be installed, in principle, with no additional wiring beyond that required to install conventional light fixtures in a building or on a street. Also, light fixtures are typically arranged to flood an area with light, ensuring a relatively reliable communication channel.

The authors are with the Laboratory for Electromagnetic and Electronic Systems, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

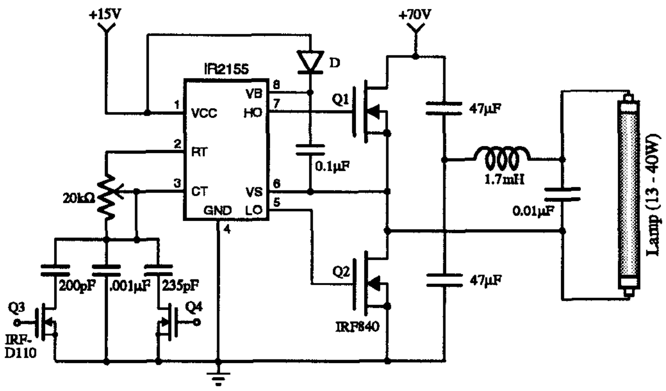


Fig. 1. Lamp ballast circuit.

The prototype transmitter is composed of a single, 16 inch fluorescent lamp in a fixture with a custom electronic ballast. The ballast transmits digital messages stored in an EEPROM. The receiver consists of an Intel 80C196KC microcontroller board [3] and an analog preprocessor, which recovers digital data by demodulating the output of an optical detector. The microcontroller displays received messages on a liquid crystal display. The next section reviews the design of the transmitter and lamp ballast. The section following describes the receiver, and the paper concludes with a review of experimental results.

## II. Transmitter

The luminosity of a fluorescent lamp is related to the frequency and amplitude of the arc current running through the lamp [1],[4]. Either the frequency or amplitude of the arc current could be varied to "key" information into the light output of the lamp. Of course, any variations must occur at a rate substantially above the range of visual perception to avoid visible flickering of the lamp light. Low frequency

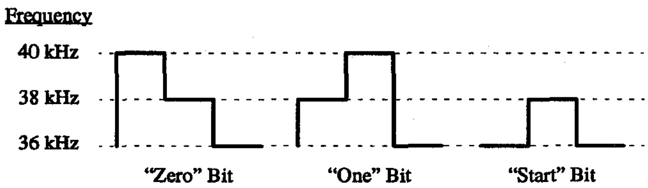


Fig. 2. Bit patterns.

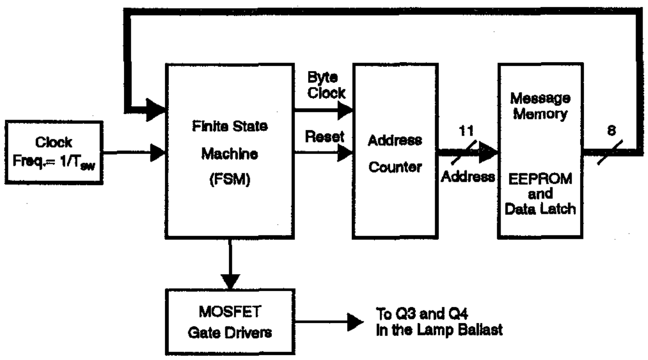


Fig. 3. Transmitter block diagram.

flicker has been linked to eyestrain and headaches [5]. The prototype uses a pulse code scheme that shifts the arc frequency to avoid such low frequency flicker.

The lamp ballast employed in the prototype is a Class-D circuit ([6], [7]) built using the International Rectifier 2155 lamp ballast controller chip [8]. The ballast circuit is shown in Fig. 1. Note, in particular, that the RC timing circuit connected to pins 2, 3, and ground on the IR2155 has been modified from the typical timing circuit shown in [8]. The net effective timing capacitance can be selected by turning *on* or *off* one of the IRFD110 MOSFETs (Q3 and Q4). With both MOSFETS *off*, the lamp operates at an arc frequency of approximately 40 kHz. With Q3 *off* and Q4 *on*, the arc frequency is 38 kHz. With Q3 *on* and Q4 *on*, the arc frequency is 36 kHz.

To transmit a data bit, it is *not* sufficient to employ, for example, a direct frequency-shift keying (FSK) scheme. Suppose a zero bit was assigned an arc frequency of 38 kHz and a one bit was assigned 40 kHz. In this case, a long run of logic zeros followed by a long run of logic ones would result in a noticeable flicker in light intensity during the transition. Instead, the ballast shifts the arc frequency to one of the three possible operating frequencies every $T_{sw} = 2$ milliseconds. This results in a steady light output, on average, with no perceptible flicker. A one or a zero bit does not correspond to a particular arc frequency, but rather, to a three level pattern in arc frequency. A logic zero bit is transmitted by varying the arc frequency first to 40 kHz, then to 38 kHz, and finally to 36 kHz. A logic one bit is transmitted by the arc frequency pattern beginning with 38 kHz, followed by 40 kHz, and ending with 36 kHz. A start bit, used to demarcate the beginning of a transmitted byte, is represented by a sequence in the arc frequency beginning with 36 kHz, followed by 38 kHz, and ending with 36 kHz.

The arc frequency pulse patterns which represent a logic zero, a logic one, and a byte start pattern are illustrated schematically in Fig. 2. These sequences offer at least two advantages. First, the patterns for zero and one have the same average arc frequency. For sufficiently rapid switching between the different arc frequencies, i.e., for a sufficiently short interval $T_{sw}$, the lamp exhibits no perceptible flickering, even during transitions between long sequences of zeros and ones. Second, since the bit patterns exhibit a transition or frequency change every $T_{sw}$ seconds regardless of the transmitted data, these transitions can be used by the receiver to generate a clock that synchronizes the receiver and transmitter. It is important to note, however, that the start bit pattern shown in Fig. 2 does not have the same average frequency as the logic zero and one patterns. As a result, the inevitable small flickering component at multiples of the byte rate which occur at frequencies below the transition rate of $\frac{1}{T_{sw}}$ may be accentuated. If the flicker at these frequencies is perceptible, a longer start sequence having the correct average frequency may be substituted with a slight reduction in throughput. This flicker was not observed in our prototype system.

Figure 3 shows a block diagram of the transmitter. This transmitter is designed to broadcast a 2 kilobyte page of text, and then to repeat transmission of the page indefinitely. There is an upper limit on the data rate; that is, $T_{sw}$ must be significantly longer than the longest arc period in order for the receiver described in the next section to work reliably. In general, messages could come from any digital or digitized source. In Fig. 3, a finite state machine (FSM) implemented with programmable array logic sets the arc frequency of the lamp by controlling the switches Q3 and Q4 in the ballast circuit. This FSM oper-

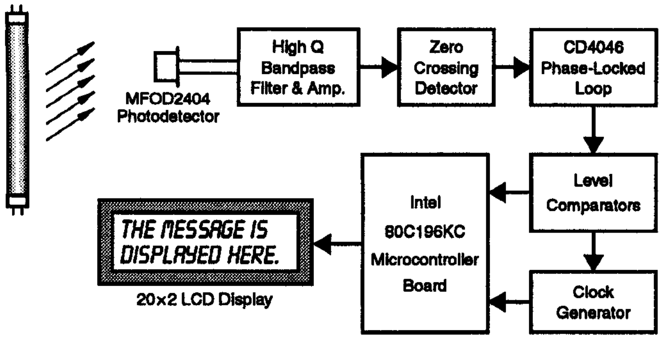


Fig. 4. Receiver block diagram.

ates at a base clock period of $T_{sw}$ and ensures that the arc frequency is altered once each period. The FSM also controls an address counter, which selects bytes of information stored in an EEPROM. The first seven bits of each byte contain an ASCII character code to be transmitted. The eighth bit signals the end of the page, which resets the address counter and triggers the FSM to start sending the message again from the beginning. Each bit in a byte is examined sequentially by the FSM, and the lamp arc frequency is controlled according to the bit patterns shown in Fig. 2. That is, the FSM "expands" each data bit into the appropriate pattern of three different arc frequencies.

## III. Receiver

A Motorola MFOD2404 photodetector, with built-in preamplifier, is used in the prototype to detect the light output of the fluorescent lamp [9]. To help reject background variations in the ambient environment which are not caused by the operation of the transmitter, the photodetector signal is first passed through an analog bandpass filter and amplifier in the receiver. Note that, while the arc frequency varies from 36 to 40 kHz, the received intensity signal varies from 72 to 80 kHz, because the intensity varies with the magnitude and not the direction of the arc current. A block diagram of the receiver is shown in Fig. 4.

Zero crossings in the intensity signal are located using a comparator, and the frequency is tracked by a CD4046 phase-locked loop (PLL). The output voltage from the loop filter in the PLL switches between three distinct levels which correspond to the three possible detected arc frequencies, i.e., 72 kHz, 76 kHz, and 80 kHz. As shown in Fig. 4, the PLL loop voltage is digitized by two voltage comparators. The reference points for these comparators are set such that if the highest frequency is transmitted, then both comparators will go high. If the mid-range frequency is transmitted, then only one of the comparators will go high. Finally, if the lowest frequency is transmitted, then both comparators will go low. The two comparator outputs are fed directly into the microcontroller board. With an appropriate synchronizing clock, the microcontroller can decode the patterns observed in the comparator outputs in order to recognize transmitted bits.

The receiver derives a synchronized clock signal from the incoming data. Four one shots are configured to fire on both the rising and falling edges of the comparator outputs. The one shot outputs are combined combinatorially to yield a clock with a period $\frac{T_{sw}}{2}$. Rising edges of this clock signal occur *in the middle* of each transmission period of length $T_{sw}$. The microcontroller samples the digitized PLL output on every rising edge of this clock, thus ensuring that the PLL has settled. As the microprocessor identifies transmitted bits, it stores the transmitted information and periodically updates the incoming message on a 2 line, liquid crystal display.

## IV. Experimental Results

A receiver was constructed using an Intel 80C196KC microcontroller (with plenty of spare processing power in this application). Code for the microcontroller was developed in the *C* programming language using a cross-compiler from Intel [3]. The transmitter and ballast circuitry were constructed as described in the previous sections on printed circuit boards. Additional details of the hardware and software are presented in [10].

Figure 5 shows some typical experimental waveforms during the transmission and reception of a byte. The top two traces in the figure, labeled (a) and (b), are inverted versions of the gate drive signals from the transmitter to the MOSFETs Q3 and Q4 in the lamp ballast, respectively. The third trace (c) is the sum of these two waveforms, i.e., the three-level modulation pattern that indicates the variation in the lamp arc frequency. The fourth trace (d) is the received three-level message pattern measured at the output of the PLL loop filter. Traces (c) and (d) are essentially identical, as they should be.

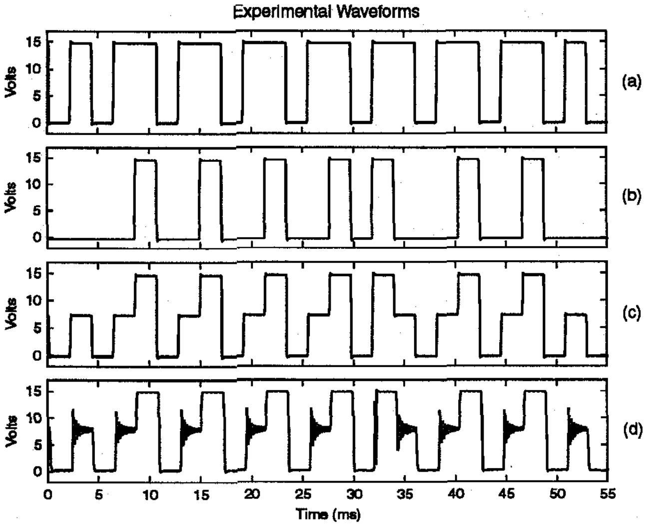


Fig. 5. Transmitted and received bit patterns.

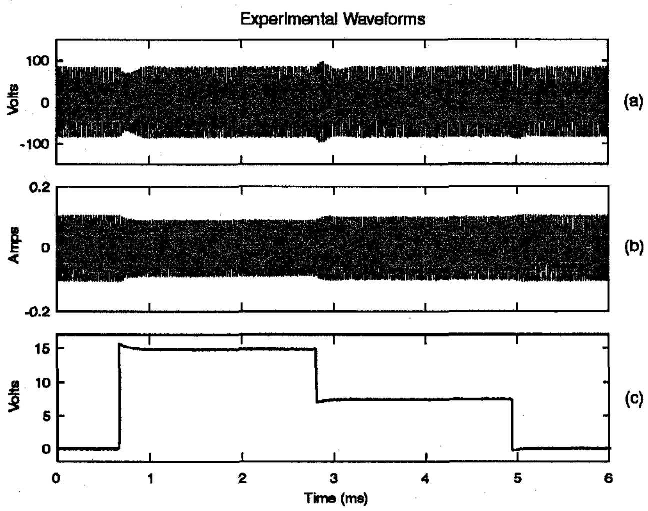


Fig. 6. Lamp voltage and current.

Figure 6 shows the voltage and current across the lamp while the transmitter is operating. Traces (a) and (b) in Fig. 6 show the terminal voltage across and current through the lamp, respectively, as the commanded arc frequency is changed. Trace (c) shows the voltage waveform corresponding to the commanded arc frequency, i.e., an expanded version of trace (c) in Fig. 5. Traces (a) and (b) in Figure 7 show expanded versions of the lamp current and the frequency command signal, respectively. The current is approximately sinusoidal, and is both frequency and amplitude modulated. The frequency modulation occurs because of the action of the transmitter

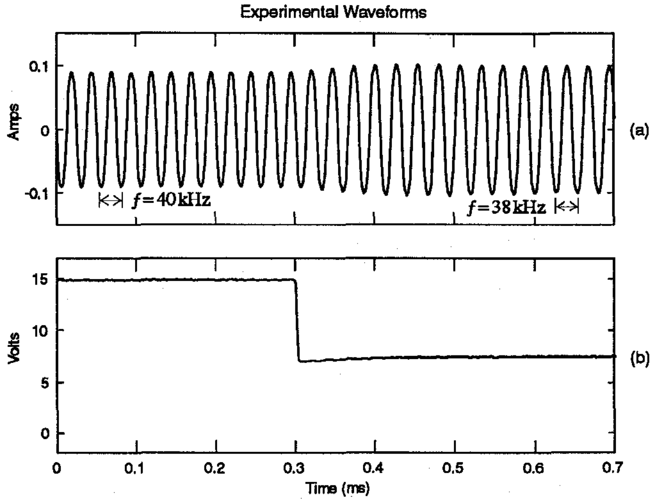


Fig. 7. Expanded view of the lamp current during a step change in frequency.

and ballast. The amplitude variations result from a slight detuning of the RLC resonant circuit in response to the commanded step changes in frequency. The transient variations which immediately follow a change in frequency are short-lived and do not significantly affect performance.

## V. Discussion

The fluorescent lamp transceiver set performs successfully. In operation, the transmitter sends the full 2 kilobytes of text stored in the page memory in approximately 100 seconds. Messages from the transmitter are decoded by the receiver microcontroller and displayed on the LCD screen. Other applications might use the data in different ways. For example, it would be perfectly reasonable to send bursts of audio information using this transceiver set. The receiver could collect a run of data bytes and reconstruct an audio message. We envision that a system like this could be used, for example, to provide low data rate location information to a person traveling in an unfamiliar building. Following a brief latency in each room or hallway to collect data, the receiver could provide visual or audio information (for a visually impaired person, for instance). This technique might also be used with HID lighting along roadways to provide street and direction information to moving vehicles. A receiver could also be constructed to provide digital data directly, e.g., as a receiver in a low bandwidth local area network.

The prototype transmits messages stored in an EEPROM, but other sources of input could be used. Coupled with a power line carrier modem, the transceiver set could be used as a paging system that broadcasts messages in near real-time. A transmitter network could be constructed in a building simply by installing new ballasts in existing fluorescent lamp fixtures, with no additional wiring. These fixtures make excellent transmission sources since they are designed to flood rooms with light, as opposed to custom wireless infra-red or low power radio-frequency transmitters.

Our prototype receiver does not employ automatic gain control (AGC) of the photodetector output. Hence, the receiver operates only within a relatively limited distance from the transmitting fluorescent lamp. A practical receiver would incorporate an AGC circuit to provide robust signal reception in an environment that might contain substantial background illumination. Also, the bit rate and arc frequency are conservative in the current design. Both could be increased with minor changes in the transceiver design to offer improved performance. Other bit patterns might improve the overall data transmission rate. A trinary coding scheme, for example, employed with the current system could increase the data rate.

Finally, we note that the current hardware could be improved or altered to provide other features. The general concept of varying the light output to transmit information could be incorporated into other ballast designs, including isolated ballasts. Clearly, the ease with which the frequency pulse code transmission scheme could be incorporated would depend in part on the chosen power electronic ballast topology. The three frequency data encoding scheme demonstrated in this paper is by no means the only approach for coding data in the lamp output. Other techniques might be used to improve transmission bandwidth or flexibility. We envision that orthogonal bit patterns could be employed in different lamp ballasts (or the same ballast dependent on a transmission "key code") to permit the transmission and reception of data on different channels in the same local area. One channel could be used, for instance, to provide location information, while another might be used for direct person-to-person paging.

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