Synthesis and Simulation of Digital Demodulator for Infrared Data Communication

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Abstract— A high performance design methodology is described for a digital demodulator, which is intended for the noise immune wireless infrared data communication. In this methodology, ASK(Amplitude Shift Keying) infrared signals detected by a photo detector are digitized into two logic-level pulses by an infrared receiver, and the demodulation of the digitized signals is implemented by a new architecture. On account of the interference with optical noises from fluorescent lamps, an ASK receiver is realized by a 1-bit digital demodulator, which is designed with use of a high level synthesis tool COMPASS so as to implement an algorithm for removing the noises. A part of experimental results is also shown to demonstrate the practicability.

I. Introduction

The explosive growth of high performance portable computers and computer-networks has created strong demands for interconnection between mobile terminals and networks. The wireless communication offers flexible connections among mobile terminals, and innovates today's computer and communication technologies.

There are two alternatives for the wireless communication; radio and infrared. The communication based on the infrared has many advantages over that on the radio. For example, the infrared communication has an abundance of bandwidth; offers high speed link, without regulation; creates solutions to world wide use; facilitates low cost and low power consumption; is suitable for portable use; etc.

The infrared communication has disadvantage as well. An artificial-light like an fluorescent lamp emits an intense infrared noises, and hence a photo detector of an infrared receiver is exposed directly to such environmental noises. Recently, fluorescent lamps capable of such high speed switching at 50 kHz appear on the market. Considering that noises from these lamps interfere with infrared signals, it is of primary importance to avoid this interference for the practical use of the infrared communication.

Since the wireless LAN using the infrared radiation was attempted[1], numbers of researches have tried to raise the performance of infrared communication. However, there have been few studies in terms of the interference with artificial-light. Motivated by this technical demand, the present paper describes a design methodology for a digital modulator, which can improve the noise immunity of the conventional ASK (Amplitude Shift Keying) infrared communication systems.

Section II overviews infrared data communication systems, and Section III analyzes the optical noises in conjunction with its interference with ASK signals. Base on the analysis, Section IV models an infrared communication mechanism under optical noises, and then simulates the output waveforms of an infrared receiver, which are input to the digital demodulator. Section V first describes an algorithm for removing such noises from the output waveforms, and then constructs a digital demodulator based on the algorithm, by means of a high level synthesis tool COMPASS. Section VI shows a part of experimented results, which indicate that this series of modeling, simulation, and noise removal mechanism approximates very well the actual phenomena of optical noises, and hence that the constructed ASK receiver is of grate use in practice.

II. Infrared Data Communication System

The asynchronous data transmission among computers is widely used in serial communication systems, as illustrated in Fig. 1. There are two signal lines in this configuration; *TxD line* for data transmission and *RxD line* for data receiving. Character data are transmitted one at a time, each with the use of the start bit of '0', eight bits for character information, and the stop bit of '1'. The

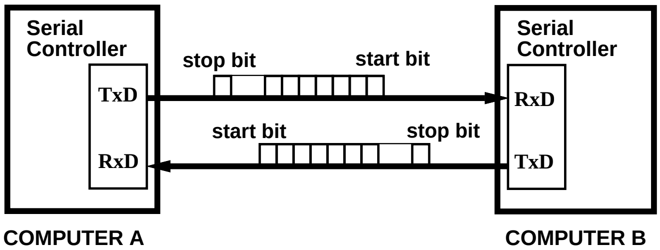


Fig. 1. Serial communication system

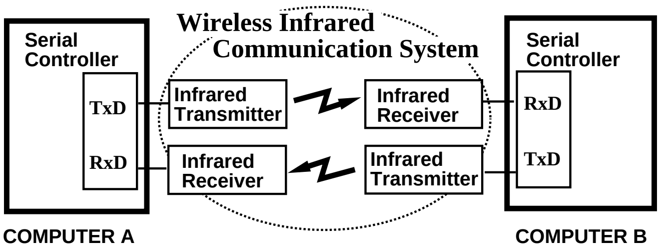


Fig. 2. Serial communication system by wireless infrared communication

receiver circuit of the serial controller resynchronizes the data sample timing at the start bit of each character data.

Fig.2 shows an example of a wireless infrared communication system adapted for the asynchronous data transmission. An infrared transmitter is connected to the *TxD line*, and a receiver is to the *RxD line*, to transmit infrared signals from the the transmitter to the receiver.

Such a wireless infrared communication system usually adopts the Amplitude Shift Keying (ASK) to convey infrared signals. The carrier is composed of infrared pulses at 500 kHz (Fig.3), and binary values '0' and '1' are represented as

binary '0': infrared pulses at 500 kHz during one bit period time.
binary '1': no infrared pulse.

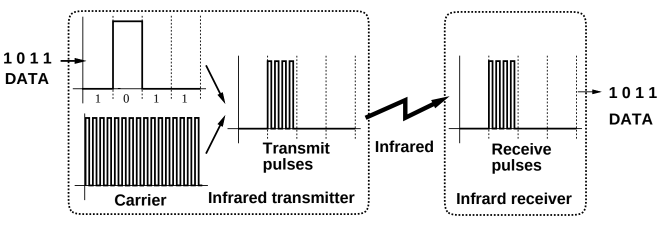


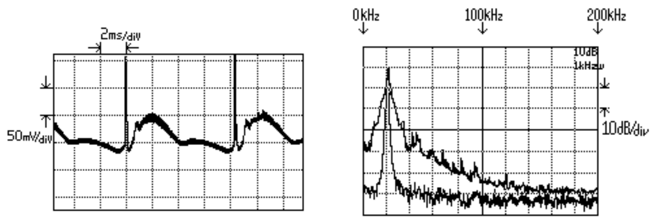
Fig. 3. Amplitude Shift Keying

III. Optical Noise Analysis

The optical noises in typical office environments are due to daylight and fluorescent lamps. These noise sources actually include the infrared, whose intensity varies by an order of magnitude according to the distance(see Table I).

TABLE I
Intensity of optical noises from lamps (unit:$\mu W/cm^2$)

distance(cm)	HF lamp	fluorescent lamp
10	80	25
20	32	13
30	17.3	8.3
40	11.7	5.6
50	8.76	4.1
80	2.5	3.2



(a) Waveform (b) Spectrum

Fig. 4. Noises from fluorescent lamp

(a) Daylight
The daylight is a high level of stationary or slowly fluctuating light, whose intensity usually varies from $7\mu W/cm^2$ to $150\mu W/cm^2$ according to measuring positions in a room.

(b) Fluorescent lamps on the ceiling
The infrared emitted from a fluorescent lamp flickers on and off with the line frequency, as shown in Fig.4(a), and Fig. 4(b) shows the spectrum of this infrared noise; its spectral lines are in the range from D.C. to 100 kHz. As shown in Fig. 5, its intensity is almost reciprocally proportional to the square of the distance from the lamp.

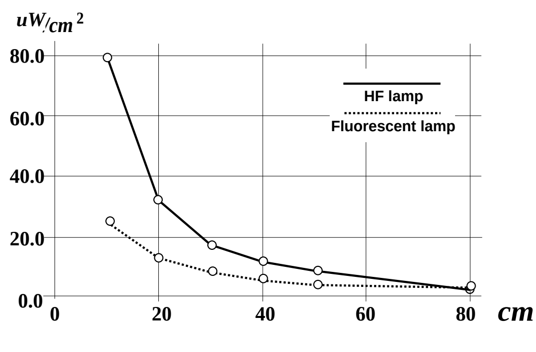
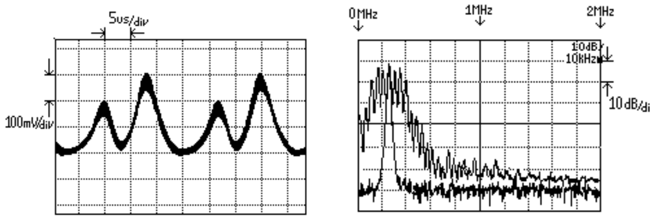


Fig. 5. Intensity of optical noise from lamps

(c) High speed switching fluorescent lamps on the desk
High speed switching fluorescent (HF) lamps are now becoming popular. More than 80 percent of desk lamps are of this HF type. The infrared emitted from such a lamp flickers around at 50 kHz as shown in Fig.6(a), with har-



(a) Waveform (b) Spectrum

Fig. 6. Noises from a HF lamp

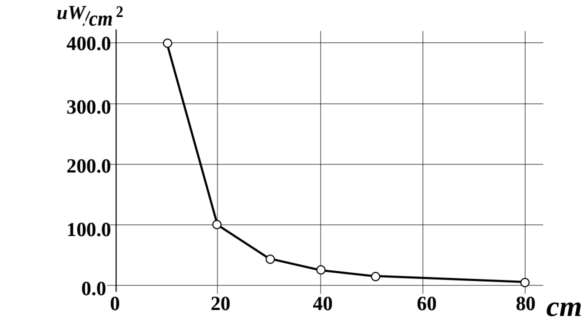


Fig. 7. Signal intensity at photo detector

monics up to over 500 kHz. Its intensity is also almost reciprocally proportional to the square of the distance from the lamp.

A. Interference Consideration

The intensity of the signal power emitted from an LED on a transmitter decreases reciprocally proportional to the square of the distance from the LED. The signal intensity at a photo detector on the infrared receiver is calculated, as illustrated in Fig.7, where it is assumed that the LED radiates at 40 mW/sr. The signal power at a distance of 1 m from the LED is $4\mu W/cm^2$.

The daylight has no spectrum around at 500 kHz, and hence it does not interfere with the ASK infrared signal. With regard to noises from a fluorescent lamp on the ceiling, the spectrum around at 500 kHz is 40 dB less than the peak of the spectrum. Usually the distance between a mobile terminal and a lamp is more than 1m, the power of the noise is less than $3\mu uW/cm^2$, and hence it is negligible. The predominant infrared noise is due to desk lamps, which has the spectrum of 500 kHz, and moreover, the distance between a terminal and a lamp can be less than 30 cm. Suppose that the distance between two terminals is 1m, and that one of them is 30 cm away from a desk lamp. Then the signal power is $4\mu W/cm^2$, whereas the noise power is $17\mu W/cm^2$. This noise may interfere with the signal in accordance with the receiver's noise rejection ratio. Thus an infrared communication receiver should be designed, taking much account of these noises from HF lamps.

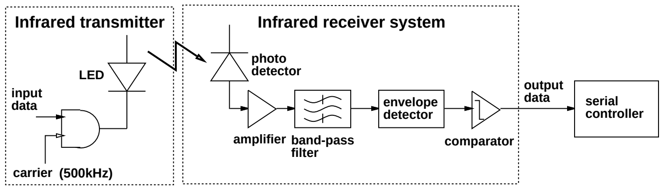


Fig. 8. ASK receiver using envelope detector

IV. Modeling Infrared Communication

The conventional ASK receiver systems use envelope detectors [2], as illustrated in Fig.8. The signals and noises received by a photo detector are amplified to usable signal level, and it is only a band-pass filter that removes noises. Hence in such a situation of $4\mu W/cm^2$ signal power with $17\mu W/cm^2$ noise power as stated above, this band-pass filter can not sufficiently remove noises.

A. Digital Demodulation Scheme

A new architecture is devised for an ASK receiver, which is composed of an infrared receiver and a 1-bit digital demodulator, as shown in Fig.9. The distinction of this receiver from that of Fig.8 is the omitting of the envelope detector. In other words, the receiver shown in Fig.9 only transforms the infrared pulses of the carrier into two logic-level pulses. This scheme has the following advantages as compared with the envelope detection and DSP based digital demodulation scheme.

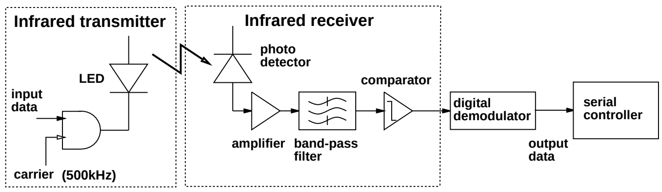


Fig. 9. ASK receiver using digital demodulator

1) The digital demodulator employs a 1-bit A/D (analog/digital) convertor composed of only one comparator, instead of an expensive multibit A/D convertor, which admits a low frequency clock operation, and therefore reduces greatly the power consumption. Hence not only the total cost but also the power consumption of the infrared receiver and the digital demodulator can be much less than that of the envelope detecting scheme.
2) The digital demodulator is to implement an algorithm for removing the interference with optical noises, and therefore it can improve the noise immunity of the receiver system.
3) Due to the simple structure, the demodulator can be easily implemented by an ASIC.

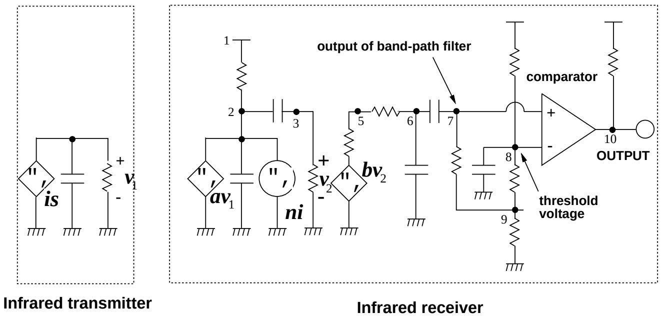


Fig. 10. Model of infrared communication

B. Modeling the infrared communication

The infrared communication can be modeled by analog circuits under the following assumption.

1) The photo current of a detector is proportional to the intensity of the infrared to which the detector is exposed.
2) The infrared power radiated from an LED is proportional to the LED current.
3) The intensity of the infrared emitted from an LED is reciprocally proportional to the square of the distance from the LED.

Now, let the infrared communication be modeled as outlined in Fig. 10. The independent current source $\boldsymbol{is}$ represents an LED current. The voltage controlled current source $\boldsymbol{av_1}$ indicates the photo current caused by an LED. The independent current source $\boldsymbol{ni}$ depicts the optical noise from an HF lamp, which is approximated by a sine wave of $100kHz$, as can be observed from Fig.6. The voltage controlled current source $\boldsymbol{bv_2}$ represents an amplifier in the infrared receiver.

V. Design Methodology for Digital Demodulator

A digital demodulator is synthesized so as to remove the noises from HF lamps, as exemplified below.

Step1: Input the noises and ASK signals to the infrared communication model attained in section 4, and simulate its output by means of a circuit simulator.

For example, given a waveform of ASK signal as shown in Fig.11(a), input it to the communication model as the independent current source $\boldsymbol{is}$, and input a sine wave of $100kHz$ as the modeled noise source $\boldsymbol{ni}$. With the use of a simulator, the waveforms of the band-path filter output and the infrared receiver output are attained as shown in Fig.11(c) and (d), respectively.

Step2: Analyze the waveform of infrared receiver output (d) so as to extract predominant factors which can contribute to discriminating the ASK signal from the noise signal.

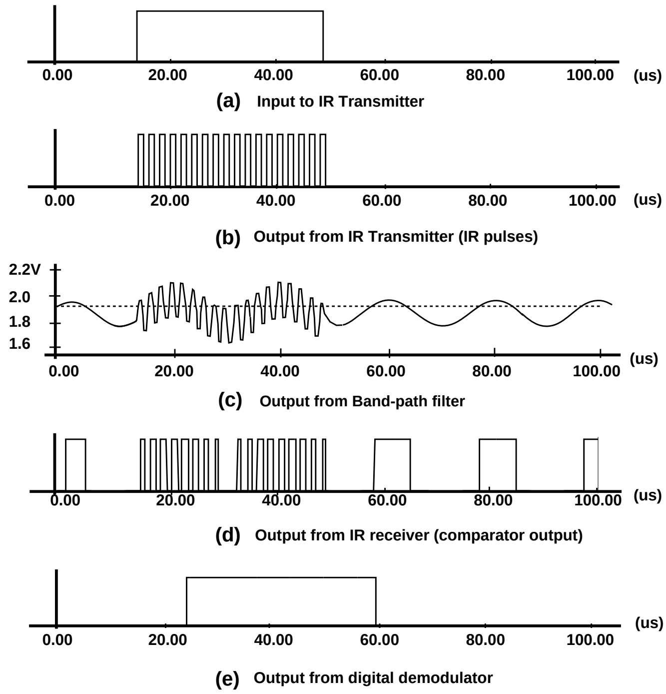


Fig. 11. Outputs of infrared receiver with modeled noises

According to the analysis, it turns out that the key factor can be reduced to the fact that regardless of the noise signal intensity, the frequency of the rising edge of carrier pulses can not deviate much from 500kHz.

Step3: Construct a demodulation algorithm on the basis of the analysis such that an output signal of the infrared receiver whose rising edge frequency falls in the band of 450kHz-550kHz can be regarded as the carrier.

Fig.12 outlines a demodulations algorithm written in the VHDL.

Step4: Synthesize a digital demodulator to implement the algorithm attained in Step 3, with the use of a high level synthesis tool *COMPASS Design Navigator*.

Table II shows a part of implementation results attained by using $0.6\mu m$, 5v standard-cell.

TABLE II
RESULT OF SYNTHESIS

chip size	power consumption	number of Tr
$0.0286mm^2$	$14mW$	519

VI. Experimental Results

We have attempted experiments for several pairs of ASK signals and actual noise signals. Fig.13(a) shows an input to a transmitter, for which the waveform of Fig.13(b) is obtained. Superpose on this waveform the

```
architecture of ASK DEMODULATOR is
   signal edgefound, up, down: bit;
begin
sampling:process
   variable sample, sampleold : bit;
begin
   wait until clk'event and clk='1';
   sampleold := sample;
   sample := input;
   if sampleold='0' and sample='1'
      then edgefound <= '1';
      else edgefound <= '0';
   end if;
end process;

filtering:process
   variable count: integer range 0 to 15;
begin
   wait until clk'event and clk='1';
   count := count + 1;
   if count >9 then down<='1'; count :=2;
   elsif edgefound='1' then
      if count >=7 then up <= '1';
      end if;
      count := 0;
      else up <= '0'; down <= '0';
   end if;
end process;
integration:process (up,down)
   variable energy: integer range 0 to 3;
   variable out_state: bit;
begin
   if up='1' and energy<3 then
      energy := energy +1; energyout <= energy;
      elsif down='1' and energy>0 then
      energy := energy -1;  energyout <= energy;
   end if;
   if energy=3 and out_state='0' then
      out_state := '1';  output <= '1';
      elsif energy=0 and out_state ='1' then
      out_state := '0';  output <= '0';
   end if;
end process;
end main;
```

Fig. 12. Digital demodulation algorithm

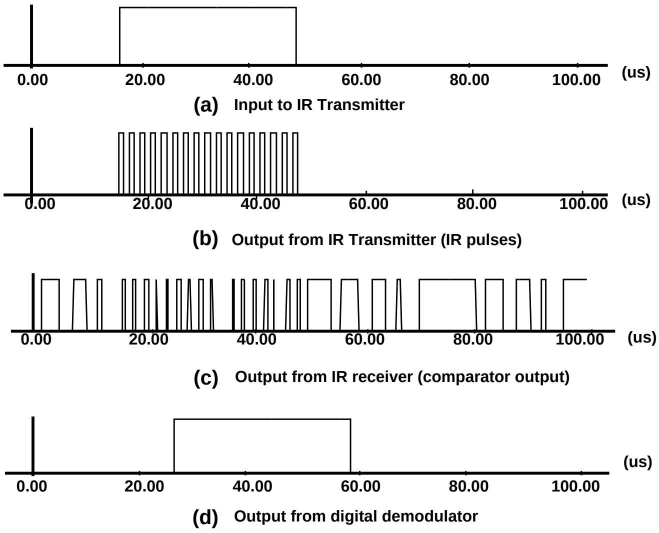


Fig. 13. Experimental results

actual noises from an HF lamp, and then input the superposed waveform to the infrared receiver. Fig.13(c) represents the waveform attained at the infrared receiver, for which the output of the designed demodulator is shown in Fig.13(d).

VII. Conclusions

A design methodology has been described for a digital demodulator which can avoid the interference between ASK signals and optical noises. First, the optical noises from lamps have been analyzed and a model of the infrared communication under these noises has been constructed. The output of an infrared receiver with the input of modeled signals and noises has been estimated by means of a circuit simulator. On the basis of this simulation, an effective algorithm has been constructed for removing such noises from the output signals of the infrared receiver, and then a digital demodulator has been synthesized so as to implement this algorithm, with the use of a high level synthesis tool. A part of experimental results shows that the ASK receiver constructed by the attained digital demodulator is of practical use.

References

[1] F. R. Gfeller and U. H. Bapst: "Wireless in-house data communication via diffuse infrared radiation," *IEEE*, vol. 67, no. 11, pp. 1474-1486, Nov. 1979.

[2] B. P. Lathi, *Modern Digital and Analog Communication Systems*, CBS College Publishing, New York, 1983.