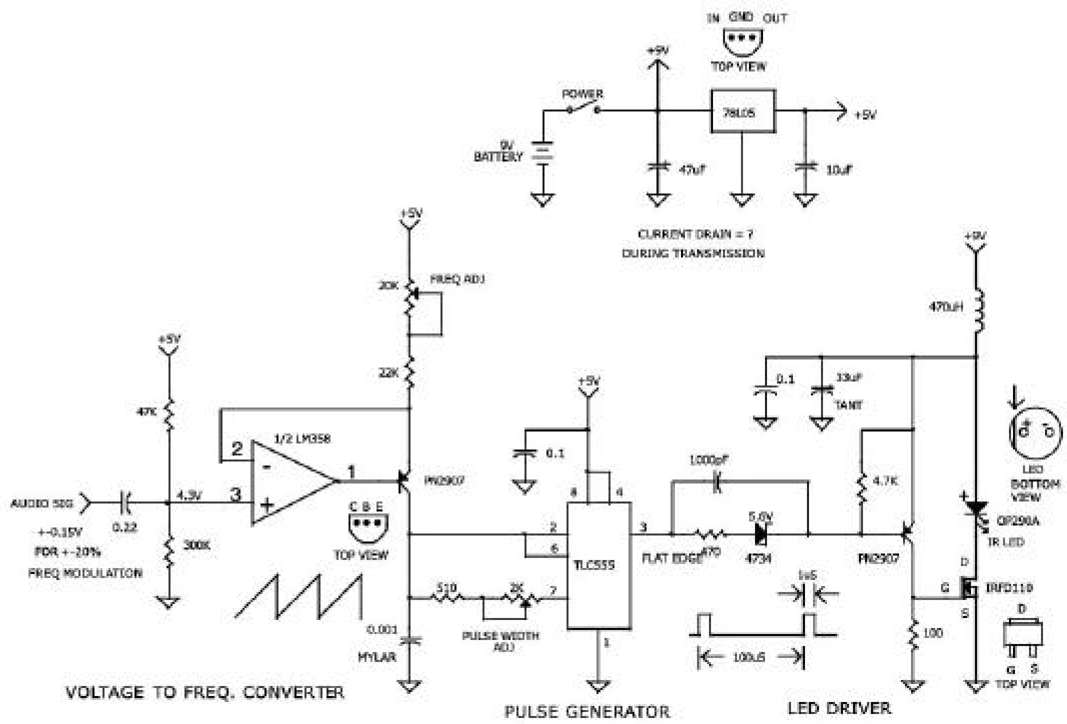
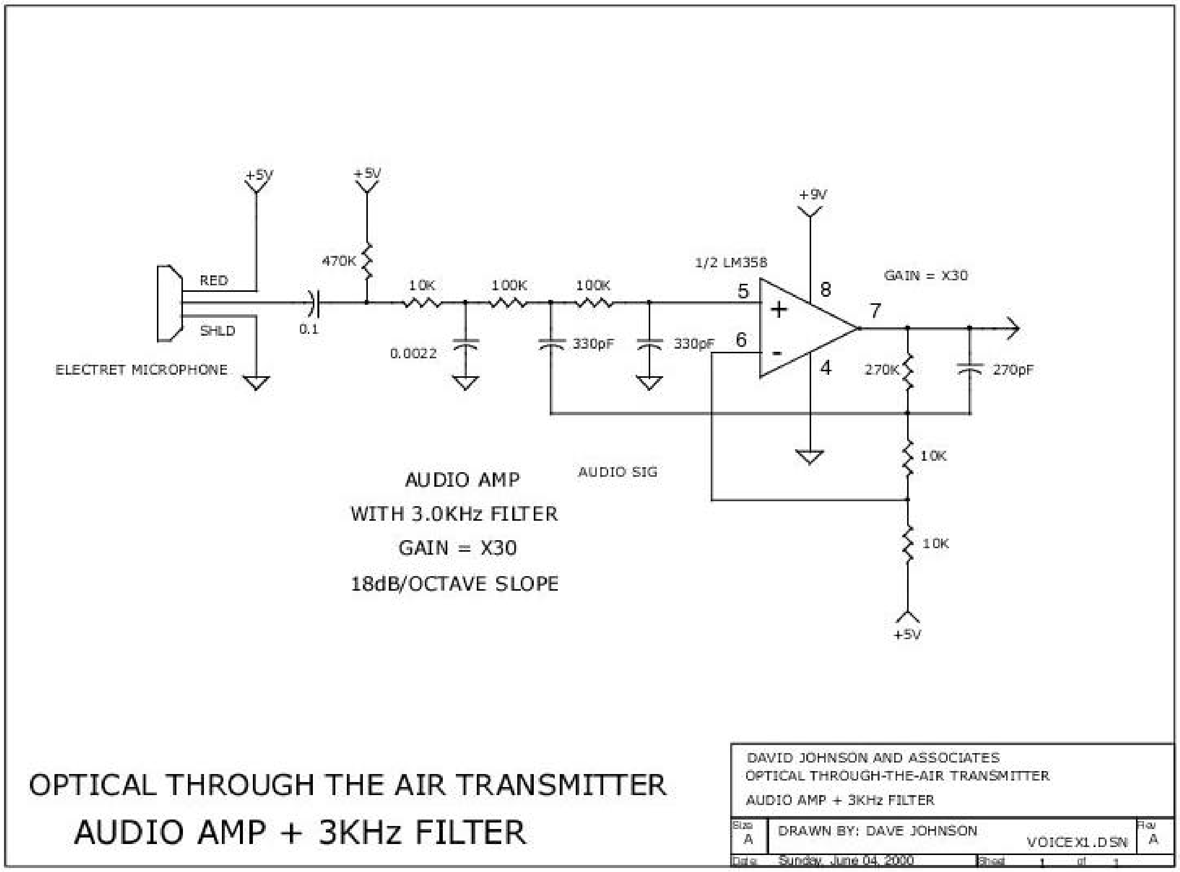
Fig



OPTICAL THROUGH THE AIR TRANSMITTER

V TO F CONVERTER + 1uS PULSE GEN + LED DRIVER

DAVID JOHNSON AND ASSOCIATES
OPTICAL THROUGH-THE-AIR TRANSMITTER
V TO F CONVERTER + 1uS PULSE GEN + LED DRIVER
DRAWN BY: DAVE JOHNSON
VOICEX2.DSN
Monday, March 22, 1999



+5V
+5V
470K
RED
SHLD
0.1
ELECTRET MICROPHONE
10K
100K
100K
0.0022
330pF
330pF
1/2 LM358
+9V
5
6
8
7
4
GAIN = X30
270K
270pF
10K
10K
+5V
AUDIO AMP
WITH 3.0KHz FILTER
GAIN = X30
18dB/OCTAVE SLOPE
AUDIO SIG
OPTICAL THROUGH THE AIR TRANSMITTER
AUDIO AMP + 3KHz FILTER
DAVID JOHNSON AND ASSOCIATES
OPTICAL THROUGH-THE-AIR TRANSMITTER
AUDIO AMP + 3KHz FILTER
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Figure 7a

bits per second. Such a data rate is far more than possible with communications systems using transmission cables.

The main objection potential investors had for my idea were the communications interruptions from bad weather. It is true that during some heavy snow storms and thick fog conditions the reception of the transmitted light signals could be blocked. But, overall I felt that people subscribing to such a service could tolerate a few interruptions each year. In spite of my arguments, I was not able to find any investors. So, It is hoped that someone reading this might someday consider the idea and make it a commercial success.

One system launches more power but spreads the light over a wider area while the other launches less power but points more of it at the target. The effect is the same. From a power consumption standpoint, the single LED system would be obviously much more efficient. But, the unit with multiple light sources and lenses would be easier to aim at the distant receiver.

Wide Area Light Transmitters

In some applications the challenge is not to send the modulated light to some distant receiver, whose position is fixed, but to send the light in a wide pattern, so either multiple receivers or a receiver whose position changes, can receive the information. Cordless audio headsets, VCR and TV remote controllers and some cordless keyboards all rely on either a direct link or in a indirect diffuse reflective link between the light transmitter and the receiver. The indirect paths would rely on reflections off of walls. Many of the light receiver and transmitter techniques discussed above could be used for wide area communications. However, keep in mind that to cover a wider area the distance between the light transmitter and the receiver would have to be shorter than a narrow beam link. Since the light being transmitted is spread out, less of it would make its way to the receiver. But, it would be possible to use large arrays of light emitting diodes or some other light sources so a large area can be bathed with lots of modulated light. If only short ranges are needed, one light source can be used in conjunction with a light detector as long as the detector had a wide acceptance angle. To achieve the widest acceptance angle, a naked silicon PIN photodiode works fine. Some large 1cm x 1cm detectors work great for receiving the 40KHz signals from optical TV remote control devices. When these large area detectors are used with a quality receiver circuit, as was discussed in the receiver circuit section, a receiver can be designed to be at least a hundred times more sensitive than conventional light receiver circuits often used in VCRs. The increased sensitivity means, when used in a direct link mode, the normal operating distance can be increased by a factor of ten. If your typical VCR remote normally has a 50 foot range, with the receiver changes, the distance could be increased to 500 feet.

Wide Area Information Broadcasting

If you increase the scale of the above methods, some interesting concepts emerge. For many years I attempted to get some communications companies interested in the idea of optical information broadcast stations. The idea was to transmit high speed digital data (up to 1Gigabit per second) from many transmitting towers scattered around a large metropolitan area. Each tower might have an effective radius of 5 miles in all directions. Such a wide area would mean only 4 towers would be needed to cover an area of 400 square miles. Since an optical broadcasting system and a radio broadcasting system could coexist on the same tower, many new towers would not have to be erected. Preexisting radio towers could be used. The light transmitters would also not require any FCC licenses. So far, no federal agency has been assigned the task of regulating optical communications.

The light being transmitted from the towers could originate from arrays of powerful lasers. Optical fiber cables could carry the light from the ground based light emitters to the top of the towers. Since the laser sources would emit light with very narrow wave lengths, the matching light receivers could use equally narrow optical filters to select only certain laser colors or wavelengths. This technique is called wavelength division multiplexing and has been used for many years in communications systems using optical fibers. The technique could be so selective that the number of different light channels that could be transmitted and received could number in the hundreds. Using such an optical approach, the data rate from each optical transmitter could exceed 100 billion illustrated in ***figure 7d***, a single lens should not be used with multiple light sources. As shown in the illustration, two light sources placed side by in front of a single lens will launch two spots of light, spaced widely apart. Only one of the spots would hit the distant receiver. This mode may be desirable in very rare situations, but for most long range systems, only one spot of light needs to be launched. Adding more light sources in front and a single lens would not increase the amount of light sent to a light receiver.

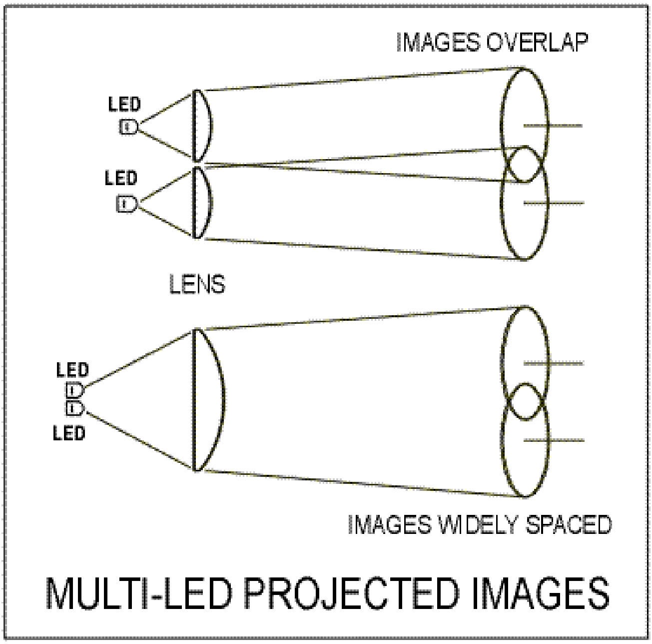

Figure 7d

As illustrated in ***figure 7d,*** a much more efficient method to send more light to a distant receiver is to use multiple LEDs, each with its own lens. The multi-source array will appear as a single light source with an intensity of XP where X is the number of lenses in the array and P is the light power launched by a single LED/lens section. A picture of an actual working unit using such a method is shown in ***figure 7e*** below. The unit uses 20 separate LEDs and 20 Fresnel lenses.

The system demonstrated a range of six miles when transmitting voice audio information. Transmitter systems should consider making some compromises between a large number of smaller LED/lenses that will be easier to aim at a distant transmitter and a system that has fewer lenses but is harder to point at a distant receiver. If power consumption is a concern, the system with fewer LEDs should be used. Consider the examples below.

Figure 7e

Let's consider two transmitter enclosures. Each enclosure has the same surface area on which to install lenses. One system used a single large lens and the second used multiple lenses. Suppose one system uses 4 LEDs with 3.5" lenses (49 sq. inches) that when combined formed a 0.4 watt source with a divergence angle of 1.0 degrees.

Now let's suppose the second system uses a single LED with a 7" lens (also 49 square inches) which yields a combined power level of 0.1 watts but a divergence angle of 0.5 degrees. As seen from the vantage point of a distant light receiver, the two systems would appear to have the same intensity Figure 7e.

To obtain the maximum practical efficiency, the LED should be driven with low loss transistors. Power field effect transistors (FET) are ideal. These devices can efficiently switch the required high current pulses as long as their gates are driven with pulses with amplitudes greater than about 7 volts. ***Figure 7b on page 66*** illustrates a FET driver that is used to power a LED directly without any current limiting resistor. The circuit takes advantage of the rather high voltage drop of the LED at high current levels to self limit the LED current. With the components selected, the LED current will be about 5 amps peak when used with a 9v supply. The inductor capacitor network between the LED and the power supply acts as a filter and helps keep the high current signals from interfering with other parts of the transmitter circuit sharing the 9v supply.

Light Collimator

For long range applications, the light emitted by the LED must be bent into a tight light beam to insure that a detectable amount of light will reach the distant light receiver. For most LED applications a simple plastic or glass lens will do. As discussed in the section on light emitters, the placement of the lens in front of the light source has the effect of reducing the exiting light divergence angle. Selecting the right lens for the application is dependent on the type of LED used. As illustrated in ***figure 7c***, the lens's focal length should be picked so it can capture most of the emitted light. LEDs with wide divergence angles will require lenses with short focal lengths and LEDs with narrow divergence angles can use lenses with long focal lengths. Keep in mind that the LED divergence angle is usually defined at the 1/2 power points. Therefore, to capture most of the emitted light, a wider LED divergence angle specification should be used when making calculations.

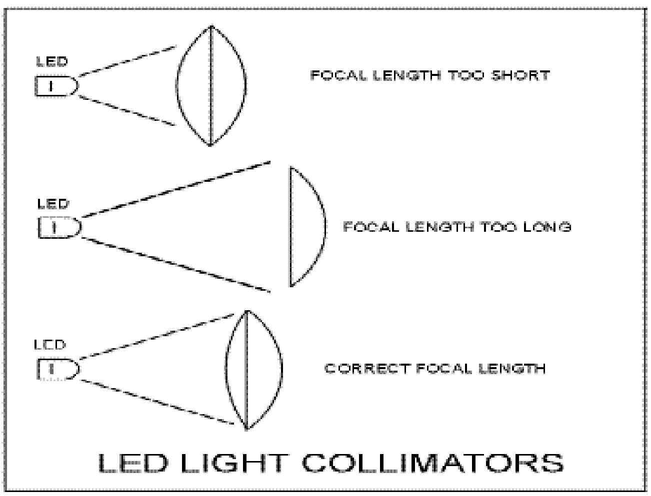

Figure 7c

The divergence angle of light launched using a lens is: (LED div. angle) x (LED dia/ lense dia)

As an example, a 1.9" lens and a 0.187" LED would reduce the naked LED divergence by a factor of 10. A LED with a naked divergence half-angle of 15 degrees would have an overall divergence angle of 1.5 degrees, if a small 1.9" lens were used. A 6" lens would yield a divergence angle of less than 0.5 degrees that is about the practical limit for most long range systems. Divergence angles less than 0.5 degrees will cause alignment problems. Very narrow light beams will be next to impossible to maintain proper alignment. Building sway and atmospheric distortion will result in forcing the light beam to miss the distant target. It is much better to waste some of the light to insure enough hits the receiver to maintain communications.

Multiple Light Sources for Extended Range

For some very long range communications systems, the light from one LED many not be enough to cover the desired distance. As discussed above, a large lens used in conjunction with a single light source may result in a light beam that is too narrow to be practical. The divergence angle may be so small, that keeping the transmitted light aimed at the distant receiver may become impossible. To launch more light at the distant receiver, multiple light sources will be needed. However, as

3.5KHz, is connected to a voltage to frequency converter. The converter is essentially an oscillator whose frequency is shifted up and down according to the amplitude and frequency of the audio signal. A shift of +-20% is usually sufficient for voice signals. As discussed above, a voice audio optical transmitter only requires a pulse rate of about 10,000 pulses per second. The most important requirement of the conversion is that it must be linear in order to reproduce the audio accurately. Circuits using a non-linear VCO or voltage to controlled oscillator will always lead to an abnormal sounding voice signal when the signal is later detected by an optical receiver.

Figure 7b on page 66 is an example of a linear VCO whose center frequency can be adjusted from about 8Khz to about 12KHz. It is made from two separate circuits. An operational amplifier and a transistor form a current source which charges a 0.,001uF capacitor at a very linear rate. The upward ramping voltage across the capacitor is connected to a C-MOS version of the popular 555 timer whose internal voltage thresholds control the amplitude of the saw tooth waveform that results. The capacitor is thus charged by the current source producing a linear ramp waveform and is quickly discharged though the timer, producing a pulse. With the values shown, the 555 produces an output pulse width that can be adjusted from about 800 nanoseconds to about 1.2 microseconds. As the audio signal that is AC coupled to the current source, swings up and down, the capacitor charging current is increased and decreased from a nominal level. The modulated current source thus produces a frequency modulation of the output pulse stream from the 555 timer. With the values shown, the circuit only requires an audio amplitude of about +-0.1 volts to produce a +-20% frequency shift.

Other linear VCO circuits are also possible using the C-MOS phase locked loop IC (CD4046), the LM766 or the National Semiconductor LM331. Sometime in the future I will include some VCO circuits using these parts.

Pulsed Light Emitter

Whether the through-the-air light transmitter is used to send high-speed computer data or a simple on/off control message, the light source must be intensity modulated in some unique fashion so the matching light receiver can distinguish the transmitted light signal from the ever present ambient light. As discussed in the section on light detectors, silicon PIN light detectors convert light power into current. Therefore, to aid the distant light receiver in detecting the transmitted signal, the light source should be pulsed at the highest possible power level. In addition, as discussed in the section on light emitters, an LED can be very effectively used to transmit voice information. To produce the highest possible light pulse intensity without burning up the LED, a low duty cycle drive must be employed. This can be accomplished by driving the LED with high peak currents with the shortest possible pulse widths and with the lowest practical pulse repetition rate. For standard voice systems, the transmitter circuit can be pulsed at the rate of about 10,000 pulses per second as long as the LED pulse width is less than about 1 microsecond. Such a driving scheme yields a duty cycle (pulse width vs. time between pulses) of less than 1%. However, if the optical transmitter is to be used to deliver only an on/off control signal, then a much lower pulse rate frequency can be used. If a pulse repetition rate of only 50 pps were used, it would be possible to transmit the control message with duty cycle of only 0.005%. Thus, with a 0.005% duty cycle, even if the LED is pulsed to 7 amps the average current would only be about 300ua. Even lower average current levels are possible with simple on/off control transmitters, if short multi-pulse bursts are used. Such a method might find uses in garage door openers, lighting controls or telemetry transmitters.

Chapter Seven
OPTICAL TRANSMITTER CIRCUITS

As in radio transmitters, optical through-the-air transmitters must rely on some type of carrier modulation technique to transmit information. The method most often chosen for optical systems is a simple on/off light pulse stream. The position or frequency of the light pulses carries the information. Flashing roadside warning lights and blinking radio tower lights are examples of low speed optical transmitters. To transmit human voice information you will need to increase the light flashing rate to at least 7,000 flashes per second. For television you will need about 10 million flashes per second. Although much of the discussion in this book will focus on voice audio transmitters, you can apply many of the same techniques for video and computer data transmission.

An audio signal optical transmitter can be broken down into 6 sections: an audio amplifier, a voice frequency filter, a voltage to frequency converter, a pulse generator, a light emitter and a light collimator. However, if you are sending only an on/off control signal you won't require an audio amplifier or a voltage to frequency converter. Transmitters used for television or high speed computer data will use variations of the same methods used for voice but would require much higher modulation rates.

Audio Amplifier with Filter

An electret microphone is commonly used to detect the speech sound. These devices are quite small in size but are very sensitive. Unlike passive microphones, an electret microphone contains an internal FET transistor buffer amplifier and therefore requires an external DC voltage source to supply some power to the assembly. Another benefit of the electret microphone is that it produces an output signal that has sufficient drive to go straight into an audio amplifier without any impedance matching circuitry as some other microphones require.

Since the development of the telephone, extensive testing has concluded that frequencies beyond 3.5KHz are not needed for voice audio communications. Therefore, most telephone systems reject frequencies higher than 3.5 KHz. An optical system designed for voice audio transmission can therefore get by with a fairly low pulse rate. Usually a 10,000 pulse per second signal will be sufficient.

Figure 7a on page 65 shows a simple operational amplifier circuit that not only amplifies (gain of x30) the speech signal from an electret microphone but also removes the high frequency components not needed when transmitting voice information. The "low pass" filter rejects signals above 3.5KHz with a 18db/octave slope. A low pass filter is recommended to prevent erratic operation from audio frequencies higher than the modulation frequency.

Voltage to Frequency Converter

Although many kinds of pulse modulation schemes are possible, the most efficient method for transmitting voice audio is pulse frequency modulation. The frequency modulated pulse stream carries the voice information. The voice audio, whose upper frequency is restricted to less than