Design of a Wireless Audio Link for a Farm Settlement in the North Central Area of Nigeria

Paul Abraham-Attah*, John Jiya Musa** and Yahaya Dantani Daudu***

The wireless audio link is aimed at transmitting audio using high power infrared beam frequency modulation within a localized farm settlement. The modulation is designed with a linear audio amplifier that drives two infrared diodes connected in series across a distance which is a function of power delivered to the diodes. Distance covered varies with a frequency of 100 kHz. This study uses a headphone capable of picking up distant sound signals with a high-gain preamplifier, a pre-emphasis circuit, an automatic gain control, limiting circuit and an FM pulse width modulator.

Keywords: Amplifier, Audio, Farm, Infrared, Signal, Receiver

Introduction

Communication systems consist of an input device, transmitter, transmission medium, receiver and output device; the input device may be a computer, sensor or oscillator depending on the application of the system, while the output device could be a speaker or computer (Xiaodong and Poor, 2003). The source section produces two types of signals, namely, the information signal, which may be speech, video or data, and a signal of constant frequency and constant amplitude called the carrier (Derickson and Muller, 2007). The information signal mixes with the carrier to produce a complex signal which is transmitted; this combination is effected by a modulator. The destination section must be able to reproduce the original information, which is carried out by separating the information from the carrier signal. The transmission medium may be a copper cable, such as a coaxial cable, a fiber-optic cable or a waveguide (Goldsmith, 2005).

Both the transmitter and receiver blocks incorporate many amplifier and processing stages; one of the most important is the oscillator stage, which is generally referred to as the master oscillator as it determines the channel at which the transmitter functions (Black *et al.*, 2008). This generates a constant-amplitude and frequency signal which is used to carry the audio or intelligence signal. The receiver oscillator is called the local oscillator

* Lecturer, Department of Electrical & Electronics Engineering, Federal University of Technology, PMB 65, Minna, Nigeria. E-mail: obafemi2099@yahoo.com

** Lecturer, Department of Agriculture & Bioresource Engineering, Federal University of Technology, PMB 65, Minna, Nigeria. E-mail: jogric2000@yahoo.com

*** Engineer, Rural Electrification Board, PMB 65, Minna, Nigeria. E-mail: yahayadaudu@yahoo.com

as it produces a local carrier within the receiver which allows the incoming carrier from the transmitter to be modified for easier processing within the receiver (Glisic, 2004). The receiver amplifies the incoming signal, extracts the intelligence and passes it on to an output transducer such as a speaker. The local oscillator, in this case, causes the incoming RF signals to be translated to a fixed lower frequency, called the Intermediate Frequency (IF), which is then passed on (Horowitz and Hill, 1980).

The objective of this study is to help modify the current state of motion of a headphone user, as his movement is limited by the length of the cable connecting the headphone to a conventional receiver/amplifier on a farmstead. This system can reliably pick up and transmit voice and other desired sounds from both near and distant locations in the area of operation, while suppressing undesired background sounds and bearing in mind the power supply on most mechanized farms in Nigeria. It can be powered with batteries while maintaining a sufficient power output for reliable transmission.

Methodology

Most infrared (IR) communication systems operate on the same general principle. With reference to this study, audio is taken from its source (such as CD player, TV or any sound producing device), converted to a frequency-modulated pulse wave, transmitted as light radiation by infrared Light Emitting Diode (LED) emitters and is ultimately received by a receiver that converts light radiation back to audio to be delivered to the listener's ear (www.electrophysics.com).

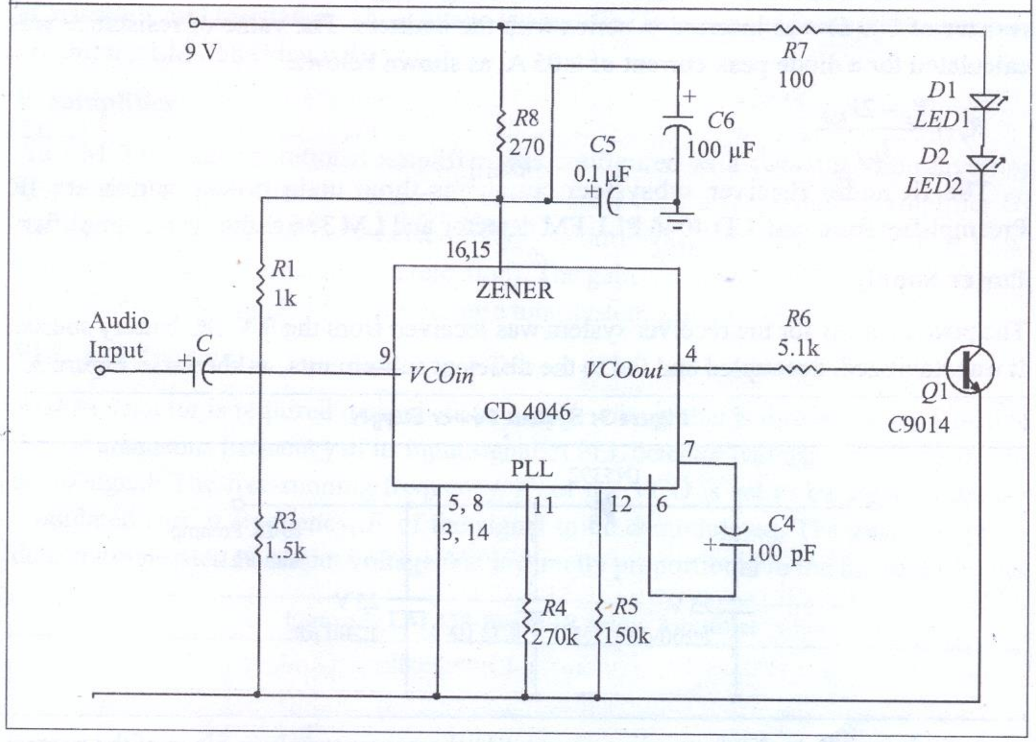
A high quality audio-in device is used for converting sound waves to electrical signals. Intelligibility is further increased by utilizing an equalization and pre-emphasis circuit. After passing through a high gain preamplifier, the audio signal is boosted in the upper speech frequencies while undergoing a low-frequency roll-off to eliminate undesired background noises (www.FLIRsystems.com). A limiting circuit, which doubles as an automatic gain control circuit, is advantageously employed to boost weak signals into a comfortable listening range and to reduce extremely strong audio signals so as to eliminate the possibility of distortion in the transmitted audio.

Design

The IR audio system comprises the IR audio transmitter and IR audio receiver. The IR audio transmitter subsystem uses a CD 4046 PLL/VCO as the FM carrier generator, which is frequency-modulated by the audio signal to be transmitted (Figure 1). The Voltage Controlled Oscillator (VCO) section of the Phase Locked Loop (PLL) was frequency-modulated by the audio signal with an RC network fixed at the VCO's center frequency at about 100 kHz.

The PLL was powered by a 9 V DC source. A 5 V internal Zener diode was used to set the chip's operating voltage. The 5 V supply was stabilized by a 16 V/220 μF capacitor using voltage divider,

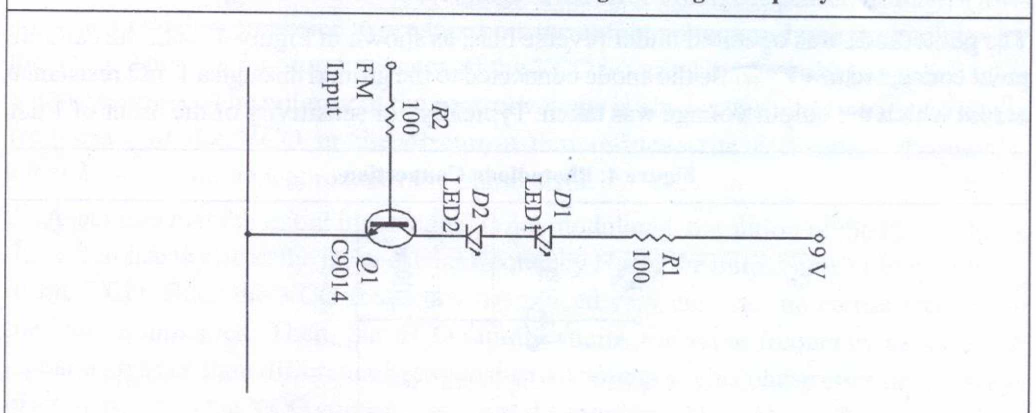
Figure 1: Transmitter Circuit



$$\frac{R_1 XV}{R_1 + R_2} \qquad \ldots(1)$$

The audio signal was superimposed in the control voltage, thus causing the control voltage to vary in consonance with the audio signal, producing a frequency-modulated output. The square wave RF output was fed into the base emitter junction of a C9014 high frequency transistor (Figure 2).

Figure 2: C9014 Transistor Running at a High Frequey



Two infrared emitters were used to radiate the generated FM wave. A current-limiting resistor of 100 Ω was inserted in series with the emitters. The value of resistance was calculated for a diode peak current of 0.05 A, as shown below:

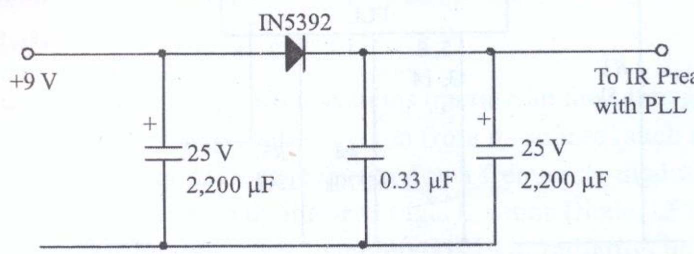
$$R_s - \frac{V_s - 2V_{led}}{I_{led}} \quad \text{...(2)}$$

The IR audio receiver subsystem comprises three main blocks which are IR Preamplifier front end, CD 4046 PLL FM detector and LM 386 audio power amplifier.

Power Supply

The power supply for the receiver system was received from the 9 V DC battery source. It was stabilized, decoupled and fed to the different sub-circuits, as shown in Figure 3.

Figure 3: System Power Supply



A diode is used as the decoupling element on the power supply in place of the normal R-C elements because it has a higher opposition to signal flow through the power rail. The 9 V DC was stabilized by a 2,200 μF capacitor and fed to the power amplifier section directly—a decoupled version of 8.3 V was supplied to the IR amplifier and PLL.

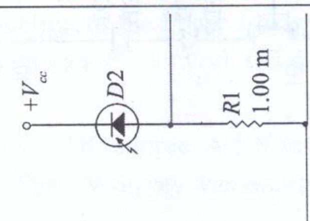
IR Amplifier

The IR amplifier front end consists of an IR photodiode, an LM 358 dual operational amplifier and associated biasing gain-setting elements.

Photodiode

The photodiode was operated under reverse bias, as shown in Figure 4, with the cathode point connected to $+V_{cc}$ while the anode connected to the ground through a 1 mΩ resistance across which the output voltage was taken. Typically, for sensitivity of the order of 1 μA

Figure 4: Photodiode Connection



for 1 nW of incident light, the excitation current of the photodiode develops a voltage V across the 1 mΩ resistance. This voltage is amplified by a two-stage amplifier designed around the LM 358 (Figure 5).

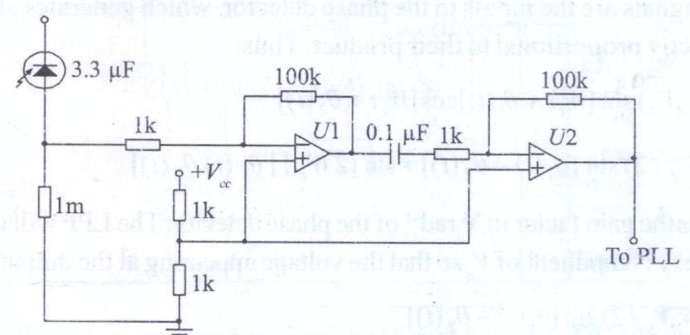
Preamplifier

An LM 358 dual operational amplifier was configured as a two-stage non-inverting amplifier. This amplifies the microvolt signal across the 1 mΩ resistance. Amplifier $U1$ has a gain given by R_f/R_i (www.electrophysics.com); where R_f = 100 kΩ and R_i = 1 mΩ (for better noise performance and rejection). The gain was thus 100. The second stage of amplification also yielded 100, providing a total system gain of 10,000.

PLL FM Detector

An FM detector is required to produce an output voltage that is directly proportional to the instantaneous frequency of its input signal. A PLL detector was used in recovering the audio signal. The free-running frequency, F_o of the VCO is set to be equal to the not modulated carrier frequency, F_c of the signal to be demodulated. The analogue phase detector generates an output voltage that is directly proportional to the phase difference

Figure 5: LM 358-Based IR Audio Amplifier



between the FM signal and the VCO voltage. This error voltage is passed through a low-pass filter and then amplified to produce both the output voltage and a control voltage for the VCO. The free-running frequency of the VCO is varied by the voltage applied to its control terminal. The polarity of the control voltage is always such that it varies with the frequency of the VCO in the direction that reduces the difference frequency, $\alpha F = F_c - F_o$, and hence, reduces the phase error.

Assuming that the initial input signal is not modulated, the action of the PLL reduces the difference between the input carrier frequency F_c and the output carrier frequency F_o of the VCO. Once the VCO frequency has moved very close to the carrier frequency, the loop attains lock. Then, the VCO rapidly attains the same frequency as the input signal with a constant difference between the two voltages. This phase error must always exist to maintain the VCO control voltage at the required value. This voltage, and hence the output voltage, is a DC voltage. When the input signal is frequency-modulated, a similar action takes place. As the input signal frequency deviates from the unmodulated carrier frequency, the error voltage also varies to ensure that the VCO tracks to minimize the phase error. Thus, the instantaneous frequency of the VCO is always approximately equal to the frequency of the incoming signal. The output of the LPF is the detected modulated signal voltage. The filter must have a cut-off frequency equal to the maximum modulating frequency $F_{m(max)}$ of the FM signal to minimize noise and interference.

When the loop is in lock, the frequency of the VCO is equal to the carrier frequency. The FM input signal is:

$$V_s' = V_s \sin [W_c t + 2\prod kf_d \int V_m(t)dt] \quad ...(3)$$

$$= V_s \sin [W_c t + K_s \int V_m(t)\, dt]$$

$$= V_s \sin [W_c t + \theta_1(t)]$$

The output voltage of the VCO is:

$$V_c = V_o \cos [W_c t + \theta_2(t)] \quad ...(4)$$

The two signals are the inputs to the phase detector, which generates an output voltage V_d that is directly proportional to their product. Thus:

$$V_d = (K_d V_s V_o) \sin [W_c t + \theta_1(t)] \cos [W_c t + \theta_2(t)]$$

$$= (K_d V_s V_o / 2) \sin [\theta_1(t) - \theta_2(t)] + \sin [2\, W_c \prod \theta_1\,(t)\, \theta_2(t)] \quad ...(5)$$

Hence K_d is the gain factor in V rad^{-1} of the phase detector. The LPF will only transmit the lower frequency component of V_d so that the voltage appearing at the output of the circuit is:

$$V_d = (K_d V_s V_o / 2) \sin [\theta_1(t) - \theta_2(t)]$$

Since the loop is locked, the phase error will be small and:

$\sin [\theta_1(t) - \theta_2(t)] \approx \theta_1(t) - \theta_2(t)$, giving

$$V_d = (K_d A_v V_s V_0 / 2) [\theta_1(t) - \theta_2(t)] \quad ...(6)$$

The instantaneous angular velocity W'_o of the VCO output voltage is:

$$W_o' = W_o + K_o V_o(t) \quad ...(7)$$

where W_o is the free-running angular velocity and K_o is the conversion gain of the VCO in rad s^{-1}V^{-1}. The conversion gain correlates the frequency of the VCO to its control voltage and is expressed in rad s^{-1}V^{-1} or in kHz V^{-1}.

Since $w = d\theta / dt, d\theta_{2/} dt = K_o V_o(t)$; also,

$d\theta_1 / dt = K_s V_m\,(t)$

Equation 1 can be written as:

$$V_o(t) = (K_d A_v V_s V_o/2)[\theta_1(t) - K_o \int V_o(t)dt] \quad ...(8)$$

and differentiating with respect to time:

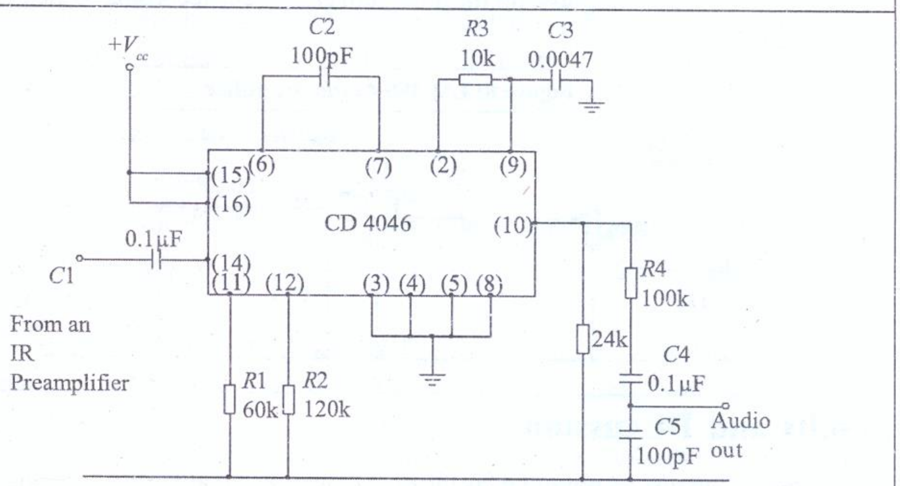
$$\frac{dV_o(t)}{dt} = \left(K_d A_v V_s \frac{V_o}{2}\right)\left[\frac{d\theta_2(t)}{dt} - K_o V_o(t)\right] \quad ...(9)$$

$$= K_o V_o(t) \quad ...(10)$$

$$\therefore K_s V_m(t) = K_o V_o(t) \quad ...(11)$$

The ratio K_s/K_o has dimensions of kHz kHz^{-1}V^{-1} or V, so the output of the detector is the required modulating voltage $V_m(t)$.

Figure 6: CD 4046 PLL Configuration



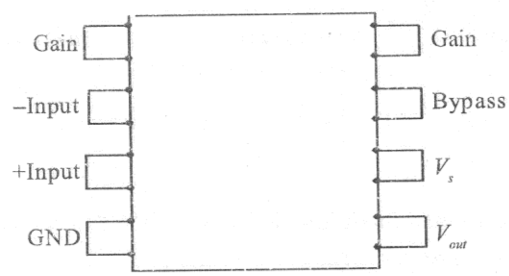
The CD4046 PLL was configured as shown in Figure 6. $C1$ is a DC-blocking capacitor for coupling the AC signal from the preamplifier into the demodulator. C_2 connected across pins 6 and 7 set the free-running frequency of the VCO. R_1 and R_2 also comprise the frequency determining network. The frequency-modulated IR signal is fed into the PLL via pin 14 into the phase comparators (there are two comparators in the PLL)—the type 1 comparator is used. Pin 9 is the VCO control voltage input, and pin 10, the VCO output (the recovered audio signal).

The recovered audio signal is fed via a 100 kΩ variable resistance (volume control) into a single-channel LM 386 low power audio amplifier. The LM386 drives a stereo handset with the radiators wired in parallel.

Audio Power Amplifier

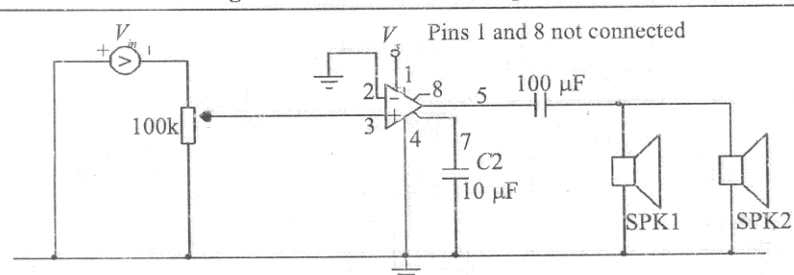
An LM 386 audio IC was used for the audio section. The LM 386 audio IC has an internally fixed gain of 20, expandable to 200 by connecting an R-C combination between pins 1 and 8. The LM 386 has inputs that are ground-referenced, with the output voltage centered on 0.5 V_{cc}. The quiescent power drain is only 24 mW on a supply voltage of 6 V, making it ideal for battery operation. The pin-out of the device is shown in Figure 7.

Figure 7: LM 386 Pin-Out



The amplifier was configured for the minimum gain of 20, according to the configuration shown in Figure 8.

Figure 8: LM 386 Audio Amplifier



Results and Discussion

Table 1 shows the results obtained, as the device was tested at various distances from the primary source. The range and quality of sound were forfeited but could be improved by pulsing more current through the LEDs, i.e., the higher the LED current, the greater the infrared emission and the farther the distance of coverage. When a higher grade of PLL is used (74HC4046 PLL/VCO), better oscillation and performance of the device were observed.

Table 1: Results of Audibility at Varying Distances

Distance of Transmission (m)	Observation and Result
0.5	Sound too low since the distance between is too close and hence does not enable amplification
1	Sound improved but is low
2	Sound is clearer and louder but with static
4	Sound is heard with a lot more static
6	Static and noise disturbance are heard as audio is still diminishing
10	Audio signal is completely taken over by static and noise

The working of the device was successful as it showed achievements behind FM modulation and the use of the electrical components to establish a link from the source to the destination of audio signals within a small community.

Conclusion

The wireless audio linking system is a frequency-modulated scheme, and so, the received signal strength at the receiver is an inverse of the distance separating the receiver and the transmitter. Greater distance can be covered if two or more photodiodes or better photo transistor are used. ⏮

References

1. Black B A, DiPiazza P S, Ferguson B A, *et al.* (2008), *Introduction to Wireless Systems,* 1st Edition, Prentice Hall, New Jersey, USA.
2. Derickson D and Muller M (2007), *Digital Communication Test and Measurement: High-Speed Physical Layer Characterization,* 1st Edition, Prentice Hall, New Jersey, USA.
3. Glisic S G (2004), *Advanced Wireless Communication: 4G Technologies*, John Wiley & Son Publishers.
4. Goldsmith A (2005), *Wireless Communications*, Cambridge University Press, UK.
5. Horowitz P and Hill W (1980), *The Art of Electronics*, 2nd Edition, Cambridge University Press, UK.
6. Xiaodong W and Poor V H (2003), *Wireless Communication System: Advance Technology for Signal Reception,* 1st Edition, Prentice Hall, New Jersey, USA.

Reference # 59J-2010-10-06-01