REACTIVE LIGHTING SYSTEM

Project Report submitted in partial fulfillment of the requirement for the degree of

Bachelor of Technology.

in

Electronics and Communication Engineering

under the Supervision of

Vanita Rana

By

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to

विद्या नत्व ज्योतिसम:

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

Jaypee University of Information and Technology

Certificate

This is to certify that project report entitled "REACTIVE LIGHTING SYSTEMS", submitted by CHIRAG SARASWATI in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

Date: 12/12/13 **Supervisor's Name**

Designation

Abstract

Humans are a remarkable species. Our abilities to see, hear, touch, and think, lend us another unique ability- the power to create. We create art, raise buildings, construct bridges, build huge spaceships to explore space, and all this, in relatively short timeframes. Our creations outlive us. Amongst the others, our senses of hearing and vision move us the most. A compelling speech can move millions, and watching the sun be eclipsed in totality is perhaps nature's way of indulging us in visual ecstasy.

"Audio" is an engineer's word for sound. Audio amplification and Audio recording are two inventions that have changed the world for good. They've helped reach the music of great artists reach great distances, a feat that was previously thought to be science fiction. All of this is the work of Audio engineers.

This project aims to create a real-time, audio dependent interaction between light and sound. Traditionally, this task is undertaken by heavily paid light managers making this type of a system out of reach for home use. The challenge is to create a system that takes an audio input, splits it into different frequency sections and behaves in a correlated way to create a unique light show, based on the audio information sent through the input. To further reduce cost and complexity, the task has been achieved by using only analogue components, which are readily and cheaply available.

Acknowledgement

I'd like to take this occasion to thank my Project guide Ms. Vanita Rana for her dedication and support in helping me understand the science behind my passion.

I'd also like to extend my thanks to the entire ECE faculty present here at JUIT for their cultured and helping nature, for the countless times I was stuck in concepts that I could not have grasped on my own.

It gives me an immense sense of pride, in belonging to this esteemed university, headed by Respected Retd. Brig. Balbir Singh, for providing me the essential resources to pursue such an interesting and inspiring project.

I'd also like to thank our Sr. Lab engineer Mr. Pramod Kumar for his patience in helping me understand the principles in practical implementation of circuits and efficient soldering.

Dated: 12th December '13

Name of student:

Chirag Saraswati

091079

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CHAPTER 1

Introduction

This project aims to create a real time systematic light show unit, that reacts to audio. Let us discuss the various requirements to be used in the hardware.

1. Input Side

To make the project musically relevant and useful, it is important that it interacts directly with a specific arrangement of frequencies. A study has thus been made on the physics of sound. This comprehensive study was performed using DAW software.

1. (i) What is DAW?

DAW stands for Digital Audio workstation, and is the primary software used in recording studios. Some older (read Vintage) studios employ analogue audio workstations, which is basically the recording system merged into the controller/mixer board, but the current more affordable norm is a digital station which is controlled by a standard performance oriented computer loaded with DAW software.

Certain examples of DAW software:

- Fl studio
- Avid Pro tools
- Cakewalk Sonar
- Acoustica mixcraft studio
- Apple Garage band
- PreSonus Studio one
- Ableton Live

For this study, FL studio was chosen for the sake of familiarity.

(ii.) Working with FL studio

Fl studio is a Digital Audio workstation software aimed for electronic musicians, and supports Virtual Studio Technology (VST) support. Virtual studio technology allows various expensive modules that are typically found in large professional studios to be loaded onto the software as virtual meters. These allow analysis and modification of sound waves to produce desired effects by altering the properties of the recorded files.

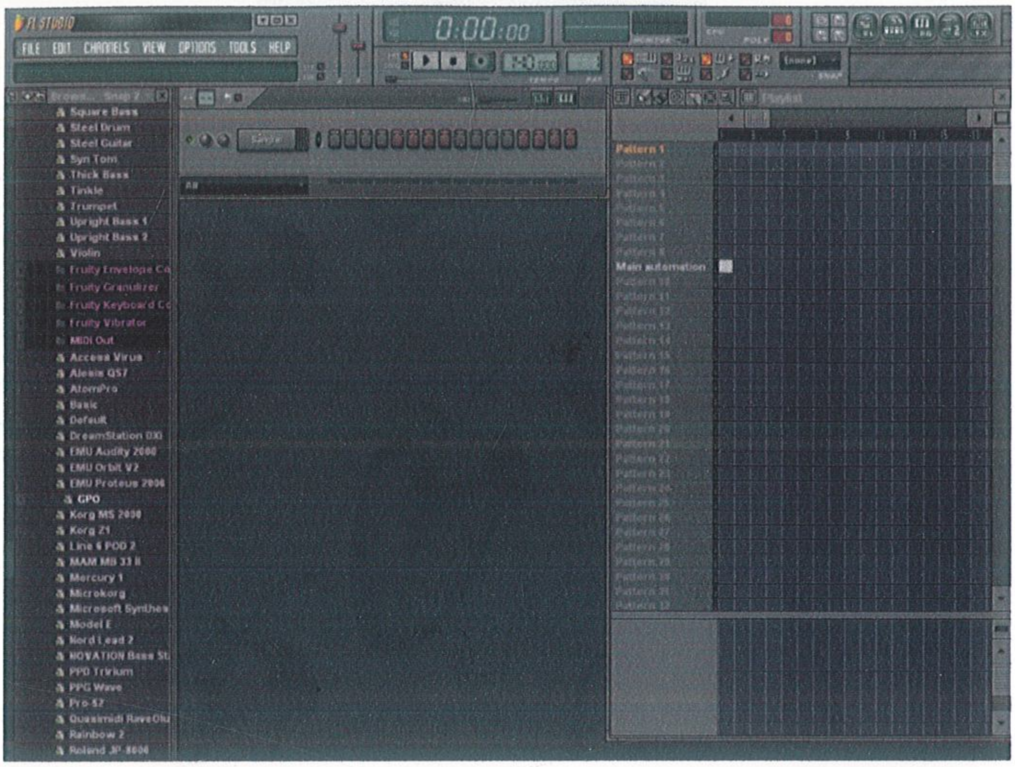


Figure 1: Fl studio main window

Modern technology has even enabled VST designers to come up with an efficient mechanism for bringing back rare and expensive instruments as VST files. These complete instruments can be loaded onto the parent software, and then a dummy instrument (known as MIDI controller) is then used to control the instrument via USB or any other latency free medium.

VST tool used to analyze audio:

ii.(a) Fl Studio(Image line)'s Wave Candy viewer

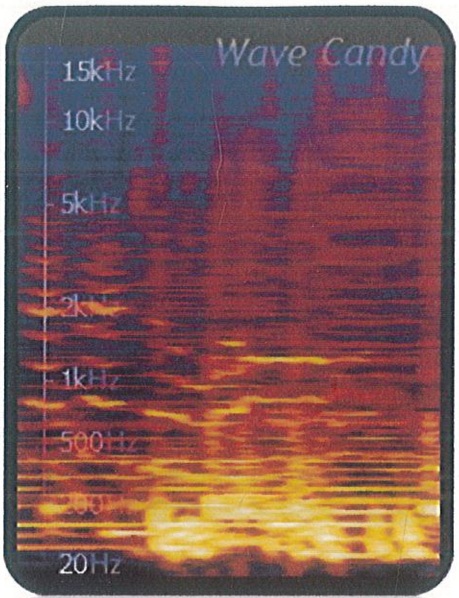


Figure 2: wave candy

Features:

Displays a moving trace of the audio signal. Color hue represents intensity (level), vertical position represents frequency (20 Hz to 20,000 Hz, bottom to top is represented) and horizontal position represents time.

- **Update** - Scroll speed, right is slower.
- **Max res** - Increases the resolution of the analysis at the expense of CPU load.
- **Scale** - Right increases the low frequency detail, left increases the high frequency detail. **Piano keyboard** - Rotate the knob fully right to see a Piano keyboard to aid in note identification from audio files. When looking at a single note, the fundamental/root pitch (note name) will generally be the lowest horizontal line in the group. The lines above this are likely to be harmonics. With practice you will be able to recognize the root notes in chords and other complex music.
- **dB range** - Changes the intensity scaling

ii.(b) **Fruity Parametric EQ 2** is an advanced 7-Band parametric equalizer plugin with spectral analysis. Equalizing is the process of increasing or decreasing the loudness of specific frequencies. The Band type (shape), center frequency and width of each Band are fully adjustable. You can choose from High Shelf, Low Shelf, Peaking, Band Pass, Notch, Low Pass, High Pass or Band Pass filters for each Band independently. There is also a global gain slider to adjust the overall volume.

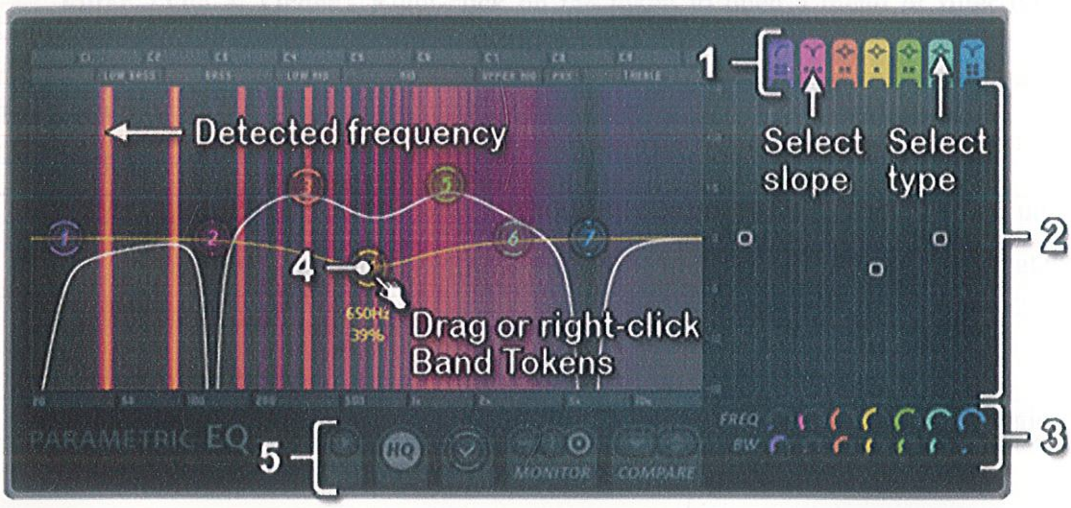


Figure 3: Parametric EQ viewer

Parameters

1. **Band Type & Filter Slope Selectors** - Note that the upper section shows different shapes (**Band Type**) with dots below each shape (**Filter Slope**). **Band Type:** Left-click and drag up/down to change the filter type between OFF, Low Pass, Band Pass, High Pass, Notch, Low Shelf, Peaking, High Shelf. **Filter Slope:** Left-click and drag up/down on the dot/s below each band shape to select filter slope. Down = Steep 4, 6 & 8, Up = Gentle 2, 6 & 8 (the steep filters give more precision in EQ isolation). **NOTE:** The**Band Tokens** can also be Right-clicked to **show menus for both filter and slope types.**
2. **EQ Sliders** - Adjust the equalization level by sliding up/down. The **Band Tokens** can also be directly clicked & dragged. Note that Low Pass, Band Pass, High Pass and Notch filters don't use this parameter (so the slider is disabled).
3. **FREQ / BW** - Controls the center frequency and bandwidth of the EQ Band.
4. **Band Token** - clicking on a Band Token and dragging with the mouse can make Most Band EQ manipulations. **Mouse wheel** controls bandwidth.
   - **Bandwidth** - Several methods. 1. Shift+Click and move mouse left/right on Bands; 2. Click the mouse-wheel and do the same, **OR** 3. Scroll the mouse-wheel while hovering over the token.

- **Reset Band** - Alt+Click a Band to reset a Band.
- **Fine Adjustment** - Ctrl+Click a Band to make fine adjustments (same for all knobs and sliders).
- **Main Level** - Left-click outside the Bands to adjust the main level control (the cursor will change from pointer to a cross).
- **Filter Type & Order** - Right-click on the token to open a menu of filter types and filter orders.

5. **Options and Settings** - From left to right:
    - **Options:**
        - **High precision monitor** - Increases the resolution of the background frequency spectrum monitoring at the expense of display latency (plugin audio latency remains unaffected).
        - **About** - Shows version details and credits.
    - **HQ** - Uses oversampling to improve audio quality, particularly in the region above 15 kHz. **NOTE:** HQ mode increases CPU load.
    - **View Band tokens** - Turns the tokens ON/OFF.
    - **Monitor** - Turns the spectral monitoring ON/OFF or shows the spectrum of the plugin output.
    - **Compare** - Click the first down-arrow to save the current EQ settings to a spare bank. Click the up/down arrow control to swap between the saved bank and the main bank. Tweaking any parameter in the spare bank will cause it to become the main bank again. Use this to compare EQ settings.

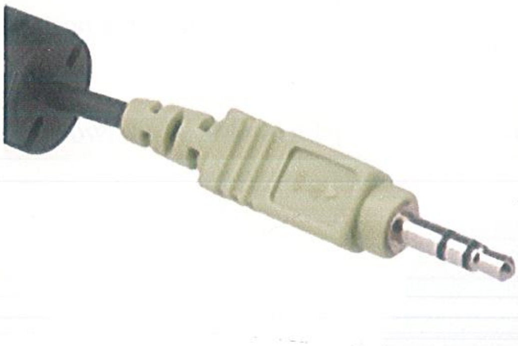
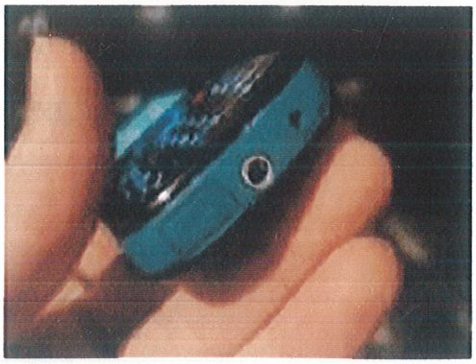
CHAPTER 2

Type of connectors commonly used in audio technology:

¼" TS cable: The TS cable is commonly used as a standard connection for all musical instruments, especially those that employ high impedance audio sources for example pickups from electric guitars or basses or violins etc


Figures 4 & 5: Input Jacks TS ¼"

⅛" **TRS** cable: The ⅛ in TRS cable is commonly referred to as the audio line in jack and it is used commonly for headphones, Earphones, Line level communication. And due to is convenient size, it is optimum for use with consumer electronics

Figures 6 & 7: 3.5mm Jack and Female port

The shortcoming in these types of cables is that they are not suited for long runs and suffer from problems such as elevated noise and susceptibility to interference

A new type of cable/Jack comparison was created to combat these problems and has been a boom for live/studio applications known as **XLR** standard, famous for their shielding capabilities.

The XLR cable should be protocol for use during mass production of onstage versions of the project.

Figure 8: XLR jacks Female and male

The excellent shielding properties of XLR type cables make their usage optimum for runs even as long as a hundred meters without much noise, and a respectable S/N ratio.

So with the usage of DI boxes (Direct Injection) TS connectors can be merged into XLR cables and the signal can be sent across long distances without worrying about significant signal loss or any loss in quality. Interference is also on a minimum.

Certain Jacks are known to be able to adapt to both TS and XLR type cables :

Figure 9: Multi input jack

XLR cables also support Phantom power supply of +48V which is used to power up High definition studio grade microphone devices, a feat that cannot be attained using standard TS or TRS cables.

For the initial representation, TRRS &TRS cables and connectors in standard sizes are used to connect audio.

Chapter 3: The Concept of Notes

3.(i)Analysis:

(a.) Hardware used

The analysis was made by connecting a real instrument (as opposed to VSTi) to an audio Interface that sent the input signal to the computer running an active DAW software.

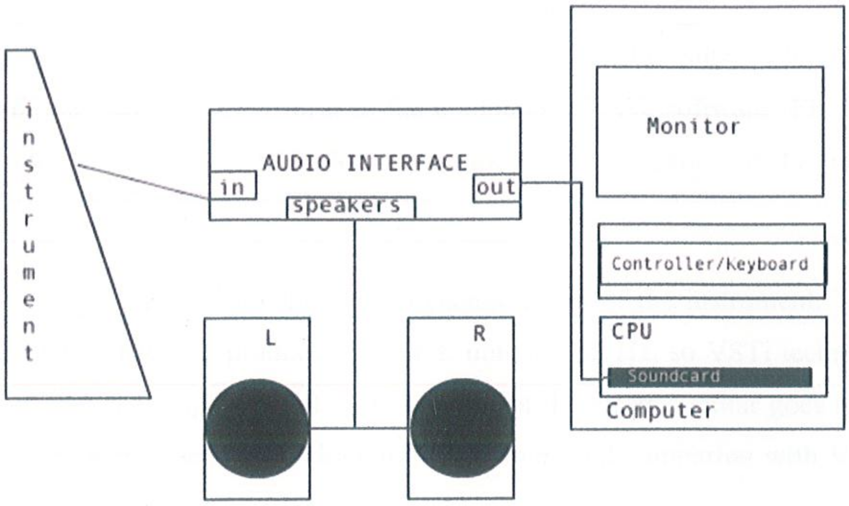


Figure10 : Block diagram of connections

The interface used was a Boss ME25 Effects processor sampling at 44.1 Khz with analogue to digital conversion in 24 bits.

Figure 11: Boss ME 25 (Boss website)

(b.) Making the Analysis

The connection was made from a tuned electric guitar to the interface using a TS cable. Then a commonly available A to B cable (usually called "Printer cable") was used to connect the interface to the computer using Universal Serial bus technology (USB). This enabled the use of the processing box as an external and extended soundcard making it a part of the parent computer used to perform the analysis. Low Latency ASIO drivers were made to ensure no delay was occurring between a note being sounded and it's digital counterpart to be heard.

After the connection was made, an individual note was sounded on the guitar, which reached the audio interface, got sampled, and sent in digital form to the computer's DAW software (FL studio), which was loaded with a Parametric Equalization VST plugin to pinpoint the frequency of the note that was being sounded.

Similarly, this operation was repeated for the entire dynamic range of the instrument. The minimum note that the electric guitar was capable to produce was the E note at ~82 Hz, so VSTi technology was used to reproduce notes behind that. The highest fundamental note that the electric guitar goes to is the E6 note at 1318 Hz, so higher values were obtained by doubling prior notes and comparing with VSTi technology to reach higher.

What are notes?

A set of frequencies makes up the musical alphabet and this set repeats in octaves with higher versions doubling in frequency. Different instruments, depending upon their dynamic range (least possible frequency vs highest possible frequency + everything in between), take up a different space in the spectrum. Every attainable, separate frequency that exists on an instrument is a note.

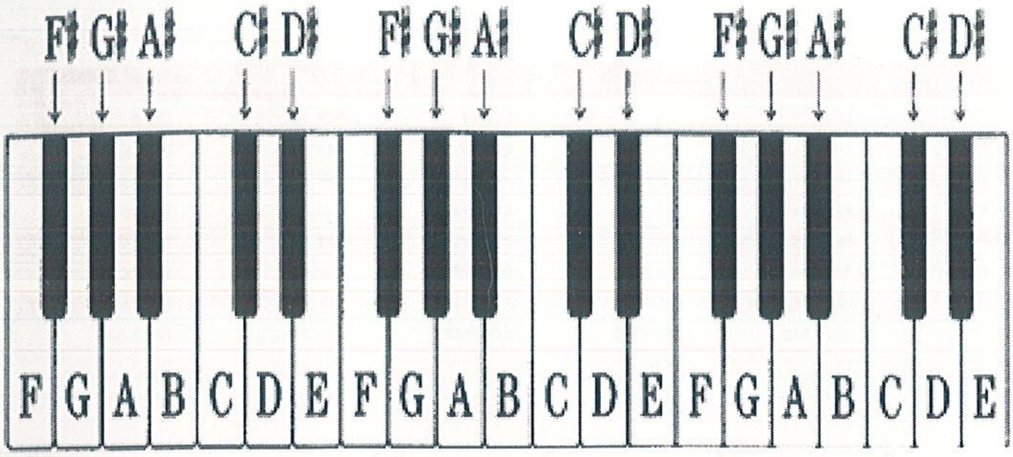


Figure 12: What notes look like on a keyboard

Why follow these "notes"?

All musical instruments are built around these notes as reference pitches, so one note being in pitch confirm the entire musical spectrum conforms to the standard pitch.

The note used to confirm pitch is usually the A note which usually peaks at around 110.000 Hz and then note comparison occurs by the means of analyzing Beats (a phenomenon in physics that occurs as a result of hearing two adjacent frequencies that are not too far apart numerically.)

To accurately understand the individual contribution of every note on popular musical instruments, experimentation was performed to expose every characteristic

Frequency chart for the spectrum (experimentally verified to +-5% in Lab using Electric guitar as Pitch Generator and DAW {Digital Audio Workstation} software used as Spectrum Analyzer through VSTs {Virtual Studio Technology})

C	C#	D	D#	E	F
16.352	17.324	18.354	19.445	20.602	21.827
32.703	34.648	36.708	38.891	41.203	43.654
65.406	69.296	73.416	77.782	82.407	87.307
130.813	138.591	146.832	155.563	164.814	174.614
261.626	277.183	293.665	311.127	329.628	349.228
523.251	554.365	587.330	622.254	659.255	698.456
1046.502	1108.730	1174.659	1244.508	1318.510	1396.913
2093.004	2217.461	2349.318	2489.016	2637.020	2793.826
4186.009	4434.922	4698.636	4978.032	5274.041	5587.652
8372.018	8869.844	9397.272	9956.063	10548.082	11175.303
16744.035	17739.688	18794.544	19912.126	21096.163	22350.606

F#	G	G#	A	A#	B
23.125	24.500	25.957	27.500	29.135	30.868
46.249	48.999	51.913	55.000	58.270	61.735
92.499	97.999	103.826	110.000	116.541	123.471
184.997	195.998	207.652	220.000	233.082	246.942
369.994	391.995	415.305	440.000	466.164	493.883
739.989	783.991	830.609	880.000	932.328	987.767
1479.978	1567.982	1661.219	1760.000	1864.655	1975.533
2959.955	3135.963	3322.438	3520.000	3729.310	3951.066
5919.911	6271.927	6644.875	7040.000	7458.620	7902.133
11839.821	12543.854	13289.750	14080.000	14917.240	15804.266

Table 1: Note chart

This note structure gives the idea of music being nothing but organized ratios in different octaves. Most often, a group of these notes is played together, which results in fundamental peaks over a group of frequencies along with a consequently rich spectrum of harmonic content

3.(ii) TONAL ANALYSIS:

Two contrasting "tones" based on Dynamic Range:

Dull sounding: With abundance of low frequency peaks and little harmonic content, usually less than ~<1Khz. Low energy harmonics may still exist.

Bright Sounding: With abundance of high frequency peaks and fundamentals with rich harmonic content, even above 3KHz

Bare in mind, that these frequencies are indicative of fundamentals. It is almost impossible to create real life instruments that mimic pure sine waves in terms of their lack of harmonics. All sound tones tend to have harmonic energy that occupies the bulk of the high frequency section.

3.(iii) **Conclusions:**

1.) It was found that a large amount of harmonic information was included with even a single note.

2.) By logic, various (higher or lower) versions of the same 12 notes are faithful across all instruments

3.) The harmonic content is different when instruments are changed. The fundamental frequencies for the notes are the exact same, among different tuned instruments.

4.) The overall dynamic range of an instrument is much higher, if the associated harmonic content is considered.

5.) It was found that "dull" or "muddy" sounding tones were primarily full of frequency content under 1khz whereas even though brilliant sounding tones primarily consisted of fundamental frequency content in the 0-1KhZ range, it had a wide range of frequencies present even above 10KhZ.

Audio information present in the real world seldom occurs in isolated sections, it is almost always found to be existing with a lot of harmonic content that adds character and richness to it. It is also the contribution of these harmonics that helps us discriminate one instrument from another, one vocalist from another, a vocalist from an instrumentalist and so on, even though they are hitting the same notes, it's these additional components that helps our brain in intelligently differentiating between these, but that is beyond the scope of this project. The branch of science that deals with our brain's analysis of audio down to this detail is called "Psychoacoustics"

CHAPTER 4: HARDWARE IMPLEMENTATION PART 1

In the first stage, the following circuit was implemented as an audio detector.

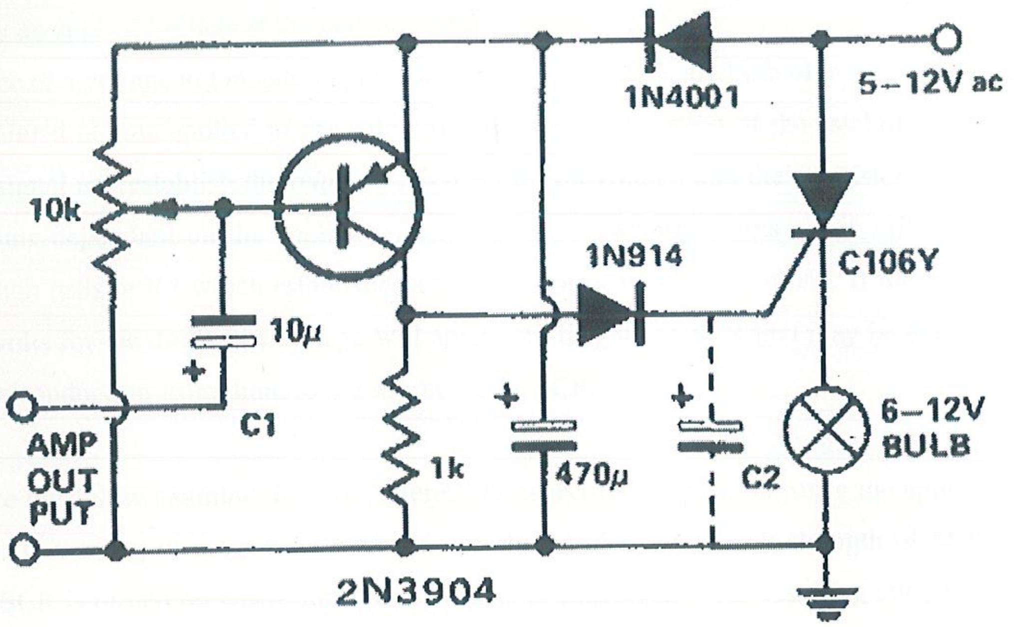


Figure 13 : Circuit Diagram for Mini Audio Light show

This circuit is an elementary model and helps in making a set of lights react to an audio signal.

Certain key concepts of this circuit are as below:

1. There was a Switch to control the working of the circuit
2. Use of One BJT (bipolar junction transistor) and one SCR(Silicon Controlled Rectifier) was made.
3. Use of TRS (Tip Ring Sleeve) Jack to be adaptable to most media sources
4. Use of bulb as output
5. Use of AC in input circuit

The light from the 12 Volt bulb will vary at a frequency and intensity sensitive to the applied signal

The applied signal may be the output of an acoustical amplifier, a musical instrument, or even a microphone. Of particular interest is the fact that the applied voltage is AC at 12 volts rather than Typical DC supply. The immediate question arises that in the absence of a DC supply, how will biasing be achieved for BJT? This is solved by using Diodes for a rectifying circuit.

The Capacitor C2 acts as a power supply filter to generate a DC level across the output branch of the transistor. The peak value of a 12Volt RMS supply peaks at about 17 volts resulting in a dc level after the filtering in the neighborhood of 16 volts. If the pot is set so that R1=320 Ohms, the voltage from the base to emitter of the transistor will be about .5Volts and the transistor will be in the off state. In this state, the collector and emitter currents are essentially 0mA and the voltage across resistor R3 is approximately 0V.

The voltage at the junction of the collector terminal and the diode is therefore 0V, resulting in D2 being "off" and 0 volts at the gate terminal of the Silicon Controlled Rectifier. The SCR is a device whose state is controlled by an applied voltage at the gate terminal.

In the absence of a voltage at the gate implies that the bulb and SCR are both off.

If an audio signal is now applied to the gate terminal, the combination of the established biasing level and the applied signal can establish the required .7Volts turn on voltage and the transistor will be turned on for periods of time dependant on the applied signal. When the transistor turns on, it will establish a collector current through resistor R3 which establishes a voltage from collector to ground. If the voltage is more than required .7 volts for the diode, the voltage will appear at the gate of SCR that may be sufficient to turn it on and establish conduction from drain to the source of the SCR.

However, we must now examine the most interesting aspect of this design. Since the applied voltage across the SCR is AC varying in magnitude with time as shown, the conduction strength of SCR will vary with time. If the SCR is turned on when Sinusoidal voltage is a maximum, the resulting current through the SCR will be maximum also. And the bulb will be brightest.

If the SCR should turn on when the sinusoidal voltage is near its minimum, the bulb may turn on, but at a lower current will result in considerably less illumination.

The result is that the light bulb turns on in sync with the input signal, but the strength of turn on will be determined by where one is on the applied 12 volts signal One can imagine the interesting and varied responses of such a system. Each time one applies the same audio signal, the response will have a different character, responding to the audio signal fed in.

In the above action, the potentiometer was set below the turn on voltage of the transistor. The potentiometer can be adjusted so that the transistor is Just on, resulting base current. The result is a low level collector current and an insufficient voltage to forward bias the diode and turn on the SCR at the gate. However the system is set up in this manner will be more sensitive to the audio signal, especially the lower components of the applied signal.

Diode D2 was included to be sure that there is sufficient Voltage to turn on both the diode and the SCR or in other words, to eliminate the possibility of noise or any other low level unexpected voltage on the line turning the SCR on. Capacitor C3 can be inserted to slow down the response by ensuring the Voltage charge across the cap before the gate reaches sufficient voltage to turn on the SCR.

Due to the dc components intermittent inability to cope with AC voltage, AC bulbs taking up too much wattage and frequent fuses blowing up, it was decided to implement this circuit with an additional diode and a group of LED lights instead.

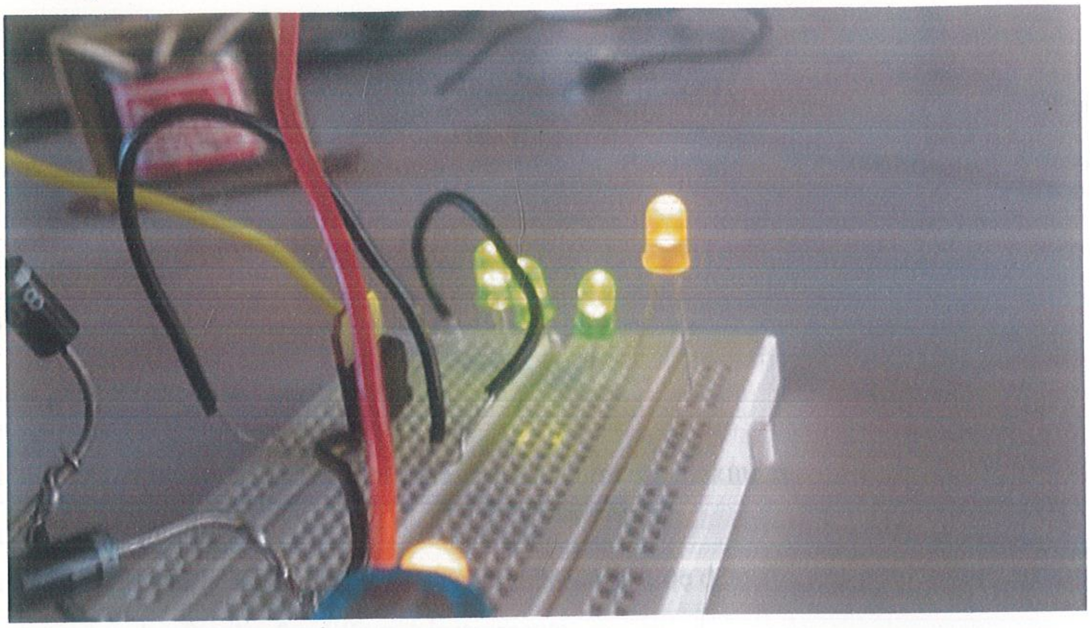


Figure 14: Reactive lighting system Version 1

This system works purely in the analogue domain and serves as a basic example of the fundamentals of the project, the reactive lighting system.

The circuit, being a temporary prototype, was implemented on a breadboard.
Based on extensive testing, the following improvements were needed:

1.) The circuit was reacting more heavily to bass frequencies under 500Hz, and the response for frequencies above 4kHz was quite less. The reactions should be balanced across all frequency contents.
2.) The circuit was not able to discriminate between frequency contents. Future versions would have to be able to make such discrimination.
3.) The response of the circuit was not instant. The response of the circuit should be faster.
4.) When bass frequencies were abundant, the overall reactions slowed down or nulled away. There should be no interference between frequency sections.
5.) AC operation should be avoided, and a permanent shift to LEDs for lighting will be made.

CHAPTER 5 : HARDWARE IMPLEMENTATION PART 2

As discussed before, there were some problems that were being faced in the previous circuit. As a result of this, some new parameters were to be observed to make the project more relevant and appropriate for practical, real life performance.

5.(i) REQUIREMENTS

1.) Use of single DC supply for entire circuit

A single DC supply eliminates wastage of time in fault isolation, making repairing and customization easier.

2.) The ability to monitor whatever is being heard

To correlate audio and visual sync up so that any anomalies can be detected and fixed.

3.) Separate bands of audio for different instruments

To enhance the experience further and establish the wideness of the spectrum

4.) Separate gain controls for different frequencies

Due to difference in every audio input's sound engineer, the different instruments are usually produced at different signal levels. Predicting these levels is impossible and so the system should have a manual control to specify the sensitivity to different bands of audio.

5.) LED based light output

LED's are world renowned for being extremely power saving as compared to traditional lighting schemes, and thus their use will be optimum as they are less susceptible to failure as compared to their Ac counterparts, which have a shelf life of only a few weeks or a few months.

6.) Switch based system so that more modules can be added later on.

The module that controls power to LED circuits should be made in a way that resembles a switch so that further modules can be added without desoldering/soldering core components

7.) Use of a Pre-Amp

The input signal must be brought up to a working level in order to be processed by the components. A pre amp should be used to bring the audio level up.

8.) Use of op Amps to improve working

Op amps are known to be high performance amplifiers and filters, and they should be utilized in the circuit wherever a filter is to be used.

5(ii.) **Design of circuit**

Based on the above mentioned parameters, the following circuit was constructed:

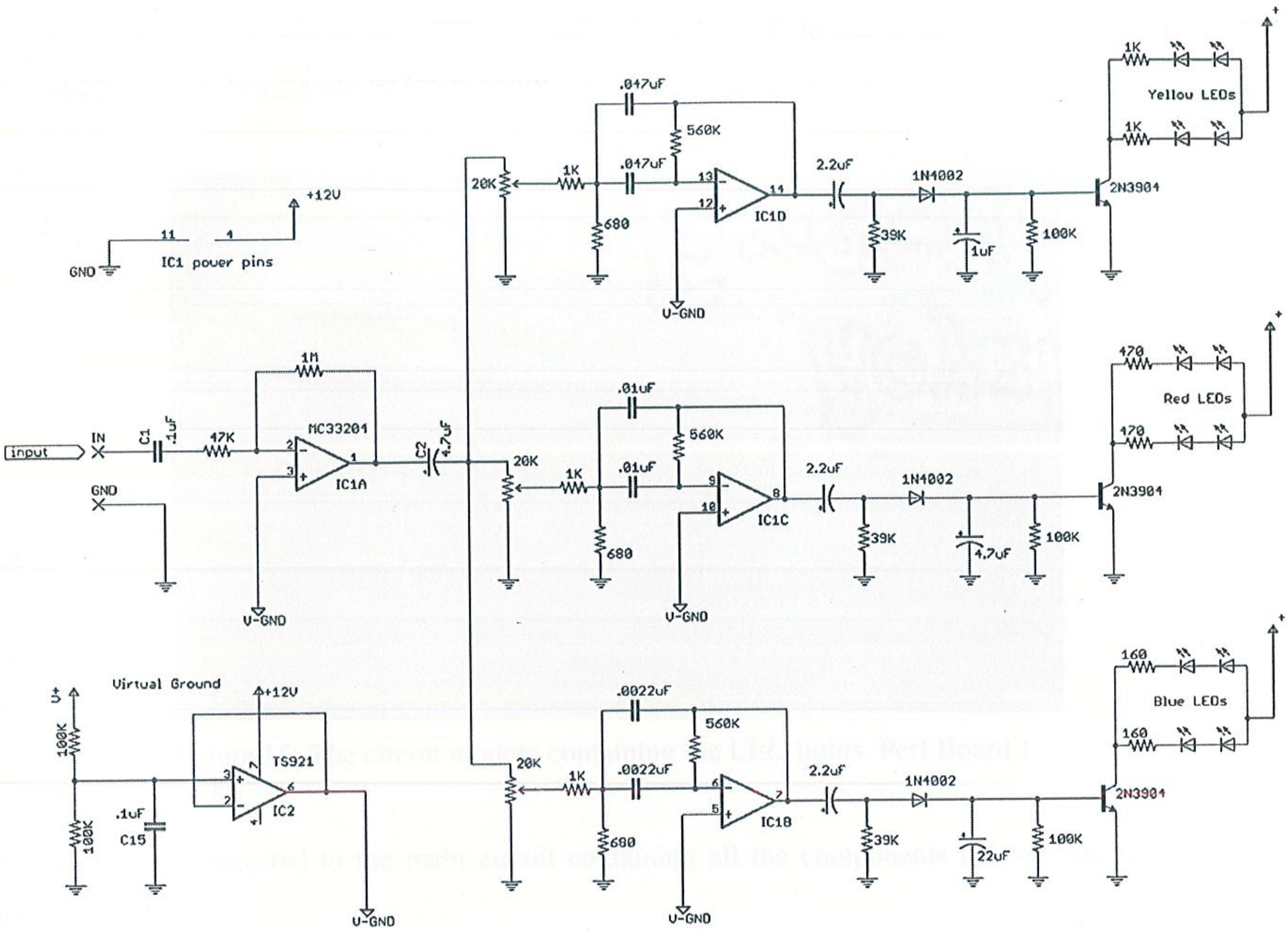


Figure 15: Circuit diagram for Reactive Lighting System

Note:

- Arbitrary colors have been chosen for convenience.
- Cutoff Frequencies are approximate indicators to bandwidth.

This circuit was made on two different project boards so as to encourage modularity so that future additions and changes can be made easily

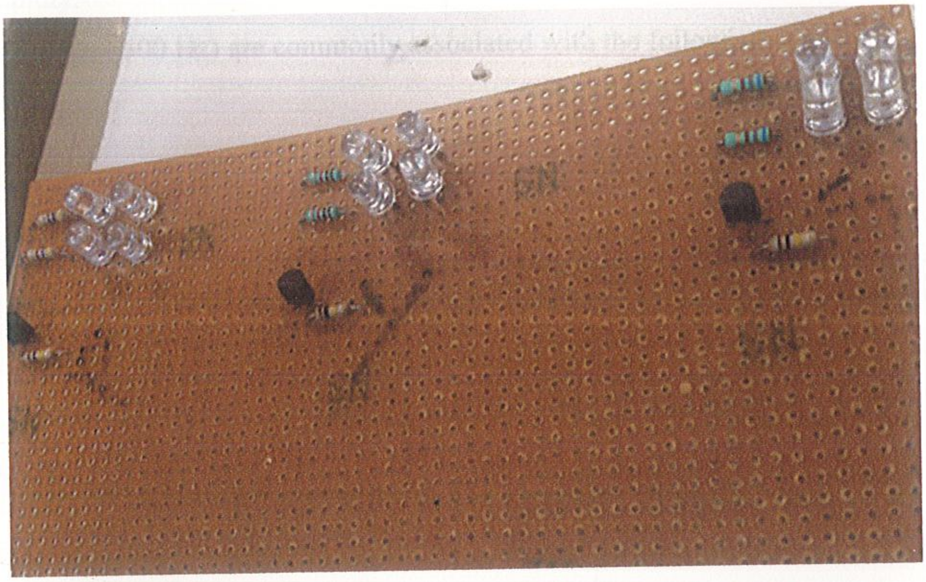


Figure 16: The circuit module containing the LED lights. Perf Board 1

This module was connected to the main circuit containing all the components soldered on to a different perforated board.

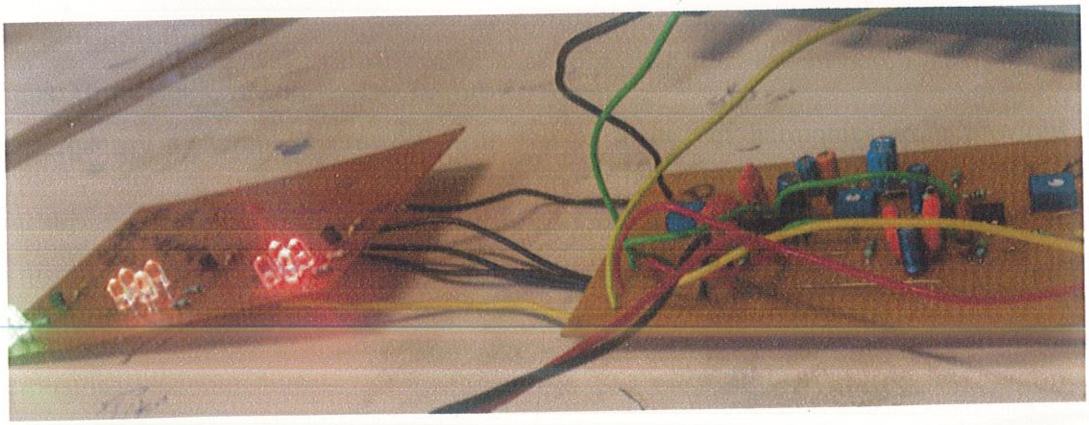


Figure 17 : Perforated boards 1 & 2

After the soldering was complete, the circuit performed the following tasks successfully:

1.) It took the input audio and performed line level amplification to bring the signal level up.

2.) The signal was then split into three frequency sections commonly associated with Low, Mid and High frequency Instruments.

3.) The output from these frequency components was then used to control a BJT working as a switch, on the collector leg of which, an LED array was placed.

4.) As per the frequency and associated amplitude content present in the input signal, the LED's would light up rapidly.

Bass frequencies (20 Hz – 500 Hz) are commonly associated with the following instruments:

1. Bass Guitar
2. Cello
3. Wind instruments

Mid frequencies (500Hz-2KHz) are commonly associated with the following instruments:

1. Electric guitar
2. Vocals
3. Sitar
4. Trumpets

High frequencies (2KHz – 20 Khz) are commonly associated with percussion instruments which take up most of the frequency content in the upper ranges of human hearing.

Such instruments as:

1.) Drums: High hats, Cymbals

Also, high frequency spectrum is crowded with the presence of harmonics from previous frequency sections.

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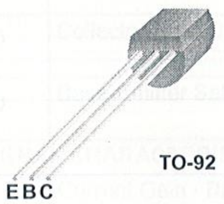

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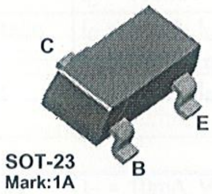

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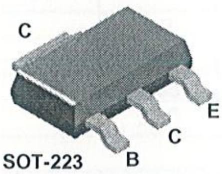


Absolute Maximum Ratings* T_a = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	60	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	200	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

* These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

NOTES:

1) These ratings are based on a maximum junction temperature of 150 degrees C.

2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

Thermal Characteristics T_a = 25°C unless otherwise noted

Symbol	Parameter	Max.			Units
		2N3904	*MMBT3904	**PZT3904	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	1,000 8.0	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	°C/W

* Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06".

** Device mounted on FR-4 PCB 36 mm X 18 mm X 1.5 mm; mounting pad for the collector lead min. 6 cm^2.

Electrical Characteristics T_a = 25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Max.	Units
OFF CHARACTERISTICS					
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	I_C = 1.0mA, I_B = 0	40		V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	I_C = 10μA, I_E = 0	60		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	I_E = 10μA, I_C = 0	6.0		V
I_{BL}	Base Cutoff Current	V_{CE} = 30V, V_{EB} = 3V		50	nA
I_{CEX}	Collector Cutoff Current	V_{CE} = 30V, V_{EB} = 3V		50	nA
ON CHARACTERISTICS*					
h_{FE}	DC Current Gain	I_C = 0.1mA, V_{CE} = 1.0V I_C = 1.0mA, V_{CE} = 1.0V I_C = 10mA, V_{CE} = 1.0V I_C = 50mA, V_{CE} = 1.0V I_C = 100mA, V_{CE} = 1.0V	40 70 100 60 30	 300	
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	I_C = 10mA, I_B = 1.0mA I_C = 50mA, I_B = 5.0mA		0.2 0.3	V V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	I_C = 10mA, I_B = 1.0mA I_C = 50mA, I_B = 5.0mA	0.65	0.85 0.95	V V
SMALL SIGNAL CHARACTERISTICS					
f_T	Current Gain - Bandwidth Product	I_C = 10mA, V_{CE} = 20V, f = 100MHz	300		MHz
C_{obo}	Output Capacitance	V_{CB} = 5.0V, I_E = 0, f = 1.0MHz		4.0	pF
C_{ibo}	Input Capacitance	V_{EB} = 0.5V, I_C = 0, f = 1.0MHz		8.0	pF
NF	Noise Figure	I_C = 100μA, V_{CE} = 5.0V, R_S = 1.0kΩ, f = 10Hz to 15.7kHz		5.0	dB
SWITCHING CHARACTERISTICS					
t_d	Delay Time	V_{CC} = 3.0V, V_{BE} = 0.5V I_C = 10mA, I_{B1} = 1.0mA		35	ns
t_r	Rise Time			35	ns
t_s	Storage Time	V_{CC} = 3.0V, I_C = 10mA, I_{B1} = I_{B2} = 1.0mA		200	ns
t_f	Fall Time			50	ns

* Pulse Test: Pulse Width ≤ 300μs, Duty Cycle ≤ 2.0%

Ordering Information

Part Number	Marking	Package	Packing Method	Pack Qty
2N3904BU	2N3904	TO-92	BULK	10000
2N3904TA	2N3904	TO-92	AMMO	2000
2N3904TAR	2N3904	TO-92	AMMO	2000
2N3904TF	2N3904	TO-92	TAPE REEL	2000
2N3904TFR	2N3904	TO-92	TAPE REEL	2000
MMBT3904	1A	SOT-23	TAPE REEL	3000
MMBT3904_D87Z	1A	SOT-23	TAPE REEL	10000
PZT3904	3904	SOT-223	TAPE REEL	2500

C106 Series

Preferred Device

Sensitive Gate Silicon Controlled Rectifiers

Reverse Blocking Thyristors

Glassivated PNPN devices designed for high volume consumer applications such as temperature, light, and speed control; process and remote control, and warning systems where reliability of operation is important.

- Glassivated Surface for Reliability and Uniformity
- Power Rated at Economical Prices
- Practical Level Triggering and Holding Characteristics
- Flat, Rugged, Thermopad Construction for Low Thermal Resistance, High Heat Dissipation and Durability
- Sensitive Gate Triggering
- Device Marking: Device Type, e.g., C106B, Date Code

MAXIMUM RATINGS (T_J = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Peak Repetitive Off–State Voltage(1) (Sine Wave, 50–60 Hz, R_{GK} = 1 kΩ, T_C = –40° to 110°C) C106B C106D, C106D1 C106M, C106M1	V_{DRM}, V_{RRM}	 200 400 600	Volts
On-State RMS Current (180° Conduction Angles, T_C = 80°C)	$I_{T(RMS)}$	4.0	Amps
Average On–State Current (180° Conduction Angles, T_C = 80°C)	$I_{T(AV)}$	2.55	Amps
Peak Non-Repetitive Surge Current (1/2 Cycle, Sine Wave, 60 Hz, T_J = +110°C)	I_{TSM}	20	Amps
Circuit Fusing Considerations (t = 8.3 ms)	I^2t	1.65	A^2s
Forward Peak Gate Power (Pulse Width ≤ 1.0 µsec, T_C = 80°C)	P_{GM}	0.5	Watt
Forward Average Gate Power (Pulse Width ≤ 1.0 µsec, T_C = 80°C)	$P_{G(AV)}$	0.1	Watt
Forward Peak Gate Current (Pulse Width ≤ 1.0 µsec, T_C = 80°C)	I_{GM}	0.2	Amp
Operating Junction Temperature Range	T_J	–40 to +110	°C
Storage Temperature Range	T_{stg}	–40 to +150	°C
Mounting Torque(2)	—	6.0	in. lb.

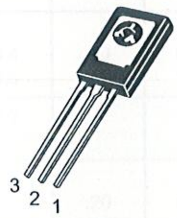
(1) V_{DRM} and V_{RRM} for all types can be applied on a continuous basis. Ratings apply for zero or negative gate voltage; however, positive gate voltage shall not be applied concurrent with negative potential on the anode. Blocking voltages shall not be tested with a constant current source such that the voltage ratings of the devices are exceeded.

(2) Torque rating applies with use of compression washer (B52200F006). Mounting torque in excess of 6 in. lb. does not appreciably lower case-to-sink thermal resistance. Anode lead and heatsink contact pad are common.

ON Semiconductor

http://onsemi.com

SCRs
4 AMPERES RMS
200 thru 600 VOLTS



TO–225AA
(formerly TO–126)
CASE 077
STYLE 2

PIN ASSIGNMENT	
1	Cathode
2	Anode
3	Gate

ORDERING INFORMATION

Device	Package	Shipping
C106B	TO225AA	500/Box
C106D	TO225AA	500/Box
C106D1	TO225AA	500/Box
C106M	TO225AA	500/Box
C106M1	TO225AA	500/Box

Preferred devices are recommended choices for future use and best overall value.

THERMAL CHARACTERISTICS (T_C = 25°C unless otherwise noted.)

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	3.0	°C/W
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	75	°C/W
Maximum Lead Temperature for Soldering Purposes 1/8″ from Case for 10 Seconds	T_L	260	°C

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted.)

Characteristic		Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS						
Peak Repetitive Forward or Reverse Blocking Current (V_{AK} = Rated V_{DRM} or V_{RRM}, R_{GK} = 1000 Ohms)	T_J = 25°C T_J = 110°C	I_{DRM}, I_{RRM}	— —	— —	10 100	μA μA
ON CHARACTERISTICS						
Peak Forward On–State Voltage(1) (I_{FM} = 1 A Peak for C106B, D, & M) (I_{FM} = 4 A Peak for C106D1, & M1)		V_{TM}	—	—	2.2	Volts
Gate Trigger Current (Continuous dc)(2) (V_{AK} = 6 Vdc, R_L = 100 Ohms)	T_J = 25°C T_J = −40°C	I_{GT}	— —	15 35	200 500	μA
Peak Reverse Gate Voltage (I_{GR} = 10 μA)		V_{GRM}	—	—	6.0	Volts
Gate Trigger Voltage (Continuous dc)(2) (V_{AK} = 6 Vdc, R_L = 100 Ohms)	T_J = 25°C T_J = −40°C	V_{GT}	0.4 0.5	.60 .75	0.8 1.0	Volts
Gate Non–Trigger Voltage (Continuous dc)(2) (V_{AK} = 12 V, R_L = 100 Ohms, T_J = 110°C)		V_{GD}	0.2	—	—	Volts
Latching Current (V_{AK} = 12 V, I_G = 20 mA)	T_J = 25°C T_J = −40°C	I_L	— —	.20 .35	5.0 7.0	mA
Holding Current (V_D = 12 Vdc) (Initiating Current = 20 mA, Gate Open)	T_J = 25°C T_J = −40°C T_J = +110°C	I_H	— — —	.19 .33 .07	3.0 6.0 2.0	mA
DYNAMIC CHARACTERISTICS						
Critical Rate–of–Rise of Off–State Voltage (V_{AK} = Rated V_{DRM}, Exponential Waveform, R_{GK} = 1000 Ohms, T_J = 110°C)		dv/dt	—	8.0	—	V/μs

(1) Pulse Test: Pulse Width ≤ 2.0 ms, Duty Cycle ≤ 2%.
(2) R_{GK} is not included in measurement.

- Low Power Consumption
- Wide Common-Mode and Differential Voltage Ranges
- Low Input Bias and Offset Currents
- Output Short-Circuit Protection
- Low Total Harmonic Distortion . . . 0.003% Typ
- High Input Impedance . . . JFET-Input Stage
- Latch-Up-Free Operation
- High Slew Rate . . . 13 V/μs Typ
- Common-Mode Input Voltage Range Includes V_{CC+}

description/ordering information

The TL08x JFET-input operational amplifier family is designed to offer a wider selection than any previously developed operational amplifier family. Each of these JFET-input operational amplifiers incorporates well-matched, high-voltage JFET and bipolar transistors in a monolithic integrated circuit. The devices feature high slew rates, low input bias and offset currents, and low offset-voltage temperature coefficient. Offset adjustment and external compensation options are available within the TL08x family.

The C-suffix devices are characterized for operation from 0°C to 70°C. The I-suffix devices are characterized for operation from −40°C to 85°C. The Q-suffix devices are characterized for operation from −40°C to 125°C. The M-suffix devices are characterized for operation over the full military temperature range of −55°C to 125°C.

ORDERING INFORMATION

T_J	V_{IO}max AT 25°C	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	15 mV	PDIP (P)	Tube of 50	TL081CP	TL081CP
			Tube of 50	TL082CP	TL082CP
		PDIP (N)	Tube of 25	TL084CN	TL084CN
		SOIC (D)	Tube of 75	TL081CD	TL081C
			Reel of 2500	TL081CDR	
			Tube of 75	TL082CD	TL082C
			Reel of 2500	TL082CDR	
			Tube of 50	TL084CD	TL084C
			Reel of 2500	TL084CDR	
		SOP (PS)	Reel of 2000	TL081CPSR	T081
			Reel of 2000	TL082CPSR	T082
		SOP (NS)	Reel of 2000	TL084CNSR	TL084
		TSSOP (PW)	Tube of 150	TL082CPW	T082
			Reel of 2000	TL082CPWR	
			Tube of 90	TL084CPW	T084
			Reel of 2000	TL084CPWR	

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

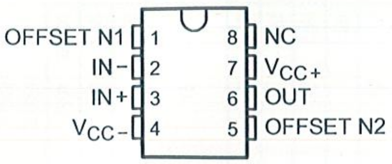
description/ordering information (continued)

ORDERING INFORMATION

T_J	V_{IO}max AT 25°C	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	6 mV	PDIP (P)	Tube of 50	TL081ACP	TL081ACP
			Tube of 50	TL082ACP	TL082ACP
		PDIP (N)	Tube of 25	TL084ACN	TL084ACN
		SOIC (D)	Tube of 75	TL081ACD	081AC
			Reel of 2500	TL081ACDR	
			Tube of 75	TL082ACD	082AC
			Reel of 2500	TL082ACDR	
			Tube of 50	TL084ACD	TL084AC
			Reel of 2500	TL084ACDR	
		SOP (PS)	Reel of 2000	TL082ACPSR	T082A
		SOP (NS)	Reel of 2000	TL084ACNSR	TL084A
	3 mV	PDIP (P)	Tube of 50	TL081BCP	TL081BCP
			Tube of 50	TL082BCP	TL082BCP
		PDIP (N)	Tube of 25	TL084BCN	TL084BCN
		SOIC (D)	Tube of 75	TL081BCD	081BC
			Reel of 2500	TL081BCDR	
			Tube of 75	TL082BCD	082BC
			Reel of 2500	TL082BCDR	
			Tube of 50	TL084BCD	TL084BC
			Reel of 2500	TL084BCDR	
−40°C to 85°C	6 mV	PDIP (P)	Tube of 50	TL081IP	TL081IP
			Tube of 50	TL082IP	TL082IP
		PDIP (N)	Tube of 25	TL084IN	TL081IN
		SOIC (D)	Tube of 75	TL081ID	TL081I
			Reel of 2500	TL081IDR	
			Tube of 75	TL082ID	TL082I
			Reel of 2500	TL082IDR	
			Tube of 50	TL084ID	TL084I
			Reel of 2500	TL084IDR	
		TSSOP (PW)	Reel of 2000	TL082IPWR	Z082
−40°C to 125°C	9 mV	SOIC (D)	Tube of 50	TL084QD	TL084QD
			Reel of 2500	TL084QDR	
−55°C to 125°C	9 mV	CDIP (J)	Tube of 25	TL084MJ	TL084MJ
		LCCC (FK)	Reel of 55	TL084FK	TL084FK
	6 mV	CDIP (JG)	Tube of 50	TL082MJG	TL082MJG
		LCCC (FK)	Tube of 55	TL082MFK	TL082MFK

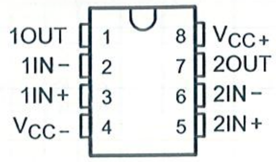
† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

TL081, TL081A, TL081B
D, P, OR PS PACKAGE
(TOP VIEW)

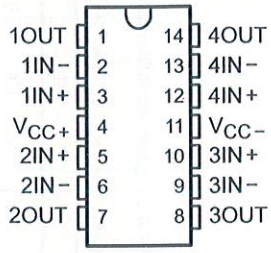


NC – No internal connection

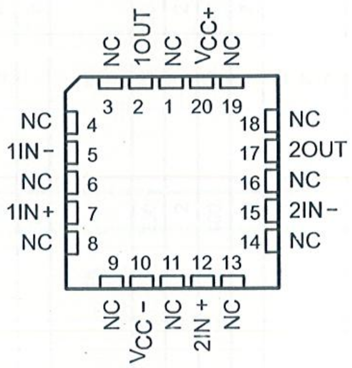
TL082, TL082A, TL082B
D, JG, P, PS, OR PW PACKAGE
(TOP VIEW)



TL084, TL084A, TL084B
D, J, N, NS, OR PW PACKAGE
(TOP VIEW)

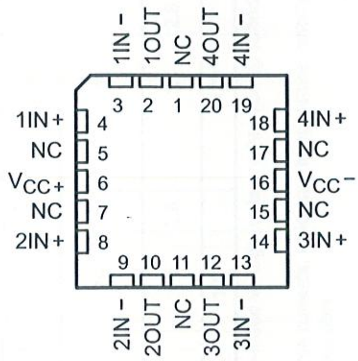


TL082M . . . FK PACKAGE
(TOP VIEW)



NC – No internal connection

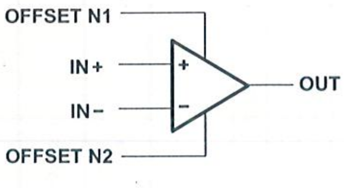
TL084M . . . FK PACKAGE
(TOP VIEW)



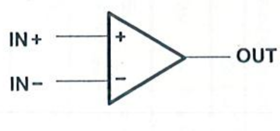
NC – No internal connection

symbols

TL081



TL082 (EACH AMPLIFIER)
TL084 (EACH AMPLIFIER)



electrical characteristics, $V_{CC\pm}$ = ±15 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	T_A†	TL081C TL082C TL084C			TL081AC TL082AC TL084AC			TL081BC TL082BC TL084BC			TL081I TL082I TL084I			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage	V_O = 0, R_S = 50 Ω	25°C		3	15		3	6		2	3		3	6	mV
			Full range			20			7.5			5			9	
α_{VIO}	Temperature coefficient of input offset voltage	V_O = 0, R_S = 50 Ω	Full range		18			18			18			18		µV/°C
I_{IO}	Input offset current‡	V_O = 0	25°C		5	200		5	100		5	100		5	100	pA
			Full range			2			2			2			10	nA
I_{IB}	Input bias current‡	V_O = 0	25°C		30	400		30	200		30	200		30	200	pA
			Full range			10			7			7			20	nA
V_{ICR}	Common-mode input voltage range		25°C	±11	–12 to 15		±11	–12 to 15		±11	–12 to 15		±11	–12 to 15		V
V_{OM}	Maximum peak output voltage swing	R_L = 10 kΩ	25°C	±12	±13.5		±12	±13.5		±12	±13.5		±12	±13.5		V
		R_L ≥ 10 kΩ	Full range	±12			±12			±12			±12			
		R_L ≥ 2 kΩ		±10	±12		±10	±12		±10	±12		±10	±12		
A_{VD}	Large-signal differential voltage amplification	V_O = ±10 V, R_L ≥ 2 kΩ	25°C	25	200		50	200		50	200		50	200		V/mV
		V_O = ±10 V, R_L ≥ 2 kΩ	Full range	15			25			25			25			
B_1	Unity-gain bandwidth		25°C		3			3			3			3		MHz
r_i	Input resistance		25°C		10^{12}			10^{12}			10^{12}			10^{12}		Ω
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICR}$min, V_O = 0, R_S = 50 Ω	25°C	70	86		75	86		75	86		75	86		dB
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$)	V_{CC} = ±15 V to ±9 V, V_O = 0, R_S = 50 Ω	25°C	70	86		80	86		80	86		80	86		dB
I_{CC}	Supply current (per amplifier)	V_O = 0, No load	25°C		1.4	2.8		1.4	2.8		1.4	2.8		1.4	2.8	mA
V_{O1}/V_{O2}	Crosstalk attenuation	A_{VD} = 100	25°C		120			120			120			120		dB

† All characteristics are measured under open-loop conditions with zero common-mode voltage, unless otherwise specified. Full range for T_A is 0°C to 70°C for TL08_C, TL08_AC, TL08_BC and –40°C to 85°C for TL08_I.

‡ Input bias currents of an FET-input operational amplifier are normal junction reverse currents, which are temperature sensitive, as shown in Figure 17. Pulse techniques must be used that maintain the junction temperature as close to the ambient temperature as possible.

electrical characteristics, $V_{CC\pm} = \pm15$ V (unless otherwise noted)

PARAMETER		TEST CONDITIONS†	T_A	TL081M, TL082M			TL084Q, TL084M			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage	$V_O = 0$, $R_S = 50\ \Omega$	25°C		3	6		3	9	mV
			Full range			9			15	
α_{VIO}	Temperature coefficient of input offset voltage	$V_O = 0$ $R_S = 50\ \Omega$	Full range		18			18		μV/°C
I_{IO}	Input offset current‡	$V_O = 0$	25°C		5	100		5	100	pA
			125°C			20			20	nA
I_{IB}	Input bias current‡	$V_O = 0$	25°C		30	200		30	200	pA
			125°C			50			50	nA
V_{ICR}	Common-mode input voltage range		25°C	±11	−12 to 15		±11	−12 to 15		V
V_{OM}	Maximum peak output voltage swing	$R_L = 10\ k\Omega$	25°C	±12	±13.5		±12	±13.5		V
		$R_L \geq 10\ k\Omega$	Full range	±12			±12			
		$R_L \geq 2\ k\Omega$		±10	±12		±10	±12		
A_{VD}	Large-signal differential voltage amplification	$V_O = \pm10$ V, $R_L \geq 2\ k\Omega$	25°C	25	200		25	200		V/mV
		$V_O = \pm10$ V, $R_L \geq 2\ k\Omega$	Full range	15			15			
B_1	Unity-gain bandwidth		25°C		3			3		MHz
r_i	Input resistance		25°C		10^{12}			10^{12}		Ω
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICR}min$, $V_O = 0$, $R_S = 50\ \Omega$	25°C	80	86		80	86		dB
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$)	$V_{CC} = \pm15$ V to ±9 V, $V_O = 0$, $R_S = 50\ \Omega$	25°C	80	86		80	86		dB
I_{CC}	Supply current (per amplifier)	$V_O = 0$, No load	25°C		1.4	2.8		1.4	2.8	mA
V_{O1}/V_{O2}	Crosstalk attenuation	$A_{VD} = 100$	25°C		120			120		dB

† All characteristics are measured under open-loop conditions, with zero common-mode input voltage, unless otherwise specified.
‡ Input bias currents of a FET-input operational amplifier are normal junction reverse currents, which are temperature sensitive, as shown in Figure 17. Pulse techniques must be used that maintain the junction temperatures as close to the ambient temperature as possible.

operating characteristics, $V_{CC\pm} = \pm15$ V, $T_A = 25°C$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	$V_I = 10$ V, $R_L = 2\ k\Omega$, $C_L = 100$ pF, See Figure 1		8*	13		V/μs
		$V_I = 10$ V, $R_L = 2\ k\Omega$, $C_L = 100$ pF, $T_A = -55°C$ to 125°C, See Figure 1		5*			
t_r	Rise time	$V_I = 20$ mV, $R_L = 2\ k\Omega$, $C_L = 100$ pF, See Figure 1			0.05		μs
	Overshoot factor				20		%
V_n	Equivalent input noise voltage	$R_S = 20\ \Omega$	f = 1 kHz		18		nV/√Hz
			f = 10 Hz to 10 kHz		4		μV
I_n	Equivalent input noise current	$R_S = 20\ \Omega$,	f = 1 kHz		0.01		pA/√Hz
THD	Total harmonic distortion	$V_{Irms} = 6$ V, $A_{VD} = 1$, $R_S \leq 1\ k\Omega$, $R_L \geq 2\ k\Omega$, f = 1 kHz			0.003		%

*On products compliant to MIL-PRF-38535, this parameter is not production tested.