SC FILTER IC BASED LOW FREQUENCY FUNCTION GENERATOR

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ABSTRACT

Switched capacitors can be modeled as resistors, and their small size and the ease with which the simulated resistance can be varied make them extremely useful in realizing digitally tunable analog circuits. This report covers the design for an oscillator, capable of producing continuous wave as well as frequency and amplitude modulated output, using switched capacitor filter. The developed instrument produces output with carrier as sinusoidal or square wave and modulating signal as square or triangular wave. The modulated waves produced have digitally selectable carrier frequency, carrier amplitude, modulation index and modulating frequency. The output is provided through a Class AB audio amplifier, with an output resistance of 50Ω.

1. INTRODUCTION

1.1 Why switched capacitors?

Switched capacitors are generally used to simulate resistances to a reasonably accurate extent. This is useful for several reasons, chief among which is that resistors are hard to build on integrated circuits since they are bulky, and the circuits can be made to depend on ratios of capacitor values, which can be set accurately, and not absolute values, which may vary between manufacturing runs. To understand how a switched capacitor circuit works [5], consider the circuit shown in Fig. 1 with a capacitor connected to two different voltages through two switches. Initially, let S_2 be closed with S_1 open. Now if S_1 is closed and S_2 opened, charge $\Delta q=C_1(V_2-V_1)$ gets transferred from V_2 to V_1.

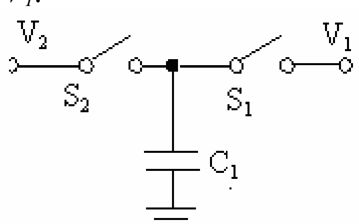

Fig 1. Switched capacitor modeling

If this switching process is repeated N times in time Δt, the amount of charge transferred per unit time, which is equivalent to the flowing current i, is given by

$$i=\Delta q/ \Delta t = C_1.(V_2-V_1).N/ \Delta t \qquad (1)$$

Rearranging we get

$$R= (V_2-V_1)/i = 1/ (C_1. f_{clk}) \qquad (2)$$

where R is the effective resistance, $f_{clk}=N/\Delta t$ is the switching frequency, V_2 and V_1 are the voltages as shown in Fig. 1 and Δq is the charge transferred from V_2 to V_1 in time Δt. According to equation 2, the switched capacitor is equivalent to a resistor. The value of this resistor decreases with both increasing the switching frequency and increasing the capacitance, as either will increase the amount of charge transferred from V_2 to V_1 in a given time.

LMF100, a switched capacitor based filter, has been used for building a variable frequency oscillator. To get an understanding of how the LMF100 works, consider the following band pass filter.

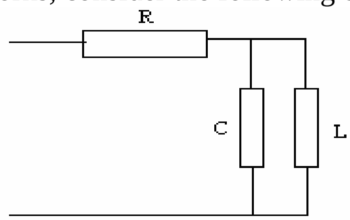

Fig 2. RLC realization

Now replace the resistor with a switched capacitor. The resistor value can then be changed based on the input clock and thus we get the variable band pass filtering action. Also the switching is done using MOSFET switches.

2. DEVICE SPECIFICATION AND OPERATION

2.1 Waveforms generated and instrument specifications

The instrument is powered by a 230 V, 50 Hz a. c. source. It produces continuous as well as frequency and amplitude modulated sinusoidal and square wave outputs with square and triangular modulating wave. The output range of the developed instrument for various output modes has been tabulated in Table 1.

Table 1. Specifications of the waveform generator

Output Mode	Carrier/Signal Frequency f_{min}-f_{max}, Δf (Hz)	Carrier/Signal Amplitude Range, Step Size (dB)	Modulation Index Range, Step Size	Carrier Frequency/ Modulating Frequency Range (x10^3)
Continuous	0.01 – 1.0, 0.01 1.0 – 100, 0.1	0 – 10.00, 1.25	N.A.	N.A.
AM – Square	0.01 – 1.0, 0.01 1.0 – 100, 0.1	5.00 (fixed)	1.25 – 5, 1.25	0.1 – 100
AM- Triangular	0.01 – 1.0, 0.01 1.0 – 100, 0.1	5.00 (fixed)	5.00 (fixed)	0.1 – 100
FM- Square	0.11 – 0.89, 0.01 1.1 – 89.9, 0.1	0 – 10.00, 1.25	1 – 4, 1	0.1 – 100
FM- Triangular	0.11 – 0.89, 0.01 1.1 – 89.9, 0.1	0 – 10.00, 1.25	1 – 4, 1	0.1 – 100

The advantage of the design is that various changes in its operation can be carried out by changing the software. Most applications require the modulating frequency to be at least 1/100 times the carrier frequency and this has been taken into account while deciding the modulating frequency range. As a preliminary design, only 9 attenuation levels have been provided. This can also be increased to as many as 64 levels. The modulation index for amplitude modulation is limited by the number of attenuation levels provided, which is explained later, and hence limited values for the modulation indices have been provided. The output resistance of the instrument is 50 Ω.

2.2 User Interface

Four switches namely up, down, forward, and backward have been provided to select the desired output. The display consists of 3 seven segment displays and 16 LEDs as shown in Fig. 3. The complete menu of the instrument has been divided into 4 menu levels namely wave, type, parameter and value, with up and down switches to be used for switching between these menu levels and forward and backward switches for selecting the desired option in the selected menu level. Of the 16 LEDs, one is a power LED, four are used to indicate the menu levels and the rest for various options in the menu levels. The 3 seven segment displays indicate the value of the selected parameter. Also a power on/off switch for switching on or off the instrument has been provided. Keeping the forward or backward switch pressed for a prolonged period keeps shifting between the options of the selected menu levels. Also forward and backward switches move circularly in the sense that pressing the up switch, when the highest option has already been selected results in the selection of the lowest option.

Changing the selection of the menu item in wave or type menu level keeps the values for various parameters common to the previous selection same as were set and provides default values only to the new parameters. The values of these parameters can then be changed, as is described later. The default frequency and amplification for continuous mode are 1.0Hz and 0dB respectively. The default values for carrier frequency, carrier amplitude, modulation index and ratio of carrier frequency to modulating frequency for frequency modulated modes are 1.1Hz, 0dB, 1, and 0.1 x 10^3 respectively, for amplitude modulated mode with square wave as modulating signal are 1.0Hz, 5.00dB, 1.25dB, and 0.1 x 10^3Hz, and for amplitude modulated mode with triangular wave as modulating signal are 1.0Hz, 5.00dB, 5.00dB, and 0.1 x 10^3Hz.

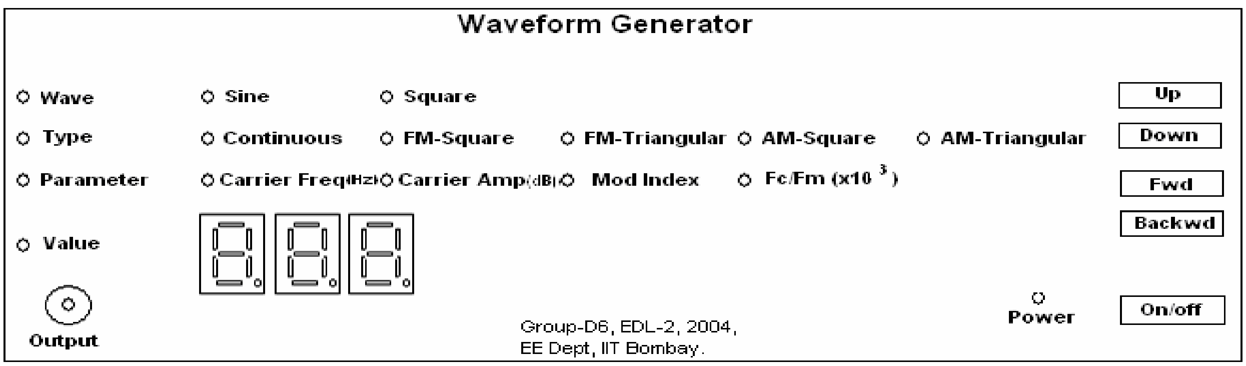

Fig 3. Instrument Front Panel

On ‘power on’, output is continuous sinusoidal wave with a frequency of 1.0Hz and amplitude of 0dB. Up, down, forward and backward switched can then be used to obtain the desired output. The values of various parameters of the output are displayed using the display unit. First we illustrate an example for how to read the display unit. Consider the display in Fig 4.

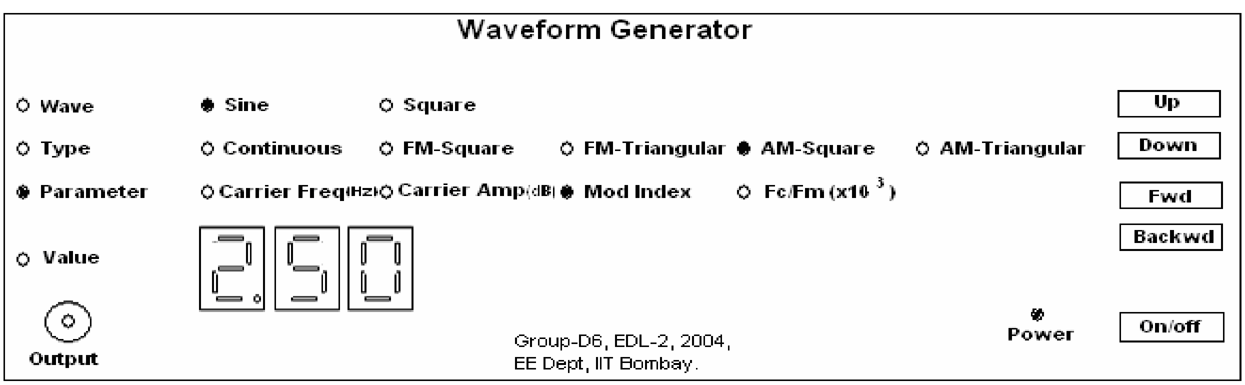

Fig 4. Indicating the situation for example 1

The complete information which can be gained from the display illustrated in Fig 4 has been tabulated in Table 2.

Table 2. Interpretation of the display shown in Fig 4

Menu Level	Selected Option	Interpretation
Menu	Sine	Sinusoidal carrier if modulated output and sinusoidal wave if continuous output
Type	AM-Square	Amplitude modulated output with square wave as modulating signal
Parameter	Modulation Index	The value displayed by seven segment displays corresponds to modulation index
Value	2.50	Modulation index (selected in parameter menu level) = 2.50
Parameter led is glowing implying that the Parameter menu level has been selected and use of forward/backward switches would select the options under this menu level.		

In order to note the values of other parameters, the required option in the parameter menu level needs to be selected.

An example for how to generate a frequency modulated output with square wave as modulating signal, carrier as square wave of 37.5 Hz, carrier amplification of 6.25dB, and default modulation index and modulating frequency starting with a switched off instrument has been illustrated below. The step by step procedure for obtaining the required output is as follows:

- Switch on the instrument
- Wave menu has been selected as default and default option is sine. Press forward key once to select Square wave
- Press down switch to move to modulation level. The default option is continuous. Now press the forward key for a prolonged period until the FM-Square gets selected.
- Press down switch to move to parameter level. The default option is carrier frequency.
- Press down switch to move to value level. The default value for carrier frequency (selected in the previous step) is 1.0Hz. Now press the forward key for a prolonged period until the carrier frequency is set to 37.5Hz.
- Press up switch to move back to parameter level. The option selected is carrier frequency. Now press the forward key to select carrier amplification.
- Press down switch to move to value level. The default value for carrier amplification (selected in the previous step) is 0dB. Press forward key to set the carrier amplification as 6.25dB.

The required output can hence be generated.

The complete menu control of the instrument has been illustrated in the flow chart in Fig 5.

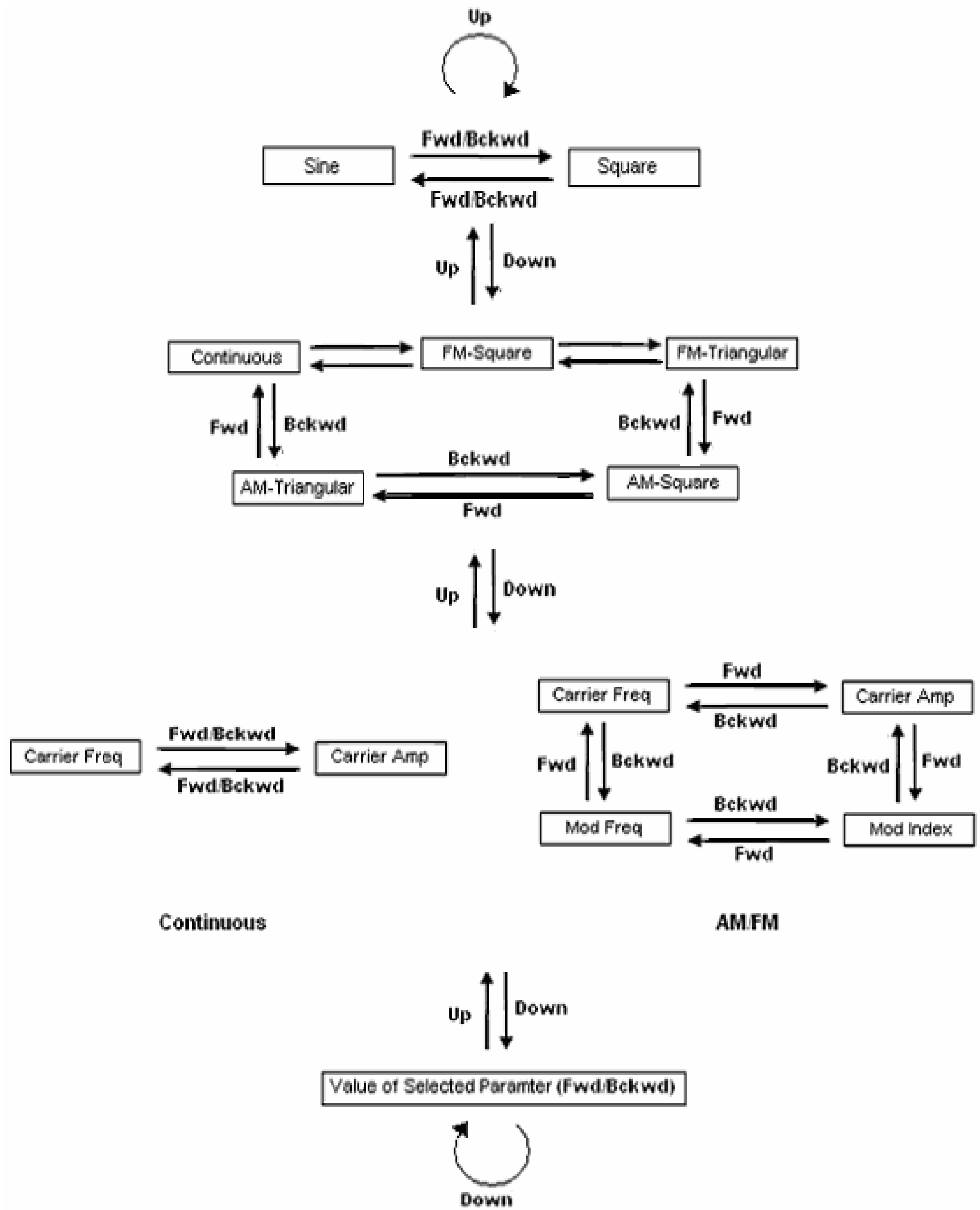

Fig 5. Menu control flowchart

3. BASIC DESIGN AND BLOCK DIAGRAM

The complete design can be divided into five modules:
A. Power Supply
B. SC filter based variable frequency oscillator
C. Microcontroller
D. Variable Attenuator
E. Audio Amplifier
F. Display unit driver

A brief description of the modules is given below, followed by the complete block diagram in Fig 6.

A. Power supplies: The ground, 5V and -5V are generated with the help of regulators, 7805 and 7905, and a transformer. A 9-0-9 center tap transformer in conjunction with a diode rectifier and capacitor filter converts the 230V supply to 9 and -9 volts.

B. SC filter based variable frequency oscillator: This is achieved by building an oscillator with the help of a band pass filter with a feedback. The band pass filter is built using LMF100. The clock to LMF100 has been provided by the micro-controller, which is 100 times the required output frequency. Thus by varying the input clock frequency, the frequency of the output is varied. This module produces both sinusoidal and square waves of the required frequency.

C. Microcontroller: The Microcontroller used is AT89C52. The four switches (up, down, forward and backward) discussed earlier have been interfaced with it. The microcontroller, depending upon the carrier frequency and amplitude selected by the user, generates a clock of frequency 100 times the required frequency for SC filter based oscillator and controls the attenuation level. It also changes the amplitude and frequency of the output in accordance to the modulation selected by the user.

D. Variable Attenuator: TDA8551, which is an audio amplifier IC capable of providing 1W power to an 8 ohm load with digital volume control, has been used. 64 attenuation levels with a total of 80dB attenuation can be achieved using this IC but for a preliminary design but only 9 levels have been used with a maximum amplification of 10dB. The volume is controlled through a serial pin which is fed as an input from the microcontroller. TDA8551 provide a differential output and hence a difference amplifier has been used to obtain a single ended output. Also, this IC handles signals in 0-5V range. Hence an additional circuit is needed for bipolar output.

E. Output Amplifier: The final output is given through a push-pull amplifier. An output resistance of 50Ω is provided by connecting a 50Ω serier resistance.

F. Display Unit: The display unit consists of 3 seven segment displays and 16 LEDs. An efficient design which reduces the circuit size has been employed by using MAXIM7219, a serial input common cathode display driver.

Complete Block Diagram

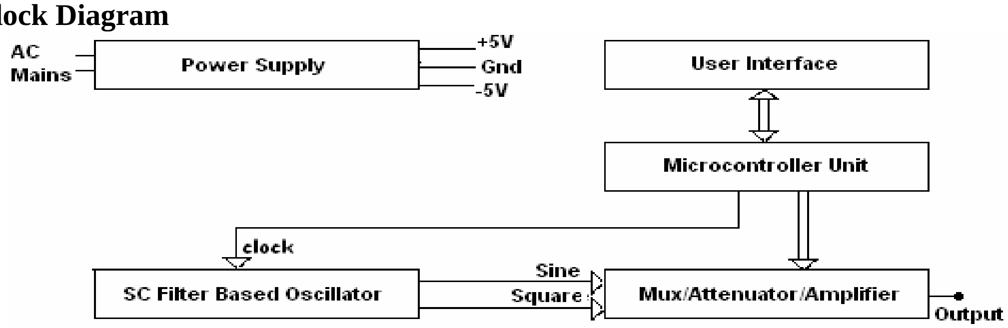

Fig 6. Complete Block Diagram

4. DESIGN APPROACH

4.1 Power Supply

The microcontroller requires only 5V while few analog ICs require a supply of -5V as well. Current draw by the circuit is of the order of 80mA. Therefore a 230V to 9V, 1-Ampere center tap transformer has been used.

The transformer in conjunction with a diode bridge rectifier and capacitor filter converts the 230V supply to 9 and -9 volts. Then, 7805 regulator is used for producing 5V and 7905 for producing -5V. The complete circuit for power supply is shown in Fig 7.

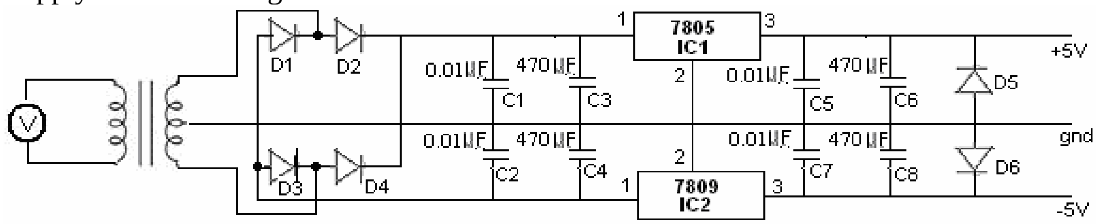

Fig 7. Power Supply

4.2 SC filter based variable frequency oscillator

To produce sine wave LMF100 [6], that provides a band pass filter, has been used. LMF100, when fed with a clock (unipolar square wave) of frequency f_c, provides band pass action at centre frequency of $f=f_c/100$ on the input, which is also fed simultaneously. An initial approach to obtain sinusoidal oscillation of frequency f was to produce a square wave of frequency f_c through the microcontroller, pass it through two decade counters to get a square wave of frequency f and feed the square wave of frequency f_c as the clock to the LMF100 and that of frequency f, generated through the decade counters, as an input to LMF100. The block diagram for this approach is as shown in Fig 8.

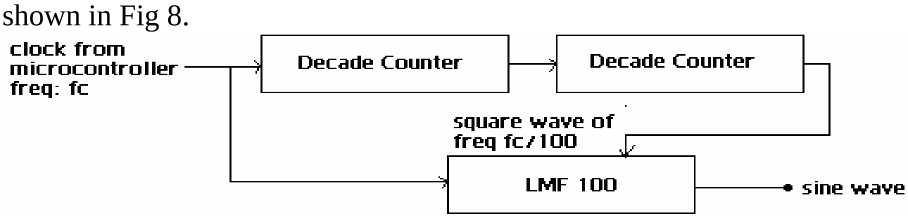

Fig 8. Sine wave generator using a decade counter and a band pass filter

But since band pass filters do not have sharp characteristics and a distorted sine wave is produced, an alternative approach has been taken up in which the band pass action has been used to make an oscillator with a hard limiter in the feedback. The frequency of the oscillator is equal to the frequency of the band pass action which is f, the clock being f_c which is produced by the microcontroller. A hard limiter is used in the feedback path of the oscillator. The hard limiter has been built such that any positive value at the input saturates the opamp in the positive direction and any negative value saturates the opamp in the negative direction. Thus the sine wave, produced at the output of the band pass filter, is converted to a bipolar square wave which is then fed as an input to the oscillator. Two zener diodes have been used with opposite polarities at the output of the hard limiter to clamp the negative and positive saturation voltages at 4V and –4V respectively. The complete circuit for the oscillator is shown in Fig 9, which is then followed by a brief description on LMF100.

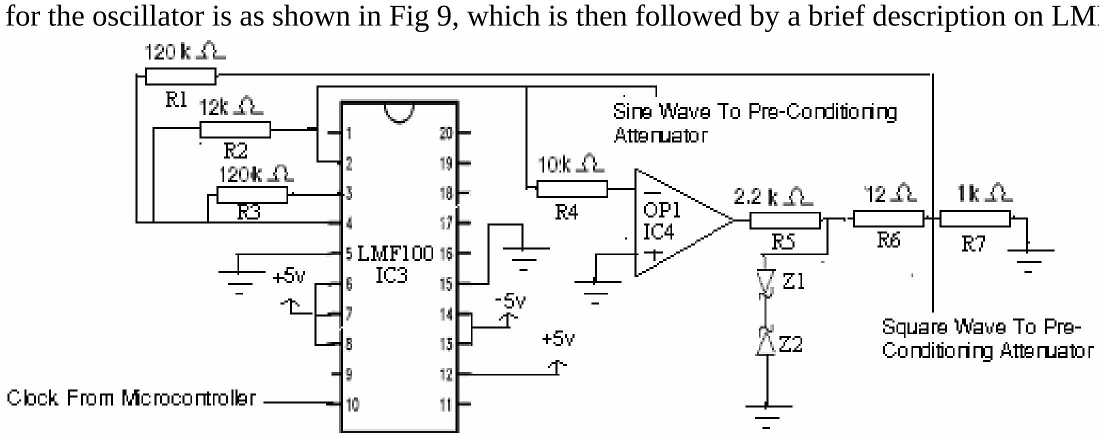

Fig 9. LMF100 based variable frequency oscillator

The LMF100 consists of 2 easy to use CMOS active filtering block. Each block along with a clock pin can produce different second order functions. Each block has 3 output pins one of which can be configured to act as a high pass, all pass or notch filtering and the remaining two pins perform low pass and band pass filtering. The center frequencies can either depend on the clock frequency alone or on both the clock frequency and some resistors. The LMF100 has been configured in Mode 1, which produces low pass, band pass, and notch filtered output at different pins. The center frequency of the band pass output is decided by the clock frequency f_c and is given by $f_c/100$. The internal circuit in mode1 is as shown along with the associated IC pins. The LMF100 may also be used in any of the other mode which is capable of producing a band pass filter.

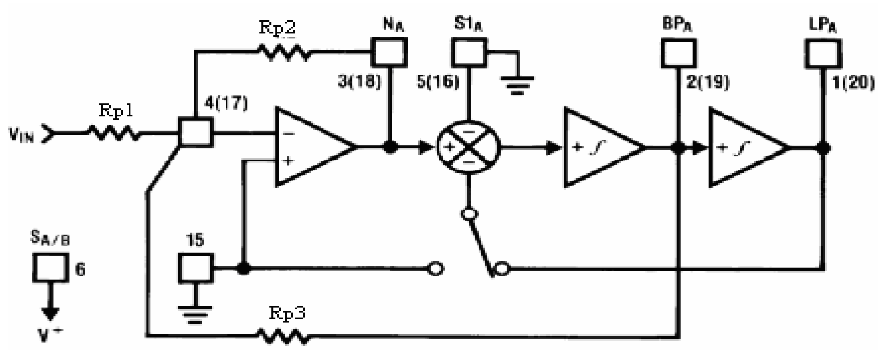

Fig 10. Internal circuit of LMF100 in mode 1 [6]

Band pass gain at *f* is given by $H=-R_p3/R_p1$ and the quality factor by $Q=Rp2/R_p1$. To get a good set of *H* and *Q*, R_p1= 120k, R_p2=120k and R_p3=12k have been used. Also, pin12 is grounded so that a division of 1:100 is achieved and pin9 is grounded as 5V and –5V supplies are used and clock with 0 and +5V TTL levels is used. Only one set of filter is used and the other is left open.

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4.3 Microcontroller

Atmel's AT89C52 [1], [2], [7] has been used and all the functions performed by the microcontroller can be divided into four sections namely user interface, sine-square select, wave generation and amplitude control. The modulations produced are all software controlled and therefore the microcontroller plays a critical role in the functioning of the instrument.

4. 3.1 User Interface

The four switches namely up, down, forward and backward, as described in section 2, are interfaced with the microcontroller. These switches are connected to P3.0, P3.1, P3.3 and P3.4 of microcontroller respectively. The microcontroller keeps on polling these four pins and as soon as it encounters a low, it calls the corresponding routine. Also care has been taken for debouncing and hence a delay routine is called whenever a change in the state of any of these four pins is detected.

The 15 LEDs (power 'on' led is connected directly) and the 3 seven segment display are controlled by the microcontroller through the MAXIM7219 display driver. Three pins P1.0, P1.1, P1.2 are connected to the clock, din and load pins of the driver respectively.

4.3.2 Amplitude Control

TDA8551 is used for amplitude control. Amplification level control in TDA8551 is through a digital trinary input (5V, 2.5V, 0V), which is controlled by the microcontroller through an analog switch as is explained in section 3.4. The two controls bits are connected to P2.2 and P2.3 of microcontroller. Normally, both these bits are low, maintaining a voltage of 2.5V at the TDA8551 amplitude control pin. If the carrier amplitude has been selected and then the up switch is pressed, a high pulse is given at P2.2, thereby giving a 5V pulse to TDA8551 through the switch and hence resulting in an increment in the amplification. Similarly, when the down switch is pressed with carrier amplitude parameter been selected, a high pulse is given at P2.3 thereby giving a 0V pulse to TDA8551 through the switch and hence resulting in a decrement in the amplification. Care has been taken that once the carrier amplification has reached the maximum level, up switch has no effect and similarly down switch has no effect once the amplification reaches the minimum level.

4.3.3 Sine-Square Select

A common output and attenuation stage has been used for both sinusoidal and square waves. Hence an analog switch has been used to select the waveform to be given as input to the variable attenuator, based on the user selection. Following the analog switch, duplication of the stages for the two waveforms will not be needed and the same attenuator and amplifier may be used. Hence it will be advantageous if we can put the analog switch just after the stage at which the waveforms are produced as then we can multiplex them using a switch for the remaining circuit based on what the user selects. Before multiplexing, it is necessary to standardize the square and the sinusoidal waves in terms of amplitude and dc offset so that they behave identically when fed as input to the next stage. In our design the wave standardization stages have been designed immediately after the LMF100 sinusoidal and square wave generation module, which is then followed by the analog switch which selects the required waveform. The analog switch is controlled through P2.1 of the microcontroller. When sinusoidal waveform is to be produced, the pin goes low and when square wave is to be produced, the pin goes high and the corresponding wave is fed to the variable attenuator.

4.3.4 Waveform generation scheme

Microcontroller is used to generate the clock of desired frequency f_c, fed to LMF100 based oscillator which then produces sinusoidal and square waves of frequency $f_c/100$. For continuous wave generation, timer0 has been used in mode0 to produce the clock of required frequency f_c.
In the case of frequency modulated output with square wave as modulating signal, the frequency of the output wave toggles between f_c+m_f and f_c-m_f in each modulating period, where f_c is the carrier frequency and m_f is the modulation index selected by the user. Frequency modulated output with triangular wave as modulating frequency is slightly more complicated. The triangular modulating wave is approximated by step wave, as shown in Fig 12, and the frequency of the output changes in each step. Thus an analog continuous modulation scheme has been made discrete. A total of 19 steps have been used to gradually change the frequency from minimum frequency of f_c-m_f to maximum frequency of f_c+m_f and vice-versa.

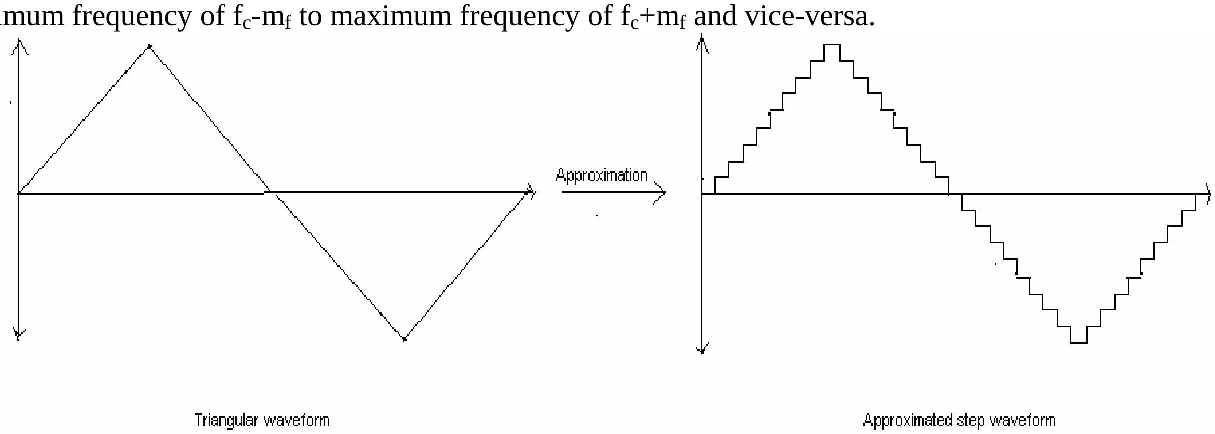


Fig 11. Approximation of triangular waveform for modulation

In case of amplitude modulated output with square wave as modulating signal, the amplification of the output wave toggles between (5.00+mf) dB and (5.00-mf) dB in each modulating period, which is done by controlling the TDA8551 through an analog switch as has been described earlier. As for frequency modulated output with triangular wave as modulating signal, in the case of amplitude modulation with triangular wave as modulating signal, the triangular wave has been approximated by a discrete counterpart with a total of 20 steps.

In case of modulated output, timer0 in mode0 produces a clock whose frequency is decided by the carrier frequency (and modulation index in case of frequency modulation) as selected by the user and timer2 in mode0 keeps account of the time period of the modulating signal. After each modulating time period, the frequency of the clock is changed for frequency modulated output and the amplitude level for the amplitude modulated output in accordance with modulation index. The clock for producing carrier signal is produced at P2.0 of the microcontroller which is then sent as a clock to LMF100. According to the level and sub-level selected by the user through the set of push buttons, the microcontroller changes the values in the registers associated and corresponding changes the output.

The circuit diagram of the microcontroller is as shown in Fig 12.

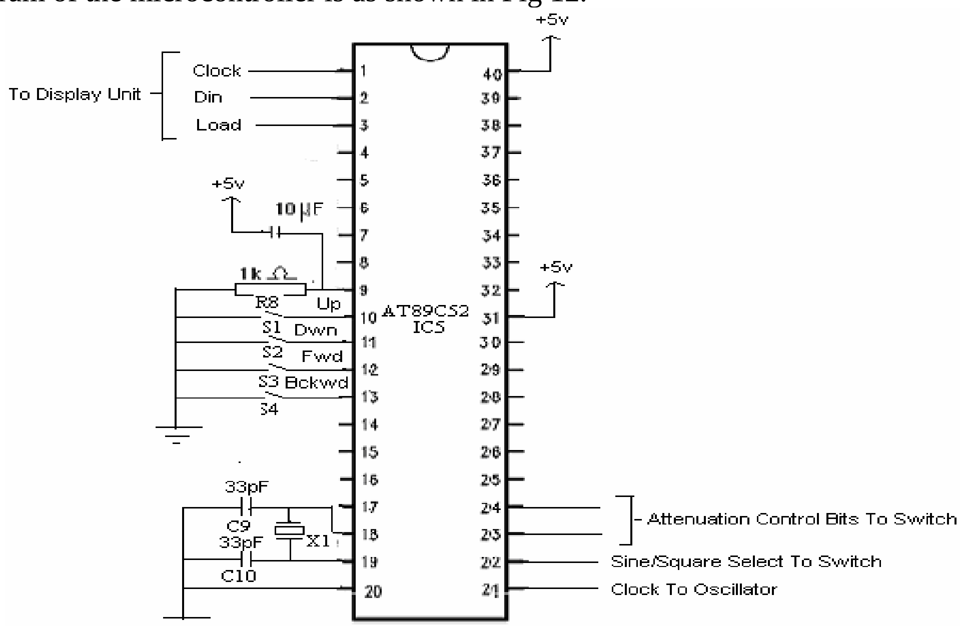


Fig 12. Microcontroller module

4.4 Variable Attenuator

In the first stage of the project, attenuation was obtained through a simple resistive ladder. Designing a resistive ladder that will provide 10 equal stages can make the circuit ungainly due to the precise value of resistors that will be needed. A more efficient design would be to use TDA8551 [8], an audio amplifier with serial volume control. TDA8551 is capable of providing 64 attenuation levels in steps of 1.25dB and a total attenuation of 80dB. For our application only 9 levels or 8 shifts have been used as discussed earlier and the levels that have been used are the highest 9 levels. The pin diagram of TDA8551 along with its working shall be discussed first.

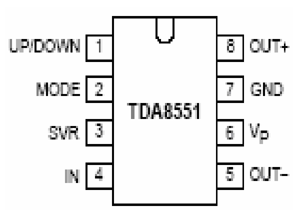


Fig 13 Pin diagram of 8551 [8]

TDA8551 requires a supply of 5V with respect to ground. It can be configured in either of three modes namely mute, stand by or operating using the pin 2. To get the TDA8551 in the operating mode this pin must be made high and for our application since we need it continuously in the operating mode, the pin has been connected to 5V. The input waveform to be attenuated is provided at pin4 and the attenuated output appears as a differential output between pin5 and pin8.

There is a digital trinary input for the up/down control. Normally, up/down control pin is maintained at $V_p/2$ (2.5V). For every up pulse of voltage Vp (5V), an increment in the attenuation level result. Similarly, a decrement in the attenuation level is caused by every down pulse of 0V (ground). The attenuation levels for this application are controlled by the microcontroller through an analog switch. To increase the amplification of the output by 1.25dB, a positive voltage pulse 5v is sent and pulses from 0v is sent for decreasing the output amplification level by 1.25dB.

The attenuation levels are controlled by the microcontroller through an analog switch. The output of the analog switch is 0V, 2.5V or 5V depending of the two control bits from microcontroller. Normally, the output of the analog switch is 2.5V, which can be changed accordingly by the microcontroller as and when required. The following circuit has been implemented for up/down level control.

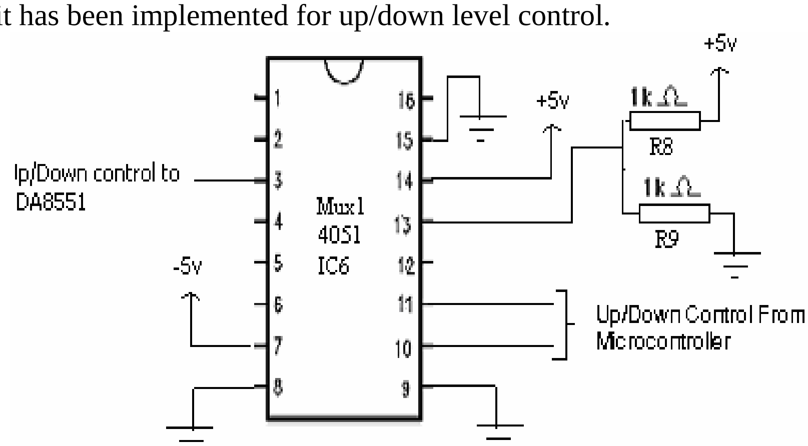


Fig 14 Switch for controlling Up/Down of TDA 8551

The peak to peak value of the analog input signal must be less than 2v. Since only a positive power supply is provided, it is not possible to use the chip directly for a bipolar input. Thus the sine wave produced from the LMF100 unit cannot be used directly owing to its bipolar nature. Any offset in the input to the attenuator will also get attenuated and will appear as a differential bias at the output. If the bias is considerable, it might saturate TDA8551 or the succeeding stages. Hence it is critical to nullify the offset of both sine wave and the square wave before they are used as an input to TDA8551.To summarize, various complications in using the TDA8551 are as follows:

1. A maximum permissible peak to peak of 2V for the input signal.
2. The inability of the chip to amplify bipolar signals, without the use of capacitors.
3. The need to nullify the offset of the input waveform as discussed.

4.4.1 Pre – Conditioning of the waveform

The pre-conditioning of the waveform is essential because of the various factors. The peak to peak voltages observed at the output of the LMF100 module for the sinusoidal and square wave are different and therefore use of different resistor ladder will solve the first problem i.e. reducing the voltage of both to $1V_{p-p}$. In this design, to get isolation between different parts of the circuit and to prevent loading, buffers have been used.

Similar circuit is also used for attenuating the square wave with the resistor of value 1.8k replaced by that of value 1.2k. The circuit is as shown in Fig. 15.

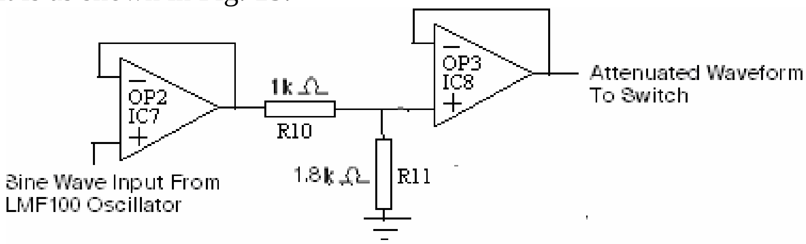


Fig 15 – Buffer and voltage divider

To address the second problem the various offset pick up points in the circuit was first identified. The dc bias values at various stages in the circuit have been tabulated in Table 3.

Table 3: Offset pick up points

Points	Sine wave offset (volts)	Square wave offset (volts)
At the LMF output	0	0.2 V (signal of $4V_{p-p}$)
After the voltage dividers reduction stage	0	0.1 V (signal of 1 V_{p-p})
After the analog switch	0.05	0.15 V (signal of $1.5V_{p-p}$)

Thus an ideal strategy would be to nullify the offset in the square wave immediately after the LMF 100 using a simple preset in a voltage ladder. Then the sine and square wave will have identical amplitudes and zero offsets and can be given as an input to an analog switch controlled by the microcontroller. Any common offset picked up after the common switch can now be nullified using a single preset for both the sine and the square wave which now optimizes the design and reduces the number of presets by 1.The circuit to nullify the offset in the square wave is show below:

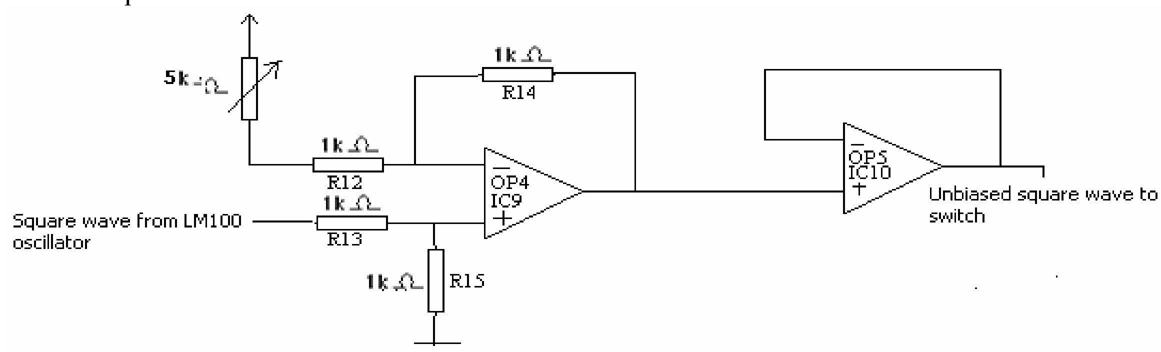


Fig 16. Removing offset in square wave

In order to select sinusoidal or square waveform according to the user's choice, another analog switch, also controlled by the microcontroller, has been used. Two inputs to the switch are the sinusoidal and the unbiased square waves produced by the pre-conditioning attenuator and offset remover. The sine/square select bit is connected to P2.2 of the microcontroller. The complete for sine/square select switch is as shown in Fig 17.

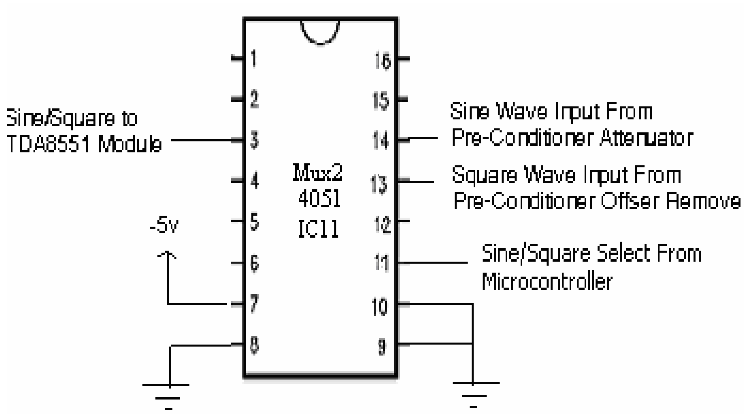


Fig 17. Switch for sinusoidal/square wave selection

As discussed above, in order to solve the problem of bipolar input, a solution could be to bias the signal and then nullify the resultant bias at the output through some means, for instance by using capacitors. Since low frequency wave are being dealt with, high values of capacitors will be required making it an unattractive option. An extremely efficient method would be to, if possible, bias the inputs in the input in such a way that the dc values at the two differential output stages is the same which will ensure that when we take a differential output, there is no dc bias. To find this ideal input bias value, a small experiment was conducted. A bipolar input was provided to TDA8551 through a capacitor. It was observed that the internal mechanism of TDA8551 introduced a voltage of 2.5V at the input pin and internally biased the bipolar input signal by that voltage (2.5V). The circuit used for this experiment is as shown in Fig 18.

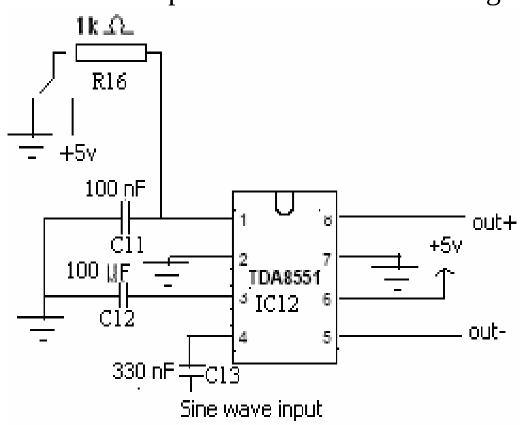


Fig 18. Experimental set up to obtain the ideal bias

Hence a bipolar input, biased by 2.5V should result in no mismatch between the internal bias developed on the wave and input bias and hence the differential output that will be observed will be unbiased. Thus a simple solution to the problem of using TDA8551 for bipolar signals would be to bias the input waveform, which has a peak-to-peak value of less than 2V, by 2.50V and then use it as an input directly to TDA8551. With such a system, the differential output is unbiased and solves the problem of dc offsets.

4.4.2 Post- Conditioning

The TDA8551 produces a differential output. Hence to convert it into a single ended output, a simple opamp difference amplifier has been used [4].The circuit is as shown in Fig 19.

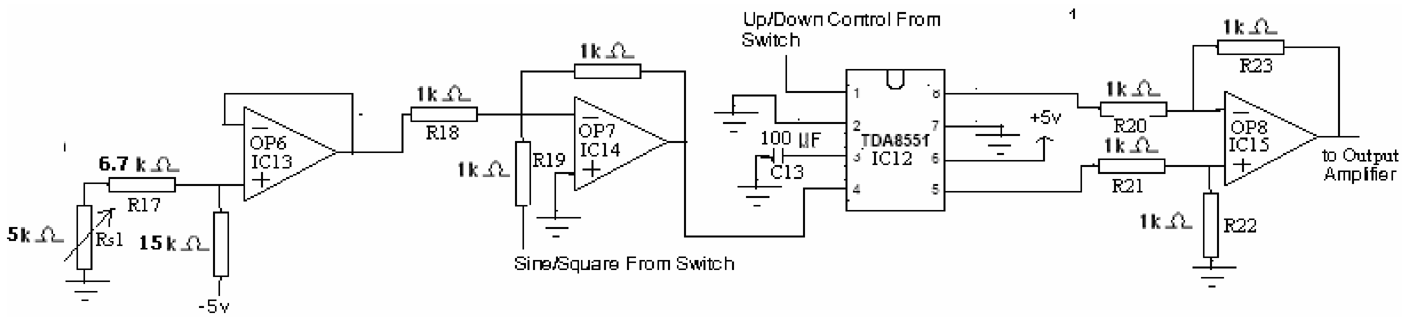


Fig 19. Providing a 2.5V bias and post processing

4.5 Output Amplifier

The external circuit that makes use of the product might need a large current. If the output is provided directly from the buffer, then huge currents can't be drawn. Therefore it is necessary that we provide the output through a current amplifier. A slight voltage gain is also provided so as to obtain the final output between 0.5V and 2V. An output resistance of 50 ohms has been provided to ensure that in spite of any shorts made at the output terminal, some load is still present. The 50 ohms is in the form of four 200 ohms resistors to limit the current through each resistor to prevent them from burning. The circuit of the amplifier is as shown in Fig 20.

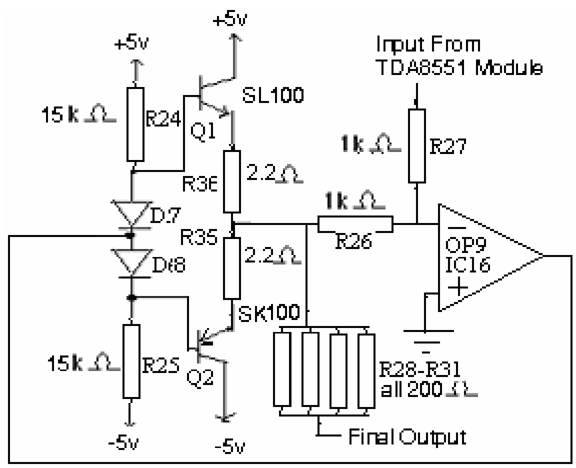


Fig 20 Output Amplifier

The amplifier used is a Class AB amplifier [3]. Class AB amplifiers have almost no cross over distortions which are present in class A and class B amplifiers. Consider the output amplifier shown in Fig 20. As the input voltage goes positive by certain amount, the voltage at the base of transistor Q1 increases by the same amount and the output becomes positive by almost an equal value. For positive output voltages, the load current is supplied by Q1, while Q2 will be conducting a current that decreases as output voltage increases. For negative input voltages, just the opposite occurs. For small input voltages, both the transistors conduct and as the input increases or decreases, one of the two transistors takes over. Since the transition is smooth, the cross-over distortion is eliminated. Initially there was a problem due to excessive heating of the transistors but then the problem was solved by first reducing the bias voltages to the transistors and by providing a resistor in the emitter path. Also the diodes help in thermal stabilization.

4.6 Display Driver

The display unit consists of 3 seven segment displays and 16 LEDs. The micro-controller drives the display unit through the MAXIM7219 [9] which is a serial input common cathode display driver. The bulk of the circuit design is reduced here as it is no longer necessary to have all the LEDs connected directly to the microcontroller port. The MAXIM7219 is capable of driving 8 seven segment displays. MAXIM7219 has been used to drive all the display unit components except for the power LED. The MAXIM7219 is interfaced to the microcontroller through just three connections namely din, load and clock. The basic principle on which the MAXIM7219 works is as follows: Data sent by the microcontroller is loaded into an internal 16 bit register in a serial manner at each rising edge of the clock. Once the load pin goes high, the last received 16 bits are latched and the corresponding output is displayed. Of the 16 bits, the 4 most significant bits are don't cares, while the next 4 bits indicate the address of the register to be changed. The 8 seven segments are given addresses D0-D8 and thus by using the appropriate control word, the desired 7-segment display can be referred to. This driver can also be used for controlling the intensity of the output. It also has an internal decoder which has been used for d0, d1 and d3 for displaying the values of the parameters of the output. 4 bits of d4 have been used to point to the selected menu level, 5 bits of d5 for pointing the output mode and 4 bits of d6 to point to the selected parameter, which can then be modified and whose corresponding value will be displayed through d0, d1 and d2.

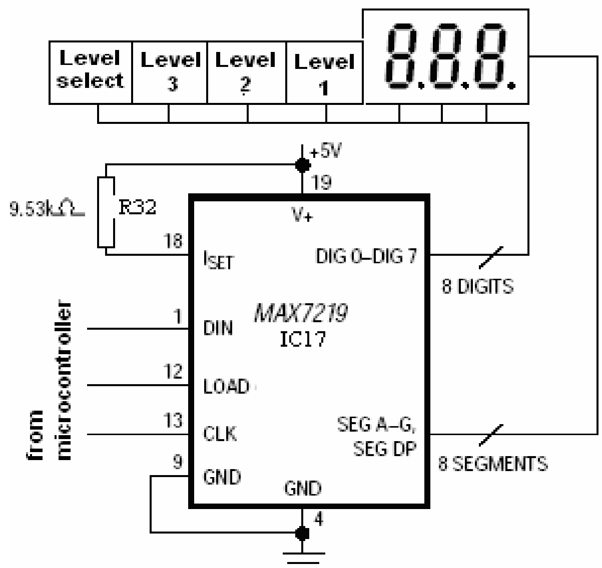


Fig 21: Display Driver circuit

5. DESIGN ON THE PCB

The circuit once tested on the breadboard, was designed onto the PCB using EAGLE4.13. The entire circuit has been divided into three separate boards namely power board, display board and the main board. On the display board, the MAXIM7219 has also been connected to minimize the number of wires interfacing it with the main board. The display board is directly visible to the user with LEDs and seven segment displays on one side of the board and MAXIM7219 on the other side. The other two PCBs have a normal design and involve no complications. On the main board, power supply for digital circuit part, analog part and the amplifier has been separated out. Grid size of 0.05 inch and wires of thickness 0.016 inch have been used. For the supply wires, wires of thickness 0.032 inch have been used. Standard resistances and capacitors were chosen and used.

6. TEST RESULTS AND OBSERVATIONS

6.1 **7805 Voltage Regulator**

The output of 7805 regulator for various inputs has been tabulated in Table 4.

Table 4: Line Regulation

S.No	Input (volts)	Output (volts)
1.	6.00	4.46
2.	7.00	5.00
3.	7.75	5.00
4.	8.50	5.00
5.	10.00	10.00

6.2. Power Supply

Positive output source: 5.01V
Negative output source: -5.02V

6.3 Continuous Wave Output

Observed amplitude levels of sinusoidal and square continuous wave output at 100Hz for various amplitude settings have been tabulated in Table 5.

Table 5: Amplitude Levels at Frequency of 100Hz

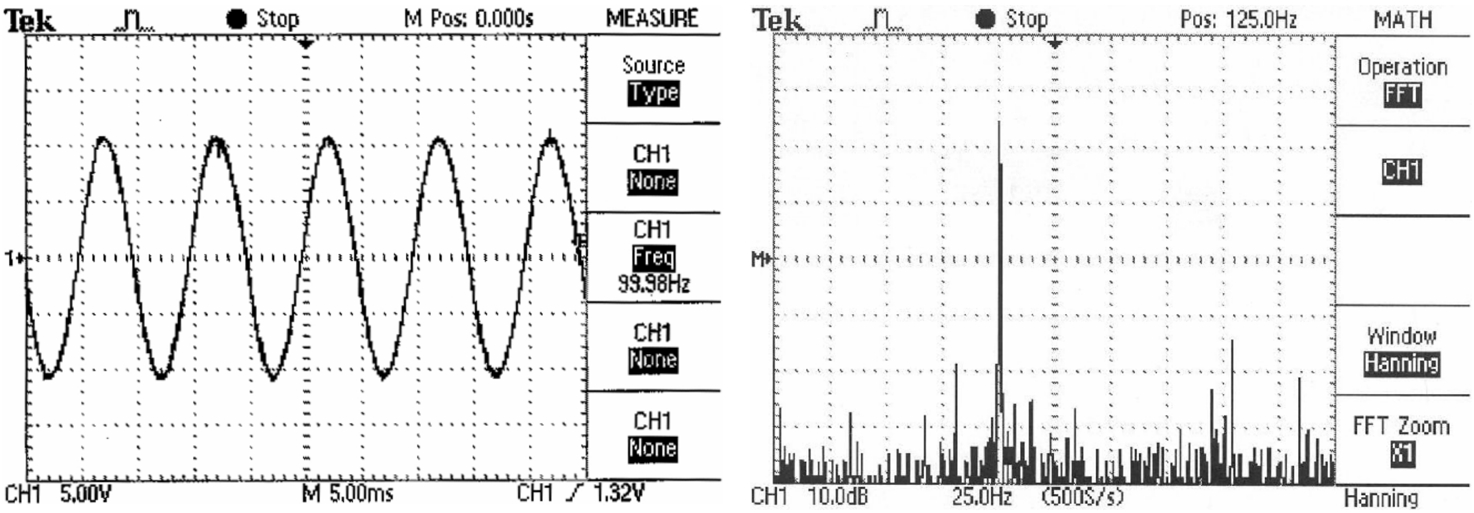
S.No.	Amplitude Level (dB)	Observed Sine Amplitude Level (p-p volts)	Observed Square Amplitude Level (p-p volts)
1.	0.00	0.64	0.64
2.	1.25	0.80	0.80
3.	2.50	0.96	0.92
4.	3.75	1.02	1.00
5.	5.00	1.20	1.20
6.	6.25	1.36	1.32
7.	7.50	1.60	1.60
8.	8.75	1.84	1.84
9.	10.00	2.04	2.00

Observed frequencies of sinusoidal and square continuous wave output at an amplitude level of 10.00dB for various frequency settings have been tabulated in Table 6.

Table 6: Frequency Calibration at Amplitude Level of 10.00dB

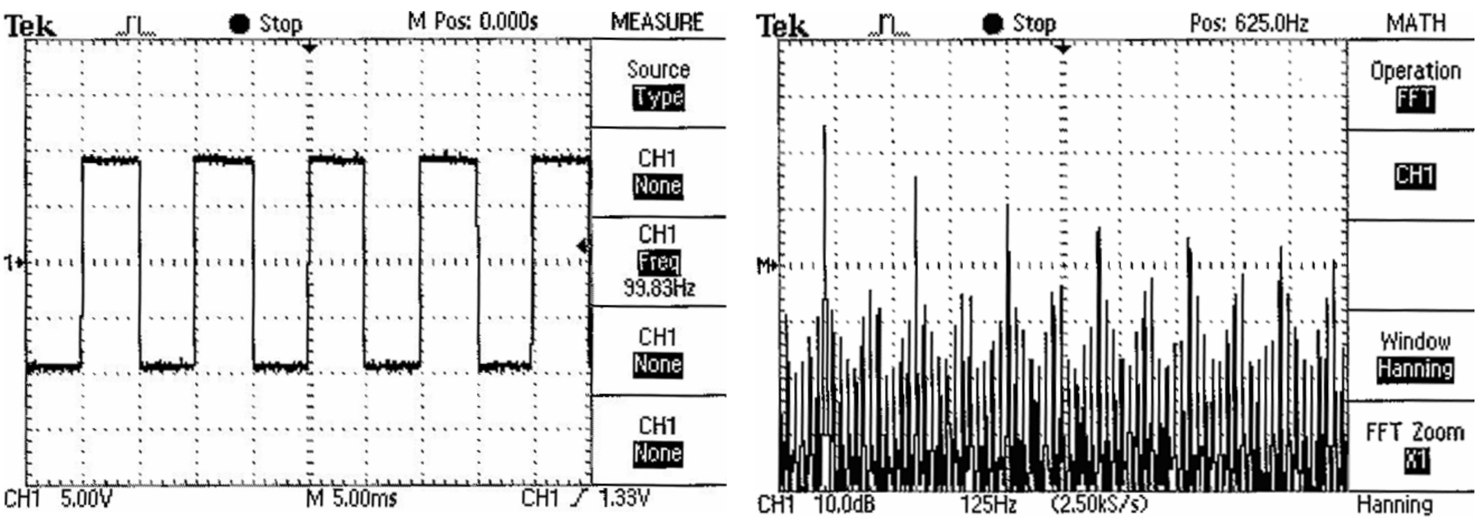
S.No.	Expected Frequency (Hz)	Observed Sine Wave Frequency (Hz)	Observed Square Wave Frequency (Hz)
1.	10.00	9.97	10.04
2.	20.00	20.06	20.14
3.	30.00	29.68	29.75
4.	40.00	40.20	40.12
5.	50.00	49.12	49.33
6.	60.00	59.98	59.92
7.	70.00	69.03	69.13
8.	80.00	79.96	79.92
9.	90.00	89.87	89.97
10.	100.00	99.98	99.83

The time domain output and the spectrum for continuous sinusoidal wave with a frequency of 100Hz and amplitude level of 10.00dB is as shown in Fig 22 and those for continuous square wave at same frequency and amplitude is as shown in Fig 23.



(a) (b)

Fig 22. (a) Time domain output and (b) spectrum for continuous sinusoidal wave with a frequency of 100Hz and amplitude level of 10.00dB



(a) (b)

Fig 23. (a) Time domain output and (b) spectrum for continuous square wave with a frequency of 100Hz and amplitude level of 10.00dB

7. Conclusion

The product developed produces continuous as well as frequency and amplitude modulated sinusoidal and square wave at low frequencies with square and triangular modulating signals. Various parameters of the output can be set digitally using the user interface. The oscillator is based on switched capacitor filter and does not include large inductors and capacitors. The prototype has been duly tested and the results have been satisfactory.

Fig 24. Final Product

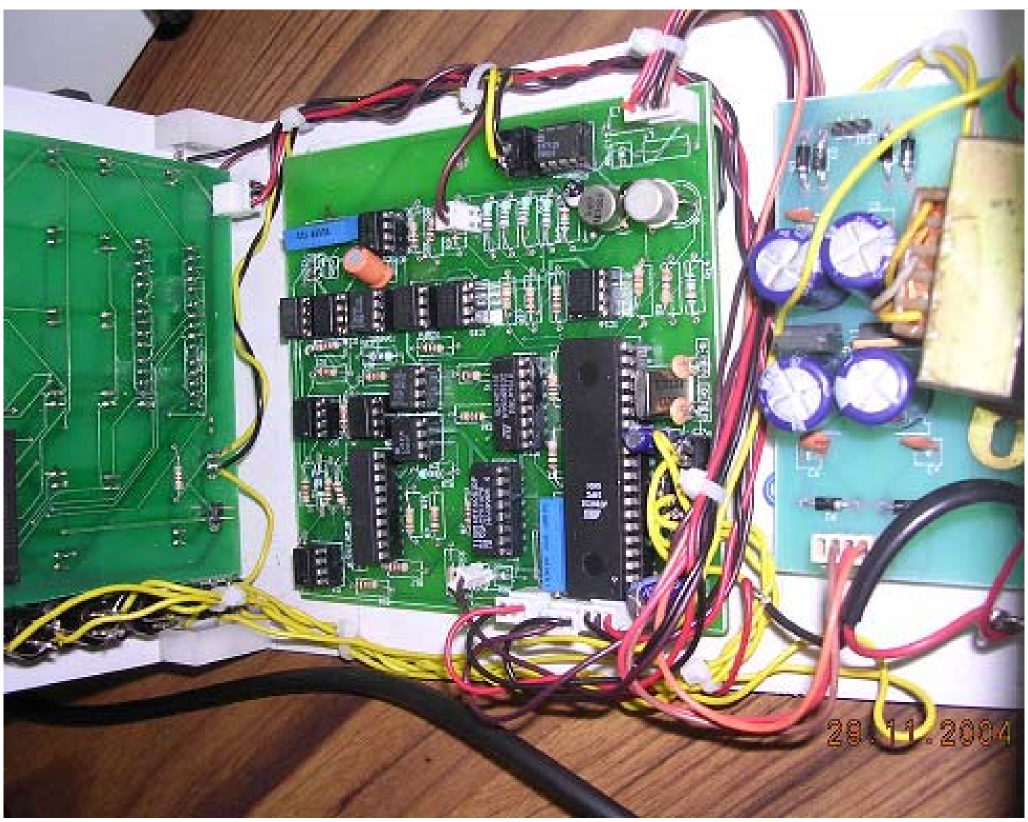


Fig 25. Internal Circuits of the Product

References:

1. M. A. Mazidi and J. G. Mazidi, *The 8051 Microcontroller and Embedded Systems*, Prentice Hall, 1999.

2. K. J. Ayala, *8051 Microcontroller: Architecture, Programming and Applications*, 2nd Ed. Prentice Hall, 1999.

3. A. S. Sedra and K. C. Smith, *Microelectronics Circuits,* 4th Ed. Oxford University Press, 2002.

4. P. Horowitz and W. Hill, *The Art of Electronic,* 2nd Ed. Cambridge University Press, 1989.

5. Swarthmore College, *Switched Capacitor Filters*, http://www.swarthmore.edu/NatSci/echeeve1/Ref/FilterBkgrnd/SwitchedCap.html**,** last visited on Nov 19, 2004.

6. National Semiconductor, *Datasheet of LMF100*, http://www.national.com/pf/LM/LMF100.html**,** last visited on Nov 19, 2004.

7. Atmel Corporation, *Datasheet of AT89C52*, http://www.atmel.com/dyn/products/product_card.asp?family_id=604&family_name=8051+Architecture&part_id=1931, last visited on Nov 19, 2004.

8. Philips Semiconductors, *Datasheet of TDA8551*, http://www.semiconductors.philips.com/pip/TDA8551_N1.html**,** last visited on Nov 19, 2004.

9. Dallas Semiconductors, *Datasheet of MAXIM7219*, http://www.maxim-ic.com/quick_view2.cfm/qv_pk/1339**,** last visited on Nov 19, 2004.

Complete Circuit Diagram