EE389 Electronic Design Lab Project Report, EE Dept, IIT Bombay, November 2006

# Spectrum analyzer for frequency bands of 8-12, 12-16 and 16-20 MHz

**Group No. D-13**

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## Abstract

The objective of our design project is to develop an analog spectrum analyzer to be used in three frequency bands i.e. 8-12, 12-16 and 16-20 MHz. The design is based on several readily available commercial integrated circuits in order to reduce design time. The device is based entirely on analog components, and output will be rendered onto a DSO display. When an unknown sinusoidal frequency signal is given as an input in the given ranges, the circuit can show the spectral components of the input signal on the DSO. The goal is achieved by using a variable frequency generator and then passing it along with the input signal through an analog mixer. The output of mixer is first passed through a low pass filter and then through a rectifier. The resultant signal is given to DSO as the Y axis signal. The Variable voltage used to produce a varying frequency is given as the X axis signal. The liner relation between X and Y signals is used to determine the input frequencies of the unknown signal. The frequency value (+/- 10 kHz) can be observed by calibrating the DSO X axis.

## 1. Introduction and Design Approach

When two sinusoids are multiplied in the time domain, the result is a frequency shift in the frequency domain.

$$e^{j\omega_0 t} f(t) \rightleftharpoons F(\omega - \omega_0) \quad \textbf{(1)}$$

If the two sinusoids are of the same frequency, then the result in the frequency domain is a 0 Hz D.C. value. Our spectrum analyzer assumes that the input signal is a sum of sinusoids and therefore, has multiple frequencies. By multiplying the input signal by a sinusoid of varying frequency, D.C. signals are created when the varying sinusoid is of the same frequency as one of the input signal's frequencies.

To create the varying sinusoid, a variable sweep generator and a voltage controlled oscillator were used. The variable sweep generator outputs a voltage that repeatedly increases between two voltages over a time period. The result is a saw-tooth waveform. This is then the input for the voltage controlled oscillator. As the input voltage increases, the sinusoidal output of the VCO increases in frequency. We now have a varying sinusoid.

The varying sinusoid and the signal that will be analyzed are then multiplied by an analog multiplier. A fourth order Butterworth filter was then used to filter out the resulting DC signals. The resolution bandwidth of the filter is related to the sweep time and the desired frequency range. Some of the theoretical spectrum's detail is inevitably lost due to the finite frequency width of the filter. As the resolution filter gets narrower, the ideal and actual spectral representations of the input signal begin to match, until the filter is of zero bandwidth and in effect is an impulse form. The transformation of the ideal spectrum into the displayed representation is simply a convolution. If too narrow a pass band is chosen for the filter, the output spectrum will be distorted because the sweeping signal does not stay at a specific frequency long enough for the filter to accurately discern the signal shape. A solution is to simply increase the sweep time until an undistorted spectrum is achieved, but this is not truly a viable solution. Spectrum analyzer theory [1] gives an equation for the optimum resolution filter bandwidth. Given a sweep time ***T***, and frequency span ***S***, the filter bandwidth is

$$B_0 = \sqrt{\frac{1}{2.27}\frac{S}{T}} \tag{2}$$

Given a span from 8 MHz to 20 MHz, and a sweep time of 1/3 s, the resolution bandwidth for the spectrum analyzer is calculated to be approximately 3.25 kHz. The filter output is passed through an amplifier and then a rectifier circuit. The performance specification aimed for are as follows.

| | |
|---|---|
| Resolution Bandwidth | +/- 10 kHz |
| Frequency Range | 8 MHz to 20 MHz |
| Sweep Time | 0.33 s full span |
| Maximum safe input voltage | +/- 1 V |
| Operating voltage | +/- 5 V DC |

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## 2. Block Diagram

The spectrum analyzer consists of 5 major components: the sweep generator, voltage controlled sinusoidal oscillator, analog multiplier/mixer, low pass filter and rectifier. The sweep generator generates the saw-tooth waveform for the DSO display, and drives the sinusoidal VCO across the desired frequency spectrum. The VCO output is multiplied with the input signal, and the result is filtered ideally for its DC component. In actuality, the selectivity of the resolution filter is chosen based on the desired sweep time and frequency scan range. The signal is then passed through a rectifier and then a peak detector, and then to a simple non-inverting amplifier to scale the output appropriately for the DSO. The block diagram is included below.

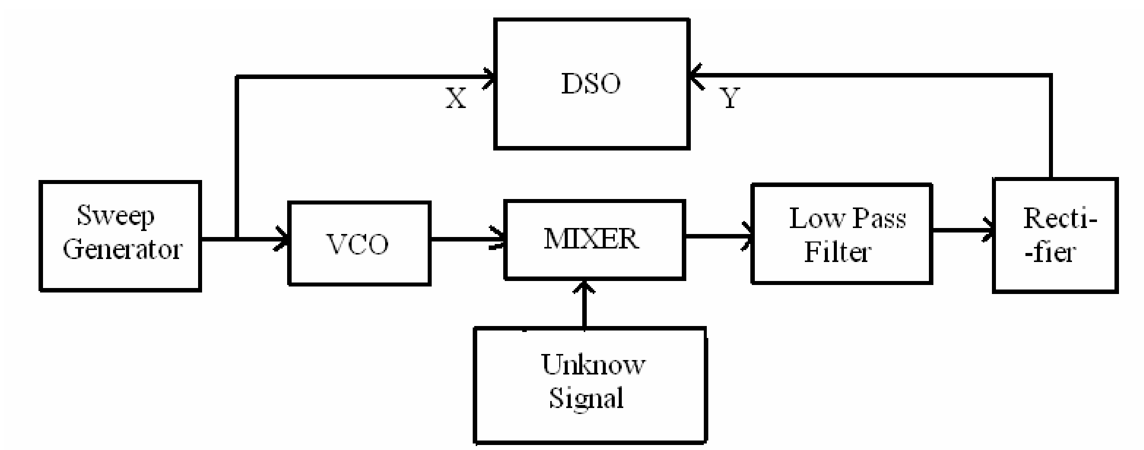


Fig. 1 Functional Block Diagram of Spectrum Analyzer

## 3. Circuit Design

**3.1 Sweep Generator:** The sweep generator is based on the MAX038 function generator IC configured to produce a 10% duty cycle triangle wave. The DSO X-axis voltage output required is a 2.68V to 6.68V signal. Ceramic bypass capacitors valued at 0.47 µF stabilize the supply voltage, and are placed in close proximity to the IC for maximum effect. Given a desired sweep time of 1/3 second, a frequency of 3Hz is set by choosing a suitable large 22 µF for *C10* appropriate for the low frequency. The appropriate *R1* is then calculated by the relationship

$$f_0(MHz) = \frac{I_{IN}(\mu A)}{C_f(pF)} \quad \textbf{(3)}$$

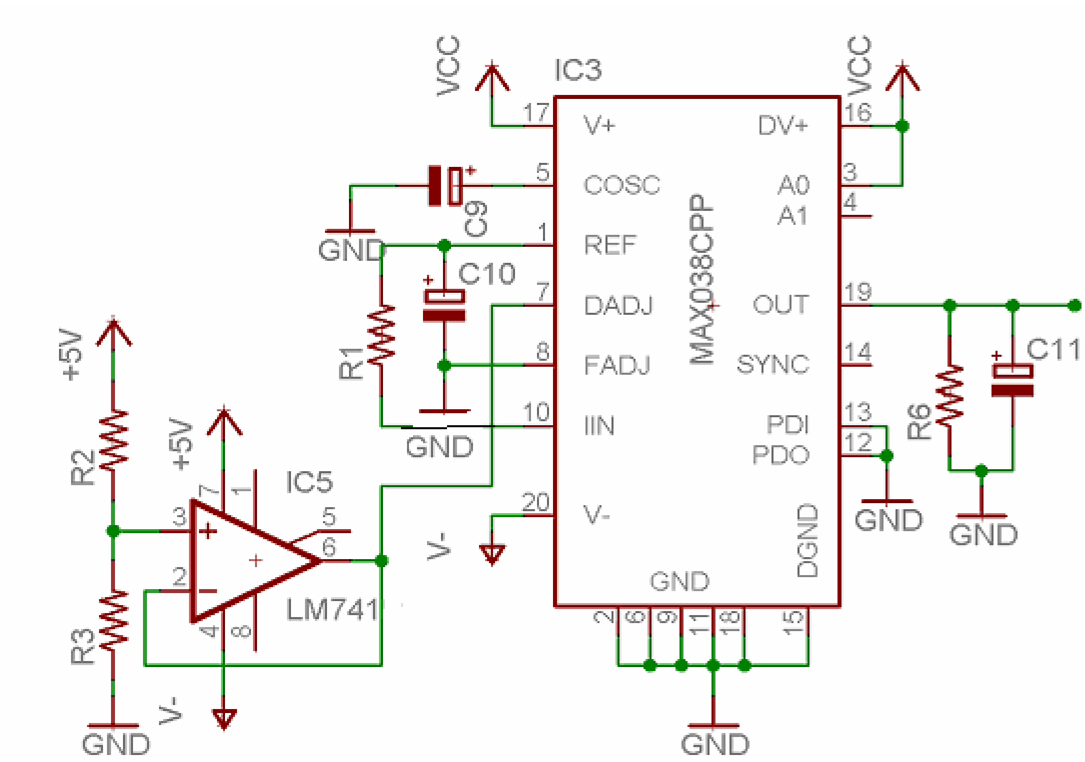


Fig.2 Circuit Diagram for 4V p-p sweep generator

Opamp *IC5* in conjunction with resistors *R2* and *R3* establish a stable reference voltage of 2.29 V on the DADJ pin of the *IC3* (MAX038) to set the duty cycle at approximately 10%. The 2.50 V reference voltage is used to establish a stable bias current through *R1* into IIN to set the frequency in conjunction with *C10*.

This gives an approximate value of 100 K for *R1*. Having set the sweep frequency, the function generator is configured with pins A0 and A1 to produce a triangular wave. Since the MAX038 output is defined as 2V p-p, a non-inverting gain of 2 is obtained with *IC13*, *R22*, and *R23*. The expected 100Ω load is simulated with *R22*, and is necessary since ideally no current flows into the Opamp *IC13*. Initial testing of the sweep circuitry showed high frequency glitches at the zero volts crossing on the output ramp from the *IC3*. The glitch was minimized by simply adding a 0.47 µF capacitor *C5* in parallel with the 100Ω load resistor to filter out the zero-crossing noise.

The output should be 2 V p-p signal but we get a -1 to 0V signal. Now, using a sweep amplifier circuit, a gain of 4 is given to the signal so that it reaches -4 to 0V signal. And then additional 6.6V is added using a voltage adder circuit so that we get the desired sweep signal.

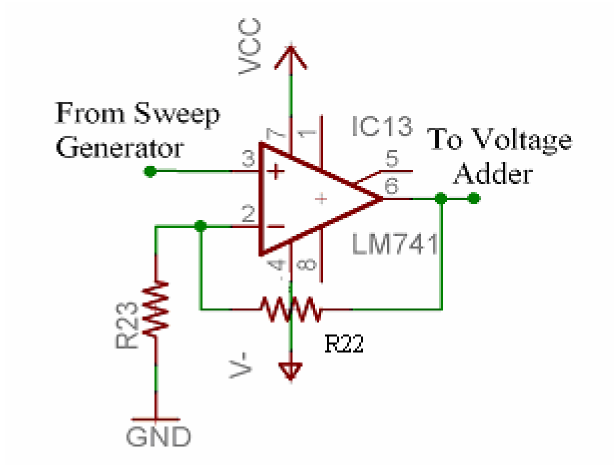


Fig.3 Sweep Amplifier

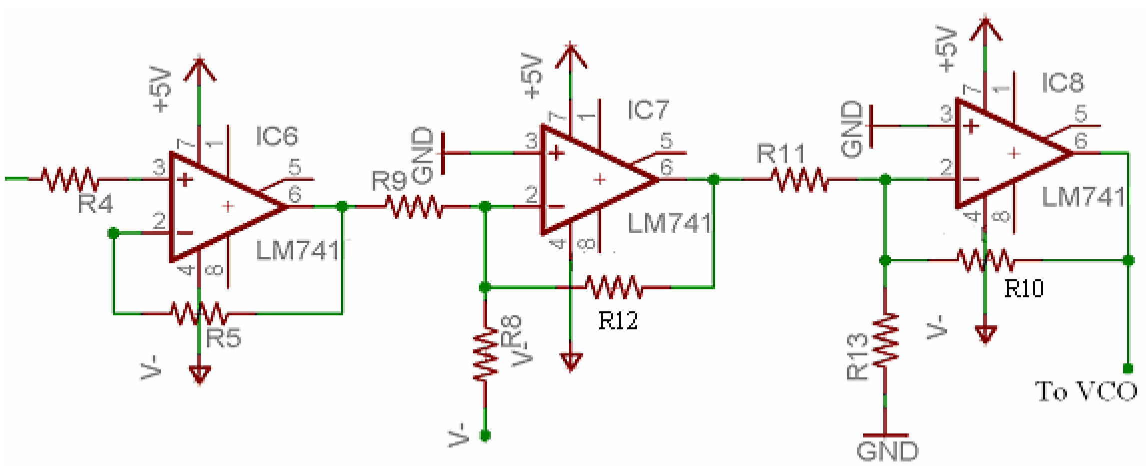


Fig. 4 Voltage adder for sweep

The resulting waveform is

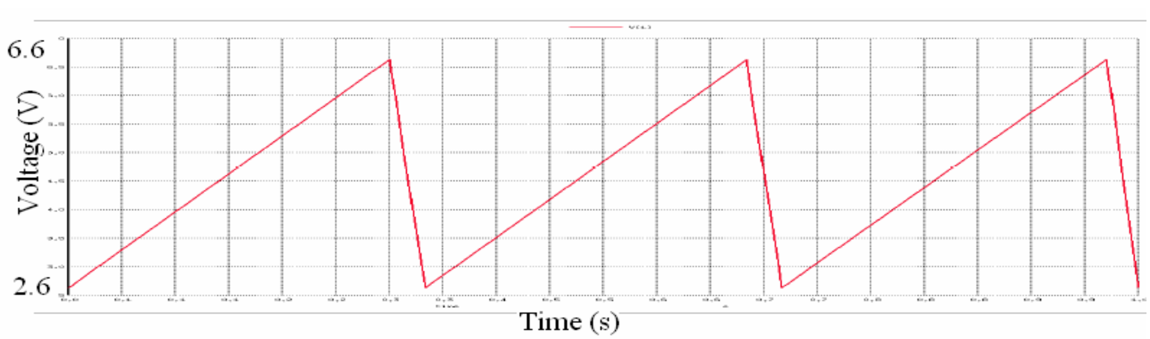


Fig. 5 Sweep Generator Block Output

**3.2 Voltage Controlled Oscillator:** The voltage controlled oscillator (VCO) generates a sinusoidal signal whose frequency is proportional to the input voltage. The input is a 2.68 to 6.68V ramp from the sweep generator, and the output is a 2 V p-p sinusoid varying from approximately 8 MHz to slightly above 19 MHz. . To save time in the lab, the duty cycle circuit was not actually built, and the DADJ pin was simply grounded. According to the MAX038 datasheet, 1-2% deviation form 50% is thus to be expected. The schematic is included below.

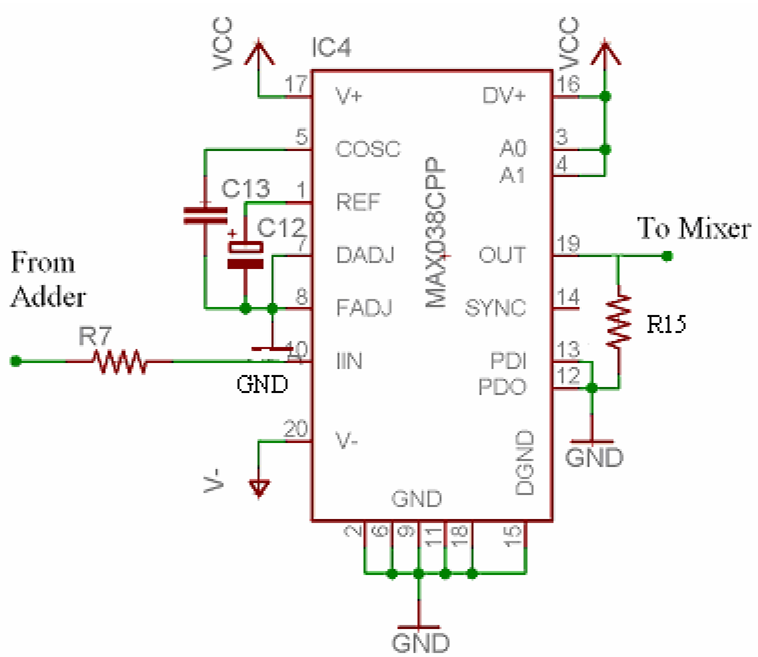


Fig.6 Voltage Controlled Oscillator (VCO) using MAX038

This voltage across *R7* establishes the frequency control bias current into $I_{IN}$. The oscillation frequency of the VCO is configured by $I_{IN}$ and *C13* as before in the sweep circuit. In the laboratory, *C13* was chosen to be 33 pF from the available capacitors. Given the ramp minimum at 4.56-4.16 = 0.4 V, 10 KΩ for *R7*, and 33 pF, the low frequency of 8 MHz. Likewise the maximum VCO frequency is calculated to be 19.07 MHz. These calculations indicate the frequency range detected by the spectrum analyzer. We may note that due the continually sweeping frequency, the oscilloscope does not properly trigger. The input for the multiplier circuit is taken directly from the pin 19 of *IC4.*

The test measurements taken by manually applying DC voltage instead of ramp show a linear correspondence between voltage applied to the IIN terminal and the output frequency of the VCO.

| Voltage (V) | Frequency (MHz) |
|---|---|
| 2.5 | 7.86 |
| 2.6 | 7.95 |
| 2.63 | 8 |
| 3 | 9.32 |
| 3.5 | 10.61 |
| 4 | 13 |
| 4.5 | 13.61 |
| 5 | 15.33 |
| 5.5 | 16.61 |
| 6 | 19 |
| 6.5 | 19.61 |
| 6.63 | 20 |

Table 1 VCO output characteristics

The measurements results in a graph which is very close to linear.

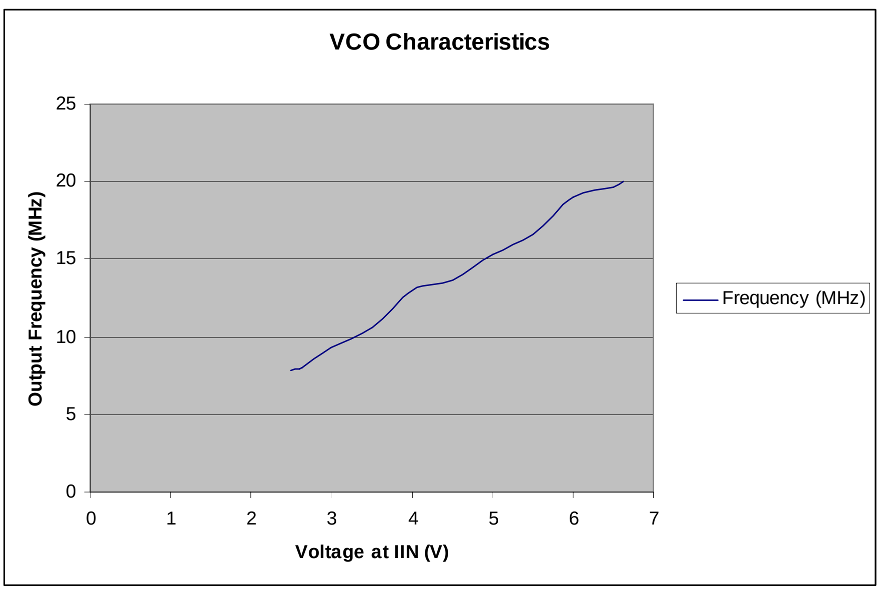


Fig. 7 VCO Output Characteristics

**3.3 Multiplier:** The multiplier was constructed using an AD835 chip with the following connection diagram:

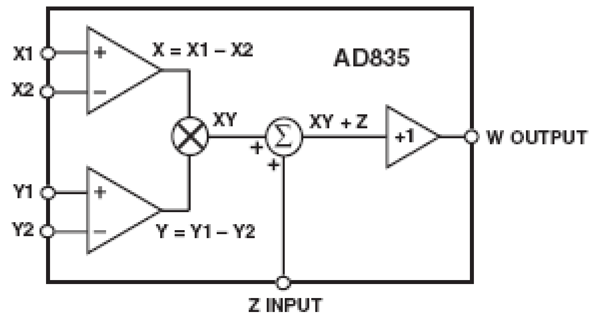


Fig .8 Functional Block Diagram of AD835

In general terms, the AD835 provides the function

$$W = \frac{(X1 - X2)(Y1 - Y2)}{U} + Z \qquad (4)$$

where the variables *W, U, X, Y, and Z* are all voltages. Connected as a simple multiplier, with *X* = *X1* – *X2*, *Y* = *Y1* – *Y2*, and *Z* = 0 and with a scale factor adjustment (Figure 8), which sets *U* = 1 V, the output can be expressed as

$$W = XY \qquad (5)$$

Now, in our case, we simply ground *X2, Y2* and *Z. X1* is our VCO output and *Y1* is the unknown frequency signal. W is the output of the Multiplier which goes to the resolution filter.

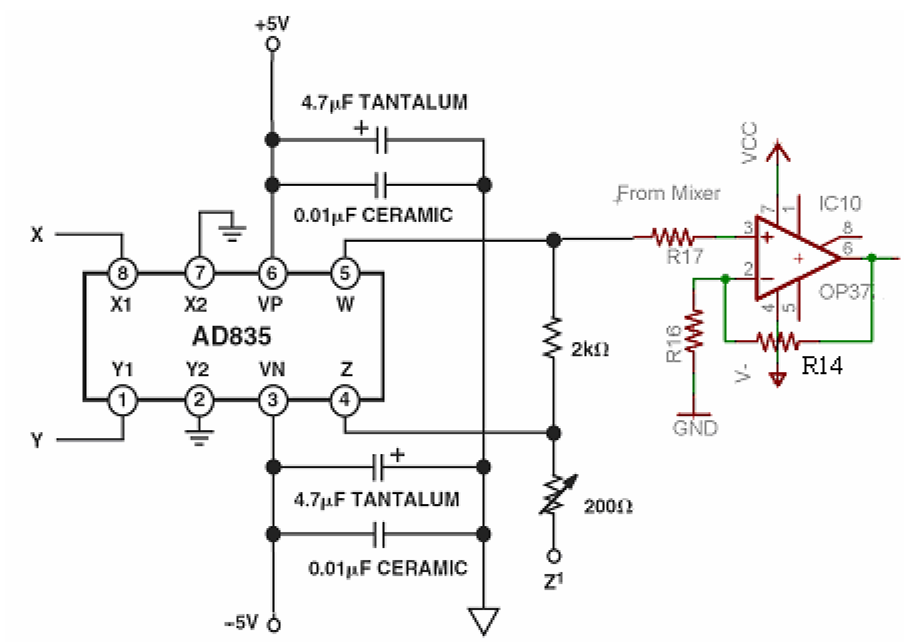


Fig. 9 Multiplier connections

**3.4 Resolution Filter:** The fourth order low pass Butterworth filter was designed by cascading two second order sections using an LM741 op amp of the following design:

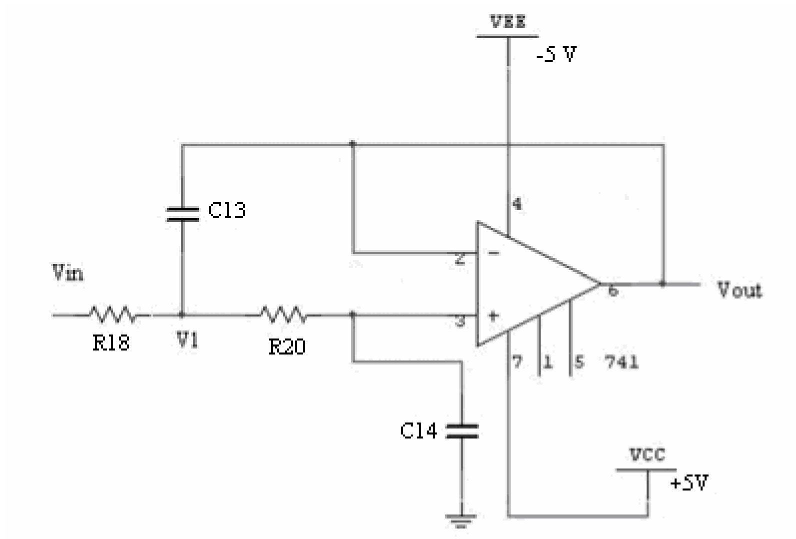


Fig. 10 Second Order Butterworth Filter

For a cutoff frequency at 4.8 KHz, $\omega_o = 2\pi*4.8*1000$. Setting *R18* = *R20* =1 KΩ,

*C13***C14*=$1.099*10^{-15}$.

Cascading the two second order filters, we have

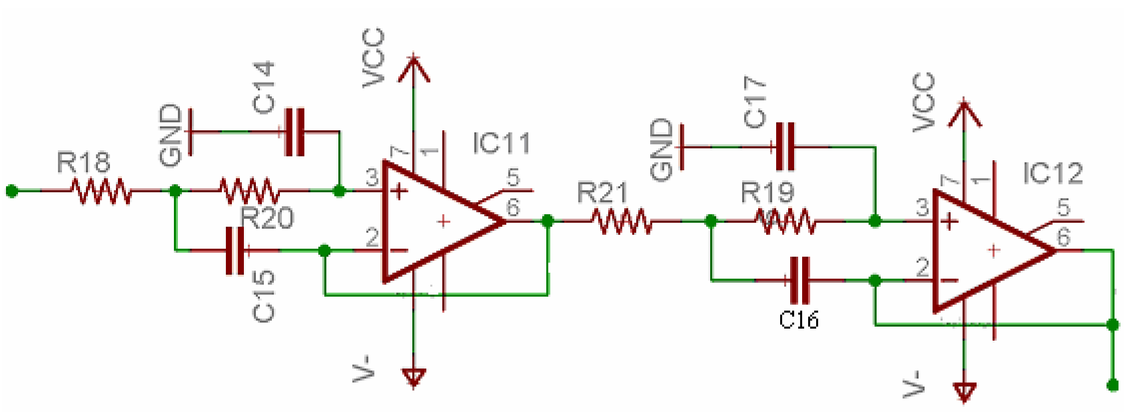


Fig. 11 Fourth Order Butterworth Filter

According to the Butterworth Low Pass Filter table, for a fourth order filter the two values for *Q* are .541 and 1.306. Knowing Q, we can solve for the ratio of *C13* to *C14* and *C16* to *C17*.

With all resistors = 1 KΩ and multiple of the capacitors for each cascade equal to $1.099*10^{-15}$, we can solve for $C_{1}$, $C_{2}$, $C_{3}$, & $C_{4}$. For $Q$ = .541, *C13* = 35.88 nF and *C14*= 30.64 nF. For $Q$ = 1.306, *C16*= 86.61 nF and *C17*= 12.69 nF. Using the capacitors available in lab

*C13* = 33 nF, $C15_{4}$= 33 nF, *C16* = 86 nF and *C17* = 10 nF.

The output characteristics of the filter are plotted below:

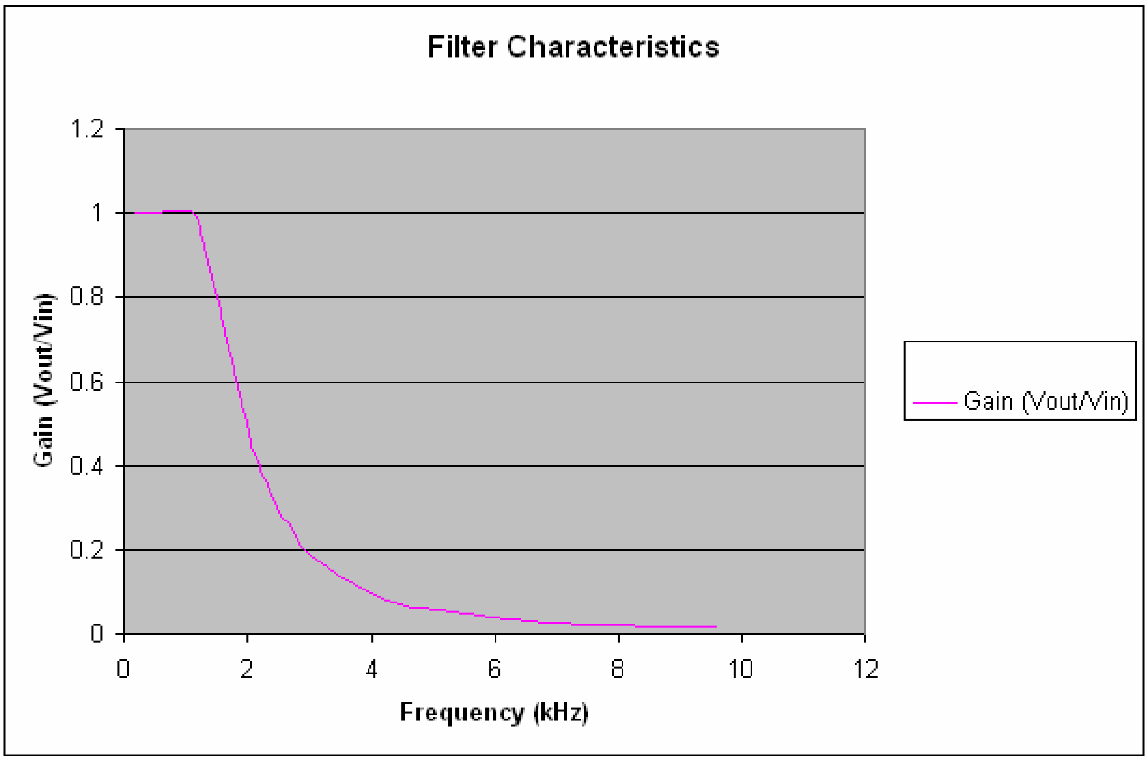


Fig. 12 Filter Characteristics

**3.5 Output Rectifier and Peak Detector:** The output rectifier and amplifier circuit takes the absolute value of the output of the resolution filter since only the magnitude of the signal is desired on the spectrum display. The circuit is preceded by a non-inverting amplifier with a gain of 11, whose output is rectified by the standard absolute value circuit. In the schematic shown below, the combination of *IC14* and *IC15* form the rectifier.

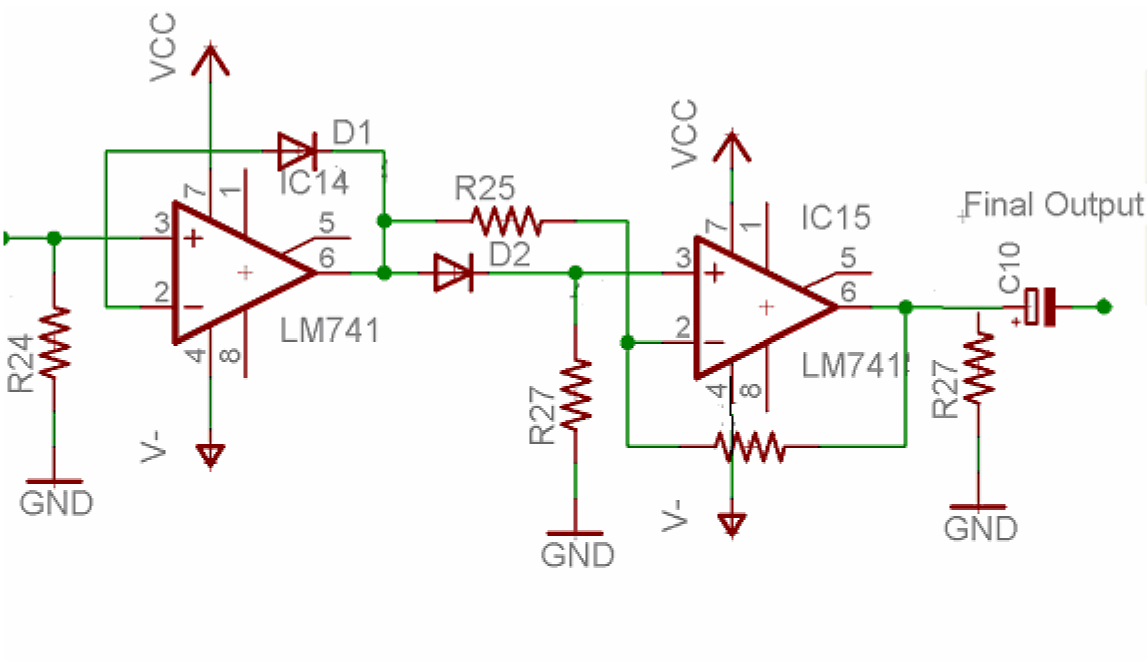


Fig. 13 Output Rectifier and Peak Detector

Since we are interested only in the peak of our output, a peak detector is added after the rectifier which consists of a simple RC low pass filter. Another advantage of peak detector is that it averages the output sinusoidal signal of rectifier which helps to make the Y axis signal of the DSO more persistent and visible.

**3.6 Regulated Power Supply:** To achieve a very clean +/- 5 V power supply, the internal breadboard supply was configured for approximately +/- 7 V, and then trimmed to +/- 5V by the straightforward circuit shown below.

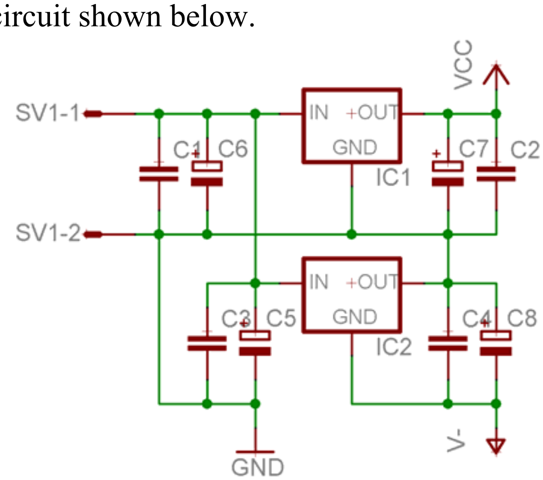


Fig. 14 Regulated Power Supply

Bypass capacitors *C3* and *C6* are chosen to be ceramic disc types, and the remaining *C1, C2, C4,* and *C5* are electrolytic to give the capability of large current drains.

## 5. Components and Description

**5.1. MAX038:** The MAX038 is a high-frequency, precision function generator producing accurate, high-frequency triangle, sawtooth, sine, square, and pulse waveforms with a minimum of external components. The output frequency can be controlled over a frequency range of 0.1Hz to 20MHz by an internal 2.5V bandgap voltage reference and an external resistor and capacitor. The duty cycle can be varied over a wide range by applying a ±2.3V control signal, facilitating pulse-width modulation and the generation of sawtooth waveforms. Frequency modulation and frequency sweeping are achieved in the same way. The duty cycle and frequency controls are independent.

ABSOLUTE MAXIMUM RATINGS

| | |
|---|---|
| V+ to GND | -0.3V to +6V |
| DV+ to DGND | -0.3V to +6V |
| V- to GND | +0.3V to -6V |

| | |
|---|---|
| Pin Voltages | |
| IIN, FADJ, DADJ, PDO | (V- - 0.3V) to (V+ + 0.3V) |
| COSC | +0.3V to VA0, |
| A1, PDI, SYNC, REF | -0.3V to V+ |
| GND to DGND | .±0.3V |
| Maximum Current into Any Pin | ±50mA |
| OUT, REF Short-Circuit Duration to GND, V+, V- | 30s |

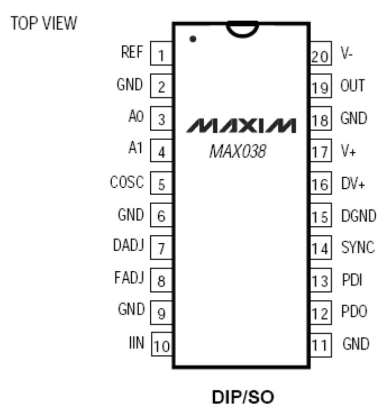


Fig. 15 Pin Diagram of MAX038

**5.2. AD835:** The AD835 is a complete four-quadrant voltage output analog multiplier. It generates the linear product of its X and Y voltage inputs with a –3 dB output bandwidth of 250 MHz (a small signal rise time of 1 ns). Full scale (–1 V to +1 V) rise to fall times are 2.5 ns (with the standard $R_L$ of 150 Ω), and the settling time to 0.1% under the same conditions is typically 20 ns. Basic Function is W = XY + Z.

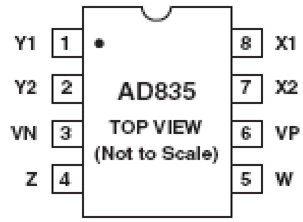


Fig. 16 Pin Diagram of AD835

ABSOLUTE MAXIMUM RATINGS

| | |
|---|---|
| Supply Voltage | ±6 V |
| Internal Power Dissipation | 300 mW |
| Operating Temperature Range | –40°C to +85°C |

**5.3. LM741:** The LM741 is general purpose operational amplifier.

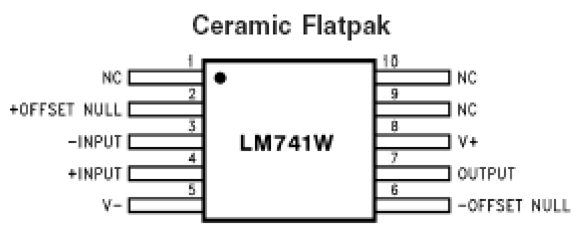


Fig. 17 Pin Diagram for LM741 OPAMP

**5.4. OP37:** The OP37 is High Frequency OPAMP with a gain bandwidth product of 63 MHz.

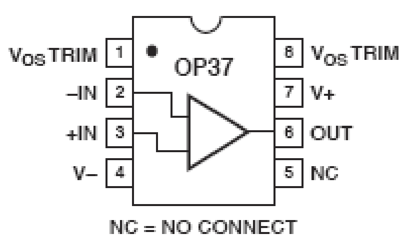


Fig. 18 Pin Diagram for OP37 OPAMP

## 6. Results

The separate blocks are working properly and the results have already been included in respective sections.

With all functional blocks integrated, we are getting a result on DSO screen in which the motion of peak is seen when the input signal's frequency is varied, but the output is not persistent. The Y axis output disappears for alternate sweeps. Possible reasons can be the use of sawtooth instead of triangular sweep, noise coming in signal due to improper ground, the stray capacitance added to the circuit due to use of breadboard rather than PCB. For removing the above problems, we are making a PCB for the circuit, making triangular sweep and reducing the frequency range of the VCO output by decreasing sweep voltage accordingly.

## 7. Further Scope

Most of the commercially available spectrum analyzers are in frequency range 100 kHz to 6 MHz and cost more than $30,000. Our model uses cheaper components and can be made with an effective cost of less than $100. So, for the lab use purposes, it can be used along with CRO/DSO as a replacement of costly spectrum analyzers. The MAX038 can be replaced with another VCO IC having high frequency range so as to extend the frequency range of the analyzer or we can have different frequency bands in the same device. The CRO/DSO output can be carefully calibrated to give accurate readings so that we can know the relative magnitude of a component in the signal along with the frequency.

## References

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