# DEVELOPMENT OF AN AGILENT VOLTAGE SOURCE FOR ELECTRICAL IMPEDANCE TOMOGRAPHY APPLICATIONS

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## ABSTRACT

The desirable features of any voltage source used for electrical impedance tomography applications are: accurate shape of the sinusoidal waveform, constant amplitude of the signal and low output impedance throughout a wide frequency bandwidth. AD9850 synthesizes a pure, programmable sinusoidal waveform up to 5 MHz. The spectrum analyses provides the proof of a stable frequency agile voltage source around 14 dBm for electrical impedance tomography applications and beyond the beta dispersion range at 10 dB attenuation.

**Keywords:** electrical impedance tomography, operating frequency, voltage controlled oscillator, AD9850, spectrum analyser.

## INTRODUCTION

Electrical Tomography (ET) is a new imaging technique well known for its portability, safety, inexpensiveness and non-invasiveness. This technique has been used in geological, engineering and medical applications. In applications where the resistance provides the tomographic information, the ET systems are called electrical resistance tomography (ERT). Examples of ERT include geological applications. In other applications, the reactive component in the form of capacitance provides the tomographic information and such systems are called electrical capacitance tomography (ECT). Examples of ECT include industrial applications. Finally, tomography applied for biological studies is called electrical impedance tomography (EIT). Examples include medical applications like, monitoring of lung function, heart function and study of breast cancer to name a few [1].

Most of the ET systems use an alternating voltage excitation source for the intended study. The output signal of a voltage source must be highly stable as it contributes towards the spatial accuracy of the reconstructed tomographic images. Hence a proper design of the voltage source is required in order to provide an accurate, constant and noise free signal over a wide range of frequency. In addition, it should be portable and economical.

## LITERATURE REVIEW

This section is divided into two parts, the first part discusses on the operating frequency of the above systems and the second part highlights on the voltage controlled oscillator circuits studied by other researchers. The study is mostly related to the EIT systems used for medical applications.

### a) Optimum frequency for EIT applications

The resolution of the reconstructed images of the EIT systems depends on the operating frequencies [2]. In general, the EIT systems can be either multi-frequency based systems or single frequency based systems. A good review on the problems faced by the multi-frequency system is found in [3] which describes that the unwanted stray capacitances and the common mode voltages are the two major sources of the errors in these systems.

For single frequency ET systems, the operating frequencies range from as low as 125 Hz for the diagnosis of the brain to as high as 10 MHz for geological applications.

The optimum frequency range for electrical impedance tomography is from 10 KHz to 100 KHz. For this range of frequencies, the EIT systems overcome the electromagnetic compatibility (EMC) between the EIT system and the test object [2]. In general, the single frequency systems can be classified under three different categories for EIT systems [4]. These are (a) alpha dispersion, where the currents cannot penetrate the cell membrane and the impedance information is related to the outside environment of the cell. This frequency ranges from 10 Hz to 10 KHz. (b) beta dispersion, where the current is capable of penetrating the cell membranes and hence the impedance measurements reflect the inside environment of the cell. The frequencies from 10 KHz up to 10 MHz fall under this category. (c) gamma dispersion, where the currents at a frequency of 10 MHz to 10 GHz can cause a change in the behavior of the cells.

Also the selection of a particular operating frequency depends on the resistivity of the various tissues. The cells or tissues show a purely resistive nature in the beta dispersion range and further the best resolution can be observed for the frequencies less than 100 KHz [2] along with less measurement voltage distortions [5]. Any lower frequencies can cause electrolysis of the cells while higher frequencies cause skin burning problems [6].

### b) Voltage controlled oscillator (VCO) circuits

In general, the ET systems work on the input current(s) derived from the VCO circuits with the output voltages being measured. This is mainly to overcome the contact impedance errors [7]. Mostly, the EIT systems use a sinusoidal signal as a source of excitation. The sinusoidal waveform can be generated by any commercially available function generator or by using a voltage controlled oscillator (VCO) circuit. The former is bulky and at the same time is expensive while the latter can be designed out of inexpensive discrete components using either analog components or digital ICs. In either way, the desired features of any function generator are: accurate shape of the sinusoidal waveform, constant amplitude of the signal throughout the frequency range, low output impedance and a wide bandwidth. Some of the VCO circuits found in the literature are discussed below.

A VCO circuit based on phased lock loops (PLL) was developed by [8] generating up to 4 MHz frequency. A crystal oscillator inputs a stable reference frequency $f_n$ to a phase detector (PD). This is then given to a low-pass filter (LPF) followed by a voltage-controlled-oscillator (VCO) as shown in Figure-1.

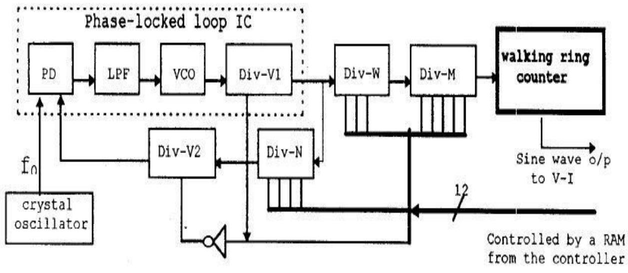


**Figure-1.** PLL based VCO circuit [8].

MAX038 IC was used as the VCO circuit [9]. This IC provides a sine wave signal up to 10 MHz frequency with few discrete components. The frequency of oscillation is given by equation (1). The IC requires only +5V for its operation.

$$f = \frac{2 \times 2.5V}{RIN.CF} \tag{1}$$

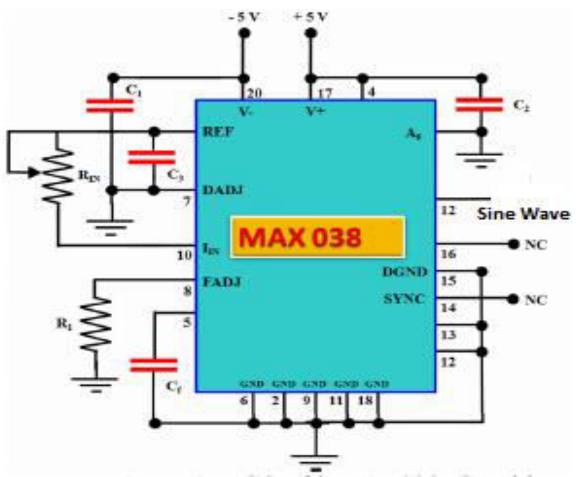


**Figure-2.** MAX038 as a VCO circuit [9].

XR2206 was used to build a VCO circuit and was comparatively less expensive than the MAX038 IC [10]. The operating frequency is given by equation (2).

$$f = \frac{1}{2\pi.R.C} \tag{2}$$

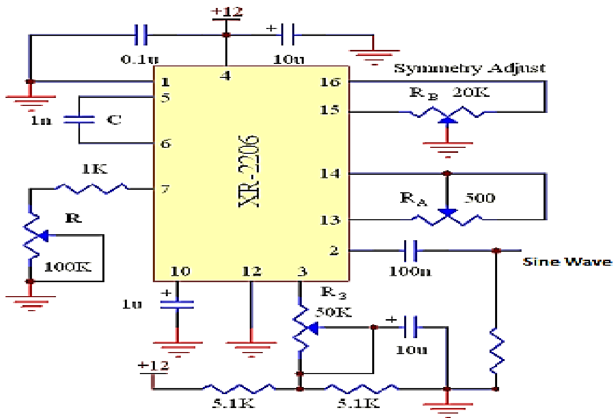


**Figure-3.** XR2206 as a VCO circuit [10].

IC741 was configured as Wien bridge oscillator circuit for an electrical resistance tomography (ERT) system [11]. The frequency of the sine wave is given by equation (3).

$$f = \frac{1}{2\pi\sqrt{R1R2C1C2}} \tag{3}$$

The maximum frequency obtained from this design was 18 KHz with a voltage of 17.2 V (Peak-to-Peak). The maximum operating voltage being ±15 V.

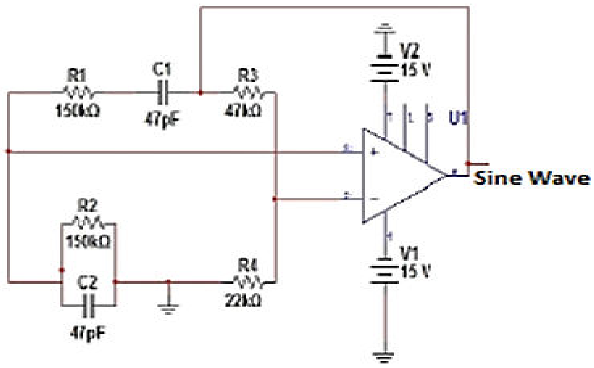


**Figure-4.** Wien Bridge oscillator as a VCO circuit [11].

ICL 8038 was used as a sine wave generator for EIT applications [12]. It operates over a range from 0.001Hz up to 1MHz. The good features of this IC include low distortion, high level outputs, high linearity and a variable duty cycle. It is a precise voltage controlled oscillator. As shown in Figure-5, the pins 4 and 5 are connected together to get 50 percentage duty cycle of the sinusoidal wave. The frequency of oscillation, f is given by the equation (4).

$$f = \frac{0.15}{RaC1} \tag{4}$$

The maximum operating voltage of this circuit is ±15V and the polarities must always be equal in magnitude [13]. The resistors R1 and R2 can be adjusted for obtaining the symmetry of the sine wave. An output voltage of 3Vpp is obtained if a well regulated power source is ensured.

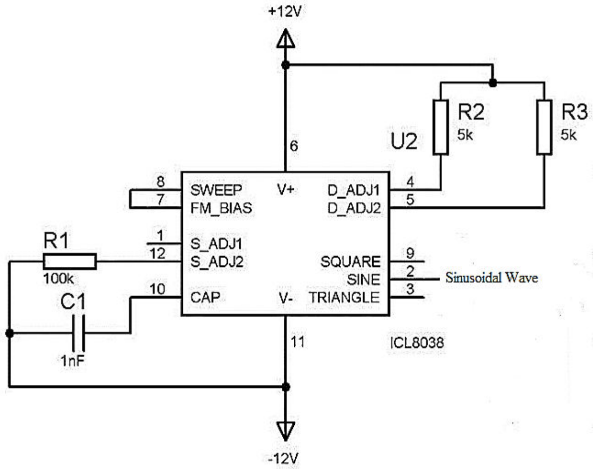


**Figure-5.** ICL8038 as a VCO circuit [12].

Recently, a direct digital synthesizer (DDS) circuit using AD9837 was used to generate a sine wave of 600 $mV_{PP}$ up to 1 MHz [14]. Also a sinusoidal waveform with an amplitude range of 11.28 mVpp to 10 Vpp with frequency range up to 40 MHz was generated using signal generation module from National Instruments (NI 5406) for the EIT studies [15]. The literature work on the VCO circuits is summarized in Table-1.

**Table-1.** Comparison table of the VCO circuits.

| No | Method | $V_{PP}$ | Hz | Comment(s) | Ref |
|---|---|---|---|---|---|
| 1 | PLL | * | 4M | Difficult to generate higher frequencies | [8] |
| 2 | MAX038 | 1 | 50K | Inconsistent sinusoidal waveform | [9] |
| 3 | XR2206 | * | * | Inconsistent sinusoidal waveform | [10] |
| 4 | LM741 | 17 | 18K | Limited frequency bandwidth | [11] |
| 5 | ICL 8038 | 3 | 300K | Requires precise resistor adjustment | [12] |
| 6 | NI 5406 | 10 | 40M | Expensive | [15] |
| 7 | Proposed Study* | 1 | 5M | ———— | —— |

*Not available

## PROPOSED METHOD

AD9850 is a high level integrated circuit device based on the advanced DDS technology. It generates a spectrally pure sinusoidal waveform from as low as 0.0291 Hz to as high as 125 MHz. The generated frequency can be digitally tuned and controlled programmatically. Arduino Uno microcontroller is used as a microcontroller for generating the clock. An LCD 16x2 is used to display the output frequency. The advanced CMOS technology enables AD9850 to operate on +5V power supply with a power dissipation of 380 mW only and withstanding a temperature up to +85°C. It generates a steady sinusoidal waveform of 1 VPP.

### a) Hardware set up

To generate various frequencies, the Arduino UNO is used to supply clock to AD9850. The sequence of the program is shown in the form of a flowchart in Figure-6.

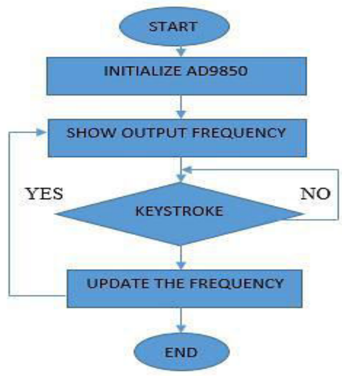


**Figure-6.** Flowchart of AD9850.

The schematic diagram of voltage controlled oscillator using AD9850 by using the Proteus software is shown in Figure-7. Due to the non-availability of AD9850 in Proteus software, the frequency is displayed on the LCD in the simulation.

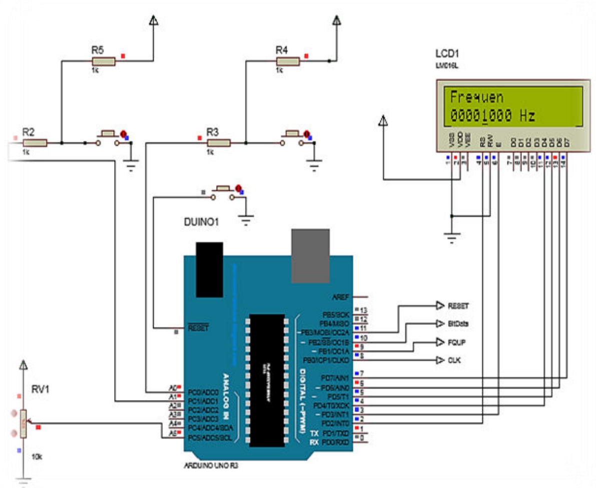


**Figure-7.** Schematic diagram of AD9850 in Proteus.

Figure-8 shows the actual hardware set up of AD9850 generating a frequency of 1 KHz. The AD9850 consists of four serial data pins W_CLK, FQ_UD, DATA and RESET pins, which are connected to digital pin number 8,9,10 and 11 respectively of the Arduino UNO.

VOL. 11, NO. 5, MARCH 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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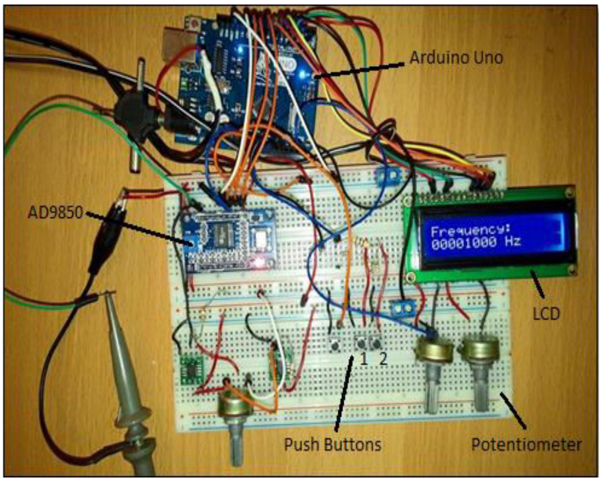


**Figure-8.** Experimental set up of AD9850.

The frequency can be course adjusted by either push button switch or fine adjusted by the potentiometer. The push button is pressed in relation with the required range of frequency. This frequency is displayed on the LCD. Two push buttons are used to adjust the frequency, which are defined as Push1 and the Push2 that are connected to the analog pins A0 and A1 of the Arduino Uno microcontroller respectively.

**b) Frequency programming**

Figure-9 shows a part of the main code used to set a particular operating frequency by the push button method.

```
void setup()
{
  pinMode (DATA,  OUTPUT);
  pinMode (CLOCK, OUTPUT);
  pinMode (LOAD,  OUTPUT);
  pinMode (RESET, OUTPUT);
  AD9850_init();
  AD9850_reset();

  SetFrequency(50000);   //Change the frequency

}
```

**Figure-9.** Code of adjusting the frequency by the push button method.

The fine method of adjusting the frequency is done by using a potentiometer. A 10KΩ potentiometer is connected to the analog pin number A5 of the Arduino Uno microcontroller. The system has been programmed in such way that when the push button Push1 is pressed, the program will run the case statement. This will start from a frequency from 0Hz up to 10 KHz that can be tuned by using the potentiometer, then by pressing the push button Push1 one more time, it will shift to the next case that allows to shift the frequency from 10 KHz up to 100 KHz. The Table-2 shows the frequency range for each case based on the number of many times the push button Push1 being pressed.

**Table-2.** Frequency range for each push.

| No. of Press | Max Frequency |
|---|---|
| 1 time | 10 KHz |
| 2 times | 100 KHz |
| 3 times | 1 MHz |
| 4 times | 10 MHz |

## TEST RESULTS AND DISCUSSION

Spectrum analysis provides the amplitude of an input signal as a function of frequency. A Spectrum analyzer, DSA 1030A from Rigol was used to test the accuracy of the sinusoidal signal. A noise of 10 dB was introduced into the signal to check the stability of the sinusoidal waveform. The test was carried out in the beta dispersion frequency range. The Figure-10(a) shows the actual spectral response at 100 KHz and Figure-10(b) shows the reconstructed graph using the USB stick support of DSA 1030A on excel.

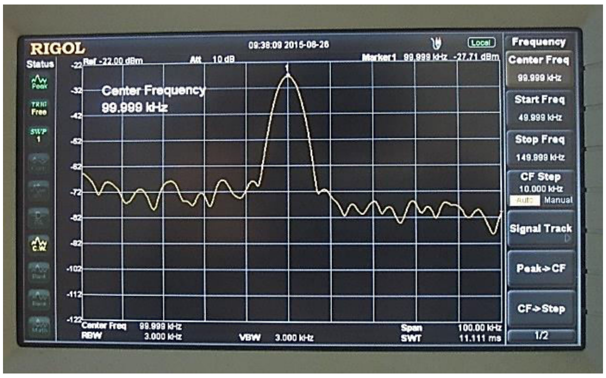


**Figure-10(a).** Spectral response at 100 KHz as seen on DSA 1030A.

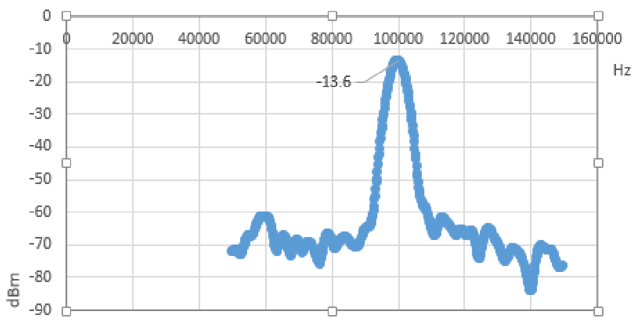


**Figure-10(b).** Reconstructed spectral response at 100 KHz plot on excel.

Similar spectral analysis was carried out in the beta dispersion frequency range by keying in the desired frequency into the Arduino Uno microcontroller. The corresponding spectral response for 70 KHz, 80 KHz, 500 KHz and 5 MHz are shown in Figure-11(a) through Figure-11(d) which are combinedly showed in Figure-11(e).

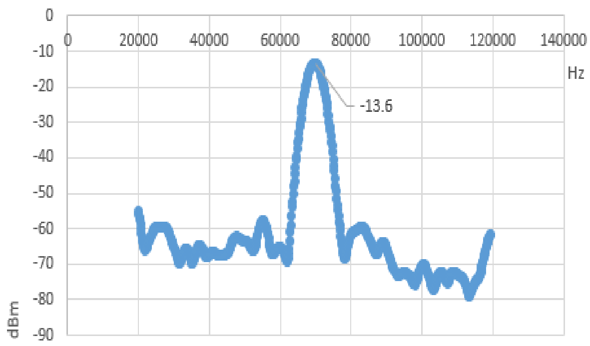


**Figure-11(a).** Spectral response at 70 KHz.

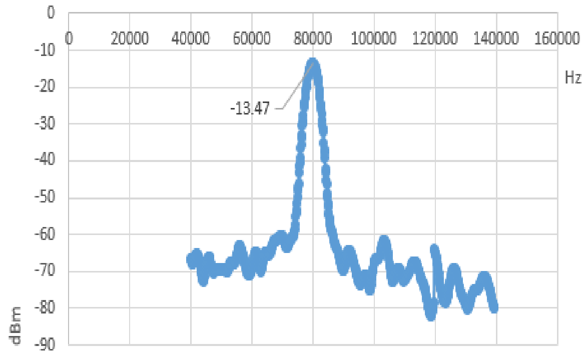


**Figure-11(b).** Spectral response at 80 KHz.

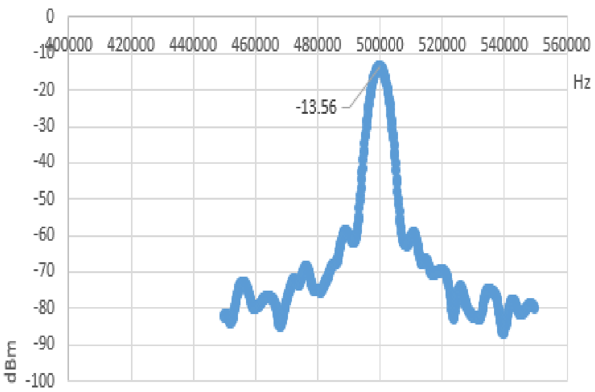


**Figure-11(c).** Spectral response at 500 KHz.

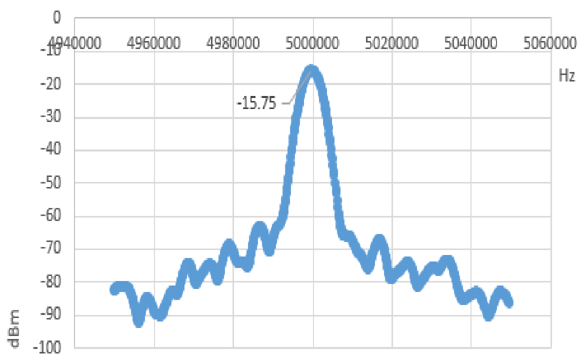


**Figure-11(d).** Spectral response at 5 MHz.

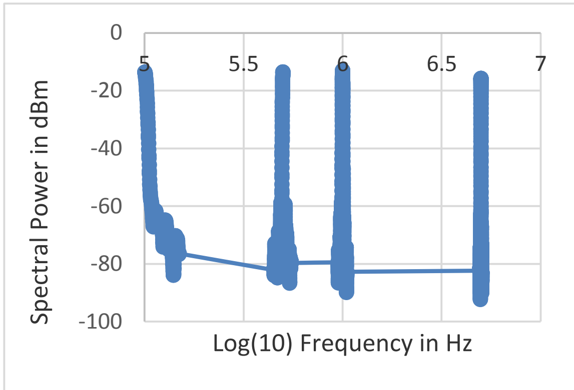


**Figure-11(e).** Combined spectral response up to 5 MHz

The combined results of Figure-11(e) show a constant power around 14 dBm with 10 dB attenuation for 1 VPP. The frequency axis is represented as a logarithmic function for a smooth plot. The spectrum analyses provide the proof of a stable frequency agile voltage source for electrical tomography applications and up to beta dispersion frequency range.

## CONCLUSIONS

A voltage controlled oscillator using AD9850 is studied for the electrical impedance tomography applications. The frequency is programmed using Arduino microcontroller. Spectrum analysis was carried out using DSA 1030A spectrum analyser. Results show the proof of a spectrally pure sinusoidal waveform of constant amplitude around 14 dBm throughout the beta dispersion frequency range with a low output impedance at 10 dB.

Hence AD9850 could be the best choice as the voltage source operating over a wide range of frequencies. The band pass filter which is usually used in the EIT systems to limit the voltage signal within a desired bandwidth, can be bypassed by using AD9850 as it readily synthesizes a pure, stable and programmable sinusoidal waveform.

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