DESIGN OF A FUNCTION GENERATOR USING DIRECT DIGITAL SYNTHESIS (DDS) TECHNOLOGY AND PIC16F877A MICROCONTROLLER

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Abstract: A signal generator, also known variously as function generator or frequency generator is an electronic device that generates repeating or non-repeating electronic signals. The objective is to build a Sine/Square wave generator based on the Analogue Devices AD9832 Direct Digital Synthesis (DDS) Generator chip which is capable of generating high accuracy waveforms. The controller chip is a Microchip PIC16F877A. Going digital allows to set the output frequency exactly from 0,1Hz to 1MHz in 0,1Hz resolution steps, and there is effectively no drift with temperature or time as the output frequency is crystal locked.

1. INTRODUCTION

There are many different types of signal generators [1], with different purposes and applications (and at varying levels of expense); in general, no device is suitable for all possible applications. Such devices contain an electronic oscillator, a circuit that is capable of creating a repetitive waveform. The most common waveform is a sine wave, but saw tooth, step (pulse), square, and triangular waveform oscillators are commonly available as are arbitrary waveform generators.

There is no unique quality criterion for all generated waveforms, each of them being definite by specific properties. The accuracy of the waveform at the generator output is mainly determined by the waveform approximation technique.

Besides waveform quality output signal requirements another quality criterion is the frequency stability. Frequency drift is an unintended and generally arbitrary offset of an oscillator from its nominal frequency. This can be caused by changes in temperature, or by problems with a voltage regulator which controls the bias voltage to the oscillator.

There are many types of electronic oscillators, but they all operate according to the same basic principle: an oscillator always employs a sensitive amplifier whose output is fed back to the input in phase. Thus, the signal regenerates and sustains itself by positive feedback. Some electronic oscillators are using tunnel diode in the negative resistance region (Parametric oscillator). The tunnel diode showed great promise as an oscillator device but it would operate at frequencies far greater than our needs, well into the microwave bands.

Although the terminology for the different classes of signal sources is not standardized, there is a general consensus on the naming conventions for signal, function and waveform generators.

A signal generator provides a high-fidelity sine wave signal ranging from low frequencies to many GHz. Attenuation, modulation, and sweeping are typical features of a signal generator.

A function generator is a lower-frequency instrument that provides sine, square, pulse, triangle and ramp waveforms. This electronic instrument generates periodic voltage or current waveforms that duplicate various types of well-defined mathematical functions. Analogue function generators usually generate a triangle waveform as the basis for all of its other outputs. The triangle is generated by repeatedly charging and discharging a capacitor from a constant current source. This produces a linearly ascending or descending voltage ramp. As the output voltage reaches upper and lower limits, the charging and discharging is reversed using a comparator, producing the linear triangle

wave. By varying the current and the size of the capacitor, different frequencies may be obtained.
A 50% duty cycle square wave is easily obtained by noting whether the capacitor is being charged or discharged, which is reflected in the current switching comparator's output. Most function generators also contain a non-linear diode shaping circuit that can convert the triangle wave into a reasonably accurate sine wave. It does so by rounding off the hard corners of the triangle wave in a process similar to clipping in audio systems.
Function generators, like most signal generators, may also contain an attenuator, various means of modulating the output waveform, and often the ability to automatically and repetitively "sweep" the frequency of the output waveform (by means of a voltage-controlled oscillator) between two operator-determined limits. This capability makes it very easy to evaluate the frequency response of a given electronic circuit. Function generators provide these standard functions from DC to a few MHz, and typically provide large voltage ranges.
An arbitrary waveform generator (AWG) is a highly flexible signal source that generates any arbitrary waveform that has been constructed point-by-point in digital memory. The constructed waveform is converted to an analogue signal using a digital-to-analogue converter (DAC) operating at clock rates up to a few GHz. An arbitrary waveform generator can also substitute as a conventional function generator by using on-instrument algorithms to generate standard functions.

2. FUNCTION GENERATOR SPECIFICATIONS

Projecting the function generator, we considered the conditions imposed by the systems wherewith it is interconnected. These conditions are usually: the accuracy of the form of the wave, the stability of the oscillation, the amplitude of the signal generated. The frequency, amplitude and offset of all output waveforms are adjustable.
Function generator (sine/ square) frequency can be set from 0,1Hz to 1MHz in 0,1Hz resolution steps. The square output is TTL compatible. The amplitude maximum output can be set from 0 to 10 V peak-to-peak and the DC offset range is $\pm$ 5 V.
Main output readings are displayed onto a 16 characters, *2*-line Alphanumeric LCD Module. There is effectively no drift with temperature or time as the output frequency is crystal locked.

2.1. FUNCTIONAL BLOCK DIAGRAM

The function generator is comprised of main functional blocks as shown in the functional block diagram (Figure1).
Block B contains a set of 8 push-button switches placed on the front panel. The function of these switches is: sine/square selection, up/down offset and frequency control, attenuator, left/right cursors.
The microcontroller is a PIC 16F877A (**PIC** is a family microcontrollers made by Microchip Technology [2]).
LCD module is a 2 line x 16 characters module and displays main function: frequency, waveform, offset and attenuation.

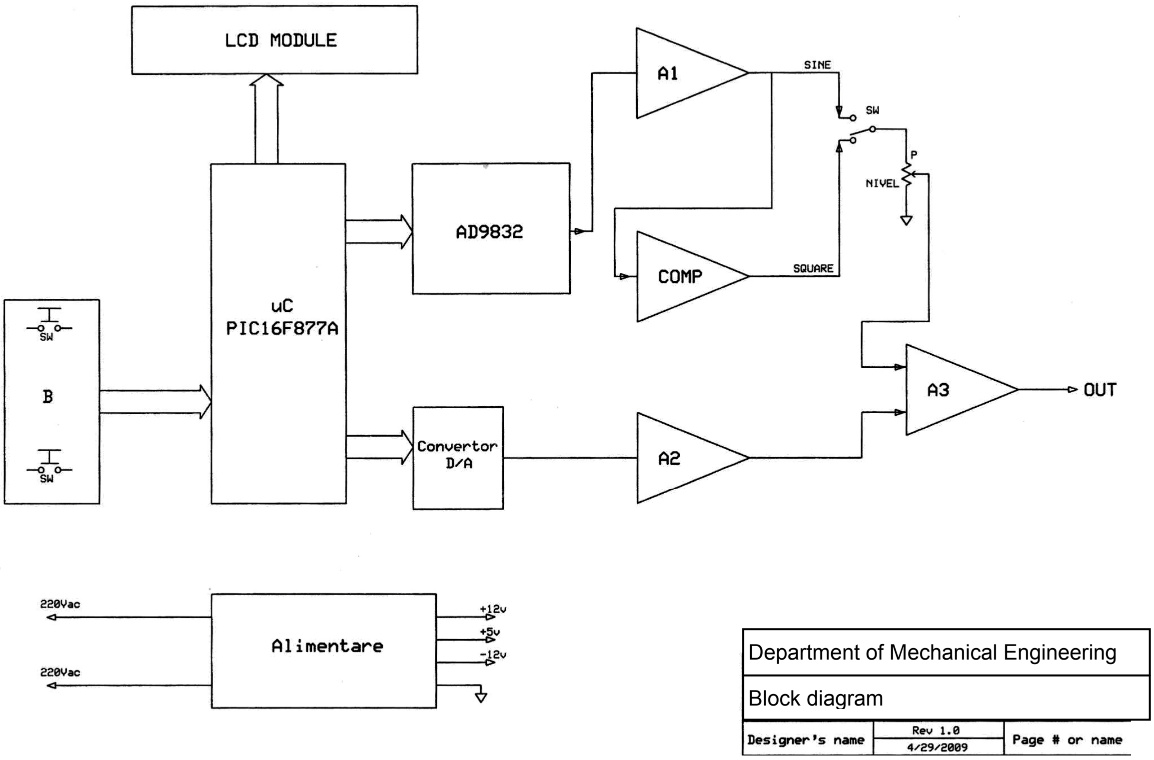

Figure 1: Block diagram of function generator with PIC 16F877A

The AD9832 is a numerically controlled oscillator using a Direct Digital Synthesis (DDS) chip [3].
D/A Converter generate the offset voltage.
A_1, A_2, A_3 are signal amplifiers and COMP is a comparator used as a sine to square wave converter.
The output waveform is selected through a 2 position switch "SW".
The output signal level is adjustable via a front panel potentiometer.

2.2. SCHEMATIC DIAGRAMS OF THE FUNCTIONS GENERATOR

PIC 16F877A Microcontroller: The microcontroller clock is generated by an external 4 MHz crystal and C_2, C_3 capacitors. This produces a single instruction cycle time of 1 microsecond, good enough for this application.
PORTB (RB_0 ÷ RB_7) is connected to the 8 push-buttons which selects the functions parameter of the generator. LCD is attached to PORT D (RD_0 ÷ RD_6), RD_0 ÷ RD_3 pins being used for data, while RD_4 ÷ RD_6 pins for control (RS, RW, and E). PORTC (RC_0 ÷ RC_7) generates the offset voltage with an 8-bit Digital to Analogue converter (DAC) using R/2R (R_2 ÷ R_{18}) resistor network**.** An 8 bit converter will divide the 5 volts into 255 steps, each step having a value of: 5/255 = 0.019 V. This voltage appears across the terminals of resistor R_{10}.
AD9832 is connected to microcontroller pins RE_0, RE_1 and RE_2, (Digital I/O) using an I2C bus [3]. A clock signal of 24 MHz, generated by a crystal oscillator ($1C_2$) is applied to pin 6 (MCLK). DDS output frequencies are expressed as a binary fraction of the frequency of MCLK. The output frequency accuracy and phase noise are determined by this clock.

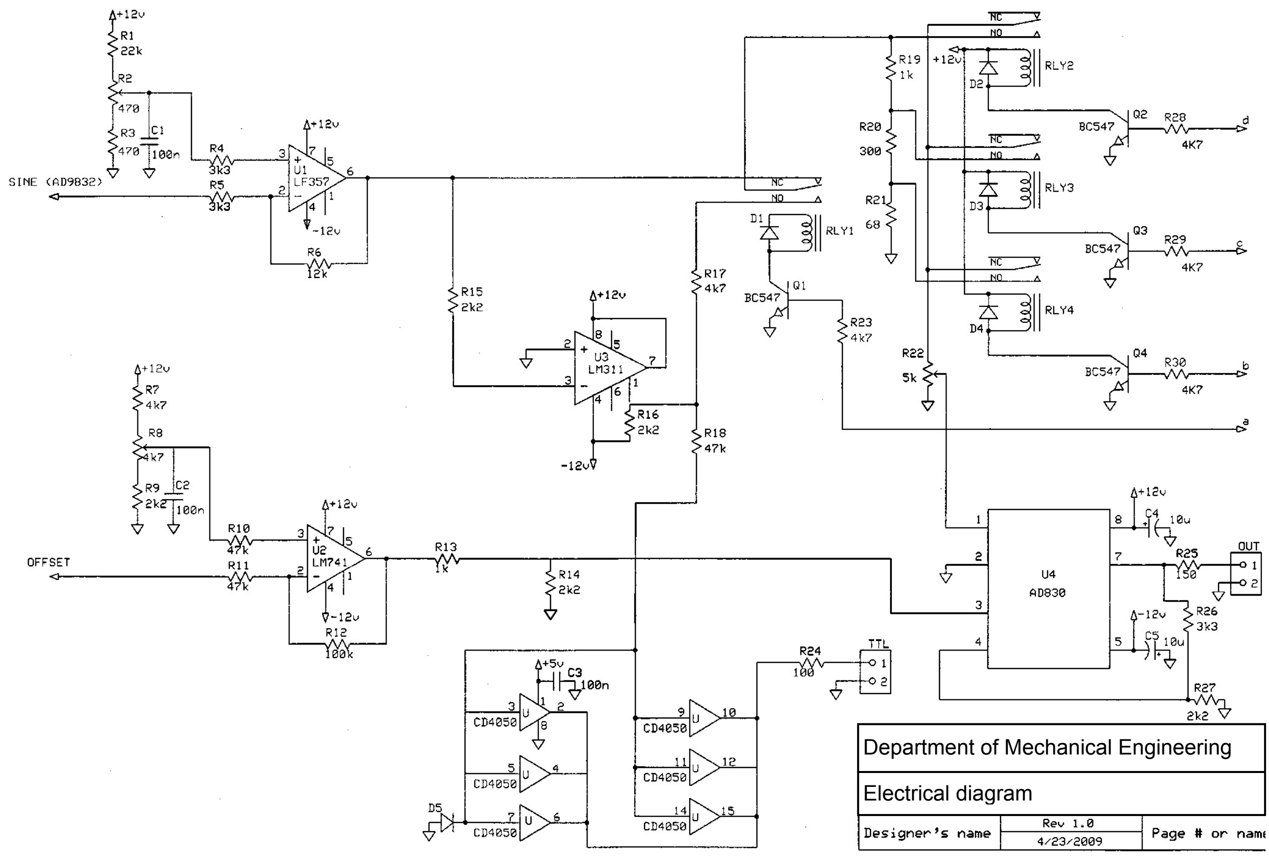

Figure 2: Electrical diagram of the functions generator.

The AD9832 has a serial interface, with 16 bits being loaded during each write cycle. SCLK, SDATA and FSYNC are used to load the word into the AD9832. When FSYNC is taken low, the AD9832 is informed that a word is being written to the device. The first bit is read into the device on the next SCLK falling edge with the remaining bits being read into the device on the subsequent SCLK falling edges. FSYNC frames the 16 bits, therefore, when 16 SCLK falling edges have occurred, FSYNC should be taken high again. The SCLK can be continuous or, alternatively, the SCLK can idle high or low between write operations.
A sine signal having a voltage level of about 1,2 V is available at pin 14 (IOUT).
Output frequency is given by:

$$f_{OUT} = \frac{24MHz}{2^{32}} N \tag{1}$$

where N is the value loaded into the selected frequency register.
The output RA_o is used for wave form switching (sine/square). The outputs RA_1, RA_2 and RA_3 are used as attenuator outputs in three steps: 500 mV, 2,5 V and 10 V.
The sinusoidal wave generated by AD 9832 is amplified by LF357 op-amp (U_1). The op-amp produces an output voltage of 5 V. This voltage is symmetric with respect to zero. This voltage amplification is needed because the output voltage of AD 9832 is only 1,2 V. LM311 (U_3) voltage comparator is a sine to square wave converter.
The output signals (sine and square) are directed to relay RLY1 contacts, then to a voltage resistor divider network made by R_{19}, R_{20} and R_{21}.The wanted signal is selected by the relays (RLY2, RLY 3 and RLY4) and applied to R_{22} potentiometer situated on the front

panel. Thus, the output voltage can be regulated anywhere from 0÷500 mV, 0÷2,5 V, 0÷10 V.
Sine or square signal, taken from the potentiometer's wiper is fed to AD830, a wideband, differencing amplifier. The absolute peak output current is set by the short-circuit current limiting, typically greater than 60 mA. The maximum drive capability is rated at 50 mA, but without a guarantee of distortion performance. Best distortion performance is obtained by keeping the output current ≤20 mA.
Offset voltage, in 0÷ +5 V range, made by R-2R ladder network, is applied to U_2 amplifier. Input signal is amplified with a gain of 2, output signal becoming even–symmetric with regard to zero. The output of this amplifier is connected to pin 3 of AD830, in this way this voltage can be summed with the sine/square voltage for the required offset. The CD4050BC hex buffers are monolithic complementary MOS (CMOS) integrated circuits [4]. These devices feature logic level conversion (TTL converter) using only one supply voltage. All six non-inverting units are connected in parallel to increase the available output current to approx. 50 mA.
The AD830 output is connected to a BNC connector (OUT) and the output of CD4050 is connected to another BNC connector (TTL).
The function generator needs 3 fixed voltage power supplies: + 12 V, + 5 V and - 5 V. These power supplies are using 3-Terminal Voltage Regulators like LM7812, LM7805 and LM7809.
The power supply consists of three main sections: a transformer (220 V / 2x12V – 500 mA), a rectifier bridge and two filtering capacitors (3300 µF and2200 µF).
$C_3 \div C_8$, connected at the output of the regulators improve stability and transient response.

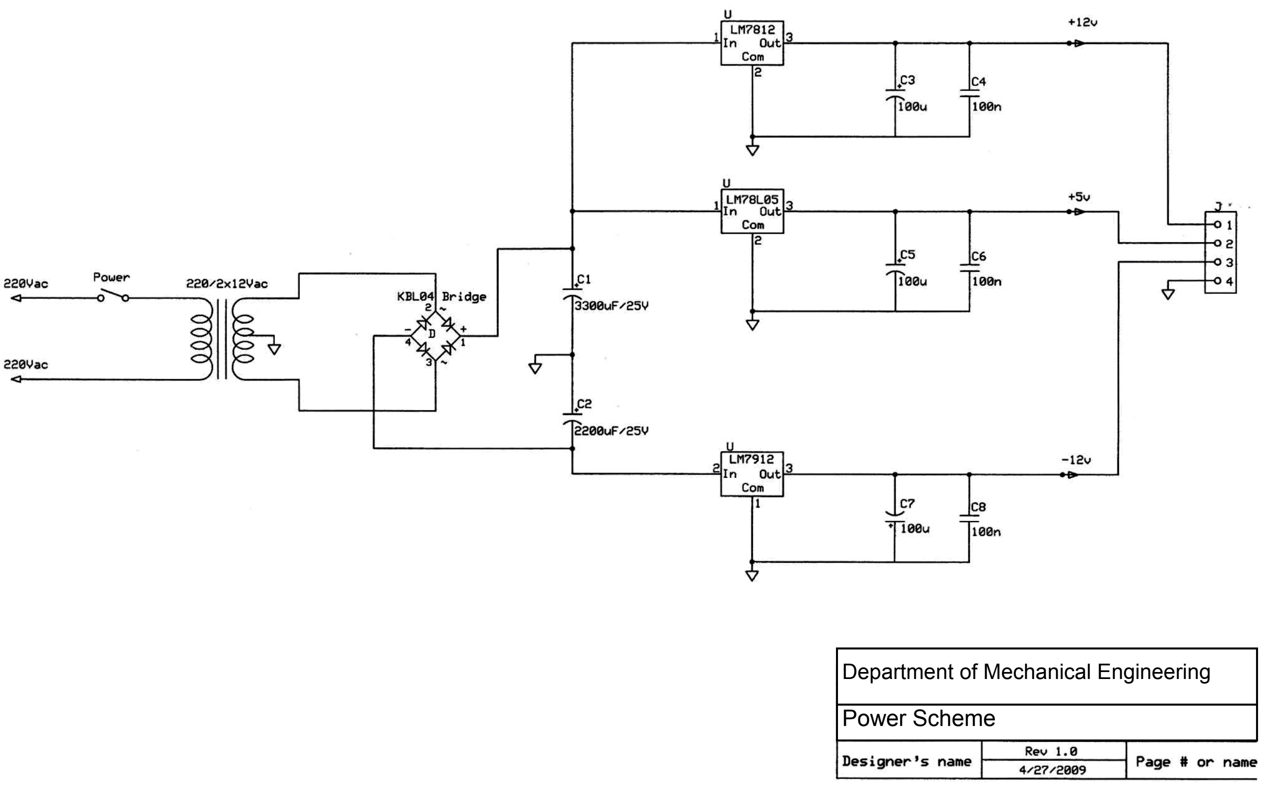

Figure 3: Supply scheme of the functions generator.

A picture of our function generator designed and built in our lab is shown in figure 4.
As one can see, all needed output values can be read on the LCD module as well as the function switches and push-buttons.

Figure 4: Functions Generator.

3. CONCLUSIONS

In this paper was described a function generator used in various testing equipments. Constructively the Sine/Square wave generator is based on the Analogue Devices AD9832 Direct Digital Synthesis (DDS) Generator chip [3, 5] and PIC 16F877A microcontroller [2]. The sine/square output frequency can be varied from 0,1 to 1 MHz. Maximum output voltage is 10V.

The device generates signals of good quality, comparable with those of dedicated function generators. The device and its description will be useful for those of you who want an alternative to expensive test equipments.

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