DDS RF Signal Generator

Frequency range: 50 Hz to over 70 MHz

Design by G. Baars, PE1GIC.

pe1gic@amsat.org

Radio amateurs and RF engineers in general will welcome this design. This contemporary RF signal generator has many bells and whistles and is just the ticket for testing HF/VHF receivers, aligning filters, IF amplifiers and AM/FM demodulators. The instrument can even act as a source for very low frequencies starting at 50 Hz.

While the combination of an ordinary multimeter and a rudimentary signal tracer is perfectly adequate for many 'kitchen table' hobbyists to get their homebrew circuits working, more sophisticated equipment is typically required by those interested in radio and higher frequency circuits in general. In particular, the more complex designs in the RF realms normally require accurate adjustment, which in practice translates into a decent RF signal generator with an internal or external modulation option available. But then, most of you will agree, we are talking of an expensive piece of test equipment and that is why we expect the present design to be highly valued, not only by the radio amateur fraternity but also by those with an interest in all things RF. The generator described in this article offers good performance, may be used for commonly required test, service and repair jobs, and is reasonably simple to build.

Concept and block diagram

The general design of the RF Signal Generator is shown in **Figure 1**. At first blush you might think that this is another circuit with a microcontroller at the heart of things, but this time the term is more appropriate for the module marked 'DDS', because this is where the RF signals are actually generated.

DDS is an abbreviation of 'Direct Digital Synthesizer'. The DDS requires a clock signal for its frequency reference. This signal is frequency-multiplied by six by the DDS. In this way, by applying a clock frequency of 30 MHz to the DDS, the internal clock frequency becomes 180 MHz, which is also the highest frequency at which the DDS can operate. Its sinewave-shaped output signal has a frequency f_0 equal to

$$f_0 = W \times (f_{clk} / 2^{32})$$

where W is a 32-bit programmable 'frequency word'. Consequently the step size becomes

$$180 \text{ MHz} / 2^{32} = 0.0419 \text{ Hz}$$

By means of software, the smallest step is set to a more familiar value, namely 1 Hz.

Because of the internal design of the DDS, a number of spurious signals are inevitably generated, particularly since the output signal is quantified at 180 MHz, there's no way to avoid a filter (module 'LPF' in the drawing). The filter applied here is a Butterworth low-pass type that's guaranteed to afford sufficient suppression of unwanted products.

An adjustable attenuator is required if we want to be able to control the output signal level. That is why the filter is followed by a digitally controlled VGA (variable gain amplifier). Using this VGA the gain can be set in set in 1-dB steps over a range of 31 dB. The VGA in turn is followed by two attenuators of 32 dB and 64 dB respectively. The total attenuator arrangement allows the output signal to be adjusted between 0 dBm (decibel milliwatt) and –127 dBm. The VGA used here doubles as a 50-Ω output signal driver.

Specifications

- Output frequency adjustable between 50 Hz and 71 MHz
- Frequency step size 1 Hz to 1 MHz
- Output signal level adjustable between 0 and –127 dBm (0.224 V_{rms} to 0.1 μV_{rms})
- Internal AM, 1000 Hz at 30%
- Internal FM, 1000 Hz, deviation 3 kHz, 10 kHz or 20-90 kHz
- 16-key keypad for frequency entry and other functions
- 2x16 character LCD showing frequency, frequency step and output signal level
- Spurious output level –40 dBc to –50 dBc (frequency dependent)
- Frequency range covers standard IFs like 445 kHz, 5.5 MHz, 10.7 MHz, 21.4 MHz, 45 MHz and 70 MHz

Arguably a microcontroller is the best choice, if not indispensable, if we want to control all of the above circuitry. Here, the micro rules over the DDS, attenuators and the 'user interface', the latter consisting of a keypad and LCD and a rotary encoder.

Circuit diagram

As you'll discover a bit further on, the circuit is spread across two printed circuit boards. The division is reflected by the circuit diagram. Broadly speaking, the schematic in **Figure 2** shows the signal generator proper, while the control circuitry, power supply and user interface appear in **Figure 3**.

The various elements discussed in relation to the block diagram are easily found back in the actual schematics. In Figure 2, the clock generator is built around IC1, while the DDS lurks in IC2. The low-pass filter is found around L6-L15, the VGA is integrated into IC3 and the attenuators are situated around relays Re1, Re2 and Re3. Connectors K1 and K2 are interconnected with Figure 3's K2 and K3 respectively. In Figure 3, most of you will immediately spot IC2 as the microcontroller. The keypad is connected to K1, the LC display to K4. S1 is a rotary encoder while Tr1,

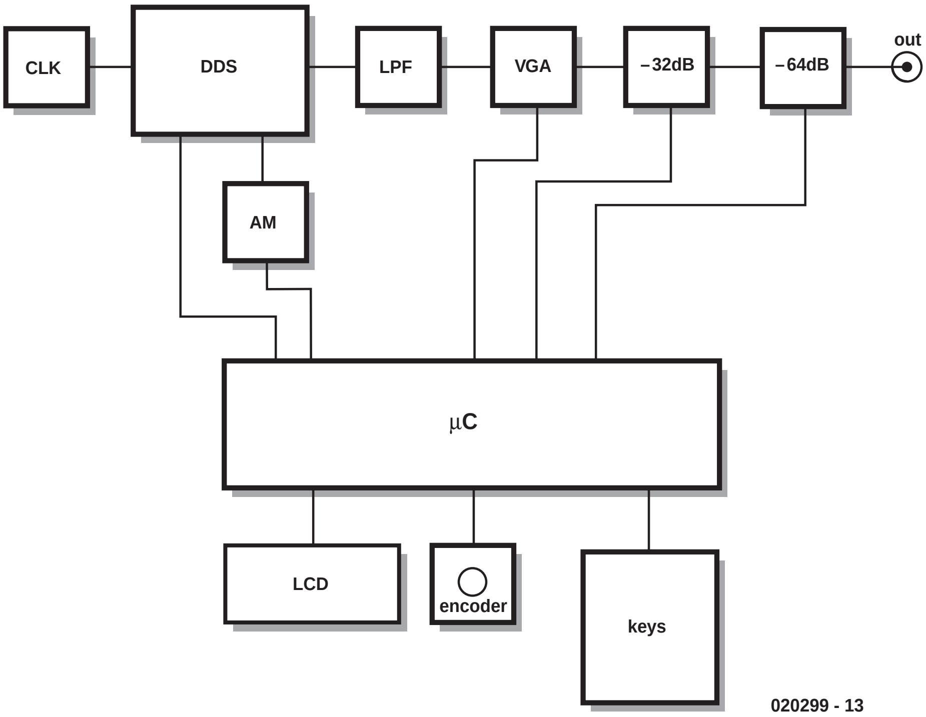


Figure 1. Block diagram of the DDS RF Signal Generator.

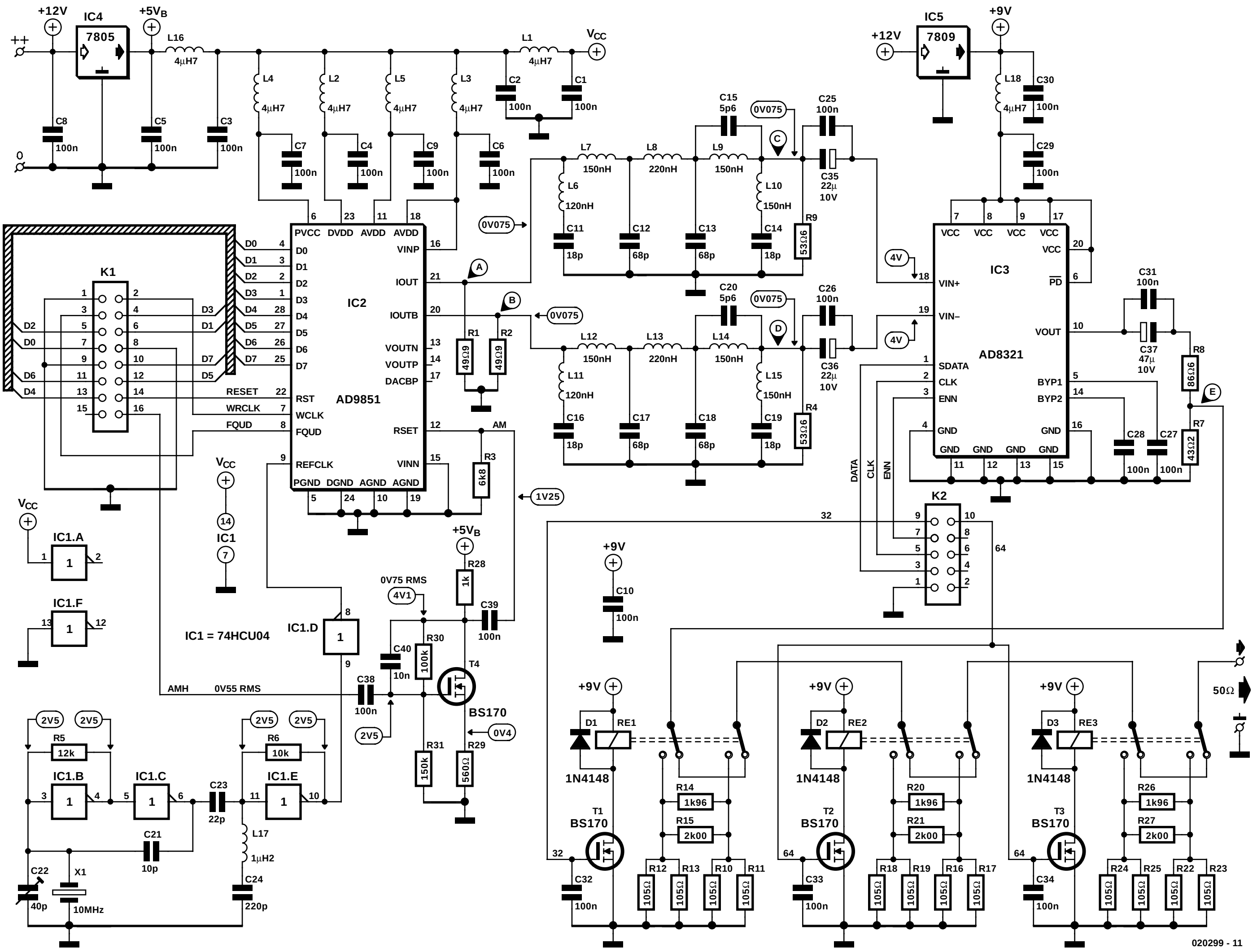


Figure 2. Circuit diagram of the RF part of the generator.

B1 and IC3 are the main parts in the power supply. The circuit around IC1 is part of an AM modulator and only happens to sit here because it could not be accommodated on the other board (Figure 2).

The operation and functionality of each of the above circuit sections will be discussed in the following paragraphs.

Clock generator

Because a 30-MHz TCXO can only be obtained as an expensive custom-made component, and 30.000 MHz quartz crystals are few and far between, a solution was found in the use of a 10-MHz oscillator in combination with a tripler. In this way we're able to employ a cheap and commonly available quartz crystal while the oscillator frequency is easily adjusted (here, with C22). Of course, the oscillator is not totally immune to temperature variations, but in practice it will operate satisfactorily because the equipment will typically be used at room temperature.

IC1b, IC1c and surrounding components form the oscillator. The frequency tripler is built around IC1e, while IC1d acts as a buffer.

The combination of X1 and IC1 may be replaced with a 14-way DIP 30-MHz quartz oscillator module (if you can get it) which may be plugged into the socket for IC1. Unfortunately, 8-pin oscillator blocks will not fit the board and require a small modification which you will have to work out for yourself.

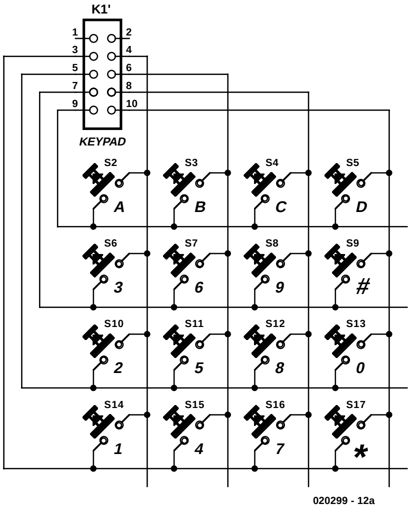
DDS

The circuitry around IC2 largely follows the application suggestions supplied by the manufacturer. The DDS chip has several voltage connections, each supplying its own part of the complex chip. To keep spurious signal levels to a minimum, all supply connections are powered via a separate supply filter consisting of a choke and a decoupling capacitor.

The resistor at pin 12 of the DDS (here, R3) serves to defines the DDS output current. However, by allowing an audio signal to vary this resistance, AM modulation is obtained.

Filter

Inherent to its design, the DDS generates not only the desired frequency f_0, but also the spurious products f_{clk}, $f_{clk}–f_0$ and multiples of these. Arguably a good filter is in order to keep spurious levels at the output as low as possible. The filter used here is a modified Butterworth low-pass dimensioned for a roll-off frequency



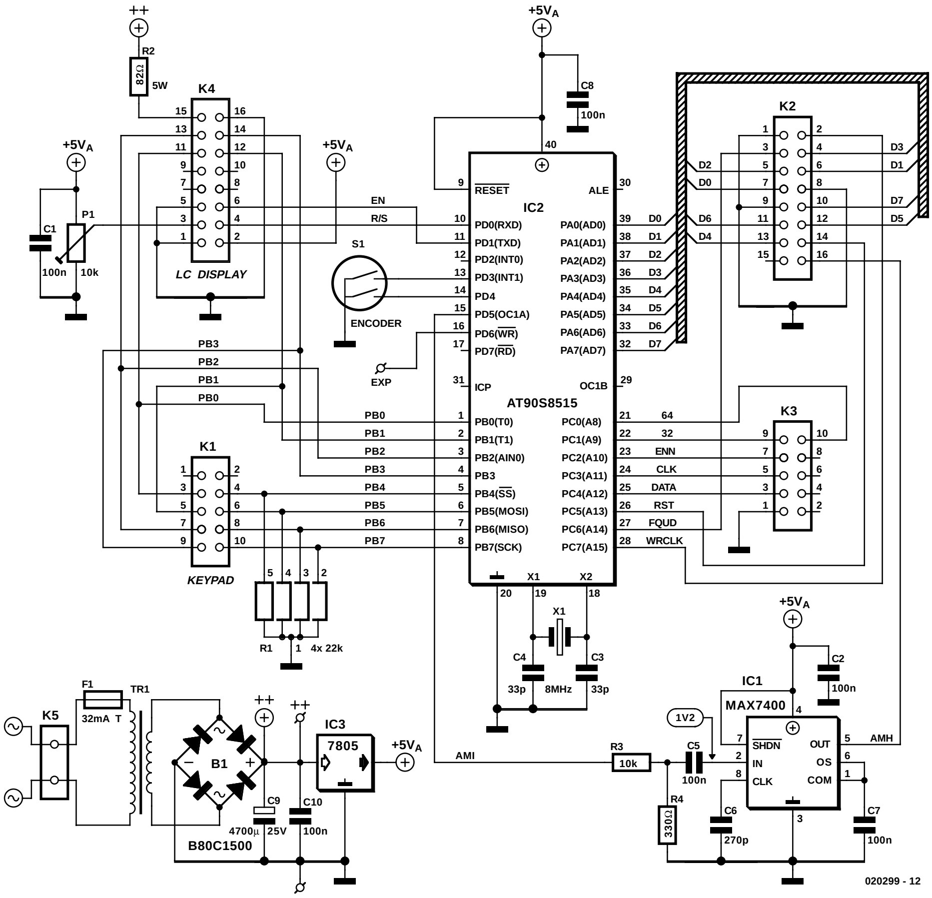


Figure 3. Control, supply and user interface.

of about 75 MHz. Since at an output frequency f_0 of 71 MHz the component $f_{clk}–f_0$ occurs at 109 MHz, the filter needs to have a fairly steep slope. This condition is fully satisfied by the filter used here because it is almost flat between 0 and 71 MHz, while a minimum suppression of 50 dB is obtained for signals above 95 MHz or so.

The filter has a double implementation because both outputs of the DDS are required to obtain symmetrical AM modulation.

VGA

IC3 comprises a digitally controlled variable-gain amplifier/attenuator with a flat amplitude characteristic over the entire frequency area we're concerned with. The gain is adjustable in steps of about 0.75 dB across a range a bit larger than the required 31 dB.

Because the VGA is intended as a 75-Ω driver and strives to dynamically maintain its output impedance, the relevant chip output must be terminated into 75 Ω. In our circuit, a couple of resistors are used to create a level converter from 75 Ω to 50 Ω. None the less, the VGA is easily capable of generating 0 dBm which equals 1 milliwatt or 0.224 V_{rms} into 50 Ω.

Attenuators

Additional attenuators are called for if we want the generator to supply a lowest output level of –127 dBm into 50 Ω (which equals 0.1 μV_{rms}). The VGA itself already provides for 31 dB of attenuation, so we need to add a

Meet the DDS

The DDS consists of three parts. First, we have an NCO (Numerical Controlled Oscillator), which in the case of the AD9851BRS is a 32-bit counter that adds a 32-bit frequency word on every clock pulse. A small value for the 'word' causes the counter state to increase slowly — a larger value, quickly. By sending the 10 MSB's of this counter to a DAC via a function called Sine Look Up Table, a sinewave-shaped output voltage is created of which the frequency is variable.

Because the output voltage is quantisized at the clock frequency, unwanted products are generated including the component $f_{clk}–f_0$. Obviously when $f_0 = 1/2\ f_{clk}$ we have the case where $f_{clk}–f_0$ will actually equal f_0. As a result, the highest usable output frequency of a DDS is usually limited to about 40% of the clock frequency. If not, a low-pass filter is required to give sufficient suppression of the unwanted product.

Another disadvantage of the use of a DDS is that its output level is not constant. In fact, the level is described by a (sinx/x) curve with $x = \text{pi} \times f_0 / f_{clk}$.

Some more calculation indicates that (sinx/x) equals 0.76 or –2.4 dB at $f_0 = 0.4\ f_{clk}$. While the error is not grave in a receiver where the DDS is used as a local oscillator, it is rather worrying in the case of an RF signal generator. Consequently, the VGA output level is corrected at various output frequencies. For this advanced function a special routine is implemented in the control software.

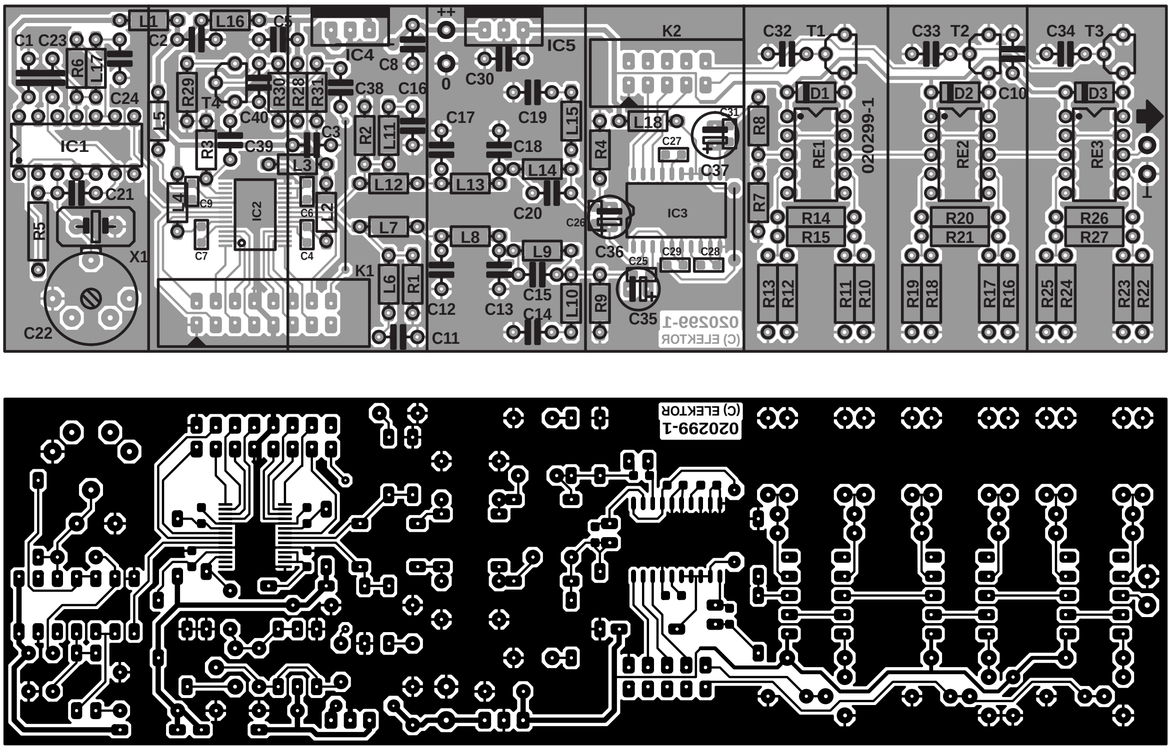


Figure 4. The PCB for the signal generator circuitry is marked by very short connections and a generous earth plane.

32-dB and a 64-dB attenuator. The latter comprises two series connected 32-dB sections, which are easier to produce in practice without the risk of inaccuracy or leakage associated with a single 64-dB attenuator.

The relays used here (Re1, Re2 and Re3) are configured to switch attenuator sections in and out of circuit under microprocessor control. Despite their relatively low price, the relays are usable for frequencies up to 1 GHz. In practice, these 12-volt models pull in reliably a just 9 volts coil voltage. In case of doubt, the relay supply voltage may be taken from the unstabilised +12-V rail in the circuit.

Control and AVR

The various circuits in the RF Signal Generator are controlled by an Atmel AT90D8515 microcontroller (IC2 in Figure 2). This 8-bit RISC controller offers 32 I/O lines and a speed of 8 MIPS which makes it perfect for the job. Parallel driving of the DDS guarantees that its programming its fast enough to modulate sufficient samples when FM is used. Note, however, that this does require 11 I/O lines. To save some I/O resources, the LCD and the keyboard share a number of processor pins.

The rotary encoder drives an interrupt line to make sure the software can not miss any pulse. The LCD is used in 4-bit bus mode where data is copied to it in two operations. That, too, is done to save I/O line capacity. Finally, sharing I/O lines between the DDS

COMPONENTS LIST

Signal generator board (020299-1)

Resistors:
R1,R2 = 49Ω9
R3 = 6kΩ8
R4,R9 = 53Ω6
R5 = 12kΩ
R6 = 10kΩ
R7 = 43Ω2
R8 = 86Ω6
R10-R13,R16-R19,R22-R25 = 105Ω
R14,R20,R26 = 1kΩ69
R15,R21,R27 = 2kΩ0
R28 = 1kΩ
R29 = 560Ω
R30 = 100kΩ
R31 = 150kΩ

Capacitors:
C1,C2,C3,C5,C8,C10,C30,C32,C33, C34,C38,C39 = 100nF, 5mm lead pitch
C4,C6,C7,C9,C25-C29,C31 = 100nF, SMD shape 0805
C11,C14,C16,C19 = 18pF
C12,C13,C17,C18 = 68pF
C15,C20 = 5pF6
C21 = 10pF
C22 = 40pF trimmer
C23 = 22pF
C24 = 220pF
C35,C36 = 22µF 10V radial
C37 = 47µF 10V radial
C40 = 10nF

Inductors:
L1-L5,L16,L18 = 4µH7
L6,L11 = 120nH
L7,L9,L10,L12,L14,L15 = 150nH
L8,L13 = 220nH
L17 = 1µH2

Semiconductors:
D1,D2,D3 = 1N4148
T1-T4 = BS170
IC1 = 74HCU04
IC2 = AD9851BRS
IC3 = AD8321AR
IC4 = 7805
IC5 = 7809

Miscellaneous:
K1 = 16-way boxheader (2x8)
K2 = 10-way boxheader (2x5)
X1 = 10MHz quartz crystal (series resonance. C_L 32pF) or 30MHz DIL14 oscillator module
Re1,Re2,Re3 = TQ2-9V or TQ2-12V
3 wire links
Enclosure, tin sheet dim. 160x48x25 mm
PCB, order code **020299-1** (see Readers service page)

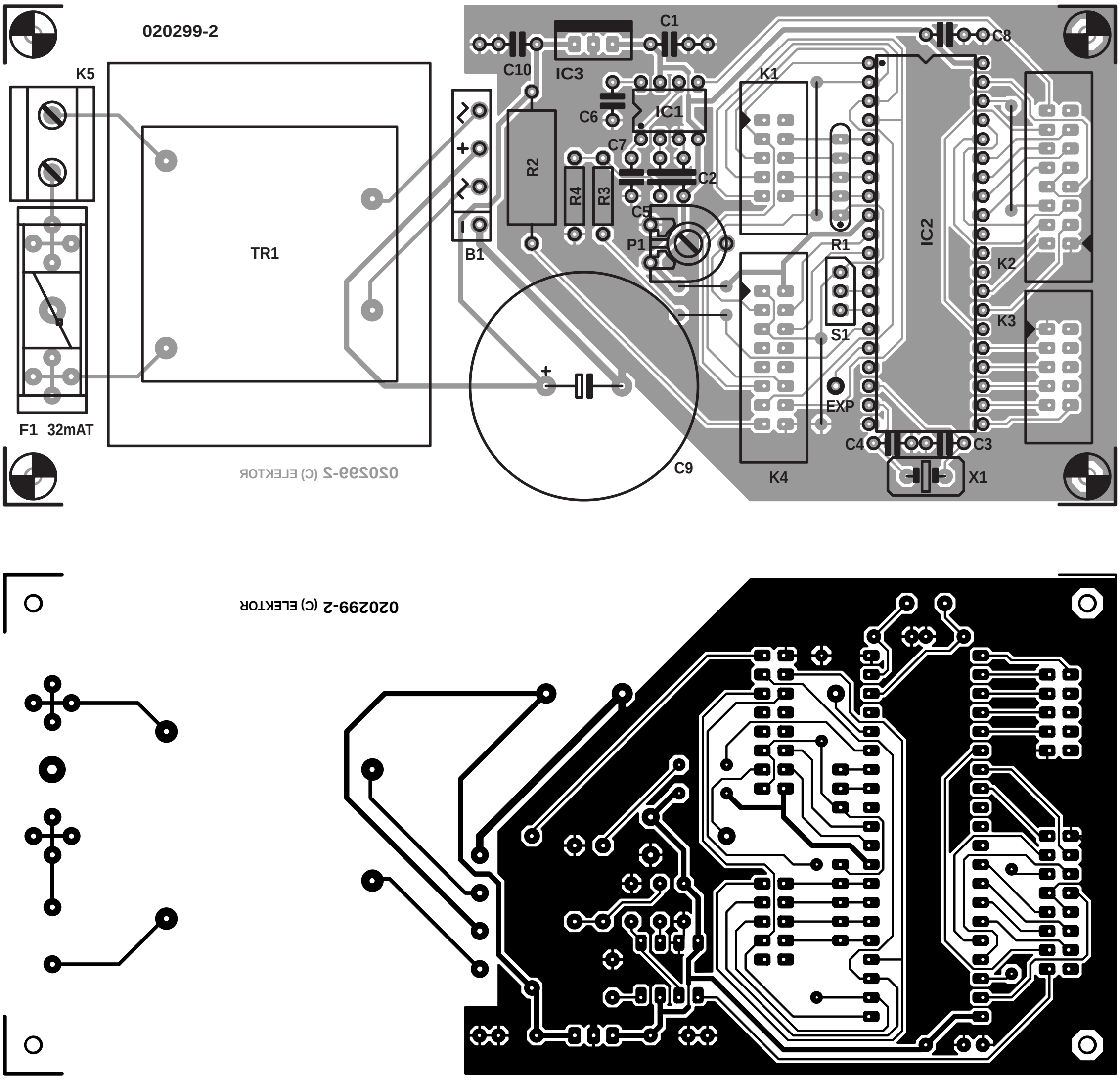


Figure 5. The supply/control board is much more spacious.

COMPONENTS LIST

Control/power supply board (020299-2)

Resistors:
R1 = 4-way 22kΩ SIL array
R2 = 82Ω 5W
R3 = 10kΩ
R4 = 330Ω
P1 = 10kΩ preset

Capacitors:
C1,C2,C5,C7,C8,C10 = 100nF, 5mm lead pitch
C3,C4 = 33pF
C6 = 270pF
C9 = 4700µF 25V radial

Semiconductors:
B1 = B80C1500, rectangular case (80V piv, 1.5 A)
IC1 = MAX7400CPA
IC2 = AT90S8515 8PC, programmed, order code **020299-41** (see Readers Services page)
IC3 = 7805

Miscellaneous:
K1,K3 = 10-way boxheader (2x5)
K2,K4 = 16-way boxheader (2x8)
K5 = 2-way PCB terminal block, lead pitch 7.5mm
S1 = rotary encoder, Bourns ECW1J or ddm427 (Conrad Electronics)
X1 = 8MHz quartz crystal, parallel resonance, C_L 32pF
TR1 = 12V/4.8VA mains transformer, e.g., Gerth 1x12V/400 mA
F1 = fuse, 32 mAT with PCB mount fuse holder
5 wire links
Keypad: 16 keys, matrixed (Velleman)
Display: LCD 2x16 characters with backlight
PCB, order code **020299-2** (see Readers Services page)

and the VGA is really out of the question with the risk of increased spurious levels in mind.

Keyboard, display and encoder

The user interface designed into the RF Signal Generator consists of a 2 × 16 character matrix LCD, a 4 × 4 matrix keyboard (connected to K1 in Figure 3) and a rotary encoder (S1). The LCD connected to K4 provides a readout for frequency, frequency step and output level. The keypad allows the desired frequency to be entered as well as various other functions to be controlled. The rotary encoder is used to adjust the signal frequency, select the frequency step size and adjust the output signal level.

The LCD backlight current is limited to a

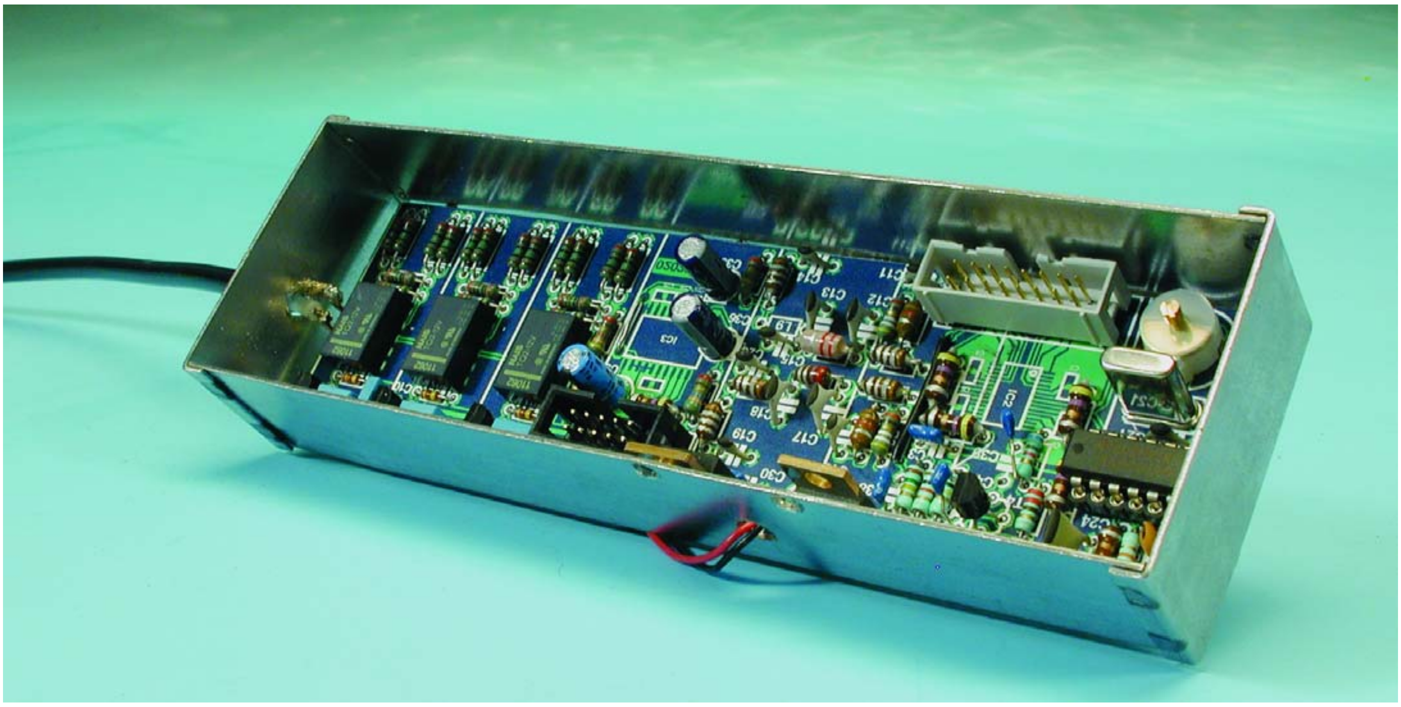


Figure 6. The signal generator board is by no means easy to construct.

safe value using series resistor R2. In practice, one third of the recommended current guarantees a sufficiently bright display. The saving in current then amounts to 200 mA!

Preset P1 acts as the LCD contrast adjustment.

AM modulator

Most RF signal generators of the affordable kind use fixed 30%, 1000-Hz AM modulation. Because the DDS has no internal provision for amplitude modulation, an external add-on had to be devised. The resistance at pin 12 of the DDS determines the DDS output level. By using a FET (T4), this resistance can be varied dynamically. The sinewave applied to the FET is obtained by filtering a square wave from processor pin 15. The filter in question is a pretty steep one, built around a Maxim integrated elliptic low-pass (IC1 in Figure 3). The filter suppresses the fundamental frequency of the square wave, which results in a clean 1-KHz sinewave.

FM modulation

Frequency modulation (FM) is realised in software, with the microcontroller employing an internal processor timer and a sinewave look-up table containing frequency steps. FM with 1000-Hz sinewave modulation is obtained by sending 32 samples to the DDS at a timer rate of 32 kHz. The number of samples and the sampling frequency distance are large enough to warrant a reasonably clean modulated spectrum.

The keyboard allows you to select FM modulation with a deviation of 3 kHz, 10 kHz, 20 kHz, 30 kHz and so on up to 90 kHz. The 3-kHz setting will typically be used for NBFM equipment like personal mobile radios, while 70 kHz is the nominal value for broadcast FM.

The sinewave tables for the FM modulation function of the instrument have been developed using a specially written Pascal program.

Software

The microcontroller executable code was created using an assembler program with well over 2,000 lines. Broadly speaking, this program consists of three flows:

Main flow

In the main flow, the keyboard is scanned and the keyboard presses are linked to their associated functions. From the main flow, a number of subroutines are called controlling, among others, the LCD. Here, too, the interrupt timer is initialised for AM and FM.

The main flow is preceded by a reset interrupt which arranges for all hardware and software initialisations to be carried out.

Timer interrupt

The timer interrupt is activated at a rate of 2,000 Hz or 32,000 Hz for AM and FM respectively. With AM, the timer interrupt causes a square wave to appear on an I/O pin. With FM, a frequency sample from the sinewave look-up table is added to the current frequency and the result is sent to the DDS.

Encoder interrupt

When an encoder interrupt occurs, either the frequency, frequency step size or the output level is increased or decreased. Next, besides other ‘chores’, the display readout is updated. The function of the encoder is determined using the keyboard.

Keyboard functions

The complete functionality of the instrument is accessible to the user via the keypad and the rotary encoder. The keyboard functions have been defined as follows:

*****	rotary encoder controls frequency step size
0	rotary encoder controls output signal frequency
#	rotary encoder controls output signal level
0-9	output signal frequency

D	enter output signal frequency
A	modulation AM/FM/off
B	attenuator display format dBm or V
C	FM deviation: C0-C9 (C0 = 3 KHz; C1-C9 = 10-90 kHz)
D	output signal on/off

Notes:

- The desired output frequency does not appear at the output until ‘D’ is pressed.
- If FM is selected using key ‘A’, the display will indicate ‘F1’. After pressing ‘C’ (display: ‘F?’) the desired deviation may be entered using the number keys.
- By pressing ‘*’ you can set the step size applied to the current frequency on the display, i.e., the increment/decrement caused by one click of the rotary encoder. The step size appears in the left-hand bottom corner of the display. The output level appears at the other side.

Power supply

The complete circuit draws up to 400 mA at a supply voltage of 12 V, which allows a relatively small on-board mains transformer to be used. After rectification and smoothing, regulators are used to create the various supply voltage rails needed in the circuit. Each part of the circuit receives its own supply voltage: C3 on the control board looks after the microcontroller power supply, while IC4 and IC5 on the main board are the respective supplies for the DDS (plus clock oscillator) and the VGA.

Because the circuit has its own mains-connected power supply, due attention should be paid to electrical safety when assembling the electronics into a case. In particular, make sure a good strain relief is used on the mains cord. If desired the mains transformer may be omitted from the board in Figure 5 and replaced by a mains adaptor (battery eliminator) rated at 12 V / 0.5 A. Finally, a tip: a few turns of the mains cord through a ferrite cord will reduce RF leakage through the mains.

Construction

As already mentioned, the complete circuit is spread across two printed circuit boards — one for the signal generator proper and another for the control and power supply sections. The first board corresponds to the schematic in Figure 2 and its artwork is shown in **Figure 4**. For the second board the correspondence is between the schematic in Figure 3 and the PCB artwork in **Figure 5**.

The combined supply/control board of Figure 5 has a spacious layout and contains conventional components only, so should be easy to build by anyone with some practical skills in DIY electronics. Do not forget to fit any of the five wire links on this board.

The printed circuit board pictured in Figure 4 is a different kettle of fish. With stability in mind and in order to keep stray radiation to a minimum the design of the board follows the ‘great RF tradition’ of short connections, the smallest possible lead pitch for components and a maximum amount of electrical separation between various part of the circuit.

Building the signal generator board requires care, precision, good soldering skills and a steady hand. After all, IC2 and IC3 are SMD devices, which also applies to a dozen or so coupling and decoupling capacitors around these integrated circuits. Al these SMD parts are fitted at the **underside of the board**.

Soldering SMD components requires special skills. While IC3 is still relatively easy to handle, soldering IC2 in place could pose unexpected problems as the part has a pin spacing of just 0.65 mm. First carefully pre-tin the footprint of the IC and then remove as much tin as you can using fine desoldering braid. Use a drop of hobby glue to secure the IC in place. Use a magnifying glass to check that all the pins are properly aligned to the copper pads. If necessary, adjust the position of the IC and then allow the glue to cure.

With the IC firmly in place, first solder the centre two pins using plenty of solder tin and not caring too much about excess solder causing short-circuits. Allow the IC to cool down between subsequent solder actions. Once all pins are covered in plenty of solder tin, the excess amount can be removed by means of desoldering braid. Here, too, the IC should not be endangered by overheating so take your time.

The next step is to use an ohmmeter to check for short-circuits between adjacent pins. If any are found, re-apply the desoldering braid until no more short-circuits are found.

The photograph in **Figure 6** shows a finished prototype of the signal generator board while **Figure 7** zooms in on the underside of the board, showing the vicinity of IC2.

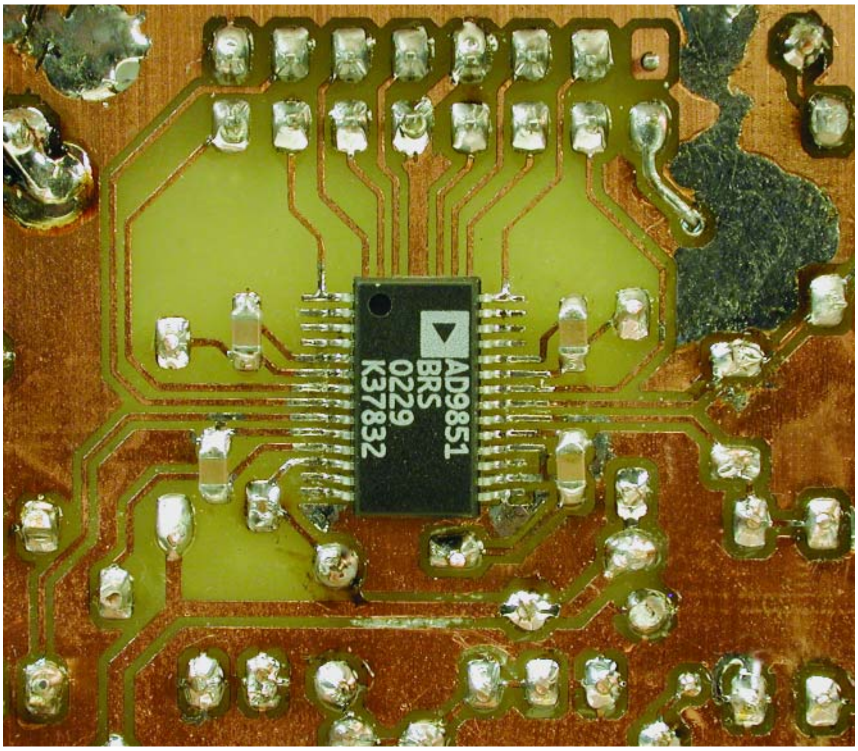


Figure 7. SMD integrated circuits IC2 and IC3 are fitted at the underside of the board, together with a dozen or so SMD passives. The mounting of IC2 is tricky owing to the small lead pitch of just 0.65 mm.

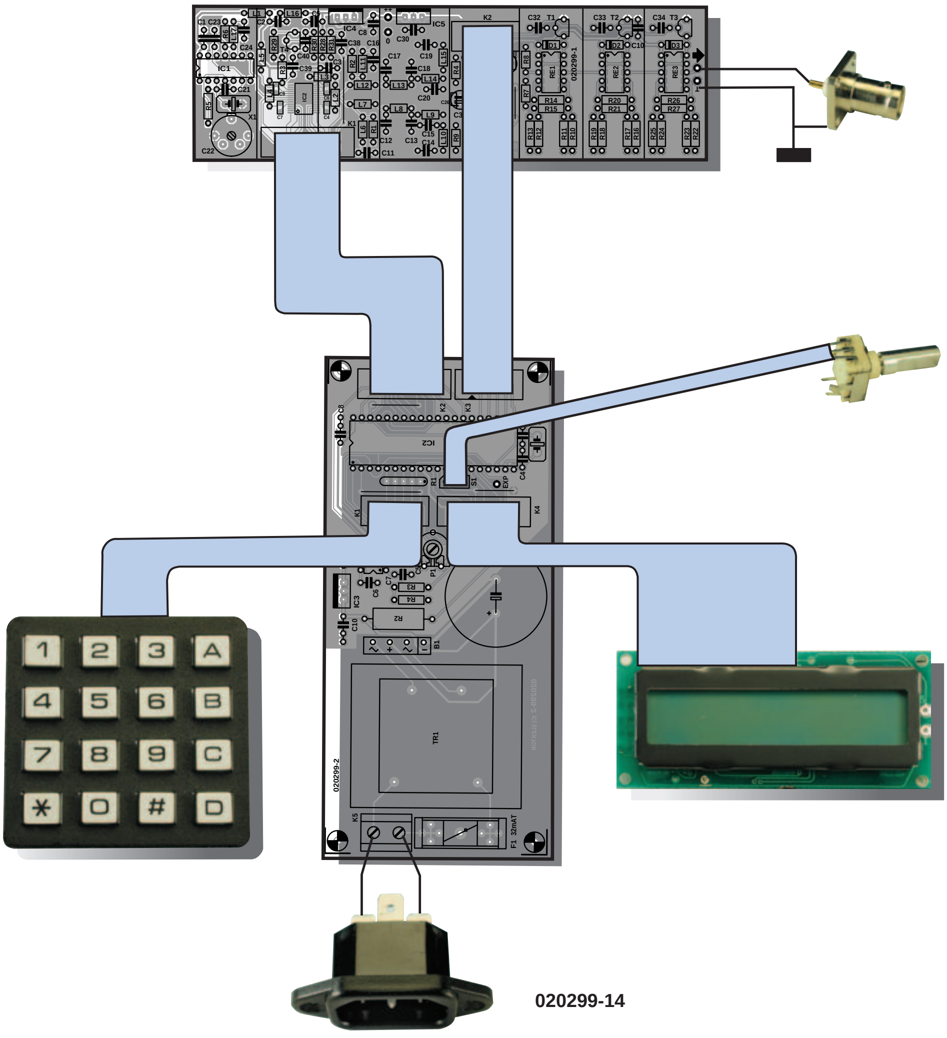


Figure 8. Wiring diagram.

Enclosure

For obvious reasons, a metal enclosure is a must for an RF signal generator and the project discussed here is no exception. The good news is that only a small enclosure is required, and suitable tin-plated steel cases with detachable lids are available in several sizes. In our case (pun intended), the required size is 160 × 48 × 25 mm. The signal generator board allows small metal screens to be fitted to separate the various circuit sections. The position of these screens is indicated by lines on the component overlay. In the case of our prototype, no differences were measured with the screens in place or removed, so we decided to leave them out. Perfectionists are, of course, free to fit whatever screens they think are necessary.

Next, the various units that make up the equipment may be assembled together allowing the complete signal generator circuitry to be mounted in a suitable case. Our prototype boards were fitted in a ‘custom’ case made from pieces of unetched circuit board of which the copper surfaces were connected by soldering. Electrically, such a DIY case is equivalent to one made from metal sheet.

As a further aid to your own construction work, **Figure 8** provides a basic wiring diagram showing how the two boards, the LCD and the rotary encoder are interconnected.

In the unlikely case of text failing to appear on the display immediately after switching on, do not panic and start emailing us, but first adjust the LC contrast control, P1. If the rotary encoder appears to ‘turn the wrong way around’, simply swap the wires to the two outer connections — the centre connection is ground.

Components

The author obtained all components for this project from RF specialist Barend Hendriksen in Brummen, The Netherlands (www.xs4all.nl/~barendh/Indexeng.htm).

The keyboard used in the prototype was a 16-key matrixed type supplied to us by Velleman (www.velleman.be). The LCD is an industry-standard 2 × 16 character alphanumeric type (Mitsubishi, Hyundai, etc.). The rotary encoder, finally, is a Bourns type with 24 detents per revolution.

Sensitivity measurements

In many cases, an RF signal generator will be used to measure the sensitivity of a receiver or IF amplifier. Usually, you’ll want to know the sensitivity in microvolts (μV) at a certain signal-to-noise ratio. The following method may be applied to obtain meaningful measurement results with a minimum of effort.

Connect the RF Signal generator to the receiver input by means of a short length of good quality 50-Ω coax cable like RG58C/U and ditto plugs. Switch off any computer equipment which is prone to leak spurious radiation into the receiver. Adjust the signal generator to the receiver frequency and then switch off the test signal by pressing the “D” key. Next, with the receiver volume control sufficiently ‘up’, use a multimeter or an oscilloscope to measure the level of the AF noise produced by the receiver. Switch on the test signal again and increase the output level from the lowest point (–127 dBm) to a level at which the AF noise level has dropped to a quarter of the that without an input signal. The difference represents a signal-to-noise ratio of $20 \log_{10}(4) =$ 12 dB, or “12 dB SINAD”. To obtain the 20-dB SINAD sensitivity value for your receiver, increase the generator output level until the noise voltage has dropped to 1/10th.

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