QEX

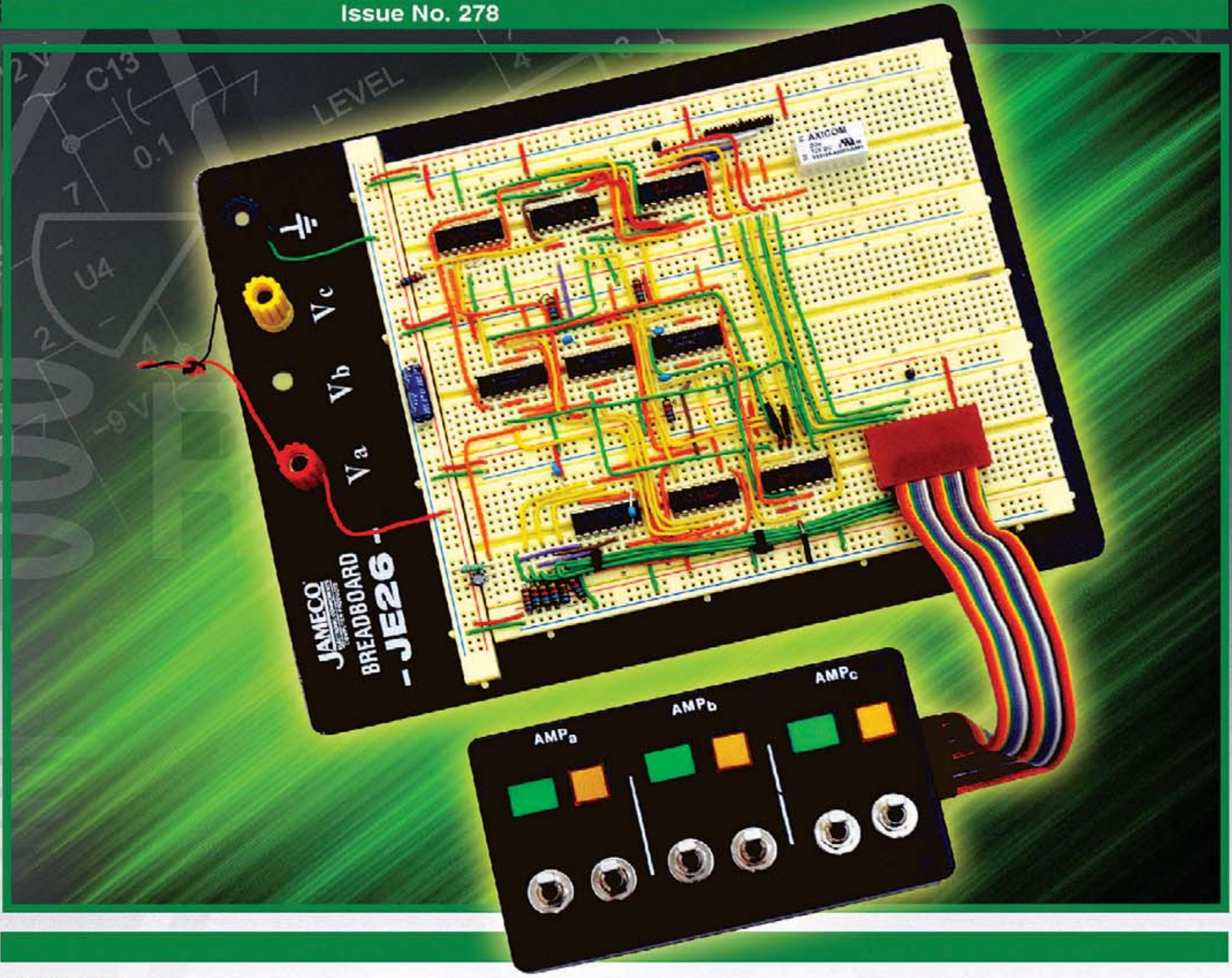
$5

May/June 2013

www.arrl.org

A Forum for Communications Experimenters

Issue No. 278



W8ZR built this breadboard prototype of the logic circuitry for his "Deluxe High Voltage Power Supply" during the design phase. This supply can select one of three different RF power amplifiers.

ARRL The national association for AMATEUR RADIO™
225 Main Street
Newington, CT USA 06111-1494

EVENT HORIZON OF DX

TS-990S

Dual TFT Display & Dual Receiver HF/50 MHz Transceiver

The main receiver has an IP3 in the +40 dB class, and the sub receiver is the already famous TS-590S receiver. Capable of receiving two signals at once, on different bands. 7-inch and 3.5-inch color TFT displays allow displaying of independent contents. Simplification of complex operations at a glance. Make no mistake, this is not a toy. Finally a serious tool is available for getting the very most from your hobby, of course it's a Kenwood.

- Covers the HF and 50 MHz bands.
- High-speed automatic antenna tuner.
- USB, Serial and LAN ports.
- Various PC applications (free software): ARCP-990 enabling PC control, ARHP-990 enabling remote control, and ARUA-10 USB audio driver.
- Clean 5 to 200 W transmit power through the 50 V FET final unit.
- Built-in RTTY and PSK.
- Three Analog Devices 32-bit floating-point arithmetic DSPs.
- DVI output for display by an external monitor (main screen display only).

KENWOOD

Customer Support: (310) 639-4200
Fax: (310) 537-8235

Scan with your phone to download TS-990S brochure.

www.kenwoodusa.com

JQA-1205
UKAS MANAGEMENT SYSTEMS
091
ISO9001 Registered
Professional Systems Business Group
JVCKENWOOD Corporation

ADS#11113

QEX (ISSN: 0886-8093) is published bimonthly in January, March, May, July, September, and November by the American Radio Relay League, 225 Main Street, Newington, CT 06111-1494. Periodicals postage paid at Hartford, CT and at additional mailing offices.

POSTMASTER: Send address changes to:
QEX, 225 Main St, Newington, CT 06111-1494
Issue No 278

Harold Kramer, WJ1B
Publisher

Larry Wolfgang, WR1B
Editor

Lori Weinberg, KB1EIB
Assistant Editor

Zack Lau, W1VT
Ray Mack, W5IFS
Contributing Editors

Production Department

Steve Ford, WB8IMY
Publications Manager

Michelle Bloom, WB1ENT
Production Supervisor

Sue Fagan, KB1OKW
Graphic Design Supervisor

David Pingree, N1NAS
Senior Technical Illustrator

Carol Michaud, KB1QAW
Technical Illustrator

Advertising Information Contact:

Janet L. Rocco, W1JLR
Business Services
860-594-0203 – Direct
800-243-7768 – ARRL
860-594-4285 – Fax

Circulation Department

Cathy Stepina, *QEX Circulation*

Offices

225 Main St, Newington, CT 06111-1494 USA
Telephone: 860-594-0200
Fax: 860-594-0259 (24 hour direct line)
e-mail: **qex@arrl.org**

Subscription rate for 6 issues:

In the US: ARRL Member $24, nonmember $36;

US by First Class Mail:
ARRL member $37, nonmember $49;

International and Canada by Airmail: ARRL member $31, nonmember $43;

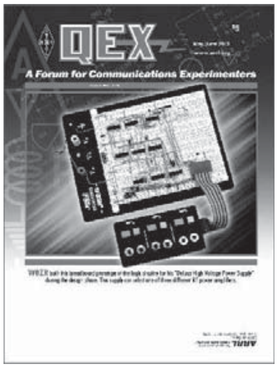
Members are asked to include their membership control number or a label from their QST when applying.

In order to ensure prompt delivery, we ask that you periodically check the address information on your mailing label. If you find any inaccuracies, please contact the Circulation Department immediately. Thank you for your assistance.

May/June 2013

About the Cover

Jim Garland, W8ZR, wanted a single "Deluxe High Voltage Supply" that could be used with three different RF power amplifiers. To design and debug the logic circuitry to control and select the appropriate amplifier, he built this prototype breadboard before converting the design to a circuit board.



In This Issue

Features

Index of Advertisers

American Radio Relay League:	Cover III
Array Solutions:	48
Down East Microwave Inc:	28
Kenwood Communications:	Cover II
National RF, Inc:	28
Nemal Electronics International, Inc:	15
Quicksilver Radio Products	Cover IV
RF Parts:	37, 39
Tucson Amateur Packet Radio:	48

The American Radio Relay League

The American Radio Relay League, Inc, is a noncommercial association of radio amateurs, organized for the promotion of interest in Amateur Radio communication and experimentation, for the establishment of networks to provide communications in the event of disasters or other emergencies, for the advancement of the radio art and of the public welfare, for the representation of the radio amateur in legislative matters, and for the maintenance of fraternalism and a high standard of conduct.

ARRL is an incorporated association without capital stock chartered under the laws of the state of Connecticut, and is an exempt organization under Section 501(c)(3) of the Internal Revenue Code of 1986. Its affairs are governed by a Board of Directors, whose voting members are elected every three years by the general membership. The officers are elected or appointed by the Directors. The League is noncommercial, and no one who could gain financially from the shaping of its affairs is eligible for membership on its Board.

"Of, by, and for the radio amateur," ARRL numbers within its ranks the vast majority of active amateurs in the nation and has a proud history of achievement as the standard-bearer in amateur affairs.

A *bona fide* interest in Amateur Radio is the only essential qualification of membership; an Amateur Radio license is not a prerequisite, although full voting membership is granted only to licensed amateurs in the US.

Membership inquiries and general correspondence should be addressed to the administrative headquarters:

ARRL
225 Main Street
Newington, CT 06111 USA
Telephone: 860-594-0200
FAX: 860-594-0259 (24-hour direct line)

Officers

President: KAY C. CRAIGIE, N3KN
570 Brush Mountain Rd, Blacksburg, VA 24060

Chief Executive Officer: DAVID SUMNER, K1ZZ

The purpose of *QEX* is to:

1) provide a medium for the exchange of ideas and information among Amateur Radio experimenters,

2) document advanced technical work in the Amateur Radio field, and

3) support efforts to advance the state of the Amateur Radio art.

All correspondence concerning *QEX* should be addressed to the American Radio Relay League, 225 Main Street, Newington, CT 06111 USA. Envelopes containing manuscripts and letters for publication in *QEX* should be marked Editor, *QEX*.

Both theoretical and practical technical articles are welcomed. Manuscripts should be submitted in word-processor format, if possible. We can redraw any figures as long as their content is clear.
Photos should be glossy, color or black-and-white prints of at least the size they are to appear in *QEX* or high-resolution digital images (300 dots per inch or higher at the printed size). Further information for authors can be found on the Web at **www.arrl.org/qex/** or by e-mail to **qex@arrl.org**.

Larry Wolfgang, WR1B

Empirical Outlook

Of Readers and Advertisers

Do you read the ads in *QEX*? Do you even look at them? Or have they become so familiar that you barely notice them?

Most magazines — *QST* included — use a "formula" of about 50% advertising and 50% editorial content for their pages. The reasoning is that the advertising revenue will pay the printing and distribution costs of the magazine. If the magazine is able to sell more advertising, more pages of editorial content are possible.

QEX does not follow such a formula. While the advertising revenue does help with some of the printing costs, the amount of advertising doesn't control the number of editorial pages we print. In many ways, the ads in *QEX* are there as a service to you, our readers. Your subscription pays a greater portion of the cost of publishing this *Forum for Communications Experimenters* than would be true for most other magazines.

If you have been a *QEX* reader for more than a few issues, you may have noticed that there aren't very many ads, and those we have tend to be pretty much the same, issue after issue. It is pretty easy to list our faithful advertisers. You probably expect a Kenwood ad on the inside front cover — Cover II in advertising terms. Within the pages of our magazine you will generally find ads from Array Solutions, Down East Microwave, National RF, Nemal Electronics International, two pages with ads from RF Parts and ad for the Tucson Amateur Packet Radio (TAPR) organization. It seems like there is an ARRL ad on the inside back cover (Cover III) much of the time.

Have you noticed a new advertiser on the back cover recently? Quicksilver Radio Products has taken a prominent place on Cover IV in 2013. This is a fairly significant leap for a small business owner trying to increase awareness of his products. The back cover of *QEX* is a high profile location.

Magazine display ads normally highlight one or two products, and represent only a small portion of a company's full product line. All of the ads in *QEX* include the URL for the company's website, where you will find a lot more information about that advertiser and the products they sell. Whether you are looking for parts for your next project, a piece of test equipment or a new radio or station accessory, our *QEX* advertisers may have just what you need.

When you are checking out the products offered by our advertisers, please let them know that you appreciate seeing them in *QEX*. They have made a choice to support our magazine with some of their money, but unless they believe the ads are attracting customers they may decide to spend those dollars somewhere else. Of course you may also see them in *QST* or even another Amateur Radio publication, so you can let them know you saw them there, too. The ads are easier to find in *QEX*, though, because there are not nearly as many of them.

QEX has a much smaller circulation than many other publications, but we also present a very targeted audience. You, our readers, represent the active builders and experimenters of our hobby. Advertisers normally look at the number of potential customers per advertising dollar spent, and a larger circulation represents more prospective customers and better value for their money. With our readership, though, they are reaching exactly the right audience.

Do you frequently buy from a supplier that does not advertise in *QEX*? Certainly there are other companies that could be advertising in our pages. When you contact those suppliers, suggest that they might attract more experimenters and builders by advertising in *QEX*. Let us know about those companies as well. Our advertising sales staff can contact them with the details about placing an advertisement. With additional advertising revenue, ARRL would be better able to control subscription costs in the face of rising costs for materials, printing and mailing *QEX*. So there is a very direct benefit for you.

While we are talking about controlling costs, I will mention another factor in the equation. One question that has been coming up more frequently is that of a digital version of *QEX*. ARRL has gained some experience with digital magazine publishing since launching the digital version of *QST* in 2012. That has proven to be quite popular with ARRL members. Why not do the same thing with *QEX*? Many readers have asked this question. In the case of digital *QST*, members have the option of receiving the printed *QST* and also accessing the digital version on their computers/tablets/smart phones.

While electronic storage is cheap and data transfer over cyberspace is free or very inexpensive, publishing a digital magazine is not necessarily cheap and certainly not free. ARRL has made the commitment to publish the digital edition of *QST* for those readers who want to have access to the journal in that way. It is a venture into a new world, and one that we see becoming more and more important.

When considering the possibilities for *QEX*, we have to consider the cost/benefit tradeoffs. The cost of preparing the pages of our magazine for digital publication would be the same per page no matter how many "copies" were being distributed. Even for a magazine with a small circulation, physical printing costs have certain quantity break points that help determine what is practical. We would probably not be able to sustain both a print and a digital version of *QEX*. That means there are many questions to consider, and careful evaluation is required before jumping off the cliff.

We are interested in your thoughts about a digital version of *QEX* versus the print version. If you would like to see a digital version, would you be willing to give up the print version? Send your thoughts to **qex@arrl.org**.

Rubens Fernandes, VK5FE

16 Tilly St, Mt Barker, SA 5251, Australia, **ruferna@gmail.com**

A Simple yet Precise Function Generator for the Experimenter

Clean sine waves from 0.1 Hz to 3 MHz, triangular waves up to 300 kHz, output from –110 dBm up to +10 dBm on 50 Ω, flat response, square waves, precise level and frequency adjustment and much more!

Many times I've missed having a general purpose generator on my workbench for testing digital circuits, audio amplifiers, filters in the audio range, keyer input of rigs, switching power supply loads on/off to check their performance when transmitting code and so on. On those occasions I normally had to quickly create simple circuits to overcome the situation until when, not long ago, I was testing a frequency counter on lower frequencies and needed a precise low-frequency generator.[1] The solution was to look among my friends for such an instrument, but I knew that wasn't a viable approach for the long term. That's when I promised myself that I would try to design my own simple, but reliable, generator as soon as possible.

The device that is presented here fulfilled my expectations, and some of the design ideas eventually can be useful to other experimenters as they build their own instruments. There are also many hams who enjoy assembling and testing quality audio amplifiers. Again, due to its spectral purity and flatness, a good general purpose generator could be helpful. For those interested in assembling the circuit shown here, fully functional firmware (a hex file) is available on the *QEX* web page at **www.arrl.org/qexfiles**. Look for file **5×13_Fernandes.zip**. I don't recommend this project for beginners as it uses SMD (Surface Mount Devices) extensively — one of them an MSOP (Mini Small Outline Package) with terminal spacing of 0.5 mm (0.02 inches).

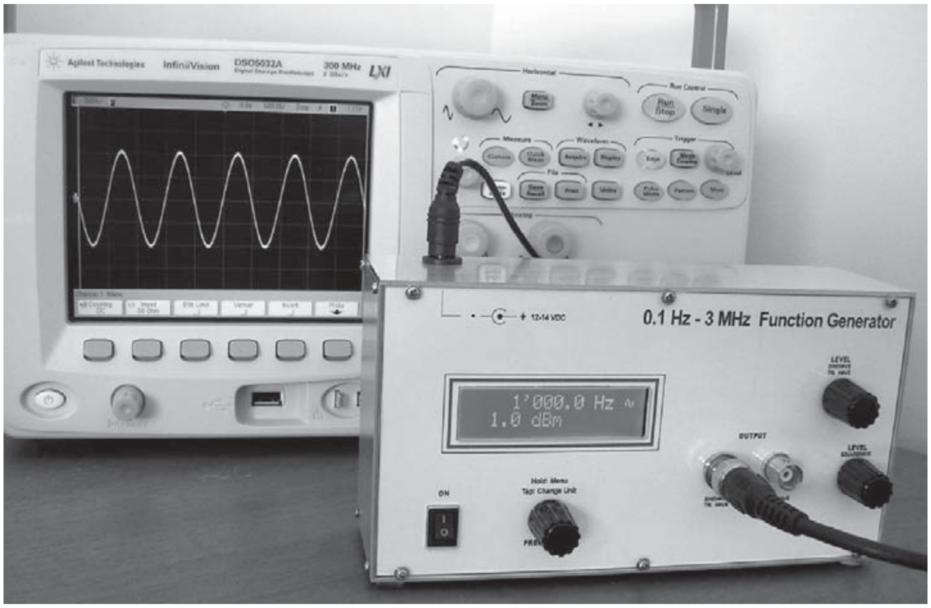


Photo 1 — The assembled Function Generator.

Architecture

The block diagram is shown in Figure 1 and the assembled unit in Photo 1. There are four boards: Main Board, that includes the time base, processor and DDS (Direct Digital Synthesis) chip, the Reconstruction Filter Board, the Amplifiers Board, with the final amplifiers and level adjustments and the Power Supply Board, which generates all the dc levels needed by the circuits.

The generator is capable of outputting fixed or swept sine waves, square waves and triangular waves. It is also a simple pulse generator. There is no provision for dc offset, adjustable rise and fall times or other fancy waveforms. Concerning the triangular waves, it's a bonus — the DDS chip can naturally output this waveform, but it had to be limited to 300 kHz as it is rich in odd harmonics and the reconstruction filter has a cut-off frequency of about 3 MHz.[2]

The auxiliary connector will output a 50 µs pulse each time a new sweep starts (when in sweep mode), that can be used for synchronization purposes. The pulse generator output is available at this same

---

[1] Notes appear on page 15.

connector and has fixed amplitude of 5 V_p only. Although very useful in the stage as it is now, eventually this generator will be upgraded to generate adjustable pulse levels, more precise pulse widths and better rise and fall times.

The 16 × 2 display has two modes; in the first one, the upper line will show the frequency and the second line the amplitude. From now on this mode will be called "normal display." The second is the menu mode, and for each menu option an adequate display disposition will be used.

Main Board

See Figure 2. I have chosen the AD9833, a not-so-new waveform generator for three reasons: first due to its low pin-count, second because I had some units bought for half the regular price from a major vendor and, finally, it has the specifications I needed.

As we know, the quality of the output of a DDS chip depends heavily on the quality of its time base. On the other hand, the quality of the output of a time base chip is dependent on its power supply. The SPX5205M5L33 is a low noise 3.3 V regulator and the CFPS-39IB is a 50 ppm time base and, working together with the AD9833, gave nice results, although not being expensive parts, as you will see in other topics. Notice that 50 ppm is the overall stability, considering the –40 to +85°C temperature range, the plus/minus 10% of supply voltage excursion and load variations. As load and supply are constant and keeping the temperature range inside let's say, 10°C, the stability will be very good. Nevertheless, the wake-up frequency of those time bases can vary and are not so accurate in respect to its nominal

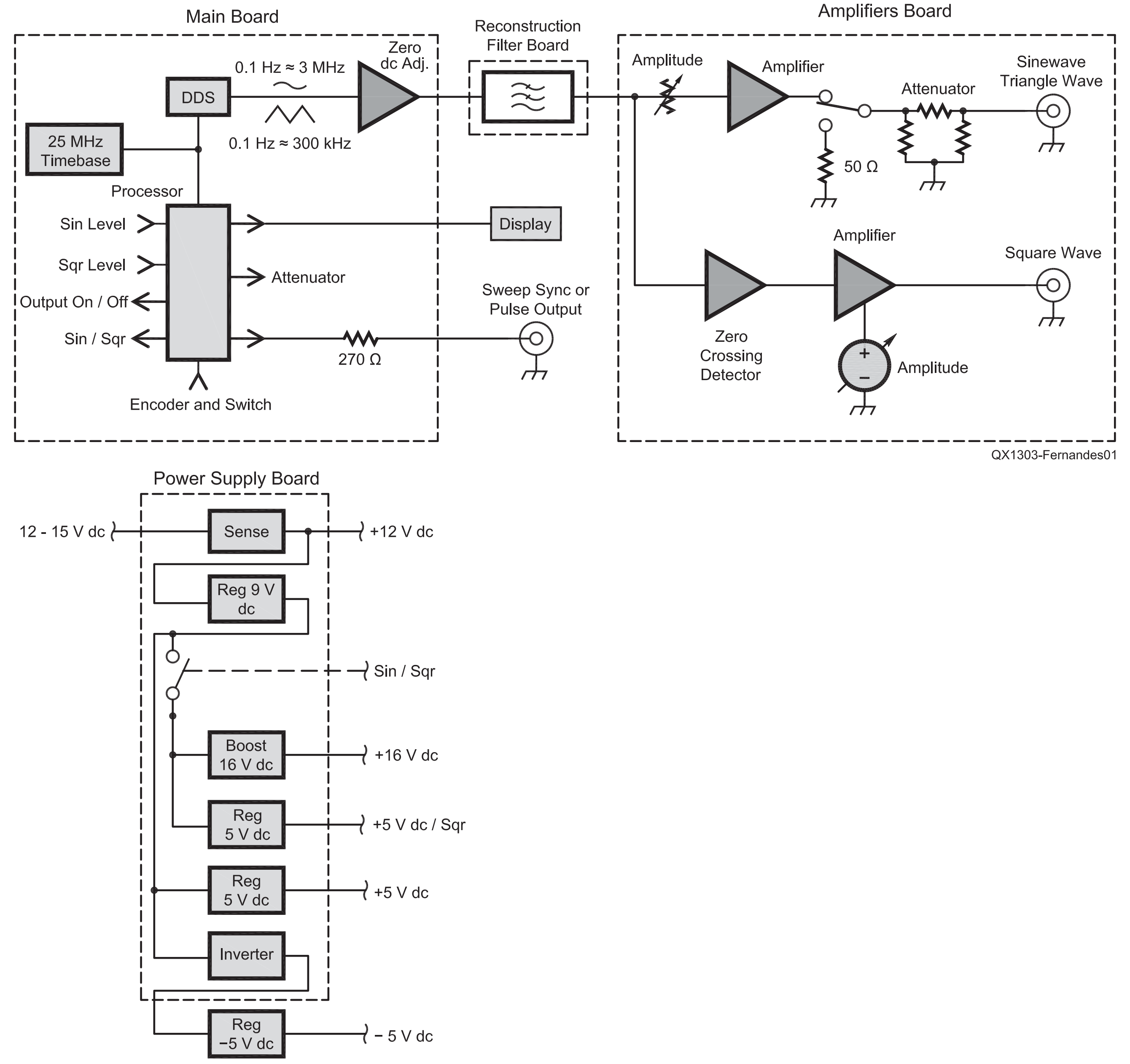
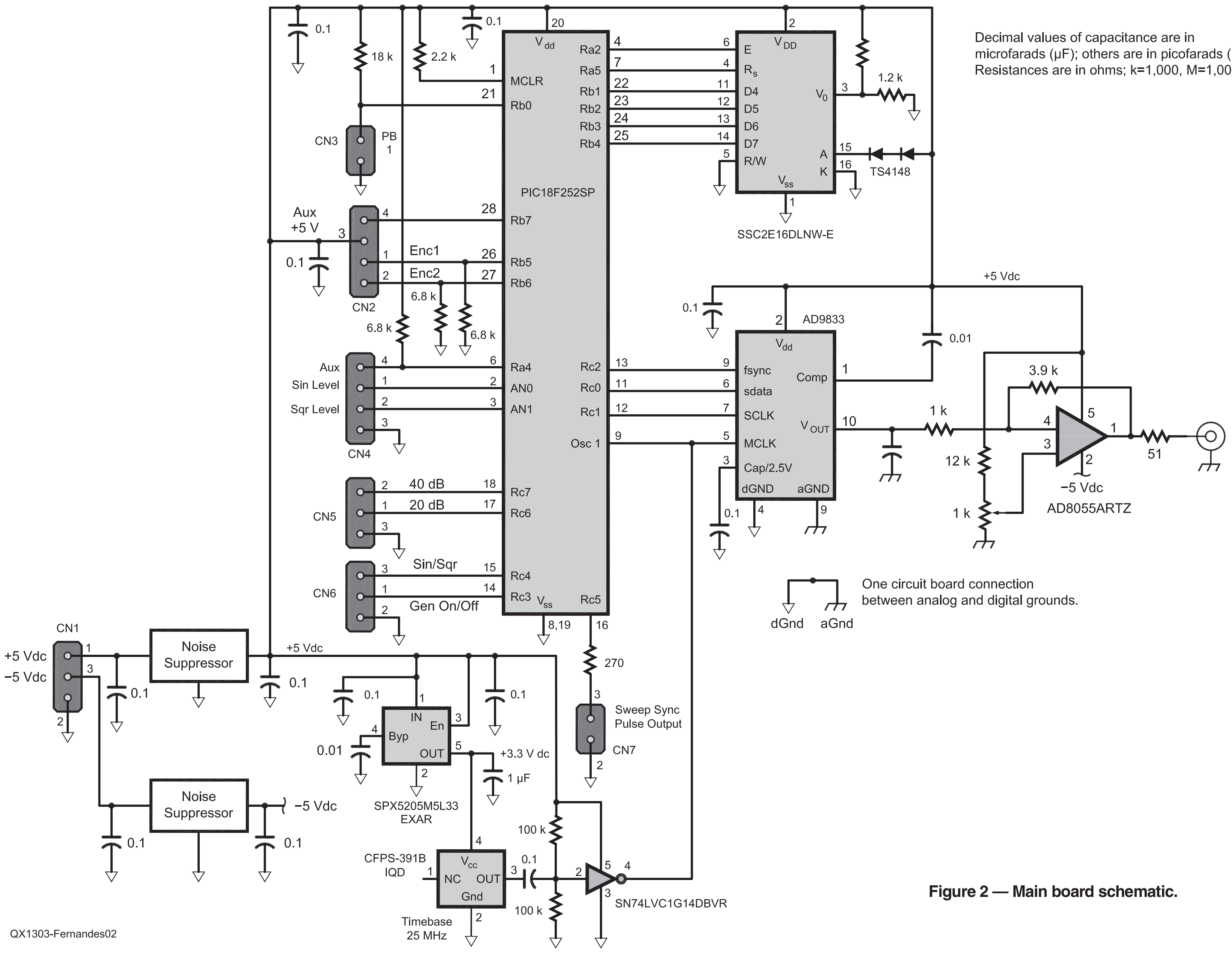


Figure 1 — Block diagram.



Decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); Resistances are in ohms; k=1,000, M=1,000,000.

Figure 2 — Main board schematic.

frequency. This creates an accuracy problem as the frequency output by the DDS is a fraction of the time base frequency. The solution was to include a calibration procedure to correct the reference frequency used in the calculations that have to be done each time the frequency in the chip is changed.

The inverter/Schmidt trigger was used mainly as a level adapter, as the time base uses a 3.3 V dc power supply and the processor and DDS are working with 5 V dc. The two components named *NS* are noise suppressors, used just as a precaution. The display is a conventional 16 × 2 unit, white-over-blue characters (less power consumption). For simplicity I avoided the use of a variable dc level for the backlight LEDs, using instead two diodes to reduce the voltage. With the same philosophy, the contrast adjustment is made with two fixed resistors. In fact, just the 1.2 kΩ resistor to ground should do the job. The external encoder is connected through CN2 and its switch via CN3. The AD8055 is a 300 MHz voltage feedback amplifier connected to have a voltage gain of about 4 and is also responsible for the 0 V dc level adjustment.

The main board implementation can be seen in Photos 2 and 3. Analog and digital grounds are separated and are connected in just one point of the printed circuit board.

Reconstruction Filter Board

See Figure 3. Although being a simple low pass filter, this circuit plays a very

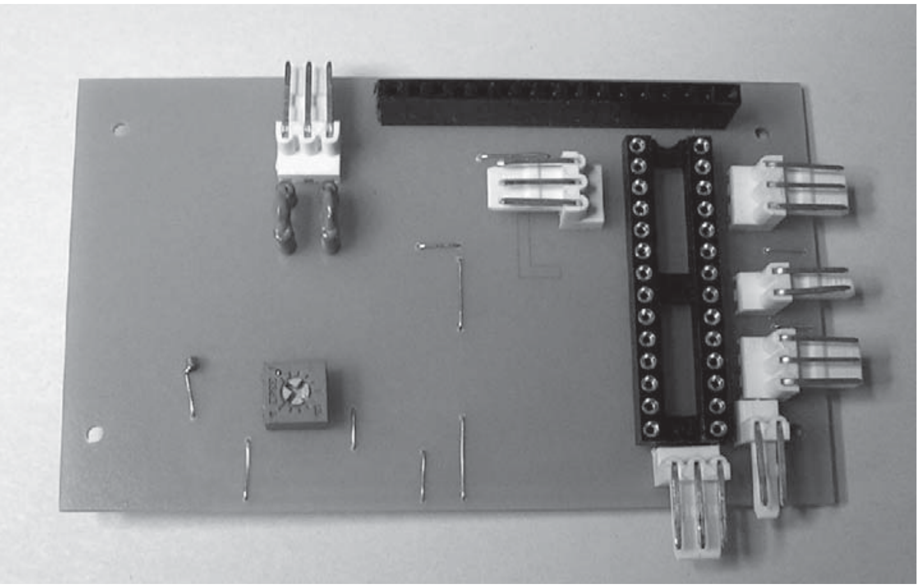
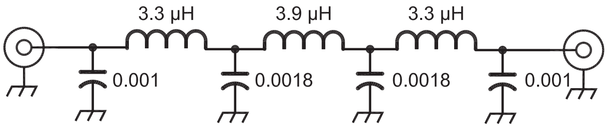


Photo 2 — Main Board, component side.



3.3 μH: 28T #28 T-37-2
3.9 μH: 30T #28 T-37-2

QX1303-Fernandes03

Figure 3 — Reconstruction filter board schematic.

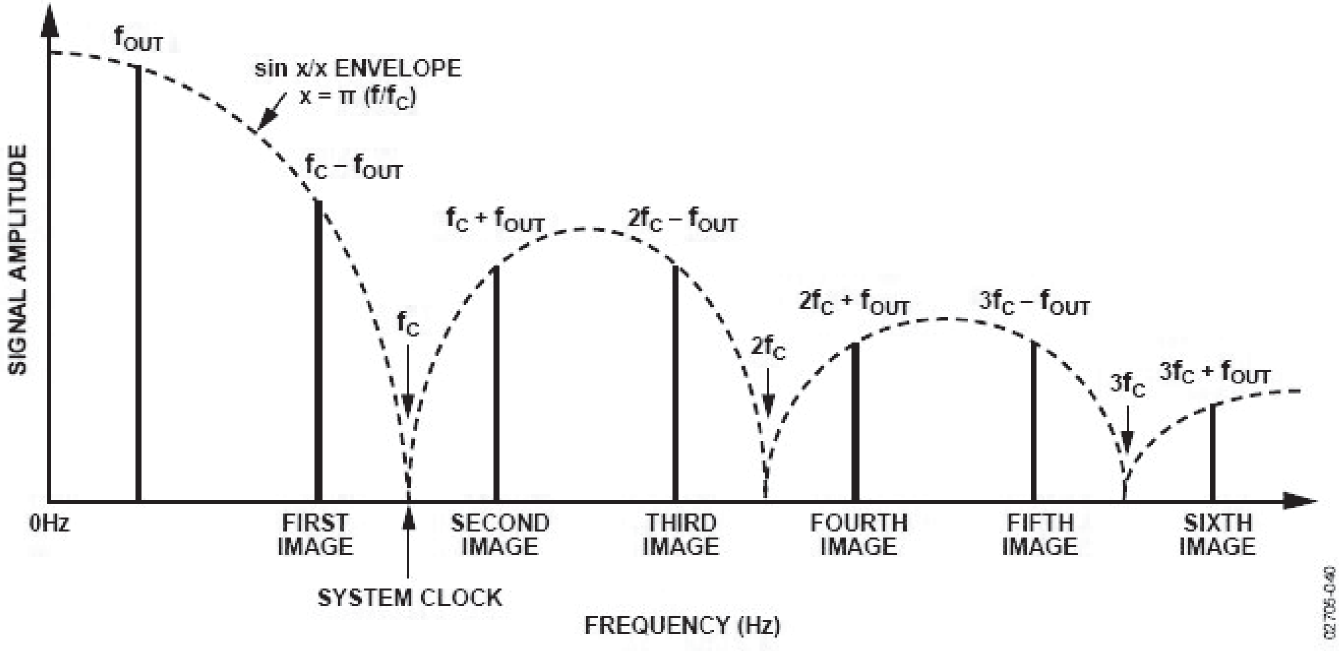


Figure 4 — Aliases (Courtesy of Analog Devices).

important role in the generator. A DDS chip like this one builds the waveform using discrete voltage samples whose amplitudes vary according to the shape you want (in this case, a sinusoid). It it is expected that the corresponding analog waveform will be reconstructed ahead, which is exactly the function of this filter — hence the name. Theoretically the chip can output signals up to half the frequency of the time base, according to the sampling theorem. However, one fact of life is that the process of generating the waveform also generates aliases. In other words, it adds distortions to the desired waveform. Aliases are images of the fundamental frequency that are repeated around the clock frequency and its harmonics; this is shown in Figure 4, borrowed from the Analog Devices documentation.[3] Additionally, things are a bit worse due to the fact that there is also an inevitable clock feed through, meaning that some amount of the clock frequency (and harmonics) is also present at the output (not shown in the figure). Other sub-products can also appear in the output.

The filter had to be designed and implemented taking into consideration the bandwidth of the amplifiers and the desired quality of the signal in the entire range. The filter had to respond far beyond the cut-off frequency, blocking all unwanted signals. The input and output impedance is 50 Ω and its shape is shown in Figure 5. The S_{21} parameter line is the gain magnitude (or the negative value of the insertion loss), and the S_{11} parameter line is the reflection coefficient magnitude (or the negative value of the return loss). Notice that there is a slight decay in the magnitude before reaching the knee, due to filter losses. Photos 4 and 5 show the assembled board.

Amplifiers Board

As can be seen in Figure 6, the input signal coming from the reconstruction filter is split in two and routed to two amplifier chains. In the upper section the sinusoidal and triangular waveforms are first amplified by the AD8055 and then directed to an attenuator having three sections of 20 dB. The first relay was included to provide a way of disconnecting the generator output, but keeping the 50 Ω output impedance. The 500 Ω potentiometer adjusts the gain of the stage and the network formed by the 1.2 kΩ resistor and 47 pF capacitor connected to Pin 4 compensates the filter losses mentioned before, actuating in the feedback loop of the operational amplifier.

One of the premises of this project was to precisely control and display the amplitude of the signal. The level of the sine and triangular waves is controlled with the association of a 10 kΩ linear potentiometer and the attenuator; the potentiometer range is a bit more than 20 dB, overlapped with each section of the attenuator. This association permits the control of the output level continuously from –70 dBm to +10 dBm.

For sensing the level of the sine and triangular waves, a different approach was used. The 10 kΩ potentiometer has a second gang connected to the +5 V supply and the center pin is connected to one of the analog to digital converter (ADC) inputs of the microprocessor. In other words, the processor keeps track of the position of the wiper and then "knows" how much the signal is being attenuated in the other gang. Although seeming very nice in theory, this procedure has a drawback: ordinary linear

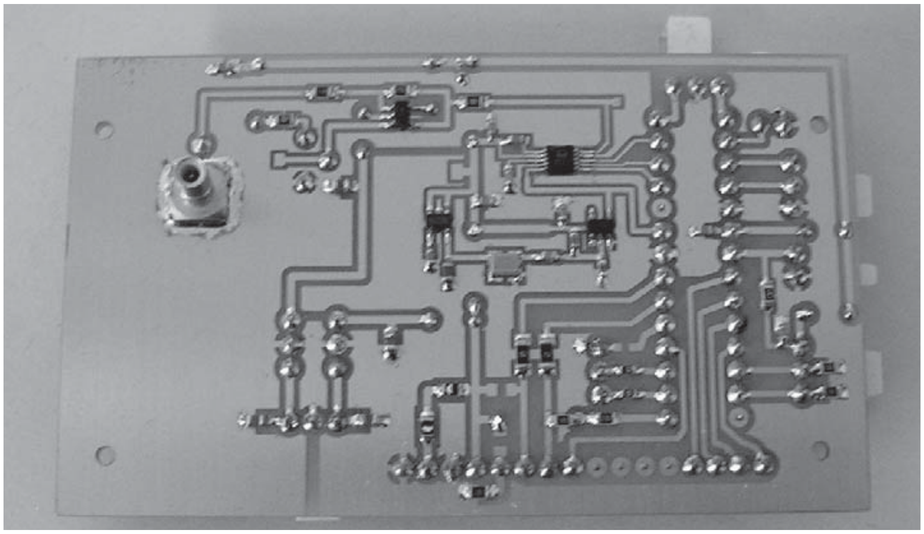


Photo 3 — Main Board, solder side.

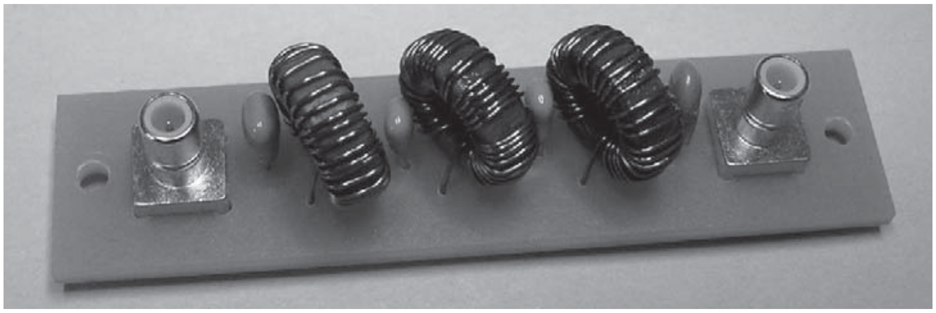


Photo 4 — Reconstruction Filter, component side.

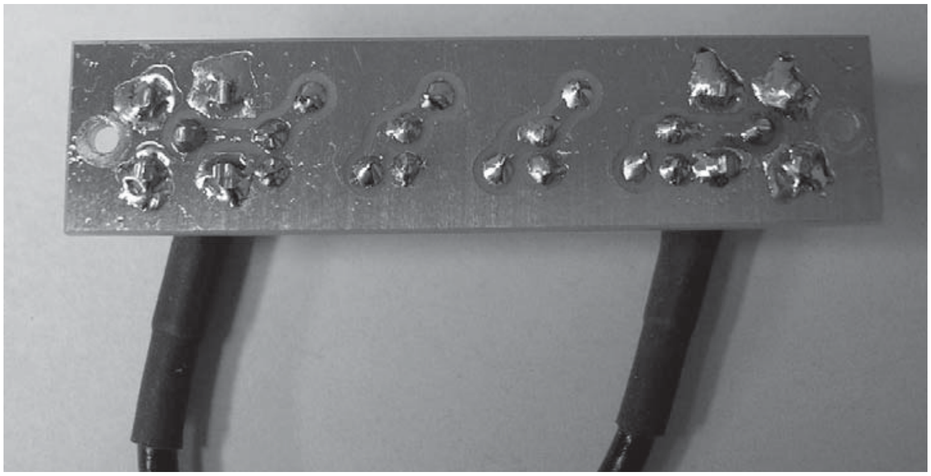


Photo 5 — Solder side of the Reconstruction Filter.

potentiometers are not so linear and have large variations in their nominal ohmic value. This was solved by "linearizing" the potentiometer (dividing the potentiometer curve in ten segments and interpolating linearly in-segment values) and creating a calibration procedure.

The other circuit section of the board is the square wave amplifier chain. The LMV7219M5 is a high speed comparator that needs just one power supply and is used to square the sinusoidal signal. This amplifier has an intentional internal hysteresis, meaning that the square wave transitions will be stable even at very low frequencies.

Since the AD9833 DDS chip can be programmed to output square waves, one may wonder why this feature was not used. The reason is that this square wave output is based on the most significant bit (MSB) of the internal digital signal before entering the DAC (digital to analog converter) and there is no guarantee that this waveform has a 50% duty cycle. The other reason is to present adequate rise and fall times to the final amplifier, as also is the inclusion of the network connected to the base of the first switching transistor.

The final amplifier has 50 Ω output and the square wave amplitude can be adjusted from about 250 mV$_p$ to 5 V$_p$ on 50 Ω, or twice this level when the output is connected to a high impedance load (>1000 Ω). The level adjustment is achieved with an LM317L and the 10 kΩ potentiometer, as can be seen in Figure 6. This level is sensed by another ADC channel of the microprocessor, reading the tension in the divider formed by the 12 kΩ and 8.2 kΩ 1% resistors.

The outputs of both amplifiers are routed to two BNC connectors and can withstand short circuits at any frequency or level. The rest of the circuit, the four BC846 transistors and associated components, are used to switch the relays. The board can be seen in Photos 6 and 7.

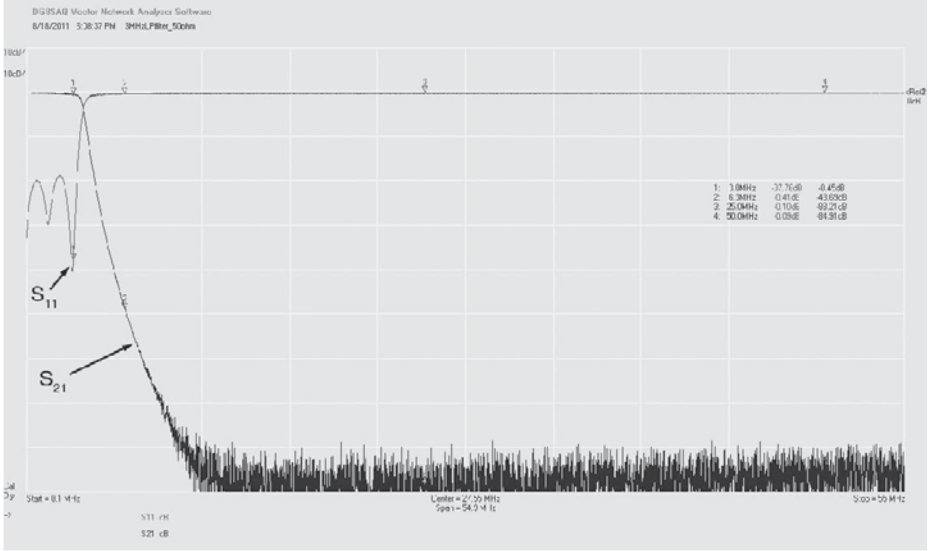


Figure 5 — Reconstruction filter response.

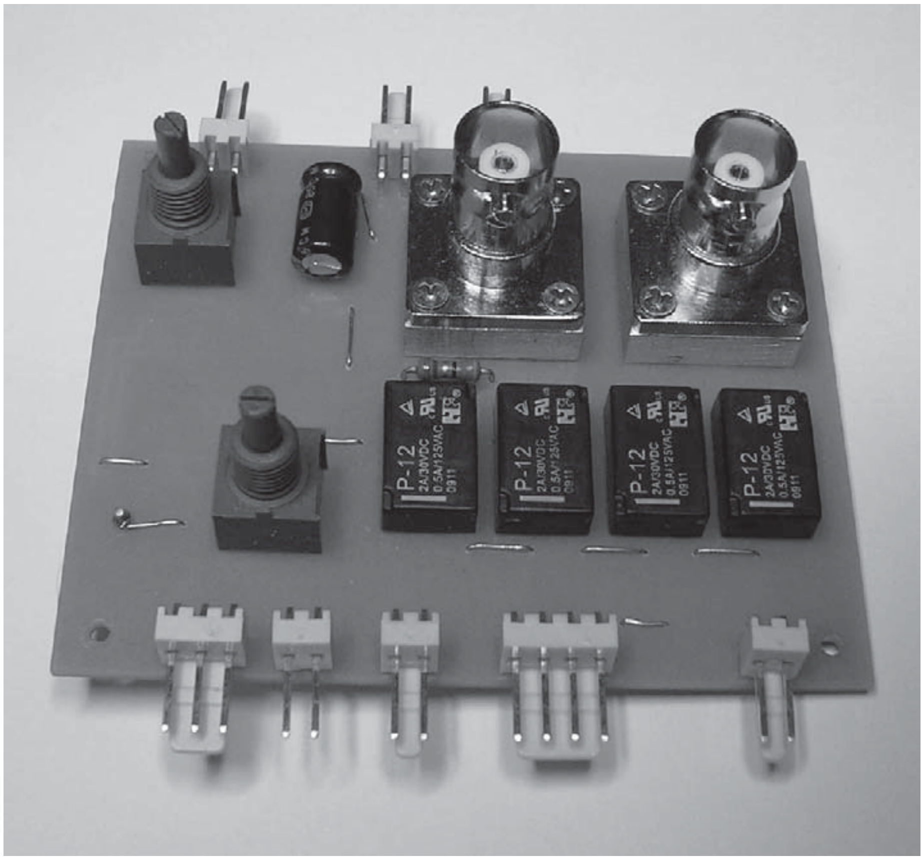


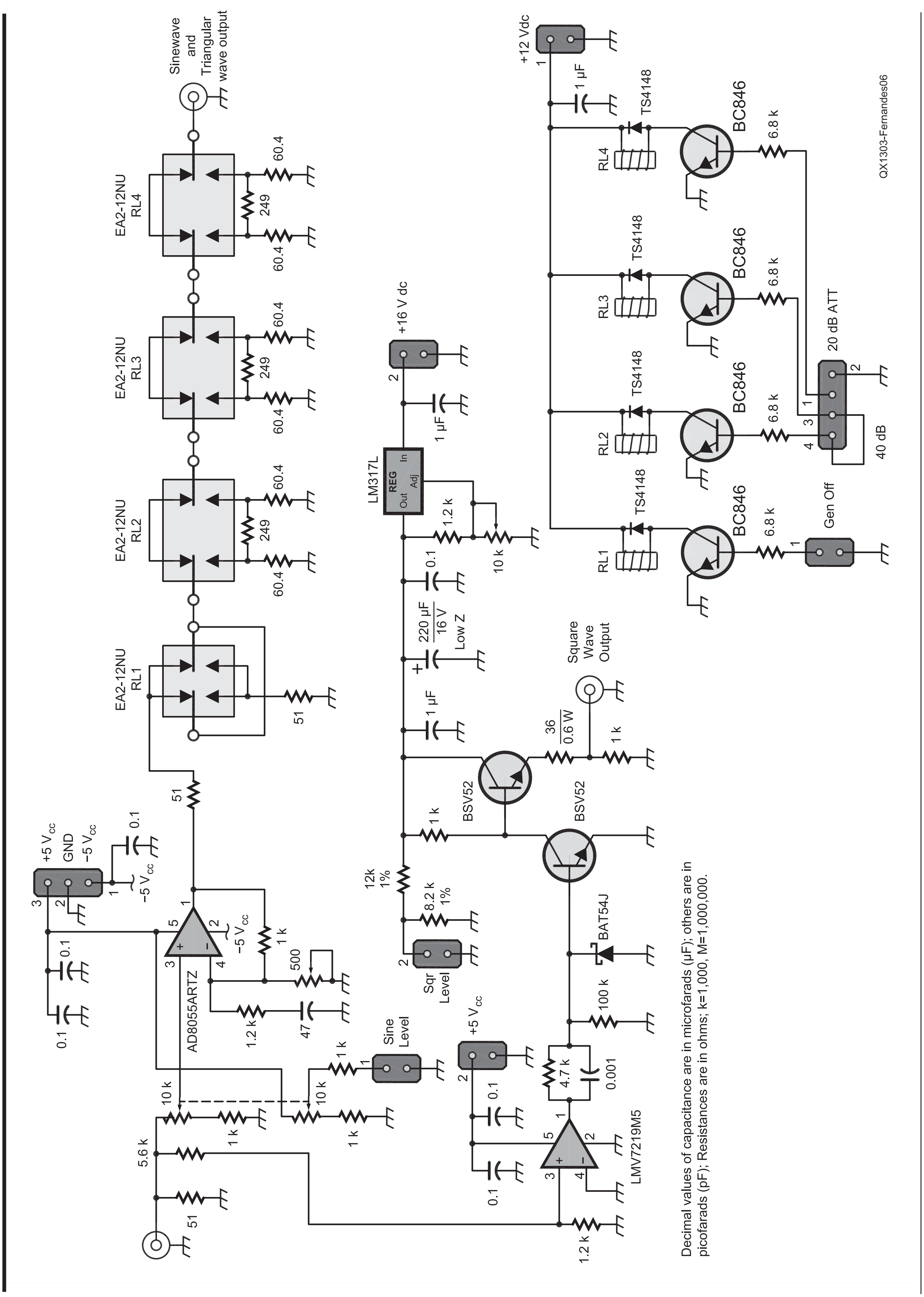
Photo 6 — Amplifiers Board, component side.

Power Supply Board

Figure 7 shows the schematic of the power supply and Photos 8 and 9 show how it was implemented. I normally prefer deriving internal supply levels from an external supply of about 12-14 V so that I can use the same supply my rigs use. At the input section we can see a protection network that will be activated in case of voltage surges, inversion of polarity or internal short circuits. This excess of precaution has its roots in past traumatic experiences from which I've yet to recover!

The LM317 lowers the level to 9 V and provides a first stage of regulation, feeding three other sections. The first section has a boost converter that generates +16 V dc and a +5 V dc regulator — voltages that are needed by the square wave amplifier. These two voltages can be switched off by means of the two PN2907As and the BC546, shutting down the square wave amplifier chain when not in use, preventing the noise generated by the fast rise and fall times from reaching the sine/triangular wave amplifier. This also decreases the total power consumption of the generator.

The lower branch has a switched-capacitor converter that generates the –5 V dc needed by the operational amplifiers and finally, the third branch has a +5 V dc regulator for general use. The +12 V dc needed by the relays is taken directly from the input voltage.



Decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); Resistances are in ohms; k=1,000, M=1,000,000.

Figure 6 — Amplifiers board schematic.

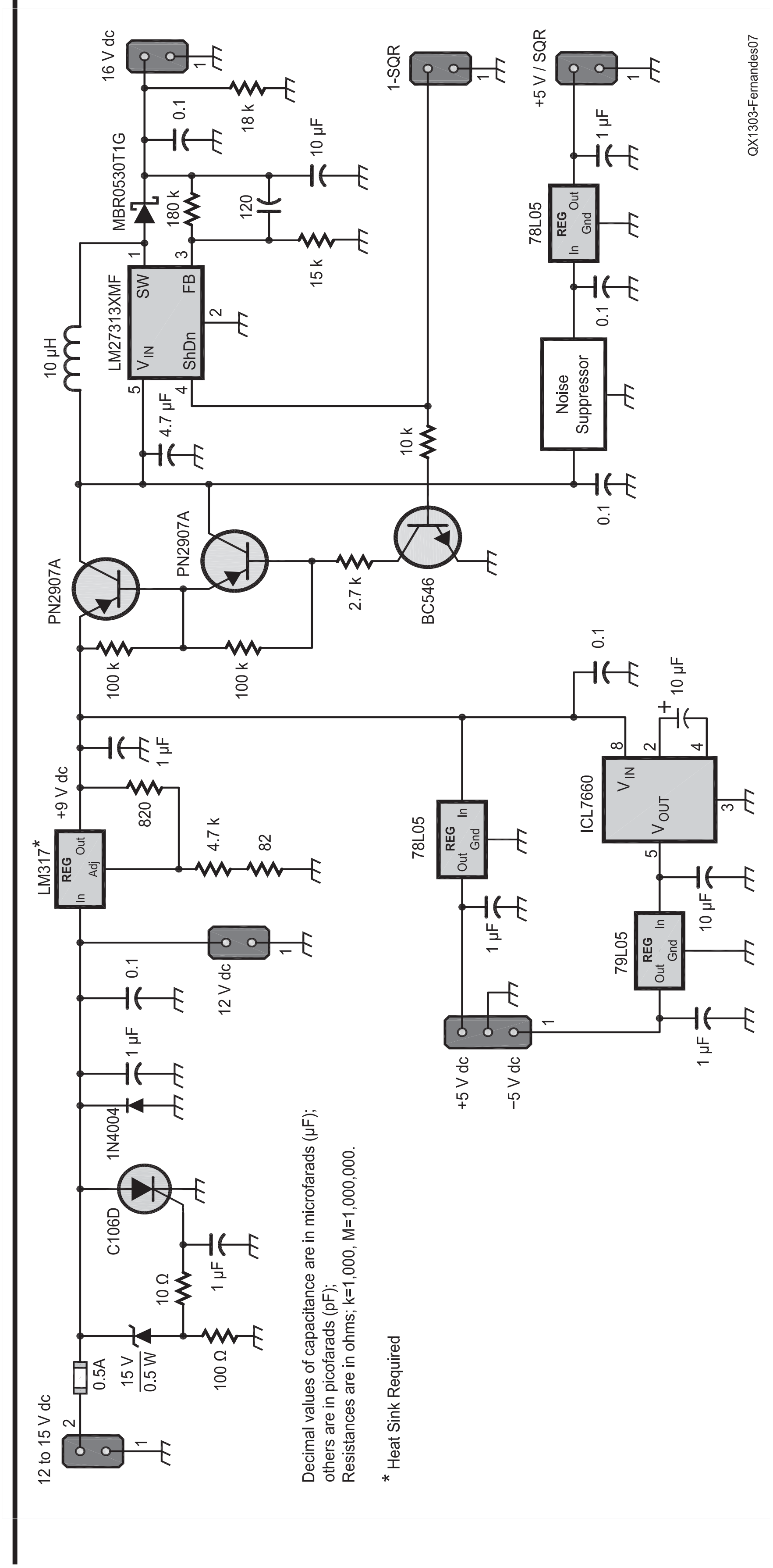


Figure 7 — Power supply board schematic.

Operation

The assembled unit can be seen in Photo 1. The encoder button is below the display and includes a switch; the other two buttons are for level adjustment of the sine/triangle wave and the square wave. Below, to the left, is the on/off switch.

For the sake of text simplicity, SCROLL is when you tap the encoder switch and ENTER is when you press and hold for a while. Optionally, you can also scroll using the encoder. You SCROLL to see the options of a circular menu or ENTER to select an option.

In normal operation, there are two lines: the upper line shows the frequency and the lower one shows the level of the signal (normal display). SCROLL to change the unit used for the level. For sine and triangular waves the units are mV_{rms}, mV_{pp}, mV_{p} and dBm (the former only with 50 Ω load). For square waves the units are mV_{p}, mV_{pp} (= mV_{p}) and mV_{rms}.

ENTER will take you to the main menu where you will have the following options: STEP, MODE, OUTPUT ON/OFF, HIGH Z/50 OHM, SWEEP, PULSE, SETTINGS, CALIBRATE and QUIT.

Step — 0.1, 1, 10, 100 Hz, 1, 10, 100 KHz, 1 MHz, Quit.

Mode — SINE, SQUARE, TRIANGLE, QUIT. When chosen, a corresponding symbol will be shown in the last position of the first line when in normal display. When the mode is sine or triangle, the square wave amplifiers will be powered down and vice versa.

Output Off/Output On — When the wave is disconnected, the sine/triangle output will still have 50 Ω and the square wave amplifier chain will be powered down.

Attenuator —100 dB, 20 dB, 40 dB, 60 dB, 80 dB, 100 dB, QUIT. The maximum internal attenuation is 60 dB; the other choices were included so the level will be presented correctly in the display when you use external attenuation. A special symbol will be shown in the second line (normal display) when there is attenuation.

High Z/50 Ohm — the level shown in the display will be corrected by a factor of two, depending on the choice. A special symbol will be shown in the second line (normal display) when High Z is chosen.

Sweep — when selected, a new menu will be shown:

Fstart — the frequency that was in the display will be the start frequency of the sweep

Fstop — the frequency that was in the display will be the stop frequency of the sweep

Finc — the frequency that was in the display will be the increment of the sweep

Go! — start sweeping

Quit — quit the main menu

Pulse — when selected, a new menu will be shown:

ON time — enter to choose the ON time of the pulses. Now scrolling will change the unit (ms, s, µs) and the encoder will change the time, inside the allowed limits.

OFF time — enter to choose the OFF time of the train of pulses. Same procedure as before.

Burst — enter to choose how many pulses to output — 0 means continuous.

Go! — start outputting pulses in the auxiliary connector.

Quit — quit the main menu.

Settings — when selected, a new menu will be shown:

Save Settings — all settings that are active at this moment will be saved and will be the new set of default settings.

Default Settings — all programmed settings will be replaced, without warning, by the "factory" default settings and will be the new set of default settings. This won't affect the calibration data.

Quit – quit the main menu.

Calibrate — when selected, a new menu will be shown:

Frequency — modify the offset using the encoder and enter to input

ADC ref. Level – modify the voltage using the encoder and enter to input

Min Sin Level – modify the minimum level using the encoder and enter to input

Sine Samples — for each of the ten entries, modify using the encoder and enter to input

Quit – quit to the main menu

Quit – quit the main menu

Calibration and Adjustments

The generator has default data saved in memory and will work reasonably without the need of calibration (except for the first item below). Nevertheless, to reach top performance, it is necessary to patiently calibrate the unit. For this, you will need a good multimeter, a calibrated counter and a scope. Any ordinary scope should work, but the multimeter must be capable of measuring ac voltages in the audio range. The calibration is done using the CALIBRATE option of the main menu and has to be done following these steps:

- Set the generator to sine wave, 50 Ω, 1 kHz, attenuation to 0 dB, level control fully clockwise (maximum output) and terminate the output with a 50 Ω load.

Move the zero line of the scope to the center of the screen (input grounded).

Connect the probe of the scope to the output of the generator and adjust the 1 kΩ potentiometer in the Main Board to center the sine wave. In other words, 0 V dc.

Without touching the generator controls, set the multimeter to ac, connect to the generator output and adjust the 500 Ω potentiometer in the Amplifiers Board to have 0.707 V_{rms}. This adjustment can also be done with a calibrated scope, setting the amplitude to 2 V_{pp}.

- Set the generator to sine wave, 1,000,000.0 Hz, output level of about 50 mV_{rms} and connect the counter to the output.

Go to the CALIBRATE menu, choosing the option FREQUENCY. Using the encoder, modify the offset for the closest reading in the counter. Notice that the offset is the correction, in Hz, that will be applied to the time base frequency and increasing the offset will decrease the output frequency. This is normal.

- Measure the dc level at pin 20 of the

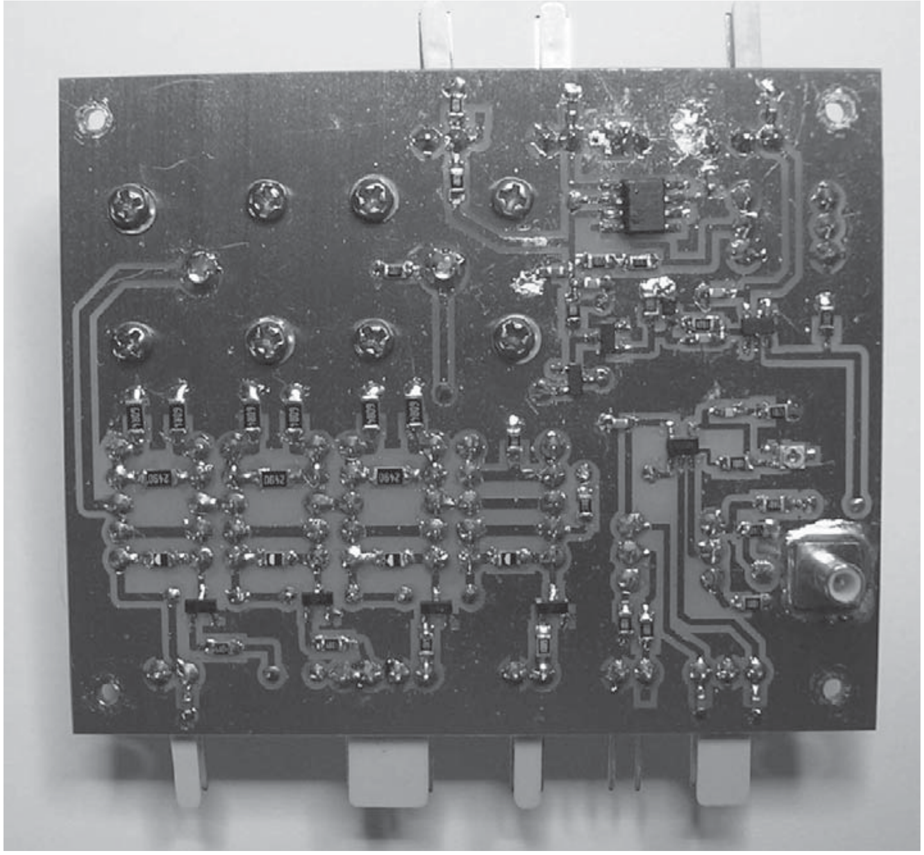


Photo 7 — Amplifiers Board, solder side.

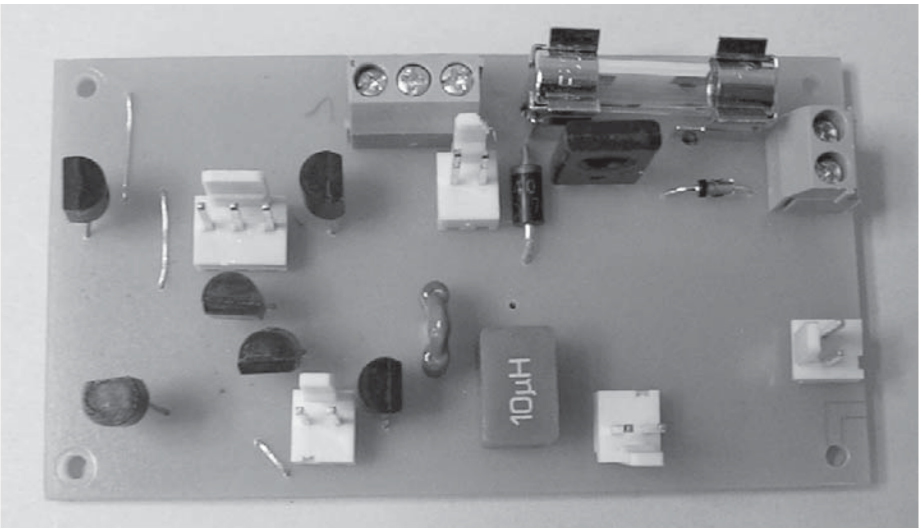


Photo 8 — Power Supply, component side.

microprocessor (+5.00 V dc supply nominal). Go to the CALIBRATE menu, choosing the option ADC REF. LEVEL. With the encoder, set the correct level. Press ENTER.

- Set the generator to sine wave, 1 kHz, level control fully anticlockwise (minimum level), 0 dB attenuation, output terminated with 50 Ω. Set the multimeter to ac, connect to the output and write down the reading. Go to the CALIBRATE menu, choosing the option MIN SIN LEVEL and adjust to the same level. Press ENTER.
- Keep the same set up used before but now choose the option SINE SAMPLES. For each entry (10 in total) adjust the level button to have the same (or as close as possible) level shown in the display and then press ENTER.

The generator is now calibrated and the data saved. There is no need of repeating this procedure unless new firmware is loaded into the microprocessor.

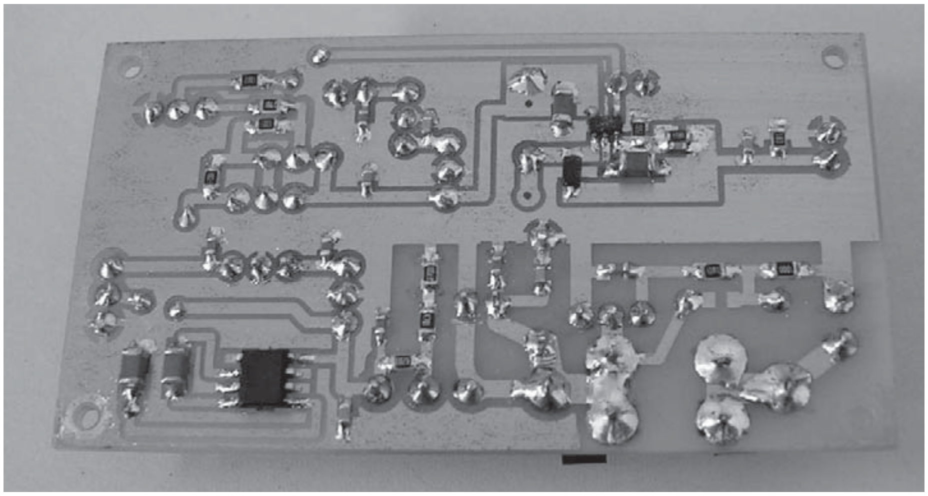


Photo 9 — Power Supply, solder side.

General Specifications/Performance

Modes — sine wave, triangular wave, square wave, pulse generator and sweep.

Frequency — 0.1 Hz to 3 MHz for sine waves and square waves and 0.1 Hz to 300 kHz for triangular waves. The stability with temperature not measured is probably around 5 ppm from 20 to 30°C

Phase Noise — please refer to Figure 8.

Spectral Purity (sine wave) — Total Harmonic Distortion (THD) = 0.07%.[6]

Level – Accuracy of indicated level better than 1.5% in the range (Sin / Vrms / 50 Ω)

Sine and triangular waves (50 Ω): < –70 dBm to +10 dBm with internal attenuation and about –110 dBm when external attenuation is added.

Square wave (50 Ω): <+240 mVp to +5 Vp — referenced to ground.

Square wave:

Rise Time: <13 ns (Figure 9)

Fall Time: <1.5 ns (Figure 10)

Duty Cycle: 50/50 (no noticeable asymmetry)

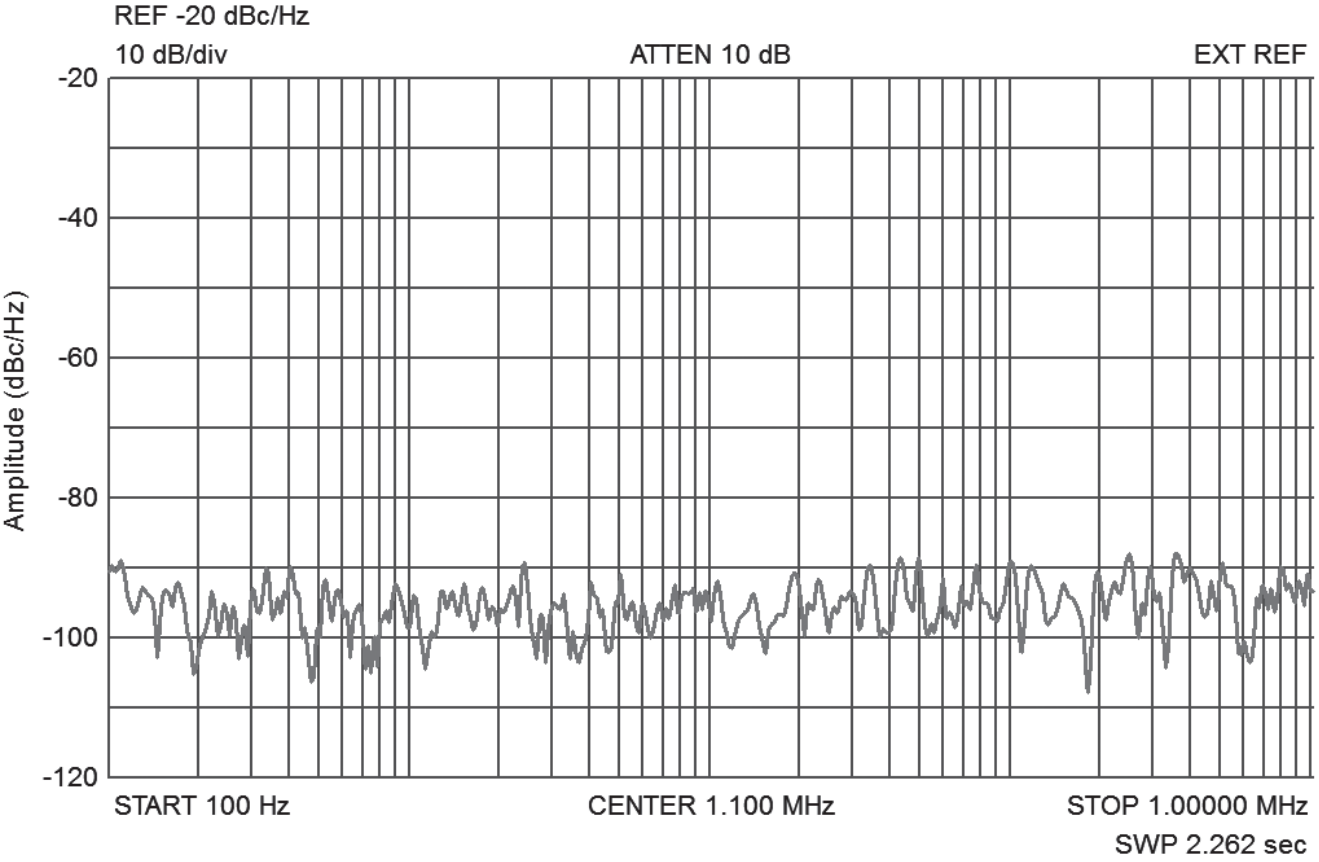


Figure 8 — Phase Noise.

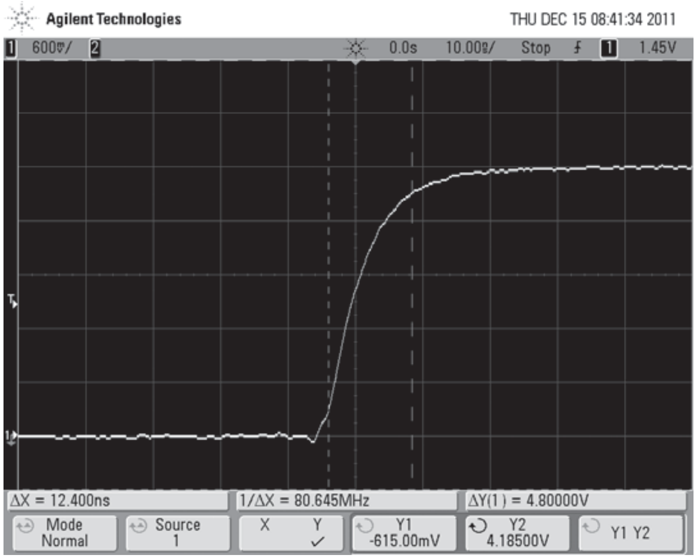


Figure 9 — Rise Time.

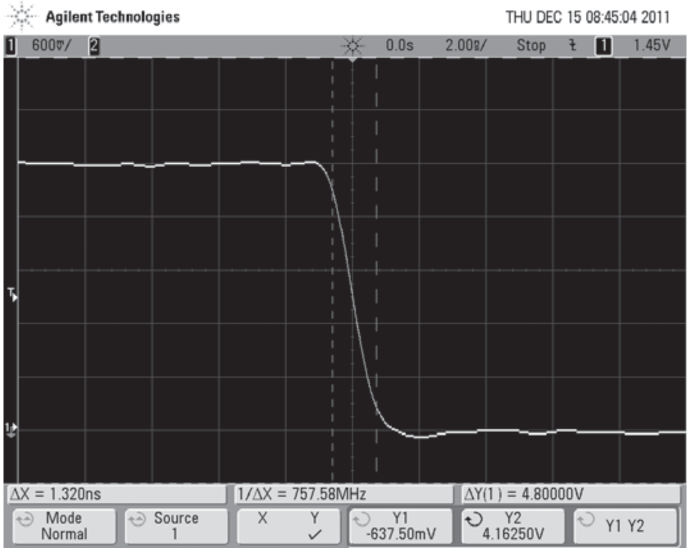


Figure 10 — Fall Time.

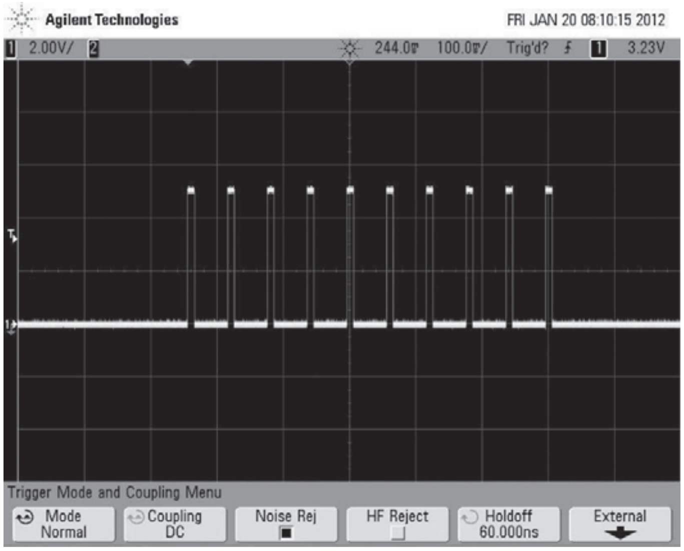


Figure 11 — Pulse Generator.

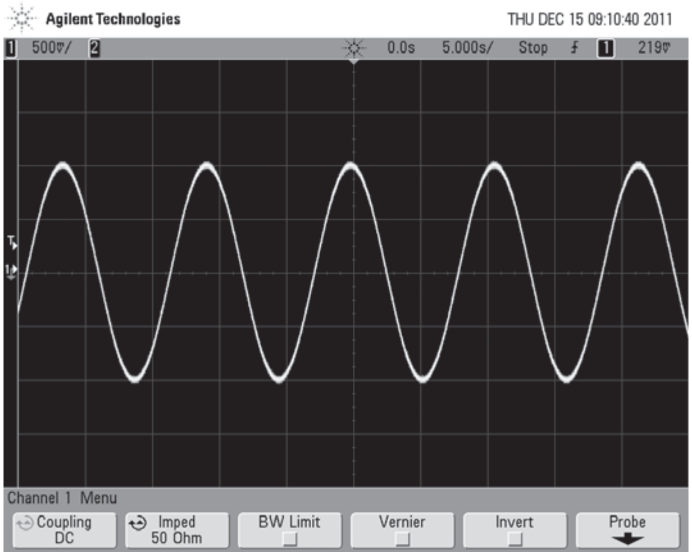


Figure 12 — Sine wave; 0.1 Hz.

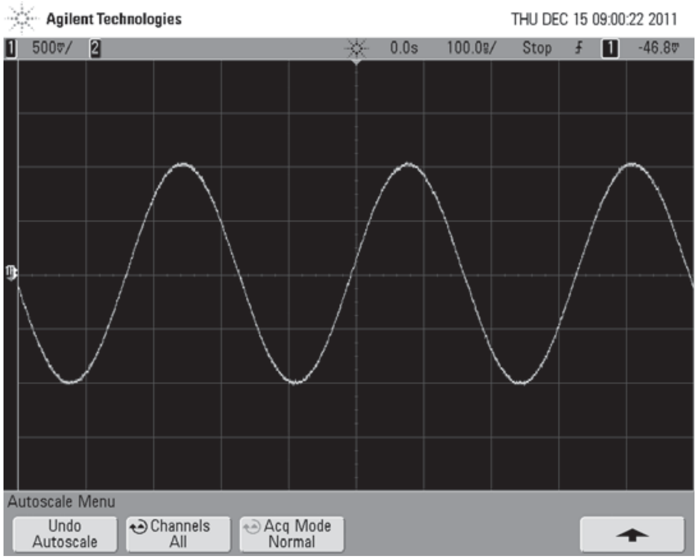


Figure 13 — Sine wave; 3 MHz.

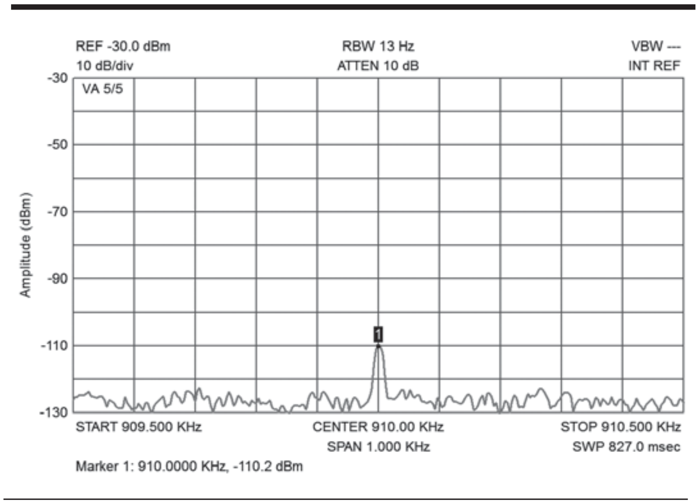


Figure 14 — Noise Floor.

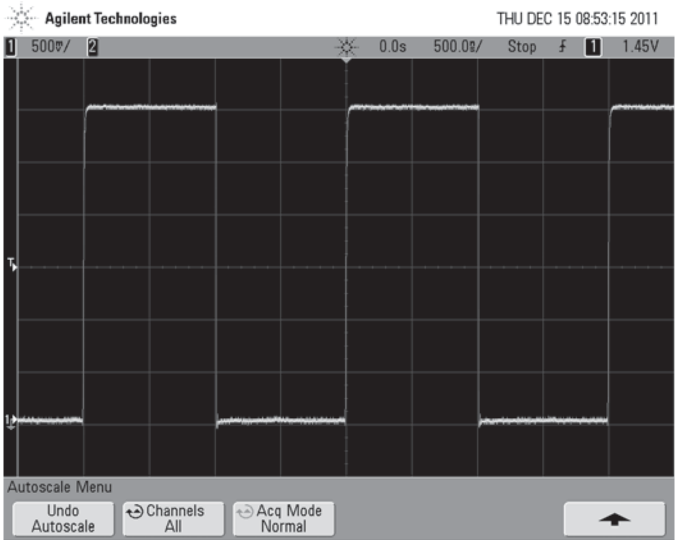


Figure 15 — 500 kHz square wave.

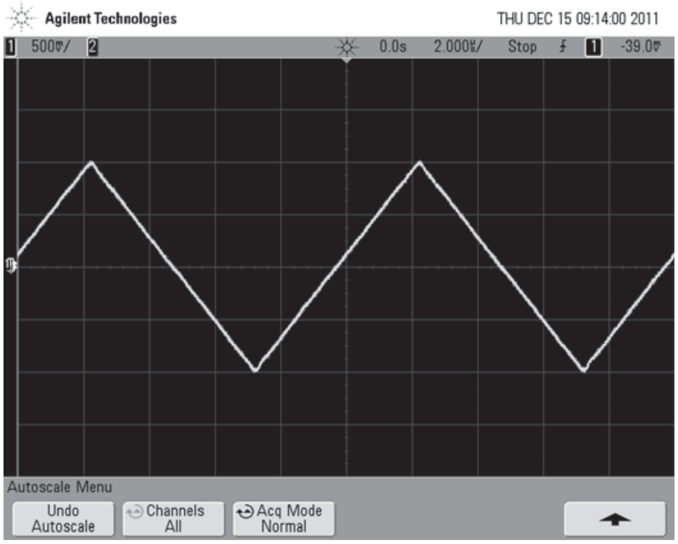


Figure 16 — 100 kHz triangular wave.

Ringing/Undershoot: <2%

Pulse generator — ON and OFF time adjustable from 10 μs to 65 s. Output on the auxiliary connector. (Figure 11)

Attenuator — only for sine waves and triangular waves, from 0 dB to 60 dB. Accepts additional 40 dB of external attenuation.

Observing the sinusoidal waveforms shown in the screenshots of Figures 12 (0.1 Hz) and 13 (3 MHz), we can't notice difference in the amplitudes. Figure 14 shows that a –110 dBm signal can easily be seen above noise level. Figures 15 and 16 are typical square and triangular wave outputs.

The THD was calculated with the help of a spectrum analyzer and the oscilloscope screenshots shown were taken with a 300 MHz bandwidth digital instrument, 50 Ω input.[6]

Implementation

The boards and enclosure were made with one-sided phenolic boards. For the signal connection among boards, I used 50 Ω coaxial cable (3 mm outer diameter) and SMB connectors. The components references are suggestions based on my own implementation; many components have thru-hole versions and some just don't, as is the case of the DDS. For simplicity, Element14 (formerly Farnell/Newark – **www.newark.com**) will be referred to as "E14" and RS Components (**www.rs-components.com**) as "RS."

The PIC18F252 has to be thru-hole and have a socket, due to the fact that there is no provision for in-circuit programming. By the way, although Micro Chip is suggesting the use of the PIC 2520 (pin compatible and almost identical) for new designs, the 252 can still be found normally in the market.

Eventually the part number for the display won't be found, although being the chip inside standard, there are many variations in the market related to the pin disposition and the LCD (Liquid Cristal Display) itself. The RS 532-6385 part is pin-compatible, the only difference being the inversion of the backlight diodes connection. Anyway, practically any standard 16 × 20 white-over-blue letters display will work.

Level adjustment potentiometers are Bourns dual-gang part number 3310H-1-103L (Element14 9353925 or RS 522-0546).The second gang is not used for the square waveform level adjustment; it is used only for mechanical reasons. Notice that those parts have ⅛ inch shafts and will require adequate knobs. I'd suggest Elma 040-3020 (E14 1209805).

The encoder is Alps, part number EC12D1524403 and will require a small adaptation board as it is not a panel mount unit. Any one of the family EC12D15XXXXX should work, as the difference is the torque required to turn the encoder and the strength to push the button. It was chosen because it is reliable and not expensive; other encoders probably will not work. It can be found at E14 (2065074) or Mouser (688-EC12D1524403) and will cost less than $2. It has a 6 mm shaft and if you intend to use the knobs suggested for the potentiometers, the knob Elma 020-3420 (E14 320419) will match in appearance. In this case, don't forget to buy three caps Elma 040-3020 (1209805).

The signal relays, although they are indicated in the schematic as NEC part number EA2-12NU (E14 25M9064), the Altronics S4130B will work nicely. For the two main output connectors I used Amphenol 31-203-RFX BNC connectors (E14 2508699276), also for mechanical reasons.

The T-37-2 iron powder torodial cores and the #28 AWG magnet wire used in the reconstruction filter can be bought from Amidon (**www.amidoncorp.com**).

Resistors are all SMD 0805 1% (although this tolerance is not really necessary in many positions), except the 36 Ω 1% 0.6 W resistor (amplifiers board – RS 148-146). Capacitors are normally SMD 0603 50V (NP0 5%, for values under 10nF). The transistors, +5 V and –5 V regulators and the LM317 in the power supply and the microprocessor are thru-hole; other integrated circuits and transistors are SMD.

Table 1 shows the Element14 codes for not-so-common components. For some of them I have included also the RS Components part numbers in the Notes column.

Final Words

I want to extend a special thanks to the WIA (Wireless Institute of Australia) that recognized my previous background and forwarded my application to the Communications and Media Authority and also to NERC, the North East Radio Club of Adelaide. I am particularly grateful for the assistance provided by Peter Watts, VK5PX, who guided me through the required tests and procedures to have my call sign granted.

I would like also to point out the importance of some resources that make the life of the experimenter easier. For instance, the excellent Tom Baier, DG8SAQ's Vector Network Analyzer published in *QEX* and the set of filter design tools made available by AADE.[4, 5]

Finally, a comment concerning printed circuit boards. It is well known that fiberglass printed circuit boards have better quality,

Table 1

Component	*Description*	*Package*	*Board*	*E14*	*Notes*
Processor	PIC18F252	SP	main	4113690	467-2047
Capacitor	4.7 µF/25 V	1206	power supply	1458912	
Capacitor	10 µF/25 V	1206	power supply	10R6412	
Capacitor	220 µF/16 V	TH	amplifiers	8126305	low Z
Noise Suppressor		TH	power supply/amp	9527508	Murata
Diode	BAT54J	SOD323	amplifiers	1261336	
Diode	MBR0530T1G	SOD123	power supply	1431036	
Diode	TS4148	0805	main/amplifiers	8150206	
Amplifier	AD8055ARTZ	SOT235	main/amplifiers	1267935	538-4088
Comparator	LMV7219M5	SOT235	amplifiers	1174640	534-4765
DDS	AD9833BRMZ	MSOP	main	1581966	523-6428
3.3V regulator	SPX5205M5L33	SOT235	main	1762871	Exar
Time base	CFPS-39IB	SMD	main	1276647	IQD
Inverter	SN74LVC1G14	SOT235	main	1470878	
Adj. Reg.	LM317L	SOIC	amplifiers	1652326	
Trimmer 1 kΩ	PVZ2A102A01B00		main	3531466	Murata
Trimmer 500 Ω	PVZ2A471C04B00		amplifiers	1771720	Murata
Booster	LM27313XMF	SOT235	power supply	1564771	National
Converter	ICL7660A	SOIC	power supply	1562068	Intersil

from the point of view of RF signals and stability, compared to phenolic boards. On the other hand, phenolic boards are very handy: they can be used for lower frequency circuits and are great to make shielded enclosures. They can be easily machined without the need of special bits, mills and tools and you won't have the highly abrasive and health-aggressive fiberglass powder in suspension or destroying your milling machine lead screws. The problem is that one sided phenolic boards have disappeared from the retail market; I have sent a message to the local Altronics but to no avail. I am still struggling to find other sources.

Notes

[1] Rubens Fernandes, VK5FE, "A Frequency Counter for the Experimenter," May/June 2010 *QEX*, pp 10-15.

[2] M. E. van Valkenburg, *Network Analysis,* Prentice-Hall.

[3] Analog Devices, *Application Note AN837.*

[4] Thomas Baier, DG8SAQ "A Small, Simple, USB-Powered Vector Network Analyzer Covering 1 kHz to 1.3 GHz," Jan/Feb 2009 *QEX*, pp 33-36.

[5] **www.aade.com**

[6] $THD (\%) = 100 \times SQRT(V_2^2+V_3^2+V_4^2+V_5^2) / V_1$

Rubens Fernandes earned a BS in Electrical Engineering in 1970 and worked for about 31 years in the telecommunications industry in research, design and production. He retired in 2004. He has been a licensed Amateur Radio operator since 1979 and held the call signs PY2FXJ and PY2QE while living in Brazil and VK5FE since September 2010 in Australia. Rubens is a CW enthusiast. He now dedicates his spare time to home brewing small transceivers and test equipment. He has a small workshop that includes mechanical, electrical and software facilities. ***(www.VK5FE.com)***

James C. Garland, W8ZR

102 Spur Ranch Rd, Santa Fe, NM 87540-7574; **w8zr@arrl.net**

A Deluxe High Voltage Supply

If you have several RF power amplifiers, here is one power supply to run them all.

A half-century ago Larry Kleber, K9LKA, published one of the most popular construction articles in the history of Amateur Radio. Appearing first in November 1961 *QST* and subsequently in eight editions of *The ARRL Handbook*, plus other ARRL publications, the article featured single-band kilowatt amplifiers that shared a common high voltage power supply. Despite the obvious financial benefits of sharing a power supply — typically the most costly part of a high power linear amplifier — this practice has seldom been imitated, even though amplifier building continues to be extremely popular among "homebrew" devotees.

Sharing a high voltage power supply is harder than it might seem. In K9LKA's original design, 2000 V was simultaneously applied to all connected amplifiers, with the filament and screen voltage (the amplifiers used 813 tetrodes with "instant-on" filaments) switched only to the selected amplifier. Today this practice would not only be considered unsafe, but technical advances in amplifier design now necessitate a more sophisticated approach requiring flashover protection, avoidance of metering interaction problems, and so forth.

Figure 1 — The two high voltage power supplies are identical, except for different voltage ranges. Each rests on the floor behind an operating table and independently powers up to three legal-limit RF power amplifiers.

Despite the obvious convenience of relegating a heavy high voltage power supply to an inconspicuous spot behind an operating desk, the practice of using a separate power supply has lost favor among commercial linear amplifier manufacturers. Once a staple of commercial designs, as in the venerable RL Drake linear amplifiers of the 1970s and '80s, external HV power supplies significantly increase manufacturing costs, in large part because of safety and liability concerns. Safely routing several thousand volts through the rat's nest of cables behind the typical operating desk is a serious and expensive enterprise, and manufacturers are no longer willing to assume the risk of using a single unshielded wire to do the job. (Although used in many commercial designs several decades ago, no manufacturer would today consider using the classic J.W. Millen HV connector, which has no strain relief and uses an unshielded conductor held in place by a single blob of solder.)

The high voltage power supplies described here (two power supplies were built, identical except for different output voltages) are intended to overcome these concerns, in effect bringing the benefits, convenience and economy of the 50-year-old design pioneered by K9LKA into the twenty first century. The results, shown in Figure 1, are contest-grade power supplies rated for legal limit continuous duty service in any mode, with substantial "headroom." They sit on the floor behind an operating table, each allowing independent control of one, two, or three remotely located RF decks. For example, one RF deck could be dedicated to 160 m and another to 6 m, both popular bands that vintage commercial amplifiers seldom cover. High power monoband amplifiers are relatively easy to build and design, with none of the tradeoffs and expenses necessitated by multiband designs. (A ceramic multideck high-power band switch, purchased new, can cost more than $500!)

For these power supplies, internal logic circuits handle all the switching and control functions for each RF deck, with vacuum relays designed specifically for dc voltages, safely routing high voltage only to the selected amplifier. (Each power supply is intended for single-operator use, in which only one RF deck is on-line at a time.) Simplicity of operation was an important design goal. Thus, operation of a power supply requires only two momentary-action pushbutton switches on each RF deck, one that toggles on and off the low voltage circuits (blowers, filaments, etc.) and a second that toggles the RF deck on-line or off-line. The low voltage circuits for each RF deck may be turned on simultaneously, but an interlock circuit permits only one amplifier at a time to be on-line. A power failure resets all the control circuitry to an off state, so that the supply must be manually powered up after the power is restored.

Features

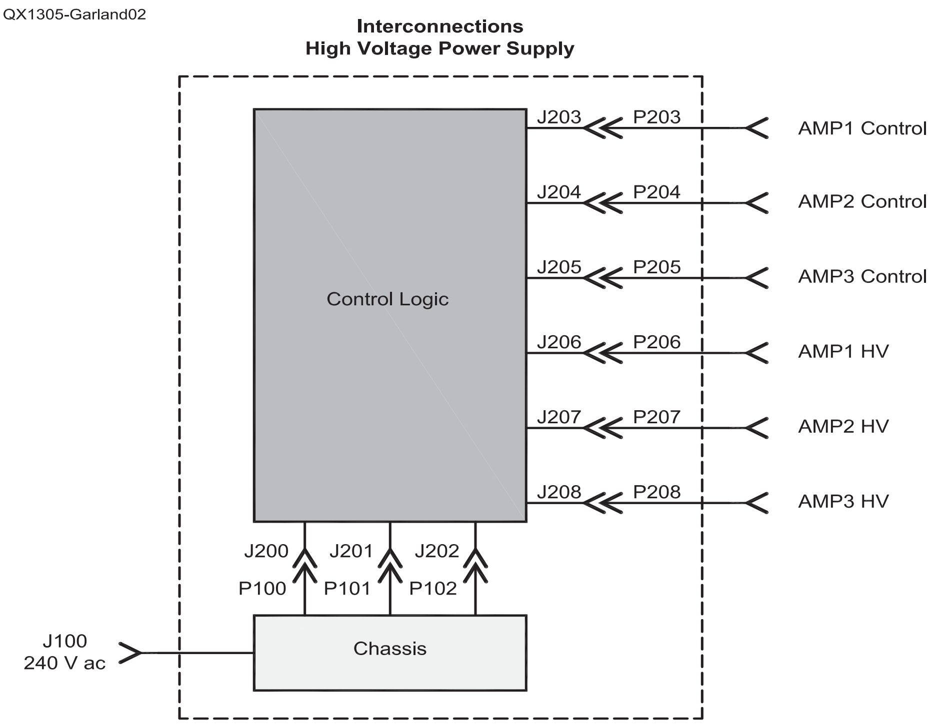
Each power supply is remotely operated by a connected RF deck via a 10 conductor shielded cable. The cable provides switched 120 V ac for powering filaments, blowers, and low-voltage circuits, as well as other connections for power and on-line switching, high voltage metering, plate current trip and reset circuits, indicator lamps, and so forth. The high voltage connection to each RF deck is made through a shielded length of RG6/U coaxial cable, using high voltage BNC connectors rated at 5000 working volts. For safety purposes, the connectors are designed with reverse polarity pins (the male pin is in the jack, rather than the plug), with recessed contacts ensuring that the grounded shield is always connected before the center conductor makes or breaks contact. Other than the 240 V ac circuit breakers and a safety "HV Enable" key-operated switch that must be closed to allow the HV circuits to operate, a power supply has no controls or switches.

Gigavac G81A vacuum relays rated for switching high voltage dc loads up to 10 kV at 5 A transfer the high voltage to the selected RF deck only when that deck is switched on-line. An internal power relay selects primary taps on the plate transformer so that different plate voltages can be automatically assigned to a selected RF deck. Thus, one power supply provides 4500 V dc to two amplifier ports (intended for RF decks using a 3CPX1500A7 triode), and 3700 V dc to the third port for an amplifier that uses 3CPX800A7 triodes. The second power supply, identical to the first except for the plate transformer and filter capacitor, is designed for lower voltage tubes running 2500 to 3000 V dc, such as the 3-500Z and the GU-74B

Circuit Description

Chassis Components

As shown in the block diagram of Figure 2,



Control (AMP1, AMP2, AMP3)
AMP 14 pin
Mouser 571-206043-1

1 - GND
2 - L1 Switched
3 - GND
4 - Ip Reset
5 - LV Control
6 - PWR Pushbutton
7 - Neutral
8 - Spare
9 - HV Meter
10 - In/Out Pushbutton
11- Standby LED
12 - GND
13 - B −
14 - GND

P102/J202 - Status LEDs
Molex 0.100 with Lock 8 pin
Mouser 538-22-01-2087
Mouser 538-22-03-2081

1 - Amp1 PWR
2 - Amp1 HV
3 - Amp2 PWR
4 - Amp2 HV
5 - Amp3 PWR
6 - Amp3 HV
7 - Standby
8- +12

HV (Amp1, Amp2, Amp3)
Kings High Voltage BNC 1 pin + GND

P100/J200 HV
HV Cable with Spade Lug (custom) 1 Pin

P206/ J206, P207/J207, P208/J208 HV
HV Cable with Spade Lug (custom) 1 Pin

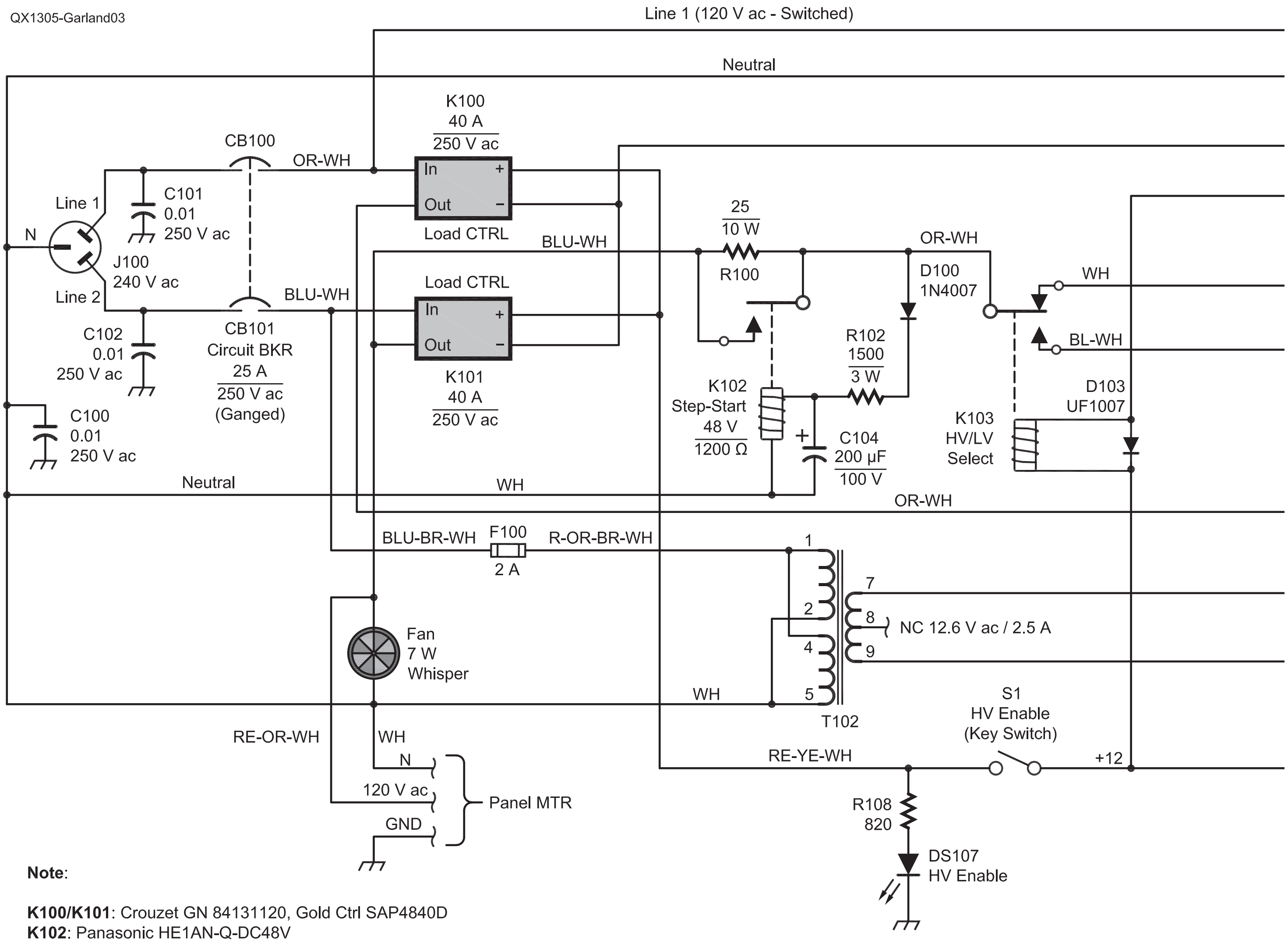
P101/J201 - Chassis Control
12 Pin mini MATE-N-LOC
Mouser 571-1-794066-0 (J201)
Mouser 571-7705811 (P101)

1 - L1 Switched
2 - L1 Switched
3 - Neutral
4 - AC Relay
5 - HV Meter
6 - B −
7 - Ip Sense
8 - 12 V ac
9 - 12 V ac
10 - HV/LV Select
11 - +12
12 - GND

P203/J203, P204/J204, P205/J205, Control
12 Pin mini MATE - N - LOC
Mouser 571-1-794066-0
Mouser 571-7705811

1- Neutral
2 - L1 Switched
3 - GND
4 - Ip Reset
5 - LV Control
6 - PWR Pushbutton
7 - Neutral
8 - Spare
9 - HV Meter
10 - In/Out Pushbutton
11 - Standby LED
12 - B −

Figure 2 —The heart of the power supply is a control logic circuit that arbitrates among three connected RF decks, allowing fully automatic operation.



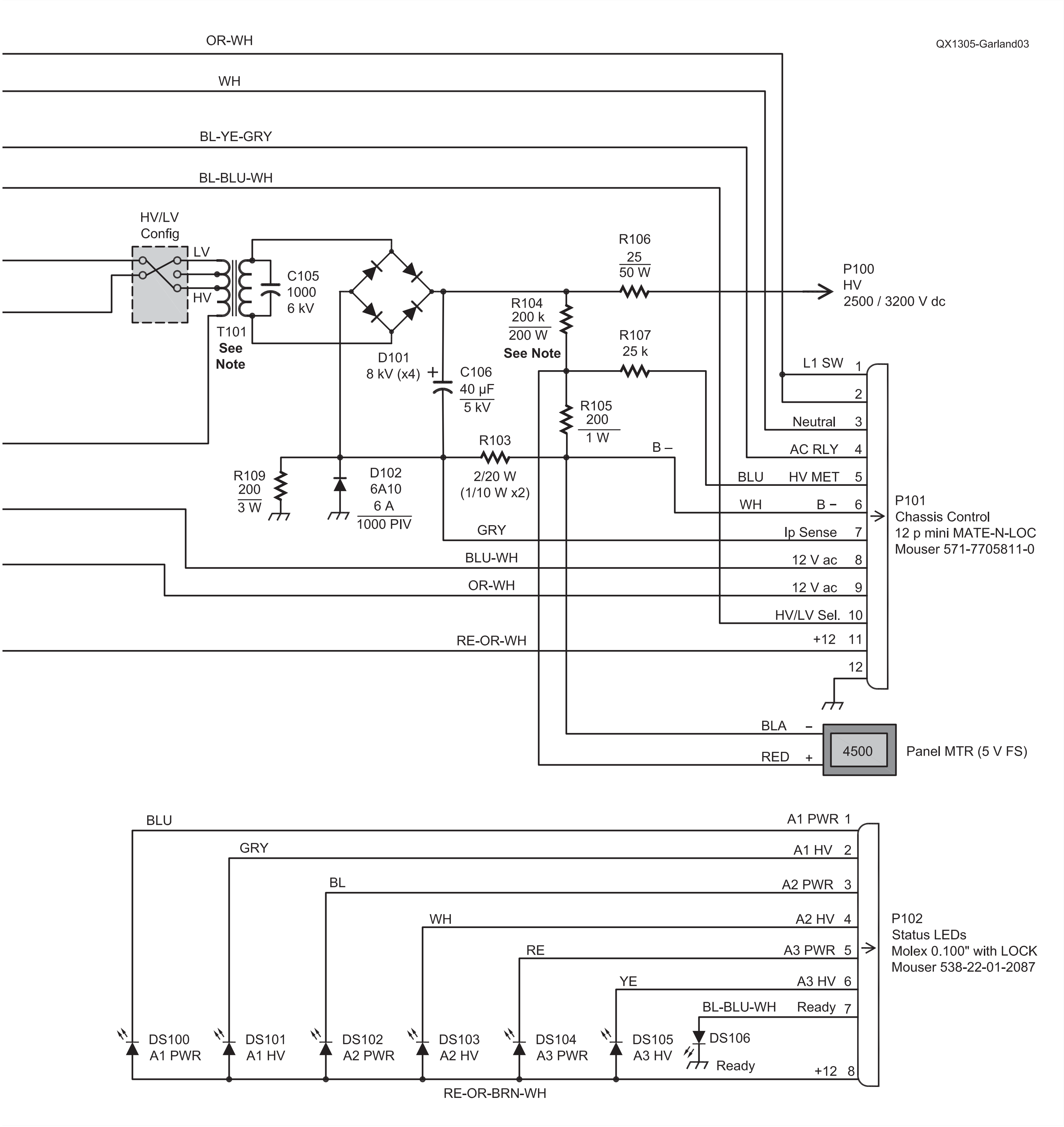
Note:

K100/K101: Crouzet GN 84131120, Gold Ctrl SAP4840D
K102: Panasonic HE1AN-Q-DC48V
K103: Tyco/P&B T92P11D22-12
R104: Two 100 k/100 W in series. 50 k/50 W okay for V < 3000 V dc
T100: Signal DP-241-6-12 (12.6 V ac at 2.5 A)
T101: Peter Dahl Custom 1.5 A CCS

v.1 - pri: P1, P2, P3 sec1: 2040 (P1)/2270 (P2)/2500 (P3)
sec2: 2695 (P1)/2995 (P2)/3300 (P3)

v.2. - pri: P1, P2, P3 sec: 1920(P1), 2050 (P2), 2250 (P3) at 245 V ac

Figure 3 — The power supply uses a capacitor input filter with a large oil-filled capacitor filtering the rectified output from the full-wave bridge rectifier. An "HV Enable" key-operated safety switch disables the plate transformer by deactivating the solid state power relays.


QX1305-Garland03
OR-WH
WH
BL-YE-GRY
BL-BLU-WH
HV/LV
Config
LV
HV
T101
See
Note
C105
1000
6 kV
D101
8 kV (x4)
C106
40 µF
5 kV
R106
25
50 W
R104
200 k
200 W
See Note
R107
25 k
R105
200
1 W
R103
2/20 W
(1/10 W x2)
R109
200
3 W
D102
6A10
6 A
1000 PIV
P100
HV
2500 / 3200 V dc
B –
GRY
BLU-WH
OR-WH
RE-OR-WH
L1 SW 1
2
Neutral 3
AC RLY 4
BLU HV MET 5
WH B – 6
Ip Sense 7
12 V ac 8
12 V ac 9
HV/LV Sel. 10
+12 11
12
P101
Chassis Control
12 p mini MATE-N-LOC
Mouser 571-7705811-0
BLA –
RED +
4500
Panel MTR (5 V FS)
BLU
GRY
BL
WH
RE
YE
BL-BLU-WH
A1 PWR 1
A1 HV 2
A2 PWR 3
A2 HV 4
A3 PWR 5
A3 HV 6
Ready 7
+12 8
P102
Status LEDs
Molex 0.100" with LOCK
Mouser 538-22-01-2087
DS100
A1 PWR
DS101
A1 HV
DS102
A2 PWR
DS103
A2 HV
DS104
A3 PWR
DS105
A3 HV
DS106
Ready
RE-OR-BRN-WH

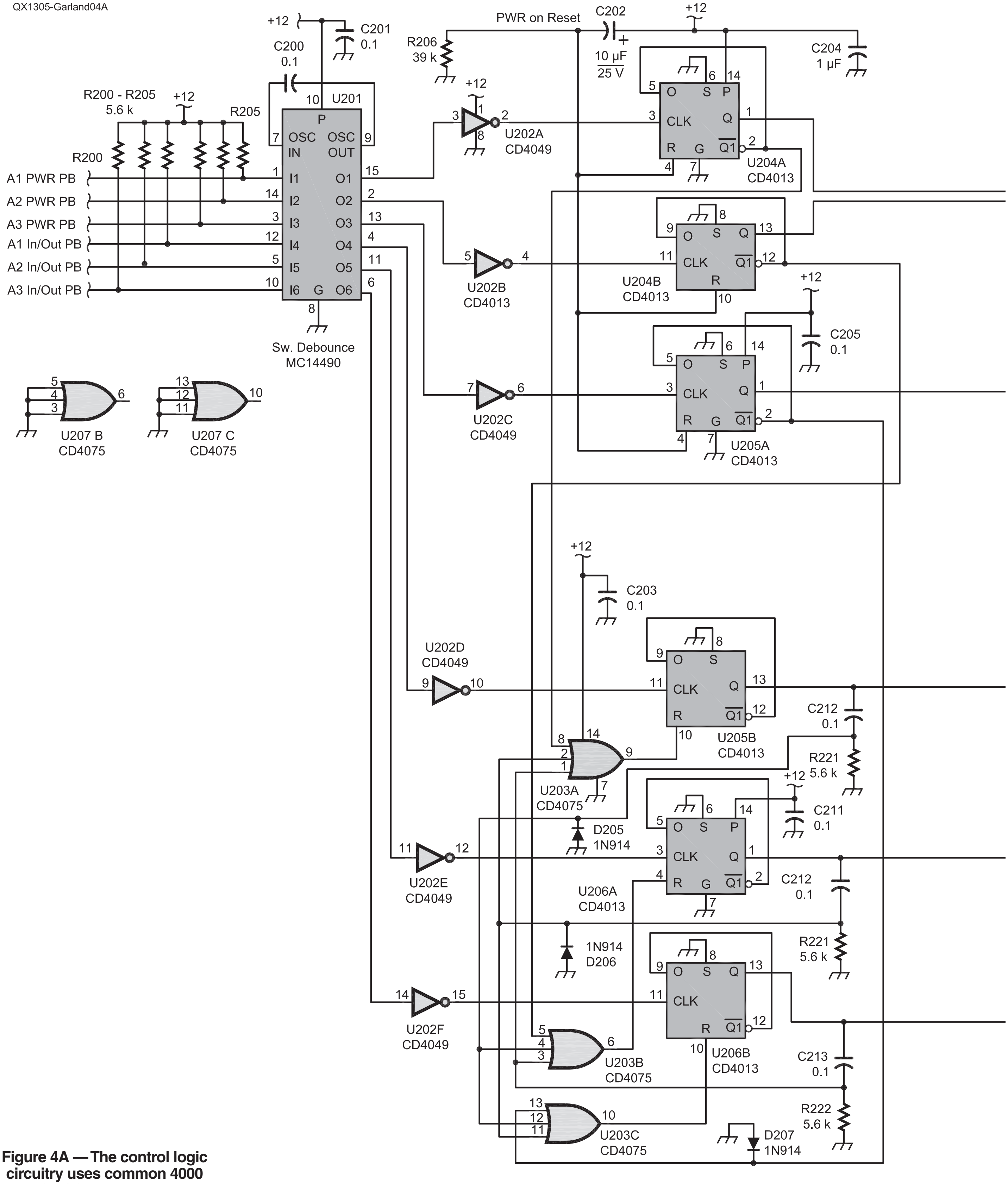
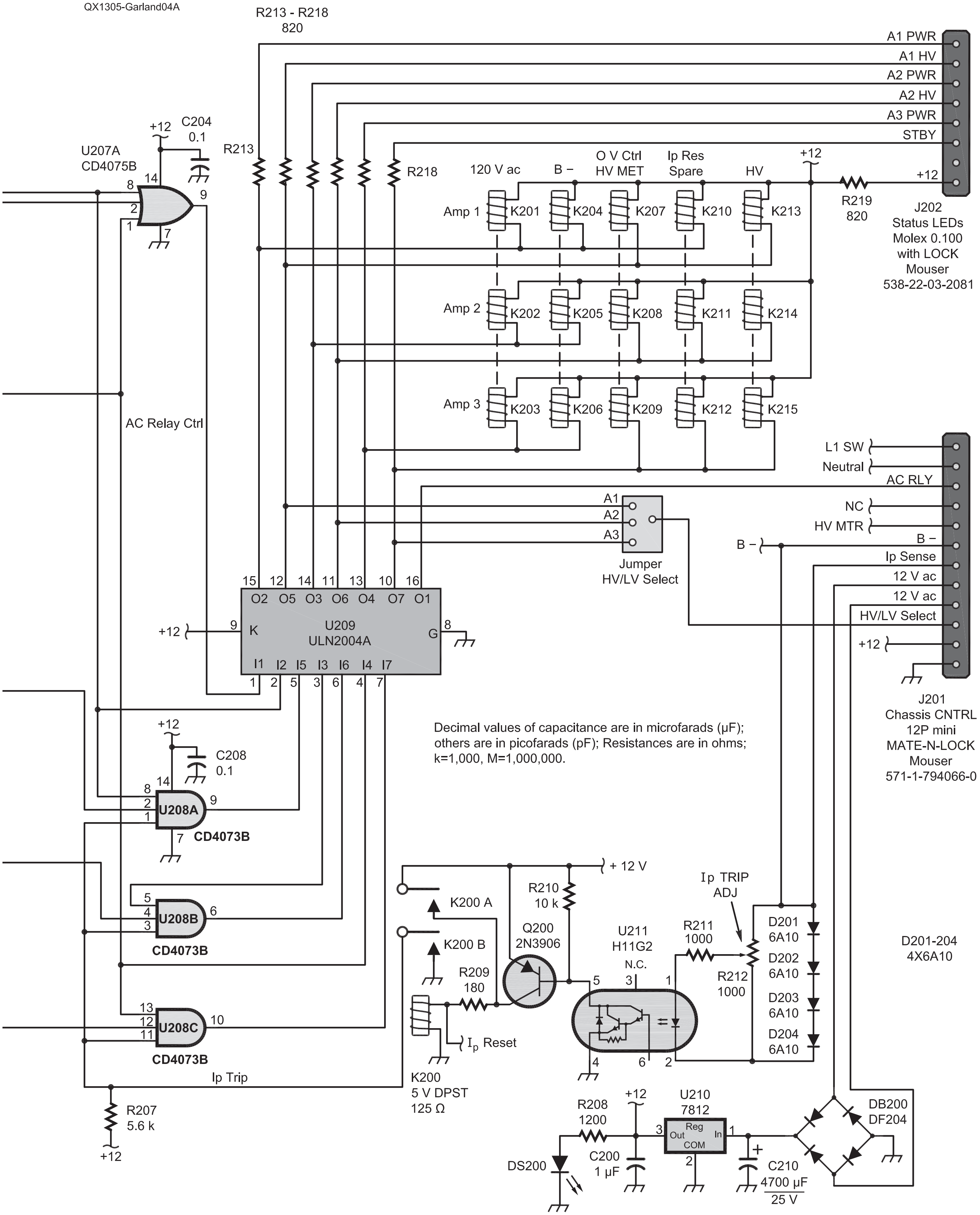


Figure 4A — The control logic circuitry uses common 4000 series CMOS integrated circuits, which operate off of 12 V dc.


QX1305-Garland04A
R213 - R218
820
A1 PWR
A1 HV
A2 PWR
A2 HV
A3 PWR
STBY
+12
J202
Status LEDs
Molex 0.100
with LOCK
Mouser
538-22-03-2081
R219
820
+12
C204
0.1
U207A
CD4075B
8
14
2
1
7
9
R213
R218
120 V ac
B −
O V Ctrl
HV MET
Ip Res
Spare
HV
Amp 1
K201
K204
K207
K210
K213
Amp 2
K202
K205
K208
K211
K214
Amp 3
K203
K206
K209
K212
K215
AC Relay Ctrl
L1 SW
Neutral
AC RLY
NC
HV MTR
B −
B −
Ip Sense
12 V ac
12 V ac
HV/LV Select
+12
J201
Chassis CNTRL
12P mini
MATE-N-LOCK
Mouser
571-1-794066-0
A1
A2
A3
Jumper
HV/LV Select
15 12 14 11 13 10 16
O2 O5 O3 O6 O4 O7 O1
U209
ULN2004A
+12
9
K
G
8
I1 I2 I5 I3 I6 I4 I7
1 2 5 3 6 4 7
Decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); Resistances are in ohms; k=1,000, M=1,000,000.
+12
C208
0.1
8
14
2
1
9
7
U208A
CD4073B
5
4
3
6
U208B
CD4073B
13
12
11
10
U208C
CD4073B
Ip Trip
R207
5.6 k
+12
+ 12 V
K200 A
K200 B
R210
10 k
Q200
2N3906
R209
180
Ip Reset
K200
5 V DPST
125 Ω
U211
H11G2
N.C.
3
5
1
4
6
2
Ip TRIP
ADJ
R211
1000
R212
1000
D201
6A10
D202
6A10
D203
6A10
D204
6A10
D201-204
4X6A10
+12
U210
7812
Reg
Out
In
COM
3
1
2
R208
1200
DS200
C200
1 µF
C210
4700 µF
25 V
DB200
DF204

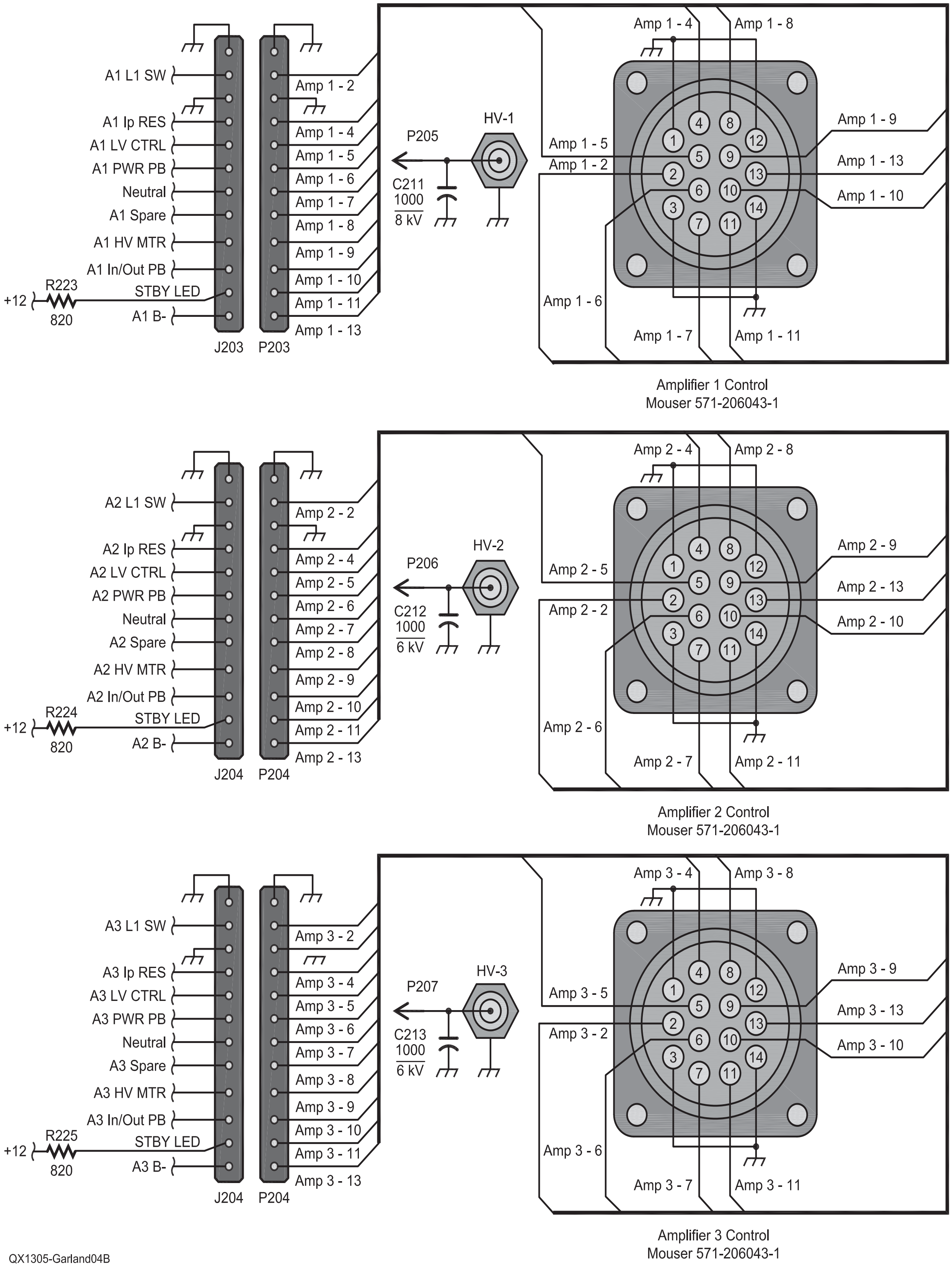
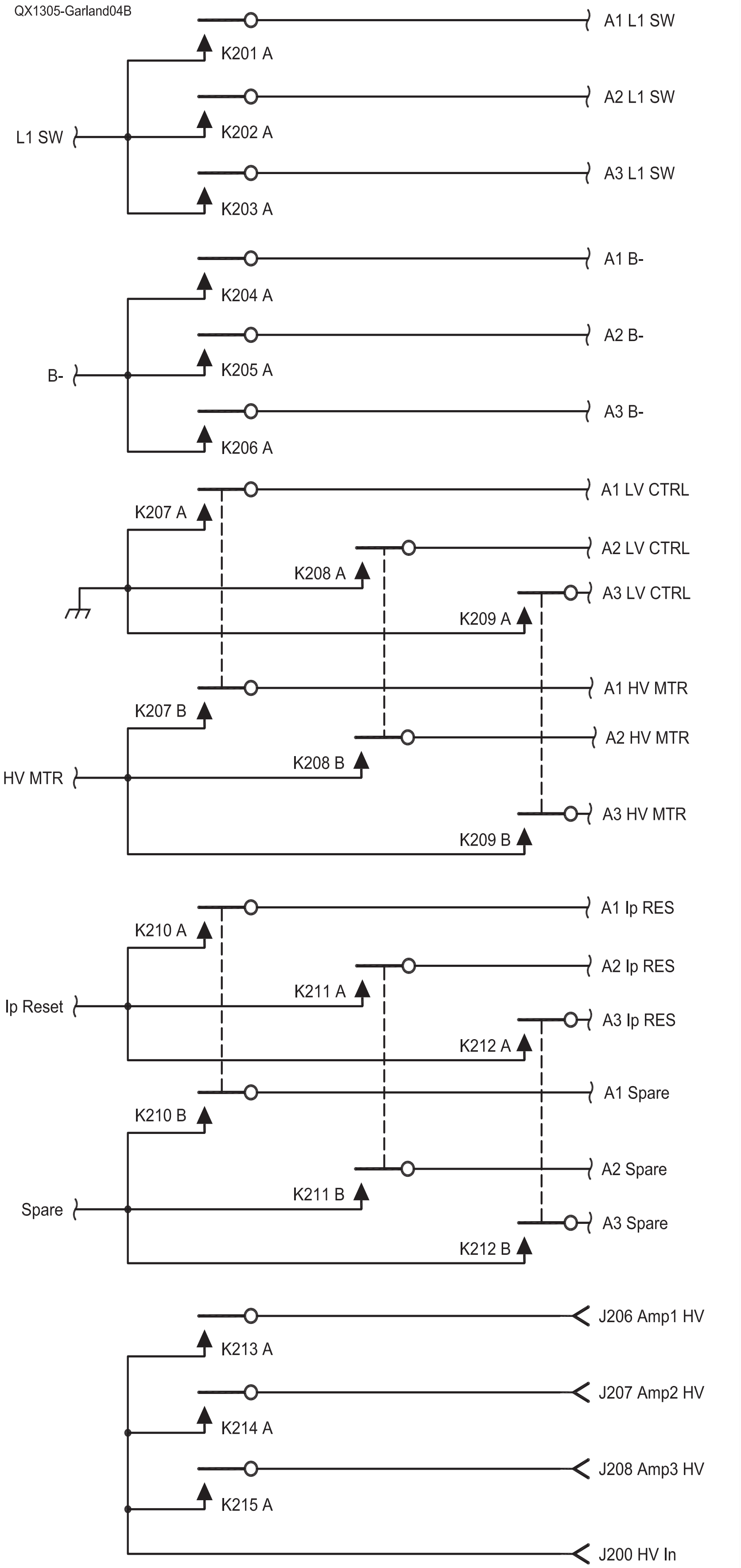


Figure 4B — Relays transfer all voltages to the selected amplifier. The high voltage switching is done using Gigavac G81A vacuum relays, rated at 10 kV.



the large chassis components of the power supply (plate transformer, rectifiers, and filter capacitor) are interfaced via three connectors to the control logic circuits contained on a single 6.0 × 7.5 inch double-sided printed circuit board. Connector pair P100/J200 carries the high voltage from the chassis-mounted components to three HV distribution relays mounted on the controller circuit board. The interconnecting cable uses 10 kV silicone-insulated test probe wire. Connector pair P101/J201 uses a 12 conductor cable and is used for all the control functions, while P102/J202 interfaces to the eight front panel LED indicators. Additional connector pairs P203/J203 through P208/J208 transfer the control lines and high voltage from the printed circuit board to the front panel control and HV connectors.

Figure 3 is a schematic diagram of the main power supply components. (Note that wire colors for the author's power supplies are shown in the diagram to facilitate servicing and circuit tracing.) As shown in the diagram, each side of the 240 V ac line is routed through ganged 25 A circuit breakers CB100/CB101 to solid state relays K100/K101. When the circuit breakers are closed, 12 V ac is applied by T102 to the control board, whose on-board regulator provides 12 V dc to operate the relays and logic circuits. The "HV Enable" key switch S1 disables the ac relays for servicing or testing purposes, but leaves alive all the other control functions. All 120 V ac components used in the power supply (muffin fan, digital panel meter) and RF decks (blowers, filaments, low voltage power supplies) use either L1 or L2 from the 240 V ac line and the N ("neutral") line. Note that it is poor design practice to ground the neutral line to the chassis, since doing so results in unpredictable and potentially dangerous paths for the power line return currents. Modern building codes often mandate a four-wire 240 V ac power cord with an integral ground wire, such as for electric dryers, but if your home has the older three-wire (L1, L2, N) configuration, then a separate station ground wire should be connected to the power supply chassis. A threaded 10-32 ground lug is provided on the front panel below the power cord for this purpose. (Note that outside the US, many countries with 240 V ac service do not use a neutral line. Builders from those countries must either use 240 V ac fans, filament transformers and so on, or else derive a "virtual" neutral from a center tap on the primary winding of the plate transformer.)

K102, R100, R102, C104 and D100 comprise a step-start circuit that limits the surge current at power-up to 10 A until filter capacitor C106 is partially charged. The intrinsic time constant of this circuit is about 0.3 s, but because D100 picks off its voltage at the downstream side of R100 the actual time delay is closer to 0.8 s. The plate transformer T101 is custom designed for the power supplies by the Peter W Dahl Company and is a versatile 67 lb (5 kVA) hypersil-wound transformer with three primary taps and two secondary taps. (Note that the secondary taps are not shown on the schematic diagram, but are selected during construction.)

[The Dahl transformer line has been available through Harbach Electronics (**www.harbachelectronics.com**) but as we prepared this article for publication Harbach announced that they would no longer handle the Dahl transformer line. Then, as we prepared this issue of *QEX* to go to press, there was an announcement that Hammond Manufacturing Company, Inc. of Cheektowaga, New York, was acquiring the line of Dahl transformers. According to the Hammond website they expect the deal to be completed and all assets transferred by March 31, 2013. Check the Hammond website for further updates (**www.hammfg.com**) — *Ed.*]

By mixing and matching taps, the higher voltage transformer can provide six RMS voltages ranging from 2000 to 3300 V ac (1920 V ac to 2250 V ac for the lower voltage transformer), each at 1.5 A CCS. Relay K103 allows each power supply to select two of these voltages. Four diode blocks, each rated at 1.5 A/15 kV comprise a bridge rectifier that rectifies the output from the transformer secondary. The rectified dc is filtered by a large 40 µF/5000 V oil-filled capacitor, C106 (50 µF/4200 V in the lower voltage power supply), which the author had on hand. Bleeder resistor R104 is made up of two 100 kΩ/100 W power resistors in series and dissipates about 100 W. D102 provides flashover protection to the metering circuits by clamping the B– return current to within 1 V of ground in the event of an arc to ground somewhere in the power supply or RF deck, while R109 anchors the B– return to ground in the unlikely event it should become disconnected from its RF deck. R103 is used to sense the power supply current and is connected to an optically isolated over-current trip circuit on the control and logic circuit board.

Control and Logic Circuits

The functions of the HV power supply control and logic circuitry are:

(1) to allow each amplifier to be independently powered on or off. When an amplifier is turned off, all power to it is removed, including all high voltage, low voltage and control circuits.

(2) to interlock each amplifier, so that only one amplifier can be placed on-line at a time. When an amplifier is brought on-line, any previously selected amplifier is taken off-line, but remains in a standby state. High voltage is applied to an amplifier only when it is on-line.

(3) to implement metering and control functions for each amplifier that are independent of one another. From the perspective of the operator, the shared power supply is essentially invisible.

(4) to control flashover surges, in order to prevent damage to the connected amplifiers.

(5) to enable simple hookup of the connected amplifiers. Each amplifier plugs into the power supply with a single control cable and a single HV cable. Any amplifier can be disconnected (unplugged) from the power supply, without affecting the operation of the remaining amplifiers. The ac power and on-line switches of each amplifier are simple momentary action SPST pushbutton switches on the front panel of each amplifier.

(6) to switch automatically primary taps on the HV power transformer, to allow the connected amplifiers to use different plate voltages.

Table 1

Each RF amplifier connects to the power supply using a 14-pin AMP control connector. The high voltage is connected separately via a shielded length of RG6/U coaxial cable, using high voltage SHV-RP BNC connectors.

Pin Number	*Function*	*Description*
1	GND	Chassis ground
2	L1_SW	120 V ac (switched)
3	GND	Chassis ground
4	Ip_RES	Plate over-current reset (switched, ground to reset)
5	LV_CTRL	Low voltage control (switched ground for amp LV circuits)
6	PWR_PB	Amplifier momentary SPST ac power pushbutton
7	NEUTRAL	240 V ac neutral line (unswitched)
8	SPARE	Unused spare (switched)
9	HV_MTR	High voltage meter output, 0-5 V dc (switched)
10	IN/OUT_PB	Amplifier momentary SPST on-line pushbutton
11	STBY_LED	Amplifier standby LED anode, 12 mA (unswitched)
12	GND	Chassis Ground
13	B–	Amplifier B– return (switched)
14	GND	Chassis Ground

(7) to facilitate easy construction of the HV power supply by mounting all logic, control, and switching circuitry on a single printed circuit board. Thus the construction of the power supply is only moderately more complicated than construction of an ordinary single-amplifier power supply. This means that an amplifier builder can incorporate multiple amplifier capability into a newly built power supply at reasonable effort and cost in order to allow for future needs.

Referring to the circuit diagrams of Figures 4A and 4B, the three RF amplifier decks are actuated by two momentary action pushbutton switches for each amplifier: one controls ac power (blower, filaments, LV supply) and one controls HV and enables the amplifier to be brought on-line. The buttons are debounced by U201, with C200 setting the maximum debounce time (50 ms) before the button states stabilize. R200 to R205 hold each button line high. These resistors are in parallel with 500 kΩ resistors internal to U201 and result in about 2 mA of current through each button when it is pressed. Grounding the button line activates the control circuitry.

The active-low button states are inverted by hex inverters U202, and the three ac power buttons are applied to the clock inputs of D flip-flops U204A, U204B, and U205A. Each flip-flop is configured so that it toggles its output states Q and Q' each time its button is pressed. A positive pulse is generated by R206 and C202 at power-on and is applied to the reset line of the three flip-flops, ensuring that they power up with $Q = 0$ and $Q' = 1$. The voltage pulse reaches a maximum of about 10 V about 200 ms after power is applied, ensuring a reset after the remainder of the circuitry has had time to wake up. The high state $Q' = 1$ of each flip-flop is passed at power-up via OR gates U203A, U203B and U203C to the reset inputs of U205B, U206A and U206B, thus ensuring that the HV logic is also powered up in a $Q = 0$ state.

The outputs of the six flip-flops have several functions. The Q outputs of U204A, U204B, and U205A are combined by OR-gate U207, whose output actuates the power supply's main power relays. The outputs of all six flip-flops are also applied, via 3-input AND gates U208A, U208B, and U208C, to the 8-port relay driver U209. Each port is grounded when active and can sink a maximum of 500 mA. The purpose of the AND gates is to interlock the power and HV buttons to prevent improper operation. One input of U208A, U208B and U208C is grounded when the over-current relay K200 is tripped and shuts off the HV supply of any on-line amplifier. A second input ensures that the HV for any amplifier cannot be turned on unless the ac power to the amplifier has previously been turned on. The third input routes the selected amplifier to the appropriate HV relay driver port.

The HV button flip-flops U205B, U206A and U206B operate in the same manner as the ac power button flip-flops, except that each HV flip-flop is interlocked to the other two HV flip-flops via the 3-input OR gates U203A, U203B, and U203C. As mentioned previously, one input to each OR gate is used to reset the flip-flops on power-up. A second input resets each HV flip-flop whenever its corresponding ac power relay is turned off. Resetting the flip-flop in this way thus keeps the HV from inadvertently turning on if the ac power relay is subsequently energized after being turned off. In other words, the only way to turn on the HV for a particular amplifier is to actuate its HV button.

The third input of the OR gates turns off the HV of any selected amplifier whenever the HV button for another amplifier is pressed. Thus, only the most recently selected amplifier is ever on-line. This function is implemented by means of a pulse caused by the positive edge of the HV flip-flop's Q output transition, in conjunction with the RC differentiator connected to the Q output. This pulse is used to reset (turn off) any previously selected HV flip-flops. Diodes D205, D206, and D207 protect the input of the OR gates by clamping to ground the negative pulse caused by a negative-going transition of the flip-flop. If desired, the user can replace capacitors C211, C212, and C213 with wire jumpers. Doing so would then disable the automatic switch-off function and require the HV of a selected amplifier to be manually switched off before the HV of any other amplifier could be selected.

The over-current protection circuit monitors the voltage developed across a 2 Ω resistor in series with the B– return of the HV power supply (shown in Figure 2). When this voltage indicates excessive current, the optoisolator turns on Q200, latching K200 in a closed position. R212 sets the current trip threshold, and diodes D201 to D204 protect the peripheral circuitry from the momentary current surge caused by flashover in the HV supply.

At the *QEX* website, **www.arrl.org/qexfiles**, you will find the zip file **w8zr_power_supply.zip** that contains a complete schematic package and a spreadsheet with parts info for all the components on the PCB logic controller.

Mechanical and Assembly Details

Figures 5 and 6 show interior views of the power supply. As shown in Figure 6, the

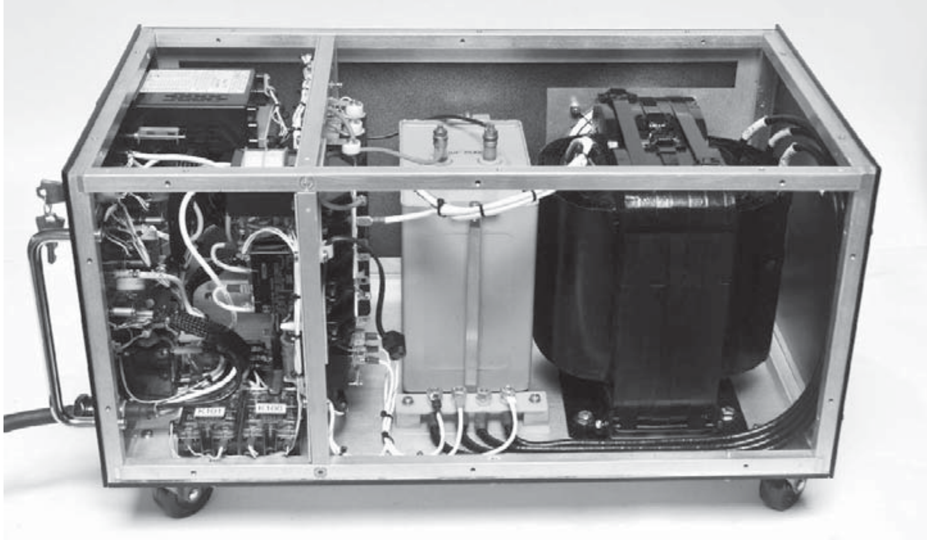


Figure 5 — An interior subpanel divides the power supply into two compartments, with all the control and metering circuits housed in the smaller front compartment, and the large high voltage components in the rear compartment.

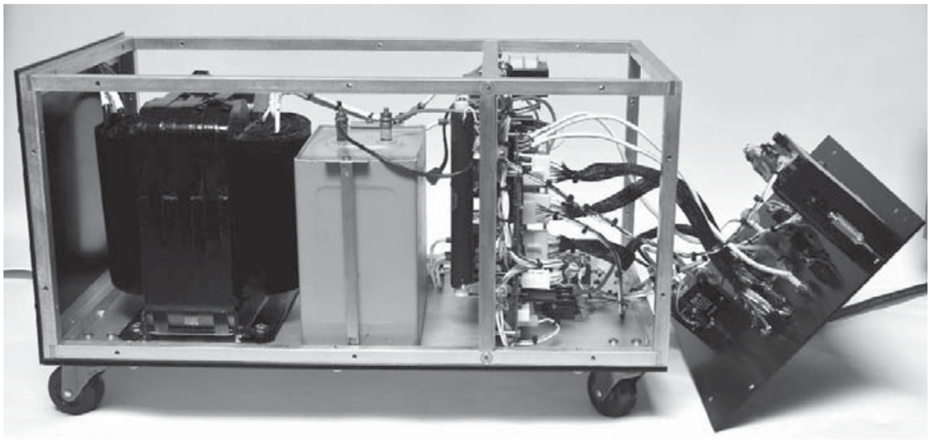


Figure 6 — The front panel detaches and tilts forward to provide access to interior components.

Figure 7 — The rectangular frame is constructed from ½ inch square aluminum stock. A single 10-32 flathead screw secures the three interlocking pieces that form each corner.

front panel removes and tilts out of the way to enable easy access to components, should servicing ever be required. The power supply enclosure measures 12 W × 10 H × 21.5 D inches (the second power supply is only 20 inches deep) and is fabricated around a frame made from ½ inch square aluminum stock. Figure 7 shows the frame detail at the corners. The bottom plate is made from 3/16 inch thick aluminum plate, while the front, rear, and top panels are fabricated from ⅛ inch thick aluminum plate. The side panels are 1/16 inch thick aluminum. An aluminum subpanel (Figures 8 and 9) divides the power supply into two compartments. The front compartment houses the control logic and switching circuitry, with the printed circuit board (Figure 10), step-start components, and 12.6 V ac low voltage transformer mounted on the front side of the subpanel.

The printed circuit board was designed using *Circad 98*, a commercial schematic capture and PCB layout package (**www.holophase.com**) that the author has used for many projects. "Gerber" files for the completed layout were then uploaded to Advanced Circuits (**www.4pcb.com**), which manufactures high quality printed circuit boards in small quantities at very reasonable cost. Figure 11 shows a breadboard lash up used to debug the logic circuitry before committing the design to a printed circuit board. The small plastic enclosure with the LEDs and momentary-action lever switches simulate three remote RF decks. Interested readers can view a short video demonstration of the breadboard logic circuitry at **www.youtube.com/watch?v=OycSQu55oFo**.

All point-to-point wiring in the power supply uses silicone insulated high voltage wire or color-coded PTFE (Teflon) insulated wire. PTFE is a very durable insulator and has excellent heat resistance and dielectric strength. The wire is costly, but can frequently be found at bargain-basement prices at hamfests and on-line auction and swap sites.

The HV diode blocks are heat sinked to a 4.5 × 5.75 × 0.125 inch aluminum plate, which is mounted on 0.5 inch metal standoffs on the rear side of the subpanel. The rear subpanel also holds the bleeder resistors, HV/LV-select relay, and miscellaneous other components, some of which are mounted on silver/ceramic terminal strips scavenged from old Tektronix oscilloscopes. "Pem" type threaded fasteners are used instead of nuts in order to facilitate component removal. All other hardware is stainless steel, using pan-head Phillips screws.

A 4.75 inch "whisper" muffin fan mounted on the right side of the enclosure silently exhausts warm air drawn through a ventilation cutout on the opposite side. The

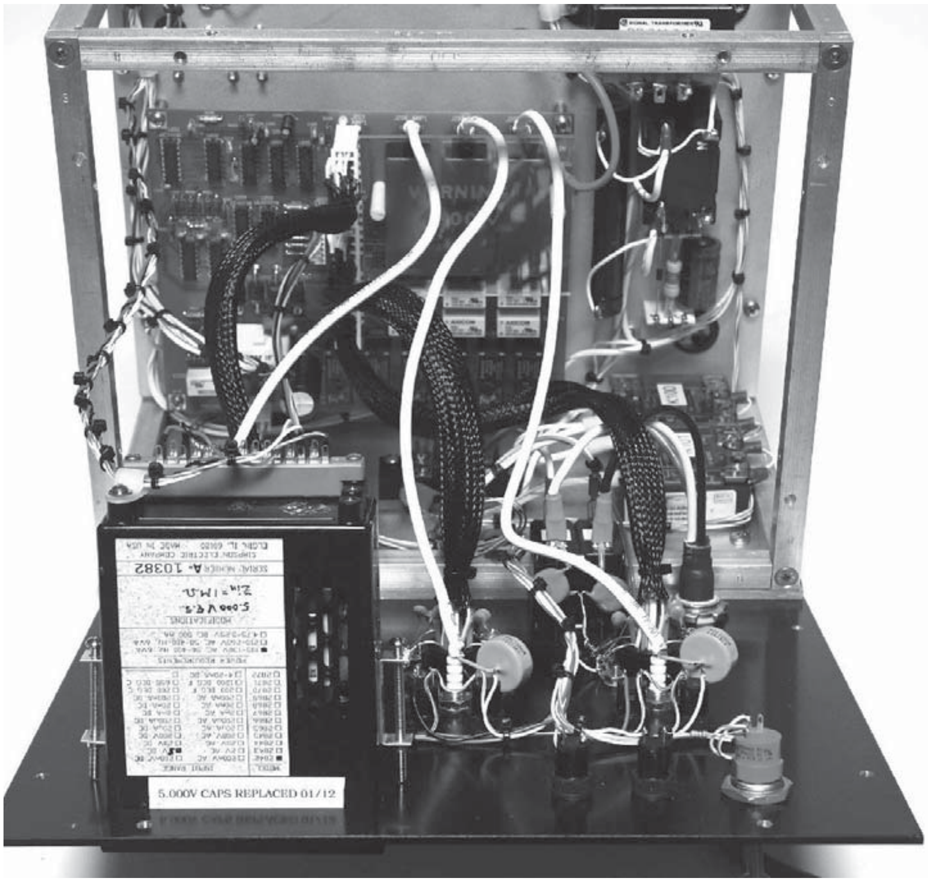


Figure 8 — The front side of the subpanel houses the controller printed circuit board, the low voltage transformer, and the step-start circuits.

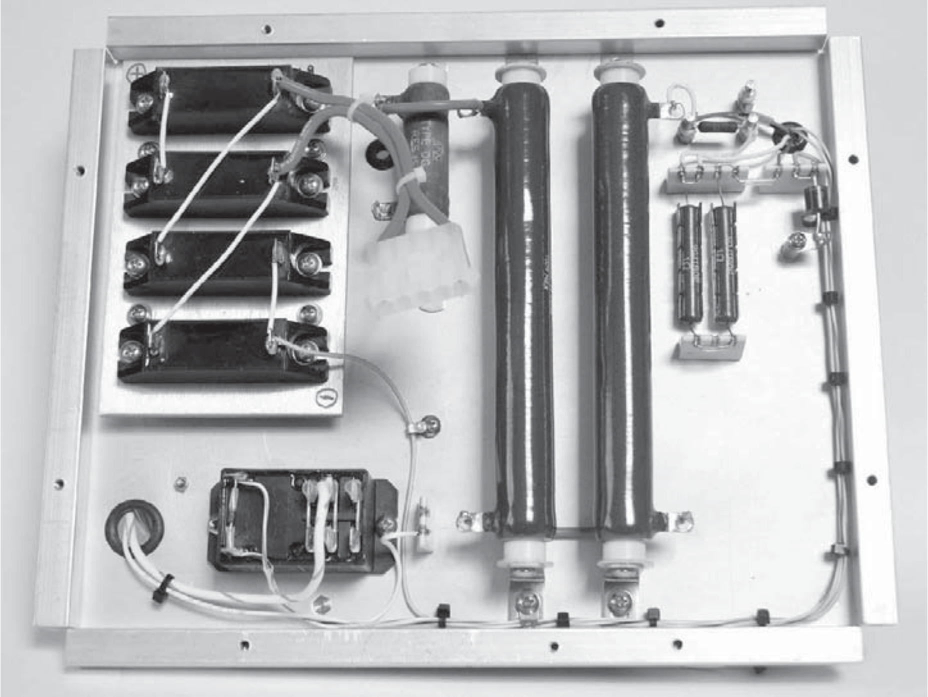


Figure 9 — The bleeder resistors, metering components and HV/LV–select relay mount on the rear of the subpanel. PTFE spacers insulate the bleeder resistors from the chassis, while the HV diode blocks are heat sinked to a ⅛ inch aluminum plate.

High Voltage Safety Considerations

We are all so besieged these days with verbose safety warnings on mostly harmless consumer goods that it is easy to forget that some things really are dangerous. High voltage power supplies definitely fall into this category, especially since many amateurs are accustomed to solid state circuits and seldom encounter any dc voltage higher than 12 V. *This power supply produces voltages that are highly lethal.* So *please* take to heart the following ten precautions. Furthermore, don't expect to learn from your mistakes, because if you don't exercise proper precautions the first time, you're unlikely ever to have a second chance.

1. Don't let your reach exceed your grasp. This is not a project for beginners. You should not attempt to build this power supply unless you're a seasoned builder who has experience with high voltage circuitry.

2. Young amateurs should not attempt this project. Working with high voltages requires the maturity and patience that comes with age and experience.

3. Never work around high voltage when you are tired, stressed, or in a hurry.

4. Never work around high voltage after drinking alcohol. Even one beer or glass of wine can impair your judgment and make you careless.

5. Before working on a high voltage power supply, always follow these three steps: *Unplug* (the ac power cord), *discharge* (the filter capacitors) and *verify* (that the output voltage is truly zero). Time-honored practice is to use a "chicken stick" (a wooden dowel or PVC tube, with one end attached to a grounded wire) to make sure filter capacitors are completely discharged.

6. When working on a high voltage power supply, remember that a dangerous time is after the power supply has just been turned off, but before the filter capacitors have fully discharged. A 50 μF capacitor charged to 4000 V holds a potentially deadly 400 Joules of energy. Even with bleeder resistors, it can take a minute or more to discharge fully.

7. When removing a recently discharged filter capacitor from a power supply, tie the two terminals together with wire. Large high voltage capacitors can self-charge to dangerous levels if the terminals are left floating.

8. Don't stake your life on the expectation that bleeder resistors, fuses, circuit breakers, relays, and switches are always going to do their job. Even though modern components are very reliable, it is safe practice always to assume the worst.

9. Don't build this power supply if you don't understand how the circuit works. High power amplifiers and power supplies are not "plug-and-play" projects with step-by-step instructions. Builders must be knowledgeable enough to improvise, make component substitutions, and implement design changes.

10. With high voltage projects, it doesn't pay to be "penny wise and pound foolish." Use high quality components throughout and save your forty-year-old junk box parts for projects where safety and reliability are not paramount requirements.

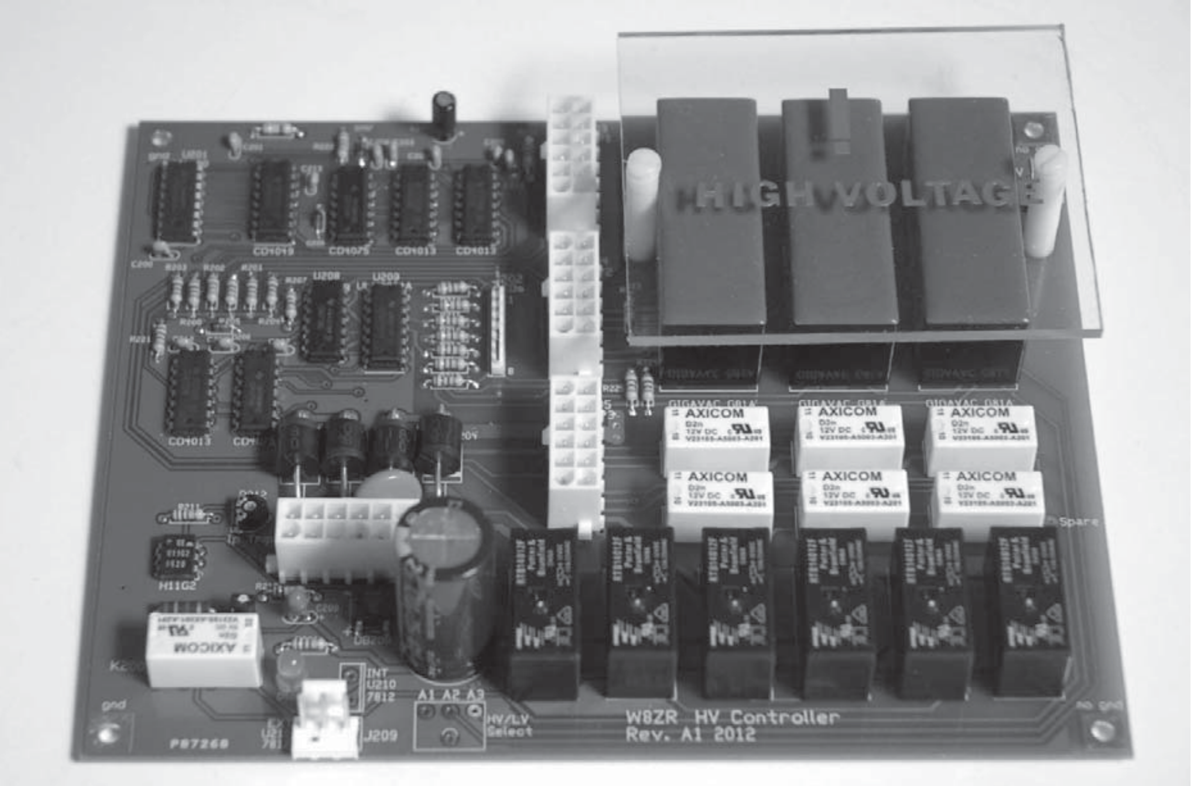


Figure 10 — A double-sided printed circuit board houses the logic and control functions, the over-current protection circuit, and the control relays. A plastic shield covers the high voltage relays to keep nearby wires and cables at a safe distance.

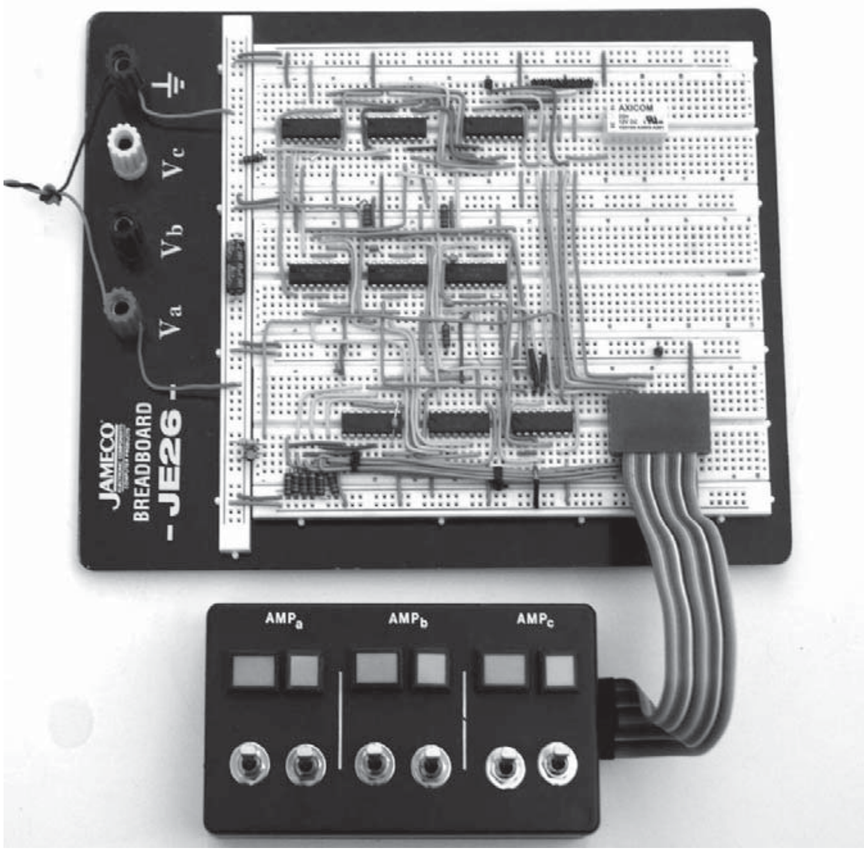


Figure 11 — This breadboard mockup of the logic circuitry preceded the design and layout of the printed circuit board.

large oil-filled capacitor sits on a rubber pad and is secured to the base plate by clamps fabricated from ⅜ inch square aluminum stock.

The enclosure panels are powder coated with a smooth black satin finish. The front panel is similarly finished, and was custom made by Front Panel Express (**www.frontpanelexpress.com**) from a CAD file supplied by the author. The panel lettering and other markings are engraved and backfilled with red and yellow paint (white paint for the lower voltage supply). Each power supply sits on two inch casters and weighs about 90 lbs.

The most tedious part of construction was fabricating the frame for the aluminum enclosure. In order for the frame to be square, tolerances for the individual pieces had to be maintained to within 0.015 inches. After the frame was completed, 60 precisely spaced holes had to be drilled and tapped into it for attaching the six panels. Obviously, other builders will likely have more sense than the author, and will spare themselves this ordeal by building the power supply into a commercial enclosure!

There are many reasons why amateurs enjoy building their own equipment. Saving money, experimenting with new circuits, learning new skills, and experiencing the satisfaction that comes from creating something innovative and useful have always motivated Amateur Radio homebrewers. For some, including the author, there is also a strong esthetic pleasure that comes from designing and building a unique piece of equipment that cuts no corners, and cannot be purchased commercially. All builders, no matter how skilled or experienced, quickly learn that there is no design that cannot be improved upon and no level of workmanship that cannot be executed more carefully. Because perfection always remains out of reach, every new project thus represents an irresistible challenge to improve one's skills and advance the state of the art. That spirit of innovation has infused Amateur Radio since its earliest days, more than a century ago, and is still alive and well today.

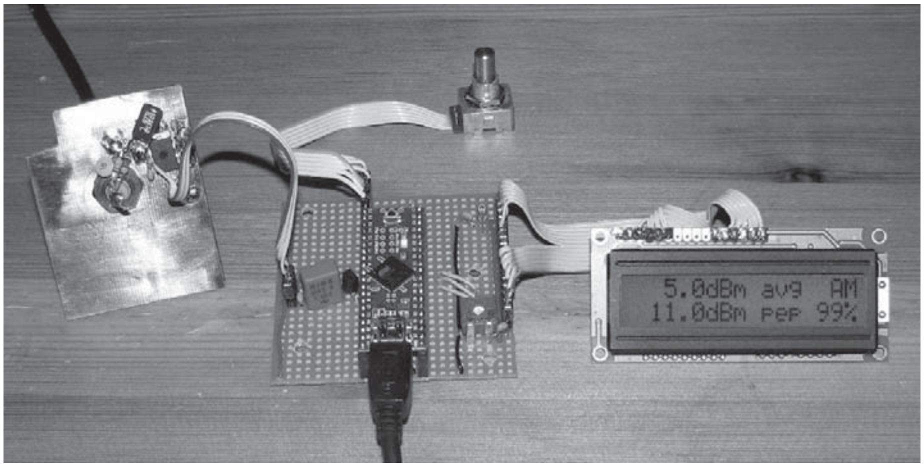
Jim Garland, W8ZR, holds an Amateur Extra Class license and is a former Ohio State University physics professor and president of Miami University (Ohio). He is a Life Member of the ARRL, a member of the ARRL Diamond Club and Maxim Society, and currently lives in Santa Fe, NM. His Amateur Radio website is **www.w8zr.net**.

QEX

Loftur Jónasson, TF3LJ/VE2LJX
4881 Melrose Ave, Montreal, QC Canada, H3X 3P4; **tf3lj@arrl.net**

Squeeze Every Last Drop Out of the AD8307 Log Amp

Accurately measures RF power in watts, dBm, volts over 50 Ω peak envelope power, modulation index...you name it!



This article describes a simple to build microcontroller project, harnessing the output of the classic AD8307 logarithmic amplifier in a slightly different manner than has typically been done before.

If you enjoy the occasional little electronics construction project, chances are you have already come across the AD8307 logarithmic amplifier. A very popular AD8307 based implementation was originally described in the June 2001 issue of *QST* (Simple RF-Power Measurement) by W7ZOI and W7PUA.[1] The high sensitivity and large dynamic range of an AD8307 based meter make it useful for field strength measurements. The good accuracy of the logarithmic to linear conversion of the AD8307 makes it suitable as the basis for accurate and reliable metering in the milliwatt to picowatt range. Add a 40 dB power tap and it is good for measurements up to 100 W and beyond. My original motivation for building this meter was the need for accurate low power measurements of my WSPR transmitter. As things progressed, however, I digressed a bit.

[WSPR — "Weak Signal Propagation Reporter" — is a computer program used for weak-signal radio communication between amateur radio operators. The program was initially written by Joe Taylor, K1JT. It is designed for sending and receiving low-power transmissions to test propagation paths on the MF and HF bands. For more information see **http://en.wikipedia.org/wiki/WSPR_%28Amateur_radio_software%29**. — *Ed.*]

The meter described in this article uses an Atmel AT90USB1286 microcontroller to sample the output from the AD8307 at 200 times per second. The relatively high sampling rate is used to generate various outputs, displayed on a 16 × 2 Liquid Crystal Display (LCD), and optionally also transmitted to a computer over a virtual serial device on a USB port. A rotary encoder with a built-in push button is used to navigate the various displays. A comprehensive configuration menu provides access to functions such as meter calibration, selection and storage of various fixed input gain (attenuator or amplifier) settings. Photo A shows two different displays, selected by turning the rotary encoder.

The meter automatically scales the output down to the picowatt range, or up to the thousands of watts range if an external attenuator or power tap is used. The avg value shows the one second average, derived by averaging the last 200 measurements. The PEP value indicates the highest value measured within the last second. The AM field indicates amplitude modulation index. The displayed measurements are updated 10 times per second.

The display given in Photo B indicates power in decibels over 1 milliwatt (dBm).

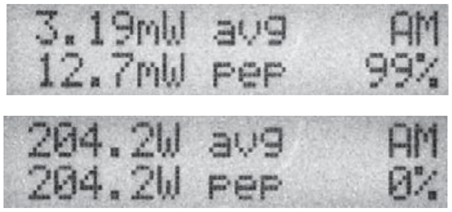
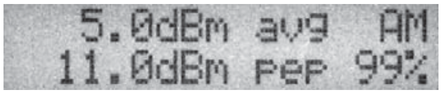

```
3.19mW avg    AM
12.7mW pep   99%
```
```
204.2W avg    AM
204.2W pep    0%
```

Photo A — An example of the displays that can be selected by turning the rotary encoder. Part A shows a power reading in the mW range and Part B shows a reading of more than 200 W. In each case, AM indicates the amplitude modulation index.

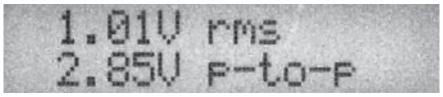
---

[1] Notes appear on page 33.



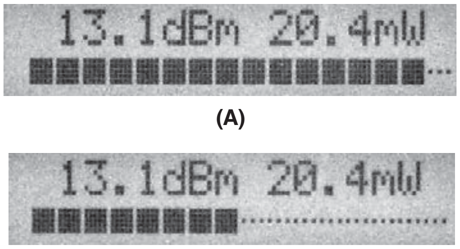
5.0dBm avg AM
11.0dBm PEP 99%

Photo B — In this example the power is displayed in dBm. Notice that with a modulation index of almost 100%, the PEP is 4 times (6 dB) greater than the average power.



1.01V rms
2.85V p-to-p

Photo C — This display is useful when evaluating against an oscilloscope reading, since the measurements are displayed as V_{RMS} and $V_{pk\text{-}pk}$.



13.1dBm 20.4mW

13.1dBm 20.4mW

(A)

(B)

Photo D — Two bargraph display functions are available. Part A shows a range from –80 to +20 dBm and Part B shows a range of ±8 dB.

With an amplitude modulation index of 100%, the peak power is four times, or 6 dB, higher than the average power. It was quite a confidence boost to note that the measured amplitude modulation index tracks the amplitude modulation setting of my Fluke 6062A signal generator to within ±1%.

The measured values displayed as RMS and peak to peak voltages, as shown in Photo C, are useful when you are comparing the measured value to an oscilloscope reading.

If you prefer the "feel" of an analog meter, there are two bar graph display

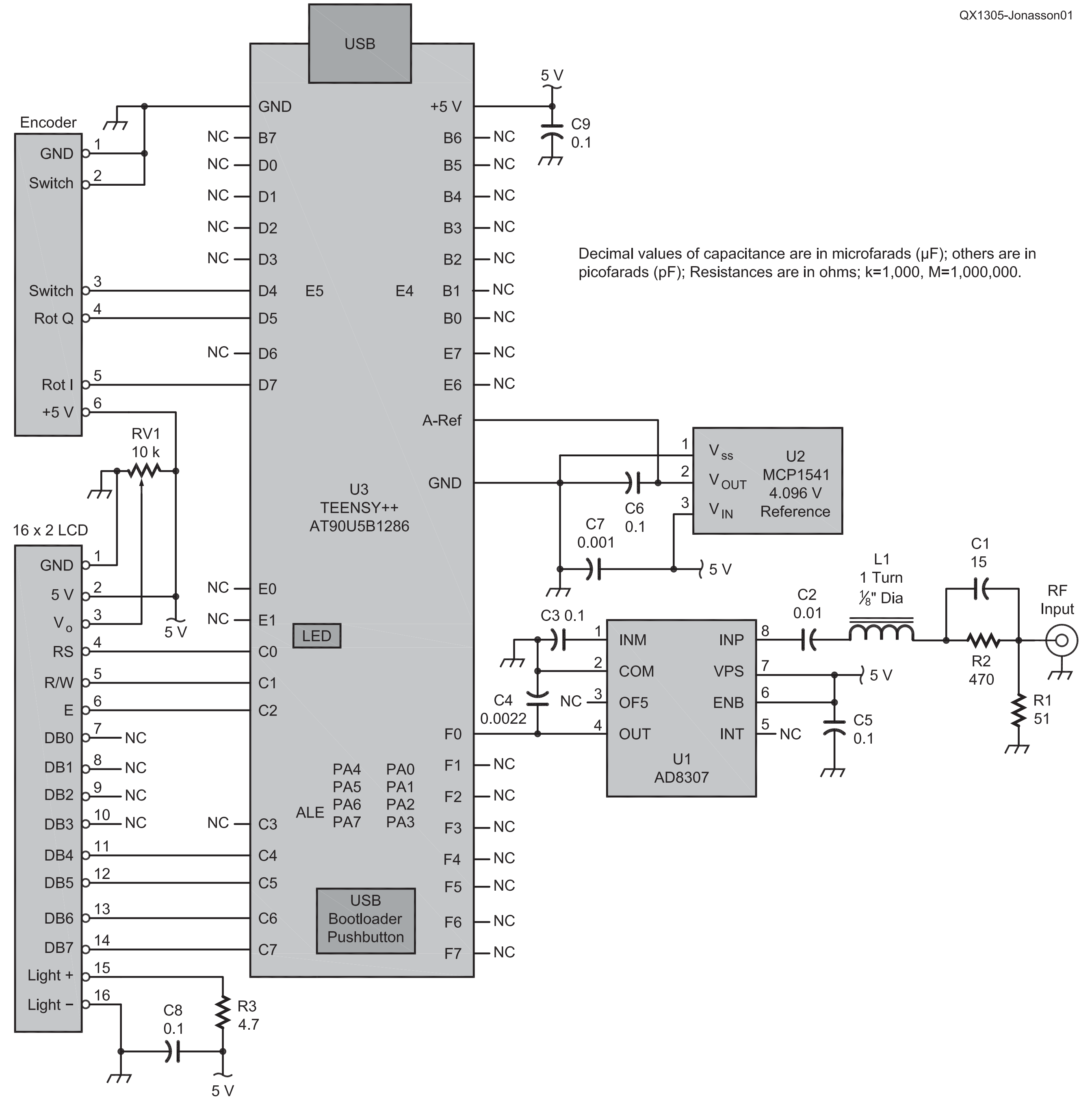


Figure 1 — This schematic diagram shows the complete circuit for the project.

modes, as shown in Photo D. The first bar graph has a range of 100 dB, from –80 to +20 dBm. The second one has a range of ±8 dB, centered to a current reading by pressing the push button.

The USB connector on the microcontroller can be configured to enumerate as a serial port on a computer, outputting a string similar to the following, 10 times per second:

12.7 dBm_AVG, 12.7 dBm_PEP, 19.0 mW_AVG, 19.0 mW_PEP, 0%_AM

Circuit Description

The meter consists of less than 20 components. R2, C1, C2 and L1 are for frequency response compensation. As originally described by W7ZOI and W7PUA, these are intended to provide an almost flat response up to 500 MHz. If these components are omitted the meter will still have a flat response in the 0 to 30 MHz range and a useful response beyond.

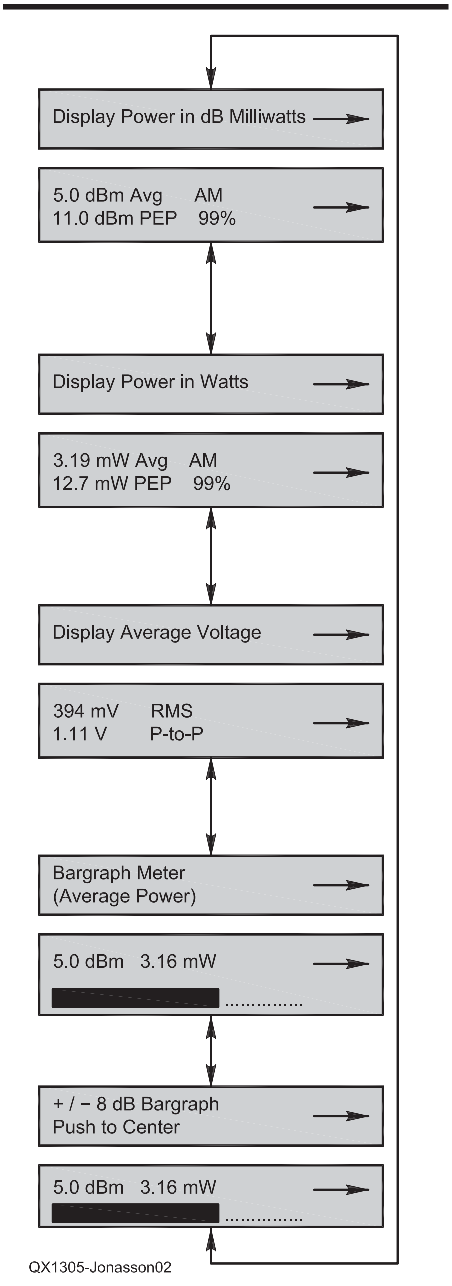


Figure 2 — Here are the menus that are directly selectable with the rotary encoder.

The output of the AD8307 has a ±0.5 dB low pass response corner frequency of approximately 10 MHz. C4, at 0.0022 µF, lowers the corner frequency to approximately 100 kHz. This is adequate to get a ripple free response irrespective of the RF input frequency being measured, while retaining the ability to track amplitude modulation index and peak envelope power with good accuracy. The output from the AD8307 varies from approximately 0.3 V at less than –70 dBm to 2.5 V at 15 dBm, with a slope of approximately 25 mV per dB.

Circuit Diagram

See Figure 1. The MCP1541 is used as a voltage reference for the built in 10 bit analog to digital converter (A/D) in the microcontroller. The purpose of the voltage reference is mainly to provide for consistent measurements, independent of power supply variations. This voltage reference should be not much higher than the highest output voltage expected from the AD8307, while being lower than 5 V. Ten bits from the A/D gives a resolution of 1024 states. 4.096 V / 1024 is 4 mV. With 4 mV divided by 25 mV/dB, the result is a measurement resolution of 0.16 dB. If the 4.096 V voltage reference were to be replaced with a 3.3 V regulator, then the measurement resolution would correspondingly be improved to 0.13 dB. The actual improvement would be less though, because the overall linearity of the AD8307 is specified as ±1 dB. Some reports indicate the linearity as ±0.25 dB.

The AT90USB series of microcontrollers from Atmel have native USB support and come with a pre-installed USB boot loader, making firmware installation as easy as the push of a button. Teensy++ is a USB development board available at **www.PJRC.com**. It contains an AT90USB1286 microcontroller running at 16 MHz. The AT90USB1286 has a program memory of 128 kilobytes and could be considered as a bit of overkill for this project; to date the firmware only uses about 15% of the available program memory.

The rotary encoder is CUI C14D32P-B3, 32 pulses per revolution (ppr) with detents and a push switch, DigiKey 102-1914-ND. A similar Mouser supplied alternative might be the Bourns EM14A1D-C24-L032N. Notice, however, the different pin layout of the Bourns encoder. In fact, any 5 V compatible optical or mechanical 8, 16 or 32 ppr gray code encoder should do, using a built in or external push button switch.

The 16 × 2 Liquid Crystal Display (LCD) is of the HD44780 compatible variety. These are available at DigiKey and Mouser, but

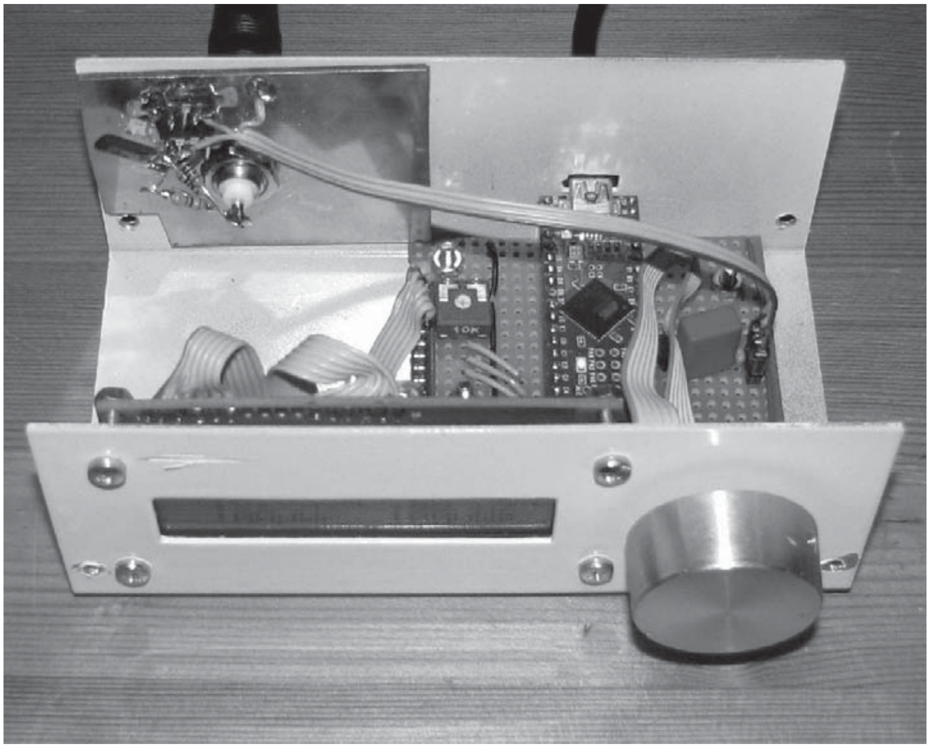


Photo E — The finished project is mounted inside a RadioShack utility box for RF shielding.

sell for as little as $10 US or less on eBay. Currently the blue backlight variety can be found for less than $3, including shipping.

Power is provided over the USB connector, either from a computer or from a repurposed 5 V USB cell phone charger.

Faithful to the original article by W7ZOI and W7PUA, the AD8307 metering circuit is constructed "dead-bug" fashion on a piece of unetched circuit board material, while the Teensy++ board sits on two 20 pin single-inline sockets, mounted on a strip-board holding the voltage reference, a potentiometer for the LCD contrast and a modest number of capacitors for RF decoupling. Everything is mounted inside a RadioShack utility box for RF shielding, as shown in Photo E.

Menus

See Figure 2 for the menus that can be selected by the rotary encoder. When navigating between menus, the first display is visible for one second, before switching to the second display. The push button is used to center the ±8 dB bargraph.

A long push is used to enter the configuration menus (see Figure 3). All configuration settings are stored in EEPROM and are retained when the meter is powered off.

The Microcontroller Firmware

To flash the precompiled firmware into the microcontroller, a free utility called *Teensy Loader* is downloaded from the website **www.pjrc.com**. If other AT90USB boards are used, these may have a different boot loader installed.

The firmware is programmed in *C*, using *Atmel Studio 6*, available at the Atmel website (**www.atmel.com/tools/atmelstudio.aspx**). This is a free download, although registration with Atmel is required. To provide for a virtual serial port over the USB connector, the *LUFA* library has been included in the source code (latest version available at **www.forwalledcubicle.com**).

The full source code and the precompiled binary file are available for download from the ARRL *QEX* files website. Go to **www.arrl.org/qexfiles** and look for the file **5x13_Jonasson.zip**. The download package includes a *Windows* driver (.inf file) if you wish to enumerate the meter as a serial device by a computer running Microsoft *Windows XP*, *Vista* or *7*.

The basic functionality of the firmware is to measure the A/D and to calculate the resulting power indication in dB-milliwatts. The "Convert Voltage Reading Into Power" function given in Table 1 is run once every 5 milliseconds.

All the meter needs is two accurate signal levels, reasonably far apart (30 to 40 dB)

Enter configuration menus with a long push.
Navigate using the rotary encoder and push button.

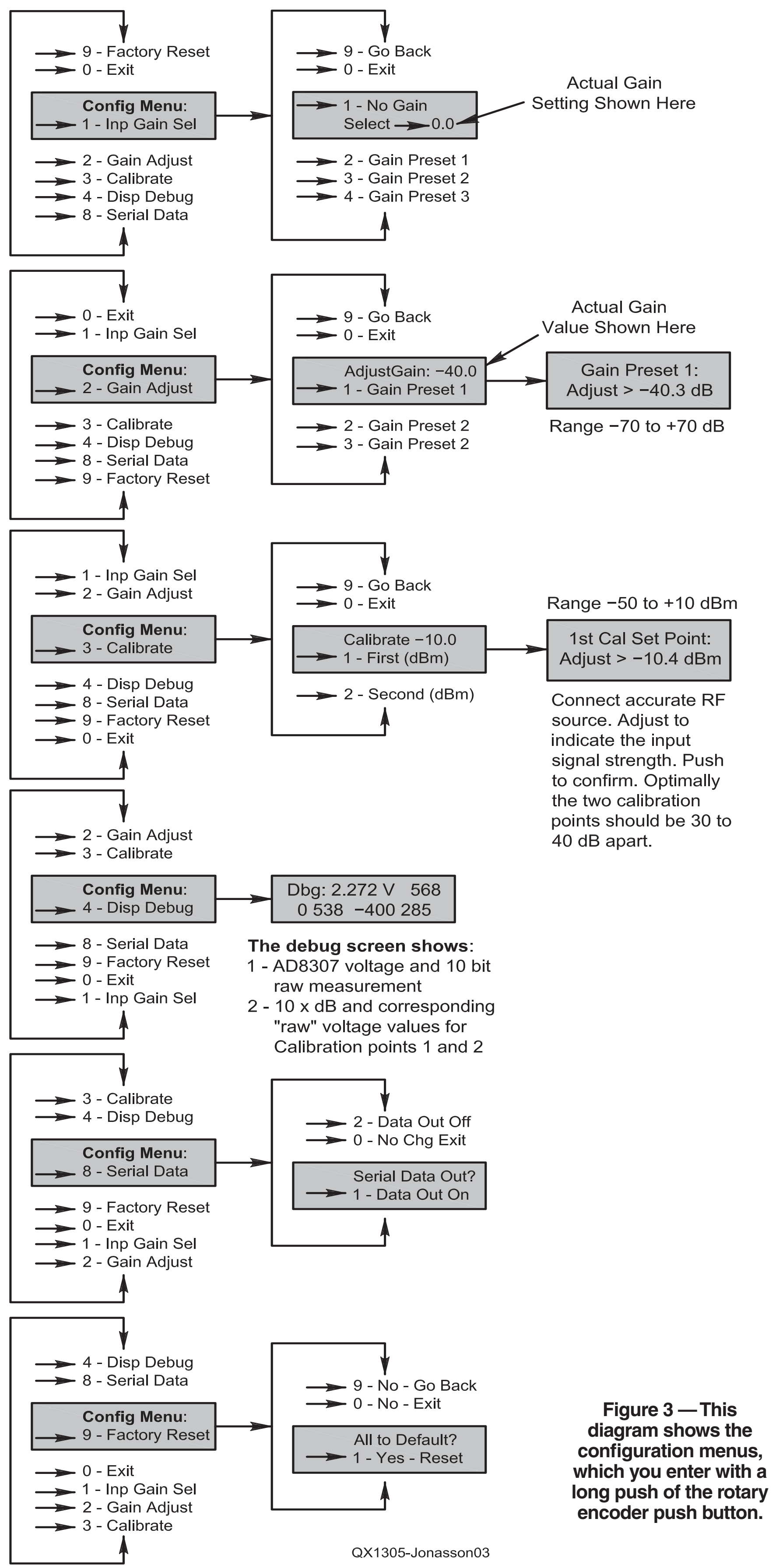


Figure 3 — This diagram shows the configuration menus, which you enter with a long push of the rotary encoder push button.

as calibration points. If you build the meter using the same voltage reference and component values in front of the AD8307 as indicated in the diagram with this article, then I would expect that you would achieve reasonable accuracy without any further calibration. On the other hand, the meter can be calibrated against pretty much anything. In fact I use the exact same piece of code in a different project, to process the output from an AD8317 log amp. The AD8317, unlike the AD8307, has a negative slope gradient.

To derive the one second average power, peak envelope power, amplitude modulation index and other goodies, the "Calculate All Kinds of Power" function given in Table 2 runs once every 5 milliseconds.

Conclusion

Although I digressed a bit along the way, the outcome is still as originally intended: a simple, no-frills power meter with some unintended versatility added. Whether you choose to build the meter and simply flash the firmware, or play with and improve the source code, I hope you will have as much fun as I had with this little project.

Loftur Jónasson, TF3LJ / VE2LJX, obtained a copy of The Radio Amateur´s Handbook *(*ARRL Handbook*) in 1977 when he was 13 years old. This was to have a profound effect on the rest of his life. Later that same year he earned his first Amateur Radio license with the call sign of TF3LJN.*

As an Electrical Engineer (Telecommunications), he has worked in the field of aeronautical and maritime radio and telecommunications since 1992. His resume includes various engineering tasks and projects, mainly in support of aeronautical air-ground and ground-ground voice and data communications and maritime vessel tracking. Currently he works for the International Civil Aviation Organization (ICAO) with his main responsibilities being Standards for aeronautical communication, navigation and surveillance (CNS) systems, and aeronautical frequency spectrum management.

Until the mid 1990s he dabbled with various Amateur Radio activities, such as meteor scatter, satellite, packet radio BBS operation, as well as HF CW and voice operation. Recently, due to nostalgia for a "real electronics experience," he has become active again as an avid home brewer/tinkerer and occasional tester on the air.

Notes

[1] Wes Hayward, W7ZOI, and Bob Larkin, W7PUA, "Simple RF-Power Measurement," ARRL, June 2001 *QST*, pp 38-43.

[2] The program code and other files for this article are available for download from the ARRL *QEX* files website. Go to **www.arrl.org/qexfiles** and look for the file **5x13_Jonasson.zip**.

Table 1
Program Code to Convert Voltage Readings Into Power

```
//----------------------------------------------------------------------------------
//                                Convert Voltage Reading into Power
//----------------------------------------------------------------------------------
void measure_Power(void)
{
            double                delta_db;
            int16_t               delta_ad;
            double                delta_ad1db;
            // Calculate the slope gradient between the two calibration points:
            //
            // (dB_Cal1 - dB_Cal2)/(V_Cal1 - V_Cal2) = slope_gradient
            //
            delta_db = (double)((R.calibrate[1].db10m - R.calibrate[0].db10m)/10.0);
            delta_ad = R.calibrate[1].ad - R.calibrate[0].ad;
            delta_ad1db = delta_db/delta_ad;
            //
            // measured current dB value is then: (V - V_Cal1) * slope_gradient + dB_Cal1
            //
            ad8307_real = (ad8307_ad - R.calibrate[0].ad) * delta_ad1db + R.calibrate[0].db10m/10.0;
}
```

Table 2
Program Code to Calculate Power

```
//---------------------------------------------------------------------------------------
//                                         Calculate all kinds of Power
//---------------------------------------------------------------------------------------
void calc_Power(void)
{
            #define BUFFER 200             // Max/Min/Average Buffer size

            // For measurement of peak and average power
            static int16_t p_avg[BUFFER];  // One second window
            static uint16_t i;

            int16_t p_inst;                // Instantaneous power (dB * 100)
            int16_t p_min, p_max;          // Keep track of Min and Max values
            double v_min, v_max, v_avg;

            p_inst = 100*ad8307_real;

            // Find peaks and averages (done with voltages rather than dB)
            p_avg[i] = p_inst;             // Store dB value in ringbuffer
            i++;
            if (i == BUFFER) i = 0;

            p_min =  32767;                // Maybe a bit excessive as max/min in dB*100 :)
            p_max = -32768;
            for (uint16_t j = 0; j < BUFFER; j++) // Retrieve the min/max values
                                                  //out of the measured window
            {
            if (p_min > p_avg[j]) p_min = p_avg[j];
            if (p_max < p_avg[j]) p_max = p_avg[j];
            }

            // Calculate max/min and average voltage
            v_min = pow(10,p_min/100.0/20.0); // Normalize dB*100 and convert to Voltage
            v_max = pow(10,p_max/100.0/20.0);
            v_avg = (v_min + v_max) / 2.0; // Average voltage in the presence of modulation

            // Average power
            power_db = 20 * log10(v_avg);

            // Average power, milliwatts
            power_mw = pow(10,power_db/10.0);
            // PEP (1 second)
            power_db_pep = 20 * log10(v_max);
            power_mw_pep = pow(10,power_db_pep/10.0);

            // Amplitude Modulation index
            modulation_index = (int8_t) (100.0 * (v_max-v_avg)/v_avg);
}
```

Rudy Severns, N6LF

PO Box 589, 32993 E Saginaw Rd, OR 97424-0025, **n6lf@arrl.net**

Some Ideas for Short 160 Meter Verticals

Few amateurs have room for full sized vertical antennas on 160 meters. Shorter verticals are possible, but you have to be creative.

While it's desirable for a vertical to be a full ¼-wavelength high, on 160 meters that's ≈130 feet and many times that's not possible. For a variety of reasons we may be restricted to much shorter verticals. The late Jerry Sevick, W2FMI, showed us how to build efficient short verticals for 20 and 40 meters using a flat circular top-hat, which is very effective for capacitive loading and practical at 40 meters.[1, 2, 3] But a flat top becomes mechanically difficult on 160 meters, at least for really short verticals where a large diameter is needed. However, capacitive top-loading is still the key to maximizing efficiency in short verticals. This drives us to consider other forms of top-loading. One traditional approach has been the "umbrella" vertical shown in Figure 1. The attraction of this approach is its simplicity: just hook some wires to the top and pull them out at an angle.

Umbrella verticals aren't new, they've been around since the early days of radio and some really excellent experimental work has been done at MF.[4] Large antennas are difficult to work with so there hasn't been a lot of experimental optimization although Belrose, VE2CV, has written about his work with VHF models and at MF.[5, 12] The advent of *NEC* modeling software has made it much easier to explore antenna optimization and this article is mostly a *NEC* modeling study. While *NEC* can be very informative, it's my policy to compare my *NEC* modeling to reliable experimental data whenever possible and I do so near the end of this article.

What's a "Short" Antenna?

What's meant by a "short" vertical? In professional literature the definition is usually a vertical shorter than one radian ($1 \text{ radian} = 57.3^\circ = \lambda/2\pi = 0.16\lambda_0$) where λ_0= free space wavelength. Sometimes "short" is defined as a vertical with a physical height $H<\lambda_0/8$ or 45°. At 1.83 MHz $\lambda_0/8 \approx 67$ feet. The focus of this article will be antennas with $H<0.125\lambda_0$.

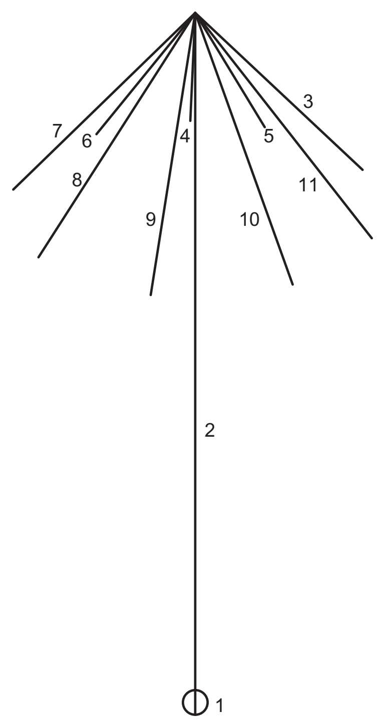


Figure 1 — Example of an umbrella vertical.

Is There a Problem?

Before starting a discussion on capacitive top-loading we need to ask if there is a problem with short verticals that justifies the added complexity of a top hat. After all, we could put up a simple vertical and load it with an inductor as is done for mobile antennas. There is certainly lots of information on optimizing mobile verticals. For a lossless antenna the radiation pattern of a very short vertical is almost the same as a $\lambda/4$ vertical. The differences between short and tall verticals show up when losses are taken into account. We also know that as H is reduced Q rises rapidly and the match bandwidth narrows.

Real antennas have several sources of loss:

- Loading coil resistance — R_L
- Equivalent ground loss resistance — R_g
- Conductor resistance — R_c
- Loss due to leakage across insulators (at the base and at wire ends) — R_i
- Corona loss at wire ends — R_{cor}
- Matching network losses — R_n

In general R_L and R_g are the major losses but in short antennas conductor currents and the potentials across insulators can be much higher than in taller verticals. In fact the shorter the antenna the greater the losses from all causes and a major part of the design effort is directed towards minimizing losses.

The impedance at the feed point is $Z_{in} = R_a - jX_c$, where $R_a = R_r + R_L + R_g + R_c + R_i + R_{cor}$, and X_c is the capacitive reactance. R_r is the radiation resistance which represents the desired power "loss." Note that when modeling lossless examples, $R_a = R_r$.

---

[1] Notes appear on page 45.

Figure 2 shows a graph of Z_{in} for an ideal vertical (R_a=R_r) over a range of heights: $0.01\lambda_0 < H < 0.125\lambda_0$. Note how rapidly R_a falls ($\propto H^2$) and X_a rises ($\propto 1/H$).

In most of the following graphs and discussion H is given as a fraction of λ_0. The physical height in feet (H') at 1.83 MHz is given by:

$$\lambda_0 = 537.471 \text{ feet} \rightarrow H' = 537.471 \times H$$

For example $H = 0.05\,\lambda_0 \rightarrow H' = 26.9$ feet and $H = 0.125\,\lambda_0 \rightarrow 67.2$ feet

In Figure 2 $Q_a = X_c/R_a$. Because R_a falls rapidly as H is reduced and simultaneously X_c increases rapidly, Q_a becomes very large for small values of H. Q_a varies as $1/H^3$!

For $H \le 0.125$, the capacitive reactance dominates Z_{in} which implies that short antennas are basically just small capacitors in series with small resistances, with the equivalent circuit shown in Figure 3.

To tune out the capacitive reactance at the feed point we can add a series inductor as shown in Figure 4 where $X_L = X_c$ and R_L is the loss resistance associated with X_L ($R_L = X_L/Q_L$).

The efficiency (η) for the circuit in Figure 4 can be expressed by:

$$\eta = \frac{power\ radiated}{input\ power} = \frac{R_r}{R_a + R_L} \quad \text{[Eq 1]}$$

Where $R_a = R_r + R_g + R_c + R_i + R_{cor}$. Ignoring for the moment $R_g + R_c + R_i + R_{cor}$, we can graph Equation 1 to show how the efficiency of a short vertical depends on Q_L and H as shown in Figure 5. A Q_L of 200 represents a pretty mediocre inductor. Q_L values of 400 to 600 are practical with a little care. A Q_L = 1000 is possible, but not easy. The efficiencies in Figure 5 are expressed in dB of signal lost due to power absorbed in the inductor. Table 1 shows the correlation between efficiency in percent and dB where η in dB = 10 Log(η(in %)/100).

Table 1
Relationship Between Efficiency in % and dB

Efficiency in %	*Efficiency in dB*
50%	–3 dB
10%	–10 dB
1%	–20 dB
0.1%	–30 dB

For small values of H, the efficiency is pretty depressing. What's even more depressing is that Figure 5 only shows the effect of R_L. When we include other losses the efficiency will be even lower.

Given the practical limitations on Q_L it's clear that short base-loaded verticals can be very inefficient. Mobile antenna work has shown that we can improve the efficiency by moving the inductor from the base up into the vertical itself. While this can help, we can do much better by adding capacitive top loading, which is practical for fixed installations.

Besides efficiency there are other problems. The match bandwidth will be proportional to $1/Q_a$, becoming very narrow as the vertical is shortened. Of course, higher losses provide damping, which increases the bandwidth somewhat, but that's not the direction we want to go. For a given input power, short antennas can have much higher conductor currents and very high voltages at the feed point. For example, if we set $H = 0.05\,\lambda_0$, $R_r \approx 1\ \Omega$ and $X_c \approx 1500\ \Omega$. If the base inductor $Q_L = 400$, then $X_L = 3.75\ \Omega$. $R_r + R_L = 4.75\ \Omega$. For P_{in} = 1500 W the current into the base will be ≈ 18 A_{rms} and the voltage at the feed point (and across the inductor) will be ≈ 27 kV_{rms}! In addition, the inductor will be dissipating ≈1200 W. Clearly, base loaded short verticals have problems. Capacitive top-loading is the way out of this box.

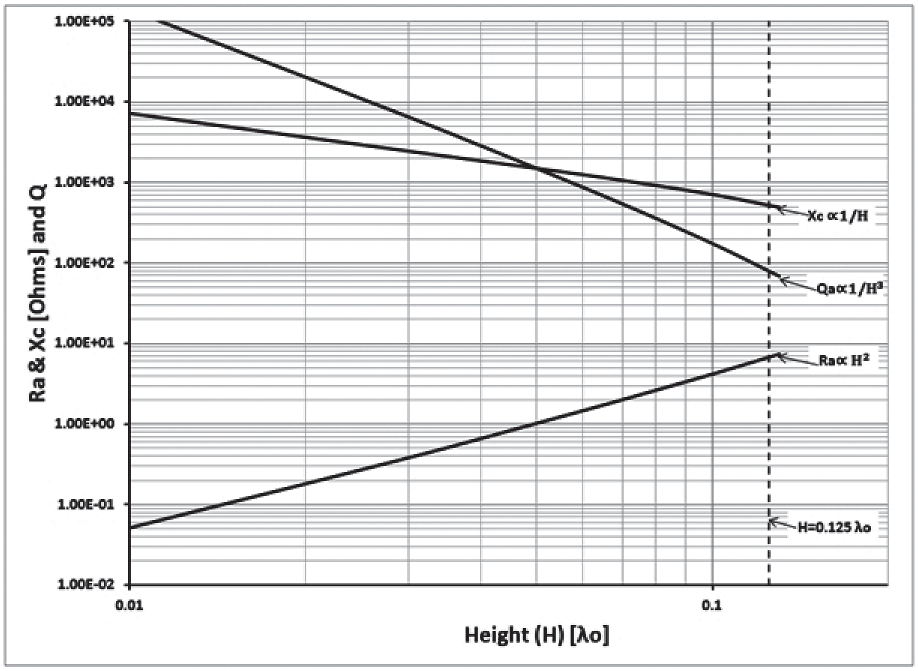


Figure 2 — Feed point impedance at the base of an ideal vertical.

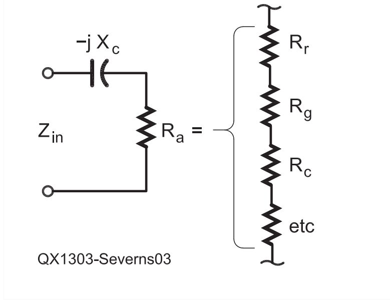


Figure 3 — Equivalent circuit for Z_{in}.

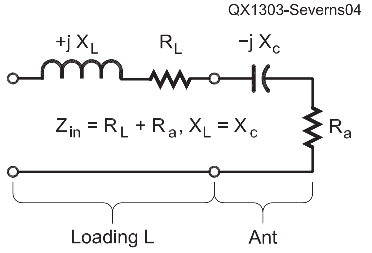


Figure 4 — Equivalent circuit for the input impedance with a series inductor.

Design Variables

There are many variables, all of which can affect performance:

- The height (H)
- The number of umbrella wires (N)
- The length of the umbrella wires (L)
- Whether or not there is a skirt tying the ends of the umbrella wires together
- The apex angle (A) between the top of the vertical and the umbrella wires
- Whether or not a loading coil is used
- The location of the loading coil if one is used
- Q_L of the loading coil
- Conductor sizing and losses in conductors

- Insulator losses
- Matching network design and losses
- Possible corona losses
- Currents and potentials on the antenna
- The characteristics of the ground system and surrounding soil.

There are many variables and we cannot work with all of them at once. What I've elected to do is deal with one or a few at a time, adding loss elements as a better understanding of the antenna develops. The initial models are very idealized, but in the end we'll be including a real ground system, inductor and conductor losses, etc. I've chosen the 8-wire umbrella with a skirt for this discussion because it's relatively simple and it works well, but we should keep in mind that this is only one of many possibilities.[6] An example is shown in Figure 6. The apex angle (A) will be varied from 30° to 90°. The modeling was done at 1.83 MHz. For the moment the ground is assumed perfect and there are no conductor losses.

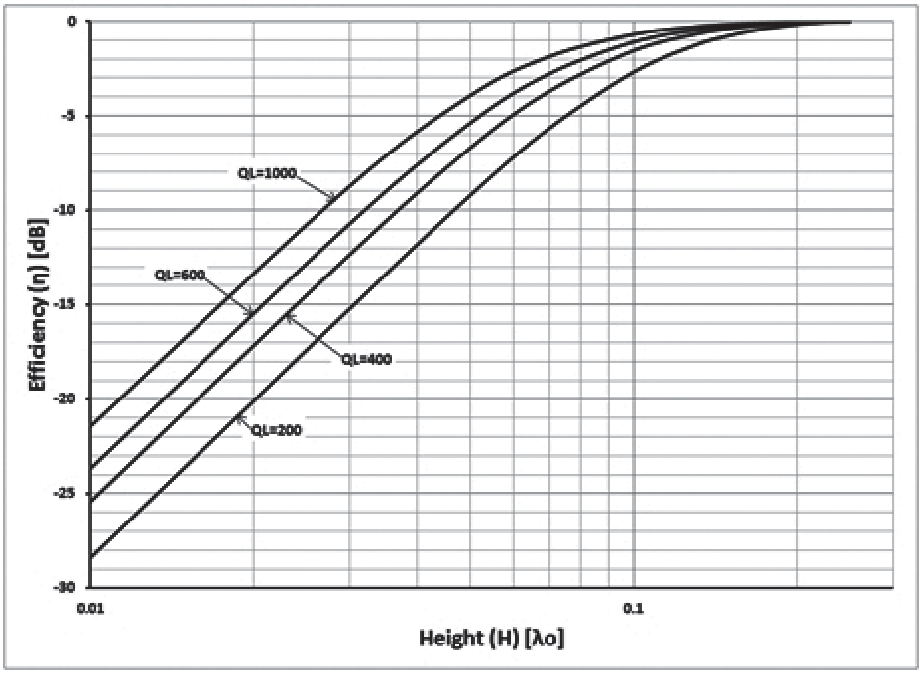


Figure 5 — Variation of efficiency in dB as a function H and Q_L.

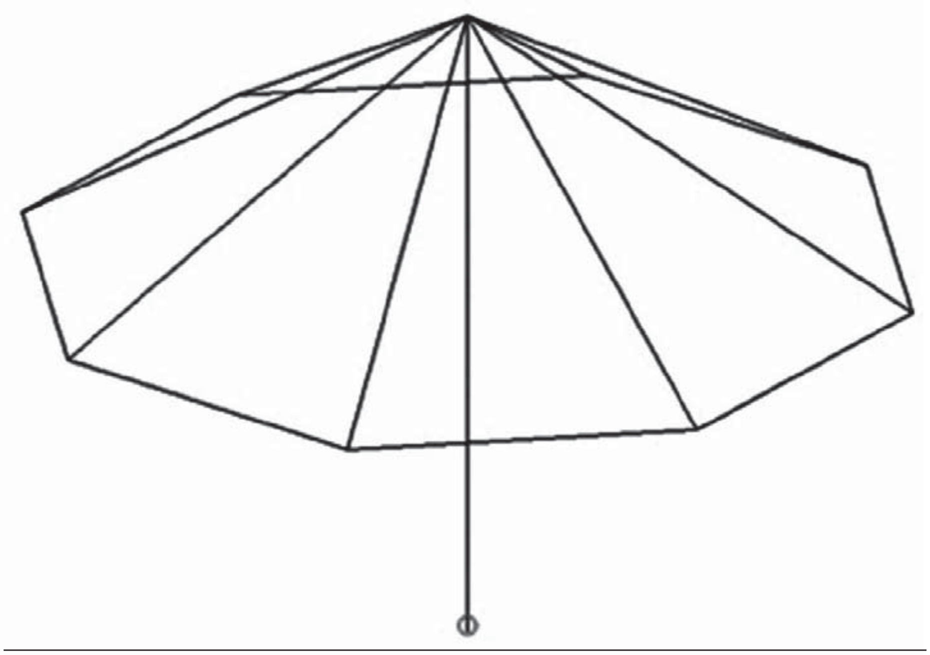
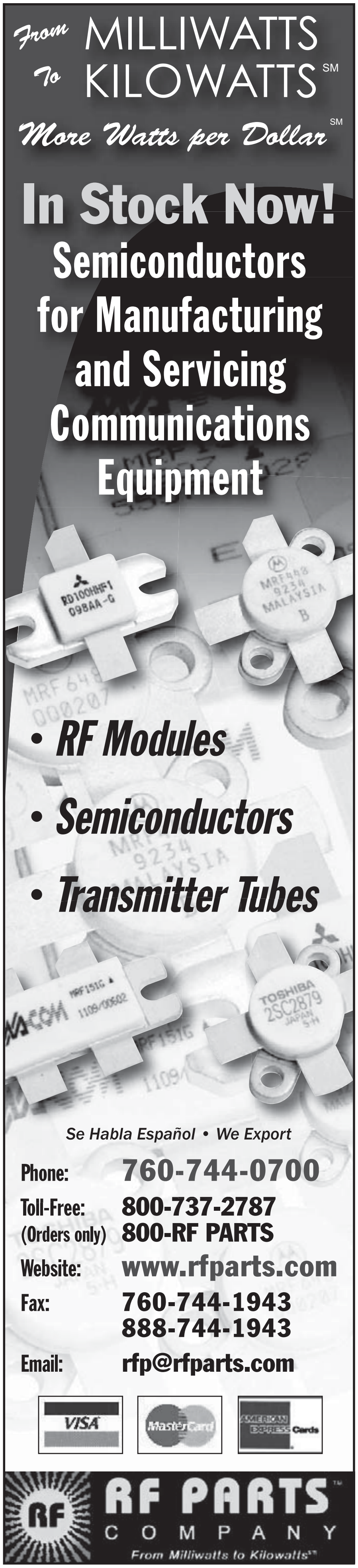


Figure 6 — *NEC* model.



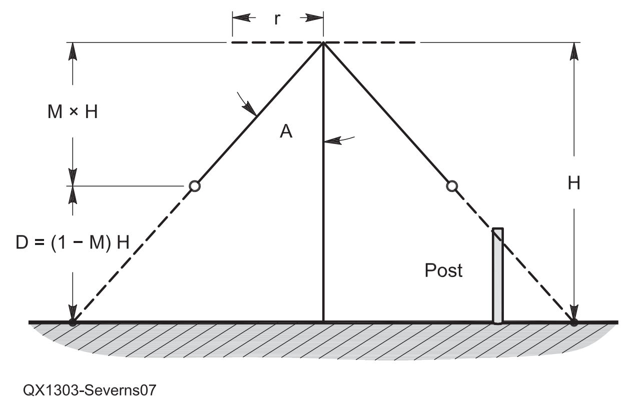


Figure 7 — Model dimensions.

Figure 7 is a sketch of a top loaded vertical identifying the dimensions. The height of the vertical is H and the vertical dimension of the umbrella is M × H (from the top of the vertical to the bottom of the skirt wires). M is a fraction of H ($0<M<1$). As we increase M, the bottom of the umbrella moves closer to ground. The distance from the bottom of the umbrella to the ground is $D = H(1 – M)$. Another dimension we may use is the radius (r) from the vertical to the outside of the umbrella skirt. All these dimensions are in λ_0 except M which is a dimensionless ratio. The angle between the umbrella and the vertical at the top is A (in degrees). Initially all the conductors are #12 perfect conductors.

Idealized Top-Loaded Verticals

There are many possible combinations of top and inductor loading we could use, but given the losses associated with loading coils, our first instinct might be to resonate the antenna *without a base inductor*, using only top-loading. This is possible for a wide range of H. We don't want to fool ourselves, however. Even without the need for a resonating inductor, we will very likely need a matching network with an inductor. Top-loading for resonance is not the only option. One widely held idea is that the top-loading should be adjusted to maximize R_r and then an inductor or capacitor should be used to resonate. It's also possible that some other combination may yield the best efficiency. We'll look at these possibilities after we've added a ground system to the model to introduce R_g into the efficiency calculation.

Horizontal Umbrellas

Jerry Sevick used flat or horizontal umbrellas (A=90°) for top loading on 40-meter verticals. This form of top-loading is very effective, but it may not be practical on 160 meters. Figure 8 shows how large the umbrella radius must be to resonate the vertical at 1.83 MHz for 20 feet $\leq$H'$\leq$70 feet. To give a better feeling for the mechanical dimensions I've shown H and r in feet (H' and r').

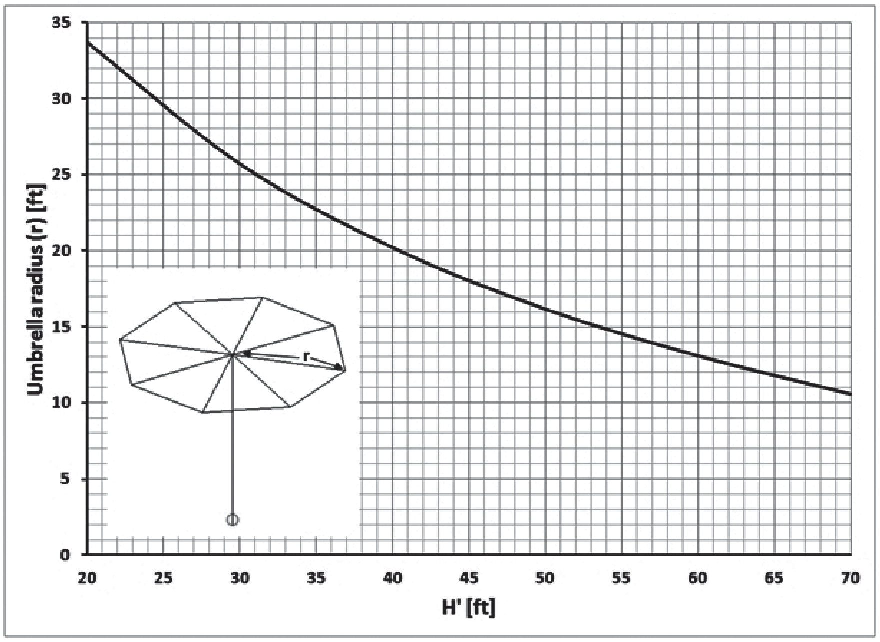


Figure 8 — Radius of the horizontal umbrella needed to resonate the vertical as a function of H'.

For H' = 40 feet, resonance requires an umbrella with r' = 20 feet. An umbrella with r = 10 feet is pretty easy, but going to r = 20 feet or more becomes a mechanical challenge, at least if the umbrella is a free standing "wagon wheel." Mechanically, it's much simpler to just attach the umbrella wires to the top of the vertical and slope them towards ground. But there's a price to pay as shown in Figure 9. For most values of H and A, R_r is higher than its value without top-loading, but for sloping umbrellas R_r is substantially lower than for A = 90°. If it's possible to use a horizontal umbrella by all means do so, but for the rest of this article, we will assume we can't do that and we'll be considering umbrellas with sloping wires.

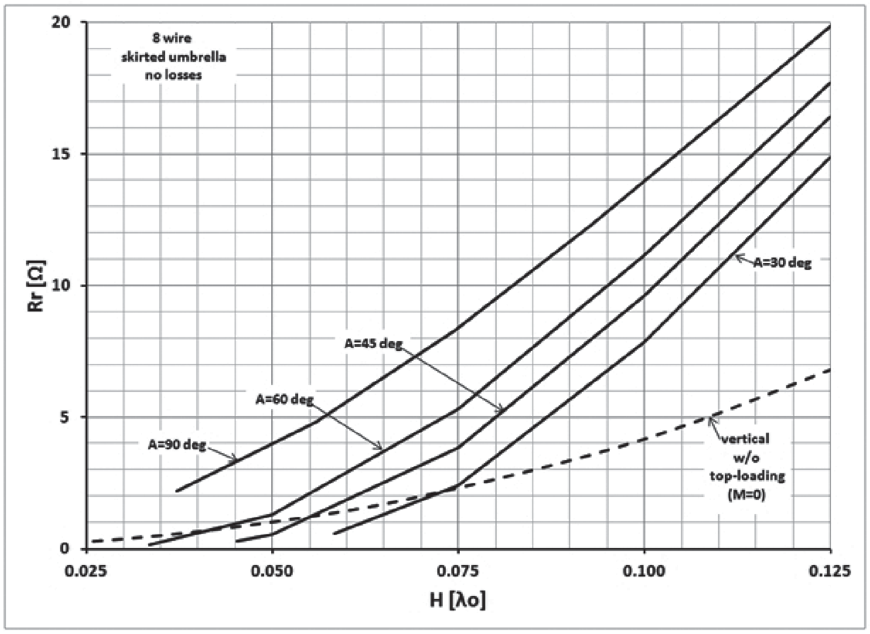


Figure 9 — R_r at resonance as a function of A and H compared to an unloaded vertical.

Umbrellas with Sloping Wires

Figure 9 makes the importance of A clear. For a given M and H, the larger we make A the larger r will be and the greater the top-loading capacitance. This allows us to reach resonance with smaller values of M. However, larger values of A require the umbrella wire anchor points to be farther from the base of the vertical, increasing the ground footprint. One way to reduce the footprint would be to place the umbrella wire anchor points on posts above ground as indicated in Figure 7. In a given installation the value for A is likely to be limited by the available space.

Resonating the vertical using only capacitive loading helps a great deal by eliminating R_L, but we still have the problem of low R_r for small values of H as shown in Figure 9. The dashed line represents R_r for a bare vertical, without top-loading. Over much (but not all!) of the graph we see that top-loading not only resonates the antenna but also increases R_r. That's great but for really short antennas, R_r with capacitive loading can be little better or even *lower* than the simple vertical.

Figure 10 shows the relationship between H and M *for resonance* for skirted umbrellas with 4 and 8 wires, for three apex angles (A).

Whether we can reach resonance depends

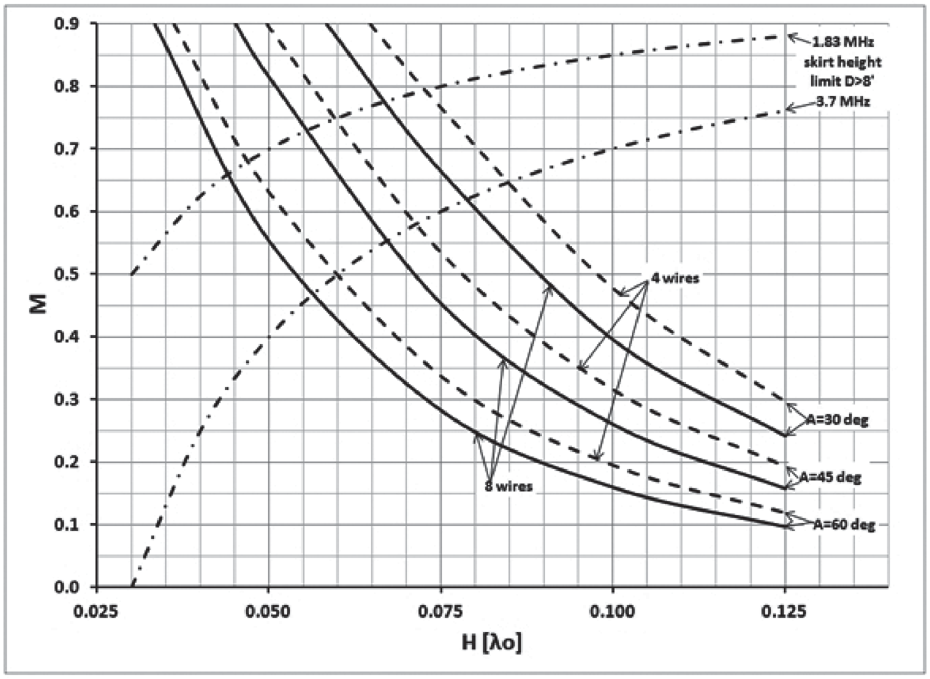


Figure 10 — Values of M for resonance when using 4 or 8 umbrella wires and a skirt.

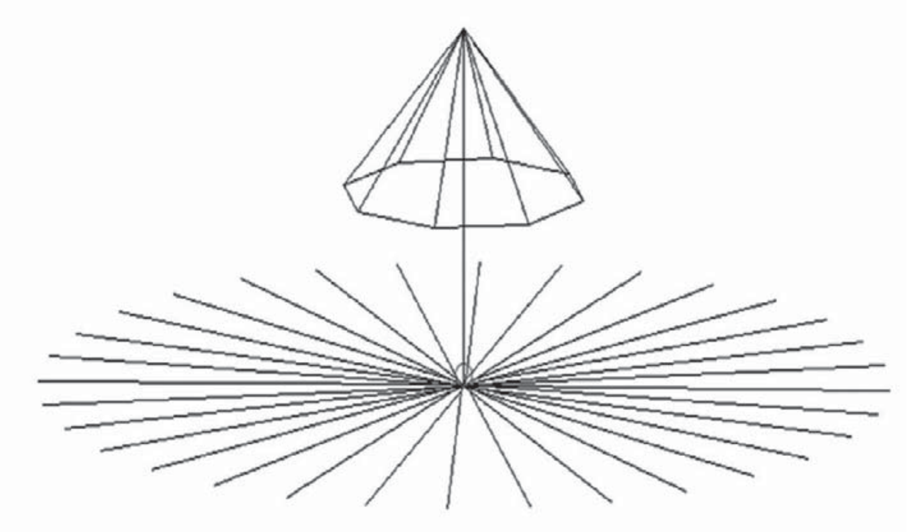


Figure 11 — *NEC* model for a top-loaded vertical with a ground system.

on H, A and the number of umbrella wires, but as Figure 10 shows we can do pretty well for antennas down to H ≈ $0.04\lambda_0$ or a bit shorter on 160 meters if we use a large value for A and more wires in the umbrella. At 1.83 MHz, $0.04\lambda_0$ = 21.5 feet, which is definitely a "short" vertical. Figure 10 shows that increasing the number of wires in the hat increases its effectiveness, but the point of vanishing returns sets in quickly. The improvement gained by doubling the eight wires to 16 wires would be relatively small. The number of umbrella wires becomes a judgment call: is it worth the cost and increased vulnerability to ice loading? The major drawback to wire umbrellas is their vulnerability to ice loading. If you live in an area where ice storms are common you'll have to carefully think through your mechanical design.

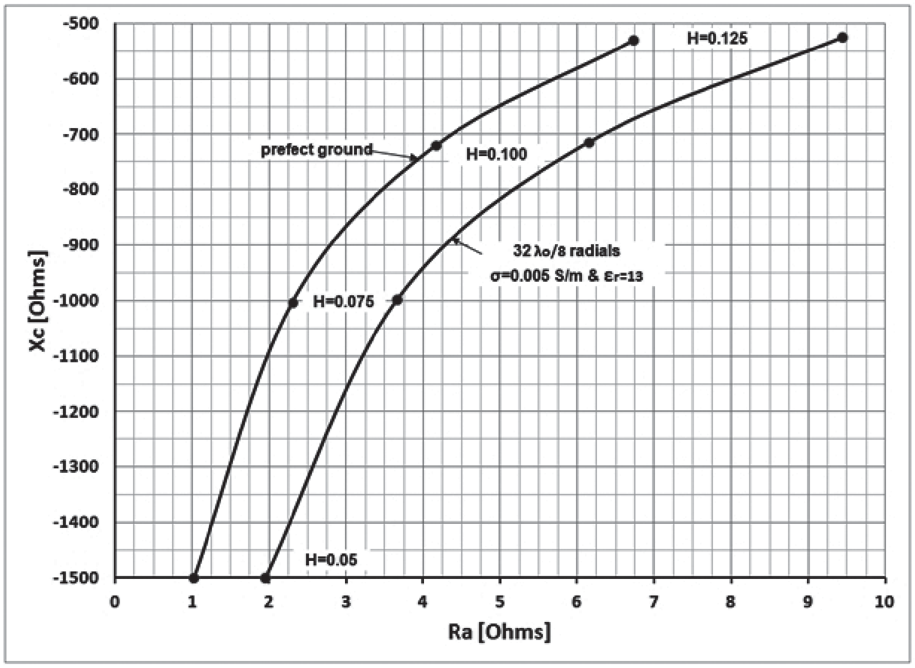


Figure 12 — R_a versus X_c as a function of H with no top-loading, with perfect and real ground systems.

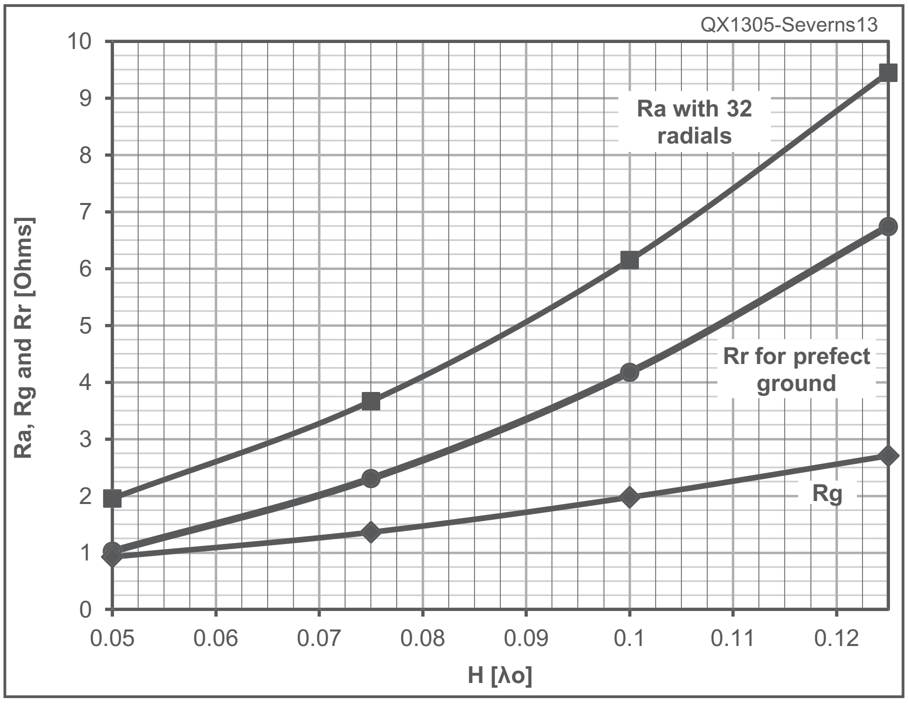


Figure 13 — R_r, R_a and R_g as a function of H *without top-loading*.

There is an important limitation on M, especially for small values of H: *the distance above ground of the lower edge of the umbrella*. Because there can be very high potentials on the skirt you must *keep the skirt out of reach*, at least 8 feet above ground so you can't touch it. This limitation is indicated in Figure 10 by the dash-dot lines. There is one set of limits for 1.83 MHz and a second for 3.7 MHz. You are limited to values of M below these boundary lines.

Non-Ideal Verticals

Now it's time to include losses in addition to R_L.

Affect of Ground System Losses

A model that includes a ground system is shown in Figure 11.

I've chosen to use 32 $\lambda_0/8$ radials (Lr ≈ 65 feet) buried 6 inches in average soil (σ = 0.005 S/m and ε_r = 13). This represents a compromise system; real systems may be larger or smaller depending on the limitations of a given installation. A = 45° is a common apex angle where the radius of the umbrella wire anchor points is about the same as H. To keep the number of graphs in bounds I've set A = 45° for many of the examples.

We need to keep our goal in mind. For a given set of limitations on H, the footprint area of the ground system and the distance to umbrella anchor points on the ground, etc, we want to achieve the maximum possible efficiency. For the moment we'll work with the major losses: R_g and R_L. In this part of the discussion we are *not* going to assume the umbrella loading alone is enough to resonate the antenna. We may use some X_L.

We can start by looking at the effect of real ground on R_a as shown in Figure 12 which compares R_a versus X_c between models with and without the ground system for four values of H. The dots correspond to the values for H at that point.

We can see that R_a increases substantially when a real ground system is used but we also see that X_c is not greatly affected. This indicates that using R_r for the perfect ground as the R_r value with a real ground is a reasonable approximation. This lets us calculate R_g from the model values for R_r and R_a:

$$R_g = R_a - R_r \qquad \text{[Eq 2]}$$

Figure 13 is a graph using Equation 2 to calculate R_g with the ground system shown in Figure 11 but without top loading.

Even though we've kept the ground system and soil characteristics constant as we varied H, R_g is *not* constant. There is a common misconception that at a given frequency, with a given ground system design and soil characteristics, that R_g is some fixed number without regard to the details of the vertical. This is not the case! R_g is not something you measure with an ohmmeter. It is how we account for the ground losses (P_g) associated with a given antenna for a given base current (I_o).

$$P_g = R_g I_o^2 \qquad \text{[Eq 3]}$$

P_g is created by E and H-fields which in turn are a function of both the base current and the details of the antenna. As we change the antenna, for a given I_o and ground system, P_g will change and that means R_g will change.

Z_{in} with a Ground System

Figure 14 shows the feed-point impedance ($Z_{in} = R_a + jX_c$) as a function of H and M: where H = 0.05, 0.75, 0.100 and 0.125 and M is varied from 0 (no umbrella, just a bare vertical) to a limit imposed by the minimum allowed ground clearance (8 feet) for the umbrella skirt. The dashed line represents Z_{in} for a bare vertical as H is varied. We can see that the addition of an umbrella drastically changes Z_{in} and Z_{in} is a strong function of both H and M. There are some square markers in Figure 14, which correspond to points of maximum efficiency. We'll discuss these shortly.

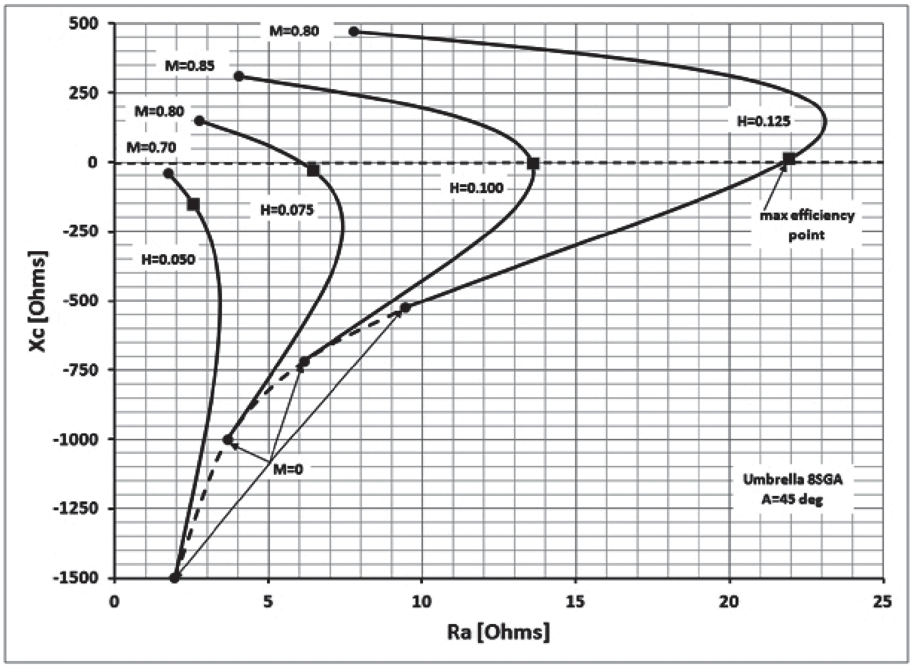


Figure 14 — Feed point impedance as M is increased for H = 0.05, 0.075, 0.1 and 0.125 and A = 45°.

Efficiency

In terms of R_r, R_g and R_L, the efficiency will be:

$$\eta = \frac{R_r}{R_r + R_g + R_L} \qquad \text{[Eq 4]}$$

We know that $R_L = X_c / Q_L$ and we'll set $Q_L = 400$ which is a reasonable value. The *NEC* model gives us R_r from the ideal antenna and R_a from the antenna with the ground system.

Figures 15, 16 and 17 show how R_r and the loss resistances R_g and R_L vary as a function of M. In Figures 15 and 16 there are markers (the diamonds) for the values of M which correspond to resonance. Note that for H = 0.050 resonance is not reached with the maximum value of M so there is no diamond marker. In Figures 15 and 18 the circles mark the values of M corresponding to maximum R_r. In all these graphs M = 0 corresponds to no umbrella.

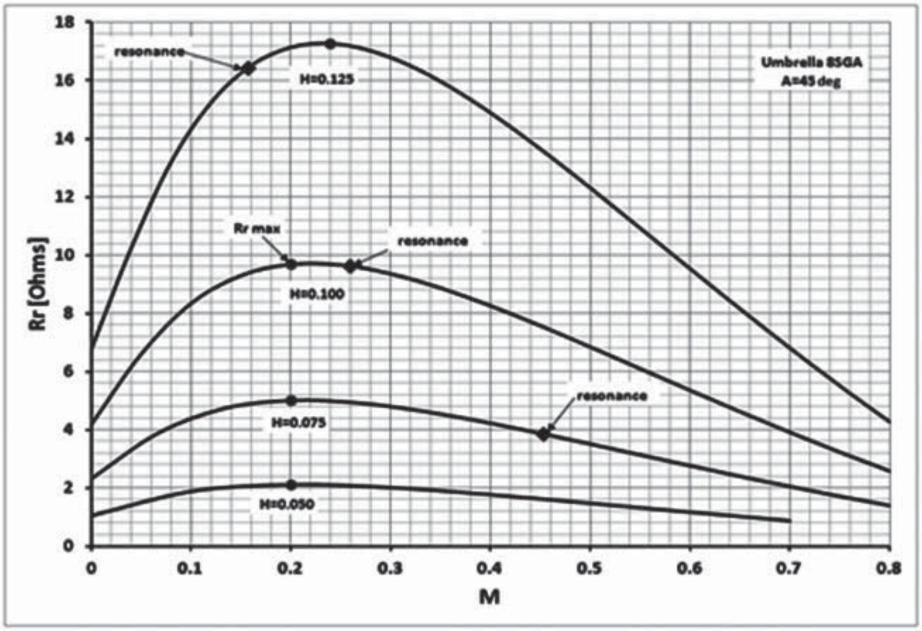


Figure 15 — R_r as a function of M with H as the parameter.

In Figure 15 as we enlarge the umbrella (increase M) R_r rises initially but there is a maximum point which depends on H. Increasing M further reduces R_r. This is not surprising given that the currents on the umbrella have a component ≈180° out of phase with the current on the vertical. This results in some cancellation, which increases as M increases. For H = 0.125 and 0.100, R_r maximum and resonance are fairly close

Table 2
L-Network Values and 2:1 SWR Bandwidths

H (λ_o)	*R_a* (Ω)	*X_a* (Ω)	*X_s* (Ω)	*R_s* (Ω)	*X_p* (Ω)	*2:1 Bandwidth*
0.050	2.56	–152.5	163.5	0.41	–12.56	15 kHz
0.075	6.46	–30.67	47.44	0.12	–19.26	33 kHz
0.100	13.60	–5.92	28.17	0.07	–30.56	56 kHz
0.125	21.94	11.42	13.39	0.03	–44.21	75 kHz

together, but for shorter antennas the two points are widely separated.

As shown in Figure 16, R_g behaves very much like R_r for smaller values of M; R_g rises but then reaches a peak and begins to fall as M is increased further.

Figure 17 shows R_L decreasing as M is increased and at some point resonance is reached ($X_c = 0$, except for H = 0.050). Above this point we no longer need X_L to resonate ($X_c>0$) so in Figure 17, $R_L = 0$ above resonance.

All three loss resistances vary with M so it's hard to see simply by inspection where the minimum loss or highest efficiency point is. Better to plug in values for R_r R_g and R_L into Equation 3 and see where the maximum efficiency occurs as shown in Figures 18 and 19.

Figure 18 shows the efficiency in dB where 100% efficiency would be 0 dB. Besides circles for maximum R_r and diamonds for resonance, there are squares to indicate values of M corresponding to maximum efficiency. One important point to notice is that while there are distinct points of maximum efficiency these maximums are very broad. For H = 0.125, resonance and maximum efficiency coincide and for H = 0.100 and 0.075 they're also nearly coincident. The choice for M is not critical but in general the shorter the vertical the larger the optimum value for M. It's also interesting to note that the points of maximum R_r don't coincide with either resonance or maximum efficiency. This brings into question the common assumption that designing for maximum R_r will result in maximum efficiency. That's actually a shame because if maximum R_r is our goal then *NEC2* modeling could easily be used to determine the value. Unfortunately, we need *NEC4*, which is often not available, to determine R_g as it varies with the design of the vertical. However, it is possible to use E and H near-field values from *NEC2* and a spreadsheet to calculate R_g as shown in the *ARRL Antenna Book* (the equations are given in the *Excel* files on the associated CD).[8]

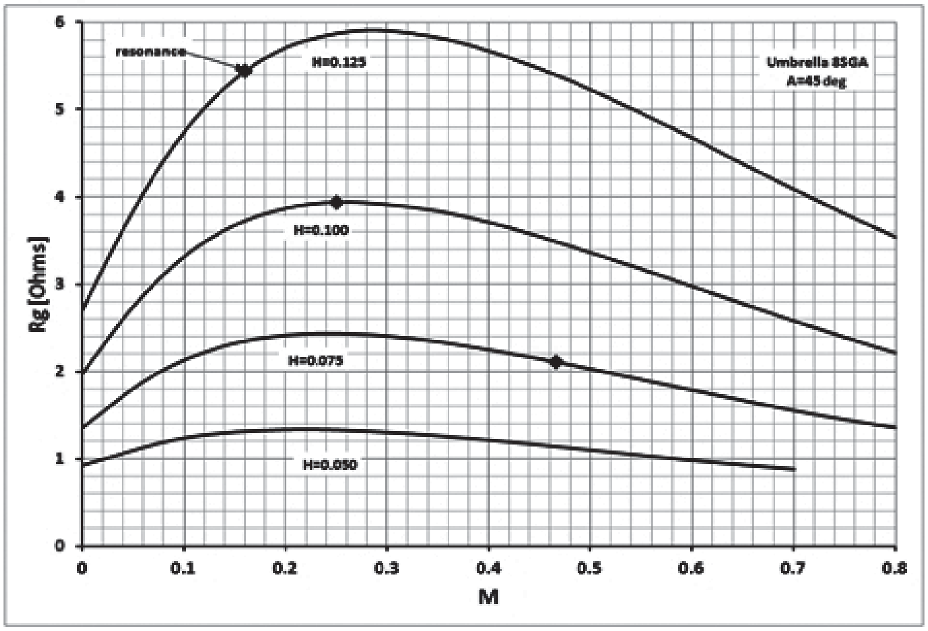


Figure 16 — R_g as a function of M with H as the parameter.

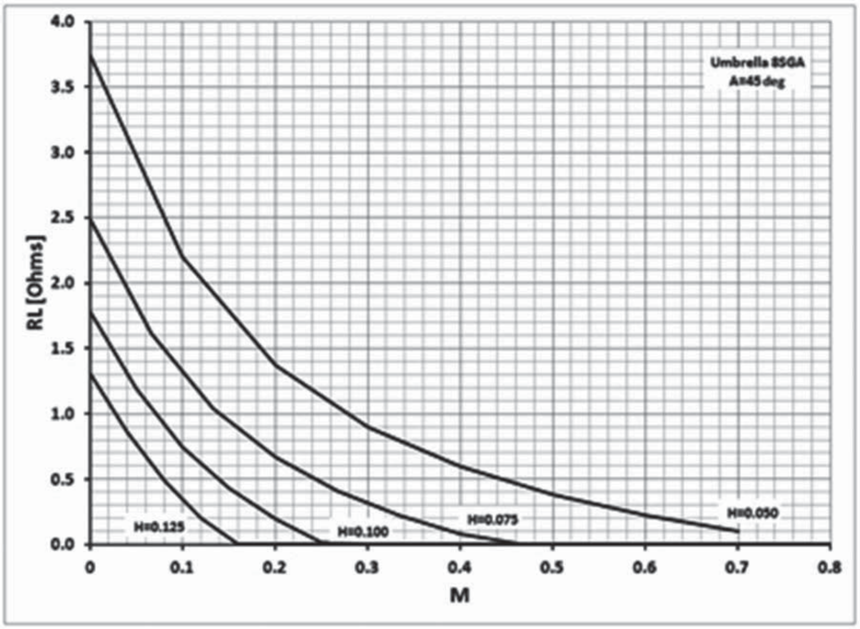


Figure 17 — R_L as a function of M with H as the parameter.

As shown in Figure 19, the apex angle of the umbrella (A) has an effect on the value for M at the maximum efficiency point. The larger A the lower the losses and the smaller (in terms of M) becomes the umbrella. Note that for larger values of A the efficiency peaks are higher but narrower. Making A as large as practical is very helpful for shorter antennas.

Figures 18 and 19 indicate that it's possible to build very short verticals with efficiencies better than 50%. Figures 18 and 19 also bring out another important point. For the examples shown, with the exception of H = 0.125 in Figure 18, resonance occurs for values of M larger than those for maximum efficiency. This implies that it might be better to not load to resonance and use a small loading inductor. However, the differences in efficiency between the maximum and the values at resonance are small in most cases, at least for H> 0.050. From a practical point of view it's simpler top-load to resonance. That value for M can easily be obtained using *NEC2* and some field tuning adjustments. For really short verticals it may pay to do some *NEC4* modeling to see where the maximum efficiency occurs. You could also make field strength measurements with a given input power or use a VNA.[9]

Conductor Losses

It's time to consider conductor losses (R_c). Figure 20 gives examples of how the current at the feed point (I_o), for a given input power (1.5 kW in this example), can vary with H and M. A is fixed at 45° and the squares mark points of maximum efficiency. Figure 20 shows how rapidly I_o increases as H is reduced. Conductor loss varies as I_o^2 so the conductor losses grow rapidly as H reduced. It isn't only that I_o is larger but the current along the entire vertical that increases with more capacitive loading as illustrated in

Figure 21, which shows examples of the current distributions on an H = 0.075 vertical. Note that these current distributions are for $I_o = 1$ A. As shown in Figure 20, for a given P_{in}, the value for the base current (I_o) will depend on R_a, where

$$I_0 = \sqrt{P_{in} / R_a}$$

As we vary the power level I_o will vary but the ratio I_{top}/I_o, where I_{top} is the current at the top of the vertical, will remain the same as shown.

The current distribution for M = 0.50 has $I_{top}/I_o = 0.99$, in other words the current is almost constant along the vertical part of the antenna. I_{top}/I_o ratios greater than 0.9 are typical for short antennas top-loaded to near resonance. As shown in Figure 21, the current without top-loading (M=0) falls almost linearly to zero (or close to it) at the top. In the case of mobile antennas the current distribution can be significantly improved by moving the loading inductor up into the vertical, which raises the question if that idea is also useful when heavy top-loading is used. It turns out that when the current distribution is nearly constant the loading coil position has limited effect on the current distribution. From a practical point of view, moving the inductor up into the vertical is a nuisance, but in some cases you may be able to gain some improvement by relocating the inductor if the top-loading is not great enough to be close to resonating the vertical. This may be the case when H < 0.05.

We can get a good measure of conductor loss by turning on the conductor loss option and then calculating the average gain (G_a) with only the conductor losses. Figure 22 illustrates conductor losses for two different conductor sizes for the vertical part of the antenna with 0.05 < H < 0.125. In each case shown the antenna is resonant with only top-loading.

The initial model had #12 wires for the vertical and four umbrella wires with a skirt. As can be seen, the conductor losses at H = 0.05 are very high, ≈–4.5 dB. Most of the loss is in the vertical conductor so increasing its diameter from 0.08 to 0.5 inch cuts the loss almost in half. An even larger diameter conductor along with eight umbrella wires would reduce the conductor loss to less than 1 dB. For example, at 1.83 MHz, 0.05 $\lambda_0 \approx$ 27 feet, a 30 foot length of 4-inch aluminum irrigation tubing along with a skirted 8-wire top-hat could have low conductor losses.

The message here is to be very aggressive in conductor sizing. If we are, we can keep conductor losses low even in very short antennas!

Voltage at the Feed Point

Not only is I_o large in short verticals but the voltage at the feed point can also be very high due to the high reactances below resonance (see Figures 12 and 14 for X_c). Figure 23 shows typical values for the feed point voltages for P_{in} = 1.5 kW as M is varied for several values of H.

Note that the vertical scale is in kV_{rms}! Fortunately, for H≤0.075 the highest efficiency point is close to resonance so the feed point voltages are relatively low. However, with H ≤0.05, you can't reach resonance, at least with A = 45° and 8 wires, and the feed point voltage is much higher. One way to improve both efficiency and reduce the feed point voltage would be to increase A to 60°. At 1.83 MHz, 0.050$\lambda_0 \approx$ 27 feet so it may be practical to increase A in shorter antennas.

If the power is reduced from 1500 W to 100 W we're still not out of the woods because the voltage varies as the square root of P_{in}. Going from 1500 W down to 100 W reduces the feed point voltage by a factor of

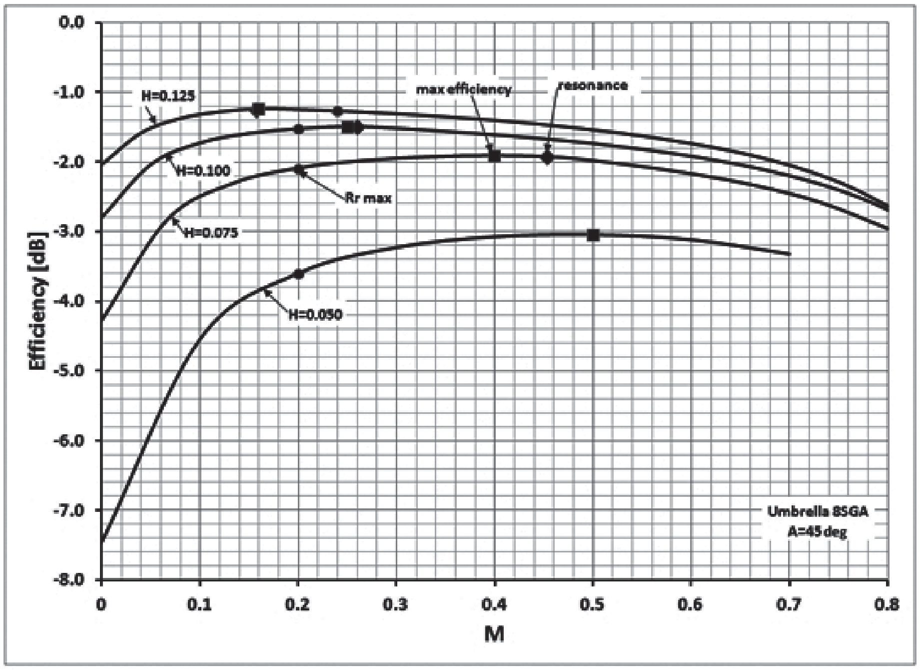


Figure 18 — Efficiency in dB as a function of M with H as the parameter and A = 45°.

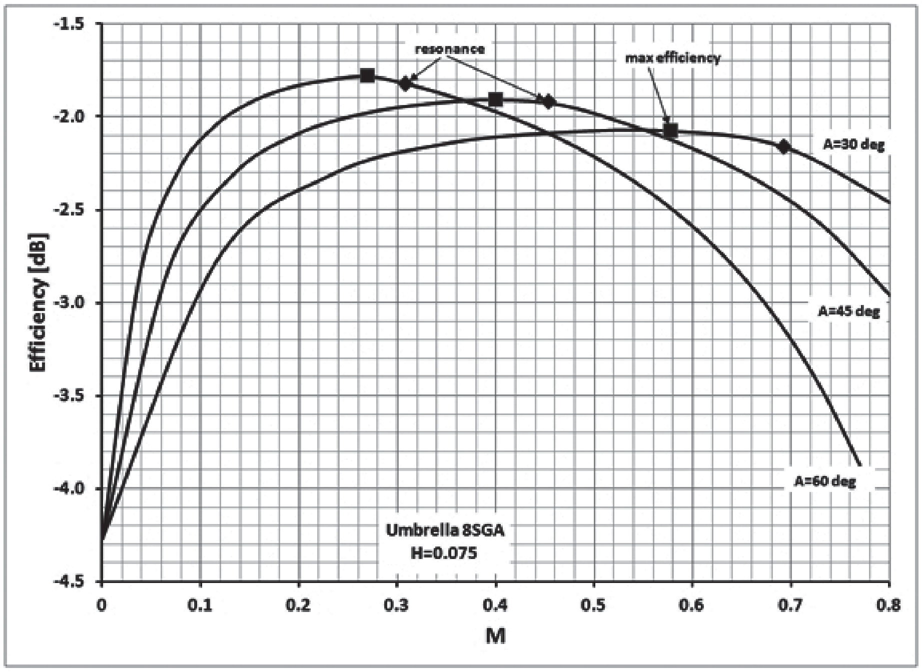


Figure 19 — Efficiency in dB as a function of M with A as the parameter and H = 0.075.

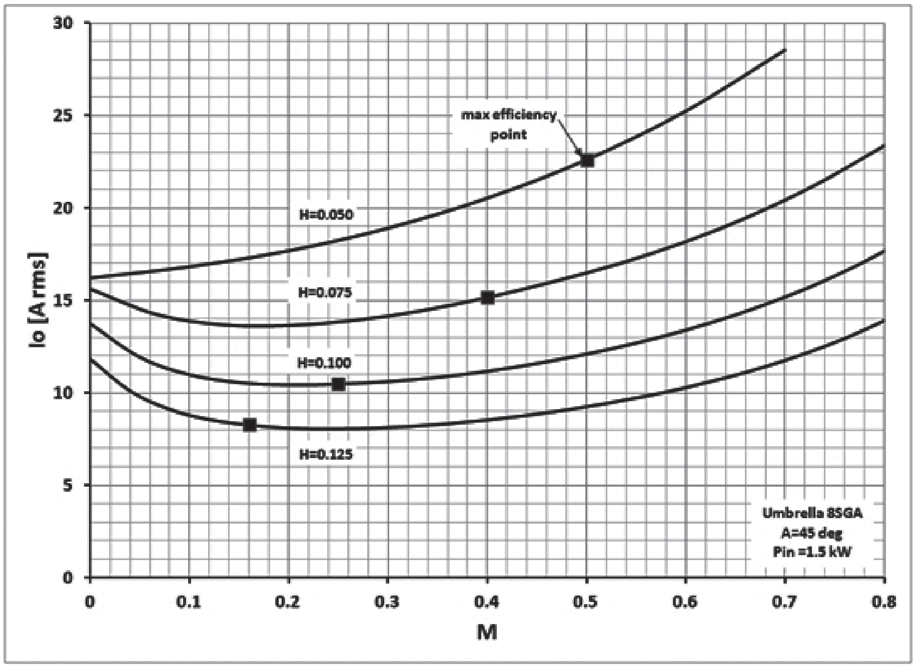


Figure 20 — I_o as a function of M with H as the parameter.

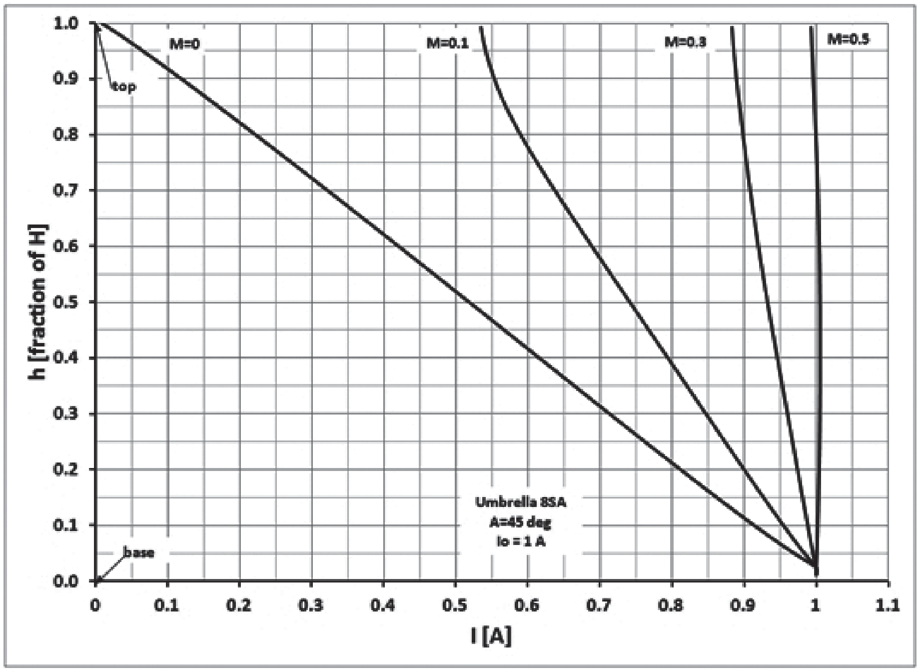


Figure 21 — Examples of the current distribution on a top loaded vertical.

1/3.9 not 1/15! Even at low power levels the voltages can be dangerous. These voltage levels at RF frequencies can introduce significant loss associated with leakage across the base insulator. A plastic bottle base insulator doesn't cut it! Keeping the insulator surface clean and dry is also important. Some form of plastic shield can help to keep achieve this. The use of equipotential rings can also help.

Besides the base insulator these voltages will appear across the base loading inductor if one is present and/or the output of the matching network. There is also the problem of dealing with the power dissipation in the loading inductor. In addition there will be very high potentials on the lower part of the umbrella. These potentials are lower with skirted umbrellas and such umbrellas are usually further above ground, but you still have to consider corona losses. Any sharp points where the umbrella and skirt wires are joined or where insulators are connected can result in substantial losses due to corona, especially if you live at higher altitudes such as Denver, Colorado. You should use high grade insulators on the support lines spreading the umbrella even if they are non-conducting.

SWR Bandwidth

The final step is to match the feed point impedance to 50 Ω. This can be done in many ways but for this discussion I assume the use of a simple L-network matching the feed-point impedance at the highest efficiency point.[10] Assuming A = 45° and f = 1.83 MHz, Table 2 summarizes the L-network components and the 2:1 SWR bandwidth for each antenna. X_s is the series matching reactance, R_s is the loss resistance associated with X_s and X_p is the shunt reactance. In this example all the X_s are inductors with $Q_L = 400$ and the X_p are capacitors. The ground system in Figure 11 is included. Note that R_s (due to the loss in the matching inductor) has only a small effect on efficiency except for smaller values of H.

Table 2 illustrates the sharp reduction in match bandwidth associated with shorter verticals. For a given H, one way to improve bandwidth without reducing efficiency is to make A larger. Making the diameter of the vertical conductor larger will also help especially if you can go to a wire cage several feet in diameter! There's a big bag of tricks along those lines that deserve discussion but this article is already too long.[11, 12, 13]

Experimental Verification

As mentioned in the introduction, *NEC* modeling is a powerful tool, but it's not perfect. Whenever possible I like to compare my results with high quality experimental work. Fortunately, such work is available for this discussion. In October 1947 Smith and Johnson published an IRE paper on the "Performance of Short Antennas" which presented their experimental work at MF on a 300 foot tower with eight sloping umbrella wires and a loading inductor at the base. (See Note 4.) This paper is a beautiful example of first class experimental work. Measurements were made at several frequencies from 120 to 350 kHz with the umbrella wire lengths varied in steps from 100 feet to 450 feet. Figure 24 is a sketch of the tower and umbrella arrangements. The angle between the tower and the umbrella wires was ≈ 48°. H = 300 feet represents $0.037\lambda_0$ at 120 kHz and $0.107\lambda_0$ at 350 kHz so despite the large physical size, this is still a "short" vertical.

The ground system had five hundred 75-foot radials and 250 400-foot radials. The 400-foot radial wires extend a short distance past the outer edge of the umbrella when its wires are at maximum length. At 120 kHz, 75 feet = $0.009\lambda_0$ and 400 feet = $0.03\lambda_0$. At 350 kHz, 75 feet = $0.027\lambda_0$ and 400 feet =

$0.14\lambda_0$. Compared to standard broadcast practice ($0.4\lambda_0$ radials) this is a very abbreviated ground system. A small ground system is just what we might expect with a short amateur vertical. The 500 75-foot radials are in effect a ground screen close to the base of the vertical where the E-fields can be very intense.

Part of the experiment was a measurement of field strength at one mile with 1 kW of excitation. This was done at several frequencies with a range of umbrella wire lengths and loading coil Qs. An example of the results is given in Figure 25 for a loading coil $Q_L = 200$.

Changing frequency with a fixed H is equivalent to changing H at a fixed frequency. Figure 25 sends a clear message: the taller the better! H is a dominate factor in achievable efficiency. There are two sets of data on the graph: the first is the solid line for the case of no skirt wire around the outer perimeter of the umbrella and the second (the dashed line) is for the case where a skirt wire connects the outer ends of the umbrella wires. The point of maximum signal can be viewed as the optimum length for the umbrella wires. The relative field intensity can be used as a surrogate for efficiency. The higher the field intensity, at a given distance, for a given input power, the higher the efficiency.

Note the correspondence between the experimental work in Figure 25 and the *NEC* results in Figure 18. Both figures tell the same story!

Using a skirt provides more capacitive loading for a given length of umbrella so we see the peak move to the left, toward shorter umbrella wires. In both cases the peak is quite broad especially for the un-skirted umbrella.

It is also interesting how the peak field point moves towards longer umbrella wires at lower frequencies (corresponding to smaller H in λ_o) and the peak field also declines indicating lower efficiency. No surprise really, the antenna is electrically smaller at the lower frequencies and less efficient. The shift of the peak towards longer umbrella wires is a reflection of increased loss (lower efficiency). Again, this agrees well with the *NEC* modeling.

I strongly recommend reading the Smith and Johnson paper as well as Belrose and Sevick. See the detailed reference information in the Notes.

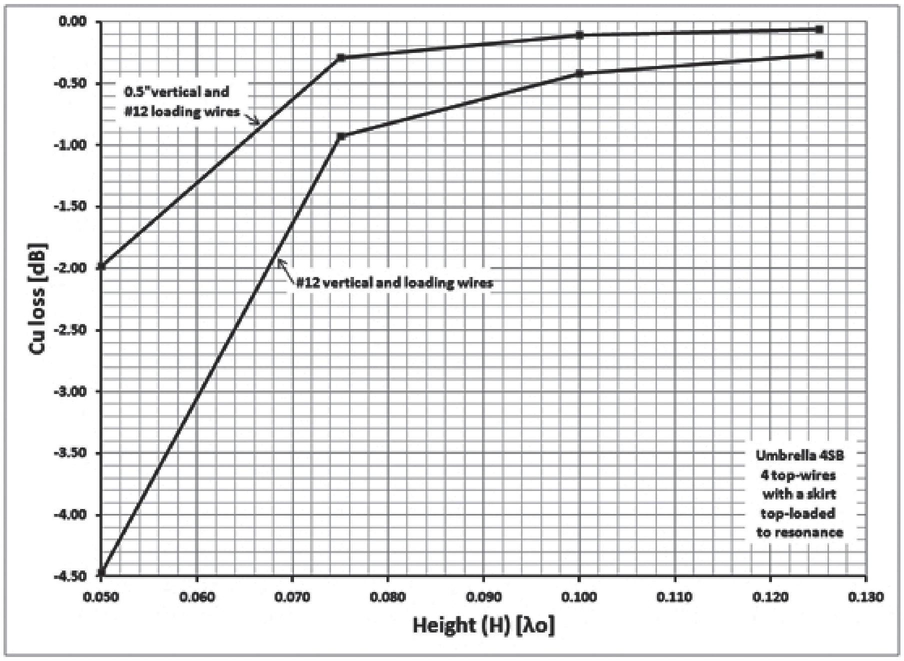


Figure 22 — Examples of conductor loss in short antennas.

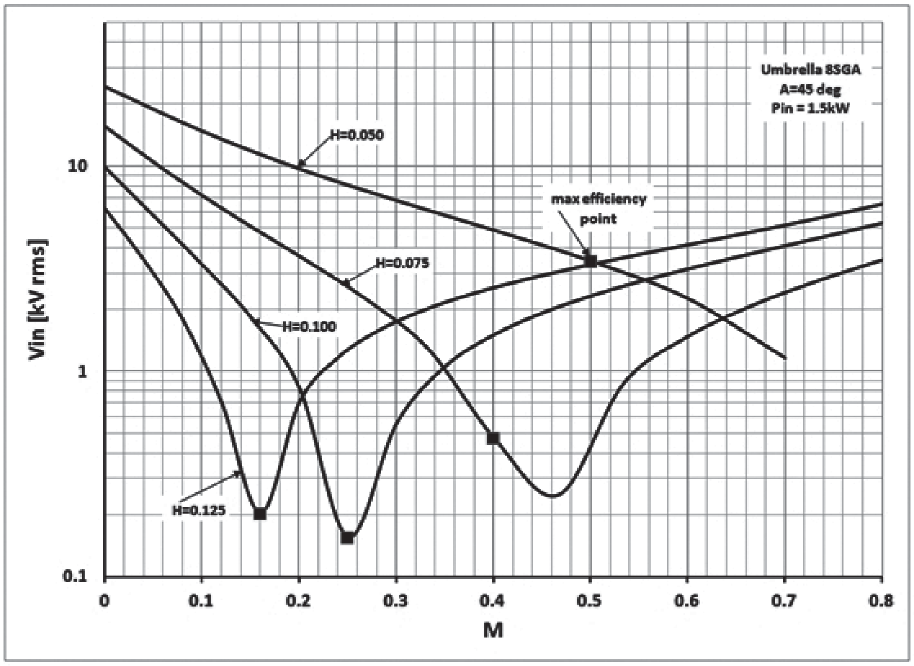


Figure 23 — Feed point voltage as a function of M with H = 0.050, 0.075, 0.100 and 0.125.

Summary

From both modeling and experimental work we can draw some general conclusions:

1. Make the vertical a tall as possible.
2. Make the ground system as large and dense as practical.
3. Make the apex angle (A) as large as practical.
4. Use at least eight wires and a skirt in the umbrella.
5. Be very aggressive in conductor sizing especially for the center conductor.
6. Use high-Q inductors for loading/matching networks.
7. Use high quality insulators both at the base and for the umbrella.

If you do these things then it is possible to have reasonable efficiencies even in very short antennas. Despite the length of this discussion there's far more that could be said and many more ideas for improving short antennas are out there.

Acknowledgements

The work in this paper was prompted by some questions on a short 160-meter antenna from Paul Kisiak, N2PK. Because I hadn't dug deeply into this subject I couldn't help him much beyond some general comments on ground systems. I want also to thank my reviewer Mark Perrin, N7MQ.

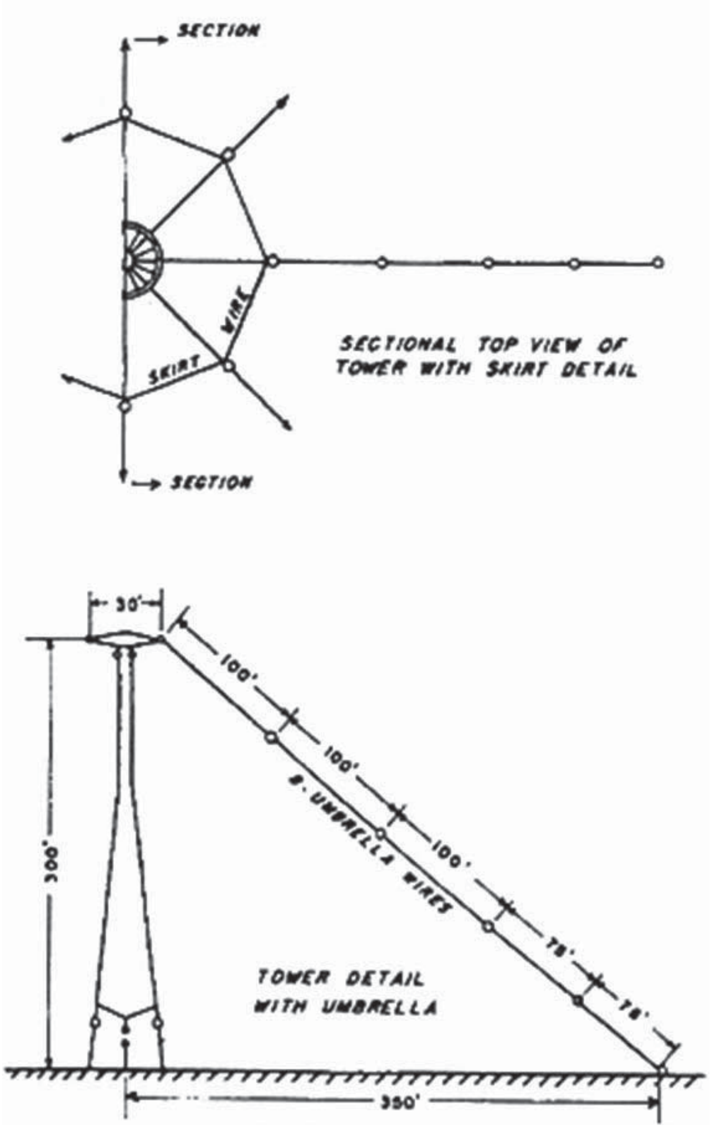


Figure 24 — Sketch of the experimental antenna from Smith and Johnson.[4]

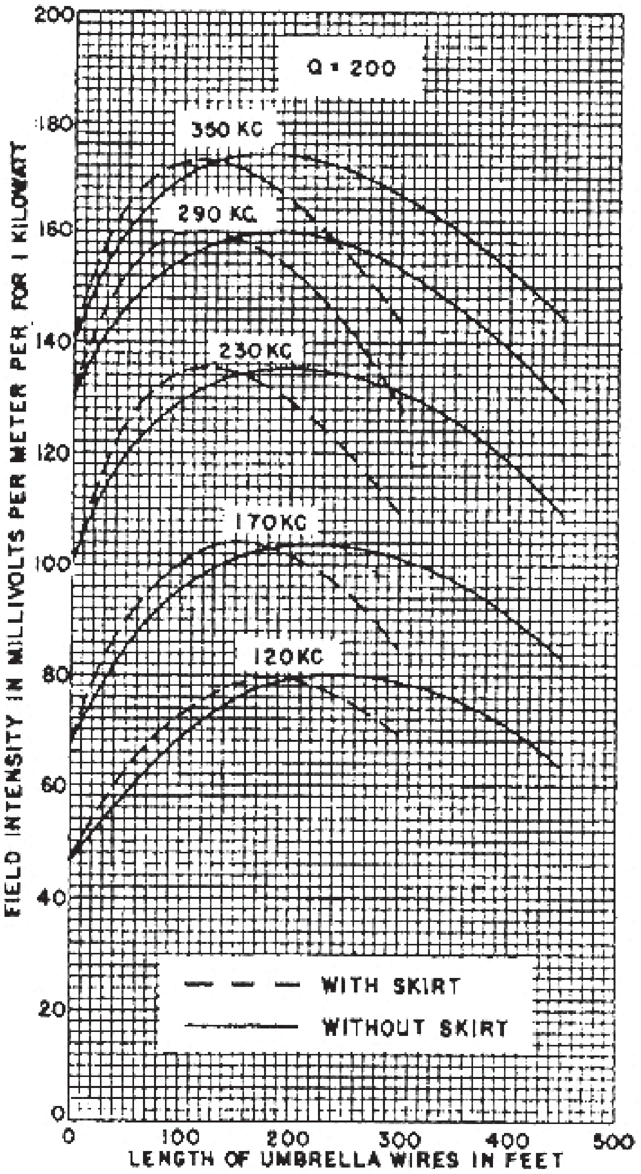


Figure 25 — An example from Smith and Johnson.[4]

Rudy Severns, N6LF, was first licensed as WN7WAG in 1954 and has held an Amateur Extra class license since 1959. He is a consultant in the design of power electronics, magnetic components and power conversation equipment. Rudy holds a BSE degree from the University of California at Los Angeles. He is the author of three books, more than 90 technical papers and a former editor of QEX. *Rudy is an ARRL Life Member and an IEEE Life Fellow.*

Notes

[1] Jerry Sevick, W2FMI, "The W2FMI Ground-Mounted Short Vertical," *QST*, March 1973, pp. 13-18 and 41.

[2] Jerry Sevick, W2FMI, "Short Ground-Radial Systems for Short Verticals," *QST*, April 1978, pp. 30-33.

[3] Jerry Sevick, W2FMI, "The Short Vertical Antenna and Ground Radial," *CQ Communications*, 2003.

[4] Smith and Johnson, "Performance of Short Antennas," proceedings of the I.R.E., October 1947, pp. 1026-1038.

[5] John Belrose, VE2CV, "Folded Umbrella Top Loaded Vertical Antenna," *Ham Radio Magazine*, September 1982, pp. 12-17.

[6] Belrose, Hatton, McKerrow and Thain, "The Engineering of Communication Systems for Low Radio Frequencies," IRE proceedings, May 1959, pp. 661-680.

[7] Howard Shepherd, W6US, "A High-Efficiency Top-Loaded Vertical," *Ham Radio Magazine*, October 1984, pp. 65-68.

[8] *The ARRL Antenna Book*, 22nd edition, 2011. See the discussion in Chapter 3 and the Chapter 3 material on the accompanying CD including the *Excel* graphs with the equations already loaded.

[9] Severns, Rudy, N6LF, "Experimental Determination of Ground System Performance for HF Verticals, Part 1, Test Setup and Instrumentation", *QEX*, January/February 2009.

[10] *The ARRL Antenna Book*, 22nd edition, 2011. See page 24-2.

[11] Breakall, Jacobs, Resnick, Eastman, Machalek and King, "A Novel Short AM Monopole Antenna with Low-Loss Matching System." This paper can be found at **www.kintronic.com/resources/technicalPapers.asp**.

[12] Stuart and Best, "A Small Wideband Multimode Antenna," IEEE 2008.

[13] Grant Bingeman, KM5KG, "Short Omnidirectional Monopole Arrays," *ARRL Antenna Compendium Vol. 7*, 2002, pp. 172-175.

Upcoming Conferences

2013 Annual Conference, Society of Amateur Radio Astronomers

July 14 – 17, 2013
National Radio Astronomy
Observatory
Green Bank, WV

The Society of Amateur Radio Astronomers (SARA) will hold its 2013 Annual Meeting and Technical Conference July 14 through July 17, 2013, at the National Radio Astronomy Observatory (NRAO), Green Bank WV. Papers will be presented on radio astronomy hardware, software, education, research strategies, and philosophy.

Advance Registration Deadline:

Because SARA Conferences require quite a bit of advance planning, early registration is encouraged. To register for the 2013 SARA Conference, your remittance in full must be *received* by our Treasurer (not simply *postmarked*) not later than 31 May, 2013. All registrations received after that date, or walk-in registrations, will be assessed an additional 15% late registration fee. SARA Treasurer, Melinda Lord, 2189 Redwood Ave, Washington, IA 52353; **treasurer@radio-astronomy.org**. There is also a link for PayPal registration.

For more information go to **www.radio-astronomy.org**.

46th Annual Central States VHF Society Conference

July 25–27, 2013
Elk Grove Village Holiday Inn
1000 Busse Rd (Route 53)
Elk Grove Village, IL, 60007
Reservation Phone: 800-972-2494

The Central States VHF Society, Inc (CSVHFS) invites you to attend the 47th annual conference in Elk Grove Village, IL, July 25–27, 2013. The Planning Committee has a fun-filled, educational event in store for you! The on-line registration form is not yet active, but you can register when you arrive.

The Saturday evening banquet speaker will be ARRL Executive Vice President David Sumner, K1ZZ.

Call for Papers

The Central States VHF Society is soliciting papers, presentations, and poster displays for the 47th annual conference. All aspects of weak-signal work on Amateur Radio bands of 50 MHz and above are sought. The papers will be published in the *Conference Proceedings*, which will be available at the conference. You do not have to attend the conference nor present the paper to have it published in the *Proceedings*. Posters describing your project will be displayed during the 2-day conference.

Presentations and Posters at the conference may be technical or non-technical but will cover the full breadth of amateur weak signal VHF/UHF activities. The presentations generally vary from 15 to 45 minutes, covering the highlights with details in the *Proceedings* paper. Topics of Interest include:

- VHF/UHF Antennas, including modeling/design, arrays and control
- Construction of Equipment – such as transmitters, receivers and transverters
- RF power amplifiers – including single and multi-band, vacuum tube and solid state
- Preamplifiers (low noise)
- Regulatory topics
- Software defined radio (SDR)
- Test equipment – including homebrew, using and making measurements
- Operating — including Contesting, Roving and DXpeditions
- Propagation – including ducting, sporadic E, tropospheric and meteor scatter
- Digital Modes – WSJT, JT65 and others
- EME (Moon Bounce).

Non weak signal topics such as FM, repeaters and packet radio are generally not considered, although there are exceptions. If you have any questions about the suitability of a topic, contact K9JK, listed below.

If you would like to contribute a paper, presentation, or poster, please contact John Kalenowsky, K9JK, as *soon as possible* with the title and a short description. You can reach John at **csvhfs2013@gmail.com** or 58 N Oak St, Palatine, IL 60067-5238. Author Guidelines and other details are available at the Society website: **www.csvhfs.org**.

Submissions Deadlines:

Proceedings – May 24, 2013
Presentations – July 1, 2013
Posters – July 1, 2013

The 32nd Annual ARRL and TAPR Digital Communications Conference

September 20-22, 2013
Cedarbrook Lodge
18525 36th Ave South
Seattle, WA 98188-4967
Reservation Phone: 877-515-2176
www.cedarbrooklodge.com

The accomodations at Cedarbrook Lodge for this year's DCC look like they will be outstanding. Now is the time to start making plans to attend the premier technical conference of the year, the 32nd Annual ARRL and TAPR Digital Communications Conference. When making your reservations, be sure to mention the TAPR Digital Communications Conference for the special negotiated rate.

Visit the TAPR website under Conferences (**www.tapr.org/dcc.htm**) for more details.

The ARRL and TAPR Digital Communications Conference is an international forum for radio amateurs to meet, publish their work, and present new ideas and techniques. Presenters and attendees will have the opportunity to exchange ideas and learn about recent hardware and software advances, theories, experimental results, and practical applications.

Topics include, but are not limited to: Software defined radio (SDR), digital voice (D-Star, P25, WinDRM, FDMDV, G4GUO), digital satellite communications, Global Position System (GPS), precision timing, Automatic Packet Reporting System® (APRS), short messaging (a mode of APRS), Digital Signal Processing (DSP), HF digital modes, Internet interoperability with Amateur Radio networks, spread spectrum, IEEE 802.11 and other Part 15 license-exempt systems adaptable for Amateur Radio, using TCP/IP networking over Amateur Radio, mesh and peer to peer wireless networking, emergency and Homeland Defense backup digital communications, using Linux in Amateur Radio, updates on AX.25 and other wireless networking protocols and any topics that advance the Amateur Radio art.

This is a three-Day Conference (Friday, Saturday, Sunday). Technical sessions will be presented all day Friday and Saturday. In addition there will be introductory sessions on various topics on Saturday.

Join others at the conference for a Friday evening social get together. A Saturday evening banquet features an invited speaker and concludes with award presentations and prize drawings.

The ever-popular Sunday Seminar has not be finalized yet, but is sure to be an excellent program. This is an in-depth four-hour presentation, where attendees learn from the experts. Check the TAPR website for more information: **www.tapr.org**.

Call for Papers

Technical papers are solicited for presentation and publication in the *Digital Communications Conference Proceedings*. Annual conference proceedings are published by the ARRL. Presentation at the conference is not required for publication. Submission of papers are due by 31 July 2013 and should be submitted to: Maty Weinberg, ARRL, 225 Main Street, Newington, CT 06111, or via the Internet to **maty@arrl.org**. There are full details and specifications about how to format and submit your paper for publication on the TAPR website.

Array Solutions Your Source for Outstanding Radio Products

Top-ranked Measurement Equipment from Array Solutions

Announcing the: PowerAIM 120

Vector Impedance Analyzer for Broadcast Engineers

- Patented, unique technology offers the broadcast engineer the full capabilities of a single port network analyzer
- Small, lightweight, software-driven instrument
- Easy to carry on airlines and in the field.
- Very simple to set up and use.
- Safe measurements in RF-dense broadcast environments.
- Time Domain Reflectometer (TDR) Functions.

Vector Network Analyzer Model VNA 2180

Measures impedance magnitude, phase and transmission parameters for antennas, filters, and discrete components - using one or two ports.

- Frequency range is 5KHz to 180MHz.
- Data plots include: impedance, SWR, return loss, S11 and S21.
- Plots can be saved for before and after comparisons.
- Dual Smith charts with zoom and rotation.
- Time Domain Reflectometer (TDR) Functions.
- New – 6 port VNA multiplexer for measuring directive arrays including Phase/Magnitude vector scope software.

Bird Wattmeter Digital Display Conversion Kits

Upgrade for your Bird analog watt meter that will transform your Model 43 into a state of the art digital meter!

AS-43A Average Power Reading Bird Wattmeter Kit Digital meter kit
AS-43AP Peak Power Reading Bird Wattmeter Kit Digital meter kit

AIM *uhf* Analyzer

- Frequency range from 5 kHz to 1 GHz.
- Data plots include SWR, RL, R + X, series and parallel, magnitude, phase, and more.
- Dual Smith charts with rotation and 20 markers.
- Plots and calibration files can be saved and used anytime in cvs and dynamic formats.
- AIM 4170C is still in production covering 5kHz to 180 MHz.
- Time Domain Reflectometer (TDR) Functions.

PowerMaster II

- New Larger, Sharp & Fast LCD Display
- Reduced Energy consumption
- USB and RS-232 interface built-in
- New - Both 3kW and 10kW couplers on one display - switched
- Hi / Lo Power Level Monitoring
- Supports 2 like couplers simultaneously (3kW & 3kW, 3kW & V/UHF, 10kW & 10kW)
- SWR Threshold Protection (with amp PTT bypass)

Single and Dual Rack Mount available
New "Power Master Basic" Software FREE!

www.arraysolutions.com

Sunnyvale, Texas USA
Phone 214-954-7140
sales@arraysolutions.com
Fax 214-954-7142

ARRAY SOLUTIONS

See our web site for other products and additional details.

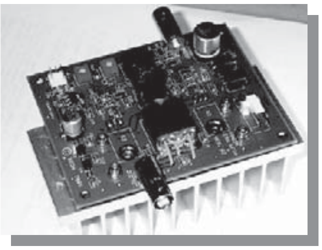
TAPR + HPSDR

©2006 AE5K

HPSDR is an open source hardware and software project intended to be a "next generation" Software Defined Radio (SDR). It is being designed and developed by a group of enthusiasts with representation from interested experimenters worldwide. The group hosts a web page, e-mail reflector, and a comprehensive Wiki. Visit www.openhpsdr.org for more information.

TAPR is a non-profit amateur radio organization that develops new communications technology, provides useful/affordable hardware, and promotes the advancement of the amateur art through publications, meetings, and standards. Membership includes an e-subscription to the *TAPR Packet Status Register* quarterly newsletter, which provides up-to-date news and user/technical information. Annual membership costs $25 worldwide. Visit www.tapr.org for more information.

NEW!



PENNYWHISTLE
20W HF/6M POWER AMPLIFIER KIT

TAPR is proud to support the HPSDR project. TAPR offers five HPSDR kits and three fully assembled HPSDR boards. The assembled boards use SMT and are manufactured in quantity by machine. They are individually tested by TAPR volunteers to keep costs as low as possible. A completely assembled and tested board from TAPR costs about the same as what a kit of parts and a bare board would cost in single unit quantities.

HPSDR Kits and Boards

- **ATLAS** Backplane kit
- **LPU** Power supply kit
- **MAGISTER** USB 2.0 interface
- **JANUS** A/D - D/A converter
- **MERCURY** Direct sampling receiver
- **PENNYWHISTLE** 20W HF/6M PA kit
- **EXCALIBUR** Frequency reference kit
- **PANDORA** HPSDR enclosure

TAPR

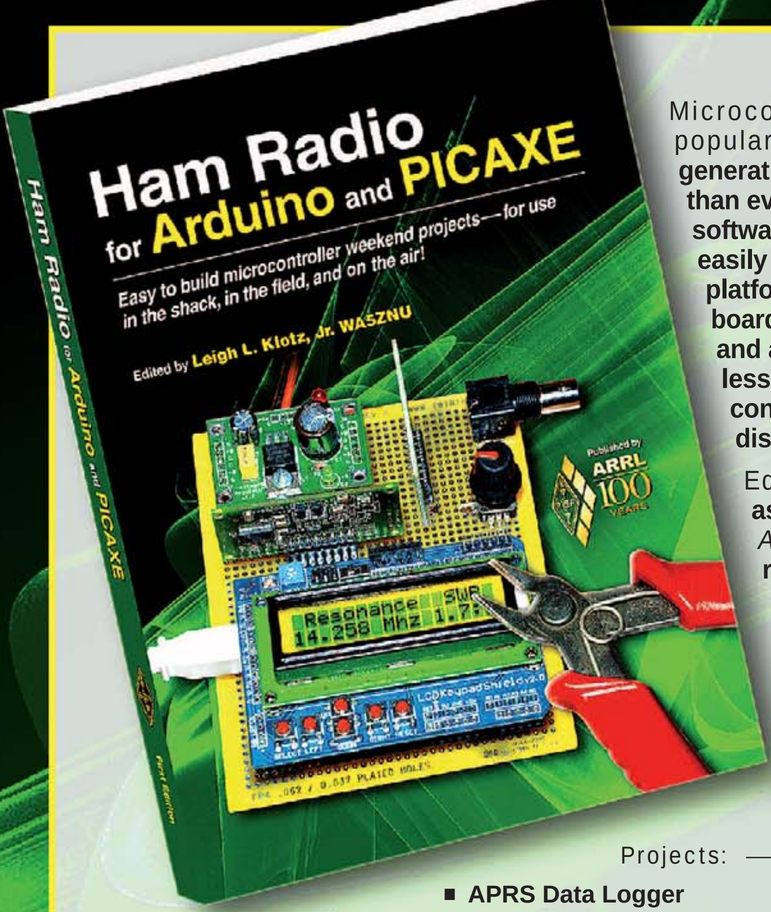
PO BOX 852754 • Richardson, Texas • 75085-2754
Office: (972) 671-8277 • e-mail: taproffice@tapr.org
Internet: www.tapr.org • Non-Profit Research and Development Corporation

Where Ham Radio Meets Open-Source Electronics

NEW!

Ham Radio for Arduino and PICAXE

Easy to build microcontroller weekend projects — for use in the shack, in the field, and on the air!



Microcontroller technology has exploded in popularity among ham radio operators. **The new generation of single-board microcontrollers is easier than ever to use, bringing together hardware and software for project-building most radio amateurs can easily dive into. With inexpensive microcontroller platforms—such as the popular open-source Arduino board—along with readily available parts, components and accessory boards, the possibilities are limitless: beacon transmitters, keyers, antenna position control, RTTY and digital mode decoders, waterfall displays, and more.**

Editor Leigh L. Klotz, Jr, WA5ZNU **has assembled this first edition of** *Ham Radio for Arduino and PICAXE* **to help introduce you to rewards of experimenting with microcontrollers. Klotz and many other contributors have designed projects that will enhance your ham radio station and operating capabilities. Or, you can take it to the next step, using these projects as a launch pad for creating your own projects.**

Projects:

- **APRS Data Logger**
- **QRSS Beacon**
- **Multimode Transmitter Shield**
- **High Voltage, High Frequency, and High Temperature Data Logger**
- **Receive-Only, Low-Power APRS iGate**
- **PICAXE Keyer and CW Beacon Keyer**
- **Solar Tracker**
- **Nanokeyer**
- **Handheld Radio Talk Timer**
- **APRS Messenger**
- **DTMF Controlled SSTV Camera**
- **APRS Display**
- **Waterfall**
- **SWR Scanner**

***…and more projects* using the Arduino, PICAXE, and ATtiny microcontrollers**

Ham Radio for Arduino and PICAXE
ARRL Order No. 3244
Special Member Price! Only $29.95* (retail $34.95)

Order Online **www.arrl.org/shop**
Call Toll-Free **1-888-277-5289** (US)

*Shipping and Handling charges apply. Sales Tax is required for all orders shipped to CT, VA, and Canada. Prices and product availability are subject to change without notice.

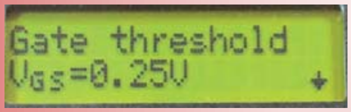
ARRL *The national association for* *AMATEUR RADIO*®
225 Main Street, Newington, CT 06111-1494 USA

SHOP DIRECT *or call for a dealer near you.*
ONLINE WWW.ARRL.ORG/SHOP
ORDER TOLL-FREE 888/277-5289 (US)

Q• • •• /2013


atlas DCA
model DCA55
PEAK
electronic design ltd
Enhancement mode
P-Ch MOSFET
on - test
scroll - off
semiconductor component analyser
automatic lead identification
warning: avoid charge/voltages


RED GREEN BLUE
Gate Srce Drn


Gate threshold
VGS=0.25V


atlas LCR
model LCR40
PEAK
electronic design ltd
Resistance
41.21kΩ
on - test
scroll - off
automatic passive component analyser
warning: avoid charge/voltages
Inductance
16.3μH
Capacitance
72.50μF