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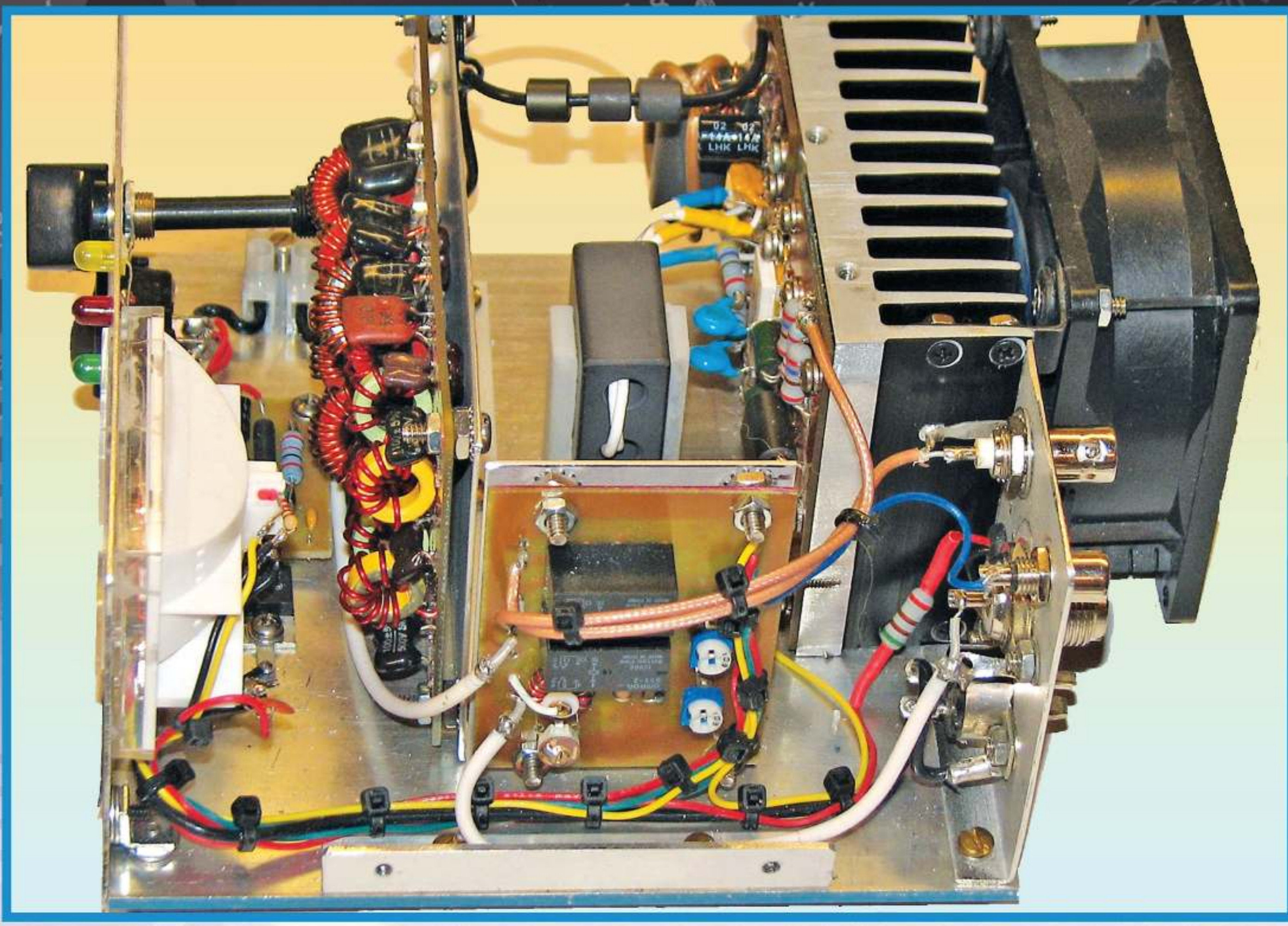
Issue No. 324



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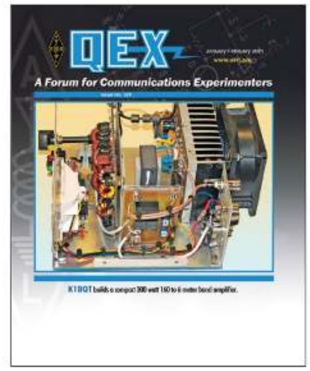
About the Cover

Rick Littlefield, K1BQT, describes a compact medium-power desk-top amplifier designed around the 50 volt MRF151G Gemini MOSFET device. Half the size of a shoebox, it can be driven with a 5 to 10 watt radio such as software defined radio, or one of the 5 to 10 watt QRP radios. The amplifier covers 160 to 6 meters and can deliver upwards of 300 W key-down on most bands. The Gemini designation features two identical MRF151 devices fabricated onto a single die, an innovation that ensures perfectly balanced matched-pair performance.



In This Issue

Index of Advertisers

Kazimierz "Kai" Siwiak, KE4PT

Perspectives

Blurring the Analog / Digital Divide

QEX began with the December 1981 issue as *The ARRL Experimenters' Exchange*. The intent was to feature original research as well as practical construction articles of an advanced nature, while striking a balance between covering *digital* electronics — including software — and the *analog* world of receivers and transmitters. We can parse a ham station layout into an antenna system, a transceiver, and a human interface (HI). In 1981 a transceiver was comprised of analog circuitry. The HI supported analog voice, CW, and sometimes digital circuitry such as packet-radio technology, and RTTY, which by then had partially encroached into the transceiver circuitry.

Today, the software defined radio (SDR) technology is moving the dividing line between the digital and analog worlds closer to the antenna on one end, and deeper into the human interface on the other end. As we mentioned previously in *Perspectives*, you can easily build a very capable radio transceiver from readily available modules that feature analog as well as digital electronics. A personal computer serves as a digital HI for either the SDR or an analog transceiver. The digital / analog divide is blurred. Innovation and experimentation flourish at the antenna end (well covered in *QEX*) and at the HI with codes and protocols like the *WSJT-X* (also covered in *QEX*). Our authors continue to provide innovative feature articles on antenna technology, digital devices, RF circuitry, and research and development topics that are advancing the communications arts.

In This Issue

Anthony Le Cren, F4GOH / KF4GOH, builds an SWR meter with vocal output.
Rick Littlefield, K1BQT, describes a 300 watt MOSFET HF amplifier.
Eric Nichols, KL7AJ, in his Essay Series, discusses EE math and Ohm's Law.
Phil Salas, AD5X, turns a Nano VNA into a more rugged test instrument.
John C. Westmoreland, AJ6BC, builds an NMEA-based GPS time display.
Robert J Zavrel, W7SX, tabulates losses in plastics that hams often use.

Writing for *QEX*

Please keep the full-length *QEX* articles flowing in, or share a **Technical Note** of several hundred words in length plus a figure or two. *QEX* is edited by Kazimierz "Kai" Siwiak, KE4PT, (**ksiwiak@arrl.org**) and is published bimonthly. *QEX* is a forum for the free exchange of ideas among communications experimenters. All members can access digital editions of all four ARRL magazines: *QST*, *On the Air*, *QEX*, and *NCJ* as a member benefit. The *QEX printed edition* annual subscription rate (6 issues per year) for members and non-members is $29 in the United States. First Class mail delivery in the US is available at an annual rate of $40. For international subscribers, including those in Canada and Mexico, *QEX* printed edition can be delivered by airmail for $35 annually, see **www.arrl.org/qex**.

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Very kindest regards,
Kazimierz "Kai" Siwiak, KE4PT
QEX Editor

Rick Littlefield, K1BQT

528 McDaniel Shore Dr., Barrington, NH 03825; **k1bqt@metrocast.net**

Compact 300 Watt HF Amplifier

This MOSFET-based design boosts RF output from QRP levels to medium power levels.

Many low power software defined radios (SDRs) now come with the same performance features found on top-of-the-line 100 W radios. No surprise then that some of us are adopting them for everyday operating. While a 5 or 10 W transceiver may lack the horsepower to blast through heavy QRM, a high-gain single-stage VMOS or LDMOS amplifier can boost QRP output anywhere up to the legal limit.

This article describes a compact medium-power desk-top amplifier (**Figure 1**) built around the 50 V MRF151G *Gemini* device. Half the size of a shoebox and designed to be driven with a 5 W radio, it covers 160 to 6 meters and can deliver upwards of 300 W key-down on most bands. The *Gemini* designation means there are two identical MRF151 devices fabricated onto a single die, an innovation that ensures perfectly balanced matched-pair performance.

Figure 1 — Author's 'Mini-shack' occupies a small corner on a writing desk.

Amplifier Circuitry

Amplifier circuitry is divided among three PCB modules: a split PA board mounted on the heat sink, a band-switched low-pass filter board, and a transmit-receive control board. Another smaller board drops 50 V down to 12 V to power the amplifier control circuitry.

PA Module

The PC layout for the PA pallet is divided between an input board and an output board with the MRF151G mounted in between, see **Figure 2**. Circuitry on the input side includes a 5 V step-down regulator (U1), bias-set voltage divider (R7), 50 Ω input network (T1), and a pi-section attenuator to set the proper drive level (R1 – R3). Normally, 5 W radios will require a 3 to 4 dB

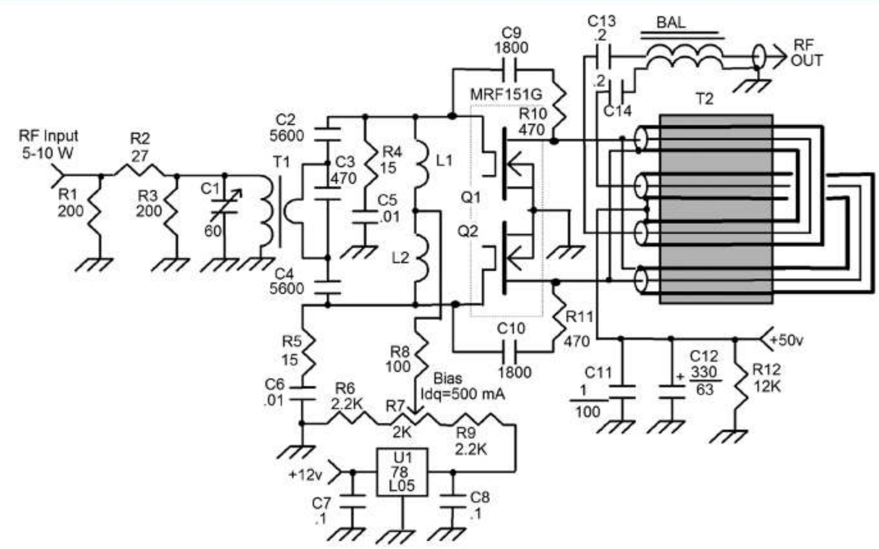

Figure 2 — Adjust C1 for lowest input SWR on 20 meters.

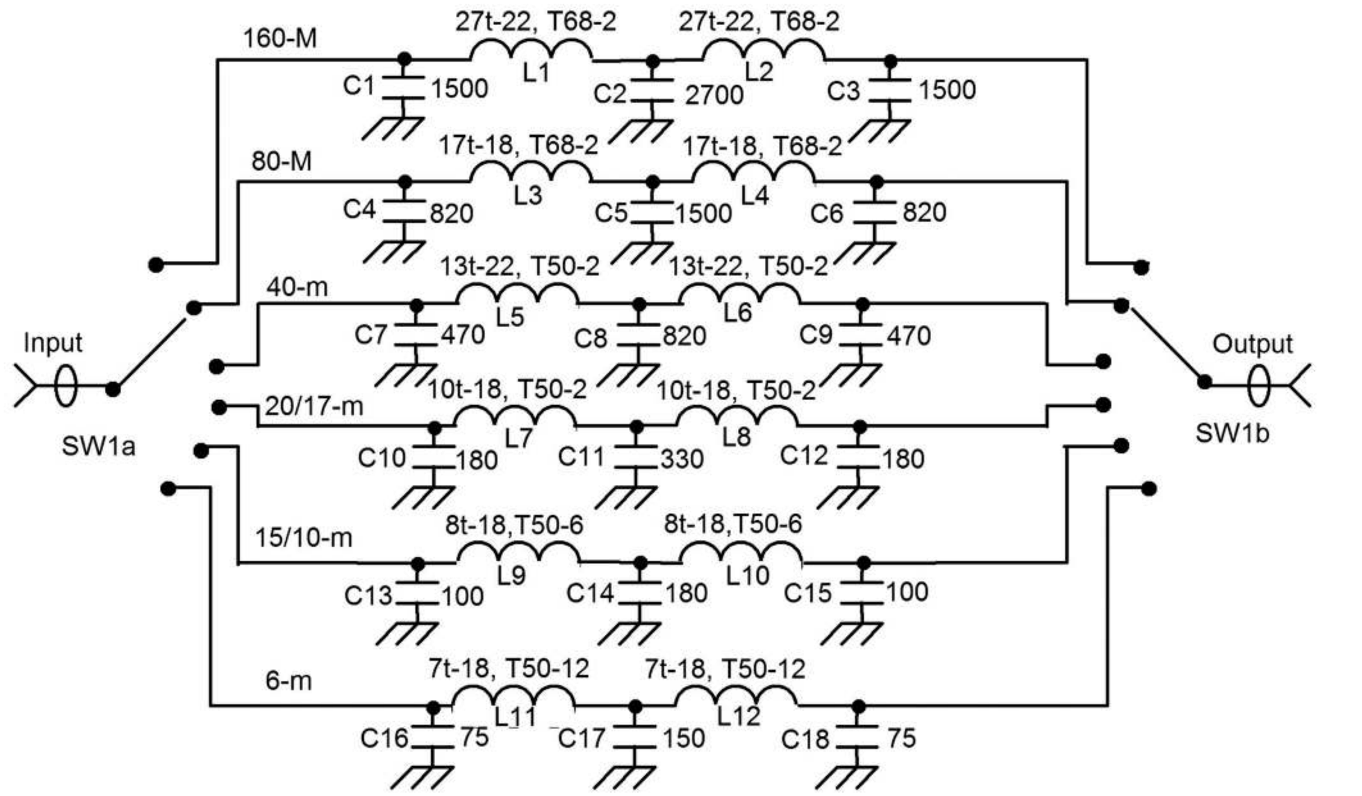

Figure 3 — Low-pass filters are half-wave, 50 Ω input and output impedance level)s.

pad, while 6 to 7-dB of attenuation is needed for a 10 W rig.

The output side of the pallet utilizes a version of the Francis Carcia, WA1GFZ, balanced transmission-line transformer network (T2). This design eliminates the requirement for shunt-fed Vds chokes and close-couples the two drains for improved IMD performance (Sept/Oct 2015 *QEX*, pp. 3-12). A series resistor and dc-blocking capacitor tack-soldered between the gates and drains of Q1, Q2 provide negative feedback for each FET.

Cooling

The MRF151G is conduction-cooled by a finned heat sink with additional cooling provided by the amplifier's 1/8" aluminum base plate. Supplemental convection cooling is provided by a 48 V muffin fan circulating air over the PA heat sink. A series resistor reduces fan speed for SSB operation. Increased airflow is recommended for higher power-density modes such as FM, RTTY, and digital modes.

Filter/Band Switch Module

The band-switch module (**Figure 3**) provides low-pass filters for 160, 80, 40, 20/17, 15/10, and 6 meters. Each one is routed to a 2-pole 6-position rotary band switch (SW1) by 50 Ω strip lines to minimize stray reactance and RF leakage. The filter module is mounted on a vertical partition and positioned so the switch's stock 2-inch shaft protrudes through the front panel (upper left in **Figure 4**).

Control Board

Two miniature DPDT relays provide T/R switching. The input-side relay (K1) controls the low-level RF-signal path and switches 12 V dc control voltage. The contacts on the output-side relay (K2) are connected in parallel to better handle the amplifier output power level. A PNP relay driver (Q1) actuates both relays when the

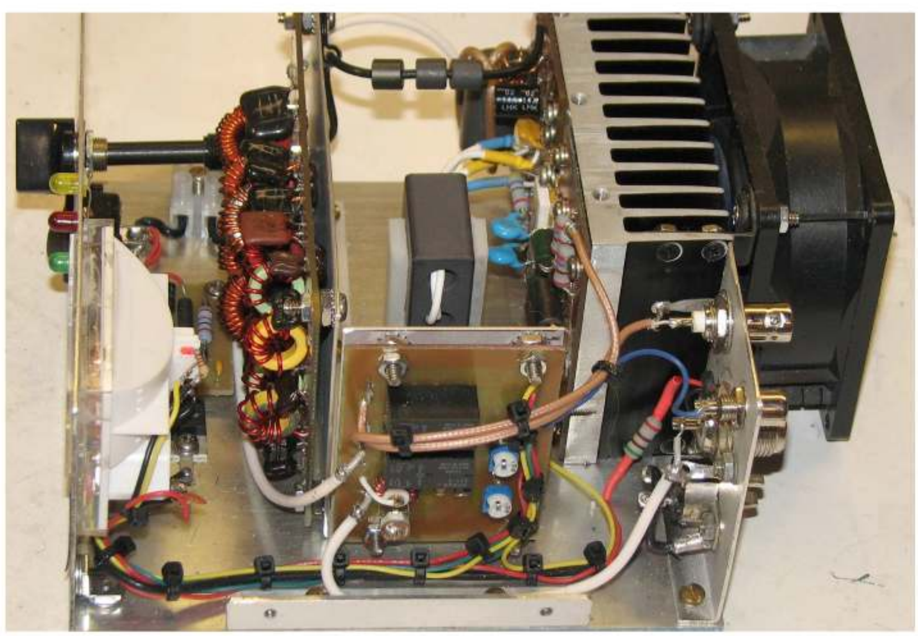

Figure 4 — Inside view shows the control board, rear panel, and interconnecting wire harness. SMD components are mounted on the underside of the control board.

base is pulled to ground potential. LEDs indicate the amplifier T/R status.

The control board also houses a two-way directional coupler for monitoring power and SWR. Voltage developed by the forward and reverse detectors feed a 200 μA cross-needle meter calibrated for 300/60 W at full scale (R9, R10), see **Figure 5**. Cross-point scales printed on the meter face allow SWR measurements at all power levels. The meter movement is available in two sizes from MFJ Enterprises

12 Volt Regulator

Voltage to operate the amplifier control board and meter LEDs is derived from the 50 V (Vds) line. In receive mode, Zener diodes Z1 and Z2 clamp the source voltage below the U1 35 V input limit (see **Figure 6**). In transmit mode, current draw increases and the Zeners drop out. The 390 Ω series resistor (R1) holds the U1 input at around 18 V.

Interconnections

Figure 7 shows how the amplifier modules are interconnected. All RF lines use Teflon dielectric RG-316 miniature coax. I used #14 AWS Teflon jacketed wire for 50 V distribution to reduce the possibility of a short to ground. To set idling current, see **Figure 8**, I remove the jumper in the Vds line and connect a VOM in its place. The MRF151G data sheet recommends running 500 mA of idling current.

PC Boards

All layouts use double-sided G-10 fiberglass board as seen in **Figure 9**. The PA circuitry uses single-sided SMD construction with a generous number of through holes added to solidify the ground plane. The control board layout is double-sided using a mix of SMD and through-hole parts. The filter network is all-through-hole construction with 50 Ω strip line traces etched on the solder side.

Power Supply

In the past, 50 V linear power supplies tended to be big, heavy, and hard to find. However, these days compact switchers are plentiful. I'm currently using a Heng Fu 700W-SA-48 supply available from Circuit Specialists for under $200. It is stiffly regulated, runs on 120 V ac, and has a voltage output trim-pot for setting Vds to 50 V.

Circuit Protection

In the name of economy and simplicity, this project lacks several commercial amplifier refinements such as relay sequencing, bias tracking, load-fault detection, and automatic band switching. Fortunately, MOS devices exhibit excellent load-fault immunity and survive nicely if operator errors are spotted quickly and corrected. To avoid trouble, I follow two simple rules.

- To avoid gate-destroying input transients, *never use a radio's RF Power Output control to set amplifier drive.* Far better to run the transceiver at its full rated output and provide the appropriate level of padding on the amplifier pallet input board.
- To avoid damage from load-fault

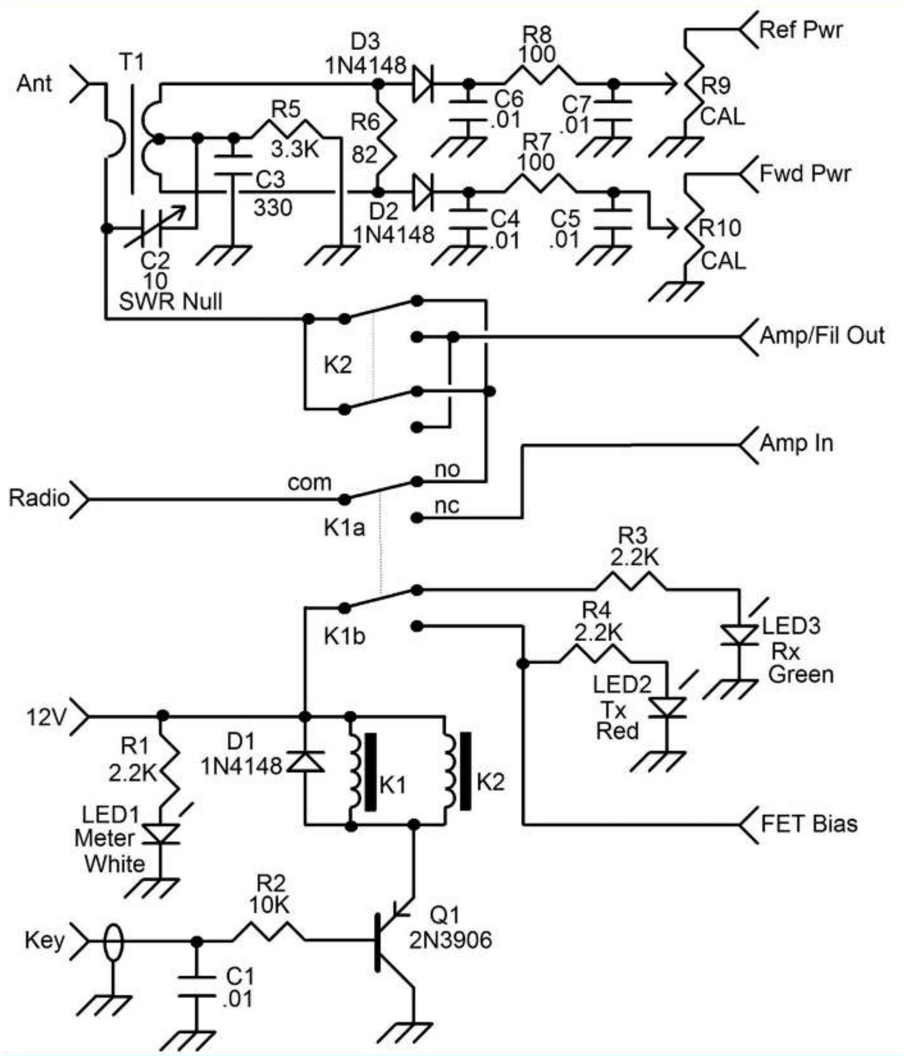

Figure 5 — Schematic shows directional wattmeter and T/R switching circuitry.

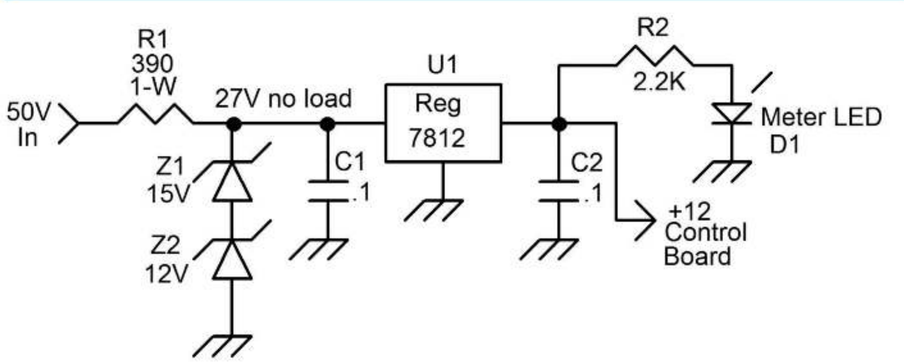

Figure 6 — Control voltage regulator drops 50 V (Vds) to regulated 12 V to power the control board and LEDs.

conditions, *double-check the band-switch setting and note the power meter readings when changing bands.* Very low output usually means the band switch is set *below* the band in use, forcing the selected filter to dissipate the fundamental signal along with the harmonics. Very high reflected power usually means the wrong antenna is connected.

Simple oversights like these are easy to commit, but equally easy to spot and correct before components overheat and break down. My amplifier has survived nearly two years of daily use without a component failure despite several bone-headed episodes of cockpit error on my part.

Headroom

This amplifier is capable of 400 W key-down output on several bands but it should not be driven to that level. The MRF151G is specified as a 300 W device and IMD performance *will* suffer if pushed into the twilight zone of heavy gain compression.

Pallet Options

The MRF-151G pallet is secured to the base plate with 6-32 screws and all interconnecting wiring is accessible, so removing the pallet and substituting another is relatively easy. To date I've tested three pallets using 50 V devices and one using 12 V Mitsubishi RD-100HHF1 devices. Looking ahead, new medium power LDMOS devices are emerging and this amplifier will likely serve as my test bed for trying them out.

Conclusion

This article isn't intended to be a step-by-step primer for constructing a high-power amplifier to supercharge your IC-705 or KX3. In fact, the MRF150G has been around for many years and hardly qualifies as cutting-edge technology. But, if you have a penchant for building, I hope the simple circuitry I've presented here will inspire you to do me one better, and take advantage of the exciting new possibilities offered by today's MOS technology.

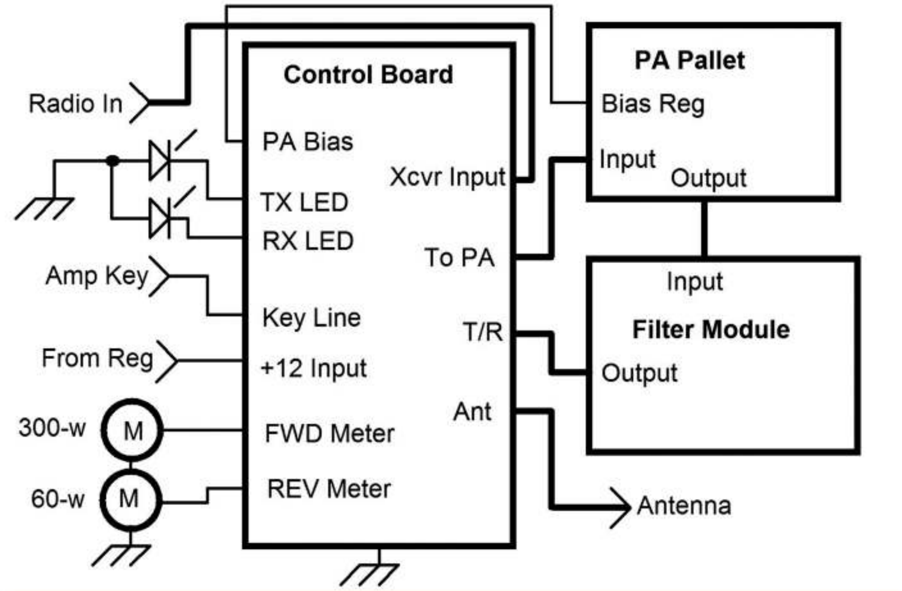

Figure 7 — Interconnections for the three main amplifier modules.

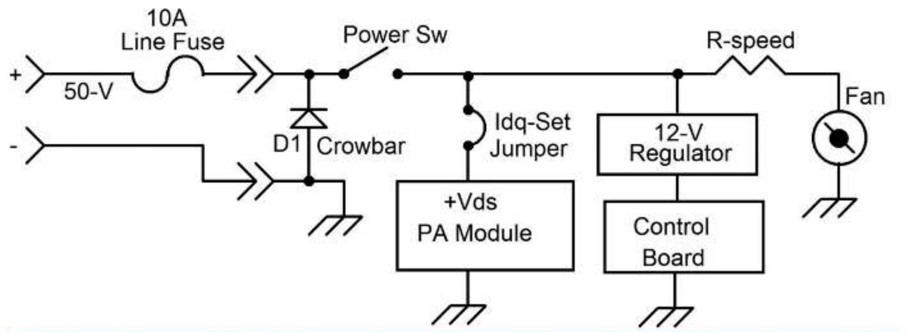

Figure 8 — 50 V wiring. The resistance in series with the fan should be selected to provide the best compromise between airflow and motor noise.

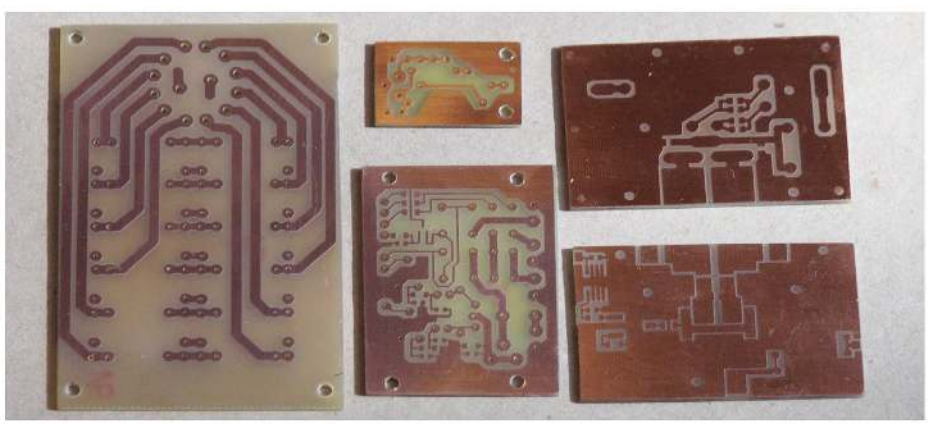

Figure 9 — All layouts use double-sided G-10 fiberglass boards.

Rick Littlefield, K1BQT, was first licensed in 1957 at age 13 and currently holds an Extra Class license. He's a graduate of Mass Radio in Boston and holds a BA and MEd from the University of New Hampshire. After a 17-year career in instructional technology, he switched to RF design and technical writing, working for Passive Power Products, MFJ, TEN-TEC, Cushcraft, Laird Technologies, and as a columnist for Communications Quarterly. *An enthusiastic builder, he was inducted into the QRP Hall of Fame in 1996. Now retired, Rick is currently writing an action-adventure novel and continues to work on projects from his home lab in Barrington, NH.*

Anthony Le Cren, F4GOH/KF4GOH

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HF SWR Meter for the Visually Impaired

This project shows how to provide a vocal output for a measurement instrument.

A version of this article was published in *Radio REF* (**www.r-e-f.org**). This SWR meter announces measurements by voice, operates over the frequency range of 1 to 30 MHz and can handle up to 100 W. It is based on the Arduino UNO, the Catalex YX5300 MP3 module**,** PC speakers, and uses customizable sound files. The cost is in the range of US$22 to US$34 (€20 to €30).

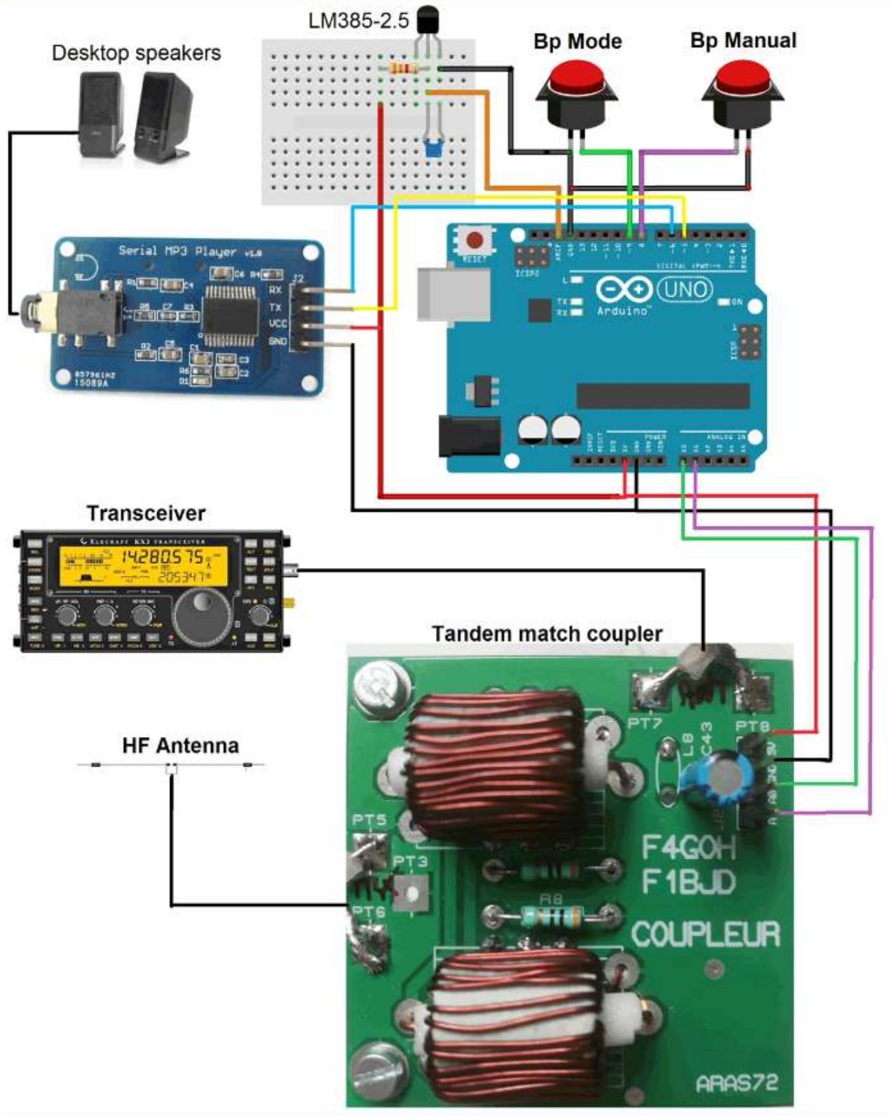

Figure 1 — Wiring diagram for the vocal SWR meter. AD8307 logarithmic amplifier modules U1 and U2 are on the reverse side of the coupler board.

1 – Introduction

At the 2019 *HamExpo* show in Le Mans, I presented to the *National Union of the Blind Radio Amateurs of France* association an SWR HF meter for the visually impaired, and immediately wanted to present the project in the *Hackathon*. The theme was carefully chosen, because projects dedicated to the disabled are not put forward often enough. I also hope that there will be more participants in future meetings. After some modifications to the source code, the project is now ready for publication. This project will also interest radio amateurs wishing to use an MP3 player for other applications such as a voice tag, or as an asset in the control of a VHF or UHF repeater.

2 – Description of the Interconnect Diagram

The pictorial diagram of **Figure 1** is based on an Arduino UNO. Very few pins are used on the Arduino, see **Table 1**. There are two analog inputs for measuring the direct and reflected voltages from the tandem coupler board. An LM385-2.5 serves as the voltage reference for the Arduino analog-to-digital converter (AREF). Two push buttons are required to use the SWR meter. Arduino internal pull up resistors (INPUT_PULLUP) are used. The push buttons are therefore active at the LOW level. Voice messages are generated by a Catalex YX5300 MP3 module, see **Figure 2**.

Figure 2 — Catalax serial player module.

3 – SWR Meter Operating Modes

The SWR meter does not have a display. All information is announced by voice. As soon as the power is turned on, a voice message indicates that the instrument is on. The 'Bp Mode' button allows you to switch from manual to automatic mode and vice-versa.

If the automatic mode is selected, the SWR meter will detect an HF signal (transmitter in transmission) and announce the power and the SWR in a loop. For example, 'Power 5 watts, SWR 1 point 5' repeated, and so on.

In manual mode, press the 'Bp manual' button to find out the power and the SWR. This does not affect the current QSO compared to the automatic mode, which is more useful for parameters or antenna impedance checks.

Table 1

Pins used on the Arduino

Arduino UNO Pin	Component
5	TX YX530 module MP3
6	RX YX530 module MP3
8	Manual Button
9	Automatic Button
A0	Reverse coupler output
A1	Direct Coupler Output
AREF	LM385 2.5 V
GND	digital ground
5V	5 volts power
GND	power GND

4 – MP3 Player Module

I used the YX5300 serial MP3 player module. The *mp3* files are stored in a micro-SD card, which can be read by a serial link at 9600 baud. Use headphones or PC speakers on the 3.5 mm jack socket to hear the audio output from the MP3 module.

It will be necessary to record the different words or samples one by one using the *Audacity* software, and note the duration in milliseconds of each file as shown in the **Table 2**.

I recommend that you record all of the words at once, with a two-second pause between each sample. This may take several tries to record your voice correctly. Once you've finished recording, don't forget to apply the two filters 'noise reduction' and 'normalize' in the 'effect' menu of *Audacity*.

Table 2 shows the names of the *mp3* files used in the directory « 02 » (English version). Examples of *mp3* files are available in my Github **[1]**. The '01' directory contains the words in French, while the '02' directory contains a version in English.

Cut the words as precisely as possible in order to avoid artifacts in the chain of

Table 2

File name and audio duration.

File name	*Data*	*Duration (ms)*
000.mp3	Zero	575
001.mp3	One	444
002.mp3	Two	313
003.mp3	Three	444
004.mp3	Four	392
005.mp3	Five	653
006.mp3	Six	679
007.mp3	Seven	522
008.mp3	Eight	522
009.mp3	Nine	470
010.mp3	Ten	549
011.mp3	Power	784
012.mp3	Watt	601
013.mp3	Manual mode	1071
014.mp3	Automatic mode	1202
015.mp3	SWR too high	1254
016.mp3	SWR 1 point	1306
017.mp3	SWR 2 point	1411
018.mp3	SWR 3 point	1463
019.mp3	SWR 4 point	1411
020.mp3	SWR 5 point	1463
021.mp3	QRT	679
022.mp3	SWR-meter power on	1593

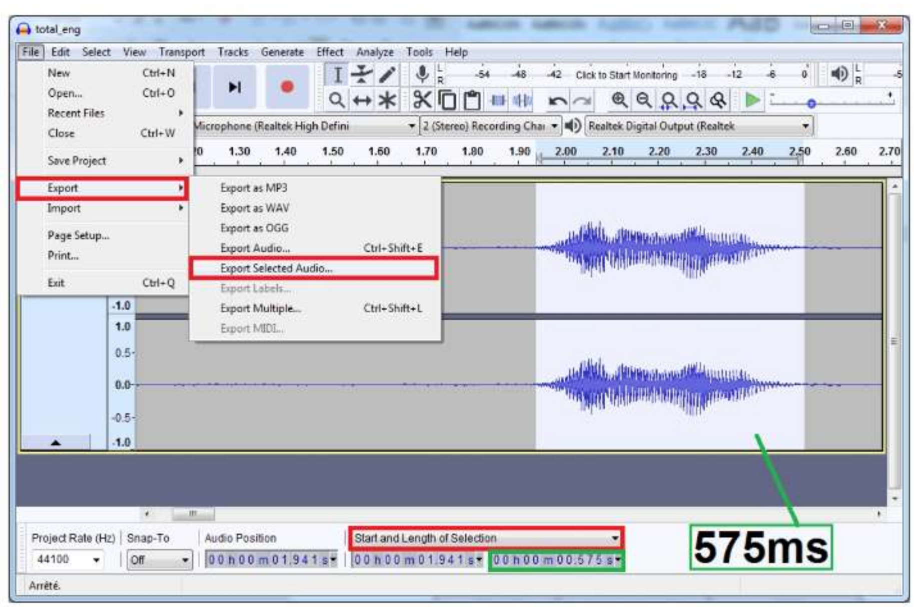

Figure 3 — Audio samples in Audacity software. Edit the audio files and note the length in ms.

voice announcements. Save each sample separately and note the sample duration in milliseconds, see **Figure 3**.

The names of files and directories must be respected. It is not possible to use alphabetical characters for the directory and file name. This is the main drawback of this MP3 player.

The sequencing of voice announcements of SWR values is performed using file numbers. When originally designing the voice sequencer, I sought to know the state of the player via the serial link (reading in progress, stop, pause) in order to chain the files naturally without using the duration table. But the rendition of the sequences was very erratic, so I adopted a simpler and shorter solution for the software, relying on the duration of the files.

The English language *mp3* files are copied to a directory named '02' on a micro SD card formatted in FAT32.

5 – Tandem Match Coupler

The tandem coupler is the same as for the coupling box project, see: **https://hamprojects.wordpress.com/2016/12/31/hf-automatic-tuner/**. A printed circuit is used that includes two 1:26 ratio transformers, two pi attenuators, and two AD8307 logarithmic amplifier modules, see **Figure 4**.

The transformer and attenuator assembly achieve a theoretical attenuation of 43 dB. Indeed, the AD8307 is not able to measure values greater than 17 dBm. If a power of 100 W (50 dBm) is injected into the coupler, the AD8307 then measures approximately 7 dBm. We thus remain in the measurement range of the logarithmic amplifier. This information will be integrated into the software in the form of a compilation directive:

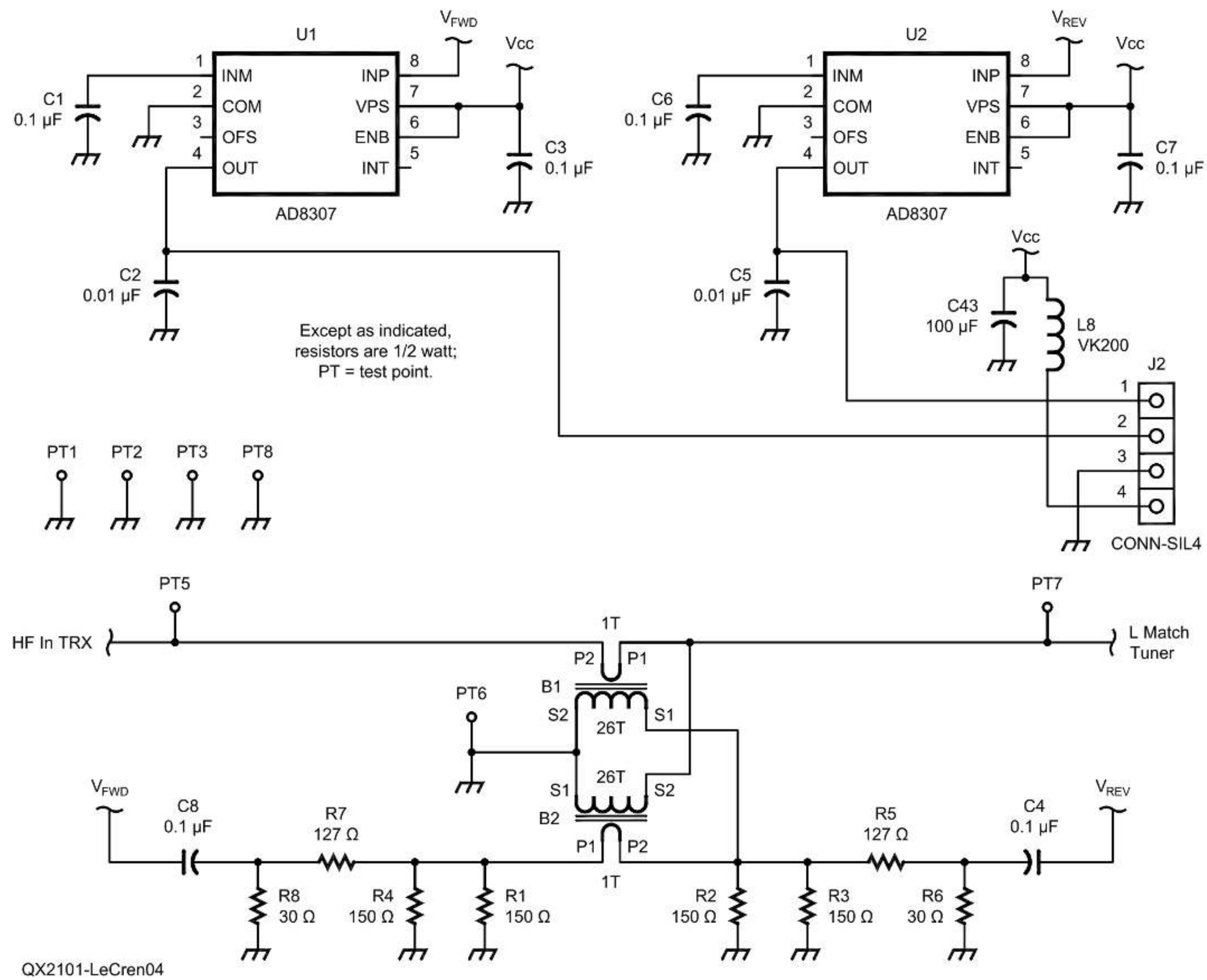

Figure 4 — Schematic diagram of the SWR meter coupler board.

C1, C3, C4, C6 - C8	**100 nF**	**R1 - R4**	**150 Ω**
C2, C5	**10 nF**	**R5, R7**	**127 Ω**
C43	**100 µF**	**R6, R8**	**30 Ω**
J2	**4 – pin connector**	**U1, U2**	**AD8307 logarithmic amplifier module.**
L8	**10 µH ferrite bead choke, VK200, https://www.ebay.fr/i/264370653494.**		

Table 3

Configuration examples. Unused configuration items are commented out with the '//' prefix.

English voice, no debug, no calibration	*French voice, debug on, calibration on*
//SWR meter configuration	//SWR meter configuration
//#define LANGUAGE_FR	#define LANGUAGE_FR
#define LANGUAGE_EN	//#define LANGUAGE_EN
//#define DEBUG_SWR	#define DEBUG_SWR
//#define DEBUG_DBM	#define DEBUG_DBM
//#define PERSONAL_CALIBRATION	#define PERSONAL_CALIBRATION
#define OffsetdBmBridge 45	#define OffsetdBmBridge 45

```
#define OffsetdBmBridge 43
```

Each transformer comprises a stack of three T50-2 toroids wound with 26 turns of enameled wire (diameter 0.6 mm or #22 AWG). The primary is a single length through the toroid center, visible in the tandem match coupler of **Figure 1.** Other couplers can be used, but the direct voltages injected into the Arduino UNO must not exceed a maximum value AREF of the analogical digital converter (ADC) of 2.5 V. Avoid using as much as possible the 5 V reference voltage internal to the Arduino for ADC, as this reduces the measurement range and the results may be erratic and less precise.

6 – Software

The *vocalSwrMeter.ino* sketch (program) does not require any specific library. The configuration of the software is done by activating or deactivating the `#define` compilation directives by adding a comment at the start of the program. Two configuration examples are shown in **Table 3**.

The default configuration (no personal calibration) uses the following `NtodBm` function calculating the power in dBm according to the value of the A/D.

```
//compute power in dbm (theoretical formula)
float NtodBm(int N)
{
  return (100 * (float) N) / 1024 - 90 +
OffsetdBmBridge;
}
```

This formula is taken from the manufacturer's documentation for the AD8307 and the Arduino A/D. The default configuration is more than enough for testing.

With a transmitter and the SWR meter connected to a 50 Ω load, inject a 1 W carrier at 7 MHz. Adjust the value of `OffsetdBmBridge` so that the power corresponds more or less within 2 dB around 45).

Personal calibration — activate debug (`#define DEBUG_SWR`) allowing display of the A/D values in the serial monitor (9600 bits per bps).

Using a calibrated HF generator, inject different power levels (between –20 dBm and +10 dBm) into the coupler (always into the 50 Ω dummy load) and read the numerical value (`A/D fwd`) of the corresponding direct voltage. Repeat the measurement for the reflected voltage by reversing the direction of the HF signal in the coupler. The values I obtained with my coupler are shown in **Table 4**. I then calculated the linear trend line in an Excel spread sheet for the direct signal, **Figure 5**, the reverse signal, **Figure 6**, and then selected trend line, **Figure 7**, for the graphs.

Figure 5 shows direct dBm versus numerical values (A/D output). **Figure 6** shows the line for the reverse channel. The same

Table 4

Sample values for a coupler.

HF generator, dBm	*A/D value fwd*	*A/D value rev*
10	552	563
0	447	460
–10	342	355
–20	239	252

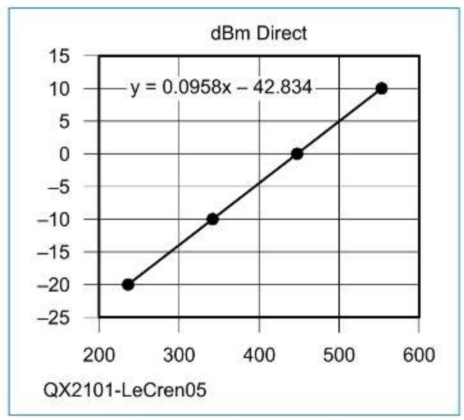

Figure 5 — Trend line and formula for the forward signal.

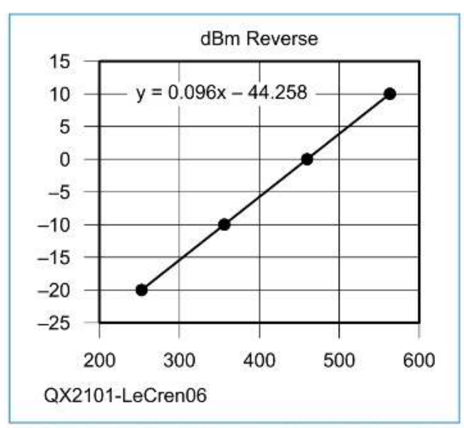

Figure 6 — Trend line and formula for the reverse signal.

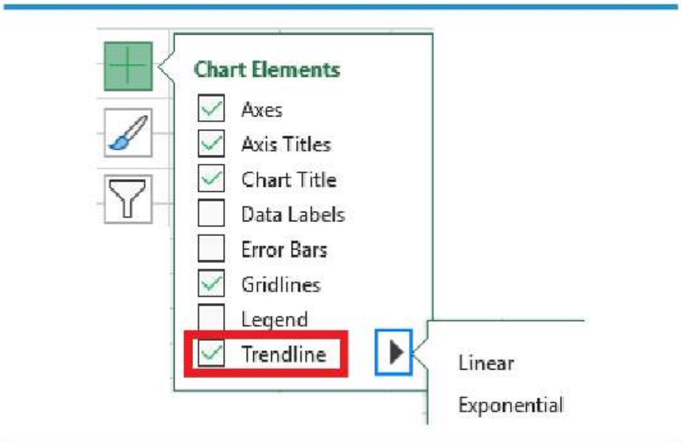

Figure 7 — Select 'Trendline' in the Excel chart elements.

formulas are used in the Arduino program. Copy the formulas into the *NtodBmForward* and *NtodBmReverse* functions at the end of the program. Don't forget to enable #define PERSONAL_CALIBRATION directive.

```
float NtodBmForward(int N)
{
 return 0.0958 * (float) N - 42.834;
}
```

and

```
float NtodBmReverse(int N)
{
 return 0.0963 * (float) N - 44.258;
```

7 – Conclusion

I think that this project will provide many services for people with or without disabilities. In this project, I was very interested in making the voice sequencer and recording the audio samples. The cost of the Catalex YX5300 MP3 module is really minimal, and it will be very useful in other experiments. The assembly is easy to build and the components are easily found on the internet. The coupler PCB (**Figure 8**) is available; please contact the author at **f4goh@orange.fr**. The vocal SWR meter files are available on my Github: **https://github.com/f4goh/vocalSwrMeter**.

Anthony Le Cren, F4GOH, has been licensed since 2010, and earned his General-class license in 2019 as KB1GOH, now KF4GOH. Anthony loves to experiment with the Arduino applied to radio. He is a professor of computer science at Lycée Gabriel-Touchard High School in Le Mans, France. Anthony has written numerous articles and maintains a web page of amateur radio projects at ***https://hamprojects.wordpress.com/***.

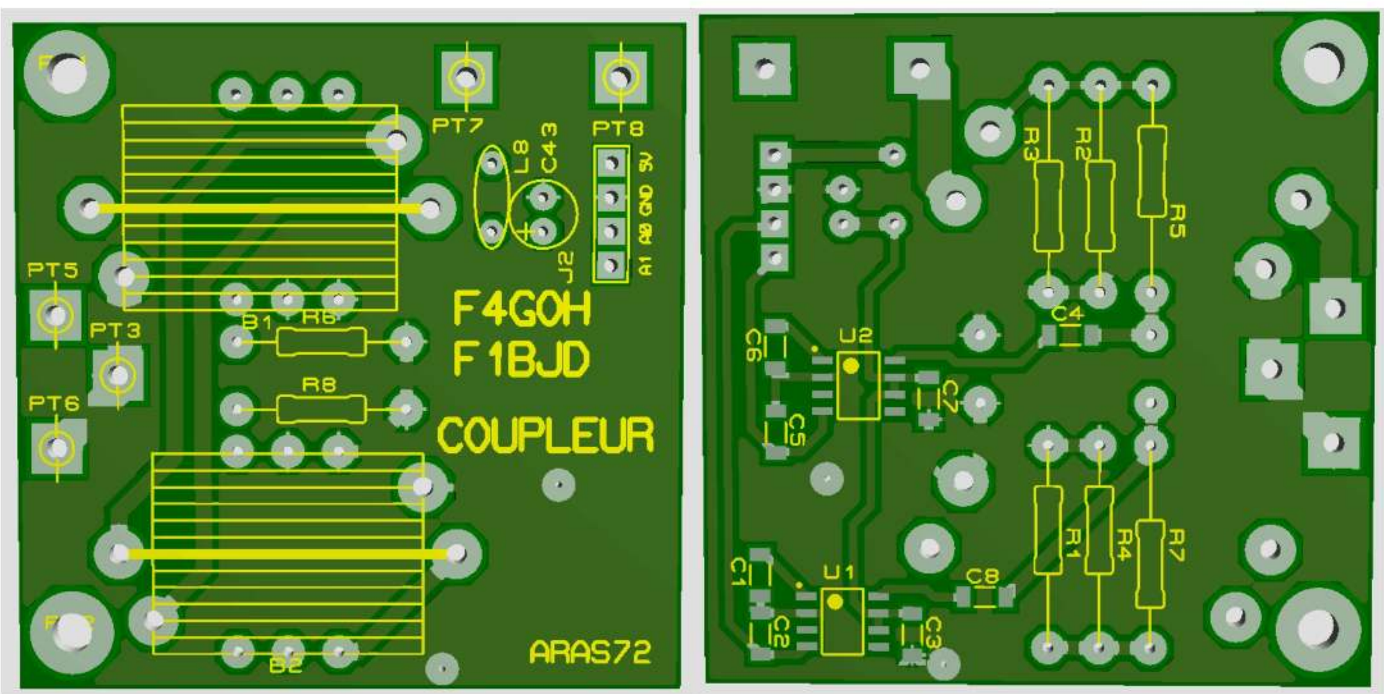

Figure 8 — Front and reverse sides of an unpopulated coupler board.

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Do-It-Yourself NMEA Based GPS Time Display

This Maker-Faire style time display project is an extension of the Themis *Project.*

Themis Project Summary

The 2019 July/August issue of *QEX* featured *Themis*, which is an experimental approach for a GPS-disciplined oscillator that can be used with OpenHPSDR **[1]** or used standalone. **Table 1** shows a glossary of terms. One of the features of *Themis* that can be exploited is the possible use of the NMEA **[2]** time sentence received from the GPS constellation as a way to display time can be used to make a DIY NTP **[3]** style server, and can also be used to set time on personal computers and laptops and some other example sample applications and enhancements.

At the 2019 Maker Faire in San Mateo, CA **[4]**; a handful of high-school student volunteers and I had a booth that displayed the *Themis* project we had a Maker Faire style of project on display as a programming exercise to demonstrate how to display GPS time.

This article explains and examines a DIY style of project in detail, with a simple programming example and some low-cost module components that can be used to make a nice high quality display to show the current local time, or for that matter can be modified to display time in any zone or customized to display what the user/programmer wishes. The tools required to make the display will be explained in enough detail that users, programmers, and readers can customize the display in any form they wish.

Everyone wants to be able to display accurate time in their ham shack – correct? This article shows a fun and relatively easy way to accomplish that task.

Project Design Goals

- Demonstrate the use of NMEA sentences to display time from a GPS source.
- A simple programming example will be supplied to demonstrate using an established programming environment.
- Use low cost components to accomplish the task.

Table 1
Glossary of Terms

AP	Access Point
ASCII	American Standard Code for Information Interchange
DIY	Do It Yourself
Egress	A path to exit a system, such as a network packet escaping though an uncontrolled or unexpected path
IDE	Integrated Development Environment such as Arduino Open Source Software Environment
IP	Internet Protocol
GPS	Global Positioning System
MKR	Arduino designation for 'Maker' family of board
NIST	National Institute of Standards and Technology
NMEA	National Marine Electronics Association
OpenHPSDR	Open High-Performance Software Defined Radio
PC	Personal computer
RGB	Red, Green, Blue
TCP	Transmission Control Protocol – connection based
UDP	User Datagram Protocol – connectionless
Wi-Fi	Wireless network protocols based on the IEEE 802.11 family of protocols

Figure 1 — DIY NMEA based GPS time displays.

- Use a colorful, bright display that can be located just about anywhere preferred.
- The display must be capable of being updated at a rate of at least once per second.
- Using the optional network interface on *Themis* as the means of transmission, put a DIY type of maker-faire project together to show a way to accomplish the task.

To accomplish the design goal of being relatively simple, one of the readily available Arduino **[5]** boards (Arduino Nano 33 IoT) has been used with a nice RGB display such as the Lumex in the LDM-6432 family **[6]**. **Figure 1** shows the DIY NMEA based GPS time displays, as well as the 4 wire interface with the Arduino Nano. All required components plus the Arduino MKR RGB shield **[7]** are totally battery driven.

What is an NMEA Sentence?

GPS receivers typically contain hardware interfaces that comply with the NMEA standard and readily supply NMEA sentences in ASCII format **[8]**. For the purposes of this demonstration, we will use the NMEA sentence to accomplish our design goal of displaying time:

ZDA – Date and Time

$GPZDA,hhmmss.
ss,dd,mm,yyyy,xx,yy*CC

where hhmmss is the HrMinSec(UTC); dd,mm,yyy are the Day, Month,Year; xx is the local zone hours (–13 to 13); yy is the local zone minute (0 to59); *CC is the checksum **[9]**.

Note that the ZDA sentence is not the only one we can use for the task at hand, it is just a convenient one. Also, since the example in the article uses a relatively simple parsing program to decode the time for display, the ZDA is one of the simpler sentences to use for the programming the task. The user, reader, or programmer is encouraged to consider and use possibly another available sentence to accomplish the display of time and perhaps the display of other important information.

The GPS receiver used on the *Themis* platform is manufactured by uBlox and uses the u-center software **[10]** from uBlox. It is relatively easy to set up the GPS receiver to supply the $GPZDA sentence to the network interface. On *Themis*, an interrupt driven process takes the data from the uBlox GPS receiver and then sends the data to the onboard network interface, which is based on the uBlox NINA-W102 **[11]**. The Arduino board chosen uses the same network interface, the NINA-W102. **Figure 2** shows

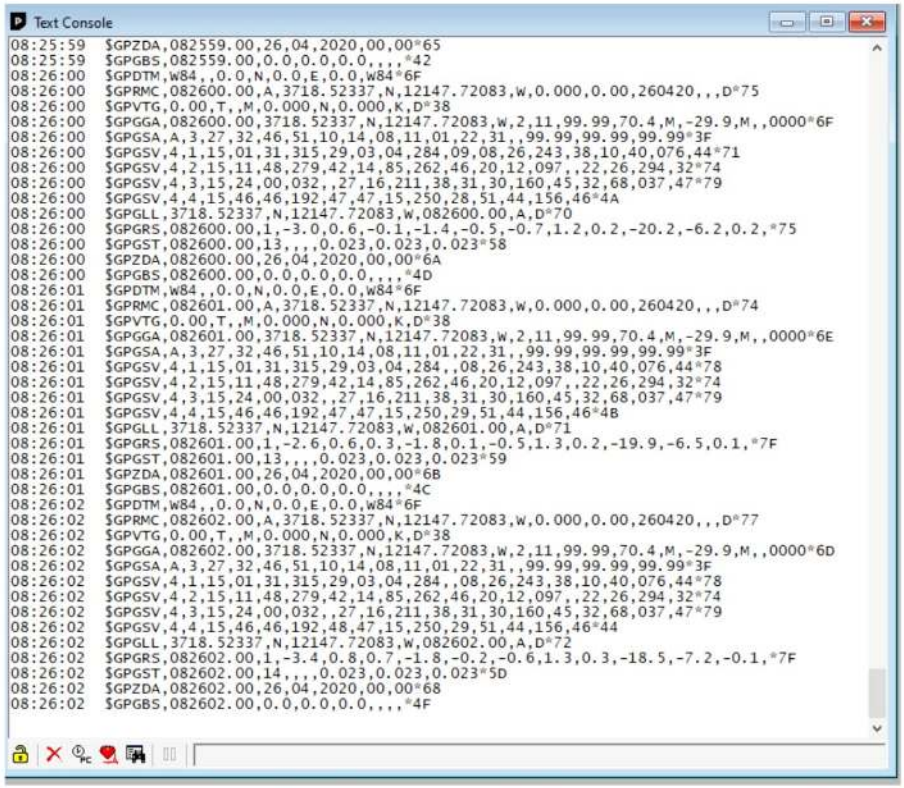

Figure 2 — NMEA Output from the GPS Receiver; Note the $GPZDA sentence.

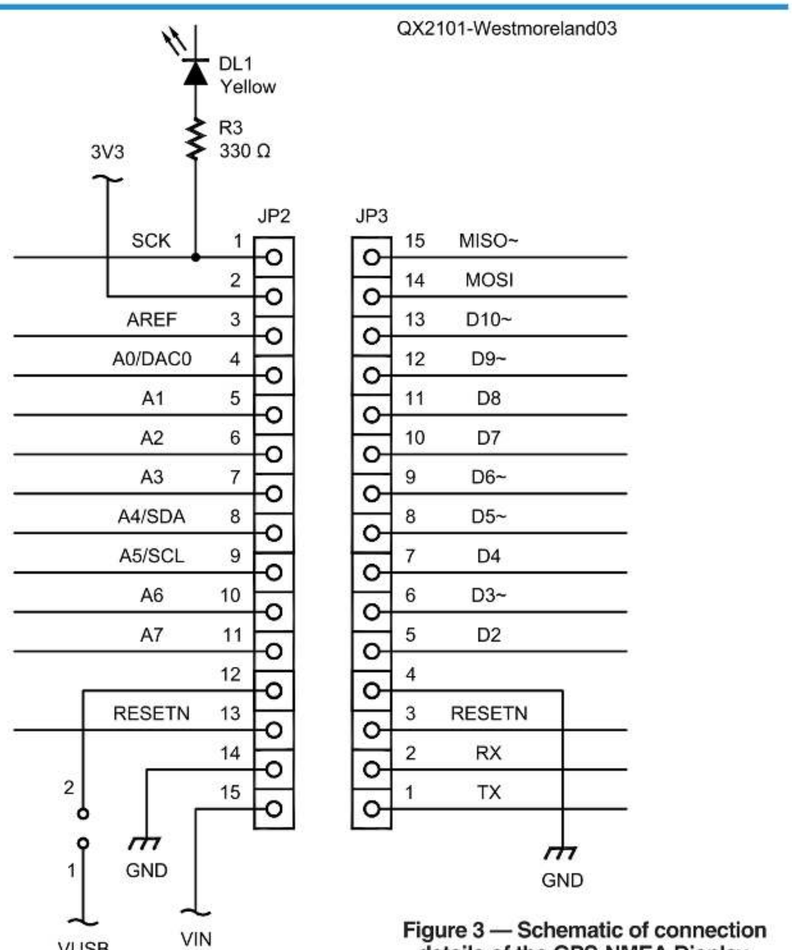

Figure 3 — Schematic of connection details of the GPS-NMEA Display.

the NMEA output supplied by the GPS receiver; note the $GPZDA sentence.

Schematic

Figure 3 shows a simple Nano 33 header schematic. The LDM-6432 comes with a 4-pin cable that is connected to the Arduino Nano 33 IoT headers. The connections are:

• Connect Pin 1 TX1 (Yellow) to Pin JP3-2 of Nano 33 (RX)

• Connect Pin 2 RX1 (White) to Pin JP3-1 of Nano 33 (TX)

• Connect Pin 3 5 V (Red) to Pin JP2-12 of Nano 33 (VUSB)

• Connect Pin 4 GND (Black) to Pin JP2-14 of Nano 33 (GND).

The LDM-6432 display can be powered via the USB connector on the Nano 33 or alternatively by the USB connector on the back of the display. To power via the Nano 33 the VUSB jumper must be soldered. The 5 V output on the Nano 33 is active only if the Nano 33 is plugged into a live USB connection. **Figure 4** shows a close up detail of Arduino 33 IoT PCBA, and **Figure 5** shows the connector detail to the LDM-6432.

Programming Details

This project uses the Arduino IDE **[12]**. The setup details are self-explanatory and as soon as the tools detect your Nano 33 IoT board you should be prompted to download all the necessary libraries needed to use and program your board.

Make sure your Arduino IDE detects your board (**Figure 6**), in this case the Nano 33 IoT board. If it doesn't, you must go to the board manager and install the Arduino SAMD (32-bit ARM Cortex-M0+) board support package.

The data stream coming from the source, in this case *Themis*, is the NMEA ZDA sentence being sent at a rate of at least one per second per the GPS signal being received from the GPS constellation. Using the *Themis* platform as the source, it is possible to send more than one data packet per second to build some redundancy into the system as necessary. The Nano 33 IoT parses each packet being received from *Themis* and determines how to present the information on the LDM-6432 display. The example code has been written to keep data parsing as fast as possible since the time display must be updated at the rate of at least once per second.

In the choice of how to transmit the data packet to the display over Wi-Fi, either a TCP server or a UDP server can be set up and a well-known port **[13]**, such as port #123 (NTP) can be used if desired. Note, if using port #123 it is considered a good practice to make sure those packets stay local to your user network and there is no path for egress. In the case of *Themis* and the time display, the *Themis* network interface has the capability to create and use its own server, so the time packets are kept local and there is no chance for egress. Network latency is also kept to a minimum since a dedicated Wi-Fi channel is used for data transmission.

The example in this article uses the UDP protocol over port #123 — the one reserved

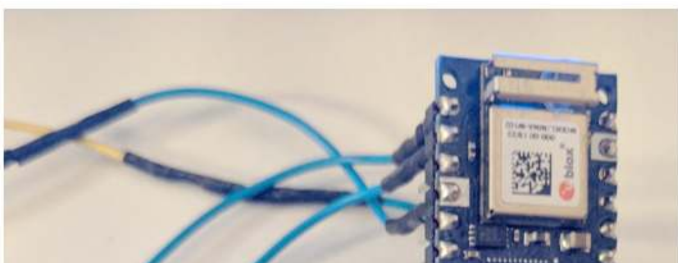

Figure 4 — Close up detail of the Arduino 33 IoT PCBA.

Figure 5 — Connector Detail LDM-6432.

for NTP — but in this example we are not officially sending NTP packets, just packets that have NMEA sentences, namely the $GPZDA sentence. We could pick another port number but for this example we will use port #123.

The source code for this project is posted on the **www.arrl.org/QEXfiles** web page. The source code is commented and is in the standard Arduino format with a *setup()* section and a main event *loop()* section. The user, reader, or programmer can choose to program either the Lumex LDM-6432 display or the Arduino RGB Shield. The program is written to decode the incoming $GPZDA packet quickly using a C-style *switch()* format. The user, reader, programmer must adjust for the local time zone. That is left as an exercise in this project. The default time zone has been set to Pacific, changing that is straight forward.

Start Without a GPS Receiver

If you would like to start on the project but you don't have a currently available GPS receiver, it's pretty easy as long as you have a PC and a Wi-Fi AP available. You can set up a manual GPS sentence simulator and send commands to the Arduino board over your Wi-Fi network. There are free tools available — one is available from the HW Group and is called the Hercules Setup Utility **[14]**.

An example UDP Server can be easily set up. This is also useful in the debug of the software application should you choose to customize or otherwise change the NMEA sentence decode in any way.

In **Figure 7** a UDP server is created using the module IP as the IP address the Wi-Fi AP assigns to the Arduino board, using port #123 on both ends of the transmission channel. The $GPZDA commands are sent and the display should appear on the Lumex display if the configuration is correct. The double $$ is for the syntax of the command within the tool's command structure, the 'Sent Data' window shows what was transmitted. In case custom commands are desired, the checksum can be calculated using an online tool **[15]**. **Figure 8** shows an example of calculating the checksum of an NMEA sentence. Using this method, you can easily test some of the other NMEA sentences. You can add this capability to the existing code to suit your development requirements.

Other Applications

Another application using this same technique — besides the obvious benefit of using a local GPS receiver to implement a NTP time of server — is using the GPS signal as a possible replacement for the WWVB signal **[16]** that originates from near Fort Collins, CO. Using *Themis* as the source, it is possible to code NTP packets on *Themis* sending them through the Wi-Fi interface that's onboard *Themis* for dissemination on your local network.

John C. Westmoreland, AJ6BC, received the Technician class license, KJ6HCV, in April 2010, and his General and Amateur Extra class licenses in 2011. In the early 1980s, while serving in the US Merchant Marine on the USNS Yukon, he constructed his first Yagi antenna per plans from the ship's radio operator. He had been interested in radio prior to this; but building that antenna from scratch, mounting it, and seeing what the performance increase was for our ship's radio

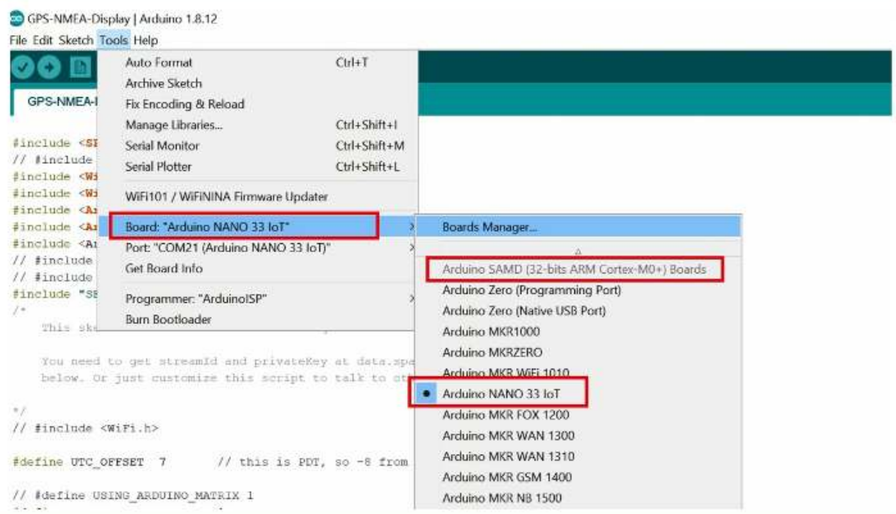

Figure 6 — Verify that the correct board (Arduino Nano 33 IoT) has been detected.

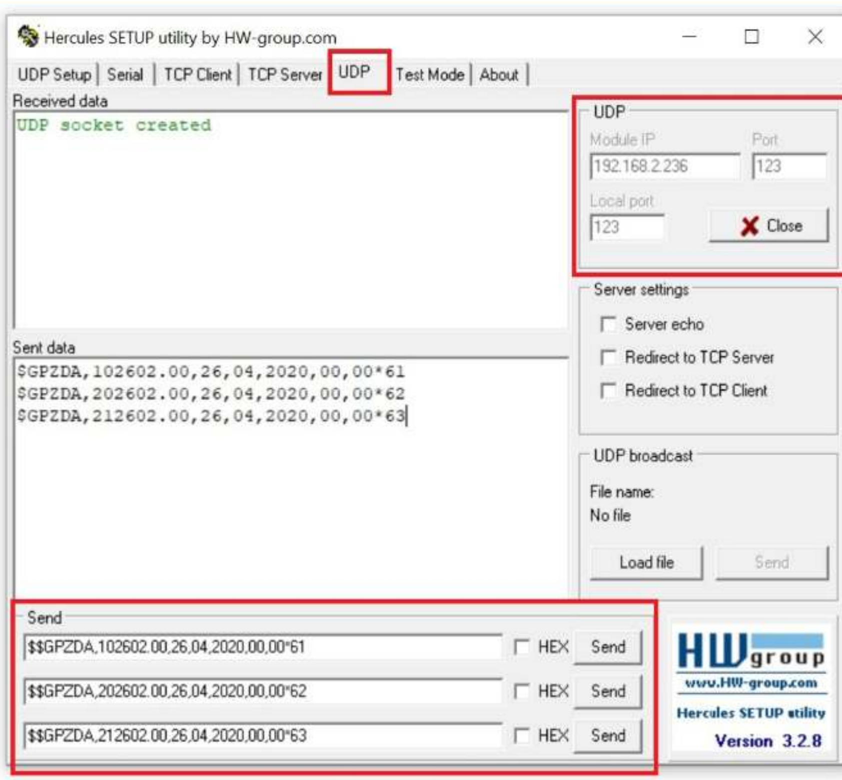

Figure 7 — A freeware utility is used to simulate NMEA sentences.

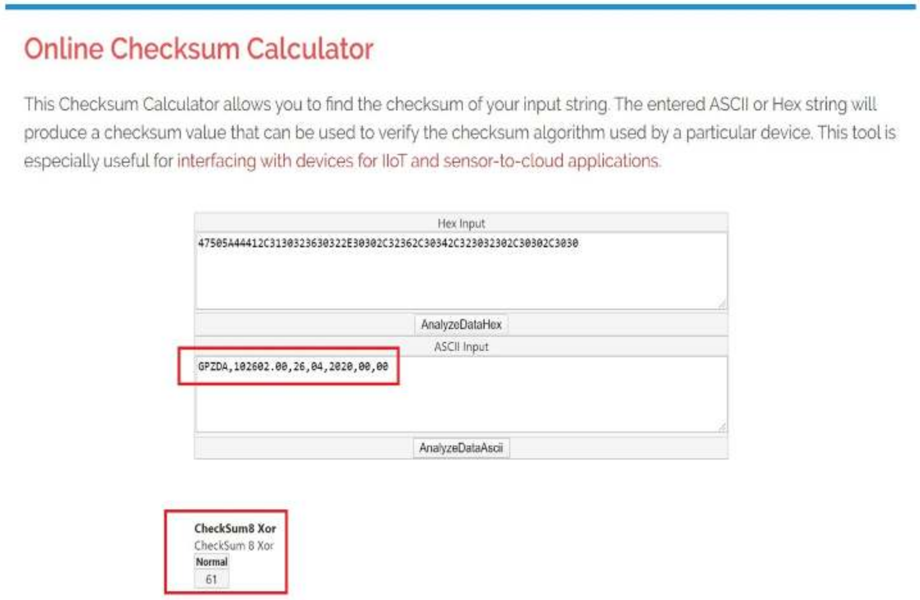

Figure 8 — Calculating the checksum of an example NMEA sentence.

systems got him hooked on radio. He became interested in the OpenHPSDR initiative and set up his first Software Defined Radio. John is a Volunteer Examiner for the ARRL and has participated with local VE groups and on-site exams at the local annual Maker-Faire.

John received his BSEE degree from Lamar University of Beaumont, TX in May, 1988 and has been a licensed Professional Engineer in Electrical Engineering in California since 2002. He's had a consulting business that specializes in embedded systems design and firmware development for over 10 years. John is the inventor on US Patent 5,325,071.

References

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[2] NMEA, National Marine Electronics Association, **https://www.nmea.org/**.

[3] NTP, The Network Time Protocol, **www.ntp.org/**.

[4] Maker Faire Bay Area 2019, May 17-19, *Themis* – An Open Source GPSDO for Open HPSDR, **https://makerfaire.com/maker/entry/69391/**.

[5] Arduino MKR RGB Shield, **https://store.arduino.cc/usa/mkr-rgb-shield**.

[6] Lumex ezDisplay Family, **https://www.lumex.com/ezDisplay-Dot-Matrix.html**.

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[11] u-Blox NINA-W10 Series, (open CPU), Stand-alone multiradio modules, **https://www.u-blox.com/en/product/nina-w10-series-open-cpu**.

[12] **https://www.arduino.cc/en/Main/Software**.

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[14] **https://www.hw-group.com/software/hercules-setup-utility**.

[15] **https://www.scadacore.com/tools/programming-calculators/online-checksum-calculator/**.

[16] Radio Station WWVB, NIST radio station that continuously broadcasts digital time codes on a 60 kHz carrier, **https://www.nist.gov/pml/time-and-frequency-division/radio-stations/wwvb**.

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Using Plastics for Dielectrics

Plastics commonly used by radio amateurs are far from lossless.

The use of commonly available and inexpensive plastic products has become commonplace among amateurs. This is especially true for PVC plumbing pipe and electrical conduit, which is often used for antenna construction. When using any dielectric material it is important to know the two basic characteristics of the plastic: dielectric constant (ε_r') and dielectric loss tangent (tanδ). Of particular importance for using plastics for coil forms and antennas is the loss tangent, which is a figure of merit for the resistance (conductivity) of the material. It is easy to assume that a plastic material is a "perfect" insulator, but how good is it? The loss tangent specification simply is a figure of merit for the electric field losses, and therefore loss of energy that occurs in the material (the lower the number the better). The loss tangent will vary with frequency.

Beyond these two basic terms, the study of dielectrics becomes rather complex. There is an excellent treatment of this study online by Dr. David Knight, G3YNH, **[1]**. The data presented here borrows heavily from David's material, including the charts. I have chosen the parts of David's paper that may be of particular interest to amateurs. Of particular importance I directly quote Dr. Knight's treatment of PVC:

"PVC, on the other hand, deserves special mention because it is a thoroughly awful dielectric. The dielectric losses which occur in plasticised PVC, in particular, are similar to those which occur in untreated wood. This is both unfortunate and pernicious; because PVC is widely used as a cable insulator in power distribution, audio, and telephone applications. The ubiquity of PVC in electrical service appears to lead amateur (and some commercial) designers to believe that it is suitable for RF purposes. The amateur literature abounds with examples of coils wound on PVC formers (drain-pipes, etc.), sometimes with PVC coated wire, all of which will exhibit abysmal Q and are likely to melt in medium power (0.4 -- 1.5 kW) applications."

Table 1 shows a comparison of PVC, which is commonly available as plumbing pipe, with other materials, including ABS.

Most of the excellent plastic dielectrics are available commercially as plate, tube, or other extruded shapes. They are more expensive, but provide much better performance than PVC or ABS. I have used both these materials and indeed, melted PVC while using it as a pipe form! This experience led me to approach plastic dielectrics in a more serious manner. ABS is an order of magnitude better than PVC and it has the added advantage of being much less subject to sunlight (UV) degradation. In the search for details, I came across Dr. Knight's web site **[1]**. More details are seen in **Table 2** and **Table 3**.

In **Table 3**, *Good* UV resistance means no significant change in properties on prolonged exposure. *Fair* means changes in surface properties or transparency, but maintains structural integrity. *Poor* becomes brittle and disintegrates. Addition of carbon black to polyethylene or polypropylene improves UV resistance by preventing light penetration but increases tanδ.

In contrast to PVC, perhaps the best dielectric qualities for commonly available plastics are found in Teflon, where Dr. Knight writes:

"PTFE deserves special mention because it manages to combine almost every desirable electrical property in a single material. It has practically no losses, its melting point is higher than that of solder, it can be machined and extruded, it is highly water-repellent, it is almost chemically inert, and

Table 1 – Material selection by loss tangent. (Source: Table E in [1])

Lossy tanδ ≥ *0.01* (δ ≥ *0.57°*)	***Good*** *0.01* > tanδ ≥ *0.001* (*0.57°* > δ ≥ *0.057°*)	***Excellent*** tanδ < *0.001* (δ < *0.057°*)
Fibreglass (GRP) PVC Wood	ABS* Acrylics (Perspex, Plexiglass)* Glass, Porcelain PET (Mylar, polyester) Polycarbonate (Lexan)	Vacuum Air Mica Polyethylene (PE) Polypropylene (PP) Polystyrene (PS) PTFE (Teflon)

* Borderline performance. Tail-end of low-frequency dispersion occurs in HF range.

Table 2 – Plastics. (Source: Table C in [1])

Material	*Dielectric Type*	*Freq Hz*	ε_r'	tanδ	*Dielectric strength, kV/mm*	*Resistivity, ρ, Ω m*
ABS (acrylonitrile-butadiene-styrene)	polar	60	2.4 - 5.0	0.003 - 0.008	-	10^{14}
		1 k	2.5 - 3.0	-		
		1 M	2.4 - 3.8	0.007 - 0.015		
Acrylic (polymethyl-methacrylate, Perspex, Lucite, Plexiglass) 20°C	polar	60	3.5 - 4.5	0.04 - 0.06	40	$>10^{13}$
		1 k	3.5 - 4.0	0.040		
		1 M	3.0 - 3.5	0.02 - 0.030		
		100 M	2.6	0.006		
		1 G	2.58	0.009		
PET (polyethylene-terephthalate, polyester, Mylar), 20 °C	polar	50	3.2	0.002	300 (1 mil) 134 (5 mil)	10^{15} - 10^{17}
		1 k	3.2	0.005		
		1 M	3.0	0.016		
		100 M	2.9	0.015		
		1 G	2.8	0.003 - 0.008		
Polycarbonate (PC, Lexan, Merlon, Tuffak) typical, 20°C	polar	60	3.17	0.0009	250 (1 mil) 80 (5 mil)	2×10^{14}
		1 k	2.99	0.0015		
		1 M	2.93 - 2.96	0.010		
		1 G	2.89	0.012		
Polyethylene (Polythene, PE) 20 °C	non-polar	50 – 1 G	2.2 - 2.35 typ 2.3	≤ 0.0003	200 (1 mil) 120 (5 mil)	10^{14} - 10^{18}
Polypropylene (PP) 20 °C	non-polar	50 – 1 G	2.2 - 2.6 typ 2.2	≤ 0.0005 typ 0.0003	106 (5 mil)	10^{13} - 10^{15}
Polystyrene (PS, Distrene, Victron, Trolitul) 20 °C	non-polar	50 – 1 G	2.7 - 2.4	0.0002 - 0.0005	200 (1 mil)	10^{15} - 10^{19}
		1 M	2.56	0.00007		
		100 M	2.55	0.0001		
		10 G	2.54	0.00043		
PTFE (poly-tetrafluoroethylene, Teflon), 20 °C	non-polar	50 – 3 G	2.0 - 2.1	≤ 0.0002	50-90 (1 mil) 40 (5 mil)	10^{15} - 10^{19}
PVC plasticized (polyvinylchloride), 20 °C	polar	1 k	4.0 - 8.0	0.07 - 0.16	60 (5 mil)	5×10^{6} - 5×10^{12}
		1 M	3.3 - 4.5	0.04 - 0.14		
		10 M	4	0.06		

it is infinitely resistant to UV light. It is for all of these reasons that PTFE is widely used for wire-coverings, insulators, coil-formers, etc., in professional radio installations. Its main disadvantage is that it is expensive, but since, in general, only small quantities are required, this is not a valid excuse for replacement by inferior materials. One minor disadvantage is that it is a soft plastic, and so cannot be used in situations where high tensile or compression strength is required (e.g., dipole centres and antenna end insulators)."

"Finally, notice that the circuit-board materials: fibreglass-reinforced epoxy, and phenolic resin bonded paper; are not particularly good dielectrics. This is of no consequence in small-signal applications; but it should explain why antenna tuners and linear-amplifier anode circuits are best built using traditional wire and solder-tag construction techniques. The sometimes-recommended practice of using pieces of double-sided fibreglass copper laminate board to make capacitors should be avoided."

Table 3 – UV resistance of plastics and rubbers. (Source: Table F in [1])

Material	*UV Resistance*
ABS	Fair
Acrylic	Good
Polycarbonate	Fair
Polyethylene	Poor* - Fair
Polypropylene	Poor* - Fair
Polystyrene	Poor - Fair
PTFE	Very Good
PVC (plasticized)	Fair

* Basic UV resistance can be improved with additives.

The Tables shown here were extracted from Tables in Dr. Knight's web site **[1]** and used here with his permission.

Bob Zavrel, W7SX, was first licensed in 1966. He has worked in RF engineering for his entire career working primarily in RF semiconductors and antennas. He published the first block diagram of an SDR system in 1988, invented the 8-circle antenna array, has published over 100 papers and articles in both professional and amateur publications, and has 7 patents. Bob has achieved DXCC Honor roll (mixed and CW) and 5BWAZ using only tree supported wire antennas. He is currently an RF business and technical consultant, a volunteer Technical Advisor to the ARRL, an ARRL Life Member, adjunct engineering professor at Gonzaga University, author of the ARRL publication **Antenna Physics, an Introduction**, *and a Senior Member of the IEEE. Bob has an BS in physics from the University of Oregon.*

Reference

[1] Components and Materials: Part 6, Dr. David Knight, G3YNH, **www.g3ynh.info/zdocs/comps/part_6.html**.

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Self-Paced Essays — #3 EE Math the Easy Way

Essay 3: Dealing with math and standards.

In the ponderous 1942 tome, Proceedings of the IRE, (the Institute of Radio Engineers was the predecessor to the present-day Institute of Electrical and Electronics Engineers, or IEEE), we find this passage from an article by Beverly Dudley, aptly entitled *Preparation of Technical Articles*:

"On the basis of these thoughts we may establish the following three points for the author to bear in mind: (1) Use mathematics only where they are needed to develop some quantitative relationships, (2) omit the use of mathematics where their employment is not essential for a clear understanding of the subject, (3) use only as much mathematics as are required, and keep these in the most simple form consistent with the development of the essential quantitative concepts."

This was good advice in 1942, and it is good advice now. While there are a probably a small number of electrical engineers and potential electrical engineers who are mathematicians at heart, it's safe to say that the vast majority of said electrical engineers are not. Most EEs consider mathematics a tool to get an engineering job done, not an end in itself.

Yet, we cannot avoid the use of mathematics altogether. After all, electrical engineering, (or any other kind of engineering) involves *quantitative relationships.* We not only need to describe things, but we need to *measure and count* them. As we will discover, we will find that, as Ms. Dudley suggests, perhaps obliquely, mathematics *are* essential for the clear understanding of some principles.

So, while we will try to not become too enamored with advanced mathematics, we might as well bite the bullet and become as skilled and agile with as many mathematics concepts as humanly possible. It will make things easier in the long run.

Electronics in general, and especially *radio* electronics, is somewhat unique in that many math concepts follow the electronics *perfectly.* In other words, electronics is very convenient and useful for teaching many mathematical concepts. Unlike, say, aerodynamics, where we have a lot of very unpredictable and *non-linear* relationships, most electrical and electronics circuits have a very close connection between cause and effect. As we begin to explore antennas, for instance, we find that they are perfectly *scalable*. We can change all the dimensions of an antenna *proportionally* to match the desirable frequency and it all works just as expected. This is definitely *not* the case — not even close — when attempting to scale aerodynamic devices. So, compared to aeronautics, or chemistry, or even biology, we electrical engineers have it easy.

Wherever possible, we will use *graphical methods* to introduce mathematical principles. For example, we will demonstrate how to work out trigonometric problems without the use of trig tables, or even having to know (at least from memory) the various trig definitions. All it requires is a bit of graph paper and a compass.

Now, a bit of a warning is probably in order at this time. Most of the mathematics that you skimmed over in high school, (if you're like me) will come back to haunt you in this course. But, don't be dismayed. If you're like the majority of "normal" math students, math was taught to you in a pretty abstract manner...without any real sense of any practical applications — at least beyond basic algebra. In this course of essays we will teach (or re-teach) mathematical concepts *concurrently* with their physical, intuitive applications. We believe you will find this method quite enjoyable and enlightening. And, by way of confession, I admit I was pretty mediocre at mathematics, at least until I started working with electronics technology. I was definitely *not* a born mathematician. So, I feel especially qualified to help typical engineering students grasp a lot of mathematical concepts that might have fallen through the cracks. I had to do it the hard way — so at least I learned how *not* to teach mathematics — which is the way it's usually taught!

Up to Speed

We mentioned in our first installment how useful the *ARRL Handbook* is for this course. With the *Handbook* there is a whole library of useful supplemental information, which is part of the purchase price of the *Handbook*, either in CD form or downloadable from the ARRL bookstore, in later editions. Chapter 2 of the supplemental material contains a lot of radio math articles. We strongly recommend you review all those articles and absorb as much of the math as you can…regardless of where you are in your math education.

The Dreaded "C" Word

Mercifully, even if you do review all of the *Handbook's* supplemental mathematics materials, you will find no mention of that dreaded "C" word, *calculus.*

Now, the question almost always comes up: do you really need to know calculus to do electrical engineering? The answer is a qualified *yes.* But, again, you don't need to know calculus the way it's usually taught! Actually, in practical electronics we do a lot of calculus without knowing it! For example, the very simple and familiar *RC* time constant is actually a calculus function, but one that's been already derived for us. Please check out the sidebar, *Derive Everything*.

The *RC* time constant is a wonderful way to learn how integrals (and differentials) work, in a very intuitive manner.

Another prime example is RMS voltage. Traditionally, we learn the magic formula for converting from Peak-to-Peak voltage to RMS voltage, but aren't usually told why that works. Well, it's a basic calculus solution. We will show you how to arrive at RMS figures using the aforementioned *graphical* methods, and then use those to explain the integral calculus concept.

So, yes, we will need to understand the *concepts* of calculus to do real engineering work, but we can cheat a bit by doing this backwards from the normal math-driven methodology.

Into the Matrix

I can remember when this thing called *linear algebra* was pretty much a mathematical curiosity. It was sort of tacked on to the last few weeks of calculus, but with the unspoken implication that there wasn't any real practical purpose for it.

All this has changed in the past few decades. All kinds of numerical processes from antenna modeling to vector graphics are based on linear algebra. Everything is a vector nowadays, and concepts such as Matrices, Arrays, and determinants are ever-present. But even more importantly, they're very *simple* to do now! And, since they are so commonplace, not only are they simple to calculate, but also simple to understand and visualize. Vector math is now very intuitive…not the abstract concept most of us "properly seasoned" engineers grew up with.

We'll do a lot of interesting engineering using *Scilab* or *Octave* (both freeware equivalents of the famous *MATLAB* matrix processing software). Of course, if you are fortunate enough to have access to genuine *MATLAB*, we will work with that too.

Model Citizens

One of the greatest advances in not only electronics technology, but electronics education is computer modeling. Electrical circuit modeling using *SPICE* and its variations allows us to design and verify everything from basic electrical laws, such as Ohm's Law, and Kirchhoff's Laws to advanced and complex circuitry. Wherever possible, we will use computer modeling to demonstrate electrical engineering principles, but with the reminder that no computer program is a substitute for actual thought.

Playing the Symbols

By definition, algebra is the mathematics of *symbols.* A symbol is a representation of some numerical value which can be manipulated by a set of mathematical rules. In our particular study, symbols represent certain electrical values, such as voltage, current, resistance, or even time. Since immutable electrical laws give us precise, predictable relationships between these values, we can derive new laws by

Raising a Standard or Two

Wherever possible, we should use standard symbols and exact quantities, especially in computer programs. For example, the speed of light c is defined as exactly 299,792,458 m/s. The magnetic constant μ_0 is, to 10 places, $4\pi\times 10^{-7}$ H/m. It follows that the derived electric constant ε_0 is $1/(\mu_0 c^2)$ F/m. Likewise, the derived intrinsic impedance of free space η_0 is $\mu_0 c\ \Omega$. Why do so? Because it is correct. — Kai Siwiak, KE4PT.

The physical universe is full of immovable identities and mathematical values. Many, if not most, of these values seem irrational to our normal way of thinking. In fact, they are called irrational numbers for this very reason. Common examples are the number π and Euler's number *e.* It is our numerical system which is imprecise, not the values they try to represent. Now, because irrational numbers tend to have a great number of decimal places, it can be a daunting task — even for a calculator! — to work out problems with extreme precision, for instance, with π run out to fifteen decimal places. However, it is not always necessary to do this. The symbol π does this for us. Whenever possible, use the actual constant symbol, such as π or *e*. You can leave the task up to someone else to carry the precision out to the level necessary for the particular application.

Errors in calculations tend to accumulate as the work progresses, no matter how much precision you start out with. If you always rely on using the actual constant in your calculations, not a numerical approximation, no matter how fine-grained, there will be no accumulated error. One can always go back to the original source of the constant.

Now, for a number of reasons, historical and otherwise, we have many different standards of measurement. No single system is intrinsically better than another, as long as the "exchange rate" between standards is agreed upon. For us radio people, wavelength has ALWAYS been measured in meters, because it is very convenient. On the other hand, the metric system seems terribly "unnatural" for everyday measurements in the US, at least for someone raised with the English standard (aka Imperial or US Customary units). [Only three countries — Myanmar, Liberia, and the US — have not adopted the International System of Units (SI, or metric system) as their official system of weights and measures. — *Ed.*]. Metric is also a lot less poetic and literate. "A miss is as good as a mile" has no acceptable translation into the Metric system. Or, even worse, "I'd walk 1.6 kilometers for a Camel". One should be comfortable switching between whatever system is more convenient and meaningful for the task at hand.

For the purposes of this course our standard of standards will be the International System of Units. The National Institute of Standards and Technology (NIST) has a publication, Guide for the Use of the International System of Unit, which we will defer to whenever a related question comes up, and they will! See: **https://physics.nist.gov/cuu/Constants/index.html**.

If you like precision, you will enjoy this video of the world's most perfect man-made object: **https://youtu.be/ZMByI4s-D-Y**. With the definition of the unit of mass fixed exactly, it explains why μ_0 is $4\pi\times 10^{-7}$ H/m to only 10 places!

the *substitution* of these symbols. In fact, a great deal of what we do in electrical engineering is *substituting* unknown values with values we know, which may, in turn, be determined by *other* substitutions. Being able to confidently identify and apply these substitutions is key to performing just about any electrical or electronics calculation.

Derive Everything

Most of us electronics technicians and engineers trained in the past millennium were taught to memorize all the relevant formulas and equations for electronics work. There is nothing intrinsically wrong with this; rote memorization does wonders for exercising the brain, something I recognize more as I get older. Learning a foreign language, or even Morse Code has been proven to stave off brain deterioration.

From a practical standpoint, having a lot of "hard-memorized" formulas at one's disposal is extremely handy; however, it doesn't always give you much insight. One notable example is the formula for calculating multiple unequal resistors in parallel:

$$R_T = \frac{1}{1/R_1 + 1/R_2 + 1/R_3} \ldots$$

We know that it works because we use it all the time, but we old-school electronics students weren't usually told *why* it works.

In this series, we will never leave you floundering as to where a certain formula comes from; we will derive it for you explicitly. Doing so gives you great agility in working out any electronics problem you might encounter.

Another commonly derived formula, which we will use extensively, is the resonant frequency formula,

$$f = 1/\left(2\pi\sqrt{LC}\right).$$

But before we use it the very first time, we will show you exactly where it comes from. It's actually a rather simple derivation but it should help wobble some unused algebraic brain follicles as we actually do the derivation together.

Most derived equations rely on the extremely useful tool of *substitution.* We can substitute basic "ingredients" from well-known, fundamental equations, and

Units and Prefixes

For convenience, we use a lot of electrical values that are *not* fundamental values. For example, while *hertz* is the fundamental unit of frequency, we will often use derived units such as kilohertz or megahertz. Often, when working electronics problems, one will be confronted with several derived units, which may not be readily compatible. Until you become adept at manipulation these derived units (which will become second nature, eventually), it is always best to convert the derived units to their *fundamental units* before performing any further calculations. For example, a problem might ask how many kilometers per microsecond a wave of some kind travels. It is best to convert kilometers to meters and microseconds to seconds before dividing. We will give more examples of this practice in later exercises.

Another good practice to follow is to always write the *units* down as you work out a problem, no matter how tedious this may seem. And don't confuse *units* with *symbols* — a very common mistake for new electronics students. Every electrical value has both a *unit* and a *symbol*. Ohm's Law is expressed in *symbols:* $E = I\,R$. But none of those symbols are units. Always writing the *unit* after a numerical value will help you keep symbols and units separated in your mind. I realize this is very fundamental stuff, but I see these errors being made all the time.

Next session, we'll dive right into an Ohm's Law problem, and a curious dilemma. Again, review all the electronics math you can before then.

Upcoming Conferences

7th Annual TECHCON 2021

February 26-27, 2021

Winter Haven, Florida

http://arrlwcf.org/wcf-special-events/wcftechconference/

The 7th Annual TECHCON, the ARRL West Central Florida Section Technical Conference, will be help February 26 – 27, 2021, at the Polk County EOC, 1890 Jim Keene Blvd., Winter Haven, FL. See website for details.

Virtual 2021 SARA Spring Conference

April 2, 2021

www.radio-astronomy.org

The 2021 SARA Spring Conference will be held on Zoom, April 3, 2021. This virtual conference will replace the annual SARA Western Conference because of the continuing COVID-19 pandemic.

Call for papers: The Society of Amateur Radio Astronomers (SARA) hereby solicits papers for presentation at its 2021 Spring Conference, to be held April 3, 2021 via Zoom. Papers on radio astronomy hardware, software, education, research strategies, observations and philosophy are welcome. SARA members or supporters wishing to present a paper should email a letter of intent, including a proposed title and informal abstract or outline to **westernconf@radio-astronomy.org** no later than February 1, 2021 (please let us know if you require more time). Be sure to include your full name, affiliation, postal address, and email address, and indicate your willingness to participate in the conference to present your paper. Submitters will receive an email response, typically within one week. Formal printed Proceedings will be published electronically for this conference and a link will be sent to each participant prior to the conference.

Contact: Please contact conference coordinator Dave Westman if you have any questions about the conference or if you would like to help: **westernconf@radio-astronomy.org**.

Registration: Registration for the 2021 Spring Conference is just US$25.00. Attendees at the conference must be SARA members; if you are not yet a member, this will cost an additional $20. See website for details.

Eric P. Nichols, KL7AJ

AlasKit Educational and Scientific Resources, 3763 Lyle Ave., North Pole, AK 99705; **eric@alaskit.co**

Self-Paced Essays — #4 Ohm's Law

Essay 4: Ohm's Law is the most fundamental relationship we use in electrical and electronics work.

Ohm's Law through the Back Door

The most fundamental relationship we use in all electrical and electronics work is Ohm's Law. However, the way Ohm's Law is normally presented can lead to some early "plateaus" in understanding some very basic principles. Instead, I would like to present Ohm's Law in a more intuitive manner than is commonly used, which should make complex parallel circuits especially more intuitive. Rather than "diving" right into Ohm's Law, we will *derive* the law from more fundamental principles, as we will do with every concept and equation in this series.

Conducting Ourselves Properly

The two most important components in any electrical or electronic circuit are the voltage source and the *conductor.* Let us begin with the conductor. A conductor is a material that has a large supply of free or *mobile* electrons. We don't need to go into a great deal of the chemical structure of conductors at this time, other than to distinguish between generally good conductors, such as metals, and poor conductors (or *insulators)*, such as glass, plastic, or paper. A conductor has an abundant supply of *valence* electrons in the atoms that make up the material. Valence electrons can be easily removed from the orbit of one atom and transferred to an adjacent atom, in somewhat of a bucket-brigade fashion. Of course this is a gross oversimplification — as are most sub-atomic models — but it is useful enough for our present purposes.

Now, while conductivity is a fundamental property of a particular material, *conductance* is a measure of the electrical properties of a specific "chunk" of a conductive material, quite typically a length of wire. The conductance of a piece of wire is a function of the diameter of the wire and the length, as well as the conductivity of the material — most commonly copper.

Unless compelled to otherwise, the valence electrons in a material will pretty much stay in the same place — on the large

The Speed of Electricity

If you've been working with electricity for a while, you've probably been taught (and even observed) that electricity flows at about the speed of light through a wire.

Is this really true? Well, we need to define the speed of electricity, as there are two very different speeds. If we were to somehow tag a single electron with a GPS and follow it through a #14 AWG copper wire, with about an ampere of current flowing, this electron would move at about a tenth of a millimeter per second, a glacially slow speed, electronically speaking. On the other hand, in most practical circuits we can't even measure the delay time of electric currents as they travel through components on our work bench. Why the discrepancy?

Imagine two 6-foot-long, half-inch diameter plastic tubes. One tube is full of marbles packed end to end. In the second tube, we place a single marble at one end of the tube. We stack the tubes right next to each other, and with a large hammer, tap the "front end" marble of each tube at exactly the same time. Which tube ejects a marble first? The tube full of marbles, of course. In the single-marble tube, that single marble has to travel the full six feet in order to come out the far end. In the packed-marble tube, each marble only moves a minuscule amount, but transfers the energy nearly instantaneously through the tube, ejecting the last marble from the tube with imperceptible delay.

This is analogous to the speed of electric current that we normally work with, which comes out to slightly less than the speed of light.

The much slower electron drift is something we don't normally concern ourselves with in electronics, with two notable exceptions, vacuum tubes and ionospheric plasmas, cases where the electron drift can approach the speed of light.

Incidentally, a lot of recent work has been done with exotic metal-like materials that conduct electrons in a laminar flow manner, greatly increasing the drift velocity, as well as greatly reducing the resistance. I think we'll be hearing a lot more about laminar flow electrons in the very near future.

scale — orbiting around their respective atoms. If a *longitudinal electrical force*, for instance, is applied along a wire, the electrons will migrate from one atom to the next, and an *electrical current* will flow. Now, this force has to be a specific *type* of force, known as the *electromotive force,* or *EMF.* We won't discuss the nature of this force in detail at this time, other than to know that it is the force that causes electrons to move, logically enough.

Now, we need to point out that this electron migration through a conductor is a painfully slow process, and we aren't as much concerned with this electron *drift*, as we are with the transfer of *energy* between electrons, which happens at just under the speed of light in normal conductors. See the **Sidebar** "The Two Speeds of Electricity." Except for vacuum tubes and plasmas, we won't be too interested in electron drift, but will be more concerned with the transfer of electrical *energy,* which we will discuss in more detail in upcoming articles.

Let's Return to Our Conductors for a Moment.

The symbol for conductance is G, while the *unit* of conductance is the *siemens*, denoted by ℧, the upside down omega, or *Latin upsilon.* The symbol for electromotive force is E, and the *unit* of electromotive force is the volt, usually denoted by V.

Now we have our two main ingredients of an electrical circuit, and we can now explore the simplest relationship between them. For a given electromotive force, the flow of electrons will be proportional to the conductance of the conductor — typically a wire — to which we apply the electromotive force. The amount of electron current flow is symbolized by I, and the unit of current is the ampere (A).

We can now put together our first equation describing the relationship between electromotive force, conductivity, and current flow:

$$I = EG$$

Now, here's where things get interesting historically. At the present time, the unit of conductance (G) is the siemens. However, before 1971 when all electrical units were standardized (more on this later), the unit of conductance was the *mho,* which is simply ohm spelled backwards. But here is why I — and others of my ilk — still prefer the term *mho.* Not only is it more poetic, but it's also more helpful because we know that with" mo' mho, you have mo' current flow!" Nothing could be more memorable!

You are free to use siemens of course, and this is the "accepted" term, but many old timers will never let go of mho — and now you know!

From our little equation above, we can see that, for a given EMF, the current is always going to be proportional to the conductance. And we will also see that $I = EG$ is actually Ohm's Law in disguise.

While conductance is a measure of how well a component, such as a wire, conducts electrical current flow, the reciprocal of conductance, or resistance, is the measure of how *poorly* a conductor conducts. The reciprocal of G is $(1/G)$, which equals R. The unit of R is the ohm, denoted by omega, Ω.

Now, if we substitute R into our original equation, $I = EG$, we now have $I = E(1/R)$, or $I = E/R$. Moving R to the left side, we have $IR = E$, or more commonly stated as $E = IR$. Ohm's Law in its normal or standard form, however, is $R = E/I$.

Resistance is Not So Futile

Our original equation and the "standard" Ohm's Law equation tell us exactly the same thing. So which is better? In reality, we want to be able to *effortlessly* work with either one, along with all their derived equations, which we will explore later. From a purely practical standpoint, manufactured "conductance" components usually come in the form of resistors. If you were go to your friendly local electronics store and ask for a 0.02 siemens conductor, he or she would probably have no clue what you're talking about. However, if you were to ask for an identical 50 Ω resistor, you might get somewhere. Of course, nowadays, the proprietor may be just as clueless about a 50 Ω resistor, but your chances might be a little bit better.

As we will learn, most of what we do in electronics ultimately results in the production or consumption of *work.* When working with work, we find that resistance is generally more useful than conductance. A perfect conductor would require no work in order to cause electrons to flow, and likewise, we can extract no work from a perfect conductor. Paradoxically, perhaps, we find electronic circuits to be the most useful when they resist our efforts — hence the preponderance of resistance in so much electronics work. As a purely mechanical analogy, if a car had absolutely no friction, it would require no power to keep it moving — though it would require work to be done *momentarily* — in order to bring it up to speed. Electrical resistance is nearly analogous to mechanical friction.

So, again, we need to be able to manipulate both resistance and conductance. Being comfortable in both paradigms will make life so much easier down the road. For instance, when working with multiple *parallel* resistors, we find conductance so much more convenient.

If you have had some electronics classes in the past, you were probably taught the formula for calculating the total resistance of several unequal resistors connected in parallel:

$$R_T = \frac{1}{1/R_1 + 1/R_2 + 1/R_3},$$

but were probably never given a clue as to where that formula came from. However, if we replace all the resistances with conductances, the light comes on. First we substitute R_T with G_T, and likewise with all the $1/R$ terms. We can now simply *add* our individual G terms, which gives us a total, G_T. Now to get back to total R, we simply take the reciprocal of G_T, and voila!

So, when working with parallel circuits of any kind, you'll be far better off working with conductances. Most electrical engineering courses save the reciprocal functions until the end; I prefer getting to them right out of the chute! I think you will also appreciate this as we move forward.

It's also a great way to double check your work. You should be able to get the same answer (ultimately) by working out any circuit problems using either conductances or resistances.

The same principle applies when we move into parallel ac circuits, containing *reactance X,* and *impedance Z.*

The reciprocal of reactance is susceptance, B, and the reciprocal of impedance is admittance, Y. We will discuss these in great detail before too long. But for now, we'll concentrate on dc circuits and mathematics.

Coming up in the next installment are two more extremely useful laws, Kirchhoff's laws for current and for voltage, which will greatly simplify life for us!

Phil Salas, AD5X
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Turn your NanoVNA into a Bench Instrument

Modify your NanoVNA to make it a more structurally sound instrument.

After reviewing the NanoVNA and NanoVNA-F **[1]**, I purchased a NanoVNA-F for my own use due to its larger display and nice metal case. While this has worked out well, I just didn't care for the SMA cables. I wanted a more structurally sound test instrument.

My solution turned out to be fairly easy to implement. I cut out a couple of small aluminum panels from some scrap pieces I had. **Figure 1** shows the panel dimensions and **Figure 2** shows the unpainted panels. I counter-sunk the two 7/64" diameter mounting holes using a larger drill bit. The 5/8" diameter hole was made with my 55-year old Greenlee punch.

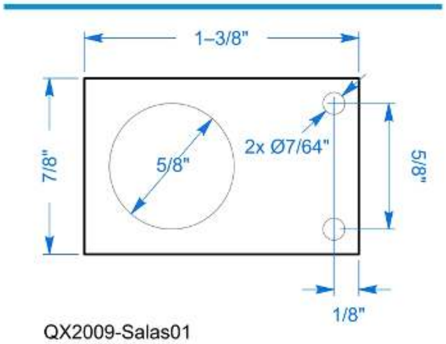


Figure 1 — Bracket dimensions.

Figure 2 — Unpainted brackets.

After painting the panels, I mounted the N to male-SMA cable adapters to the panels, and then attached the panels to the NanoVNA-F with the original front-panel screws as shown in the front and top views of **Figures 3** and **4**.

I purchased the 2-pack of DZS RF connector / coax cable assemblies (15 cm SMA male cable to N-female bulkhead) from Amazon. The 2-pack was $10.99. From Amazon I also purchased a 2-pack of DGZZI UHF female to N-male adapters, and a 2-pack of BNC female-N male adapters for interfacing to these other popular connectors.

Figure 3 — Front view of the modified instrument.

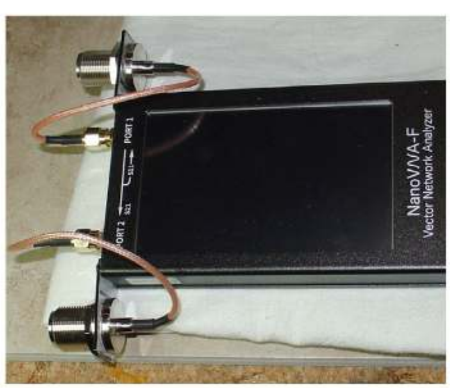


Figure 4 — Top view of the modified instrument.

Figure 5 — N-connector adapters, cable and calibration loads.

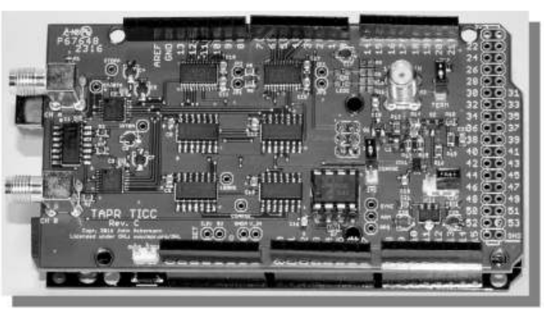
Finally, from Amazon I purchased two 2-packs of DGZZI N-male to SMA female adapters and a 12-inch N-male to N-male cable. The cable facilitates through-cable calibration. I used the N to SMA adapters to make precision open / short / 50 Ω loads for calibration using an Amphenol SMA shorting cap (Mouser 523-132331 at $3.70), and an Amphenol SMA 50 Ω termination (Mouser 523-132360 at $2.97). I measured the Amphenol 50 Ω termination on an Agilent / HP 8722D vector network analyzer and found that the return loss exceeded 40 dB through 1,200 MHz. When the SMA termination was installed on the N / SMA adapter (the calibration load), the worst-case return loss was 32 dB (SWR < 1.05:1) at 1,200 MHz, improving to better than 40 dB return loss (SWR < 1.02:1) below about 650 MHz — a very good load indeed! Of course, I could have just used a single N to SMA adapter and screwed on the load, short, or left it open. But I wanted a dedicated calibration kit, and the components are quite inexpensive. **Figure 5** shows the adapters, cable and calibration loads.

That's it. For just a little work and very little money you can turn your NanoVNA-F into a nice desktop instrument.

ARRL Life Member Phil Salas, AD5X, has been licensed continuously since 1964. His interest in ham radio led him to pursue BSEE and MSEE degrees from Virginia Tech and Southern Methodist University respectively. He had a 35 year career in RF, microwave and lightwave design holding positions from design engineer to Vice President of Engineering. Phil is now fully retired and enjoys tinkering with ham radio projects and spending time with his two grandsons.

Notes

[1] Phil Salas, AD5X, "NanoVNA Vector Network Analyzer", Product Review, *QST*, May 2020, pp. 39-43.



2020 *QEX* Index

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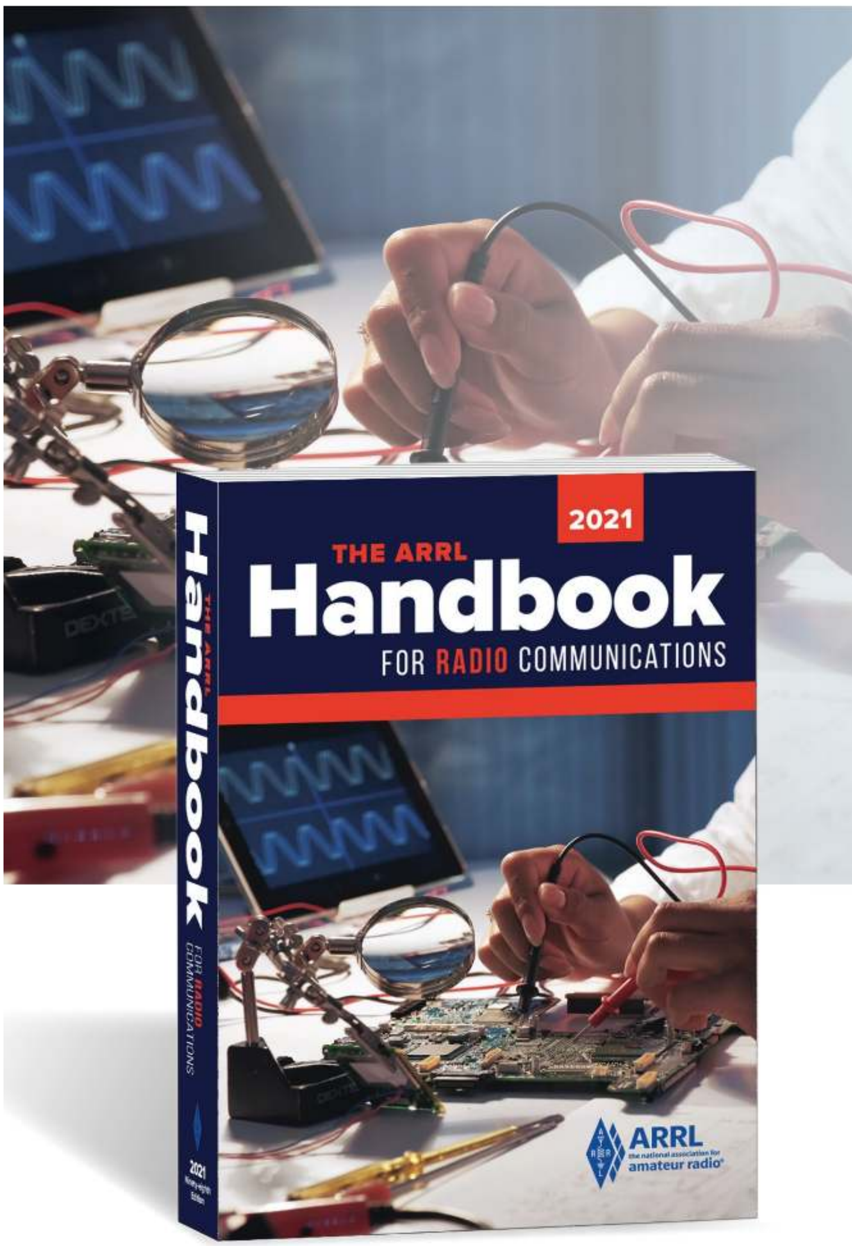

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New from COMPACtenna, this tiny high-performance beam directional gain antenna for 2 meters is designed to fit in tight spaces and through attic openings that won't accommodate standard beam antennas—even small ones. Measuring 19" L x 28" W x 28" H, the lightweight antenna requires little assembly and lets you use an inexpensive TV-antenna-style rotor. **Enter "COMPACtenna" at DXEngineering.com.**

RigExpert

Antenna Analyzers

RigExpert has added three new analyzers to its impressive lineup: the AA-650ZOOM (0.1-650 MHz), AA-1500ZOOM (0.1-1,500 MHz), and AA-2000ZOOM (0.1-2,000 MHz). These tools for antenna building and troubleshooting deliver the benefits you've come to expect, including measuring the capacitance or inductance of reactive loads, checking coax cable, tuning an antenna to resonance, and measuring SWR and impedance. **Enter "RigExpert" at DXEngineering.com.**

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Noise Cancellation Products

Noise Canceling Desktop Speaker

The audio pros at bhi have great news for Hams—an upgraded version of its 10W DESKTOP DSP Noise Canceling Speaker. The DESKTOP-MKII is enhanced with the latest technology to ensure an even more impressive listening experience. The speaker removes noise and interference to leave crisp and clear speech; allows users to select from eight filter levels in real-time to suit current conditions; and works with all types of transceivers. **Enter "bhi" at DXEngineering.com.**

Icom IC-705 HF/50/144/430 Portable Transceiver and Accessories

ICOM

With the features and functionality of the IC-7300, IC-7610, and IC-9700, Icom's new QRP rig is like owning a base transceiver you can hold in one hand. It boasts SDR Direct Sampling technology for stellar transmit and receive performance; 4.3 inch color touchscreen; real-time spectrum scope and waterfall display; and full D-STAR capabilities. Accessories sold separately include Backpack, Bluetooth Headset, Magnetic Loop Antenna, and mAT-Tuner Automatic Tuner. **Enter "IC-705" at DXEngineering.com.**

YAESU | ICOM | KENWOOD | ALINCO | ACOM Outstanding HF Power Products | Ciro Mazzoni Radiocomunicazioni | RF-KIT POWER AMPLIFIER | KENT KMK KENT MORSE KEYS GERMANY

Check DXEngineering.com for the most up to date shipping information!

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THE HEARING AIDS... FOR HAMS!

During a solar minimum, HF band conditions can be a challenge. Many hams are discouraged by this potential for reduced performance. Do not despair! A low sunspot period can be a great time to work rare DX, break into DX pileups and also win a contest or two, but it's critical to have the correct equipment – nothing is more important than having the ability to hear the signal you want to work.

SteppIR antenna products allow the user to remotely adjust each active antenna element to the exact length required, so the antenna is optimized at every single frequency within its range, including non-ham band frequencies. This significantly enhances the ability to HEAR the signal, which is why we call our products "The Hearing Aids, for Hams"!

Adam Blackmer
K7EDX

"When signals start to approach the noise floor – as they often do at a sunspot minima – SteppIR Yagi's, with their support pattern and gain, allow users to hear and work stations that others cannot."
– Mike Mertel K7IR

An interlaced or trapped Yagi can't touch the performance of my tree mounted 3 element SteppIR Yagi – The odds are always in my favor to work the station in competitive situations.
– Michael Fischer K7XH

steppIR
COMMUNICATION SYSTEMS

FOR DETAILS ON PRODUCTS AND TO ORDER:
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