Introduction to Digital Mobile Radio (DMR)

This professional digital voice technology is now gaining fans in the Amateur Radio world.

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Digital voice involves the conversion of analog voice into a digital data stream for transmission over the RF or wired media. This conversion process utilizes a vocoder. The transmitted digital voice data stream is then encapsulated inside a protocol that handles the addressing and communication management. Both sender and receiver must use the same vocoder and protocol to communicate. Among the digital voice technologies used in the amateur bands, the most popular are D-STAR (Digital Smart Technologies for Amateur Radio), DMR (Digital Mobile Radio), and System Fusion. This article focuses on DMR technology.

Digital Voice on VHF/UHF

Both D-STAR and System Fusion were designed specifically for the Amateur Radio market. DMR, developed by the European Telecommunications Standards Institute (ETSI), is used worldwide by professional and Amateur Radio users. Currently, only Icom manufactures handhelds, mobiles, and repeaters for D-STAR. Yaesu is the only manufacturer for System Fusion handhelds, mobiles, and repeaters. There are over a dozen manufacturers producing DMR compatible equipment, including Kydera (Figure 1), Motorola Solutions, Hytera, Vertex Standard, Connect Systems, Baofeng Telecom Technologies (BFDX), Kirisun, and Kenwood (although not distributed in the US).

Amateurs have implemented DMR with over 1400 repeaters and 16,600 user radios registered worldwide. A majority of the repeaters are interconnected over the Internet. There are a number of US amateur regional and state networks, and most are interconnected with the DMR-MARC (Motorola Amateur Radio Club) and DMRX core servers.

D-STAR and System Fusion both include the radio amateur's call sign in their protocol. DMR utilizes a Radio ID number that amateurs must obtain from DMR-MARC, which serves as a central registry for worldwide amateur users.

DMR Standard

DMR is divided into three tiers. Tier I is a single channel specification designed for the European unlicensed dPMR446 service. It is a single channel Frequency Division Multiple Access (FDMA) signal in a 6.25 kHz bandwidth. The standard supports peer-to-peer (mode 1), repeater (mode 2), and linked repeater (mode 3) configurations. The use of the Tier I standard has been expanded into radios for uses outside the unlicensed dPMR446 service.

Tier II DMR occupies a 12.5 kHz bandwidth shared by two channels using Time-Division Multiple Access (TDMA). IP Site Connect (IPSC) for interconnecting repeaters over the Internet is vendor specific and is not part of the ETSI standards at this time. Most Amateur Radio implementations of DMR use voice on both time slots.

Figure 1 — A DMR handheld transceiver can have no display, a monochrome display, or a color display like this Kydera model. [Image courtesy of Kydera]

Tier III builds upon Tier II, adding trunking operation involving multiple repeaters at a single site. Not all manufacturers' trunking implementations are Tier III compatible. Vender specific protocols have expanded the trunking to multiple site operations.

Amateur Radio Implementations

Amateurs are implementing DMR Tier II in their MOTOTRBO™ and Hytera infrastructure networks. The IPSC protocols used by those different brand repeaters are not compatible, and it is doubtful the equipment manufacturers will ever standardize for business reasons. However, conversion between the two vendor protocols is possible. Any brand DMR (Tier II) user radio will work on any Tier II system, although some manufacturers offer additional proprietary features for their infrastructure.

The Vocoder

Although it is not specified in the ESTI standard, by agreement of the manufactures, the current implementation of DMR utilizes the Digital Voice Systems, Inc. (DVSI) AMBE+2™ vocoder. Many of the radio manufacturers have implemented the vocoder in licensed software, others use a DVSI chip. The forward error correction in the AMBE+2 is an improvement of the voice quality of older technology vocoders.

Networks

Amateur MOTOTRBO and Hytera DMR networks operate the same way from the end user standpoint. Amateur MOTOTRBO networks are much larger, cover many more areas, and most are interconnected. Not all of the amateur DMR repeaters are connected to the wide area networks. Some are standalone, either because they have yet to obtain an ISP connection at their repeater site or because they just prefer to use the repeater for local communications. Some standalones are operating in dual-mode (analog/digital), which allows the repeater to support both digital and legacy analog users. MOTOTRBO repeaters operating in dual-mode do not support interconnection via the Internet using IPSC.

Playing in the Sandbox

Some hams have installed DMR repeaters in vehicles, relying on 3G/4G cellular wireless services for Internet access. Others have implemented remote bases to interconnect to other networks or radios. Wide area networks typically have policies prohibiting interconnected traffic, however local implementations that stay local are acceptable.

Policies prohibiting interconnection to different types of networks help keep large networks functioning. Network operators have expended much time and great efforts to keep a linked system running smoothly. DMR-MARC maintains a "sandbox" that is separate from the main DMR-MARC network, which is available for persons interested in developing and experimenting.

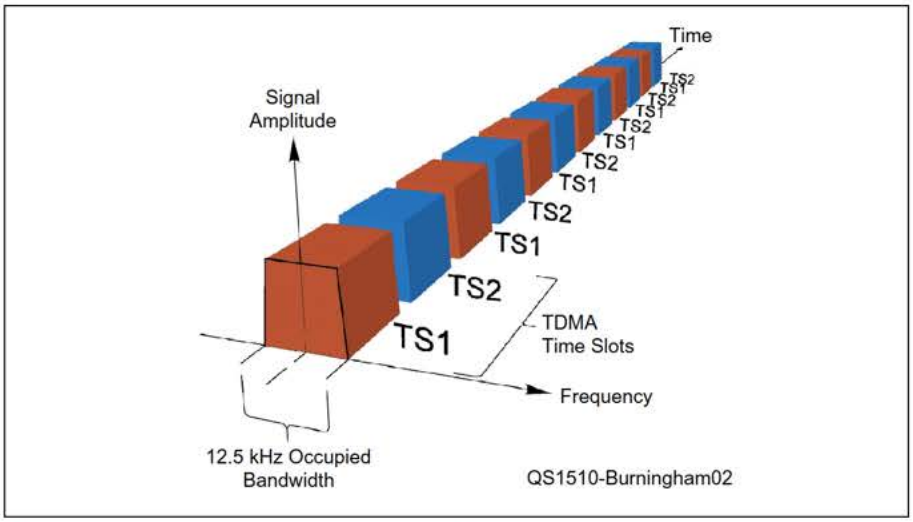

Figure 2 — The DMR signal occupies 12.5 kHz, which supports two time slot channels.

DMR Equipment and Programming

Early era amateur analog repeaters originated with surplus commercial radios. Over time, equipment designed and targeted for the radio amateur reached the marketplace. Today you can find used commercial DMR gear, but new DMR radios in the typical ham budget range ($165– $200) are readily available.

Most of the DMR radios require a programming cable to program the radio using the manufacturer's software, while other radios support programming using Bluetooth and even over-the-air programming. FPP (Front Panel Programming) is available on some models.

Any Tier III capable radio will also work on Tier II systems but neither will work on Tier I.

Digital vs Analog

If you operate on analog FM repeaters, you will have noticed that the audio quality degrades as a signal into the repeater (uplink) gets weaker. As distance to the repeater increases, the signal from the repeater (downlink) also gets weaker until you can no longer hear the repeater. A combination of the weak signal into a repeater and a weak signal from the repeater can rapidly degrade the audio quality and usability.

A basic difference with digital repeaters is that the audio quality remains the same on the uplink and downlink until the very edge of the coverage range. Then the audio on DMR systems starts sounding broken (missing portions of the speech) caused by lost packets. The Internet can also drop UDP packets used for moving traffic between repeaters and bridges, causing the same broken audio effect. Analog static is a thing of the past using any of the digital voice technologies. DMR implements Forward Error Correction (FEC), which can slightly extend the usable communication range.

Two-Slot TDMA

DMR Tier II and Tier III occupies a 12.5 kHz bandwidth shared between two time slots (TS1 and TS2) using Time-Division Multiple Access (TDMA), resulting in a spectrum efficiency of 6.25 kHz per channel (Figure 2). Each time slot can carry either voice and/or data. You can think of the two time slots as separate channels. This means one repeater allows two separate channels at the same time. Currently most amateur DMR repeater system implementations utilize both channels for voice and some limited text messaging. Typically one channel (time slot) is used for wide-area and the second is local and regional. For repeater operators, a single two-slot TDMA repeater offers a significant savings over two standalone repeaters to obtain two separate communication channels, since only one repeater and one antenna system is required. The two-slot TDMA DMR uplink uses 30 ms for each time slot (27.5 ms frame and a 2.5 ms gap). Your transmitter is on for just 27.5 ms of every 60 ms, resulting in extended battery life for portables.

The DMR repeater transmits (downlink) a continuous data stream even if only one time slot is being used. The 2.5 ms uplink gap is replaced with a CACH burst (Common Announcement Channel) that is used for channel management and low speed signaling. The 27.5 ms frame comprises 264 bits (108 bit payload, 48 bit SYNC, and a second 108 bit payload). The vocoder compresses 60 ms of audio including FEC (forward error correction) into 216 bits of data for transmission. The 2.5 ms gap includes guard time to allow power amplifier ramp up and for propagation delay.

Table 1
Some DMR-MARC MOTOTRBO Network Supported Talk Groups

Slot	Talk Group	Description
TS1	TG1	World Wide
TS1	TG3	North America
TS1	TG13	World Wide English
TS2	–	Local, State, and Regional

Talk Groups

Talk Groups (TG) allow groups of users to share a time slot without distracting and disrupting other users of the time slot. Only one TG at a time can use a time slot on a repeater. Unless your radio is programmed to listen to a TG, you will not hear that TG traffic. The DMR-MARC MOTOTRBO network supports a number of Talk Groups (Table 1). Check with your local repeater operator to find out what Talk Groups/Time Slots are available on a repeater.

Although the DMR standard supports private calls (one-to-one), encryption, and data, private calls are not allowed by most

Table 2

DMR Information Sources

DMR-MARC (Motorola Amateur Radio Club)	www.dmr-marc.net
DMR-MARC Canada	www.va3xpr.net/dmr-marc-canada/
DMR-UK	www.dmruk.net
Digital Communications Interconnect Group (DCI)	www.trbo.org
DMRX	www.dmrx.net
Digital Mobile Radio Association (Professional DMRA)	www.dmrassociation.org
Amateur Radio Guide to Digital Mobile Radio (DMR)	www.k4usd.org/guide.pdf

Regional DMR Groups

Central Michigan Emergency Network (CMEN MI5)	w8cmn.net
K0USY Group (Kansas)	k0usy.strikingly.com
K4USD Network	www.k4usd.org
Massachusetts Interconnect Team (MIT)	www.mitcom.com
NC-PRN (VA/NC/SC/TN)	www.ncprn.net
New England Digital Emergency Communication Network (NEDECN)	nedecn.org
NJ-TRBO Network (NJ/NY/PA)	www.n2jti.net
NorCal DMR	www.norcaldmr.org
NOCO DMR Group (Northern Colorado)	www.w0dmr.org
Rocky Mountain Ham Radio	www.rmham.org

of the amateur networks. Many consider private calls not amateur friendly, and they can tie up a large number of repeaters across the network. Encryption is not permitted in Amateur Radio in most parts of the world. Data and text messaging are supported on some networks.

TGs are implemented for individual states and regions on many networks. Some are available all the time, while others are available at preprogrammed times or require a local user to activate it for a period of time. Only one TG can be active at a time on a time slot, so many systems will disable other TGs when a local user is active on a TG in the time slot. Be ham friendly and try to use TGs that tie up the fewest number of repeaters if you are going to be chatty. Further information about specific Talk Groups can be found on the DMR-MARC, DMRX, and regional group websites (Table 2).

Zones

DMR radios support Zones. A Zone is a grouping of individual channels. Some radio models limit the number of channels per Zone and the number of Zones allowed. You can program Zones for local channels (DMR or analog), another Zone for a neighboring state, and a Zone for business and government channels. If you program non-amateur channels in your radio, make sure they are receive-only unless you are licensed and authorized to use them as per FCC 90.427(b), otherwise you can be in violation of FCC rules and regulations, and enforcement action could be taken against you. If you have a VHF model, you could program a Zone for the National Weather Service broadcast channels (again, in receive only). Zones are just a way to manage large numbers of channels.

Color Codes

DMR repeaters use Color Codes (CC) much like analog repeaters use CTCSS or DCS. To access a repeater, you must program your radio to use the repeater's CC. There are 16 different CCs (CC0 – CC15). The use of Color Codes is not optional on DMR systems. If your Color Code is not set correctly, you will not be able to access the repeater.

DMR Channels

A DMR radio channel is a combination of frequency, CC, TS, and TG. A single repeater may occupy six or more programmed channels depending on the number of TGs available.

Code Plugs

A code plug is simply the radio configuration file. You configure the channels and operating parameters of a radio using a manufacturer's programming software. Upload this file to the radio and save a copy on your computer as a backup. You can also download the code plug from a radio to modify it. Building a code plug can take many hours, especially if you want to program hundreds of channels. The code plug can also contain a contact list of Radio IDs, call signs, and names to be displayed. You can find copies of configured code plugs on the web for different radio models. [Search "DMR code plugs" in your browser. — *Ed.*]. Check out the different Yahoo! DMR groups.

Table 3

Recommended DMR simplex frequencies and radio settings:
(Use TG99 / CC1 / TS1 /Admit Criteria: Always / In Call Criteria: TX or Always]

Channel	Freq, MHz
VHF 1	145.790
VHF 2	145.510
UHF 1	441.000
UHF 2	446.500
UHF 3	446.075
UHF 4	433.450

All DMR radios with an alphanumeric display support a limited number of entries in the Contact List. Radios without an alphanumeric display do not support Contact Lists.

Talk-Around and Simplex

DMR Talk-Around refers to simplex operation on a repeater output channel. This allows direct communication while still being able to hear the repeater. Amateurs, however, typically use dedicated simplex channels (Table 3) so as not to interfere with repeaters. Do not use 146.520 or 446.000 MHz — they are the national *analog* simplex channels. Operating DMR on these commonly used analog frequencies will just cause disharmony within the amateur community. Also, avoid repeater inputs and outputs, locally used non-DMR simplex channels, satellite subbands, and any other frequencies that could disrupt other amateur communications.

Admit Criteria

The Admit Criteria determines when your radio is allowed to transmit. The recommended setting for repeater channels is *Color Code Free*; this configures your radio to be polite to your own digital system. You should configure your *In Call Criteria* to *Follow Admit Criteria*. Simplex channels should be configured as *Always* for both *Admit Criteria* and *Always* or *Follow TX* for *In Call Criteria*.

Accessing a DMR Repeater

You must have the frequency, CC, TS, and TG set correctly to access a DMR

repeater. Keying your transceiver sends a signal to the repeater, and the repeater responds to you with an acknowledgment that you can transmit your message. If you do not receive an acknowledgment from the repeater, your radio will stop transmitting and you will hear a negative confirmation tone. This is an advantage of TDMA — allowing bidirectional communications between user radio and the repeater when transmitting. The DMR repeater can signal your radio to stop transmitting if there is contention on the network because more than one station is transmitting at a time.

Not all DMR repeaters are interconnected on the Internet. Some repeater operators may just prefer to keep their repeater for local use, without connecting to the larger regional and worldwide networks.

IPSC and Bridges

IP Site Connect (IPSC) is a vendor-specific repeater feature offered by some manufacturers. MOTOTRBO repeaters (see Figure 3) will interconnect over the Internet only with other MOTOTRBO repeaters. Motorola Solutions MOTOTRBO IPSC implementation (not part of the ETSI Specification) allows up to 15 MOTOTRBO repeaters operating in DMR mode to be connected on a fully meshed IPv4 network, with one of the repeaters or a bridge serving as a Master and all of the others are Peers. Any traffic originating on one of the interconnected repeaters is relayed over the IP network to each of the other repeaters. The Peers will first establish a connection with the Master and obtain the database of the other Peers along with their IPv4 and port addresses.

The more repeaters in this fully meshed IPSC network, the more IP network bandwidth required for each repeater. To expand beyond the limits of basic IPSC network requires the utilization of a bridge to interconnect the different IPSC networks. Rayfield Communications (c-Bridge™) and BridgeCom Systems (TL-Net) are the current preference in North America. SmartPTT is common in Europe. These bridges require static IPv4 addresses and larger network bandwidths than individual repeaters.

The bridges support individual managers for each repeater (micro-segmentation), which is an improvement over having the bridge connected to a network of IPSC repeaters. This reduces bandwidth requirements and allows TG customization for individual repeaters. The bridge manager can serve as either a Master or Peer on an IPSC network.

Remember, someone is paying for all of the infrastructure and monthly operating costs. If a club is operating your local DMR repeater, join and support the operation. If an individual is operating the local repeater, donate to support their ongoing expenses. Repeater operators should also be supporting their bridge operators. Besides the cost of the infrastructure equipment, there are also recurring monthly expenses for rent, utilities (power and Internet), insurance, and maintenance.

Figure 3 — A pair of Motorola DMR repeaters. [Image courtesy of F1ZOI repeater]

User Radios

There are many sources for new and used DMR radios, but as of this date, you can't walk into an Amateur Radio store and buy a DMR radio. All current DMR radios are professional (commercial) radios marketed primarily to commercial radio users. You can easily find a dealer if you want to purchase a new DMR radio for ham use. Some dealers are "ham friendly" and will offer reasonable discounts to hams. Check with other DMR users or on DMR related websites for further information.

Search eBay, online flea markets, and hamfests for both new and used radios. Here are a few things to know before buying a DMR radio.

New or Used

Buyer beware of used DMR radios! Remember that you will not be able to repair a non-working DMR radio unless you have the technical skills and necessary test equipment. That test equipment can cost hundreds of times the cost of the radio. The street price for new DMR radios ranges from $165 – $200. Name-brand used radios, such as those from Motorola or Hytera, typically sell for more than brand-new radios cost from newer entrants into the DMR market. You typically get what you pay for. Higher-priced radios usually have more features, are better constructed, and can handle more abuse than less expensive radios. For the average amateur, one of the new lower-cost models makes a good initial radio.

VHF, UHF, or 900MHz

UHF is the most commonly used band in the US and worldwide for DMR, but because of military radar in some US areas VHF repeaters may be the local choice. There are few 902 – 928 MHz amateur DMR repeaters in the US. If you are purchasing UHF equipment, make sure it covers the amateur band (420 – 450 MHz) from the factory. No one currently sells a multi-band DMR radio in the US.

Programming Software

Some manufacturers supply programming software at no cost. Motorola Solutions

charges around $260 for a 3-year subscription (which covers all their models within a region) to their software and updates. DMR radios, because they are professional radios, typically do not allow keyboard programming. If a vendor charges for the programming software, do not ask another ham to bootleg a copy for you. If you have an authorized copy, you may program radios for others, but you cannot legally distribute the software. Software piracy is against the law.

Some radios use standard USB cables for programming, others use cables that can cost upward of $80.

Number of Channels

Radios can have from two channels to 1000 or more channels. You will need a channel for each frequency, CC, TS, and TG combination. You can easily use six or more memory channels for each DMR repeater you program into your radio.

Displays and Keypads

Some radios have just a channel selector knob, while others include monochrome (Figure 4) or color displays (Figure 1) to show TG and ID information. Some displays show only channel numbers. For visually impaired operators, consideration must be given to the channel selection knob on the radios. Most of the non-display models have channel selection knobs that have fixed stops rather than 360 degree continuous rotation to allow the operator to find channel one. Some LCD display models also have fixed stops on the channel selector knob, including some Hytera and CSI radios. Many models offer programmable voice announcements.

Some radios include a 12-button DTMF keypad. MOTOTRBO repeaters support an optional proprietary autopatch feature (Digital Telephone Interconnect) that works only with MOTOTRBO radios.

GPS

GPS is available on some models, but DMR does not support APRS (Amateur Packet Reporting System). On professional networks, one of the time slots is typically allocated for location reporting and is interconnected to server-based dispatch applications. If enabled, GPS will shorten battery life.

Bluetooth

Higher-end radios may have Bluetooth built in for wireless headsets. Some radios with Bluetooth support data and programming via Bluetooth. Some models have Bluetooth adapters optionally available. Bluetooth will shorten battery life if enabled.

Analog

Most radio models support analog FM. Current FCC rules require narrowband FM for most commercial/government services. For DMR radios from some manufacturers, this requires a programming entitlement key or a different version of the programming software if you require wider-band FM that is still used on many amateur analog repeaters.

Some manufacturers are discontinuing their analog non-DMR radios, while offering the DMR radios at a reduced price if the digital mode is not enabled. On these radios, the customer can later upgrade the radio to operate DMR if their needs change, for an additional fee.

Figure 4 — This Vertex Standard mobile DMR transceiver has a monochrome display. [Image courtesy of Vertex Standard]

External Antenna on Portable

Not all portable radios support connection to an external antenna, except for testing and alignment. Using an adapter to connect an external antenna can place undue stress on the portable antenna connector, which may result in premature equipment failure and expensive repair. If you intend to use an external antenna adapter, I recommend an adapter cable that uses RG-174 size coax cable to reduce stress on the radio connector. Some MOTOTRBO models, such as the XPR6000 series, support an external microphone with an antenna mounted on the top.

Portables, Mobiles, Amplifiers

Portables are available in the 2 to 5 W range, and mobiles are available with a maximum output of 10 to 45 W. I recommend a handheld transceiver for your first DMR radio unless you live beyond handheld coverage of your local DMR repeater. If you spend significant time in your vehicle commuting, you will find the mobile a good investment (Figure 4). You can also use a mobile transceiver as a base station with the addition of an external power supply. Many external amplifiers will not work with DMR radios unless they are specifically designed to meet the fast switching requirements of TDMA on DMR.

Batteries and Chargers

Most radios include a wall-type charger and offer a desk charger for optional purchase. You may want to consider a mobile charger or 12 V battery adapter. Some models can be charged using a USB cable, just like cell phones. You should rotate through at least one spare battery to be prepared for extended operation in emergencies. Follow manufacturer instructions for initial charging for maximum battery life.

Warranty and Service Contracts

If you buy an expensive new radio, you may want to consider the warranty and possibly purchase an extended service contract. Few amateurs have the technology or skills to repair these radios.

Programming Your Radio

Your new radio must be programmed before first use. Check the DMR-MARC website for basic parameters that need to be configured to get your radio working correctly on the amateur network.

First, you need a subscriber ID. The DMR-MARC website issues all subscriber

IDs for amateur users and repeaters. Click on CONTACT US in the top right corner of their page (**www.dmr-marc.net**) and then follow the instructions. IDs are assigned based on your geographic location (country/state). If you use an unauthorized subscriber ID, you may find that you can't access repeaters or the wide area network.

Your radio may stop transmitting while you are talking because of contention on the network or because you have travelled beyond the range of the repeater. Your radio is receiving control information from the repeater while you are talking. Network contention occurs when more than one station is transmitting at the same time on the same TS.

Operating on DMR

Announce what Talk Group you are on when you make an initial transmission, or when you place a call to another station, or make a general call, because some users may be scanning or may have radios without a display. Please avoid calling CQ. DMR is not like HF operation, and operating DMR over the network is not DXing.

Talking on one of the wide area TGs ties up hundreds of repeaters. If you are unable to move to a more localized TG, be considerate of the other users on the network. While one TG is active, other TGs on the same time slot will be blocked. Leave space between transmissions so others can break in. Remember that emergency traffic always has priority over all other traffic. See Table 2 for sources of more DMR information.

First licensed in 1970, John, W2XAB, has been involved with amateur repeaters since the early 1970s and currently teaches computer networking technology after having worked in the aerospace and telecommunications industry. You can reach John at 3110 Mount Zion Rd #1302, Stockbridge, GA 30281 and **w2xab@arrl.net**.

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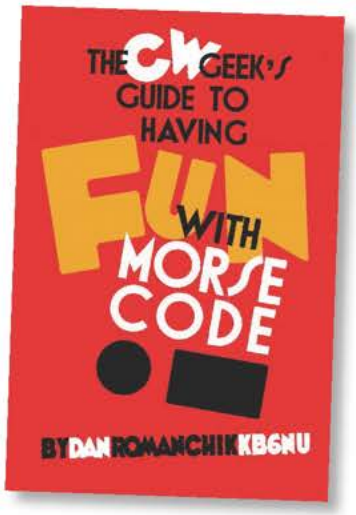
New Products

The CW Geek's Guide to Having Fun with Morse Code

The CW Geek's Guide to Having Fun with Morse Code, by Dan Romanchik, KB6NU, is intended to help amateurs learn Morse code, choose the right key, get on the air and make CW contacts, and use abbreviations, Q signals, and prosigns properly. The book is available in several different formats — PDF, Nook, or Kindle e-book — from **www.kb6nu.com**. It's also available as a paperback or Kindle e-book from **www.amazon.com**. Price: e-book, $2.99 or paperback, $9.99.



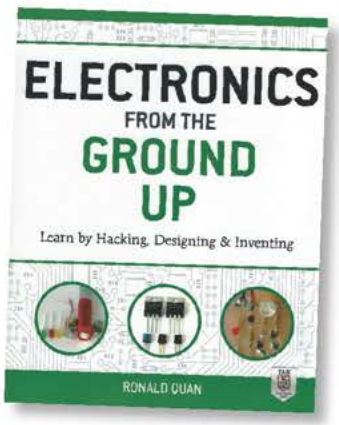
New Books

Electronics from the Ground Up — Learn by Hacking, Designing & Inventing

Ronald Quan, KI6AZB

Reviewed by Rick Lindquist, WW1ME

Electronics from the Ground Up is just what the title reflects. This is a terrific self-training/teaching manual, or perhaps even a textbook for a high school or early college electronics course. It's also a fun read for those times when you find yourself at loose ends on a contest-free weekend or feel the urge to tinker.



The reader can jump in at any point. Quan starts out at the component level and takes the reader through a journey that includes some rather simple laboratory-style experiments, the use of various pieces of test gear, half- and full-wave power supplies and progressing through amplifiers and oscillators, AM and FM detectors, the principles of negative feedback, the application of filters, circuit analysis, and some of the mathematics that tie all of these things together.

One experiment I found interesting was one that lets you "hear" the signals from a remote control unit — the kind that sends a series of light pulses with frequencies in the audio range. Older radio amateurs may well recall having to learn the schematic for a vacuum-tube Colpitts oscillator. The Colpitts lives on in Quan's book, but in solid-state form. By the way, Quan does not altogether ignore vacuum tube technology.

A chapter you might not expect to find, "Video Basics, Including Video Signals," discusses both standard-definition (480 lines) and high-definition (1080 lines) television signals and what the "i" as in 480i, and the "p" as in 720p mean (i = interlaced; p = progressive scan). The following chapter covers "Video Circuits and Systems."

While *Electronics from the Ground Up* may not stress RF circuits sufficiently to suit some radio amateurs, the principles are the same. This book offers a practical, hands-on approach to learning or reviewing electronics basics and some advanced aspects, with a little bit of the math thrown in along the way. A handy reference appendix tells where to obtain electronic components.

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