

Digital Two-Way Radio Technology Reaches Consumer Market

Frequency-Hopping Spread-Spectrum Trickles Down To The Mainstream

by **Bernard Bates**

For over a quarter century, *Popular Communications* has progressively covered developments in CB, GMRS, FRS, and MURS because they've been the most popular forms of personal two-way radio communications. Now a paradigm shift is about to dramatically change how we communicate via two-way radio, thanks to developments in digital frequency-hopping spread-spectrum (FHSS). This represents a logical progression in the trend from analog to digital radio that has so changed the cellular radiotelephone industry and numerous local, state, and federal two-way radio systems.

To see where we're headed with personal two-way radio communications it's helpful to look back at its history, so we'll briefly cover its evolution. We'll also explain some of the reasons behind the emerging trend from analog to digital personal two-way radio communications, while examining the greater capabilities and advantages digital radio offers (as well as its potential downsides).

Personal Two-Way Radio History

Analog two-way radio has been around for over a century, first using Morse code (CW) and later voice communications using amplitude modulation (AM) technology. But the average consumer had no readily accessible form of personal two-way radio communications until over half a century later, when CB radio entered the scene. What followed was a series of evolving popular communications explosions, demonstrating that the American public has an insatiable appetite for low-cost, portable, two-way radio communications options. The evolution of these communications options is accelerating and is poised to enter a new era.

Citizens Band (CB)

The first popular two-way radio service used by the general public (without any required technical exams, such as Amateur Radio requires) was the Citizens Band Radio Service,

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Actress Hedy Lamarr is the mother of FHSS (Frequency-Hopping Spread-Spectrum) communications. Her secret pioneering work during WWII laid the foundation for a communications revolution that touches most of us every day, but she never received any compensation for its commercialization.

which was originally created by the FCC in 1958 by reallocating much of the 11-meter amateur radio band's 27-MHz frequencies. CB became a staple of personal communications for millions of Americans, and it skyrocketed in popularity during the 1970's CB culture craze. But its relatively long 11-meter wavelength made handheld CB radios unwieldy with their long antennas, so CB was relegated primarily to vehicular use.

CB's amplitude modulation makes it vulnerable to noise problems from electrical devices like vehicle ignition systems, electric motors, light dimmers, computers, etc.—much like regular AM broadcast receivers are. And an annoying AM heterodyne whine is heard when receiving simultaneous CB transmissions. Other issues that have plagued CB include an 11-year sunspot cycle, which at times propagates so many distant 27-

MHz skywave signals (or “skip”) that the background noise level can greatly reduce CB radio’s usable range to a fraction of the service’s intended five miles.

Channel overcrowding was addressed in 1977 when the FCC increased the number of channels from 23 to 40, but that didn’t help much as the number of CB users increased. To be heard over the crowd, some CB users resorted to violating the FCC’s 4-watt RF power limit with illegal “linear” RF power amplifiers. This created more interference that also affected users of other radio services, including TV viewers. The problem became so bad that Congress enacted a law permitting local police jurisdictions nationwide to investigate and stop these CB-related RFI/TVI problems. Predictably, lack of police expertise and training exacerbated what was an ineffective approach to begin with.

Originally the FCC required CB operators to be licensed, but eventually gave up on that, along with the enforcement of other CB regulations, due to a lack of resources. Privacy is nonexistent with CB radio; the NSA even squelched a 1977 patent application for a scrambling device that would prevent casual eavesdropping on CB conversations.

General Mobile Radio Service (GMRS)

GMRS appeared to be an answer to the seemingly insurmountable problems with CB. Although GMRS had also been around for decades, its use of 23 UHF frequencies in the 462- and 467-MHz bands and its frequency modulation (FM) once made the cost of entry rather expensive. A personal GMRS license cost \$75 and GMRS radios once cost hundreds more. GMRS shared many characteristics of most commercial and government two-way radio systems of the latter part of the 20th Century: FM provided clean-sounding audio with relatively little interference, and its capture effect let users hear only the strongest signal without those annoying AM heterodynes.

Higher power limits and the authorization of repeaters allowed even low-power GMRS radio users to communicate with others across dozens of miles. GMRS’s shorter 65-centimeter UHF wavelength made compact antennas on handheld transceivers possible. Privacy is nonexistent with GMRS, but unlike CB, users of GMRS can choose to hear only desired transmissions by setting all radios in their group to an identical CTCSS tone encoding/squelch setting. The FCC requires GMRS users to be licensed, but a later development in personal two-way radio communications would cause mass violations of this regulation.

Family Radio Service (FRS)

In 1994 RadioShack saw a burgeoning market opportunity for low-cost, low-power, license-free UHF handheld radio transceivers for families, outdoor enthusiasts, and small businesses needing to communicate up to a mile or two away. In 1996 the FCC largely embraced and granted RadioShack’s request and established the Family Radio Service (FRS). Fourteen FRS frequencies were allocated; seven channels in the 467-MHz band, plus seven more in the 462-MHz band were to be shared with incumbent GMRS users.

RF power output is limited to 500 mW (one-half watt) into a permanently attached low-gain antenna. This effectively limits FRS radio configurations to portable handheld units for communicating over relatively short distances, despite FRS radio marketers’ exaggerated claims about many miles of usable range with their products. FRS repeaters are disallowed.



TriSquare’s TSX-300 and Motorola’s DTR-410 FHSS radios—the dynamic duo of the digital domain! Now the general public can get in on the FHSS radio action.

Like CB and GMRS, FRS offers no privacy (don’t be fooled by the description of the standard CTCSS tone encoding/squelch feature as “38 Privacy Codes”).

Industry analysts have estimated that 50 to 80 million FRS/GMRS radios have been sold in the United States. (The author purchased one for a mere \$5 at a national drugstore chain.) Not surprisingly, in urban areas and at crowded events, the FRS/GMRS channels are often in a state of congested anarchy. Meanwhile, many of the approximately 80,000 licensed GMRS users lament that their once well-managed radio service has been “trashed.”

Multi-Use Radio Service (MURS)

MURS is the most recent personal two-way radio service, established by the FCC in late 2000 as “a private, two-way, short-distance voice or data communications service for personal or business activities of the general public.” MURS provides license-free use of three VHF frequencies in the 151-MHz band, plus two frequencies in the 154-MHz band. RF power output is limited to 2 watts, but external gain antennas are permitted.

While MURS repeaters are disallowed, the higher power level and the ability to use gain antennas—including fixed and vehicle-mount antennas—can give MURS users several miles’ farther range than FRS. Therefore MURS has found a niche market for certain users, even though personal two-way radio industry sales figures indicate the popularity of MURS is much lower than that of CB, GMRS, and FRS. As with those services, there is no privacy with MURS communications.

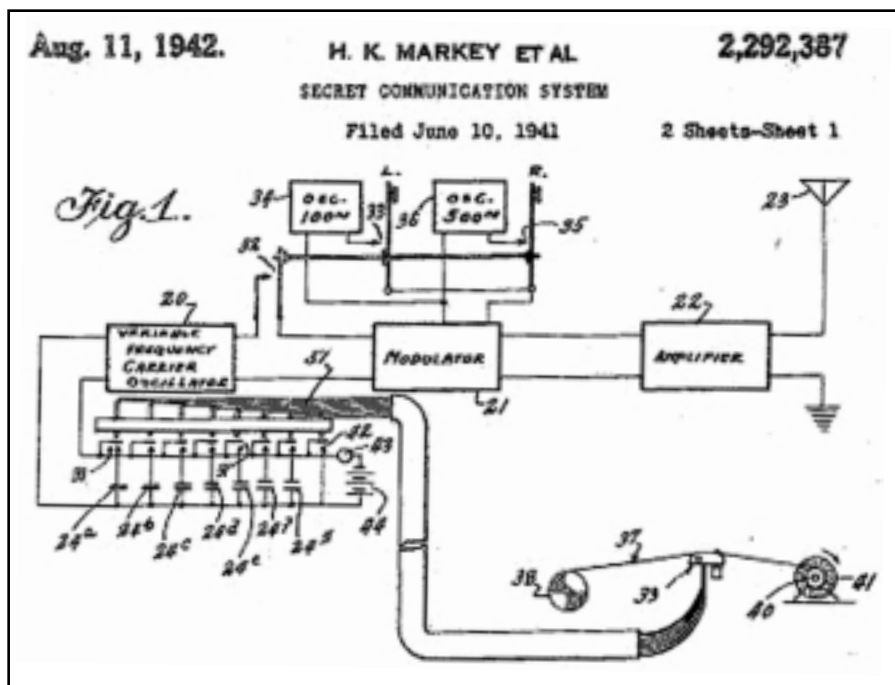


Figure 1. Hedy Lamarr used her married name, H. K. Markey, on her 1941 U.S. Patent application for a "Secret Communications System." Her brilliant concept wasn't formally acknowledged in public until the Electronic Frontier Foundation presented her with a special EFF Pioneer Award in 1997.

Analog Aggravation?

So far, every form of personal two-way radio communications mentioned here shares the following problems:

- Electrical interference
- Propagation interference (skip)
- AM/FM mode interference (heterodynes; multipath fading)
- Insufficient channels; overcrowding
- License cost & usage restrictions
- No privacy of communications

While not all users are bothered by the above, for those who are, digital radios—or more specifically FHSS radios—offer potential solutions.

FHSS To The Rescue

FHSS is nothing new. Surprisingly, actress Hedy Lamarr and composer George Antheil co-patented the concept in 1942 (see **Figure 1**). Their intended application used something like a player-piano roll to rapidly switch frequencies and make radio-guided torpedoes difficult for enemies to detect and jam. But FHSS probably wasn't used tactically until 1962, when the U.S. Navy used it to coordinate its blockade during the Cuban missile crisis.

The COMSEC (Communications Security) and interference-rejection potential of FHSS worked well then, and has been refined ever since for both military and civilian applications. TDMA (time division multiple access) and CDMA (code division multiple access), both used in many cellular/PCS and digital cordless phones, as well as the ubiq-

uitous 802.11 wireless networking, are all forms of FHSS—but faster microprocessors have replaced the piano rolls.

Until recently, handheld FHSS transceivers cost well over \$1,000 and were primarily purchased by big-budget users like government agencies where cost isn't a primary concern. But now they're available in a relatively inexpensive, license-free package.

Again, for personal and business radio applications this is merely a logical extension in the trend from analog to digital radios, which has already occurred with cellular/PCS and many government two-way radio systems. Spectrum efficiency, interference rejection, and communications security are some of the benefits. There are downsides, too, however: Digital voice communications have noticeable audio latency due to digital signal processing (DSP), low fidelity, and audio artifacts (robotic-sounding audio) that users of Nextel and digital cellphones are all too familiar with.

The Theory Behind Frequency Hopping

Frequency-hopping radios transmit briefly on one frequency, and then hop rapidly through numerous other frequencies in a pseudorandom pattern. Each pattern represents a virtual "channel," and a radio can have a very large number of patterns or channels programmed into it. Frequency hopping allows large numbers

A Word On Unlicensed Spectrum

The new personal digital two-way radios hitting the consumer market are *not* the result of a new radio service offered by the FCC, but they do take advantage of a long-existing chunk of unlicensed UHF spectrum called the 900-MHz ISM (Industrial, Scientific, and Medical) band. These frequencies between 902 and 928 MHz were allocated by the FCC in 1985 for unlicensed consumer radio applications, such as cordless telephones, baby monitors, wireless video cameras, etc., and for various industrial and medical applications. It is also shared by the Amateur Radio Service as the 33-centimeter band.

Since late 2000, FCC Part 15.247 regulations have permitted 1-watt FHSS voice communications in the 902- to 928-MHz ISM band if certain technical conditions are met, like using at least 50 hopping frequencies with the average time on any one frequency less than 400 ms during any 20-sec period. But until fairly recently it wasn't cost-effective to build personal digital two-way radios using sophisticated FHSS technology. Recent developments in DSP and software-defined radio technology now make it feasible to design and build personal FHSS two-way radios for a tiny fraction of what it would have cost back when this FCC regulation took effect.

Unlike CB, GMRS, FRS, and MURS handheld transceivers, these new personal FHSS two-way radios look more like a Nextel iDEN (for integrated digital enhanced network) phone or a cellphone, and have more digital electronics than radio inside them.

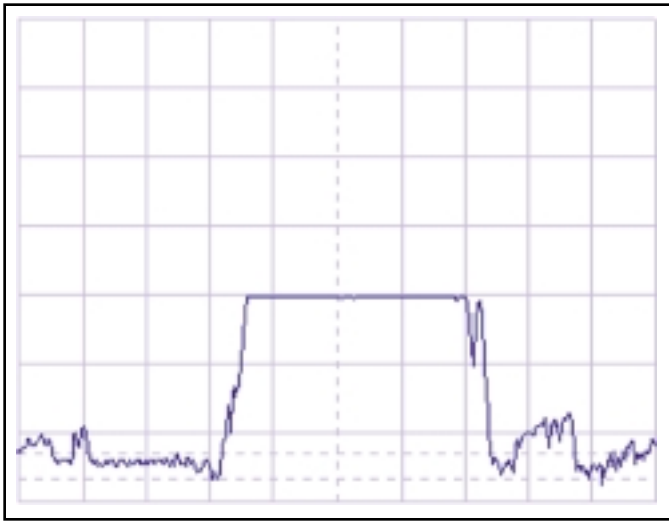


Figure 2. The TriSquare TSX-300 FHSS signal (30-sec cumulative sample). Rapid pseudorandom frequency hopping across the 902- to 928-MHz band can't be heard on scanners. A synchronization signal can be seen near the band edge.

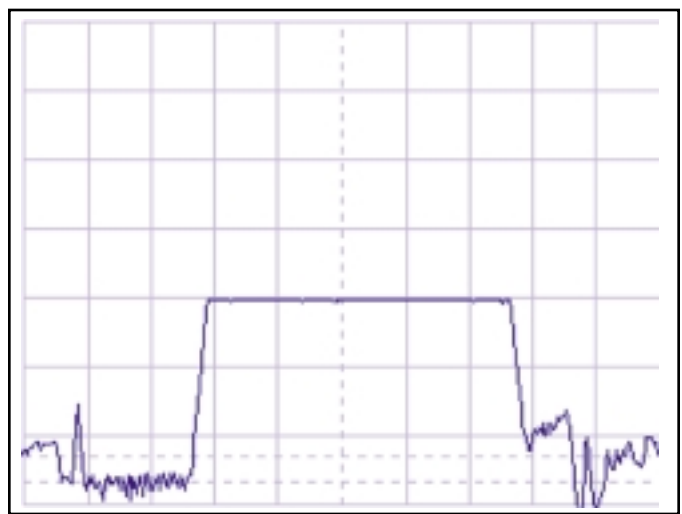


Figure 3. The Motorola DTR-410 FHSS signal (30-sec cumulative sample). Rapid pseudorandom frequency hopping across the 902- to 928-MHz band is nearly too fast to see on a spectrum analyzer—or be heard on a scanner.

of transceiver pairs or groups to simultaneously communicate in a given area, because of the large number of frequency patterns or channels to choose from. The pseudo-random selection of hopping frequencies flattens out the total signal energy across the entire band, minimizing interference between large numbers of concurrent users (see **Figures 2 and 3**).

This can be a huge advantage over traditional fixed-frequency narrowband AM and FM radios (see **Figure 4**) which have a relatively small number of channels from which to choose. Frequency hopping also provides much better interference rejection than traditional fixed-frequency narrowband AM and FM radios; the rapid hopping over a wide range of frequencies means no interfering signal can substantially affect the communications. (It's kind of like diversifying your investment portfolio: if a small number of your many diverse investments do poorly, the others will keep you from losing the farm.)

A common problem with traditional fixed-frequency narrowband FM radios is multipath fading (commonly known as picket-fencing), but it, too, can be largely eliminated by rapidly hopping across different frequencies. Because each frequency has a different multipath effect, multipath fading on one frequency will not affect the other frequencies.

Each time a FHSS radio transmits, and depending on the "channel" it is set to, the radio begins transmitting a signal that other radios listen for to determine if the transmission is for them (based on the transmitted ID code). If it is, the receiving radio acknowledges itself to the transmitting radio, and the radios negotiate and synchronize a shared frequency-hopping sequence.

Digital IDs And TalkGroups

The new personal digital two-way radio models hitting the market are manufactured with a unique 10- or 11-digit ID code, or require the user to program one in. This ID code identifies that radio to the other radios on a network. This ability of these radios to uniquely identify themselves allows users of some FHSS radio models to set up private talkgroups. You can set up private communications between specific groups of radios, or just between two radios ("fleet management" is a buzzword for

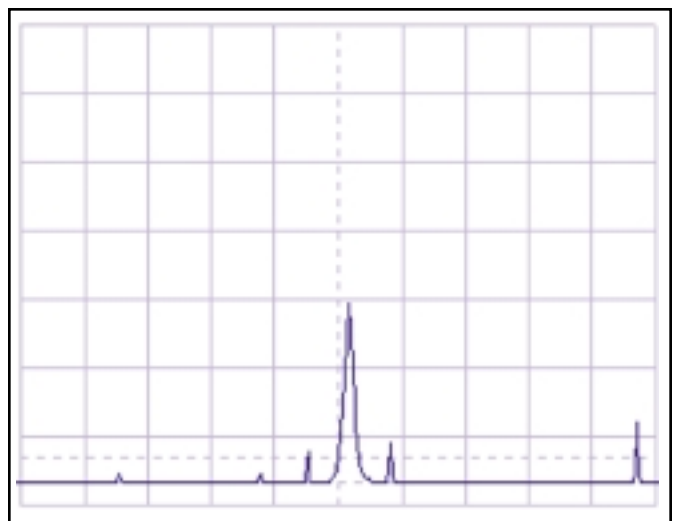


Figure 4. Typical low-end FRS/GMRS narrowband FM signal (real-time sample). Has this popular consumer analog two-way radio service become a victim of its own success?

this). If you're managing separate teams of people who don't all need to hear each other on a big party line, this can be very useful. Of course, you can also establish public talkgroups in which everyone hears everyone else.

An alphanumeric name like Frank or Warehouse can be associated with each ID code to allow that radio (or group) to be easily selected from a calling radio's navigable menu, similar to looking up a contact on a cellphone. When receiving a transmission, the name or ID code for each calling radio shows up like caller ID. Some radio models even let you associate unique "ring tones" for audibly identifying specific radio callers.

Affordable FHSS Radios

One such radio comes from a familiar source: Motorola (www.motorola.com). The company's DTR-410 uses FHSS with the VSELP (Vector Sum Excited Linear Predictive)

vocoder, the same vocoder used in Nextel's iDEN phones. A vocoder converts voice to data and vice versa, similar to a computer modem, but it also reduces the resulting bit stream by approximating the human voice with a computer algorithm. The result is that your communications will be more reliable but have less voice fidelity.

The DTR-410 has an 11-digit ID code and is limited to six virtual channels and public talkgroups. It can be cloned with a cloning cable. Motorola claims a two-mile range and penetration ability through 25 building floors. It's intended for the business market, but anyone can purchase it from resellers for a street price of under \$240 per radio. Higher-end DTR models are available with more features at a higher cost.

Another offering comes from TriSquare (www.trisquare.us), which has been designing and manufacturing two-way radios since 1999. Its TSX-300 uses FHSS, but rather than a vocoder, employs a proprietary narrowband FM modulation technique. The radio uses a 10-digit ID code, can reportedly emulate *10 billion* virtual radio channels, and can be used in both public and private talkgroups. This radio can be cloned over the air at short range. It also supports text messaging to individuals and groups of TSX-300 users and has a NOAA weather receiver (without SAME).

TriSquare refuses to make specific operational distance claims, and instead claims the usable talk range of its radios will equal or exceed *any* other portable UHF two-way radios in most cases—even 5-watt models. TriSquare has very ambitious plans to overtake the FRS/GMRS market with its eXRS radios over the next two to three years, which would be quite a feat. The TSX-300 is intended for the consumer market and can be purchased from retailers for under \$140 per pair. A lower-end model is available at a lower cost.

Interoperability And Communications Security

Motorola's and TriSquare's radios are not interoperable with each other and use proprietary modulation schemes. This is one downside of personal digital two-way radios. Conversely, analog narrowband FM radio is by its nature an open standard that any manufacturer can build and sell for interoperation with their competitors' radios. Not so with digital radios.

At the same time, proprietary modulation schemes provide a form of communications security-through-obscurity. Patent and licensing issues will likely prevent scanner manufacturers from ever releasing models that will demodulate these radios' communications.

Personal Digital Two-Way Radio And The Future

One could argue that the FCC's various attempts over the years to establish personal two-way radio communications services were largely failures of their own success. Eventual channel overcrowding and mass unlicensed use of licensed services has turned many users away from various personal two-way radio communications services, but digital radio technology could change that.

According to TriSquare, and the Kansas State University engineering study it commissioned, more than *100,000* eXRS users within talk range can enjoy uninterrupted communications. Several

dozen FRS/GMRS users in the same physical space could render that band unusable. Channel overcrowding, as we know it, may become a thing of the past.

Spectrum overcrowding elsewhere may eventually spur the FCC to permit FHSS operation in other parts of the two-way radio spectrum available to consumers, just as it did with the cellular radiotelephone and 902- to 928-MHz ISM bands. Time will tell.

But what is known right now is that both Motorola's DTR and TriSquare's eXRS radio technologies use different and interesting approaches to some inherent problems with analog two-way radio. This represents the beginning of a dramatic development in the evolution of personal two-way radio communications.

Editor's Note—Look for reviews of Motorola's DTR-410 and TriSquare's TSX-300 radios in an upcoming issue of Pop'Comm.