Spread Spectrum in the Amateur Radio Service: Current Status and Historical Notes

Barry McLarnon, VE3JF
Dewayne Hendricks, WA8DZP

Amateur SS in the USA

The beginnings of amateur SS experimentation date back to late 1980, when Paul Rinaldo and a few others in AMRAD formed an SS Special Interest Group. The group decided to seek an STA from the FCC which would allow SS experiments to take place in some of the amateur bands, and they found a receptive audience at the Commission. Thanks in large part to the urging of Mike Marcus of their Office of Science and Technology, the FCC was interested in initiatives that would help SS technology make the move from its military roots into commercial applications. The STA was granted in March 1981, permitting FH experiments in the 80, 40, 20 and 10m HF bands, DS in the 420-450 MHz band, and SS EME experiments. About 30 amateurs were named in the initial STA. An amendment permitting FH experiments in the 144 MHz band was added later in the year. The group initially focused on the HF bands, and then on the 144 MHz tests. The emphasis on FH is not surprising, given its roots in narrowband technology. Much of the work involved experimentation with various synthesized amateur rigs to see which could be effectively frequency-hopped, and construction of controllers to perform the hopping and synchronization. These were early days as far as amateur digital communications were concerned, so these initial efforts concentrated on application of SS to analog voice transmission.

Again showing its interest in fostering non-military SS development, in late 1981 the FCC proposed to change the rules of the amateur service to permit SS operation (for Advanced and Extra class licensees only) in the VHF (50, 144 and 220 MHz) bands. The proposal was not met with great enthusiasm in certain quarters, however, and it slipped onto the back burner. This was the beginning of a fairly lengthy hiatus on the regulatory front, but some experimentation continued. Things began to heat up again in 1984, when the FCC granted a second STA to AMRAD, and also let it be known that it was again considering rule changes to open SS experimentation to all US amateurs, in the VHF bands only. In May 1985, the new rules were unveiled, and, lo and behold, an about-face had taken place: SS was to be permitted, but only above 420 MHz! Much of the opposition to the initial idea of permitting SS in the VHF bands no doubt came from within the amateur community (especially where the 144 MHz band is concerned!). In addition, there was concern expressed in some quarters (such as the National Association of Broadcasters) about the potential for interference to TV receivers. As far as 220 was concerned, there were already rumblings that commercial interests had designs on the band, so it's not surprising that it was dropped from further consideration for amateur SS work. Actual implementation of the rule changes was delayed for one year; in the meantime, the ARRL formed an ad hoc committee to consider standards for amateur SS. Later in 1985, the FCC reinforced its new-found commitment to not allow amateur SS operation at HF and VHF by abruptly canceling AMRAD's STA.

The new FCC rules went into effect on June 1, 1986, beginning a new era of access to SS experimentation for all US amateurs (albeit one with a number of restrictions). The highlights:

- both DS and FH permitted, but only three different spreading codes authorized
- above 420 MHz only
- 100W PEP maximum transmitter power
- all transmissions must be logged
- domestic communications only
- transmissions to be ID'ed by means decodable with narrowband receivers

Unfortunately, this noteworthy event went by virtually unnoticed by amateurs. A small core group in AMRAD, led by N4ICK and N4EZV, continued SS experiments, but were not joined by a host of new recruits. Although details about much of their SS hardware were published, duplicating the designs presented a daunting task for most amateurs.

Although the new rules were a major step forward for SS in amateur radio, some of the restrictions presented obstacles to serious experimentation, particularly the lack of access to the VHF bands and the choice of only three spreading codes. The latter restriction eliminates the possibility of experimenting with CDMA techniques. It also means that most of the chipsets and other commercial spread spectrum hardware developed in recent years could not be used for amateur applications. This led Bob Buaas, K6KGS, who had participated in the previous AMRAD STA, to request a new STA. The new STA, granted in 1992, removed the spreading code limitations, permitted experiments in the VHF bands, and also allowed use of hybrid DS/FH modulation techniques. The requirements for logging and ID'ing of transmissions remained. The STA was renewed the following year, and in 1994, it was renewed for an indefinite period.

Now, let's fast-forward to the end of 1995. Nearly ten years after the rules were changed to permit amateur SS experiments above 420 MHz, and fifteen years after the first SS STA was issued, there were still only a small handful of amateur experimenters working with SS. In an effort to change this, the ARRL petitioned the FCC for some additional rule changes, the purpose of which were to "facilitate, to a greater extent than is done by the present rules, the contributions of the Amateur Service to the development of spread-spectrum communications". The major changes requested were to:

- drop the restrictions on spreading codes and permit hybrid DS/FH emissions
- permit SS communications with amateurs in other countries where SS emissions are permitted
- add a requirement for automatic power control when transmitter powers of more than one watt are used

Notably absent from the petition are any requests to relax the logging and ID requirements, or to extend SS experimentation to the HF and VHF bands. The petition also stipulates that SS transmissions be "brief".

In its comments on the ARRL petition, TAPR was generally supportive, but urged the Commission to go further in relaxing the SS rules. TAPR proposed that the ID requirements be dropped completely, that SS tests not be restricted to "brief" transmissions, and that SS be permitted in the VHF bands covered by the Buaas STA (plus the new 219-220 MHz allocation). TAPR also commented that the automatic power control provisions should be phased in over a period of time rather than taking effect immediately. Other commenters also took up the theme that the the Buaas STA become the basis for the rule changes. Some felt that if power control is to be mandated, it should apply to all services and not just SS. And, not surprisingly, there were a number of negative comments filed by the weak signal and repeater community. The full text of most of the comments and reply comments can be found on TAPR's web site.

Given the controversial nature of the ARRL petition, it appeared that a resulting NPRM from the Commission might be some time in coming. Consequently, TAPR filed a petition in April 1996 to have the Buaas STA extended to its membership. The ARRL, steadfast in its opposition to SS in the VHF bands (with the exception of 219-220 MHz), filed comments objecting to that aspect of the STA request, despite the fact that those bands are already accessible to any US amateur SS experimenters who join the Buaas STA. After a series of discussions took place between TAPR and the ARRL, the League removed their objections to the TAPR petition and the FCC granted TAPR an STA on November 6, 1996. Information on the TAPR STA and how to join it can be found at http://www.tapr.org/ss/.

On March 3, 1997 the FCC issued WT Docket 97-12 which basically incorporated all of the ARRL's proposal. Comments, which were due sixty days later were filed by several amateur radio organizations, a few individual hams, and some non-amateur radio groups. Most of the comments and reply comments filed in this proceeding are available on the TAPR website at the URL cited earlier. Basically, the comments fall into three general categories: 1) Those who approve of the proposed rules as is or who wants the rules loosened up even more, 2) Those who approve in concept, but who want to see the rules reflect more protections for other modes, and 3) Commercial interests who don't want interference from hams using SS who are sharing spectrum, even though we're a licensed service and they are not, The comment/reply comment period for the NPRM closed on June 5, 1997. As of the writing of this article, the FCC has yet to issue a Report and Order stating just what the new SS rules are be. In the meantime, TAPR continues conduct SS experiments under its STA and submits reports to the FCC every six months documenting its results. Last year, TAPR embarked on a major effort to develop a 900 MHz SS radio that could be made available to its members. Details on the project can be found at http://www.tapr.org/tapr/html/taprfhss.html. As of the writing of this article, the project is still on-going.

Amateur SS in Other Countries

Thanks to rule changes which took place a few years ago, Canada's amateur radio service is largely deregulated. Detailed regulations defining subbands and permitted types of emissions have been replaced simply by bandwidth limits. On the downside, these limits are too low in the bands below 430 MHz to permit effective SS transmissions, except at very low data rates. The maximum bandwidths are 6 KHz in the HF bands below 28 MHz (except the 10.100-10.150 MHz band, where it is 1 KHz), 20 KHz at 28-29.7 MHz, 30 KHz at 50-54 and 144-148 MHz, 100 KHz at 220-225 MHz, 12 MHz at 430-450 and 902-928 MHz, and no limit other than the band edges in the higher bands (1240-1300 MHz, 2300-2450 MHz, etc.). The ID requirements simply state that callsigns be transmitted at the beginning and end of each "period of exchange of communication", and at intervals of not more than thirty minutes during these periods. Maximum transmitter carrier power is 750 W for holders of Advanced Class certificates, and 190 W for Basic Class. So, at UHF and above at least, Canadian amateurs have considerable latitude for SS experimentation. The regulatory agency (Industry Canada) has no mechanism comparable to the

STA in the US for granting waivers to the existing rules, so it may be difficult for Canadians to participate in SS experimentation in the lower bands.

We haven't heard much about amateur SS experiments taking in place in other parts of the world. It is probably safe to say that the regulatory atmosphere in most countries regarding the amateur service is less permissive than in the US and Canada. One exception is Israel, where experimentation is strongly encouraged, and there are few restrictions on emission modes and data communication protocols. Some experimental work with FH equipment is currently taking place. A similar attitude towards experimentation prevails in the UK, although the amateur regulations do not yet permit SS transmissions. The main sticking point has been in determining a method by which the spreading sequence being used can be made known to stations monitoring the SS signals. Discussions are continuing, and it seems likely that amateur SS in some form will be legal in the UK before too long.

What We've Learned So Far

Like most programmers, who love to write code but hate to document it, SS experimenters have not done a great job of publishing the results of their work. What follows is therefore not a comprehensive summary of the results to date, but simply some comments based on a few publications, STA reports and private communications.

Much of the early amateur SS work has focused on the adaptation of conventional narrowband amateur gear to SS. What this boils down to is controlling the synthesizer of an analog FM or SSB voice radio to cause it to frequency-hop, plus providing a means of synchronization. This has been accomplished with some degree of success, but the synthesizer implementations in these radios are clearly sub-optimal when it comes to frequency hopping. This leads to relatively slow FH systems, which in turn increases both susceptibility to interference of the FH system and the severity of interference to other services. In particular, the channel dwell times were long enough to key up repeaters in some tests. This problem was dealt with simply by reprogramming the synthesizer controller to avoid hopping onto repeater input frequencies.

These early SS implementations were fairly rudimentary, and it is unlikely that slow FH analog voice transmissions have a great future in amateur radio. Nevertheless, they provided a good demonstration that a working form of SS could be accomplished with simple equipment, coupled with some amateur ingenuity. This work helped to demystify SS; more importantly, it showed that even a low-end SS system could be operated with minimal interference to existing services.

In more recent work, attention has shifted to SS data communications. Under the Buaas STA, experimental equipment for DS, FH and hybrid DS/FH transmission and reception was constructed and tested in several VHF and UHF bands. Data rates ranged from 12 Kbps to 0.5 Mbps, over ranges of up to 50 miles. These tests again demonstrated that SS could coexist with narrowband emissions in the amateur bands without causing significant interference to those activities. On the other hand, the performance of the SS systems was considerably hampered by the high-power narrowband transmitters. One conclusion that can be drawn from this is that in order to take full advantage of SS, particularly in the bands below 450 MHz, the SS systems will need to be quite sophisticated (compared to, for example, the current crop of Part 15 devices). Techniques such as the use of very high processing gain, adaptive frequency hopping, forward error correction (FEC), notch filtering, automatic power control and new philosophies for determining subband allocations will become important keystones in making SS work. Another conclusion is that power control (using no more power than is necessary to maintain communications) should be practiced by ALL users of the amateur bands.

In addition to the work mentioned above, there are a number of people in the amateur community who have extensive practical experience with ISM band SS devices and other commercial SS hardware. They have shown that excellent performance can be obtained over considerable distances with properly-engineered RF links. Their experience and expertise will be invaluable in helping SS to take its rightful place in amateur radio communications.

The Way Ahead

More than 15 years have passed since the beginning of amateur SS work, and yet it has attracted only a small handful of intrepid experimenters. This is indicative of the changes which have taken place in the amateur radio hobby over the past few decades: few hams build their own radio hardware anymore. Even for those inclined towards hardware construction, building a working SS system from scratch is a daunting task. SS will clearly not become a significant activity in amateur radio until kits or ready-to-run RF modem hardware becomes available. Like the TNC before it, this is a breakthrough which TAPR would like to facilitate. RF projects are always difficult to complete successfully, but the enormous commercial interest which has developed in PCS and wireless LAN systems lately will be a great help. Many components, modules and chipsets developed for commercial applications can be applied to amateur SS development. Moreover, the numerous ISM band SS modems now available in the marketplace provide an easy means of getting one's feet wet in SS. Although a few amateurs have been using these devices for some time, many others have been unaware of their existence. The cost has also been an impediment; until recently, nothing was available for under $500, which might be considered the "pain threshold" for radio purchases. Now, however, it is possible to get some of the devices for well under this figure, and some of the more mature products are occasionally becoming available at deep discounts. For example, a batch of 900 MHz WaveLAN cards recently came on the market for only $200 each. Think of it - this is a device that does 2 Mbps, CSMA/CA media access, and includes the antenna (dual-diversity, short range), radio, modem and ISA bus computer interface. There are packet, NDIS, ODI and Linux drivers available for the card. Now consider what most hams using 9600 bps packet (less than 1/200 the raw data rate of WaveLAN) have invested in their equipment - the mind fairly boggles at the comparison!

Up until now, the amateurs using these ISM band devices have simply operated them as unlicensed devices under Part 15 (or the equivalent outside the US). However, if the regulations permitted operating them in the amateur service, then we could overcome the ERP limits imposed on unlicensed operation and use high-gain antennas to increase their range. Since modifying the frequency of operation of most of these devices is probably quite difficult, it is fortunate that there is considerable overlap between the UHF ISM bands and the amateur bands. In North America, the 902-928 MHz ISM band coincides exactly with the 33 cm amateur band, so operation of ISM SS devices in the amateur service is straightforward, provided that ID and other regulatory requirements can be met. The 2.4 GHz ISM band, on the other hand, runs from 2400 to 2483.5 MHz (in North America - the band for unlicensed operation varies in other parts of the world), whereas the amateur segment stops at 2450 MHz. For some devices, this presents no problem; for example, 2.4 GHz WaveLANs are DS units with about 22 MHz bandwidth and several choices of center frequency which can be programmed with a software utility supplied by the manufacturer. There are several choices of center frequency which confines the emission to the 2400-2450 MHz portion of the ISM band, making it a candidate for amateur experimentation. FH units operating at 2.4 GHz present more of a problem, since they generally use nearly the full ISM band. They are required to use at least 75 non-overlapping channels, so for the higher bitrate units at least, they must use most of the band. However, the hopping sequences and center frequencies are usually programmable, so it is generally possible to create an amateur band version of the FH units without any hardware modifications. This must be done by the manufacturer, however; they are understandably reluctant to release the reprogramming software to users. One of the authors (McLarnon) has experimented with RangeLAN2 hardware which has been programmed by Proxim to hop within the 2400-2450 MHz amateur allocation. The other author (Hendricks) has also experimented with a wide range of Part 15 devices. The details of that work can be found at http://wireless.oldcolo.com.

Make no mistake, the ISM band units are not the ultimate in SS technology. Most of them have quite low processing gain (especially the higher-speed systems), and none of them have automatic power control. They are not designed for building CDMA networks, and their tolerance for narrowband interference tends to be quite limited (especially in the DS systems). You probably won't find exotic features such as RAKE receivers and adaptive hopping patterns. Nonetheless, these are very useful devices which could play a very significant role in amateur packet networking.

The times are a-changing in amateur packet radio. Once upon a time, there was a dream of nation-wide and even worldwide networks, all connected by radio links. This didn't seem like too farfetched a dream when the major packet application was the BBS and store-and-forward movement of mail and bulletins. The amazing rise in popularity of the Internet has changed all that. Instead of the stodgy old BBS interface, Internet users have fallen for the seductive charms of multimedia web browsing, real-time conferencing, digital audio and video, Usenet news, mailing lists, etc. Traditional packet radio pales by comparison (especially at the "standard" bit rate of 1200 bps!). Although some still pursue the idea of wide area low-speed BBS-based radio networks, most of the "best and the brightest" have drifted away to more rewarding pursuits. The truth is, building a wide area packet radio network with enough bandwidth to support the applications that most people now want to use is simply unrealizable - radio amateurs do not have the resources nor the collective will and coordination to pull it off. Does this mean amateur packet radio is doomed to wither and die? Not necessarily. The new paradigm which is starting to emerge in packet radio is the coupling of the TCP/IP-based applications of the Internet with the building of higher-speed packet radio MANS. In other words, think globally, but act locally. Rather than expend your energy on long-haul radio links which are difficult to build and maintain, concentrate on putting up as much local bandwidth as you can muster, and then link your MAN to other areas of similar activity by the most expedient means available. This may be a radio link, or landline, or satellite - but the easiest means is usually the establishment of an Internet gateway. When radio-based MANs offer speeds substantially greater than landline modems can deliver, packet radio starts to look interesting again. Add to this the possibility of mobile and portable operation, and you have a recipe for putting the excitement back in packet radio.

So, here's the scenario: we need the capability to transmit data at speeds ranging from, let's say 56 Kbps at a minimum, to T1 rates or more. The radio links will be short or medium range (up to 50 km?) and will be predominantly in urban environments. For maintainability, most of the nodes of the network will be at users' homes, apartment and office buildings, etc. Some of them will be mobile. Multipath will nearly always be present to some degree, and interference from other services and other amateur operations are very likely. Our network must continue to perform well in the face of such adversity, and it should cause minimal disruption to the other services. Of course, it should carry all of the Internet-type applications transparently, and work with all of the popular computer hardware and operating systems. This may sound like a pipe dream, but it is actually very doable. The magic ingredient needed to make it happen is - you guessed it - SS modem technology. The current generation of ISM band SS devices can take us a long way towards this goal. To take us the rest of the way, development work spearheaded by TAPR will be aimed at higher-performance SS systems, with capability to use other amateur bands in addition to 900 MHz and 2.4 GHz.

Resources

To get plugged into what's happening with SS in amateur radio SS, your starting point should be the TAPR Amateur Radio Spread Spectrum Communications page at http://www.tapr.org/ss/index.html. You'll find updates and historical notes on the STAs and other initiatives on the regulatory front, the current SS rules in the US, tutorial information, and links to other SS resources on the net. Elsewhere on the TAPR web site, you can find out how to sign up for the SS SIG/mailing list (hint: send email to listserv@tapr.org with

subscribe ss YourName

as the first line of text). This mailing list is intended to be the place for SS experimenters to exchange information, talk about new products, plan tests, etc. If you're interested in SS applications in the HF bands, you should also join the TAPR HFSIG. For information on the many ISM band SS modem products, check out VE3JF's survey at <http://hydra.carleton.ca/info/wlan.html>. It includes summary tables of the product specifications and links to the manufacturers' web pages, product reviews, and other relevant references. As far as Usenet news is concerned, there is no newsgroup dedicated to SS technology, but discussions about SS wireless LAN hardware sometimes show up on the comp.std.wireless newsgroup.

Printed reference material is somewhat more limited. The definitive guide to the first ten years of amateur radio SS work is the ARRL Spread Spectrum Sourcebook. It also includes useful tutorial information, and some construction details for determined homebrewers. Beyond that, you'll have to hunt down journal articles and textbooks - again, see the references in TAPR's web pages. The books by R.C. Dixon are quite readable, with a minimum of math.