DOCKET FILE COPY ORIGINAL

Before the
Federal Communications Commission
Washington, D.C. 20554

RECEIVED
MAY 5 1997
FCC MAIL ROOM

In the Matter of	)	
	)	
Amendment of Amateur Service	)	
Rules to Provide For Greater	)	WT Docket No.97-12
the Amateur Radio Service to	)	
Use of Spread Spectrum	)	
Communication Technologies	)	

To: The Commission

COMMENTS OF WILLIAM A. TYNAN W3XO

Background

I have been a licensed amateur since 1945, obtaining the call sign W3KMV early 1946. I upgraded to Class A (later called Advanced) in the fall of 1946 and to Extra in the early 1970s. I obtained my present call sign, W3XO in 1976. Throughout those 50 years, my principal interest has been in the bands above 50 MHz. I am currently operational on all bands from 50 to 1296 MHZ. For 18 years, from 1975 through 1992, I served as a Contributing Editor of QST Magazine, responsible for the monthly column "The World Above 50 MHz". I was one of the founders of the Radio Amateur Satellite Corporation (AMSAT) and have been serving as its President since 1991.

Summary

I generally support the intent of the Commission's proposed Rule Making contained in this Proceeding - namely liberalizing the rules governing the use of Spread Spectrum (SS) in the Amateur Service. I have always wholeheartedly supported the development of new technologies in and for the Amateur Service and Amateur-satellite Service. I believe that SS

No. of Copies rec'd 0+10

may represent a significant vehicle for facilitating improved communication between licensed amateurs. I further believe that the Commission's rules should provide the maximum degree of flexibility for accomplishing this objective, consistent with preserving the viability of current communications capabilities, especially including those associated with various kinds of terrestrial "weak signal" and amateur satellite work. I contend, that, to promote the development of a variety of SS techniques and still not materially impact existing amateur activities, certain provisions must be included in any rules which the Commission may adopt. My views with respect to such provisions will be outlined in these comments, along with supporting technical justification for them.

In addition, I believe that, to maximize the flexibility for developing SS techniques for uses other than its apparent advantages in local communication applications, two classes of SS should be defined by the Commission and implemented in any new rules. These will be defined and certain frequency bands suggested for each type.

Discussion

While SS promises a great deal of benefit for improving amateur and amateur satellite communication, I contend that its unbridled authorization and widespread use, particularly in a wide bandwidth embodiment, has the potential of rendering current techniques, as practiced on the VHF and UHF Amateur bands, unusable. I made this argument in my Reply Comments in RM-8737 and provided supporting calculations to show that SS has the potential of raising the noise floor for other stations by as much as 50 dB. (Note 1)

Those promoting greater use of SS in Amateur Radio may claim that these calculations are flawed because they do not address their particular concept of how SS will be employed by amateurs. Largely, their concept is based on commercial cellular telephone experience, involving quite short path lengths and very low power levels. I acknowledge that, if this is the approach that amateurs take to SS, interference to other modes of operation is likely to be quite low. However, it is not clear that this will be the type of SS operation that evolves in the Amateur Service. It is more likely to be similar to that existing today with repeaters and packet nodes. These applications involve a well located central station covering an area of perhaps thirty miles in diameter and a number of participating users within that area. In this kind of situation, the powers of SS stations are likely to be considerably higher than in the "small cell" cellular telephone arrangement. In this case, the calculation I presented are quite applicable. Since no one can accurately predict how SS will develop in the Amateur Service, interference calculations must be based on permitted power levels, rather than on some imagined low-power-short-range model.

As part of their argument that SS offers little or no interference to other modes, SS proponents also say that, even if its level does exceed a signal being received in a narrowband receiver and captures the receiver, it will produce only occasional short lived signals on that specific channel. This, they say will cause very little loss of information. (Note 2) While I acknowledge that this scenario may be valid for the case of a single SS station, or even a few such stations; I contend that it is an unrealistic if SS becomes as popular a mode as its proponents obviously hope it will. If that comes to pass, short bursts of interference will be repeated by each SS station on the air at

the time. If there are, for example one-hundred SS stations on the air in a major metropolitan area, these short bursts of interference will be repeated one-hundred times as often as in the case of a single SS station. Thus, SS interference to other modes could eventually take the form of a continuous "buzz" rather than a few short "pops". Some might contend that the potential for having one-hundred stations operating in an area at a time is small. I submit that this is not necessarily true. A reasonable scenario can be envisioned which calls for continuous 24 per day operation of amateur SS stations. Such operation is already present in commercial applications of SS techniques. One example is the Internet connectivity offered by Metricom in several cities. Many, who use this service leave their computers and radio transceivers on all the time connected to the Internet through the system. Thus, even when they are not actively using the connection their transceivers are continuously exchanging signals with the local site. While I do not share their view, a growing number or licensed amateurs today feel that inexpensive Internet access should be one of the major applications of Amateur Radio. If such activity gains favor, it is easy to envision local amateur SS links being up continuously, connected to a central station which is connected to the Internet. Even if Internet connectivity does not become a common use for Amateur Radio, various other amateur-only applications such as DX clusters are likely to employ SS and be active continuously. Many amateurs today maintain constant connection with DX clusters via AX-25 packet radio links. They can certainly be expected to do so using SS.

A number of SS proponents participating in RM-8737 claimed that ten years of SS authorization have produced little or no complaints of interference to other modes, thus presumably supporting

their contention that SS operation does not cause interference to such modes . I submit that this claim cannot be substantiated for two reasons. The first, and most compelling, is that, even those proposing further liberalization of SS rules, admit that there has been an extremely small number of amateurs using SS during this period. Second, there seems to have been a concerted effort to "hide" any operation that did take place. To my knowledge, there have been no tests conducted by SS operators in which non-SS operations were invited to take part. Indeed, I know of at least one prominent weak signal VHF operator in a large West Coast metropolitan area who has repeatedly requested that tests be conducted by SS equipped stations so that he could assess possible interference. All such requests were met with indifference, or even hostility, on the part of the SS operators he contacted. And no such tests were ever conducted. Another indication of the lack of testing during this over-ten-year period, is the fact that no reports of any such testing has ever been published in magazines of general amateur circulation. I am unaware of any reports published even in specialty periodicals. So, claims that SS will not affect current amateur operation are completely unsubstantiated.

Contained within the Commission's NPRM is an indication that some apparently informed people believe that SS does represent a threat, even to other SS operation. The NPRM notes that Metricom has urged the Commission to limit amateur SS power in the 900 MHz and 2400 MHz bands to the same levels presently authorized for them and other Part 15 users. While I believe that the Commission should reject any such proposal on the basis of an unlicensed service claiming that a licensed service should be limited to prevent interference to it, I believe the

Metricom statement clearly indicates that SS may not be as immune to interference, or as unlikely to cause interference, as claimed by amateur SS advocates.

Automatic Power Control

The Commission's proposed rule making includes a provision for automatic power control (APC) for SS stations running more than 1 Watt. I believe that this is another clear indication that even the Commission is concerned that SS will cause interference to other modes. While amateur Rules have always called for stations to use the minimum power necessary to maintain communication, a Rule calling for AUTOMATIC POWER CONTROL is unprecedented. Furthermore, while I support the apparent intent of the proposed rule, to minimize the impact of SS on other types of operation, I contend that APC is impractical in the Amateur Service.

I further contend that requiring its use will have minimal effect on the impact of SS on other modes an may well inhibit SS's growth and development. I cite the following scenario to illustrate my case for the minimal protection APC will afford:

Let's assume that two SS stations located 12 miles apart are in contact, and that they are spreading their direct sequence signals over one megahertz and operating at powers of 0.5 Watts each, with a processing gain of 50. If a single station using 25 W of FM, and operating on a frequency anywhere within this 1 MHz band, and located 12 miles from each of the SS stations, comes on the air; the SS stations will automatically increase their powers in order to maintain the same level of communication. This power increase will amount to the 23 dB (a 200 to 1 ratio) or 100 Watts - the maximum permitted for SS operation. Thus, the assertion that APC will reduce

interference does not appear to be true.

I note that several SS proponents commenting on RM 8737 were not in favor of APC. Both TAPR and the Naval Post Graduate School expressed reservations about it. (Notes 4 & 5) While APC may provide some marginal benefit in terrestrial point-to-point (one-on-one) situations, such as encountered in cellular telephony, it has little application to amateur radio. For example, amateur communication is often from one station to a number of listening stations ("bulletin mode"), rather than one-on-one. In such a case APC breaks down no matter how it is implemented. Even in the "one-on-one situation, mandating APC requires a higher degree of standardization than is typical of amateurs. It may even require that all stations participating in the power adjustment must have equipment from a single manufacturer. Does the Commission want to support such a potential monopoly situation? APC is certain to mitigate against "home brewing" of equipment. As already noted, it may be just the "straw" that prevents SS from becoming popular with amateurs. It certainly runs counter to the objective of making amateur SS rules as flexible as possible. In fact, any such requirement seems to represent the height of inflexibility.

A Proposed Approach for Peaceful Development of SS in the Amateur Service

How can the development of SS techniques be encouraged and still prevent potential serious harm being caused to existing modes and the inevitable bad feelings that will result from such harm? I contend that the solution to this dilemma lies in the establishment, in any Rules which the Commission may invoke, of provisions proscribing certain frequency segments for SS operation.

In addition, in order to take advantage of the potential capability of SS techniques for long-haul weak signal work, *I propose that a Narrow Band versions of SS be defined and authorized.* I believe that it should be able to be used more generally throughout the spectrum than the "wideband" version apparently being addressed in the NPRM.

Two Kinds of SS

The case for the potential utility of a narrowband version of SS was made in a paper presented at the Central States VHF Conference held in Minneapolis in July 1996. (Note 6) In this paper, Tom Clark W3IWI and Phil Karn KA9Q outlined a possible use of SS techniques for enhancing weak signal communication such as Earth-Moon-Earth or long haul terrestrial paths. Their presentation convinced me that this application of SS should be accommodated in any new rules which the Commission may adopt. *I feel that to accomplish this, while not allowing SS operation to materially impact other operation, the Commission should define two types of SS. One type might be called Wide Band" and the other "Narrow Band".* .

Proposal

In light of the above, I propose that a "Narrow Band" version of SS be authorized on *all of the amateur frequencies above 50 MHz on which voice is permitted, so long as the bandwidth of the transmitted signal does not exceed that of a properly modulated double sideband AM signal, i.e. 10 kHz.* I also see no reason why stations using this Narrow Band type of SS should not be enabled to use as much power as those using existing modes.

I further propose that the "Wide Band" version of SS should be authorized only in the following

frequency segments:

219 - 220 MHz
435 - 438 MHz*
904 - 928 MHz
1240 - 1270 MHz*
2390 - 2450 MHz*
All Amateur frequencies above 3300 MHz

* In the segments 435 -438 MHz, 1260 - 1270 MHz and 2400 - 2410 MHz, SS emissions shall, except for short tests to confirm proper operation of equipment, be only be for the purpose of work in conjunction with amateur satellites.

The rationale for stipulating limited use of SS in the segments denoted by * is to protect relatively weak amateur satellite downlink signals from being interfered with by terrestrial SS stations and also to prevent terrestrial SS stations from transmitting signals that might be inadvertently picked up and re-transmitted by amateur satellites. However, permitting the use of SS in these segments allows it to be used in conjunction with amateur satellites.

While there is weak signal experimentation occurring around 3456 MHZ, 5760 MHZ, 10368 MHz and at specific frequencies in the higher microwave bands, I have become convinced that amateur SS operation poses little threat to these activities. The principal reason for reaching this conclusion, is the power levels that might be expected to be used in these bands and the effect antenna directivity characteristically involved.

Conclusion

I believe that SS operation should be encouraged. I further believe that it may well eventually

prove valuable for both terrestrial and satellite applications. <u>However, I contend that the development of SS in the Amateur Service can best be encouraged if it is done so as not to result in major conflicts with those using existing modes.</u> I submit that such conflicts are inevitable if SS is merely "plopped down on top of everything else. Such conflicts, in my opinion, can only weaken Amateur Radio and inhibit the growth and development of SS. Therefore, I urge that its use should be restricted to particular frequency segments outlined above. These are relatively lightly used segments and SS operation there should cause very little difficulty and hence I feel that some of the restriction presently placed on SS operation, such as non-interference to other modes, should be eliminated . I submit that such frequency "segregation" is consistent with established Commission policy in the Amateur Service. I cite, as examples, the fact that voice operation has been limited to certain segments in the HF and VHF amateur bands for many years. Unattended digital operation is restricted to certain narrow segments of the HF bands. Unattended Beacon Operation is allowed only in limited segments of the 10 meter, 6 meter, 2 meter, 1-1/4 meter and 70 cm bands. Also, there are frequency limits placed on repeater operation. All of these limitations have served Amateur Radio well for many years. A similar approach to authorizing more flexible SS Rules, should serve it, and the rest of Amateur Radio, well also.

I recommend that the Commission incorporate these suggestions in formulating new rules designed to foster widespread use of SS among amateur radio operators. I further recommend that the Commission place no greater restrictions on SS use, such as station

identification and authorized spreading codes, than it feels is absolutely necessary, and that automatic power control not be required. Appendix A contains my attempt at putting these recommendations into Part 97 Rule form.

I contend that the course I have outlined will foster growth of SS among amateurs, including those using it in connection with extended range weak signal communication as well as through amateur satellites. In addition I propose that the Commission authorize two types of SS. One that could be termed "Narrow Band" would be authorized on all frequencies above 50 MHz, presently open to voice operation, as well as a satellite downlink in the 10 Meter band above 29 MHz. The transmitted bandwidth of Narrow Band SS emissions should not exceed that of a properly modulated double sideband AM signal. The other, form of SS could be called "Wide Band", should be authorized anywhere in the segments listed above, with the limitations stated.

I believe that this course will allow amateurs to develop SS technology and continue in their historic pursuit of all new technologies as well as their march to higher and higher frequencies. At the same time, other valuable amateur operation will be preserved..

RESPECTFULLY SUBMITTED,

By William A. Tynan
William A. Tynan W3XO

May 2, 1997

Mailing Address:
HCR5 Box 574-336
Kerrville, TX 78028
E-Mail: biltynan@ktc.com

Notes:

1. AMSAT said in its Reply Comments, "To obtain a measure of the possible interference that could result from only a single spread spectrum station, the following parameters are assumed:

Spread spectrum station with an effective power of 100 W ERP = +20 dBW (The power specified in the Docket)
If spread over 10 MHZ -50 dBW/Hz
Free-space attenuation at 20 km from the spread spectrum station at 432 MHZ = -110 dB
Spread spectrum signal at 20 km = -160 dBW/Hz

A receiver with a 1 dB NF (common in satellite & weak signal work) = -210 dBW/Hz
So the spread spectrum signal could be as much as 50 dB above the noise floor that would exist without it.

One can use these calculations to cite other scenarios:

For example, if the spread spectrum station had a power of only 1 W ERP, this is 20 dB less, yet the noise floor would still be as much as 30 dB higher because of its presence. Similar calculations for other distances can also be done. For example, the spread spectrum signal would be 20 dB stronger at a 2 km distance. As another example, a 100 W transmitter and 10 dB gain antenna could create 10 dB more interference. Obviously, if the spread spectrum station is in close proximity to the satellite or terrestrial weak signal station, the degradation from the spread spectrum station's operation would be much greater."

2. Reply Comments of Robert A. Buaas, K6KGS 20271 Bancroft Circle Huntington Beach, CA 92646. Mr. Buaas postulates the following scenario: (His paragraph numbers are included for ease of reference.)

(3a)"Use Voice modulation type F3E(conventional NBFM):

(3b) Use only Frequency Hopping of the carrier frequency to accomplish the SS function:

(3c) Operate within the 450 MHZ repeater spectrum and conventions: receive within the 5 MHZ allocated for repeater receivers and transmit within the 5 MHZ allocated for repeater transmitters: use carrier frequencies aligned with those of current repeaters: this provides 200 discrete receiver and transmitter operating frequencies, each of width 25 Khz (Choosing

20 Khz bandwidths provides an additional 50 hopping channels: this may eventually be operationally desirable, but for the purpose of this model it only complicates the arithmetic for interference assessment. It does not significantly alter the impact of or nature of signal collision):

(3d) Dwell on each channel for exactly 10 milliseconds, then hop:

(3e) Choose a hopping function which:
(3e1) uses every available channel before any reuse. We will call the total time required to use all the channels the "period" of the hopping function (taking (3c) and (3d) together, it is 200- milliseconds) and,

(3e2) during one period, selects channels for each use such that the time since the same channels use in the previous period is statistically random: ....."
"With the system parameters give above, interference impact evaluation is very straightforward. Parameter 3d is chosen so that SS activity does not activate the noise squelch of NBFM receivers. When the FHSS arrives on an active repeater channel, FM capture rules apply. In the case where the SS station captures the other user, the capture lasts 10 milliseconds in 2000, or for 0.5% of the transmission. This impact is so slight as to be neglected in real operations."

3. Reply Comments of Charles M. (Marty) Albert Jr. KC6UFM Paragraph entitled "Additional General Comments. Mr. Albert says in part "Using the 10 millisecond dwell time cited by Buaas, this means that you will miss only ONE-FIFTH of ONE WORD sent. If we assume that the voice transmission lasts 5 minutes and the SS makes a "hit" as often possible...."

4. In part: "NPS does not agree with the changes proposed to 97.311(g) requiring the addition of "automatic transmitter power control." T Reply Comments submitted by the Naval Post Graduate School state his is clearly counter to making the spread spectrum mode of communication more flexible and is itself superfluous as noted by Mr. Buaas' reference to 97.313(a). The technical hurdles implied by this rule change are not trivial: and as pertains to space-based stations in particular, would pose an unnecessary burden on the design of the space segment of the communications link."

5. In its Comments, TAPR says in part: "Third, TAPR supports the ARRL's proposed change to 97.311(g) which would provide for automatic power control to limit the output power of and SS

station to that which is required for communication, when more than one watt of output power is used. TAPR, however differs with ARRL as to just how simple to control the output power of a transmitter, it is quite another matter to make this control automatic and foolproof...."

6. In an unpublished paper presented at the 1996 Central States VHF Conference, Drs. Tomas A. Clark, W3IWI and Phillip Karn, KA9Q outlined the possibility of using SS techniques over a fairly narrow band to enhance the capability for weak signal amateur communication. ((A copy of this paper is attached for the convenience of the Commission.)

Appendix A

Part 97 of Chapter 1 of Title 47 of the Code of Federal Regulations is proposed to be amended as follows:

Part 97 Amateur Radio Service

All other provisions contained in NPRM 97-12 are retained except as noted:

97.305 Authorized emission types

SS (spread spectrum) emission with bandwiths wider than 10 kHz are authorized on the following frequency segments:

219 - 220 MHz
435 - 438 MHz*
904 - 928 MHz
1240 - 1270 MHz*
2390 - 2450 MHz*
All Amateur frequencies above 3300 MHz

* In the segments 435 -438 MHz, 1260 - 1270 MHz and 2400 - 2410 MHz, SS emissions shall, except for short tests to confirm proper operation of equipment, be used only in conjunction with amateur satellites.

SS (spread spectrum) emissions with bandwidths of 10 kHz or less are authorized on the following frequencies:

50.1 - 54.0 MHz
144.1 - 148.0 MHz
219.0 - 220.0 MHz
All frequencies above 222.0 MHz subject of other existing limitations.

Emission Types.

***

(b) A station may transmit a test emission on any frequency authorized to the operator for brief periods for experimental purposes, except that no pulse or SS modulated signals with bandwidths greater than 10 kHz may be transmitted on any frequency where pulse or SS are not specifically

authorized.

97.311 SS Emission types
(a) SS emission transmissions by an amateur station are authorized only for communication between points within areas where the amateur service is regulated by the FCC and between points within areas where the amateur service in regulated by the FCC and amateur station(s) located in countries that permit SS by its amateur stations. SS emissions must not be used for the purpose of obscuring the meaning or content of any communication.

(b) deleted

(g) (1) For spread spectrum emissions with bandwidths greater than 10 KHz, the transmitter output power shall must not exceed 100 Watts under any circumstances. .

(g)(2) For spread spectrum emissions with bandwidths of 10 KHz or less, the transmitter output power must not exceed 1.5 KW under any circumstances, subject to other restriction already existing in the particular frequency range and location.

EME 2000: Applying Modern Communications Technologies to Weak Signal Amateur Operations.

Tom Clark, W3IWI (clark@tomcat.gsfc.nasa.gov)
Phil Karn, KA9Q (karn@qualcomm.com)
July, 1996

1. Introduction:

The availability of several new communications technologies permit significant advances in amateur weak-signal operation. In this paper we will outline some ideas which could achieve ~20 dB improvements over conventional practice. We will focus our discussions in the Moonbounce (EME) arena at VHF/UHF/Microwave frequencies, but the ideas are applicable to other activities.

As an idea of the kind of gain that can be achieved, we look back in history to 1964/5 when Gordon Pettingill and Rolf Dyce (*Nature* 206, 1240, 1965) used the Arecibo 1000' antenna at 430 MHz to determine that Venus had a rotation period 2/3 of its orbital period. Comparing their achievement with a modern amateur EME QSO at 70cm between a "big" and "small" station:

Item:	RADAR ASTRONOMY	AMATEUR EME	dB
Transmitter Power	250 kW	1.5 kW	22.2
Transmitting Antenna	250 Meter dish	9 Meter dish	27.9
Distance	67,500,000 kilometers	350,000 kilometers	-91.4
Receiving Antenna	250 Meter dish	20 dBd Yagis	34.8
Receiver Tsys	250 K	80 K	-4.9
	NET dB DIFFERENCE =		-11.4

Notes and assumptions:

- The radius of Venus's orbit around the sun is 0.72 AU, so the closest it gets to earth is 0.38 AU. The 1965 radar observations were made around closest approach, so a distance of 0.45 AU is taken for these calculations. For the moon, we have taken a distance near perigee.
- Although the Arecibo dish is 1000' (305m) in diameter, its spherical shape leads to inefficiencies so the effective diameter is taken as ~250m for this calculation and an aperture illumination efficiency ~ 40% has been assumed (57 dBi = 54.8dBd gain).
- The amateur transmitting station is "state-of-the-art": a 9m (30') dish with 50% aperture efficiency (29.2 dBi = 27 dBd gain) and a 1.5 kW transmitter.
- The amateur receiving station is running a "small" Yagi array with 20 dBd (22.2 dBi) gain.
- Modern FET/HEMT LNA technology gives the amateur better Tsys receiving performance than was available in 1965 (~250K in 1965 vs. ~80K easy to obtain now).
- Even in 1965, The Arecibo radar performance with the 1000' dish was so good that EME echoes could be obtained with a Model-80 signal generator, and "EMEME" (i.e. double-hop reflections, with a net R^8 path loss) were observed with the big transmitter! With the same radar system, Arecibo was able to obtain the first maps of the surface of cloud-covered Venus.

30 years ago, the professional community could do valuable scientific research with link margins more than 10 dB poorer than we have today. They did it by clever signal processing. Can amateurs with the technology available now obtain similar performance enhancements? We think that the answer is a re-

sounding YES! For a target, let's look at a comparison between the amateur EME example used above and a pair of typical OSCAR satellite stations shows

Item:	AMATEUR EME	OSCAR Station	dB
Transmitter Power	1.5 kW	150 W	10.0
Transmitting Antenna	9 Meter dish	17 dBd Yagis	10.0
Receiving Antenna	20 dBd Yagis	17 dBd Yagis	3.0
Receiver Tsys	80 K	100 K	1.0
	NET dB DIFFERENCE =		24.0

Our goal in this paper is to examine ways that amateurs can "buy" performance improvements of 10-15 dB better than Pettingill and Dyce used 30 years ago for the purpose of making valid QSOs. The "purchase" must use technology that is inexpensive, readily available and easy to replicate. The key elements that the amateur will need are:

1. A Pentium-class PC, which is augmented with a SoundBlaster card to provide A/D and D/A conversion at audio frequencies.
2. Millisecond accuracy timing clock (a small GPS receiver -- W3IWI's "Totally Accurate Clock" will work fine. See Appendix A)
3. A low-speed digital logic plus audio frequency analog adapter "widget" to "glue" the computer, clock and radios together.
4. An OSCAR-class (or better) satellite station.

2. What's a QSO?

The initial questions/comments from the skeptics when advanced signal processing schemes are discussed always seem to start with the age-old premise:

YOU'VE GOT TO HEAR 'EM TO WORK 'EM !!

And then follow with the dictum:

A QSO ISN'T VALID UNLESS IT'S IN REAL-TIME !!

The schemes we discuss here are not "earball" based, and the S/N ratios will be very low, so we have to dismiss the first point as irrelevant. As a *reducto ad absurdo* analogy, consider the case of two deaf amateurs who succeed in making an EME QSO with RTTY. Would even the most hardened "you've got to hear.." advocate deny the validity of the RTTY QSO?

The "real-time" issue stems from people's pre-conceived notions that a QSO shouldn't take hours of off-line data analysis. To answer this issue, we extend the deaf amateur analogy to the use of packet radio instead of RTTY. The sending amateur types in an entire line of text and hits the return key. The computer in the TNC assembles the text into a standardized packet and appends control information and a check-sum which is sent as a single burst. The receiving station disassembles the packet and if the check-sum is verified presents the entire line at one time a few seconds later. Is this real-time? Would the deaf amateurs be able to count a packet QSO?

The scheme we are proposing can be envisioned as a glorifed (albeit slow) form of packet radio. We envision that the information needed for a QSO takes about a minute to transmit and that the information will be presented a few seconds later at the other end. So we regard the "real-time" arguments as moot.

The requirements for a "legal" QSO read something like:

- Each station must copy the call of the other station and know that the transmission is directed to him.
- Some unknown information must be exchanged in both directions. This is usually a signal report but might also include a Grid Square.
- Each station must receive an acknowledgment that the other station has copied the required information.

3. Raw Bits!

Clearly, we are thinking in terms of true digital communications. On our computers we all use utilities like PKZIP to compress data into its most compact form. A program like PKZIP uses a well-defined mathematical algorithm that looks for redundancies in the entire block of data and represents repeated material as a much shorter "token". It keeps a dictionary of the tokens it finds and appends it to the tokenized data. A partial PKZIPped file is useless since only the complete file can be restored.

Since the information needed to complete a QSO is well defined, we have attempted to pre-define the "QSO dictionary" in order to reduce the information to the minimum possible number of raw data bits. To these "raw" bits, we will add additional bits for error correction in order to improve the reliability and to facilitate signal processing; we'll return to this topic later, but first let's examine the "raw" information needed to conduct an EME QSO.

In communications theory, this is called 'source coding'. Our goal is to get the most out of every user data bit by encoding all our information as compactly as possible. It's a lot like playing 'twenty questions' by carefully phrasing each question to have a 50-50 chance of being answered with a yes or no. Later on when we do 'channel coding' we'll add some carefully designed overhead back in the form of error correction coding (ECC). Even though source coding removes redundancy while channel coding puts it back in, it's important that these two steps be kept separate to maximize the overall performance of the system, as well as its modularity. This philosophy is stressed by Andy Viterbi in an article that can be viewed at:

http://www.qualcomm.com/people/pkarn/viterbi_lessons.html

Presently, most EME communications involves Morse Code. The Morse alphabet was optimized for the transmission of plain text. The characters ETOIANS which have a high occurrence frequency were assigned the shortest symbol length, while infrequently used characters like QYZ were given long symbols. The digits 0...9 were given still longer symbols. But the information in a QSO is more random. For example in amateur calls, all letters have nearly equal occurrence probabilities. An amateur with a short call like N5EE is more "Morse efficient" than an EMEer suffering with a call like ZJ9QYP. In Morse, a dot (counting the separator space) takes 2 bit times and a dash takes 4. Another 2 bit times are required as a character separator. Therefore a call like N5EE is 28 bits long while ZJ9QYP is 94 bits long.

We might consider coding in ASCII so that all characters require the same number of bits. The 7- and 8-bit ASCII sets have symbols we never will use, with both upper and lower-case letters plus punctuation and a lot of control characters. A 6-bit subset (often called Half-ASCII, using the ASCII range with decimal values 32 thru 95) gives upper case characters, numbers and punctuation and is more than adequate. With this character set, a call like ZJ9QYP becomes 36 bits long. Even this character set has symbols which are not needed to conduct a QSO and it is trivial to reduce the required number of bits even further.

All amateur calls consist of a 1 or 2 character prefix (one of which is a letter), a digit, and a 1 to 3 letter suffix. Let's consider all calls as being a 6 character field, and fill any use a space character to pad empty

positions. If a field can be a letter character or a space there are 27 possible values. If it can be a letter or digit, there are 36 or 37 possible values depending on whether a space is needed. A digit has only 10 possibilities. Let the 6 characters of an amateur call be denoted *a b c d e* and *f*. The *a* field can be a digit, letter or space, the *b* field is either a letter or digit, and *c* must be a digit. The *d e* and *f* fields are either letters or spaces:

	a	*b*	*c*	*d*	*e*	*f*	28-bit Value in HEX
Digit [0-9]	10	10	10				
Letter [A-Z]	26	26		26	26	26	
space character	1			1	1	1	
TOTAL POSSIBILITIES	**37**	**36**	**10**	**27**	**27**	**27**	
Examples		W	3	I	W	I	F957F68
	K	A	9	Q			8935D6F
	J	Y	1				86D0869
	A	7	3	M	B		44F474C
	9	M	2	E	M	E	40FD27E
		K	5	J	L		F72108B
				Miscellaneous			FA08318
				Functions			- to -
	C	Q	C	Q	C	Q	FFFFFFF

Note that a space is included in the *d* field. The only call we are aware of that needs this is JY1, but we don't want to exclude King Hussein from EME!

Based on this formulation, the total number of possible calls is 37*36*10*27*27*27 = 262,177,560. Since this is smaller than 2^{28} = 268,435,456, we find that every call can be represented as a 28-bit number. For the examples shown in the table, the 28-bit values for one possible coding are given in hexadecimal notation. The 2^{28} maximum value allows 6,257,896 additional special "calls" which can be allocated as tokens for special functions like ***CQCQCQ*** or ***TEST*** or weird "special event" calls that don't obey the normal rules.

Now we continue to enumerate the bits needed to make a QSO. While we could transmit the 2°x1° Maidenhead Grid Square in ASCII or compress it like we did with the calls, a more bit efficient representation is possible. On the earth there are 180 possible 2° longitude values and 180 of 1° latitude bands, so there are only 32400 possibilities. This can be packed into a 15 bits number (2^{15} = 32768) with 268 cases left over for special tokens (like "***I don't know my grid square. I'm lost!***").

Three bits (8 possible values) seems adequate to send the other station's signal report. This would range from zero indicating that nothing has been heard up to 7 to indicate "*Why are we bothering with this signal processing? Lets go on SSB and talk about the weather!*". This scale is similar to conventional EME practice with 1="T", 2="M", 3="O", 4="5", 5="539", 6="569" and 7="599".

Now let's allocate 4 bits for acknowledgements (Ack) and 4 bits for confirmation (QSL).

Ack Bit 1 = I have copied your call
Ack Bit 2 = I have copied you sending my call
Ack Bit 3 = I have copied a non-zero signal report from you
Ack Bit 4 = I have copied your Grid Square

When the receiving station copies a non-zero Ack bit, he sets the matching QSL bit. (i.e. QSL bit 1 means "*I know you have copied my call*", or bit 4 meaning "*I know you have my Grid Square*"). Thus when a station hears the 8-bit Ack+QSL field filled with all ones, he can quit, equivalent to sending "ROGER SK".

Finally we tally up our assessment of the "raw" bit requirements to make a QSO:

Sending Station's Call	= 28 bits
The other Station's Call	= 28 bits
Signal Report	= 3 bits
Grid Square	= 15 bits
Ack+QSL Bits	= 8 bits
Total	= 82 bits

As a preview of our subsequent discussions on coding, these "raw" data bits would be combined with a large number of carefully chosen error correction bits to make up the message actually transmitted. The resultant message is x•times the length of the "raw" data and is called a "rate 1/x" code. This process is known as convolutional encoding and has been the key to decoding the very weak signals from inter-planetary spacecraft like Galileo.

The 82x bits of data would be transmitted as a narrow-band spread spectrum signal occupying the ~2kHz passband available with typical SSB radios. As we will discuss later, m-ary FSK modulation (with a single one of m frequencies being transmitted at a time) looks optimum. The m discrete states result in $\log_2(m)$ bits being sent at any instant.

Each second, **B** signalling elements will be transmitted, resulting in a baud rate = B and a total data rate of $B*\log_2(m)$ bits/second). The timing of the **B** elements would be precisely synchronized to the UTC second (using GPS timing receivers) so that the receiving station can optimally detect the data (i.e. GPS would provide the clock synchronization function).

Back to the EME QSO and assuming that all 82x bits can be sent in a one minute sequence – the minute-by-minute progress of an "easy" QSO might go something like this (not much different than normal EME practice):

- Minute 0: Station A sends with the Signal, Ack and QSL bits set to zero
- Minute 1: Station B sends. If he copied A, then he sends a signal report and sets Ack bits 2,3,4
- Minute 2: Station A sends a signal report and Acks everything and sets QSL bits 2,3,4
- Minute 3: Station B sets Ack bit 1 and QSL bits 1,2,3,4
- Minute 4: The QSO is complete, and Station A sends a "courtesy SK" by setting QSL bit 1

As an aside, if the QSO isn't "easy", the coding and the fixed message formatting allows data from subsequent transmissions to fill in "holes".

5. Looking at the Moon:

So far, we've only hinted at the hard part of the problem. The transmitter sends a pure CW carrier, it is reflected from the moon and finally received back on the earth. In this process, a lot happens. In this section, we will discuss a bit of physics and astronomy that applies to EME.

First, the signal is severely attenuated – it drops as $1/R^2$ on the way to the moon and it loses again as $1/R^2$ on the way back to earth for a net $1/R^4$ path loss. But amateurs are crazy enough to try to dig weak signals out of the noise. If it was easy, there would be no challenge!

Second, the signal is reflected from a large, rough, moving (ne ly) spherical object. From the center of the moon's visible disk (where the first signal is reflected) to th limb, we can observe up to 11.6 msec of time delay (The radius of the moon is 1738 km = 5.8 msec he round-trip delay is twice the one-way value). Figure 1 shows contours of the reflection point at delay f 0,2,4,6,8 and 10 msec and the limb at 11.6 msec.

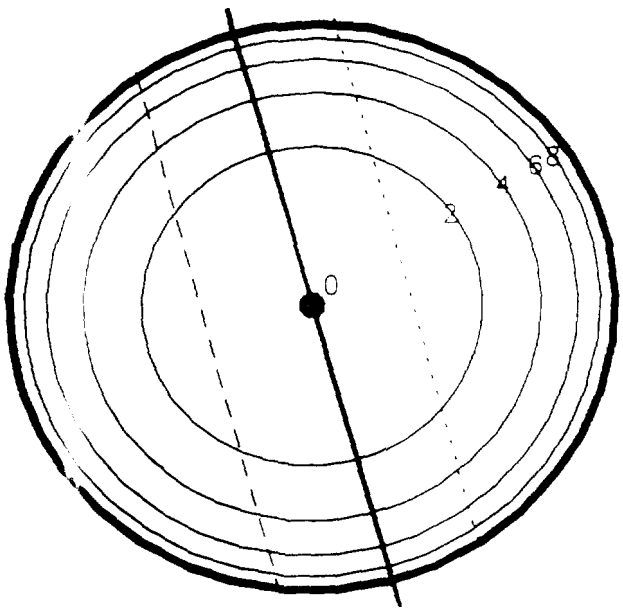

Figure The radar moon with contours of constant delay Doppler

The moon has a prolate spheroidal shape (rather like a football). Thru the 4.5 billion years that the moon has orbited the earth, energy losses due to tidal friction have caused the moon to be captured so that one face is presented to the earth and we never see the backside of the moon. The means that the lunar rotation period is the same as the lunar month.

An exaggerated version of the basic geometry of the moon in its orbit is illustrated in Figure 2. The orbit of the moon is an ellipse with an eccentricity of 0.055. The rotation of the moon on its axis is uniform and keeps the *average* center facing the earth. But since the orbit is elliptical, a point on the surface appears to move thru several degrees of lunar longitude throughout the lunar month. This is illustrated in Figure 2 by a fixed "spot" on the moon as seen at 4 different phases during the lunar month. The total motion of a spot on the moon's equator amounts to ±7.9° (see for example A.E.Roy, *Orbital Motion*, Hilger Press 1988, pg 288).

In addition, the moon's orbit is inclined about 5° to the ecliptic, so we can see a bit over the north and south poles of the moon. These effects are known as Optical Librations (as distinguished from the much smaller Physical Librations which reflect small deviations from "smooth" rotation). This apparent wobbling of the moon permits earth based observers to see about 60% of the total surface of the moon.

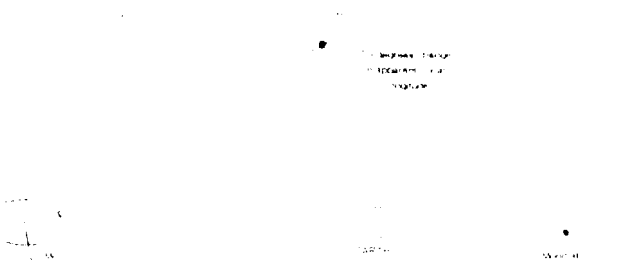

Figure 2: Optical Librations of the Moon.

The apparent location of a lunar feature varies thru the lunar month because of:
a) the moon's eccentric orbit, and
b) the 5 degree inclination of the lunar orbit to the ecliptic.

The total apparent motion of a spot on the moon by up to ~±10° of lunar longitude and latitude is of considerable importance in EME. At any given time, the moon appears to be rotating slowly and any "hot spot" that gives good EME echoes is changing its range accordingly, giving rise to a Doppler offset. If there are several "hot spots", the relative phases of the reflected signals changes and the signal can fluctuate wildly. The contours of constant Doppler shift are illu rated in Figure 1. The zero velocity contour is the intersection of the plane defined by the apparent angul velocity vector and the line from the center of the moon to the observer on earth (a great circle on the oon's surface). Other velocity contours are parallel to this plane and are like the moon was cut by a g t bread slicer. Half of the bread slices are

moving towards the observer and the other half away from the observer. The peak velocity at the limb of the moon is:

(Moon Radius = 1738 km) * (Apparent Angular Velocity radians/second)

As an estimate of this velocity, we note that the position of a spot on the moon moves as a monthly sinusoid with ±8-10° amplitude (depending on the current astrological conditions) corresponding to peak velocities of 60-75 cm/sec with the maxima occurring at apogee and perigee (and minimum libration motion midway between apogee and perigee). The opposite limbs of the moon therefore have relative velocities of up to 120-150 cm/sec. On Figure 1 we have schematically shown ~3 velocity contours, so each contours represent ~20-25 cm/sec intervals at apogee and perigee.

Most of the usable EME signal arrives in the first ~2 msec which Figure 1 shows corresponds to the central half (radius-wise -- it's actually only ~¼ of the *area*) of the visible moon. Over this area we see somewhat less than half of the peak libration-induced velocity (i.e. ~±25-35 cm/second). For the EME case the 2-way Doppler shift in frequency units (with the ± sign reminding us that half the moon is turning towards us and half is retreating) that we see over the reflecting moon is:

$$\Delta f_{Hz} = \pm 2 * F_{Hz} * \Delta v/c = \pm 0.067 * F_{GHz} * \Delta v_{cm/sec}$$

The signal bandwidth is about 2π larger than the Doppler shift since about 1 radian of random phase shift will cause a loss of coherence. We double this to get the full bandwidth (accounting for the ± velocity range):

$$BW_{Hz} \approx 2*2\pi*\Delta f_{Hz} \approx 0.84 * F_{GHz} * \Delta v_{cm/sec}$$

and, taking the coherence time as the reciprocal of the bandwidth, we also get:

$$\tau \approx 1/BW_{Hz} \approx 1.2 / (F_{GHz} * \Delta v_{cm/sec}) = 1.4 * \lambda_{cm} / \Delta v_{cm/sec}$$

The lunar surface consists of flat areas (Mare) and mountains. The Mare are covered with dust and strewn with boulders. Any signal we get back from the moon is the vector sum of the voltages from all these regions and the resultant signal is spread in both time and frequency.

In the time domain, most of the signal comes from the area within the 2 msec contours of figure 1. Therefore the signals have a coherence bandwidth ~500 Hz to 1 kHz (essentially independent of signal frequency). This means that the signal fading seen at frequencies ~1 kHz apart are uncorrelated and there it is possible to achieve some improvement with frequency diversity even with the ~2 kHz bandwidth of an SSB radio. This also accounts for the fluttery, hollow sound of EME SSB signals. It also places an upper limit of ~300-500 baud on the signalling rates for EME digital communications. In 1986, W3IWI/KL7 had a "legal" packet radio QSO with W3IWI/KL7 on 70 cm EME using 300 baud FSK (the 2.4 second EME delay allowed the same 85' dish antenna to be used for both transmitting and receiving).

At longer EME wavelengths (like λ=2M), several effects occur:

- 10-20 cm/sec libration velocities mean that signals maintain coherence for several seconds.
- The signal is "reflected" from a region about one wavelength thick so the limb "smooths" the reflection. Boulders and other small-scale surface roughness is relatively unimportant.
- This gives rise to signals with lots of "glints" much like the reflections from a "discoteque mirror ball". QRP EME on 2M thrives on waiting for a "glint" to happen.

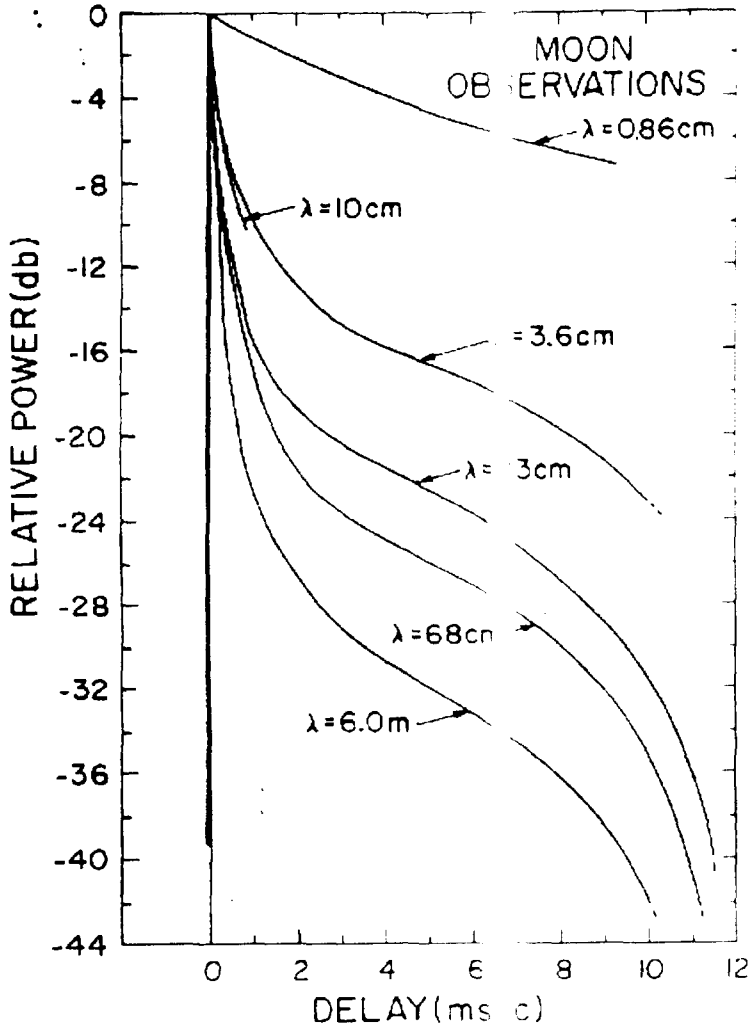

Fig. 5-9. **A composite plot of the short pulse observati[illegible] made by the authors listed in Table 5-3. The results have been normalized at zero dela[illegible] Because the resolution of the experiments differed somewhat, it is possible that the rela[illegible] positions of these curves are slightly in error. Despite this, a clear wavelength dependen[illegible] is evident.**

By contrast at frequencies above 1 GHz, the "rules" are different:

- 10-20 cm/sec libration velocities reduce coherence times to small fractions of a second. The signals sound increasingly "rough" as shorter wavelengths are used
- The surface "roughness" (measured in wavelengths) increases and boulders/rocks become much more important.
- "Glints" become unimportant – it's the overall average properties that matter

And the λ=70cm band represents a transition region. Since the typical Oscar satellite station is equipped for 2M and 70 cm operation and since equipment is readily available for these bands, we envision it will be the "home" the signal processing ideas we present here. Since our ideas are based on spread-spectrum techniques, we note that the bandwidth that can be used depends on three factors:

- The added bandwidth due to spectral broadening described above. Physics makes this the ultimate limit!
- intrinsic frequency stability of the radios. Frequency stability can be improved by using high stability frequency standards; in Appendix A we discuss the possibility of using GPS-aided crystal oscillators to achieve performance equivalent to a Rubidium frequency standard.
- The ability of the stations to set their frequencies to compensate for Doppler. It is easy for our computers to calculate the Doppler offsets since both the moon's orbit, the rotation of the earth and the stations locations are well known; It is only necessary to devise a scheme to "steer" the radio's frequencies to values predicted by the computer.

All these factors become more serious direct proportion to frequency. Schemes which may work at 2M or 70 cm will probably fail miserably at 10 GHz! The following section will develop a design which ends up with 64-ary FSK occupying a ~2 kHz bandwidth (i.e. channel spacing ~ 30 Hz), symbol rates ~2 baud and some degree of coherent detection suitable for 2M and 70 cm. At λ=13 cm or λ=2.8 cm, we may have to use binary or 4-ary FSK, symbols several seconds long and rely totally on incoherent signal processing.

Now with an idea of the limitations imposed by signal characteristics, we turn to the topics of coding error correction, modulation and signal processing.

6. Modulation and coding for the EME channel:

The design of any modulation and coding scheme must be carefully tailored to the channel. What works well on one kind of channel (e.g., a dialup telephone circuit) may perform poorly or not at all on others (e.g., EME). Although our understanding of the problem is still incomplete, we already know enough to suggest an approach that is likely to work.

a. The EME channel as seen by a communications engineer

The most conspicuous feature of the EME channel is its very high path loss. This is obvious from the large antennas, high power amplifiers and high performance preamps typical of amateur EME. On the other hand, amateur EME signals are usually narrowband; plenty of extra bandwidth is usually available.

So in communications engineering parlance, the EME channel is very much power limited -- as opposed to bandwidth limited -- and just about anything we can do to reduce the required signal power will be worth it. One way to reduce required signal power is to lower the user data rate. But we should first maximize the efficiency with which we use our power.