C-C Rider

A new transponder concept for amateur satellites

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ABSTRACT: The Amateur Satellite Service has several microwave allocations in the 1-10 GHz range. AO-40 and the planned Echo satellite make use of the L/S combination permitted by combining the Amateur Satellite uplink allocation at 23 cm (1260-1270 MHz) with the 13 cm (2400-2450 MHz) band. Unfortunately, the FCC's "Part 15" and ISM rules have caused the 13 cm band to be seriously compromised by unlicensed consumer devices – microwave ovens, 802.11b and 802.11g wireless LANs, cordless telephones, video relay, etc.

Another very desirable amateur band is C-Band (5 cm) where the Amateur Satellite Service has a pair of 20 MHz wide allocations: 5650-5670 MHz is set aside for uplinks, paired with 5830-5850 MHz for downlinks. This spectrum is also at considerable threat; it is already experiencing the intrusion of 802.11a LANs, cordless phones and other unlicensed applications and has been targeted for expansion by a number of new wireless services. Unless we begin to use this band very soon, it may become a bigger sewer than the 13 cm band has become.

This paper presents a conceptual design for an "in band" transponder making use of the pair C-band allocations. Although microwave frequencies imply huge doppler tuning problems for narrow-band signals typical of most amateur satellite activity, by placing a single local oscillator midway between the pair of frequencies (5750 MHz) we cancel 97% of the doppler shift, equivalent to operating at the difference frequency (180 MHz).

Until satellite resources can be deployed, low-cost versions of the transponder can be deployed at terrestrial locations as a wide-band "bent pipe" transponder with bandwidths capable of supporting many digital applications. These terrestrial developments could be a logical expansion of the ARRL's 13 cm "HSMM" "Hinternet" effort which makes amateur use of off-the-shelf low-cost commercial hardware.

THE MICROWAVE SPECTRUM: Let us begin by examining the amateur frequency allocations between 1 and 10 GHz in Table 1[1]:

Table 1: United States Microwave Allocations

Amateur Service		Amateur-Satellite Service	
Band (MHz)	**Bandwidth (MHz)**	**Band (MHz)**	**Bandwidth (MHz)**
1240-1300	**60**	**1260-1270 ↑**	**10**
2300-2310 **2390-2450**	**10** **60**	**-** **2400-2450**	**-** **50**
3300-3500	**200**	**3400-3410**	**10**
5650-5925	**275**	**5650-5670 ↑** **5830-5850 ↓**	**20** **20**
10000-10500	**500**	**10450-10500**	**50**
24000-24250	**250**	**24000-24050**	**50**

↑ means Earth-to-space (uplink) direction only
↓ means space-to-Earth (downlink) direction only

[1] Thanks to Paul Rinaldo, W4RI for supplying an early version of this table.

One sad lesson we have all learned from recent S-Band (2.4 GHz) experiences is that amateur activities have been seriously compromised by unlicensed users –- 802.11b & g WiFi, BlueTooth, cordless telephones, room-to-room TV links, microwave ovens, etc. We have learned that “listen only” and weak-signal services like the AO-40 downlink and EME are nearly powerless to convince millions of unlicensed users that our needs “trump” their usage. Since our applications are listen only (or mostly), we don’t even announce our presence[2]!

Realizing that many future amateur activities will want more bandwidth, the ARRL has formed the High Speed MultiMedia (HSMM) working group to explore ways to adapt low-cost commercial wireless computer widgets for use in amateur applications. The HSMM working group is headed by John Champa, K8OCL (an AMSAT Director and Executive Vice President in the late 1980’s). You may get more information on HSMM on the ARRL website[3] and an excellent article on HSMM by N5KM is in the April 2003 QST[4]. The ambient RFI level from unlicensed devices has proven to limit coverage on HSMM links and I understand that the HSMM group and TAPR have begun efforts to figure out ways to QSY from 2400 MHz to either the 902-928 or 3300-3500 MHz amateur bands[5] in order to improve operating range.

In this paper, I plan to concentrate on the idea of making a “fresh start” using the pair of C-Band Satellite allocations seen in Table 1: 5650-5670 MHz (uplink) and 5830-5850 MHz (downlink). Time is short -- C-band has begun the process of becoming another S-band-like “sewer” with 802.11a wireless LANs, cordless telephones and the like. On the CISCO website one can find details[6] of the current 802.11a WLAN channelization. At present, the 802.11a activity is confined to WiFi channels[7] 149-157 in the 5740-5790 MHz range[8]. This segment is in the middle of the 5655-5925 MHz amateur allocation, but it has no overlap with either of the 20 MHz-wide Amateur Satellite allocations, as seen in Figure 1.

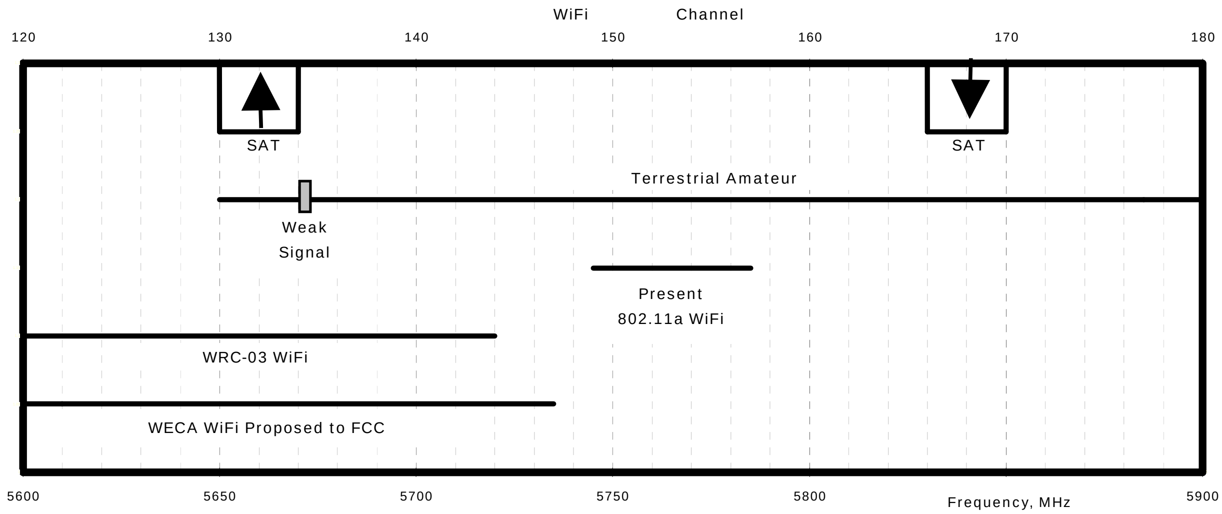

Figure 1: The 5600-5900 MHz C-band Microwave Spectrum

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[2] One exception: some S-band amateur TV repeaters have had some success in making life quite unpleasant for WiFi and BlueTooth users although this was not the intent of their activities.

[3] See http://www.arrl.org/hsmm

[4] See http://www.arrl.org/tis/info/pdf/0304028.pdf

[5] In point of fact, even the unlicensed users are starting to feel the pollution of the microwave spectrum. One (unconfirmed) report I have heard – in a small city in the Pacific Northwest, a wireless LAN installed a few years ago has become useless; the proliferation of unlicensed devices has raised the background noise level by some 67 dB!

[6] See http://www.cisco.com/univercd/cc/td/doc/product/wireless/airo1200/accsspts/ap120scg/bkscgaxa.htm

[7] WiFi channels are 5 MHz wide and are defined as Channel ## = (frequency-5000)/5

[8] In the USA, 802.11a also uses Channels 34-66 in the 5170-5330MHz range.

The wireless industry has formed the Wireless Industry Compliance Association (WECA) to promote the development of WiFi hardware[9]. WECA has petitioned the FCC for a large chunk of spectrum spanning 5470-5740 MHz (Channels 95-147). The recent WRC-03 has set aside the range 5150-5720 MHz for low-powered wireless usage on a worldwide basis. It appears that we must concede that the uplink region will soon be over-run. For C-C Rider to work, we need to be certain that the aggregate of all these low-powered signals will not overwhelm the distant satellite.

What is important to note is that, while the 5650-5670 MHz Amateur Satellite uplink band will soon be occupied by unlicensed wireless services, the 5830-5850 MHz downlink band is not under the same pressure (yet). We need to conduct some detailed RFI surveys of the existing environment. It is my hope that we will be able to make enough noise so that they can hear our uplink signals, and that our downlinks will be in the clear!

The rest of this paper will explore what we might do with our valuable and untapped resource – the matched pair of C-band allocations.

A CAVEAT: I want to stress that **none** of us have suitable C-band equipment in our shacks. Any program to develop satellite hardware will need to be matched with a parallel development of user hardware. These developments will undoubtedly make use of bits and pieces developed for consumer-grade applications, but I doubt that the consumer hardware *per se* will be suitable.

C-C RIDER[10] – A PROPOSAL: This proposal suggests a new concept – a **single-band in-band**[11] **transponder**. By "in-band" we mean that uplink and downlink will use the same frequency band – in this case, the pair of C-band allocations seen in Figure 1. These two allocations are separated by 180 MHz, so the equivalent "Q" of the band separation filters needs to be ≈ [5800/180] = 32. [12]

In Figure 2, I show a simplified block diagram of a possible "C-C Rider" transponder. One thing to note is that the design uses a **SINGLE** local oscillator at 5750 MHz; this frequency is midway between the uplink and downlink bands (separated by 180 MHz), and results in a 90 MHz IF. Note that this configuration has the LO above the receive passband, and below the transmit passband to create an inverting transponder. This has the interesting property that Doppler offsets are nearly cancelled – I say "nearly" because the Doppler on the uplink and downlink happen at frequencies that differ by 180 MHz. The net Doppler effects are the same as they would have been if the satellite were to operate at 180 MHz. Imagine – a microwave satellite with Doppler rates only one-third of those we have learned to tolerate since the 1970's Mode-B and Mode-J satellites![13]

As with any other satellite program, the selection of a suitable orbit is a prime concern. The possibilities generally sort into two categories: LEO (Low Earth Orbit, with altitudes below about 1000 km and orbital period in the 90-120 minute range) and HEO (High Earth Orbit with altitudes greater than 10,000 km and periods longer than about 6 hours). By these broad definitions, the HEO category includes **GTO**

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[9] See http://www.wi-fialliance.org/OpenSection/pr/pr_pdf/Wi-Fi_Fall_01_Briefing.pdf

[10] The song "***CC Rider***" (sometimes called ***See See Rider***") was one of more than 100 songs written by the great jazz/blues singer, Ma Rainey (http://www.redhotjazz.com/rainey.html) in 1925. In addition to Ma, it was made famous in versions by Mississippi John Hurt, Big Bill Broonzy, Ray Charles, Bruce Springstein, Elvis Presley, Ian & Sylvia and even the Kingston Trio. I take the blame of picking it as a name for this project!

[11] Actually, OSCAR-III in 1965 carried a 50 kHz wide 2 Meter in-band transponder with a 145.9 MHz uplink and 144.1 MHz downlink.

[12] Contrast this with a conventional 2 Meter repeater which requires a "Q" ≈ [146/0.6] = 243, a technical challenge ≈ 7.5 times harder.

[13] Instead of having Doppler effect the frequency, the entire passband "slides", much like the Passband tuning on an HF radio. Thus stations near the passband edges may "fall off the edge" as the satellite goes from "away" to "towards" as it moves in the orbit.

(Geostationary Transfer Orbits), **GEO** (Geostationary orbits), **Molniya** (high inclination but otherwise similar to GTO), and the 12-hour orbits used by GPS and GLONASS navigation satellites.

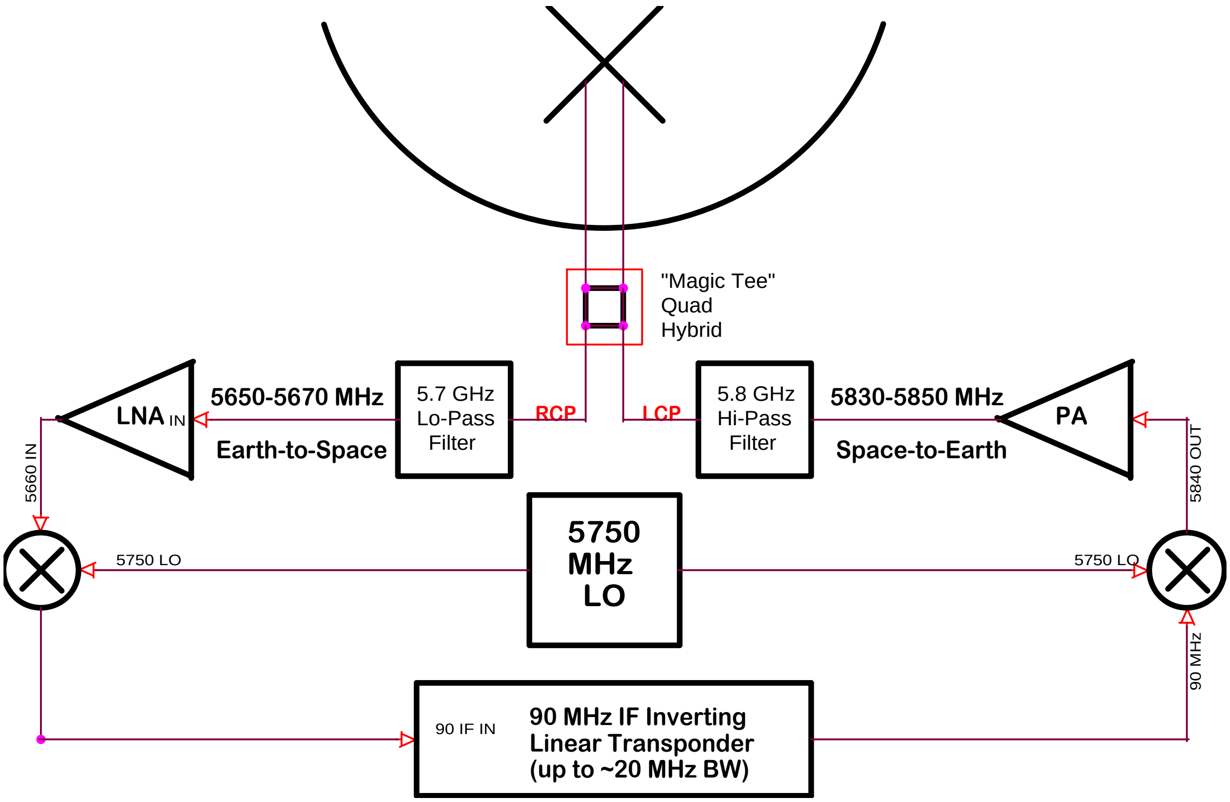

Figure 2: Simplified design of C-C Rider Spacecraft Transponder

LEO: If C-C Rider were to fly on a LEO satellite (~800 km), the Earth (and hence the users) fills much of the "down" half of the sky. A low-gain, wide beamwidth antenna is needed, like a small patch antenna (~6 dBiC gain). Computing the link budget[14] we find that the both the uplink and downlink path loss is about 175 dB. Let's put about 2 watts (output) of transmitter on the satellite.

On the ground, let's use a 30 cm dish (or a 3x3 phased array of patch antennas, as we discuss later) and a 70K LNA. Under these conditions, the downlink will just support a 64 kb/sec digital link (or a 64 kHz analog passband) without the addition gain that would result from coding and error correction. The use of these techniques could push the digital rate up to ~100 kb/sec. The user uplink will require about 5 watts of transmitter.

The 26 dBiC up/downlink antenna has a beamwidth ~12 degrees. This will need to be pointed at the spacecraft (mechanically or electronically) at levels of 2-3 degrees. An overhead satellite pass will produce peak satellite motion in the ½°/sec range, so the antenna will need to point very rapidly! In a later section I propose a possible "no moving parts" solution to this problem.

HEO: We all had a lot of hope in the promise of AO-40. Alas, the mission was only partially successful. We all have great hopes for AMSAT-DL's P3-E satellite and AMSAT-NA's Eagle satellite. Let's now look at how CC-Rider might work on Eagle.

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[14] I used an Excel spreadsheet template provided by Jan King, W3GEY for LEO mission planning.

To evaluate a typical HEO link, I assume a GTO or GEO satellite at ~36,000 km range. From that altitude, the one-way C-band path loss is 200 dB, 25 dB more than the LEO case we considered earlier. We also find that from the spacecraft, the earth now has a diameter of about 17°. To achieve a 17° beam, the downlink antenna can have only ~22 dB of gain, corresponding to an aperture of about 20 cm (i.e. about 3.5λ). Finally, I assume that we can generate 5 watts of RF.

On the ground I assume a 30 cm aperture (probably a phased array for reason described later), 70K LNA and 10 watts of transmit power.

Using a different link budget analysis tool[15], we find that the C-C Rider could handle ~120 kb/sec of data without regeneration[16], or about 600 kb/sec with regeneration. This could be apportioned out to multiple users for digital data or voice use following the model suggested by Phil Karn, KA9Q.

HEO ANTENNA IDEAS: I envision that the same antenna will be shared by the uplink and downlink. Figure 2 showed how this might be done with a dish antenna. The inherent problem with this scheme is that the antenna's mechanical structure must be mechanically stabilized to levels of about ¼ of the beamwidth. In the case of a LEO ground station, and for both the spacecraft and ground stations for HEO, antenna gain in the 20-25 dBiC range ends up imposing a requirement of a few degrees on the antenna pointing. But with CC-Rider we have the interesting situation: The receive and transmit antennas share a common physical structure, and we want the two antenna beams to point in the same direction.

It is common practice in the professional spacecraft world to use a "monopulse" feed. At the focus of a dish antenna we find an array of 4 antenna feeds which we might denote LEFT, RIGHT, UP and DOWN. Four separate receivers compare the RF phase of the signals seen by the L-R-U-D antennas. The antenna is then mechanically steered for zero phase difference. Then a 5th receiver makes use of the sum of all 4 antennas to get the full antenna gain.

Figure 3 shows a "no moving parts" approach we might use at C-band. I show 9 antennas arrayed in a 3x3 square (although a 4x4 or 5x5 array might be used if more gain is needed). On the receive side, each antenna is connected to a separate LNA and mixer, and then into a separate receive IF channel. The data from all 9 (or 16 or 25) is compared to measure the offset of the array from "boresight" relative. All the channels are summed to generate the low-noise signal needed by the transponder. As you can see, this is a phased array implementation of the traditional monopulse feed.

The receive signal processor has now determined how to pont the antenna to optimize the received signal; the desired transmitter direction is precisely the same as we "peaked" the receiver! So the same processor knows how to generate the phasing data needed to point the transmitter in the same direction.

I envision that the transmit phased array will use a separate power amplifier for each antenna. This makes it feasible to use multiple low powered transmit elements, like those already available in the consumer marketplace[17].

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[15] Also by Jan King, W3GEY, designed for the evaluation of the "KarnSat" digital payload for Eagle.

[16] The uplink signal is demodulated at the spacecraft, applying the gain of error correction. The "clean" signal then the signal remodulates the downlink. This provides for a significant improvement in end-to-end sensitivity

[17] Some very interesting, low cost ½ watt 5.8 GHz amplifier chips costing < $10 are available from Hittite: http://www.hittite.com/product_info/product_specs/amplifiers/hmc408lp3.pdf (thanks to Grant, G8UBN for the pointer).

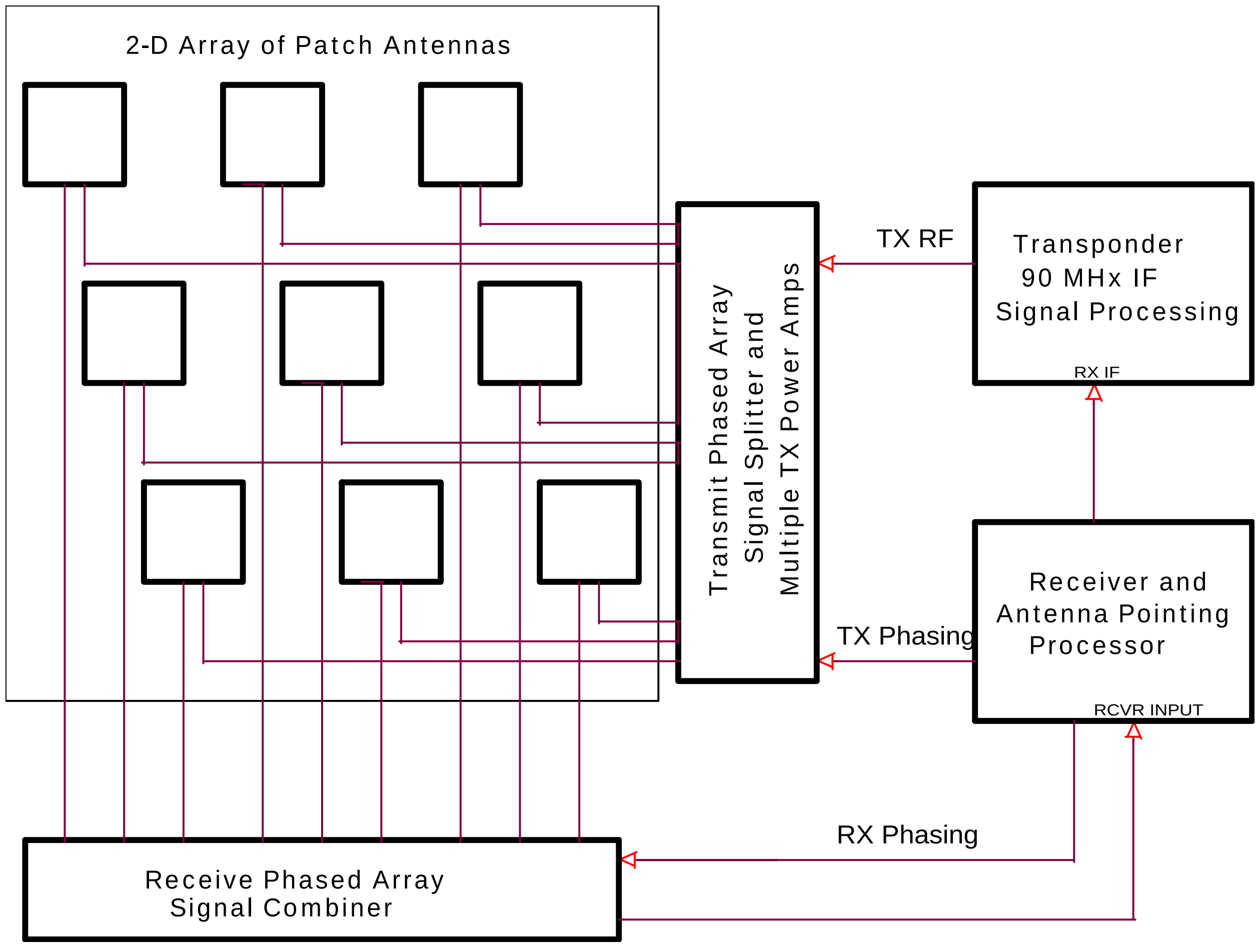

Figure 3: Using an Array of Patch Antennas instead of a Dish.

The use of separate receive LNAs and transmit power amplifiers for each antenna element provides a useful measure of reliability. If one of N elements should fail, then the array performance only drops by a factor of 1/N. Depending on spacecraft real estate, some extra elements could be flown to provide for the need for extra gain in an emergency. The amplitude illumination of the individual elements can be trimmed to provide active control of beams shape.

Some Other Ideas: So far I have not discussed any details of the inner transponder "guts". Figure 2 shows only a basic linear transponder. Certainly this could be made to work, and we could have a microwave replacement for Mode-B (or Mode-L/S). The interesting numerology of the two C-band channels causing Doppler to (nearly) cancel is neat. But we must ask if there might be alternate uses that make sense.

In thinking about these ideas, I asked myself a rhetorical question: What will be the thrust of Amateur Radio (and by implication Amateur Satellites) in the year 2018? Such a long vision is needed because it would take a few (let's guess 5) years before a new concept could fly. What will be the "hot button" technology in 2008? Then we hope that any satellite we build will continue to be a viable, exciting, living entity for at least a decade if not more.

Let me use historical hindsight to think about the implications of the need for long-range vision.
Back in the early 1970's, when we had OSCAR-6 flying, our members yelled that Mode-A was what they needed. Everyone had 10M capability; and a 2M TX was technically tough but possible. Many said "Why

even consider Mode-B in OSCAR-7? -- 70cm is like microwave and we mere mortal amateurs should not venture there!" Little did they know about all-mode, all-band radios!

In the early 1980's, as we were preparing Phase-3A, I saw the need for software to track elliptical satellites, so I wrote and published an "open source" ORBIT program. The naysayers said "Don't waste space in the AMSAT magazine – amateurs will never have their own computers". Little did they know that we would all have PCs connected to the Internet a decade and a half in the future.

The 1990's saw the birth of amateur digital satellites. AO-40 proved that L/S microwaves really are now in the grasp of amateurs. The folks planning missions now need to think about where amateur radio will be in the 2010's.

One of the imaginative views of the future has come from Phil Karn, KA9Q. His thinking is based on the success of creative mixtures of RF, digital and signal processing like we have seen with modern cell phones and the satellite phones used by correspondents in the middle-east which operate in the L/S band spectrum. DirecTV at and similar systems 12 GHz have shown that satellite-based microwave hardware can be combined with sophisticated digital coding and signal processing to provide robust, low-cost one- and two-way wireless paths.

Phil asked if we couldn't make similar capabilities for amateurs. Many urban amateurs have problems erecting antennas: can't we invent a system that could use technology developed by amateurs to provide the functional characteristics of 20 meters to the amateurs living in apartments?

Various AMSAT people have thought a lot about these ideas and have concluded that the answer is YES. We could augment Eagle to include some of the needed technologies. Let's morph Figure 2 into Figure 4 to see what the spacecraft might look like[18]. Here we see that the IF portion of C-C Rider has been replaced by three packages: a linear transponder, a "KarnSat" digital transponder and a 3rd package called (for historical reasons) RUDAK.

On the Ground – As seen from the User's Point of View: As I noted earlier NOBODY has the hardware that a ground-based user might need. If we build CC-Rider, we **must** develop the ground-based hardware at the same time. Figure 5 shows a view of what a user terminal might look like.

If you compare Figure 4 and 5, you will see few differences, except that the transmit and receive roles are reversed. Transmit filters become receive filters, upconverters become downconverters, etc. I envision that the microwave part of C-C Rider (inside the dashed lines in both Figures 4 and 5 on the next page) would be constructed on 2-3 microstrip boards and there is little difference between the user terminal and the spacecraft – we can get double duty from a good RF design. This would also be possible with the phased-array alternative.

[18] Of course, the antenna might be a phased array instead of a dish following the ideas in Figure 4.

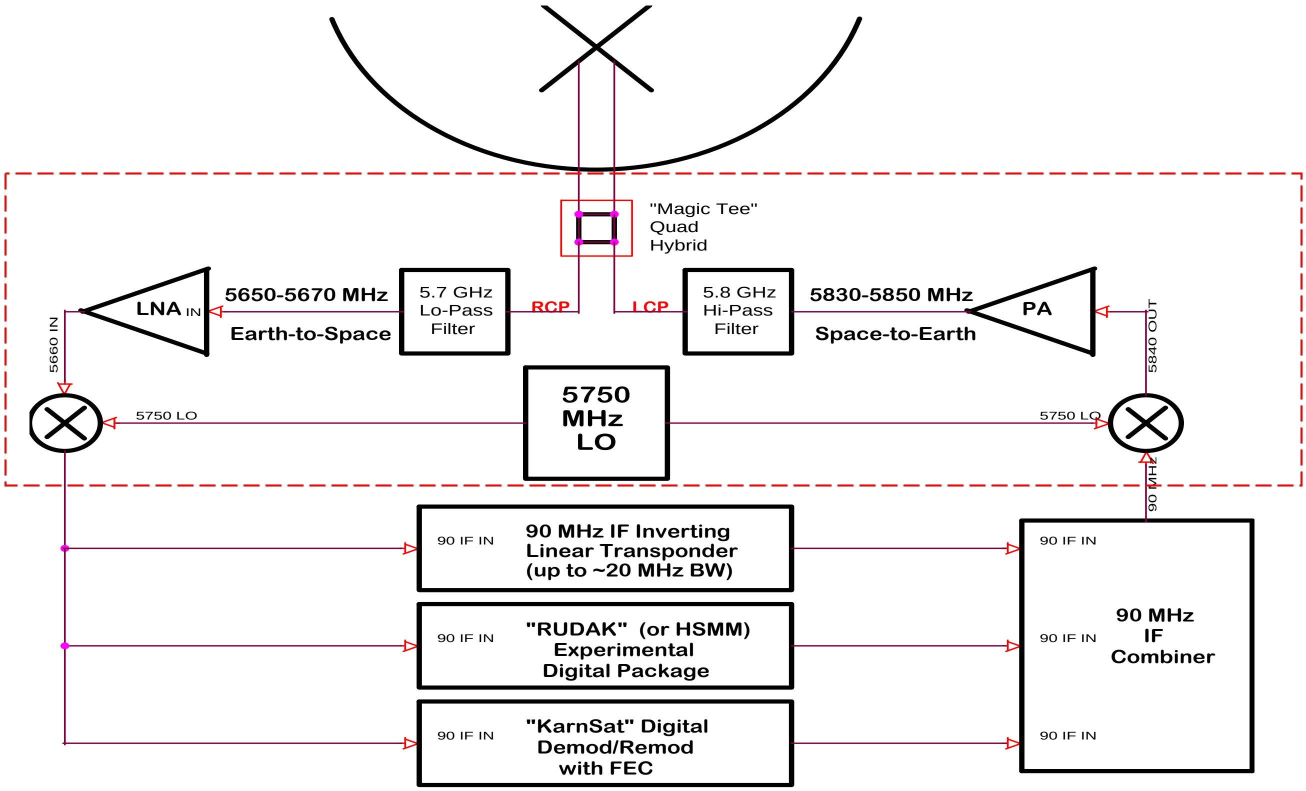

Figure 4: A possible C-C Rider Spacecraft Transponder for Eagle

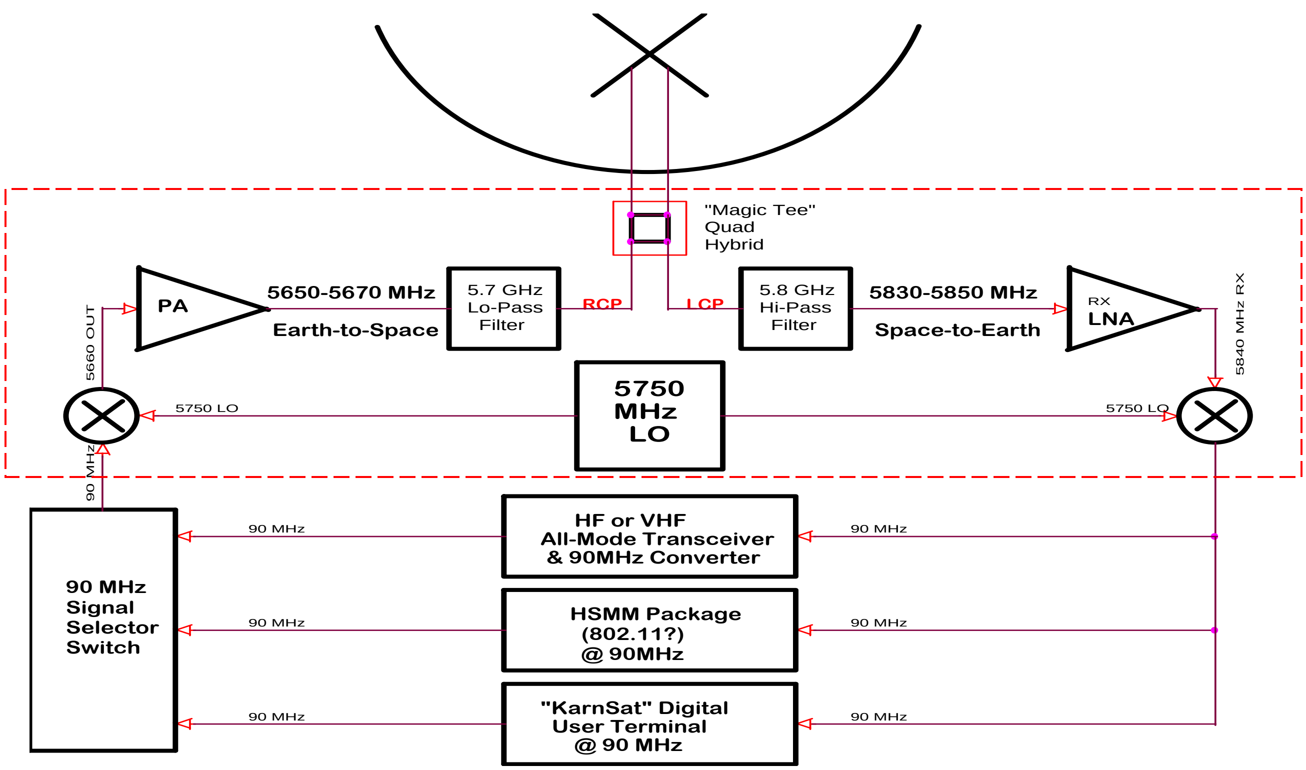

Figure 5: A C-C Rider Ground-based User Terminal

Terrestrial Possibilities: I mentioned earlier that the ARRL's HSMM effort has concentrated on the use of 2.4 GHz WiFi hardware, but that activity might want to try C-band. If some good RF hardware is developed that is suitable for both space and ground use, there is no reason that it should not serve as a technology resource for terrestrial use. "Dummy spacecraft" on mountain tops seem a logical development. Some low cost terrestrial hardware is already available.[19] So far, the "Hinternet" activity is based on 802.11x protocols, which in turn are derived from Ethernet; therefore they look a lot like packet radio. They require a timely packet-by-packet acknowledgement in order to achieve a good data thruput. These protocols look very different from a satellite link with light-travel-time limitations. So, while terrestrial and satellite applications might share a lot of hardware, they will probably require different software. But after all, that's not a serious limitation – there is an old adage:

It's only $oftware! It's the Hardware that's Hard.

In Conclusion: In this paper I have tried to present the radical idea – the Amateur Satellite folks need to lead the rest of Amateur Radio in the preservation of a valuable resource – our Microwave spectrum. We have already seen our 2.4 GHz turn into a "sewer" as unlicensed users move in to grab spectrum for their needs. Unless we begin a program to preserve our resources at C-band, they too will fall under the guillotine of consumer technology.

Let's not sing the blues[20] "Might not be comin' back at all" to our precious microwave allocations. Let's carry thru on the upbeat note "Just might find me that good girl, and everything would be alright".

Tom Clark
August 2003

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[19] Off-the-shelf ½ watt C-band amplifiers (intended for terrestrial WLAN use) are available at http://www.hyperlinktech.com/web/amplifiers_5800.html

[20] One version of Ma Rainey's CC Rider goes something like this. Note the highlighted lines:

CC RIDER

Well now see, C.C. Rider
well now see, see what you have done
Well now see, C.C. Rider
well now see, see what you have done
Well you made me love you woman
Now your man has come

So I'm goin' away now baby
And I won't be back till fall
I'm goin' away now baby
And I won't be back till fall
Just might find me a good girl
Might not be comin' back at all

Well now see, C.C. Rider
See now the moon is shining bright
Well now see, C.C. Rider
See now the moon is shining bright
Just might find me that good girl
And everything would be alright