Bringing the One True Rule of Doppler Tuning into the 21st Century

(*Or, "What frequency is the DX on?!)*

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Abstract

In 1994, Paul Williamson, KB5MU, discussed extending the existing conventional wisdom on Doppler correction to what is known as the One True Rule. [1] This describes a method where each operator tunes his transmit frequency, corrected for Doppler, so that it arrives at the same frequency *at the spacecraft* as every other operator. Likewise, each operator tunes the receive frequency, adjusted for Doppler, to the same downlink frequency *at the spacecraft*. This optimizes the use of the linear transponder passband, and if fully automated, greatly reduces operator workload. Due to limitations in existing software, it could only be approximated at the time. Only 5 years later, software existed to support this in a basic form. Today, all the major tracking and tuning software supports this in a largely transparent fashion. It is time to review the benefits of this approach as currently implemented, and to extend this to a new, unambiguous method of specifying operating frequencies.

Introduction

One of the most significant differences between terrestrial and satellite operations is the need to track not only the satellite, but the uplink and downlink frequencies. The closest we have come to date to "normal" terrestrial operations is a Phase 3 satellite near apogee. It appears to be nearly stationary in the sky for several hours, and once the matching uplink and downlink frequencies are found, you can tune around as you do on HF. When you tune the receive frequency a certain amount, you tune the transmit frequency an equal and opposite amount for most transponders. Some rigs such as the Yaesu FT-847 have a hardware method of locking this in. Away from this approximation of a stationary repeater in the sky, and particularly as the operating frequencies move into the microwave region, things become more complicated.

Historically, the manual method of tuning has been to adjust the highest frequency, whether the uplink or downlink. Since Doppler shift is proportional to the frequency, if you only tune one knob, this is the one. A refinement used by some is to do a quick "touchup" of the transmit frequency at the start of each station's transmission. This is simple, in principle easily understood, and is usable with old equipment. It requires no additional equipment, which can substantially simplify operations in remote locations. It has served us for decades, and is widely used to this day. However, it has major deficiencies, over and above the workload, particularly when applied to Low Earth Orbit (LEO) and Middle Earth Orbit (MEO) satellites.

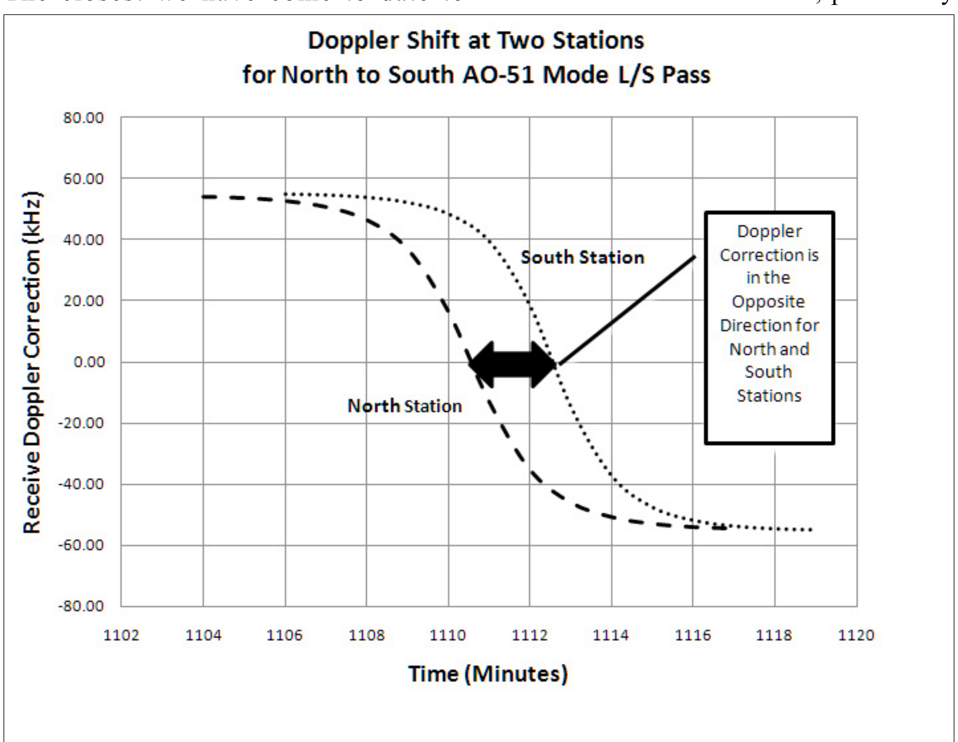

Figure 1: Doppler shift at two stations in a north to south AO-51 mode L/S pass.

It is easy to think that the other station is doing essentially the same correction you are, with only slight differences. In the Phase 3 example above, that is essentially true. For LEO or MEO satellites, this similarity is the exception rather than the rule due to the much shorter windows and rapidly changing velocities. Each satellite pass is unique to each station except for special geometries. If the stations are very near each other geographically, then they will tune the same way. For another case, consider two stations on the same latitude but different longitudes. If a satellite in a North-South orbit passes exactly between them, then they will in fact make exactly the same tuning corrections. While possible, these are configurations rarely seen.

A much more realistic scenario would result in one station seeing the satellite pass close to overhead, and the other station seeing it much closer to the horizon. Whatever tuning method is used, these stations would make corrections at different times and amounts. For instance, the Time of Closest Approach (TCA) is the time in any pass where the rate of change in Doppler correction is most rapid, and changes from a positive to a negative correction of the receive frequency. Most importantly, the TCA (and rapid frequency change) occurs at different times for each station except for the sort of artificial situations discussed above. Figure 1 shows the difference in Doppler correction at my station and another station approximately 600 miles to the north. For the indicated period, about 2 minutes, the northern station is applying a large, negative Doppler correction while I am still applying a large positive one.

KB5MU discussed these factors in an abbreviated manner in the original article. [1] He also discussed in detail optimizing the use of traditional tuning methods. Tony Langdon, VE3JED, has an extended discussion [2] of the differences in Doppler shift, with excellent graphics, of high and low elevation passes. Both are highly recommended for those desiring more detail and a better feel for the subtle aspects of Doppler shift and correction. Since it really does depend on how you look at the

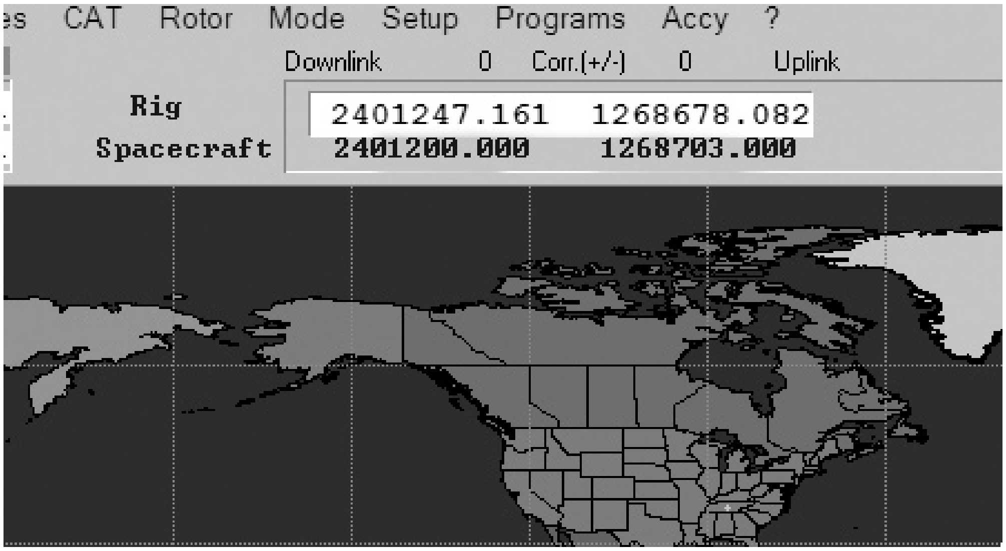

Figure 2: Mockup of program display optimized for spacecraft frequency tuning.

satellite, the brief following discussion of the limitations of traditional manual tuning is necessarily simplified. Hopefully it gives a good qualitative feel without covering all the unique ways problems can arise.

First, if we use the traditional manual tuning methods, there will be at least some drift through the satellite passband. Ideally, if everybody is using the same technique, most of the QSOs will drift roughly in parallel, most of the time. Again, around TCA, a particular station may jump in the opposite direction, or "over" an adjacent QSO. Still, as long as nobody starts near the edge of the passband, all is reasonably well. New stations just find an unused frequency pair, and go with the flow. Even this idealized situation is complicated by the fact that everybody has their own way to implement a given technique. The real world result is that you have QSOs colliding with each other in a crowded passband.

Second, you have the situation of round table QSOs. I have not quantified this, but qualitatively they seem more common today than in the AO-10 and AO-13 days. Also, there is a more natural flow of conversations, rather than a series of monologs. The result is that if you wish to tweak your uplink on each transmission, you are doing this more often. (Since most tracking programs call their implementation of the One True Rule something like Full Doppler Tuning (FDT), I will use that term for simplicity.) By comparison, I have worked multiple stations in a round table on AO-7, all using FDT, from AOS to LOS, without significant manual tuning. A recent listening survey of stations on AO-7, FO-29 and VU-52 showed about half were using FDT.

Finally, techniques which work well in practice on modes V and U are challenging at mode L and higher frequencies, even for the relatively less critical FM modes. Table 1 shows the typical maximum Doppler shift found in selected orbits. The three altitudes shown are roughly those of AO-51 and other LEO satellites, AO-7 and a higher MEO orbit which is currently being considered. Except around TCA, even mode U Doppler shift changes slowly enough for normal human intervention. At mode S, 2.45 GHz, the shift is 5-6 times as large. More importantly, so is the rate of change. Lacking an ideal stationary satellite, the change in the Doppler shift is too rapid for all but those with the skills of a virtuoso pianist. For even MEO satellites, the uplink can drift so far from the previous frequency that the tuning required for a new transmission resembles more closely the initial hunt at the beginning of the QSO.

Table 1

Maximum Doppler Shift (kHz) at Selected Altitudes for Circular Orbits				
Satellite Mode Frequency (MHz)	**V 145.9**	**U 436.0**	**L 1280.0**	**S 2401.0**
800 km	+/- 3.0	+/- 9.0	+/- 26.2	+/- 49.6
1500 km	+/- 2.9	+/- 8.6	+/- 25.0	+/- 47.3
8000 km	+/- 2.1	+/- 6.4	+/- 18.5	+/- 35.0

Using what we have

How does FDT really work? Imagine a satellite transponder on a very tall tower, or equivalently on a spacecraft in geosynchronous orbit such as the fabled Phase 4 satellite. It is stationary with respect to all stations. In this case, there is no Doppler shift. All stations transmitting on the same frequency will listen on the paired downlink frequency. Should another FTD station wish to use the transponder, they simply find an unused downlink frequency and call on the matching uplink frequency. The operation is very similar in concept to terrestrial repeaters, though most are FM and only accommodate a single channel.

FDT uses modern computing power and rig control to work the problem backwards, making the Doppler shift nearly invisible to the operator. The program actually "thinks" in terms of the frequencies *at the satellite* and constantly computes the matching rig frequencies. While both the uplink and downlink *on the rig* may be changing rapidly, the frequencies *at the satellite* do not. In a practical sense, the satellite appears *from an operator tuning standpoint* to be stationary.

Making this happen requires only a simple setup for each satellite transponder. You need to specify the relationship between the uplink and downlink frequencies. The nominal values are given for the transponder in various places including the AMSAT Weekly Satellite Report. All of the major tracking programs have this capability and explain its usage. Think of this as equivalent to "locking in" the frequency offset of a Phase 3 satellite discussed in the introduction. However, there is an important difference. Once this is done, it is good for all parts of the orbit, every orbit! [3]

Once this is achieved, you can tune around the passband. The matching uplink frequency will follow. Whatever your receive frequency, when you key the transmitter, you will hear your voice or CW come back to you. No tuning around, no "aaaaaahhhhhh" dragged across a QSO in process, and better, no one doing so to you. In practice this makes satellite tuning very much like terrestrial HF. You can largely forget about what the transmitter is doing, since the computer takes care of that for you.

Now assume someone answers who is also using FDT. You will hear the reply on the frequency you are currently listening. More importantly, over time the satellite position and hence relative velocity will change, and both station's uplinks and downlinks will be changed, but the signal will remain in tune at both stations. Should another FDT station join the QSO, all three will be able to concentrate on talking, not tuning. That is because each station will always put his uplink on the same frequency *at the satellite*, and so each station knows on a second by second basis where to look for the downlink. By contrast, the traditional methods place the uplinks scattered over a few hundred Hz to a few kHz of the satellite passband as the QSO progresses.

Is this useful with other stations still using manual tuning? Yes and no. Most programs have a way to select whether you wish to tune the uplink, downlink, or both. By selecting the one which corresponds to the higher frequency, you can decrease your workload a bit and receive most of the benefits of FDT. As a practical matter, it works better if you use either full automatic or full manual methods. People are used to using one method or the other, but not a combination. The few times I have tried a mixed mode, it generated both interest and confusion in equal parts. Of course, this is a matter of preference.

A slightly heretical technique, if you feel you must keep your hand in by tuning the receiver, is to let the computer tune the uplink, regardless of frequency. If the other operator wishes to use FDT he can, or can manually tune his receiver as well. It has the effect of keeping your uplink locked to the same frequency *at the satellite,* which is the primary QRM issue for other operators.

Another practical application is in working stations which have a very limited window of mutual visibility. The topic has come up on the AMSAT bulletin board with regard to AO-7 and other satellites with linear transponders. In a window which may be measured in a minute or less, you do not want to waste time in netting in the uplink and downlink frequencies. With FDT if you hear someone calling CQ, you already have his downlink, and your uplink will already be zeroed in for you. The only unknown is where he is listening. If he is also using FDT, you don't care! Key the rig and you should have a QSO. What happens if he is not using FDT? He will be listening to his downlink, so at that instant he will in effect be doing FDT. Depending on how closely he matches his tuning, he will hear you exactly on frequency, or at least close enough that you will get his attention. In either case, you have your QSO.

So what is missing? FDT allows us to work a station easily which we hear while tuning around. What about a scheduled contact? A terrestrial traffic net, or a scheduled QSO with old friends, is easily specified as a frequency, +/- QRM. Everybody starts there, and then tunes around slightly. Even with FDT, we still lack a way to do the equivalent. For instance, two stations planning to meet "on 435.000 MHz" can tune their rigs to that frequency, but because Doppler shift is different for each station, they may not even be close enough to hear each other. We would like to have a frequency which each station can use in the same unambiguous way as terrestrial stations. Such a frequency exists, as we shall see, though neither the rig nor current tracking program displays it.

Where do we go from here?

With full implementation of the One True Rule, we have largely taken the busy work out of satellite communications. There is one question we have not made it easy to answer yet: "What frequency are we on?" Unless you are talking with a station across the street, each station will have his rig tuned to different receive and transmit frequencies. As we can see from Table 1, in the case of microwave frequencies, these can be significantly different frequencies. However, in the case of FDT, every station will be listening to the same frequency *at the satellite*. No matter how many are in the QSO, this will be an invariant all operators can agree upon.

This seemingly privileged frequency is not really a new idea. Modern tracking programs actually use this idea in two ways. For channelized FM satellites, you specify the repeater input and output. The program does the rest. We just say that the uplink is 145.920 MHz and the downlink is 435.300 MHz for short. The "+/- Doppler" is simply assumed, but we don't put it on a QSL card. (The classic TAPR/JAMSAT TrakBox, among other hardware implementations, also has this capability.)

The other way is when configuring the reference frequency pairs for a linear transponder. For AO-7, I find that an uplink of 432.14768 MHz and a downlink of 145.950 MHz is a good match for the "Hello Test" calibration. The tracking program will start here, just as it would for the FM case. The difference is that as you tune around the downlink, the transmit frequency will change appropriately. While clumsy, we could specify our SSB/CW frequencies *at the satellite* here, and achieve the goal.

As we have seen, we work daily with satellite-centric frequencies, even though they are not normally visible in tracking programs. How can we make them visible? A tracking program will normally display the rig frequency, and the Doppler shift being corrected. If you add those two numbers, including the sign, the sum will not change, even though both of the components may be changing rapidly. Why? This sum is what we are looking for; the frequency *at the spacecraft*!

Assume that the authors of satellite programs make this display an option. See Figure 2 for a conceptual display. How would we use it, and how would it change our operating techniques? First we would change the way we think about and specify the QSO frequency. The full version would be "Fox, 2401.200 MHz, Spacecraft." This gives the spacecraft, and the receive frequency *at the spacecraft*. No questions or ambiguities, no matter your QTH. (This is also the frequency to which your rig would be tuned near TCA.) Do we need to specify the full mode, such as L/U or V/U? No! Both AO-13 and AO-40 had modes in which more than one uplink was translated to the same downlink simultaneously. While knowing which uplink the other operator is coming in on is interesting and appropriate for a QSL card, it is redundant so far a making a QSO is concerned. Any uplink which gives the same downlink frequency *at the spacecraft* is equivalent.

Second, the primary tuning reference would move by necessity to the computer screen rather than the rig. One could tune the rig dial, but watch the "Spacecraft Frequency" on the screen, or presumably enter it manually. With the steady progress toward software defined radios, or at least control software, this will soon seem natural, and already is for many.

Implementation

How do we get from here to there, and should we? The many existing tracking programs make this relatively easy to approximate. With your tracking software's version of FDT engaged, one can look at the rig frequency and Doppler shift, and mentally combine them to get the needed frequency. If you have a schedule with another station using this technique, it will get you much closer than just tuning the rig to the schedule frequency, and then having to hunt around. Usually you will get close enough to hear the other station. A quick tune of your receive frequency, and you are done, except for the QSO. If this option is added into existing and future programs, it will become a true “HF mode” in terms of simplicity, both hypothetical and practical. Manual tuning, while still viable, especially for portable stations, may eventually be considered in the same way we consider Straight Key Night.

Considering that the basic One True Rule is not yet universally used 10+ years after the software to use it became readily available, it is to be expected that such a radical paradigm shift in how we specify “the frequency” will require another generation to fully assimilate and implement. Still, this extension can be tested, verified, and refined with minimal to no impact on more traditional users as operating frequencies continue to expand.

My thanks to KB5MU for valuable suggestions and insights for this article. Any mistakes and omissions are my own.

Footnotes

[1] “The One True Rule for Doppler Tuning,” Paul Williamson, KB5MU. OSCAR Satellite Report #284, Jan 1, 1994. http://www.amsat.org/amsat/features/one_true_rule.html

[2] “A Close Up of Doppler Shift” Antony Langdon, VK3JED, http://vkradio.com/doppler.html

[3] For FM operations, the nominal values are usually accurate enough. For CW and SSB, it is necessary to specify the values closer than the nearest kHz. For natural sounding reception, 25 Hz or better is desirable. This is nominally a onetime calibration, though in practice it needs to be touched up due to aging and temperature shifts in the spacecraft a few times a year. This compares well with updates for every QSO with traditional methods.