Working the LEOs – Part 1-4, an introduction to amateur radio satellites.
by Andrew Barron ZL3DW. (August 2006)

When I was four my mother bought me a book called, “You will go to the moon”. I am still waiting for the call from NASA, but I have been interested in space and science fiction ever since. I guess it was natural for me to combine that interest with amateur radio and have a go at satellite operation. I started a few years ago by beginning to set-up a station for operation on AO-40. I retired my old FT-301 in favour of a Yaesu FT-847, which has all the HF bands as well as 2m and 70cm. The FT-847 is designed with special features for working satellites. Most importantly, it can receive on UHF while transmitting on VHF (and vice versa), which is almost essential when working SSB on satellites. I decided to concentrate on getting the receive side going first so I got an 800mm dish, made a patch feed and got a, “modified for S band”, down converter from California Microwave. Unfortunately by the time I got all this together the AO-40 control station was having problems with the satellite and they tuned off the S band pass through. So although I could hear the beacon, I could not hear any QSOs. Then disaster struck and the satellite failed completely, so it was back into the garage for all the satellite gear.

My interest was rekindled when I down loaded some APRS software from the Internet. I had fun scaling maps and plotting stations all around New Zealand via the local APRS channel. Then my thoughts turned to the International Space Station (ISS). I tried APRS through the ISS, then the packet store & forward, it worked great, but once it was done it lost its appeal. I could see my APRS beacon plotted on the map and a few others from New Zealand and occasionally Australia, and I could retrieve the message I had stored on the ISS bulletin board, but I was not actually communicating with anyone. Next I moved on to the “analog” satellites, which I have found much more interesting.

There have been 58 OSCAR satellites so far, starting with OSCAR 1 which was launched 12th December 1961. This was a remarkable achievement when you consider that it was launched only four years after Sputnik, the first man made satellite and was the first non-governmental communications satellite. By the way, OSCAR stands for Orbital Satellite Carrying Amateur Radio. An OSCAR number can be allocated to any satellite which carries an amateur radio payload such as a beacon or repeater (transponder). The OSCAR number is not allocated until the satellite is in orbit, so unsuccessful launches do not count. The AMSAT website is currently listing 21 OSCAR satellites with some form of amateur radio equipment operational. Some only have working beacons, but ten of them have operational transponders. The satellite status page is at http://www.amsat.org/amsat-new/satellites/status.php

Probably the most amazing AMSAT story so far, is AO-07 “Oscar 7”, which was launched in November 1974. It continued working until in 1981, after a very creditable seven years of operation, it failed due to the battery going short circuit. In 2002 some 21 years later, AO-07 began transmitting again. It is assumed that there has been corrosion in the battery bank which has now become open circuit. The satellite will now work, powered from its solar panels, while in full sunlight and can be used for amateur radio QSOs. It is pretty impressive that amateurs could build a satellite that is still working after 32 years in space. <38 now and still working!>

There are three broad classes of satellite, GEOS, HEOS & LEOS. The first type, geostationary satellites are in circular high equatorial orbits, around 35700km above the equator, where their velocity is slow enough for them to remain over approximately the same point on the Earth's equator, as the Earth revolves. This type of satellite is used for TV broadcasting and telephony etc. There are no geostationary OSCARs. The next group is the high Earth orbit satellites, which are usually in big elliptical (Molniya) orbits. AO-40 and AO-10 were HEO satellites. At present there are no active HEO amateur radio satellites, but P3E "Express" is due for launch next year and AMSAT "Eagle" in 2008. <Eagle is cancelled and we are still waiting for P3E> Working through P3E or Eagle from New Zealand, a ham will be able work stations in all of North and South America, the Pacific and most of Africa.

The last and most common type of amateur radio satellites are the low Earth orbit satellites. These include the International Space Station (ISS), GPS satellites, weather satellites and all of the currently active OSCAR satellites. The LEO OSCARS are in low elliptical, usually polar, orbits with perigee (closest point to Earth) of around 680km – 800km and apogee (farthest point from Earth) of around 800-1320km. Since the LEO satellites are closer to Earth, the coverage area or "foot-print" is much smaller than the foot print of a HEO satellite. A ham in New Zealand can expect to work all of New Zealand and Australia through the LEO OSCAR satellites. The ISS has a more circular orbit 333 perigee - 348km apogee. For comparison AO-40 has an apogee of 58,776km and a perigee of 1,044km.

There are many exciting AMSAT projects underway around the world. In Germany a team is working on P3E "Express" a high orbit satellite which will carry a whole range of transponders plus a camera and other experiments. The Americans are <no longer> working on "Eagle", another high orbit satellite, designed to complement P3E and provide nearly continuos satellite coverage. The local New Zealand AMSAT group is working on Kiwi-Sat and was able to demonstrate a working "space ready" FM transponder at the recent NZART convention. It would be a shame if only a handful of ZL hams used the satellite after it is launched in 2008, so I hope some Break-In readers will get a station together to work the LEOs. If you have any questions drop me an email at zl3dw@nzart.org.nz and I will try to answer them or at least try to point you in the right direction.

Part 2 will describe the currently active OSCARS and what you need to start using the LEO satellites from your shack.

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Working the LEOs – Part 2, the OSCARS and how to work them.

by Andrew Barron ZL3DW.

Working the low earth orbit satellites can be done with reasonably modest equipment and need not cost mega-bucks. I have worked through SO-50 using a dual band Alinco "hand-held" while standing in the dark, in the middle of my back yard. However that is really a bit too minimal.

The most useful LEO satellites are:

AMSAT	Name	Owner	Mode	Type
FO-29	Fuji Oscar29	AMSAT Japan	VU	SSB/CW
VO-52	VUSat HamSat	AMSAT India	UV	SSB/CW
AO-07	Oscar 7	AMSAT NA	UV or VA	SSB/CW (sunlight only)
AO-51	Echo	AMSAT NA	VU, LU, LS	FM voice and Packet BBS
ARISS	ISS	NASA / Russia	VV	APRS, Packet, Crew FM
SO-50	Saudi Oscar50	KAUST	VU	FM voice
GO-32	Gurwin TS1b	Israel	VU	Packet BBS
AO-16	PacSat	AMSAT NA	VU or S	APRS

Note that AO-27 is operational but is not turned on over the Southern Hemisphere.

Web pages: The AMSAT web page has reasonably up to date information on the status of flying and future ham radio satellites, plus full details of the frequencies to use etc. You can also down load the Kep data as a text file for your satellite tracking program. http://www.amsat.org/amsat-new/satellites/status.php P3E “Express” information is at http://www.amsat.org/amsat-new/express unfortunately it is well out of date.

If you don’t have software to predict when a satellite will be above the horizon, you can use the online “passes” calculator on the AMSAT web site. You will need to know either your QTH latitude & longitude or Maidenhead Grid square for this to be accurate.

Transceivers: You can operate the FM voice satellites with a dual band FM transceiver with 5kHz channel spacing (or better), but for digital modes and SSB satellites, multi mode transceivers with FM and SSB (both USB and LSB), are required.

While not 100% essential on FM satellites, it is best if your satellite setup has the ability to receive on 2m while transmitting on 70cm, and vice versa. This can be achieved by having two transceivers or by having a transceiver capable of full duplex cross band operation. In my opinion, the three best transceivers for satellite work are the Kenwood TS2000, Yaesu FT-847 and Icom IC910H <IC9100>. The Kenwood and Icom transceivers have optional upgrades for L band operation as well.

When the satellite is high above the horizon, 2W of transmit power into a short Yagi antenna is plenty. Closer to the horizon the path is longer and more cluttered so more power is required, 35W on UHF and 50W on VHF is common. Particularly when using the satellites with linear passbands (SSB/CW types), it is important to reduce your TX power as the satellite rises, to avoid overloading the satellite transponder. With a linear transponder all users in the passband share the power of the satellite transmitter. Big input signals cause other users to get less of the power budget available. This is particularly important when using AO-07, because the satellite is operating without batteries and is prone to “FM” distortion. The satellite has a linear transponder so large signal peaks on the satellite input causes the transmitter to draw more current off the solar panels, this pulls down the voltage rail, which pulls the transponder off frequency, effectively FM modulating all downlink signals with your modulation. Apart from distorting your downlink signal, any other users will not appreciate your modulation affecting their downlink signals.

Antennas and polarisation: The minimum antenna for satellite work is an omni directional antenna capable of working on 2m and 70cm. I initially used a Discone with a UHF/VHF diplexer to combine the two antenna connectors on the FT-847. Two antennas is better, Colinear antennas should be OK and many hams use small loops or the “Texas Potato Masher”. Yagi antennas are better still, particularly if you can adjust the elevation as well as the azimuth. I am using a 5 element Yagi on 2m and a 12 element Yagi on 70cm.

Crossed Yagis, helixes and other circular polarised antennas are a definite advantage. On LEO OSCARs the satellite’s VHF and UHF antennas are usually diploes. But the satellite could be tumbling and in any case the polarisation of the RF signal you receive will change as the satellite passes. The fading that this causes can be minimised if your antennas are circular polarised. Cross polarisation fading affects your uplink signal as well.

The satellite’s SHF antennas for L and S band are always rhcp, (right hand circular polarised), so a gain penalty of around 3dB will apply if your antennas are linear polarised. Common antennas for L and S band are helixes or dish antennas fed with either a short helix or patch antennas. Horn feeds or Yagis will work but are usually linear polarised. Arrays of patch antennas would be an interesting alternative.

Computers: You do not have to have a computer in the shack, but it is a really big advantage if you do. It does not have to be a super-computer, I am getting by with an old P166 running Windows 95. There is a lot of shareware available on the Internet to help you find when and where the satellites will arrive over the horizon. I use SatPC32 which can track multiple satellites, predict the times the satellite will appear and disappear over the horizon, show you the area covered by the satellite’s antennas, display the heading and elevation to point your antenna, and control your transceiver frequencies complete with automatic Doppler adjustment. I also use “Dimension 4” which will set your PC clock to an atomic time reference in Adelaide or several other places. If you are using automated rotator tracking, the satellite tracking software needs the clock on your PC to be accurate to within a minute. A LEO can travel from horizon to horizon in ten minutes, that means the elevation and azimuth could be changing by 18 degrees per minute. If your clock was out by two minutes the rotator could be pointing 36 degrees away from the actual satellite bearing.

Modes: VU mode means that the uplink to the satellite from your QTH is on VHF (2m band) and the downlink is on UHF (70cm band). Naturally, UV mode means that the uplink to the satellite from your QTH is on UHF and the downlink is on VHF. The “A” band is 10m, “S” band is 2.4GHz and “L” band is the 1268MHz band. The NZART callbook has charts, which show the satellite portion of each band. Some satellites such as AO-51 have transponders on a variety of bands which can be turned on and off by the control station. The AMSAT web page has the frequencies for each satellite. Generally where there is a “linear transponder”, i.e. the SSB/CW satellites, the calling frequency is near the centre of the frequency range available. Some linear transponders are “inverting” which means that as the uplink frequency increases the downlink frequency will decrease, also LSB input to the satellite becomes USB on the downlink.

Assuming the editor has not got sick of me, Part 3 will attempt to take the mystery out of some of the jargon, explain why a satellite stays in orbit and take a quick look inside the “Kep” data.

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Working the LEOs – Part 3, satellite jargon and Kepler data unravelled.
by Andrew Barron ZL3DW.

When writing part 1 and part 2 of this article, I realised that I was using a lot of terms that may be unfamiliar to hams not already working ham satellites. This section contains more about satellite orbits and the jargon used.

How does your tracking program know when the satellite will be above the horizon? I am tempted to say that it is all done with "smoke and mirrors", but really it is mathematics. I do not propose to get into the maths but I will explain the basics. First the tracking program needs to know where your QTH is. The program will store your Maidenhead Grid or Latitude and Longitude as a reference. Secondly the AOS, Doppler and tracking calculations are only as accurate as the clock on your PC. Normally PC clocks are not very accurate, so check it regularly. I use a small freeware program called Dimension 4, which resets the PC clock to an atomic time source. The purists will know that the packet delay (latency) in the Internet will degrade the accuracy of this, but it should be within a few seconds which is plenty good enough. Finally the program needs to know the shape of the satellite's orbit, how long the satellite takes to orbit the Earth and the angle of the orbit relative to the equator. This information is contained in the Keplerian data, [invented by Johann Kepler 1571-1630], down loaded as a text file from the AMSAT Internet site. You can type it in by hand if feeling masochistic.

The Kep data uses six numbers to describe the shape of the satellite's orbit and is also a snapshot of where the satellite was in its orbit at a particular "Epoch" time. From that information the satellite tracking program can work out the number of orbits the satellite has completed since the Epoch time and therefore its current position. Luckily we don't have to understand the mathematics involved in using the Kep data, the PC does all that for us. I do have some of the formulas. If anyone is interested email me at zl3dw@nzart.org.nz.

There are two standard formats for Kep data, AMSAT "verbose" as shown below and the more concise NORAD "2 line" format, used by the majority of satellite tracking programs. NASA produces Kep data for every satellite in orbit plus misc bits of space debris. There is a tutorial on Kep data at http://www.amsat.org/amsat-new/tools/keps_detail.php The table below has a summary;

Table 1. AMSAT Kepler data – verbose format.	
Satellite: AO-07	Self explanatory
Catalog number: 07530	NASA number for AO_07
Epoch time: 06193.72461558	Reference time for this Kep data set. Year 06, day 193, time 0.*72461558 of a day*
Element set: 627	Sequential number for this Kep data set
Inclination: 101.5658 deg	Degrees above the equator of the orbit. AO-07 has a Polar orbit 101.56 degrees above the equator. (0-180 degrees).
RA of node: 236.0155 deg	Angle relative to longitude lines where the sat crosses the equator when heading South to North

Eccentricity: 0.0011915	How circular the orbit is. 0= circular, greater than 0 is more elliptical, E can never reach 1.
Arg of perigee: 195.6462 deg	Part of the orbit (ellipse) where the satellite comes closest to Earth ref to RA of node.
Mean anomaly: 164.4238 deg	Range 0-360 degrees. MA=0 at perigee and 180 at apogee. This figure defines where the satellite was at Epoch time. AO-07 was at MA 164.4238 so nearly at apogee.
Mean motion: 12.53571525 rev/day	How many times the satellite orbits in one day. The Apogee and Perigee can be calculated from Mean Motion and Eccentricity.
Decay rate: -2.8e-07 rev/day^2	Rate at which the satellite is slowing down due to orbital drag.
Epoch rev: 44858	Number of orbits since the sat was launched (may not be accurate).
Checksum: 307	Use unknown

Orbits and gravity, (a layman's explanation): When a satellite travels in a circular or elliptical orbit around the Earth, the circular motion exerts centrifugal force on the satellite. The centrifugal force is the same as the force you feel when you whirl a bucket of water around on the end of a string. The centrifugal force causes the satellite to want to fly off into space at a tangent to the Earth's surface. This is the same as what would happen if you let go the string on the bucket. The satellite is also affected by the force of gravity pulling it towards the centre of the Earth, (that's the string). A stable orbit is achieved when the speed of the satellite around the Earth is high enough to cause the centrifugal force pulling the satellite away from the Earth to exactly balance the force of gravity. As the satellite, attracted by gravity, moves closer to Earth, it speeds up. The faster speed causes more centrifugal force which causes the satellite to move further out. The same is true if the satellite drifts further away from Earth. It slows down, centrifugal force drops and the satellite drifts back inwards. In this way the satellite orbit stabilises itself.

A satellite in a circular orbit stays at approximately the same speed all the time. For instance the International Space Station has a perigee of about 333km and an apogee of about 348km. To maintain this orbit the space station travels at about 7.7km per second or 27,720kph. It completes an orbit of the Earth every 91.48 minutes. Satellites in elliptical orbits speed up as they race in towards Earth and slow down as they reach apogee.

The satellite's inclination is important to us in the Southern Hemisphere. For a satellite to pass over your location, its orbit must have an inclination greater than or equal to your latitude. If a satellite has an Inclination > 43.5 degrees it will pass over Christchurch on some orbits. A satellite with an inclination of 0 degrees orbits the equator.

If you know a satellite's altitude you can calculate its speed, if you know its speed you can calculate the Doppler shift.

More tech talk:

- AOS - acquisition of signal. Time the satellite appears above the horizon
- LOS - loss of signal. Time the satellite sets below the horizon
- Uplink – the signal you send to the satellite
- Downlink – the signal you receive from the satellite
- Mode – frequency band of uplink & downlink (UV, VU, LS, VA)
- Pass – the time the satellite is above the horizon and can be used
- Passband – frequency range of a transponder (FO-29 has a 100kHz passband)
- Beacon - most satellites have a fixed cw or telemetry beacon transmitter, some have several.
- Transponder - A transponder is a wide band repeater. It accepts a range of frequencies on the input and retransmits the entire range on the output.
- Repeater – a single frequency transponder, just like a standard FM repeater except it works cross band. All satellite repeaters and transponders are full duplex, meaning you can and should listen to your signal on the downlink while you are transmitting.
- Digipeater – a transponder which regenerates a digital signal and retransmits it on another frequency. As opposed to a repeater which does not regenerate the digital signal.
- Pilot tone - some FM sats need a tone, usually 67.0Hz on your transmission to open the satellite receiver squelch. Most modern rigs can generate these DCS tones. AO-51 needs 67.0Hz. SO-50 needs 74.4Hz for a few seconds to turn on a 10 minute timer, then 67.0Hz on each transmission.
- Inverted – The satellite receives on LSB and transmits on USB. Generally inverted transponders are also “reverse tracking”.
- Reverse tracking – The downlink frequency increases as the uplink frequency decreases. Generally reverse tracking transponders are also “inverted”.
- Kep data – Reference Kepler data downloaded as a text file
- Doppler – frequency shift caused by the relative speed of the satellite
- Analog satellite – satellite transponder for voice or cw, (or audio based digital transmissions).
- Digital satellite - satellite transponder for digital modes often AX25 FSK, used for APRS, often carry bulletin boards, digipeaters or packet store & forward.
- ISS – International Space Station
- ARISS – Amateur Radio aboard the International Space Station
- perigee – satellite orbit closest point to Earth
- apogee - satellite orbit farthest point from Earth
- Footprint – area covered by a satellites antennas
- Spin modulation – fluttering or fading caused by the satellite spinning or tumbling
- Attitude – angle of the satellite with respect to Earth
- Squint – angle of satellite’s antennas to your location. (If the satellite’s antennas point straight down they are not pointing directly at your QTH).
- OSCAR – <u>O</u>rbital <u>S</u>atellite <u>C</u>arrying <u>A</u>mateur <u>R</u>adio

Part 4 if there is anyone still interested, is about coping with Doppler shift.

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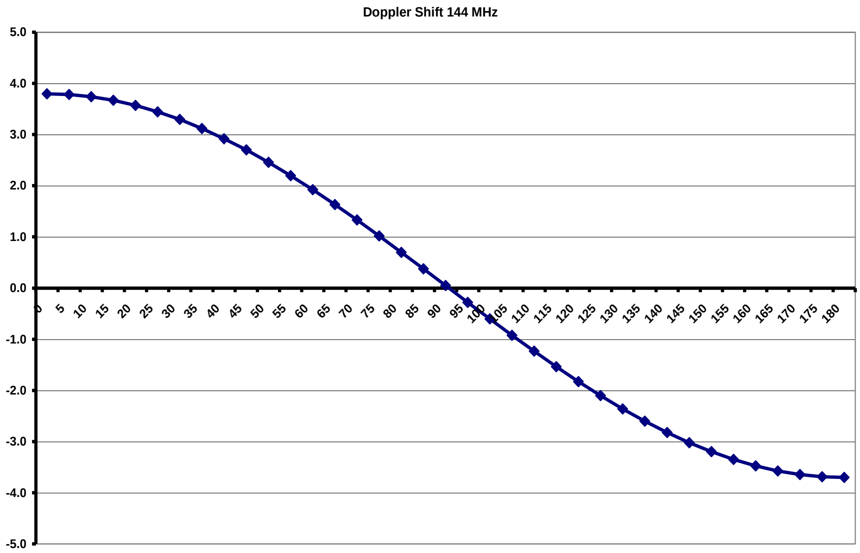
Working the LEOs – Part 4, “The dreaded Doppler effect”.
by Andrew Barron ZL3DW.

I guess everyone knows about the way a car horn sounds higher in pitch as a car approaches and then lower as the car moves away. This is known as Doppler shift after its discoverer, Johann Christian Andreas Doppler (November 29, 1803 – March 17, 1853). As well as sound waves, Doppler affects electromagnetic radio waves and light. It is important to note that the frequency of the sound wave emitted by the car horn or the radio signal from the satellite transmitter does not change, it just seems that way to a stationary observer. The Doppler shift in light, known as “Red Shift”, is used in Astronomy to measure the distance and relative speed of distant stars and galaxies.

Because the LEO satellites are travelling very fast compared to the ground station the signal received from the satellite is affected by a noticeable amount of Doppler shift. The uplink signal to the satellite is also affected. For instance a signal from the International Space Station (ISS), on 144MHz can be shifted plus or minus 3.7kHz. On 70cm this increases to plus or minus 11kHz. As the satellite rises above the horizon it is coming towards you so Doppler shift causes the signal from the satellite to be higher in frequency than the frequency transmitted by the satellite. At the maximum elevation of the satellite pass, the satellite is neither coming towards you nor receding from you, so there is no Doppler shift. Actually there is a little bit, due to time dilation which was described by Albert Einstein, but that is another story. [Some readers will be aware that the GPS satellites correct their transmitted time signals for time dilation]. As the satellite passes your QTH and heads towards the other horizon, it is receding from you so the signal received from the satellite is lower than the transmitted frequency.

Doppler is a problem for hams working through OSCAR satellites because the downlink frequency received in your shack changes continuously as the satellite passes overhead. On SSB any change in receive frequency causes a corresponding change in receive audio frequency, so the receiver must be constantly retuned. The problem is not nearly as severe on FM satellites because the FM receiver is able to pull in a signal several kHz off frequency.

For a satellite that is in a circular orbit which passes directly overhead your QTH, the approximate amount of Doppler shift can be worked out with a fairly simple formula. A plot of the Doppler shift at elevations from 0 to 180 degrees produces a S shaped curve with (almost) zero Doppler shift when the satellite is directly overhead, at 90 degrees elevation.



The amount of Doppler shift is proportional to the frequency so Doppler shift is a bigger problem at higher frequencies. Table 1 shows Doppler shift for a satellite travelling at 7700mps, (ISS).

Table 1:				
Maximum Doppler Shift (zero degrees EL) circular orbit				
2m	70cm	L band	S band	Band
144	435	1268	2401	Frequency MHz
3.797	11.338	32.986	62.460	Doppler shift kHz

A satellite in an elliptical orbit is not travelling through space at a constant speed. As it moves from perigee to apogee, it is moving away from Earth and also slowing down. Then as the satellite races back towards Earth, it speeds up again. For LEO satellites the elliptical orbit is small, so Doppler shift makes the receive frequency decrease continuously as the satellite passes over.

For LEO satellites like FO-29 there is only around 380Hz less Doppler shift on a 435MHz signal when the satellite is at apogee than at perigee. But for high orbit satellites like P3E there can be 5.4kHz less Doppler shift on a 435MHz signal when the satellite is at apogee than at perigee, so depending where the satellite is on its orbit the receive signal could actually increase in frequency during part of the pass. To calculate the velocity vector towards your QTH for a satellite in an elliptical orbit that does not pass directly over your QTH, requires much more complex mathematical equations which must take into account the real shape of the Earth and other factors.

Doppler correction is probably the most difficult part of satellite operation. To make things more difficult, the Doppler shift is different at different locations and will be changing at a different rate. The Doppler shift changes fastest as the satellite goes through the point of highest elevation.

A VK station might be listening to a signal at 435.857MHz, at your QTH the same signal could be on 435.835MHz. If you set your transmit frequency so that you can hear your downlink signal on the same frequency as you heard the other station, the other station will be able to hear your signal. This is why it is almost essential to be able to hear your downlink signal as you transmit. If you make the common mistake of moving your receiver frequency so that you can hear your downlink when you start to transmit, the far station will have to retune his receiver to hear you. This is quite common and causes QSOs to hop around different frequencies as everyone chases each other around. It can be quite a handful on three or four way group QSOs, as each station may be on a different downlink frequency.

LEO satellites are only available for between 10 and 18 minutes on a typical pass. During that time the Doppler shift is changing continuously, causing the receive signal from another station to seem to slide down the band. If the far station is not correcting his uplink frequency, you may need to adjust your receiver by up to 2kHz a minute on a 70cm downlink. The HEO satellites may be above the horizon for fourteen hours or more, so the rate that the Doppler shift changes is much slower and therefore easier to deal with. This makes it feasible to use higher frequency bands on HEO satellites. P3E is scheduled to have transponders on 28MHz, 145.8MHz, 436MHz, 1260MHz, 1268MHz, 2.4Ghz, 5.6GHz, 24GHz and 47GHz.

On the satellites with linear transponders, (the SSB/CW ones), most QSOs occur near the centre of the transponder frequency range. If you don't take Doppler shift into account you may end up 10kHz off frequency and other stations may not hear your signal at all. Some method of keeping up with the Doppler shift is required.

<u>Doppler Correction:</u>

There are three ways to cope with Doppler shift, uplink correction, downlink correction and both uplink & downlink correction. It is best if all stations on a QSO use the same method of Doppler correction. In the USA where the SSB satellites often have several QSOs on the passband at the same time, the convention is to use “the one rule”, which says that because there is more Doppler shift on higher frequencies, the higher frequency should be corrected for Doppler shift. So for a satellite with a UV transponder the uplink would be adjusted but for a satellite with a VU transponder the downlink would be adjusted. SatPC32 with rig control set up, can adjust the uplink, downlink or both, automatically.

Locally the trend seems to be to opt for either uplink or “both” correction.

Uplink Correction; is where you leave your receiver frequency alone and change your transmit frequency so that you can continue to hear yourself on the downlink. As the satellite passes you change the transmit frequency to adjust for the Doppler shift. Because you are adjusting your transmit frequency for the combined Doppler shift on both the uplink and downlink, your transmission moves across the satellite transponder by the amount of downlink Doppler, (plus or minus 10.7kHz on FO-29). This is not ideal as your transmission could cross over another QSO. A station at another location will be experiencing different Doppler conditions so will have to move their receiver frequency to track the difference between your “corrected” signal and their local Doppler shift.

Downlink Correction; is where you leave your transmit frequency alone and change your receive frequency so that you can continue to hear yourself on the downlink. As the satellite passes you change the receive frequency to adjust for the Doppler shift. This method also has the disadvantage that your transmit frequency will move across the satellite passband, which could interfere with other QSOs. But on a VU mode satellite like FO-29 it does have the advantage that the transmit signal will only move around a maximum plus or minus 3.6kHz which is far better than the plus or minus 11kHz using the uplink correction mode.

In **“Both” mode**, both your transmit and receive frequencies are corrected for Doppler shift, so that your transmission stays on the same frequency at the satellite. This is the best method since your transmission will not move over other users of the passband and you wont have to shift around to catch up with the other stations on the QSO. If everyone is using “Both correction”, no manual tuning should be required by any station. The problem is that it is very difficult to do with manual tuning. Simultaneous Doppler correction of both your uplink and downlink frequencies can really only be achieved using computer control of the Rig frequencies. You could try manual tuning to frequencies calculated by the PC, but I don’t have enough hands to adjust a transmitter, receiver and operate a microphone, not to mention moving the antennas.

I have done a lot of research into Doppler shift and I believe that SatPC32 should always be set to “Both” mode, irrespective of the Doppler correction used by the other station. If you are doing manual Doppler adjustment, I believe that the “one rule” should apply. Using Uplink correction on a VU satellite like FO-29 may sound OK at your QTH but you will have to cope with heaps of Doppler shift on the VK you are working. He will have the same problem with your transmission. Conversely using Downlink correction on a UV satellite like VO-52 is a bad idea for the same reason. I have lots of spreadsheets to back this up.

If you want to use an FM transceiver with 5kHz channel spacing for working the FM satellites, set up 3 (or 5) channels. For example AO-51 “Echo” has an uplink frequency of 145.920MHz. The satellite has been designed to cope with the +-3kHz Doppler shift on the uplink, so all three channels can be programmed with a transmit frequency of 145.920MHz and 67.0Hz tone. The AO-51 downlink is on 435.300MHz. Set channel 1 with a receive frequency 5kHz high, 435.305MHz, set channel 2 with a receive frequency of 435.300MHz and set channel 3 with a receive frequency 5kHz low, 435.295MHz. As the satellite passes, switch from channel 1 to 2 then 3 to adjust for Doppler shift. You could use 5 channels to cover plus and minus 10kHz.

Here are my three rules for beating Doppler shift.

1. The “Golden Rule”. If you are netting to another station move your **Transmit** frequency until you can hear yourself on the downlink, at the same frequency as you heard the other station. This applies irrespective of what type of Doppler correction you are using.

2. If you have software that can adjust your rig frequency for Doppler correction, use the “**both** uplink and downlink” correction mode. For manual Doppler correction use the “one rule”.

3. The “One Rule”. Because there is more Doppler shift on higher frequencies, the higher frequency should be corrected for Doppler shift. So for a satellite with a UV transponder the uplink should be adjusted but for a satellite with a VU transponder the downlink should be adjusted.

If you have read all four parts of this article you must really be interested in working amateur satellites. I hope I managed to explain a few of the mysteries. Working the LEOs is a fascinating and challenging aspect to the ham radio hobby. Unfortunately it is a big subject and there is not space to do more than an overview. There is a heap of stuff on the Internet, the AMSAT pages are a great place to start. I am happy to answer questions so send me an email no matter how basic it might seem. I am not an expert and I am a poor mathematician, but I have made most of the common mistakes like transmitting on the downlink frequency and wondering why I wasn't hearing anything. So I may be able to help sort out your problems. There is very little ZL activity on the AMSATs, I am hoping to hear some new signals soon.

73 Andrew ZL3DW.

Formulae

Doppler shift for a satellite in a circular orbit passing directly over your QTH.
FDoppler = FMHz-(FMHz*(SQRT(1-(v/C)^2)/1-((v/C)*COS(RADIANS(EL)))))

Period of orbit, (minutes to complete one orbit of the Earth)
P = 2 * pi() * r / v /60

Velocity of satellite
v = SQRT(G * M / r)

- C = speed of light 299792 km/s
- EL = Elevation of satellite (degrees)
- FMHz = transmit frequency
- Velocity of satellite in mps = v
- FDoppler = Frequency offset (kHz) due to Doppler shift for a satellite in a circular orbit passing directly over your QTH.
- P = Period of orbit, (minutes to complete one orbit of the Earth)
- Pi() = PI (3.14159…….)
- G = 6.6726E-11
- M = 5.7972E+24 (mass of Earth kg). The satellite is assumed to have negligible mass
- RE = Radius of earth (mean radius) 6371 km
- RE + height of satellite (km) = r