Selecting Antennas for GPS/GNSS

1. Circularly Polarized Signals

A characteristic of Electro-Magnetic (E-M) waves is that two independent signals can be conveyed over the same carrier frequency, either with orthogonal linearly polarized signals or in the case of circularly polarized signals, on each of the two possible rotations of the signal wave, Right Hand or Left Hand (RHCP and LHCP).

Civilian Global Navigation Satellite Systems (GNSS) signals broadcast by the U.S. GPS system, the Russian GLONASS system, the European Galileo system, the Chinese BeiDou system and all of the SBAS systems use RHCP signals.

For a circularly polarized signal, the electric field vector spins either right or left in a fixed plane orthogonal to the propagation direction. This can be decomposed into two linearly polarized signals rotated 90° to each other, and, in addition, offset in phase by 90°. The relative phase of the two signals determines that the signal is either RHCP or LHCP.

RHCP or LHCP signals can be received with two independent linearly polarized antennas co-located, and disposed orthogonally, with the feeds combined in quadrature. Then, depending upon the rotation of the leading phase signal the antenna will receive one specific circular polarization and reject that with opposite rotation.

In either case, ALL of the available power from a co-polarized circular wave will be received.

Patch antennas have two orthogonal elements by construction, and these can be configured to have either a single feed, or dual feeds, each connected to a specific axis.

Single feed patches generate or receive circularly polarized signals by phase sensitive coupling between the two axes, resulting either from the feed position, or from features etched in the patch metallization. Single feed patches perform very well with narrow band signals such as GPS L1. Thus small, single feed narrow band patches are the preponderant form of antenna for GPS-L1 receivers

A dual feed patch has two feeds, each connected to one of the orthogonal axis. Typically the two received signals are combined in quadrature to provide a single output. Dual feed patches perform substantially better than single feed patches over a wider bandwidth, provided the patch element has sufficient gain bandwidth, this being a function of size.

2. Degradation of Circularly Polarized Signals and Patches

Circularly polarized (CP) signals are generally less vulnerable to destructive interference from reflections than are linear signals. Destructive interference must occur at exactly the same location from two polarizations for a CP signal and so is just less likely.

However, even with CP, multipath interference is to be expected, the result of this being a more or less elliptically polarized signal (one axis dominant). This will likely be a directional effect, and can result in highly variable signal strength from specific satellites.

Another cause of signal variation is attenuation by vegetation (tree canopy), and this too is to be expected, directional and cause highly variable signal strength.

While single feed patch antennas may be ideal for single frequency signals when used over a wider bandwidth the radiation patterns at the band edges becomes quite elliptical (high axial ratio). In addition, if the antenna is small some gain roll-off can be expected at the band edges. This is relevant because GPS L1 and GLONASS L1 center frequencies are 35MHz apart. In fact, the L1 GNSS band ranges from 1,559 MHz up to 1,610 MHz; a range of 51 MHz.

In real world applications, signal strength will be variable and the performance of the antenna (and LNA) will determine the extent which GNSS signals may be transiently lost, and/or experience reduced accuracy arising from lower Horizontal Dilution Of Precision values (HDOP).

Antennas with small patch elements are generally not a good choice for wider band circularly polarized applications, especially if they have a single feed.

3. Antenna Bandwidth

Both axial ratio and gain are important measures for antenna bandwidth.

The axial ratio of an antenna is the ratio of the gain at maximum and minimum orthogonal gain orientations, when illuminated by a linearly polarized signal, expressed in dB. An ideal circularly polarized antenna has an axial ratio of 0dB, i.e. the output power is the same for any antenna rotation. This is an indicator of how well the antenna will receive circular signals. Antennas with poor axial ratios have an elliptical response that is stronger at one rotation angle and weaker at others.

The axial ratio of a "good", circular antenna should be 3dB or better, over the full bandwidth (i.e. the gain in one orientation gain is not more than half that an orthogonal direction). Even less good antennas should not be worse than 6dB.

The axial ratio of dual feed antennas is inherently good over the full gain bandwidth. If the received signal is initially amplified prior to combination in a 90 degreed hybrid, the combination is effectively lossless (from a noise figure perspective, because the two branches have correlated signals but non-correlated noise).

Tallysman's *Accutenna*™ antennas, which utilize dual feed patches, are typically better than 2dB.

On the other hand, gain-bandwidth is a measure of the antenna "Q" and is the bandwidth over which the output level remains above a ratio threshold, relative to the peak signal. A good GNSS antenna should not be worse than 0.5dB down over the required bandwidth, and even a less good antenna should not be worse than 1dB down within the required bandwidth.

A perfectly tuned 25mm single feed ceramic patch (typical GPS L1) has a 0.5dB gain-bandwidth of about 13MHz, and a 3dB axial bandwidth of about 7MHz.

Even smaller patches can be used for GPS L1 (12mm x 12mm x 4mm !). However, there is no free lunch, and the cost of small size is very narrow gain bandwidth, reduced gain, and "cranky" performance that requires a well defined environment.

GPS L1 and GLONASS signals are separated by 35 MHz (centre frequency to centre frequency), and so require more bandwidth than is available with a 25mm patch. In fact the full upper range of GNSS signals, covering BeiDou B1, Galileo E1, GPS L1, and GLONASS G1, is over 50 MHz wide.

Even Globalstar and Iridium satcom antennas (centered at 1615MHz and 1621MHz respectively) ideally require a 3dB axial-ratio and 0.5dB gain bandwidth over 10MHz, which is very marginal for a 25mm patch, especially once manufacturing tolerances are factored in..

Increased gain-bandwidth requires increased patch size; nothing beats size. Radiation resistance, and hence Q, and hence gain-bandwidth, is a function of the separation between the fringing fields on each side of the patch. Larger patch size requires substrates with lower di-electric constants. In addition, an increased separation between patch metallization and ground further reduces radiation resistance and extends bandwidth.

4. Patch Antenna detuning

Patch elements are intimately coupled with the electro-magnetic environment in close proximity to them and consequently can be "pulled" both in frequency and axial ratio. Most particularly the factors are:

a) the proximity and thickness of plastic immediately above the patch (the radome), and
b) the size and proportions of the ground plane beneath the patch.

This is an important issue for OEM antennas. These are antenna or GNSS antenna-receiver modules that are integrated into an application-specific housing. The plastic "radome" and the effective ground plane both contribute significant effects on tuning. Given that GPS L1 patch elements are narrow and tuned specifically for 1575.42MHz, custom tuning for each application is a good idea; especially because it is relatively inexpensive, and can involve MOQ's in the order of approximately 2k pieces.

Housed GNSS antennas enjoy a well defined environment for the patch element and, typically, each manufacturer uses patches that are tuned specifically for their particular housings, and the most likely ground plane scenario. Thus, even standard antennas have application tuned patches.

5. Signal Loss and C/No

In recent years, clever techniques have been developed to extract tiny GNSS signals from the background noise. But, the fundamental limitation to what can be achieved is limited by the ratio of the gain of the antenna element to the total receiver noise, referred to the input, or "G/T". This is an absolute indicator primarily of antenna-plus-front-end performance, and determines the ultimate value of C/No for a given signal level. C/No is the ratio of carrier power to the noise power mixed with the signal, in a 1Hz bandwidth. This ultimately defines a limit for the GPS receiver sensitivity. So, simply put, antenna gain should be maximized (the "G"), and LNA noise figure minimized ("1/T"); a complicated way to state the obvious.

If the C/No ratio is diminished by any cause, be it bandwidth limitations or increased LNA noise figure, GNSS sensitivity will be reduced by the same amount. Once impaired, there is no way to recover C/No for a given receiver. Even additional gain does nothing because C and No are amplified equally, and so is to no avail.

From a casual perspective, performance may seem acceptable even with a moderately poor antenna. An example is the number of GPS/GLONASS antennas being sold with 25mm patches. At the band edges, where the two wanted signals are, these patches become almost linear with concomitant loss of signal power and increased vulnerability to multipath.

There is a simple C/No test that can be used to directly compare the performance of antennas. It is also simple to do and is discussed later in this paper as a good selection tool. The C/No test is like a "drug test" for the effectiveness of the antenna / front end LNA. It cannot be bamboozled!

If GPS availability is important, then at times when reception is compromised by multipath or attenuation antenna performance becomes especially important. If the antenna performance cannot be allowed to contribute to loss-of-GPS events, it is wise to err on the safe side.

6. A Dual Feed Antenna Example:

The output impedance for a dual feed antenna terminated into a 90° hybrid, with a balancing termination, is almost perfect (see the simulation in figure 1). Real life is not quite as pretty, but with good circuit execution it is usually very good (VSWR typically 1.1 or better).

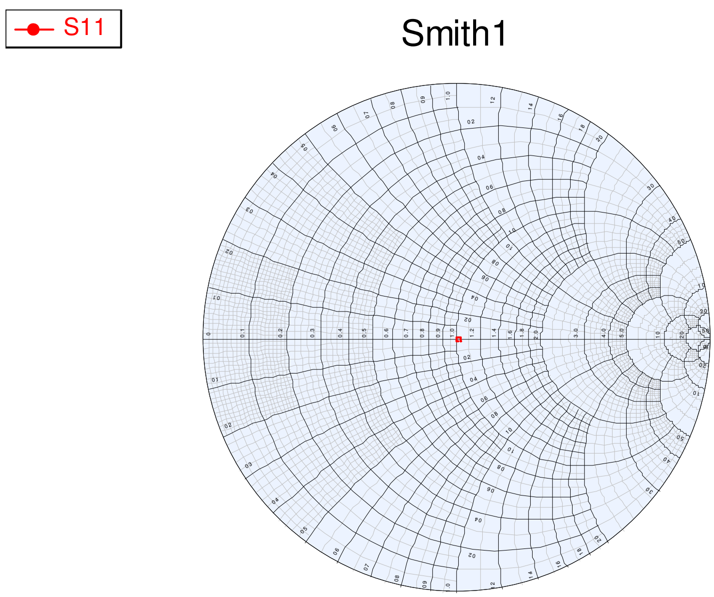

Fig 1 Simulated output impedance of dual feed patch with 90° hybrid summing network.

Similarly, the response of a dual feed antenna to a circularly polarized wave is also nearly perfect. Figure 2(a) shows the measured normalized response of the Tallysman TW2410 GPS L1/GLONASS G1 antenna to an incident RHCP wave. Note that the sharp pass-band response is due to an in-line SAW.

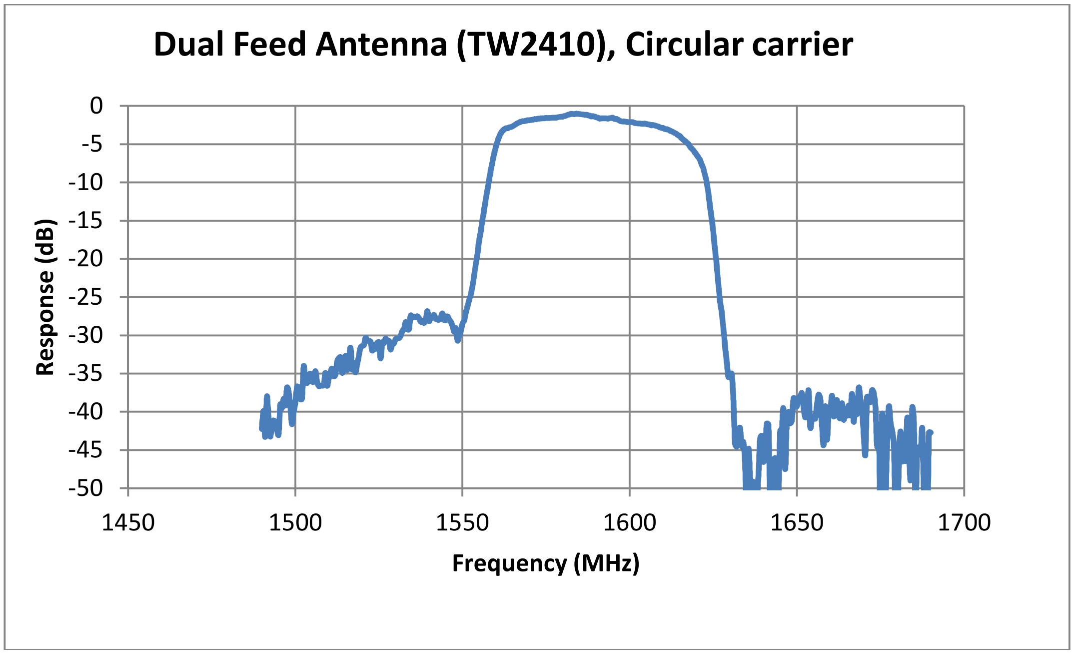

Fig 2(a) dual patch response to with RHCP wave,

In figure 2 (b) below, the two superimposed traces are the normalized responses for two measurements with two orthogonal linearly polarized waves. Note that the antenna response is the virtually the same for circular or linear waves, except of course a 3dB loss with linear polarization which is not apparent with a normalized plot. The measured antenna has a near ideal response with axial ratio of about 1dB.

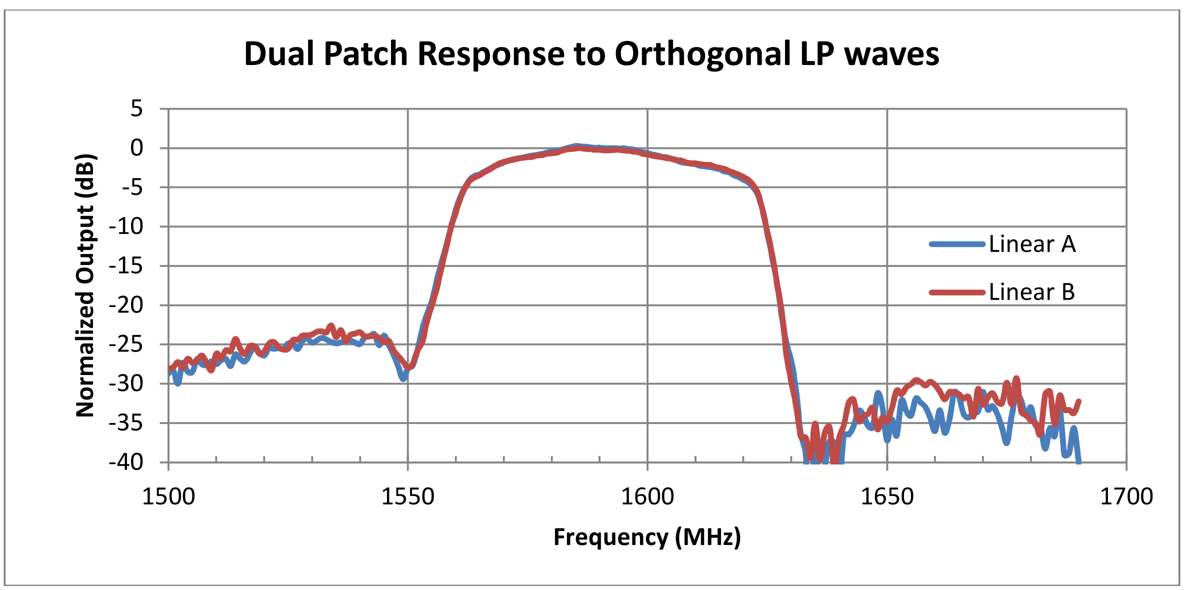

Fig 2(b), Normalized responses to orthogonal, linearly polarized waves

7. A Single Feed Patch Comparison

As above, single feed antennas can provide a near perfect response at a single specific frequency (e.g. GPS-L1). However, on either side of the natural "resonance", the axial ratio increases so that the patch becomes increasingly linearly polarized as the band edges are approached. The extent to which this happens is a function of the patch bandwidth, which is more-or-less a direct function of patch size.

The behavioral equivalent circuit of a single feed patch is two "phantom" orthogonal feeds summed into a 90° combiner, but without a balancing termination. A typical input impedance of a single feed patch is shown in figure 3 below.

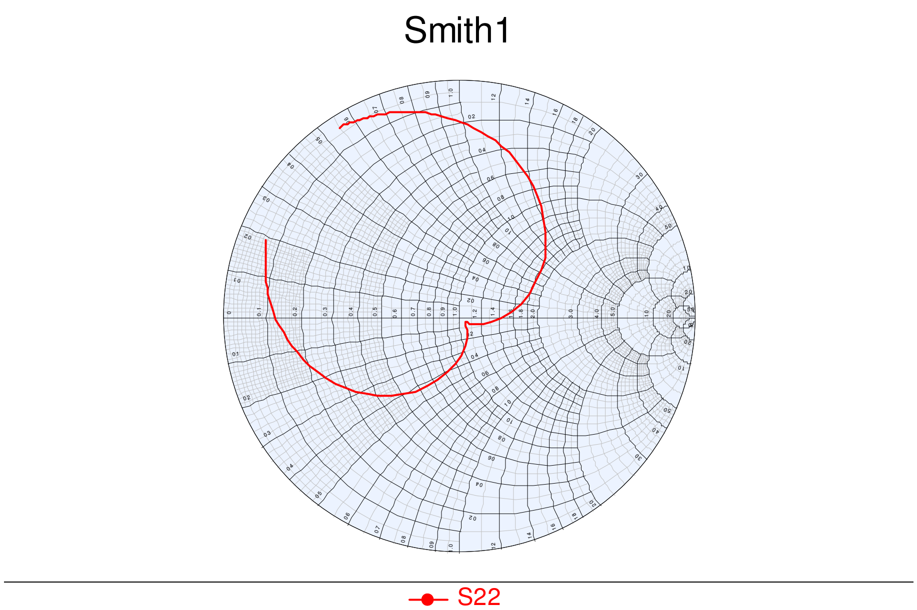

Fig 3, Typical input impedance of a single feed patch

The following compares the measured performance of a non-Tallysman mid-price GLONASS / GPS L1 (with a 25mm single feed patch) to a Tallysman TW2410 *Accutenna*™ antenna. All measurements have been normalized for clarity.

First, the responses of both to an incident RHCP wave are show in fig 4

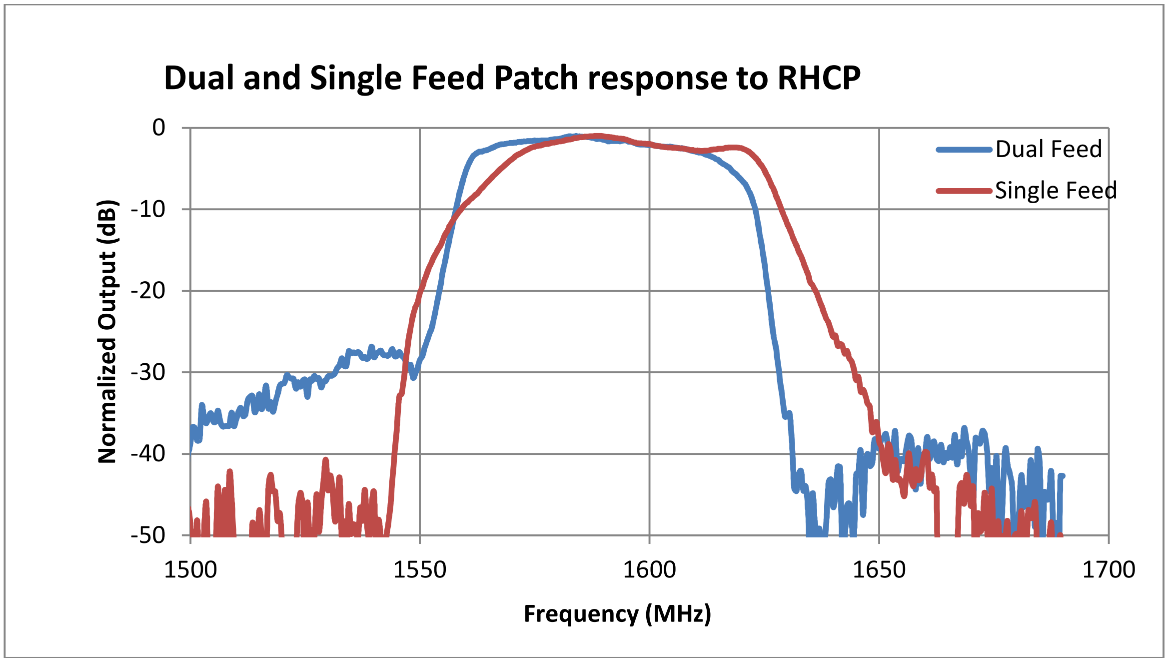

Fig 4, Response of dual and single feed antennas to a circularly polarized wave.

There are small differences in the pass-band, mostly resulting from slightly different SAW characteristics but otherwise the two are quite similar.

However, when the single feed patch antenna is illuminated with linearly polarized signals (the extreme example for single axis multipath interference), the responses are quite different, as shown in figure 5 below. Note that this shows the response for two orthogonal linear polarizations

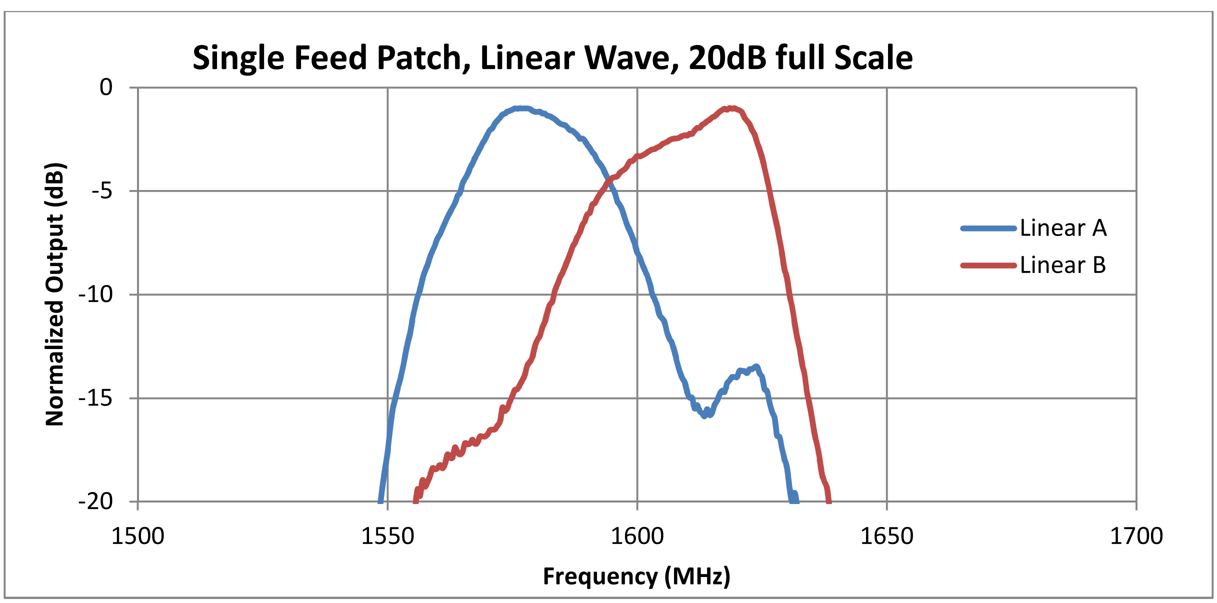

Figure5 Response of a single feed 25mm patch to orthogonal linearly polarized waves

Of course, this is not a normal operating mode, but the measurement reveals the axial ratio response, which otherwise is "hidden" by a circular polarized wave response. The above shows that the antenna becomes quite linearly polarized at the band edges, but in orthogonal directions at each end.

For comparison, the response of a Tallysman TW2410 *Accutenna*™ antenna to the same linearly polarized wave is shown in Figure 6. This is essentially the same as figure 2(b) but at a larger scale.

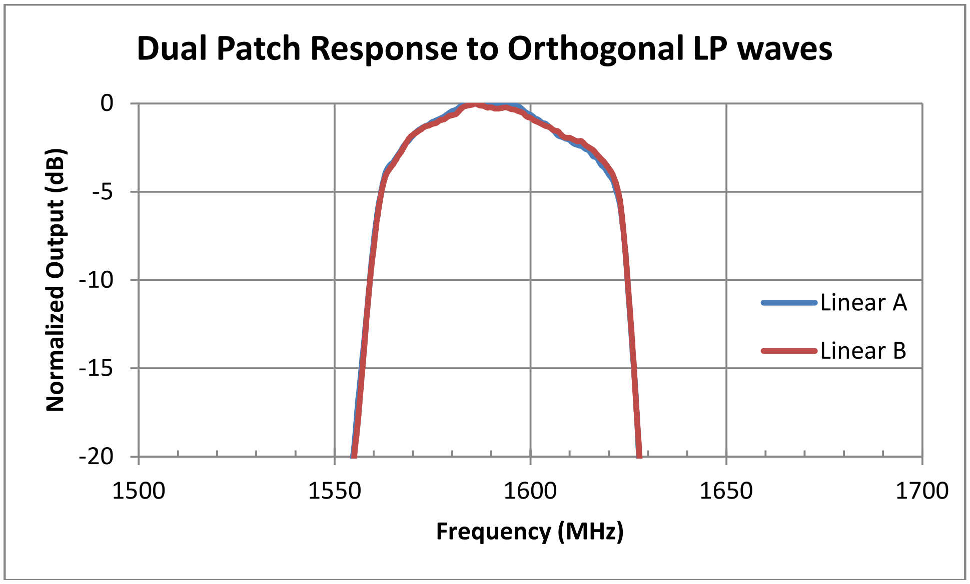

Figure 6: Response of a 46mm dual feed patch to orthogonal linearly polarized waves

The differences now are quite clear. The axial ratio of the Tallysman dual feed patch remains close to 1dB across the entire bandwidth of the antenna. This antenna will receive circularly polarized signals over the full bandwidth without loss, and reject cross polarized signals (odd number reflections).

The smaller patch has quite an elliptical response because of the poor axial ratio and is thus more subject to interference.

The acid C/No test (see below) also reveals additional antenna losses due to marginal patch bandwidth.

To brag just a little (well, maybe a lot), the axial ratio of the TW2410 is close to constant with frequency so that the GLONASS G1 and GPS L1 signals at the opposite ends of the bandwidth are received equally well.

8. A Method to Compare Antenna Performance

A very simple way to compare G/T values for different antennas (and hence judge merit) is to compare the values of C/No for particular satellites. Most GNSS receiver producers provide a PC utility to display values of C/No for each tracked satellite, often in a bar graph format. This will require that the $GPGSV message output from the receiver be enabled.

To compare antennas, the general idea is to sequentially install the antennas to be compared on a single receiver and to compare the reported values of C/No for the best specific two or three satellites. It is important to relate reported values to specific satellites. It is also important that the sequence be quick, and the measurement repeated a few times. The satellite constellation changes over the course of a few minutes, so that reported values will also reflect variation in instantaneous signal strength.

A better way to do this test is to capture the NMEA output with logging terminal software

The GNSS receiver and the antennas to be evaluated should be arranged so:

a) The antenna(s)-under-test must have clear sight of the whole sky, with a relatively low horizon
b) The receiver is set-up to output the NMEA $GPGSV message ($GLGSV for GLONASS),
c) The serial port of the receiver is connected to a computer running either a C/No bar-graph utility (for visual inspection) or a terminal utility with logging (Hyperterm).
d) each antenna is placed on near identical ground plane (100mm, round or square is ideal),
e) the antennas-under-test are not closer to each other than 0.5meters (to ensure no coupling), and
f) it is possible to very quickly switch the antennas at the receiver.

The method is to connect each antenna in sequence for no more than a minute, and to record the NMEA data stream during that time. If the antenna replacement is sufficiently slick, the receiver will be quick to re-acquire. The terminal utility can quickly log the NMEA output data.

Each NMEA $GPGSV message reports C/No at the antenna for up to 4 satellites in view (see excerpted NMEA spec. below for sentence parameters). The best reported parameter for any specific satellites above 48dB are the values of interest. Satellites with low C/No values are not useful for comparison because low signal levels mask the antenna performance.

Quickly repeated measurements are useful to overcome variability in reported values and to accommodate continuous changes of the satellite constellation. The logged data allows the clerical work to be done later.

To give some idea of values to be expected, 54dB is amazing, 53dB is excellent, 52dB is good, and 49/50dB is "ho-hum". These are small differences in log values; an antenna 3dB down is half as good. It is rare, but possible to encounter situations in which all reported values of C/No are below 48dB, in which case it may be better to wait for an hour or so for the constellation to change.

Comparative C/No tests will allow the antennas to be ranked in order of performance; a pre-requisite for selection.

Format for the NMEA $GPGSV Message

The GSV message provides detailed satellite data.

$GPGSV,x,x,xx,xx,xx,xxx,xx,…………….xx,xx,xxx,xx*hh

GS = Number of SVs in view, PRN numbers, elevation, azimuth & SNR values.

*$GPGSV,3,1,11,03,12,174,,06,20,159,,13,14,315,,14,02,139,*7C*

1 = Total number of messages of this type in this cycle
2 = Message number
3 = Total number of SVs in view
4 = SV PRN number
5 = Elevation in degrees, 90 maximum
6 = Azimuth, degrees from true north, 000 to 359
7 = SNR, 00-99 dB (null when not tracking)
8-11 = Information about second SV, same as field 4-7
12-15 = Information about third SV, same as field 4-7
16-19 = Information about fourth SV, same as field 4-7
20 = Checksum

9. Putting it all together

Surprisingly, even in relatively low-rise urban environments GNSS tracking can transiently drop out more often than one might expect. This is where multi-constellation receivers truly shine because of the increased number of satellites available for ranging. Virtually every new receiver chip set on the market is capable of receiving multiple constellations. Employing current technology, Tallysman manufactures antennas which match these receivers' capabilities.

Higher signal levels either from more satellites or from a better antenna also results in better accuracy because the GNSS Horizontal Dilution of Precision (HDOP) is reduced.

So, balancing GNSS signal availability and improved accuracy against size and cost is a difficult call:

- In a consumer product, occasional transient GNSS signal loss might be acceptable. This being the case and if the aesthetics of low cost antennas are acceptable, the choice is plain.
- If maximum availability is a requirement, then the choices will be between a good antenna and an excellent antenna, and a comparative evaluation of C/No of the contenders would be a good place to start.
- For precision or near precision GNSS applications, the only choice is a high quality *Accutenna*™ antenna

Another consideration is that the antenna is usually a very visible part of a bigger system, and unavoidably represents the quality of the user equipment. In that case, the antenna housing robustness and appearance may also be a criterion to maintain the image of the end product.

10. Unabashed Advertising

Tallysman designs and manufactures GNSS antennas with performance previously available only from larger, more expensive antennas.

Our highest performing *Accutenna*™ antennas feature dual feed patches with near perfect axial ratios across the full bandwidth. These are near-survey grade antennas, with an axial ratio typically 1dB or better across the full bandwidth, LNA gain of 28dB minimum, with 1dB Noise Figures and excellent output VSWR.

Tallysman TW38xx family of products are the smallest GPS L1/L2 + GLONASS G1/G2 antennas available on the market. These antennas have been measured and calibrated by NGS enhancing their utility in RTK systems.

Tallysman has a range of antennas which cover GPS L1, GLONASS G1, BeiDou B1, and Galileo E1. These antennas incorporate Tallysman's *Accutenna*™ technology.

Tallysman also offers GPS L1 antennas with pre-emptive protection against L-Band systems. These are also particularly well suited to applications where close in high level RF signals can be troublesome. This is available as brick-wall pre-filtered version with 25dB rejection at 1560MHz and or with a Low-Lband pre-filter with 25dB rejection at 1536MHz.

Tallysman single feed GPS L1 patch antennas include the very economical TW2010 GPS L1 antenna, available in mag mount or through-hole mount for fixed installation (TW3010).

Our timing antenna range feature LNAs with 40dB gain in a through-hole mount with a conical radome to shed snow, ice, and birds. These are available to receive just GPS L1 or GPS + GLONASS or GPS + GLONASS + BeiDou + Galileo. The front ends are highly protected against transient ESD. These too are available with or without brick-wall pre-filters.

Our products are solid, professional devices that reflect well on the quality of the user equipment. The magnet mount products have a white metal base and strong magnetic mounts to stay in place even at very high wind speeds. Our through hole mount housings also feature a metal base, double panel nuts and firm silicon rubber gasket for reliable, waterproof, and tight installation. An attachment bracket for pole or wall mount is also available.

We offer a range of OEM antenna modules, for integration with custom equipment.

We also manufacture a fully integrated GPS + GLONASS antenna-receiver for timing (with differential 1PPS output), navigation, positioning, and for use with mobile radios. These feature interfaces compatible with several LMR standards, operational voltage up to 12v, and USB, CMOS or RS232 signaling options depending on the housing selection.