Crowded streets of spectrum – is GPS being walked all over?

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Biography

Greg Gerten is the navigation and electronic warfare point of contact for Analytical Graphics, Inc. (AGI). He has received his Masters Degree in electrical engineering from the University of Dayton, including graduate courses in GPS at the Air Force Institute of Technology. He has more than 10 years experience in constructive mission simulation development in the areas of communications, navigation warfare, EW tactics, and weapon effectiveness. He has been responsible for the design, development, and deployment of several NAVWAR simulations and has been involved in using these models to support numerous trades' analysis and campaign studies.

Key Words

Spectrum management, GPS interference, jamming

Abstract

The RF spectrum has increasingly become more crowded because only a limited amount of frequencies exist and new devices and needs are continually being developed. The radio spectrum, seen in Figure 1, depicts how crowded frequency slots are today.

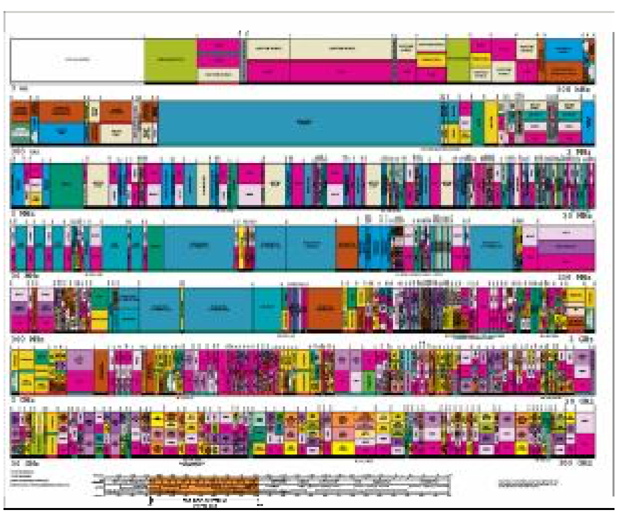

Figure 1: Radio Frequency Spectrum

Radar, communications, and radio navigation systems all have to share and in some cases overlap each others spectrums. Systems that may cause problems to GPS uplinks, cross-links, or downlinks include emissions and spurs from radar systems, communications systems, other navigation systems, and other high power RF systems (weather radars, television, and radio transmitters). While there are standards set up by the International Telecommunications Union (ITU), these are constantly being reevaluated and "bartered" by competing systems and countries to squeeze in more systems in tighter allocations. In this paper, I will investigate the spectrums' "bottlenecks" and analyze the effects spectrum overlap has on GPS. These effects will be analyzed at the engineering level (interference power into the receiver) analyzing the measured power spectral densities (PSD) of several systems and then summarized at a higher level to determine what the impact is of RF overlap on GPS performance.

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1. Introduction

GPS has become a key utility in much of the world's infrastructure. GPS is being used not only as a primary source for accurate position and velocity information, but also as a source of important precise timing. From precision agriculture to space vehicle launches, GPS is being employed to help its users perform tasks faster, cheaper, and more accurately than before. As our infrastructure becomes more reliant on GPS, what happens if the system is interrupted or is interfered with? Currently the users will see a loss in data and the GPS system will act as though it is confused, but will give no warning of GPS anomalies. When a power grid, cellular telephone tower, communications link tower, or any other system using GPS for accurate time loses GPS, the effects are not instantly realized. The bandwidth and system performance degrade as the back-up clock begins to drift. Eventually the system will have such poor performance that the system will discontinue and shutdown, reference [2] and [3]. Other systems such as weather balloons, uninhabited aerial vehicles, and other GPS-equipped platforms using position data may become unusable at the onset of the anomaly. While GPS is free and easy to use, interference with low power signals, whether unintentional or intentional, may cause large area outages.

At the same time, there is an increased demand for radio frequency (RF) spectrum. Similar to land, there only exists a finite amount of space/spectrum and an increasing number of users wanting to occupy it. Wireless systems are being designed, developed, and deployed at an exponential rate – creating even a greater need for spectrum.

2. Problem Statement

GPS is purposely designed as a very low power system, utilizing spread spectrum signal processing techniques to acquire and track the satellite signals. Because of this low power signal, GPS is very vulnerable to interference, particularly the signal and code structure available to civilian users of the system. This interference may be intentional, such as deliberate jamming by an adversary military or terrorist threat, but in most cases it is due to unintentional sources, such as broadband noise from electrical equipment in the vicinity or spurious harmonics.

This vulnerability cannot be completely eliminated for a variety of reasons: it is a low power signal in an already crowded spectrum and multiple sources of noise exist due to the increasing use of radio-frequency emitters in our everyday lives. Furthermore, currently there are only limited means for determining whether our operational systems are being affected by interference or jamming. Most users of GPS simply assume the signal will be there and it is usable and accurate.

To exacerbate the problem, GPS threats are proliferating and numerous critical applications use GPS and our dependence on the system is becoming even more publicized. It is extremely apparent to us and our potential adversaries that the loss of GPS accuracy or functionality may result in the loss of time, money, and more importantly life.

3. Interference Systems

Interference is defined as noise, electrical, or acoustic activity that can disturb communication. This paper will focus on unintentional interference which is noise that is not intended to disturb GPS, but because of the RF level transmitted in the GPS bands (L1 – 1575.42 Mhz or L2 – 1227.6 Mhz) causes the signal to noise (S/N) level to drop. This drop in S/N may or may not cause the receiver to loose lock – but will still impact the tracking accuracy.

Many sources of interference exist in nature or by devices that may not seem to be RF sources (arc welders, high voltage power lines, tree canopy-foliage, ionosphere effects, and other troposphere effects). The arc welder (Figure 2) was tested and was determined to be an urban myth (little to no effect on GPS) and did not show any RF spectrum in other bands (Figure 3).

Figure 2: Arc welding test

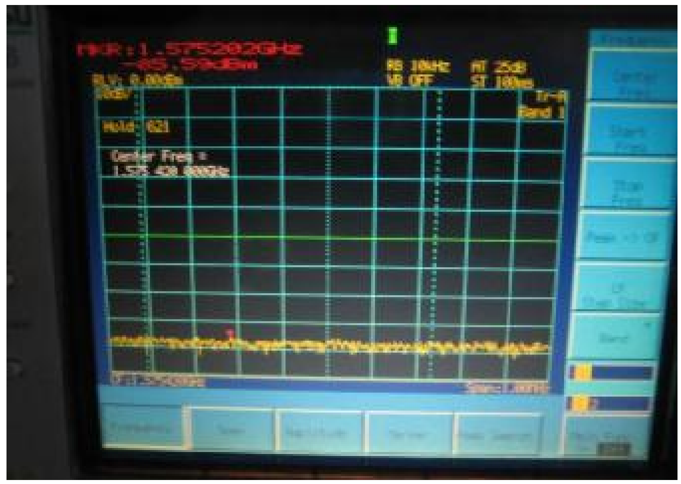

Figure 3: Arc welding test spectrum

There have also been reports of cellular towers causing interference to GPS receivers, but after analysis and site surveys, no evidence has proven their effects (Figure 4).

Figure 4: Cellular spectrum test

After searching for one single culprit to GPS interference, it has been determined that the larger threat is the noise floor and its continual rise due to an increasing number of RF sources and loosely held restrictions on in-band RF levels dictated by the

Federal Communications Commission (FCC) Part 15. According to Title 47, Chapter I, Part 15, Subpart C (Intentional Radiators), "(a) Except as shown in paragraph (d) of this section, **only spurious emissions are permitted** in any of the frequency bands listed below" [which include L1, L2, and L5]. These spurious transmissions must be tested (3 meters away) to be below the Part 15 limit of -41 dBm watts per Mhz (Figure 5).

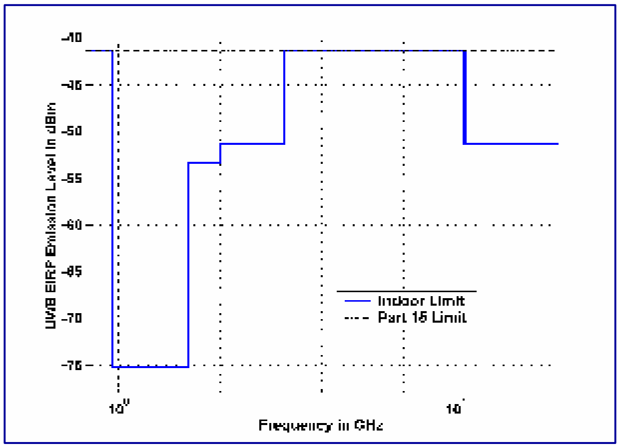

Figure 5: Part 15 Limits (-41 dBm watts)

Therefore, if your system is tested to have -42 dBm watts of noise per Mhz at 3 meters away, you would be legally operating to Part 15 limits. This is equivalent to a 1 Mhz 0.08 milliwatt interference source centered at 1575.42 Mhz. This may look very small but keep in mind there are no limits on the density or number of sources you could have in any area. These sources will add non-coherently and can sum to become much larger than GPS receivers can tolerate.

With the advent of ultra-wideband (which has been shown not to impact GPS in small numbers), additional GNSS in-band systems such as Galileo and our own GPS signals (which again have been shown not to impact GPS in small numbers), and numerous other RF systems (weather/search track radars, communications systems, etc) could easily sum to become a source of interference (or at least add to it).

4. Interference Modeling

Several modeling efforts have been completed to analyze each potential source of interference and its impact of GPS receivers. But each tool has been designed under a particular program to investigate one application. In this case, we needed to use a tool that was built to model any system and capable of reading in the actual spectrum as well as predicted spectrums, transmission effects, environmental effects, and receiver types.

Satellite Tool Kit (STK) has a complex RF communications package capable of handling numerous modeled modulations as well as external spectrums, power levels, polarizations, antennas, data rates, filtering, and bandwidths (Figure 6).

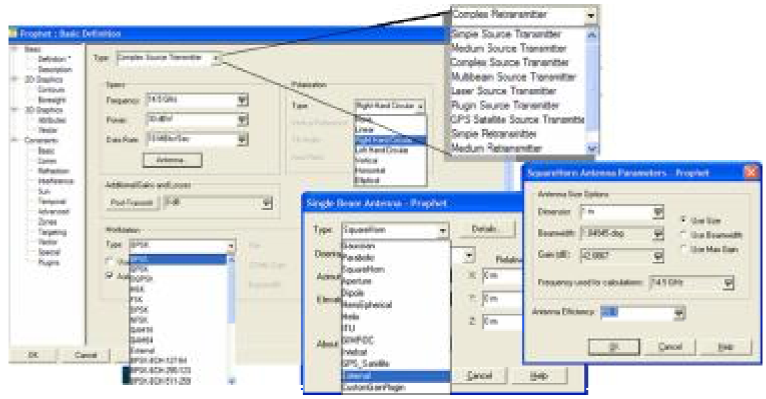

Figure 6: STK transmitter input page

STK also models the environment to include terrain effects using numerous different propagation models, rain models, cloud and fog models, tropospheric scintillation, and other plug-in models (custom attenuation models for example). This allowed us to model the effects/attenuation caused by the environment on the transmission path (Figure 7).

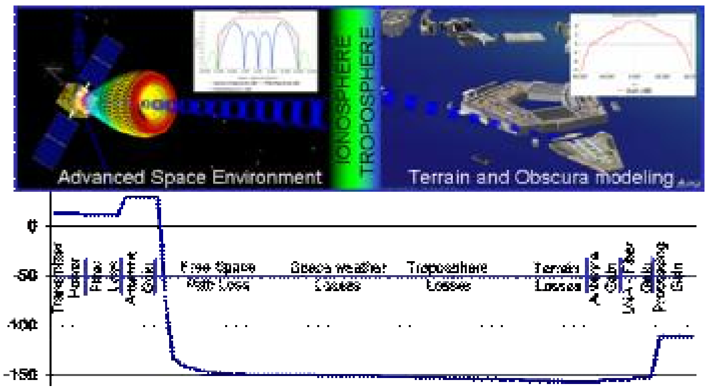

Figure 7: STK path loss contributors

The final component is the user receiver. Whether GPS or a spectrum analyzer, STK was able to model the RF front end to include the center frequency, bandwidth, antenna, polarization, processing gains, and system temperature (Figure 8).

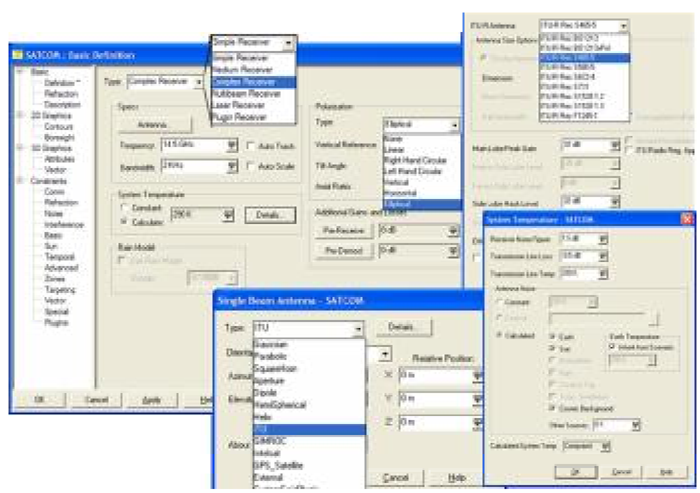

Figure 8: STK receiver input page

These transmitters can be placed at static locations pointing in fixed locations or in more realistic cases be attached to an object (land, air, sea, space) that is dynamic in nature including attitude (targeting) or temporal (on/off times) (Figure 9).

Figure 9: Dynamic transmitters

The effects can then be modeled for land, air, sea, or space platforms. These effects could include any value from the complex link budget (EIRP, Path loss, Received Isotropic Power-RIP, power into the receiver, total RF power, J/S, power flux density, S/N, S/N+I, Eb/No, or even bit-error-rate BER). Any of these values can be put into a table, graphed, displayed dynamically in a strip-chart or on the 3D display as numerical data or coloring the route via a color contour (Figure 9).

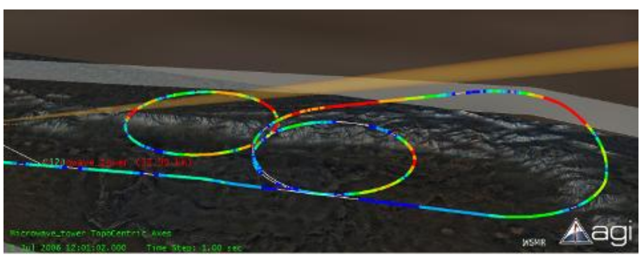

Figure 9: Power received route coverage contour

Another option would be to look at the interference impact over a region over time at altitude (3D) (Figure 10).

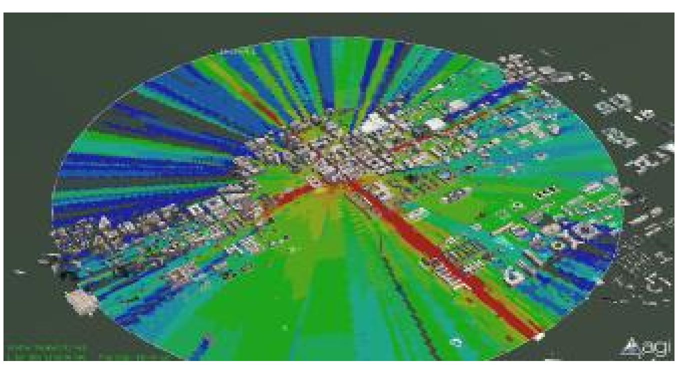

Figure 10: Urban dynamic jamming contour

This same principle can also be used to model the desired signals (communications, radar, or in our case, GPS).

5. GNSS Modeling

In a similar manner we need to model the desired signals. These transmitters may be from the ground in terms of ground-based augmentation systems (GBAS) or from space (GPS, Galileo, Glonass, Compass, QZSS, IRNSS, GAGAN, WAAS, EGNOS, etc). Figure 11 depicts the expected GPSIII-blue, Galileo-green, and GlonassK-red constellations.

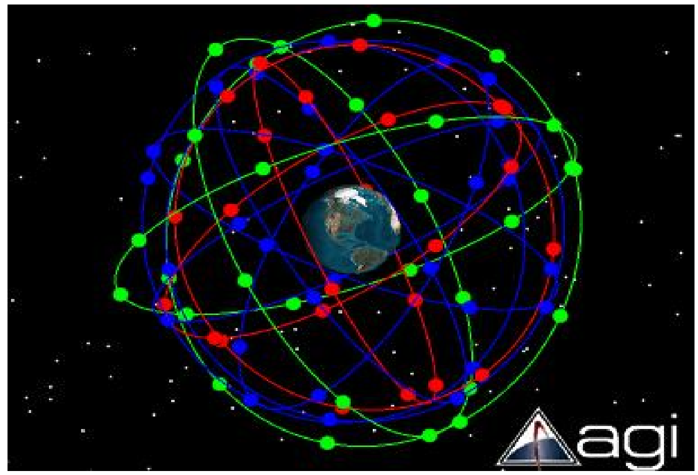

Figure 11: GPS/Galileo/Glonass Constellations

The satellite's position and attitude change according to the propagation models (ICD-GPS-200d for GPS and similar ICDs for Glonass and Galileo). One easy analysis to investigate is that the better the geometry of the satellites, called dilution of precision (DOP), the better accuracy of the users. STK can compute these DOP plots across the globe and provide the max, min, average over time, and grid points (Figure 12) using fixed or variable elevation masks using a variable time step over hours, day,s or even weeks (completed in only minutes).

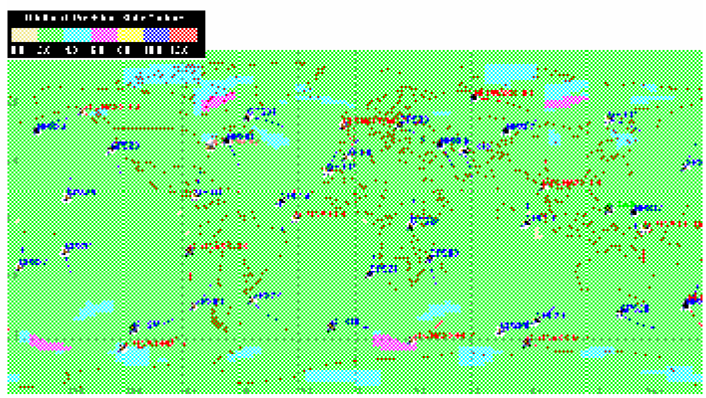

Figure 12: STK DOP global plot

The GPS satellites are 10,900 nmi from the Earth's surface, making the 100 watt transmitted signal (see antenna pattern in Figure 7 above) approximately 0.0000000000000001 watts (-160 dBW) by the time it reaches your GPS receiver. Figure 13 depicts the power received by a ground user over time. Notice the max power received is not directly at nadir – but rather at 40 degrees elevation. This antenna pattern has been created purposefully to give added power in the case where the signal will be traveling through more ionosphere and troposphere.

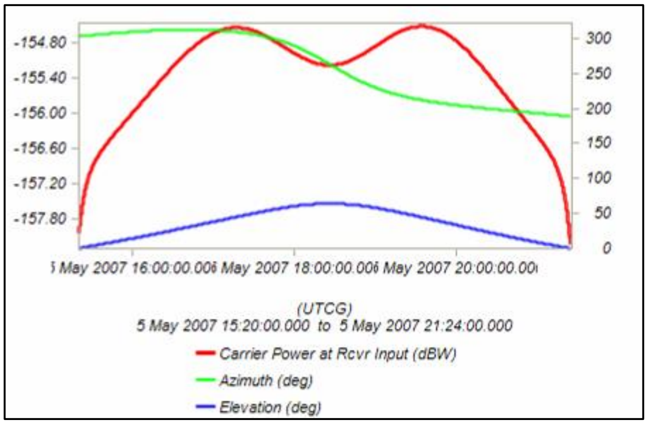

Figure 13: GPS signal strength versus elevation/Az

This weak received power creates the vulnerability with seemingly small interference sources even if the interference sources are -120 db watts, results in a 40 dB jammer to signal (J/S) ratio, a ratio too high for civilian users to track. This is the reason for limits to be created and enforced to control the amount of spurious noise that any one transmitter can emit in the GPS protected bands (FCC Part 15).

6. Part 15 study analysis

Part 15 limits the amount of spurious noise to -41 dB watts per Mhz in the restricted bands including GPS. While this number is seemingly small, the user of the transmitter may change the antenna (from 0 dBi gain to maybe 7 dBi) or in some cases add an external amplifier to extend his systems range (seen many times on Wi-Fi systems). In this case if we use the Part 15 limit and assume an antenna swap to 7 dBi the effected region would look something like Figure 14.

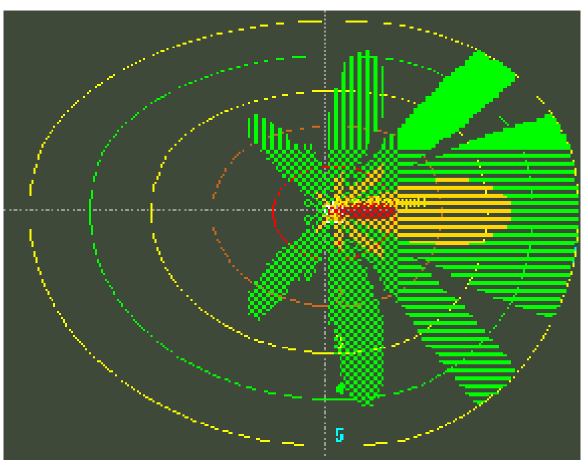

Figure 14: Jammed region from 1 source

The green region meaning above the GPS power but could still acquire (<24 J/S), yellow meaning the civil user can no longer acquire but can track (24<J/S<35), and the red region depicting the jammed region (~1 km range). This was for a single noise source. Let's imagine for a moment we would be in a metropolitan area that is inundated with RF, ultra-wideband (UWB), and other interference sources. These numbers can be extrapolated to look at 10, 100, or even 1,000 sources (Table 1).

Number of Sources	Prevent Tracking (35 dB) Km	Prevent Acquisition (24dB) Km
1	1	3.5
10	3.1	11
100	10	35
1K	31.4	110.5

Table 1: Summary of range effected per number of sources

7. Validation and Verification

Validation and verification (V&V) by a third party is crucial to trusting a model or simulation and understanding the limits on its results' accuracy. STK has been independently validated and verified by the Aerospace Corporation [4].

The Air Force Operational Test and Evaluation Center (AFOTEC) has also conducted an independent evaluation on STK's communications models, quantifying the RF performance of different prorogation models [5].

8. Summary

Weak desired signals (still in the new GPS design specification) and a growing number of competing noise sources create the need to evaluate the future of FCC guidelines and GPS signal/receiver performance.T hese trades need to be conducted using high-fidelity RF models that include all sources of potential interference, not just a single static threat at a time. As RF devices continue to compete for bandwidth and range/increased power, the noise floor will continue to rise and we will witness a "global warming" in the RF domain and interference issues causing GPS dropouts unless we take action before it is too late (after systems are fielded, satellites launched, and guidelines are set).

9. References

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