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Front

Spoofer Detection

With 864 channels and about 130,000 quick acquisition correlators in our TRIUMPH chip, we have resources to assign more than one channel to each satellite to find ALL signals that are transmitted with that GNSS satellite PRN code.

If we detect more than one reasonable and consistent correlation peak for any PRN code, we know that we are being spoofed and can identify the spoofed signals.

When we detect that spoofing is in effect, we use the position solution provided by all other clean signals (L1, L2, L5, etc... GPS, GLONASS, Galileo, Beidou, etc...) to identify the spoofer signal and use the real satellite measurement. If all GNSS signals are spoofed or jammed, then we alarm you to ignore GNSS and use other sensors in your integrated system.

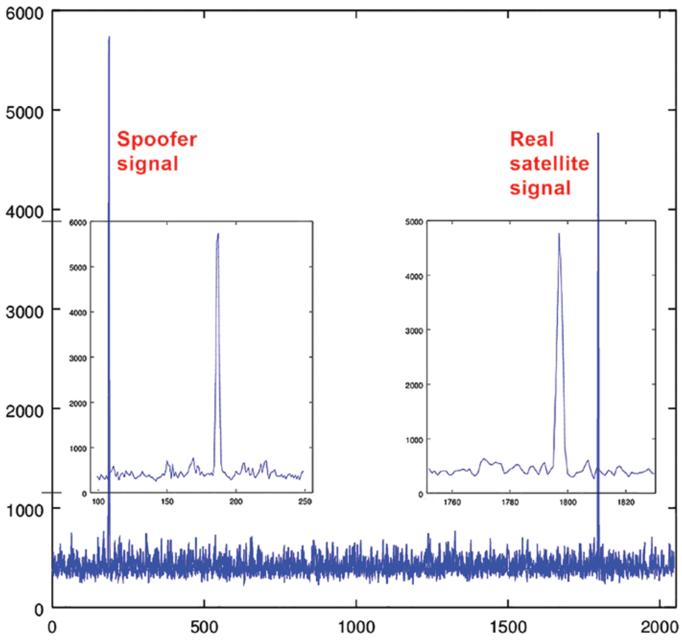


Figure 1
shows an example of a spoofer signal and a real satellite signal received at GNSS receiver.

Satellite and Spoofer Peaks

The screenshots below are from a real spoofer in a large city. The bold numbers are for the detected peaks. The gray numbers represent highest noise, not a consistent peak. "*" symbol next to the CNT numbers indicate that signal is used in position calculation. Each CNT count represent about 5 seconds of continuous peak tracking.

SAT	EL	S...	Range 1	Dopp...	CNT 1	S...	Range 2	Dopp...	CNT 2	dRng	dDop	N
GPS5	33	16	61.14	1382	184*	4	25.95	181	1	29.32	1201	29
GPS7	51	21	14.39	1146	184*	4	18.21	-453	1	2.80	1599	29
GPS8	30	18	65.10	-918	184*	4	4.26	-1318	1	3.68	400	29
GPS9	12	14	40.46	2966	184*	4	2.08	3765	1	26.13	-799	29
GPS13	40	16	46.92	-3525	184*	4	8.21	-4325	1	25.80	800	29
GPS15	12	14	12.46	-4336	30*	5	33.00	-1536	1	19.52	-2800	28
GPS20	24	12	13.19	-1707	107*	4	29.32	-3307	1	15.11	1600	29
GPS27	16	11	10.26	1264	184*	4	43.55	63	1	31.22	1201	29
GPS28	53	19	9.41	-2724	184*	4	7.93	-4724	1	0.46	2000	29
GPS30	81	22	13.79	-332	184*	5	34.16	1266	1	19.35	-1598	28
GLN-4	54	20	62.08	1498	1158*	5	21.72	2697	1	24.16	-1199	25
GLN5	46	20	18.04	-2897	524*	4	26.26	-3697	1	7.20	800	25
GLN0	37	18	30.37	2355	1469*	4	38.37	1554	1	6.98	801	25
GLN-1	82	18	34.92	-776	189*	4	12.54	-1576	1	21.35	800	25
GLN-2	26	12	30.96	-4358	229*	4	11.80	-3158	1	18.13	-1200	25
GLN2	21	10	59.73	288	551*	4	47.55	1087	1	11.16	-799	25
GLN4	22	15	30.59	-3361	208*	4	11.74	-5361	1	17.83	2000	25
GLN-5	21	14	20.17	276	187+	3	25.45	2275	1	4.26	-1999	25

Esc Sat: 10 7 6 4 4 0 dPos: 19.0m Age: <1s

Figure 2 *No spoofer. Only one reasonable peak for each satellite.*

Satellite Name | Elevation Angle | First Peak: Signal above noise level, Range mod 1 ms, Doppler, 5 sec count | Second Peak: Signal above noise level, Range mod 1 ms, Doppler, 5 sec count | Delta range | Delta Doppler | Noise level

SAT	EL	S...	Range 1	Dopp...	CNT 1	S...	Range 2	Dopp...	CNT 2	dRng	dDop	N
GPS1	14	14	231.08	-2627	140*	9	155.13	-2627	60	74.93	0	28
GPS10	9	12	267.44	-2078	74*	4	238.41	-3278	1	28.01	1200	28
GPS11	22	13	297.36	-847	301*	3	6.45	1151	1	289.89	-1998	29
GPS13	55	21	136.95	1154	301*	9	21.70	1153	73	114.23	1	28
GPS15	49	20	278.00	-453	301*	9	168.03	-453	73	108.95	0	29
GPS17	41	22	83.28	-3212	301*	10	277.41	-3212	69	193.11	0	28
GPS19	23	14	133.13	-4590	164*	7	19.06	-4590	69	113.05	0	29
GPS20	5	8	170.96	2215	36*	3	50.73	614	1	119.21	1601	29
GPS24	22	15	54.25	-4022	177*	9	250.43	-4022	82	195.16	0	29
GPS28	58	18	50.14	1040	301*	3	268.62	1439	1	217.46	-399	29
GPS30	23	17	290.02	2593	301*	3	214.66	4592	1	74.34	-1999	28
GLN-7	30	22	159.09	2505	213*	7	274.16	2104	1	114.05	401	28
GLN-4	39	18	72.21	-450	282*	7	220.15	-3250	1	146.92	2800	28
GLN-1	34	18	92.17	-3838	259*	6	299.41	-1838	1	206.22	-2000	28
GLN0	72	23	271.81	147	283*	7	78.08	2146	1	192.71	-1999	28
GLN1	23	15	297.65	3244	129*	6	8.21	2443	1	288.42	801	28
GLN2	42	18	200.78	-742	282*	6	234.83	2056	1	33.03	-2798	28
GLN3	17	18	158.51	2584	282*	6	44.03	4583	1	113.46	-1999	28

Esc Used: 11+9+4+8+0+1=33 1 2 dPos: 21.2m Age: <1s

GPS GLN GAL BDU IRN QZ ◂ Number of satellites used in position calculation

Figure 3
In the screenshot all GPS satellites have two peaks and all are spoofed. We were able to distinguish the spoofer signal and use the real satellite signals in correct position calculation as indicated by the "" next to the CNT numbers.*

PATENTS PENDING

Concepts Behind RTK Verification

Fundamental in the determination of GNSS solutions is calculating the correct number of full wavelengths (so-called ***fixing ambiguities***) in order to figure out the distances from the satellites to the receiver. In doing Real Time Kinematic (RTK) surveying, we need it fast and we need it to be correct.

Multipath, the reflections of GNSS signals from ground and nearby objects and structures create their own indirect measurements from the satellites to the GNSS receiver. It's as if your measuring tape is bent around an obstacle such as a tree instead of a free and clear line of sight between two points. No calculator is going to improve this result.

TRIUMPH-LS has sophisticated hardware to distinguish between the direct and indirect signals and remove most of the indirect signals. It also reports the amount of indirect signal that has been removed. The worst case is when the receiver doesn't see the direct signal at all; e.g., the satellite is behind a building, but it's still receiving the signal reflected off of the nearby structure. It is the task of the RTK engines to isolate such indirect signals and then exclude them from the calculations.

If too many of the signals are affected by severe multipath or indirect signals, no solution may be found. Remember, indirect signals are analogous to the bent measuring tape! When you're preforming RTK surveying, observe your environment and come to recognize that the structures around you are like mirrors for GNSS signals.

The other aspect impacting the veracity of a fixed solution is when there are weak GNSS signals. Frequently, weak signals are due to their penetration directly through tree canopy.

While the **TRIUMPH-LS** can't move the obstacles that are creating multipath out of the way, its sophisticated hardware has advanced multipath reduction sub-system, its tracking software is designed to handle even the weakest signals, and its **J-Field** software provides reliable RTK solutions like no other system with its **Automatic RTK Verification System** (patent pending). J-Filed also has ample tools to demonstrate the reliability of the solution or warn against questionable results. You can readily see that without such tools other systems can provide you wrong and misleading solutions.

J-Field uses six RTK engines (Figure 1) running in parallel plus a support engine to monitor and aid the six engines. Each engine uses a different criteria and mathematical method tailored to resolve ambiguities in different conditions. These six parallel engines not only verify robust solutions but also maximize the possibility of providing solutions in all conditions.

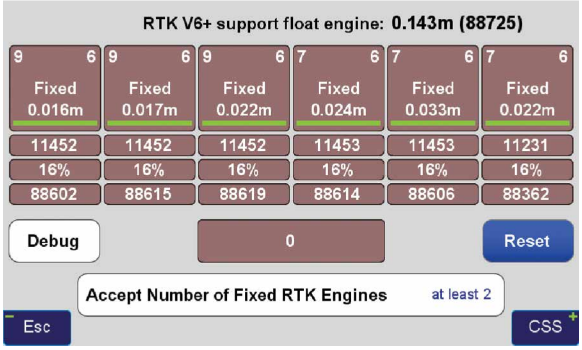


Figure 1 *V6+ six RTK Engines*

User Defined Verification Tools

J-Field provides the option for you to specify the **Minimum Number of Fixed RTK Engines** in verifying solutions **N** times before a position is automatically accepted where **N** is a user defined value.

J-Field employs two metrics to evaluate the performance of its RTK system of six engines: **1) Confidence Counter, and 2) Consistency Counter.** (Figure 2)

Confidence Counter

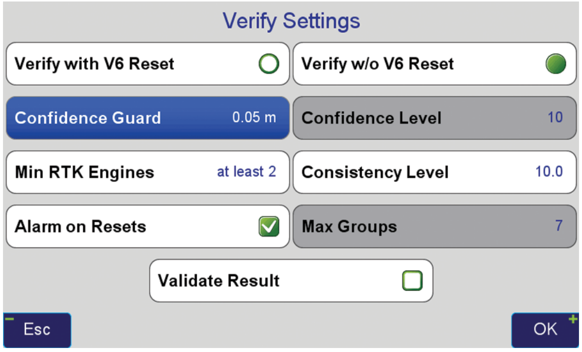


Figure 2 *Verify Settings*

This metric is incremented each time an engine is reset, ambiguities are recalculated, and the solution is in agreement with the previous ones (as defined by the **Confidence Guard (CG)**, default value 5 cm) is achieved. The Confidence Counter increments by 1, 1.25, 1.5, 1.75, 2.0, and 2.5 depending on the number of reset engines that fix in that epoch.

Consistency Counter

The Consistency Counter is incremented each time a solution is in agreement with the previous ones (as defined by the Confidence Guard) irrespective of engines being reset or not. The Consistency Counter is incremented by 0.0, 0.1, 0.25, 0.5, 1.0 and 1.5 depending on the number of fixed engines used in that epoch. Note that one fixed engine gets no credit and 6 fixed engines gets a **Consistency Credit** of 1.5.

Using these Confidence and Consistency verification tools, J-Field has two options to achieve reliable RTK solutions: **1) Verify With Automatic RTK Engines Resets** and **2) Verify Without Automatic RTK Engines Resets.**

Verify with Automatic RTK Engines Resets

This method has two steps: **1) Confidence Building** and **2) Smoothing and verifying**.

• **Step One.** In Step One, fixed engines are reset and solutions are collected into groups. Each group contains all the epochs located within a specified radius (the CG value) from its center and new groups are created as necessary so that all epochs fall into at least one group. Each group has its own Epoch Counter, Confidence Level and Elapsed Time. A point may fall into more than one group. The groups are sorted from best to last by the sum of their Time and Confidence with the current best group being shown within [ ] and others within ( ). Step One continues until a group reaches the Confidence Level. (Figure 3)

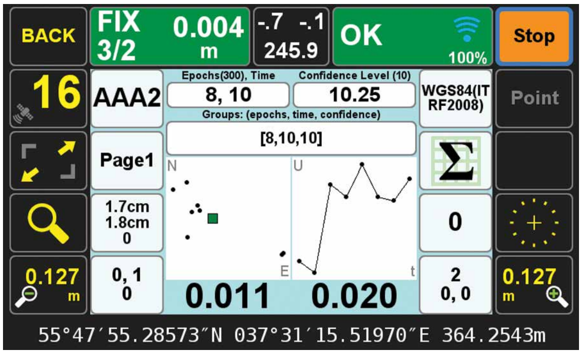


***Figure 3** End of Step one*

• **Step Two.** During Step Two the engines are not reset and solutions which are located inside the CG of the selected Group are added to that Group for the remaining number of epochs that user has requested (Epoch Number, EN) in the How to Stop screen. Epochs which are outside the CG of the selected Group will be stored in a new (or previously created) group; the RTK engines are reset if the epoch falls outside a sphere with a radius twice that of the CG and the process will then revert back to Step One and the Confidence Level of the current group will be reset to 0.

If the number of epochs falling outside of the current group (but less than 2X outside it) reaches 33% of epochs collected so far, the process will revert back to Step One. Previously created groups will remain intact and once an existing or previously created group meets the Step One criteria, it will pass to Step Two. (Figure 4)

In both steps the Consistency Counter is also incremented as mentioned earlier.

You can manually reset all RTK engines via the

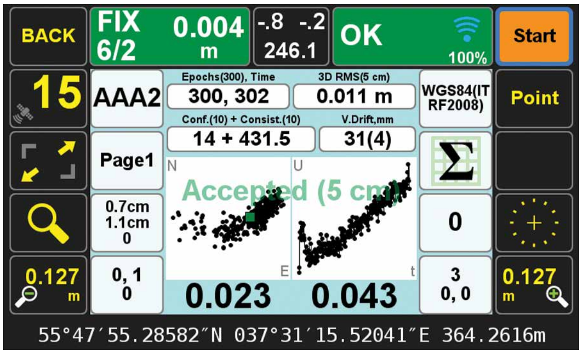


***Figure 4** End of Step 2*

V6-RTK engines screen (Figure 1), or assign this reset function to any one of the U1 to U4 hardware buttons in front of the TRIUMPH-LS for easy access.

Verify without Automatic RTK Engines Resets:

In this method we don't force the RTK engines to reset but rely mostly on the Consistency Counter. There will be only one group as selected by the first epoch. Solutions that are not within the Guard band of the current average will be thrown out. If more than 30% of solutions are thrown out, the process will restart.

The horizontal and vertical graphs presented in both approaches also help the surveyor to evaluate the final solution. The linear drift of the vertical solution and its drift RMS are also shown above the vertical graph. A high linear drift (more than few centimeters) reveals severe multipath or, in rare cases, a wrong ambiguity fix. Pay close attention to the vertical drift and the horizontal and vertical scatter plots of epochs. Consider the scatter plots as doctors examine X-rays to determine anomalies.

The desired **Confidence Level** and **Consistency Level** are user selectable. Default values are 10. These parameters along with the desired number of epochs must be reached before a solution is provided.

In either case there is also a **Validate** option which, when selected, will reset all engines at the end of the collection and continues with 10 more epochs to validate if the solution is within the desired boundary of the Confidence Guard. (Figure 2) Minimum number of engines for the Validation Phase is user selectable.

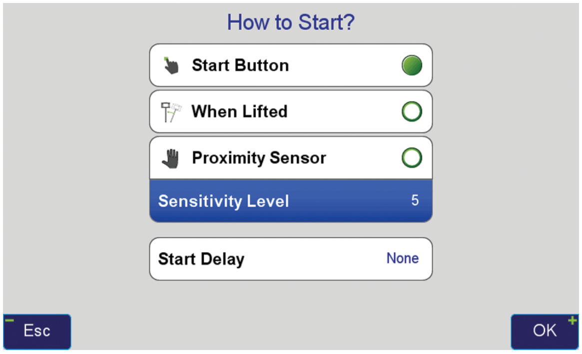


***Figure 5** How to Start*

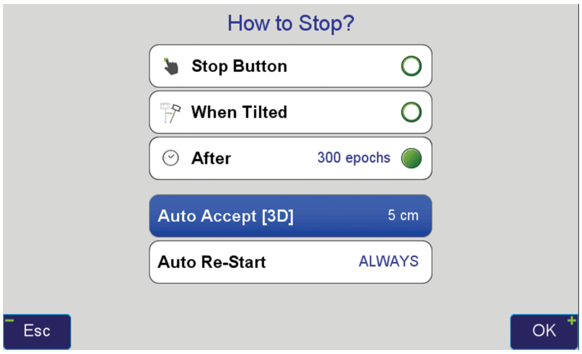


Figure 6 *How to Stop*

In either case, if Auto-Accept is activated, the position will be automatically accepted if the RMS of the final solution is less than what user has selected in the Auto-Accept screen. (Figure 6)

You can also use **Auto-Restart** if you want to monitor structures or test the RTK system unattended. (Figure 6)

Screen Shots of Action Screen

Action Screen shows detailed information about each point collected. Screen shots can automatically be attached to each point and saved at the end of each collection (Figure 7). In **Verify with Automatic RTK Engines Resets** screen shots at the end of both Step One and Step Two are saved (Figures 3

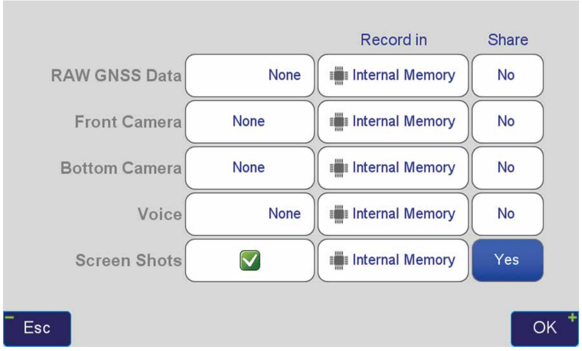


Figure 7 *What to record screen*

and 4). In Action screen there are 8 white boxes that selected items can be viewed on them.

Review Screen

View cluster of all points. Select the desired point to see its point cluster (Figure 8). Click the icons to see additional details about that point (Figure 9) including the distance and direction to the current point (Figure 10).

The effects of multipath, ionosphere, orbit, and other sources of problems somewhat exponentially increase as the baseline length increases. In a VRS/RTN scheme your **actual** baseline length is the actual distance to the nearest base station. The **virtual** base station that is mathematically created is not the actual length. We strongly recommend using your own base station near your job site in a

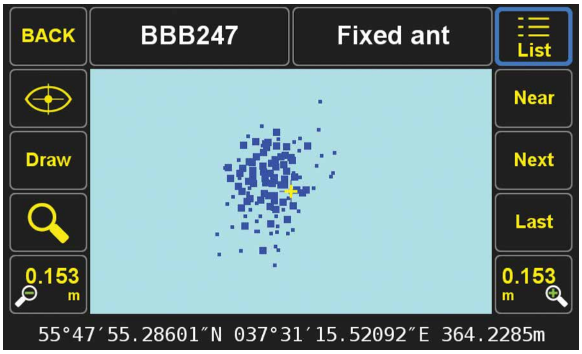


Figure 8 *Review screen shows cluster of 386 points*

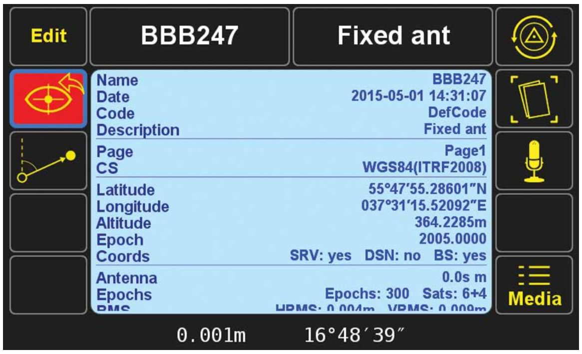


Figure 9 *Detailed information on selected point (scroll to see all information)*

Figure 10 *Distance and direction from the current point to the selected point*

Verified-Base RTK (VB-RTK) scheme.

In addition to providing you with the most reliable RTK solutions (especially true in remote areas where cell coverage is hit or miss), using your own base receiver allows you to easily tie your solutions to well-established IGS/NGS spatial reference systems through Javad's exclusive Data Processing Online Service (DPOS) and J-Field's user-friendly Base/Rover Setup. Note that post-processed results returned to the TRIUMPH-LS using DPOS are dependent on the availability of orbital data from NGS and may require several hours. For further reading about DPOS, its integration into J-Field and the streamlined approach developed by Javad for setting up the base and rover, please check out Shawn Billings' excellent article on VB-RTK on our website. Point your browser to: *http://www.javad.com/jgnss/javad/news/pr20150219.html*

Alternatively, if you don't have access to IGS-type stations to use DPOS, you can select an open area near your job site and use TRIUMPH-LS to obtain its position via RTN networks for about 5 minutes. You may repeat a couple of times for assurance. Then transfer this position to the TRIUMPH-1 or TRIUMPH-2 to use as the base station near your job site. The Base-Rover setup screen in the TRIUMPH-LS makes this job very easy.

Instantaneous Multipath charts

TRIUMPH-LS removes most of the multipath instantly on every epoch. Click on the Satellite icon to see the Signal Strength of satellites and then click the "+" key to see the multipath charts.

Figure 11 shows the amount of code phase multipath that TRIUMPH-LS has removed; relative to a fixed level. That is why negative numbers are in this figure. Units are in centimeter. Noting the signs in this figure, the amount of multipath in some satellites is in excess of 5.6 meters.

Figure 12 shows the amount of carrier phase multipath that TRIUMPH-LS has removed relative to a fixed level. Units are in millimeter. Noting the signs in this figure, the amount of multipath in some satellites is in excess of 4 centimeters.

SAT	EL	L1	P1	P2	L2C	L5
GPS2	29↑	273	281	-76	--	--
GPS6	44↑	55	201	-60	-5	189
GPS12	70↑	183	190	-90	-94	--
GPS14	25ˆ	281	317	-97	--	--
GPS17	23↓	332	364	-74	6	--
GPS24	53↓	117	566	67	-64	124
GPS25	30↑	243	218	-42	-50	-34
GLN1	10↑	305	229	-126	-404	--
GLN8	16↓	26	87	-484	-617	--
GLN9	32↑	359	301	-246	55	--
GLN15	31↓	276	203	-93	-2	--
GLN16	84↑	235	309	-133	-109	--
GLN17	39↓	52	-84	-156	-52	--
GLN18	69↑	190	168	-177	-184	--
GAL12	68ˆ	680	-121	246	--	32
SB127	25ˆ	469	--	--	--	319
SB128	15ˆ	206	--	--	--	322
QZ193	13↑	550	513	--	56	55
BDU2	16ˆ	299	--	--	--	275
BDU5	25ˆ	269	--	--	--	230
BDU8	25↓	145	--	--	--	143

SAT	EL	L1	P1	P2	L2C	L5
BDU11	75↑	362	--	--	--	305
BDU12	36↓	288	--	--	--	200
GPS3	10	--	--	--	--	--
GPS29	3	--	--	--	--	--
GPS32	3	--	--	--	--	--
GLN7	3	--	--	--	--	--
GLN19	12	--	--	--	--	--

Figure 11 *Code Phase multipath removed (cm)*

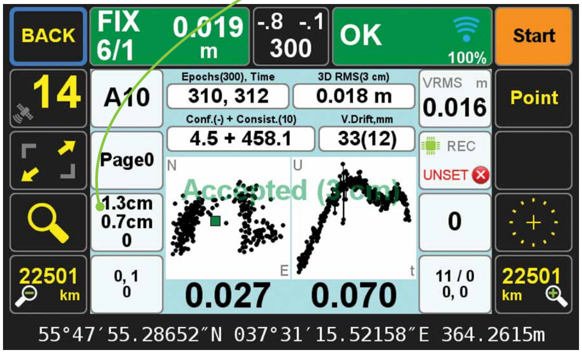
SAT	EL	AZ	L1	P1	P2	L2C	L5
GPS2	29↑	154	7	7	2	--	--
GPS6	44↑	98	11	9	2	2	-13
GPS12	70↑	282	7	8	-2	-2	--
GPS14	25ˆ	302	5	8	-4	--	--
GPS17	23↓	58	6	9	-6	-2	--
GPS24	53↓	196	1	4	13	1	-12
GPS25	30↑	282	4	8	7	1	-32
GLN1	10↑	34	1	4	-15	-23	--
GLN8	16↓	344	12	15	17	25	--
GLN9	32↑	316	0	2	-3	-6	--
GLN15	31↓	142	5	5	0	1	--
GLN16	84↑	266	2	2	-11	-18	--
GLN17	39↓	44	-1	-4	-12	-10	--
GLN18	69↑	188	-1	3	-1	-6	--
GAL12	68ˆ	108	0	-26	0	--	-14
SB127	25ˆ	160	7	--	--	--	-4
SB128	15ˆ	130	9	--	--	--	-11
QZ193	13↑	68	-3	-1	--	1	-19
BDU2	16ˆ	132	-7	--	--	--	-17
BDU5	25ˆ	154	-4	--	--	--	-7
BDU8	25↓	54	-10	--	--	--	-20

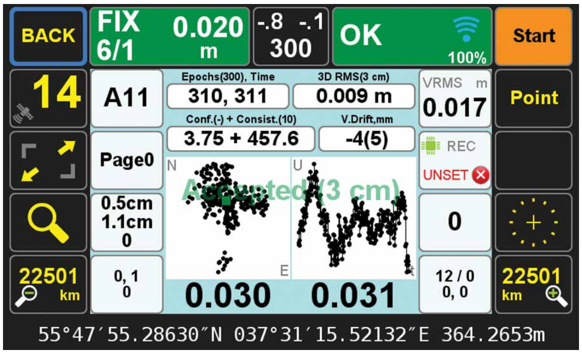
SAT	EL	AZ	L1	P1	P2	L2C	L5
BDU11	75↑	158	-6	--	--	--	-5
BDU12	36↓	60	-6	--	--	--	-14
GPS3	10	26	--	--	--	--	--
GPS29	3	229	--	--	--	--	--
GPS32	3	346	--	--	--	--	--
GLN7	3	297	--	--	--	--	--
GLN19	12	210	--	--	--	--	--

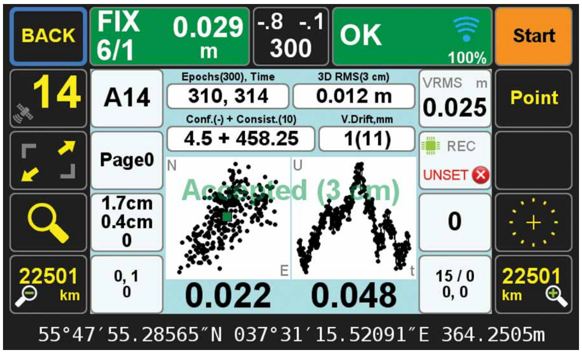
Figure 12 *Carrier Phase multipath remove (mm)*

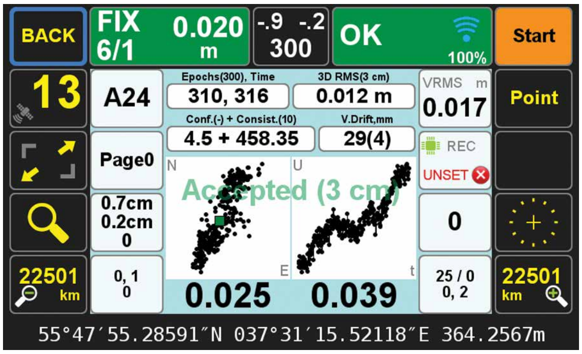
Multipath Showcase

Graphs in the following examples show multipath effects in a 13.8 km baseline where about 1/3 of the rover sky was blocked by a tall building. This box shows horizontal (top) and vertical (bottom) offsets from the actual coordinates of the point (earlier surveyed for test).





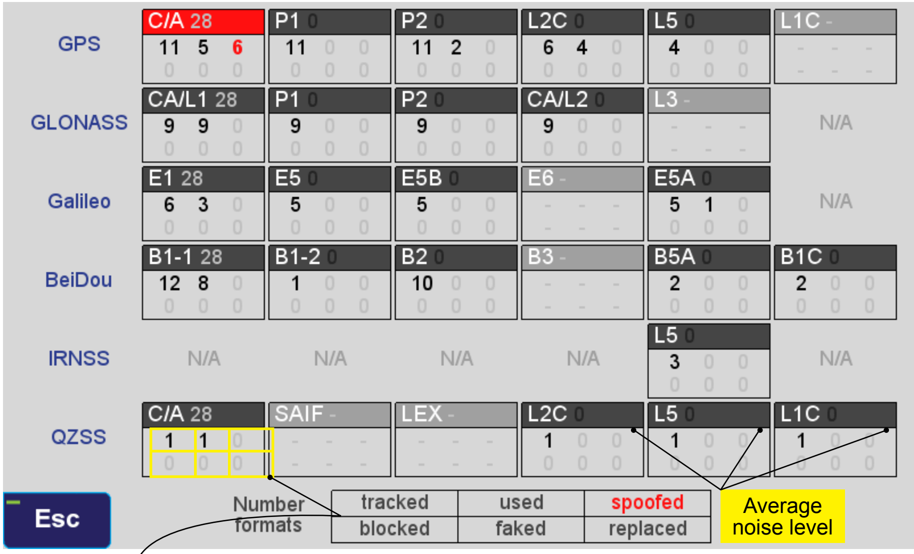




Javad Ashjaee, Ph.D.

GNSS Overall View

The format and the signal definitions are explained below.



GPS L2C: L+M
GLN L3: I+Q
GAL E1: B+C
GAL E5: alboc
GAL E5B: I+Q
GAL E5A: I+Q
BeiDou B2: B5B
QZSS L2C: L+M
QZSS L1C: I+Q

Figure 4
The screenshot shows the status of all GNSS signals.

Definitions for the number of signals:

Tracked: Tracked by the tracking channels and has one valid peak only.

Used: Used in position calculation.

Spoofed: Has two peaks. Good peak is isolated, if existed.

Blocked: Blocked by buildings or by jamming. If jammed, shows higher noise level.

Faked: Satellite should not be visible, or such PRN does not exist.

Replaced: Real signal is jammed and a spoofed signal put on top of it. Because of jammer, it shows higher noise level.

Spoofer Orientation

When you detect that spoofers exist, you can also try to find the direction that the spoofing signals are coming from. For this, hold your receiver antenna (e.g. TRIUMPH-LS) horizontally and rotate it slowly (one rotation about 30 seconds) as shown in the picture and find the direction that the satellite energies become minimum. This is the orientation that the spoofer is behind the null point of the antenna reception pattern.

After one or more full rotations observe the resulting graph that shows approximate orientation of the spoofer as shown in figure 5.

Number of Satellites
Direction of minimum
Total SNR
Direction of minimum

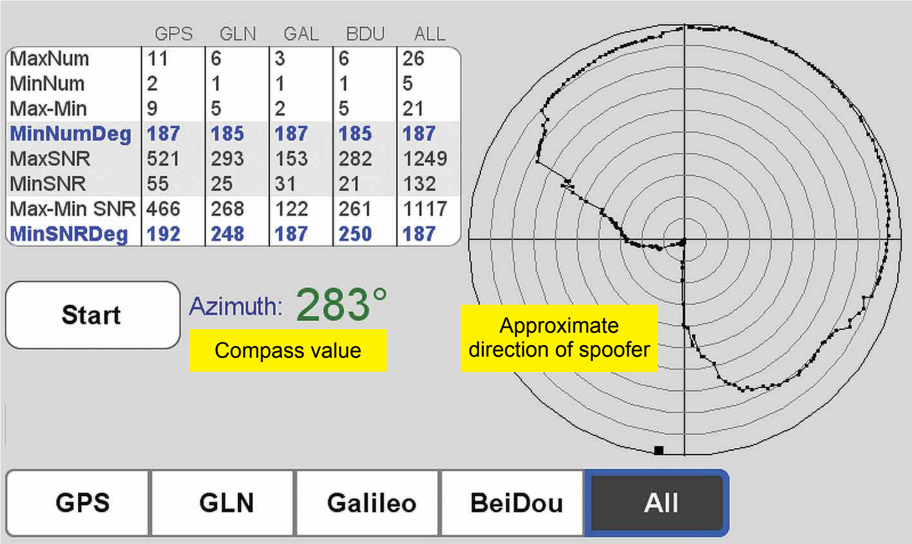
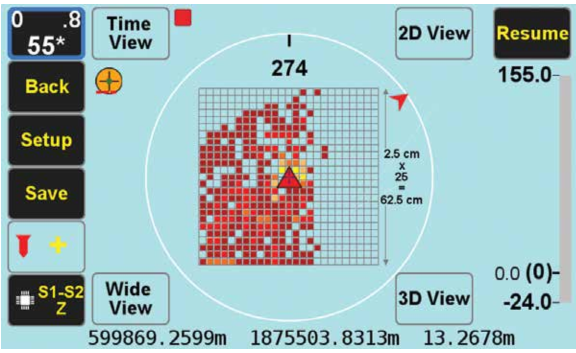


Figure 5
This screenshot is from the experiment within an anechoic chamber. That is why the picture is clean and smooth.

J-Tip

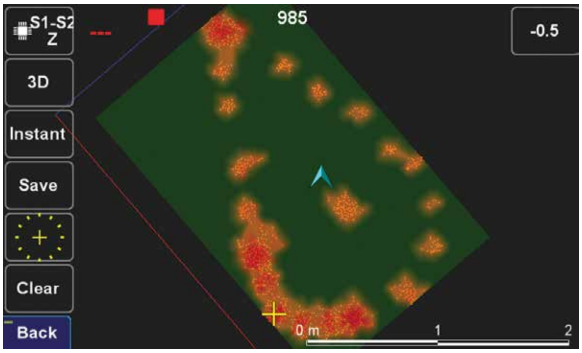
TRIUMPH-LS tags coordinates with magnetic values, It also guides you to top of the item to survey it.

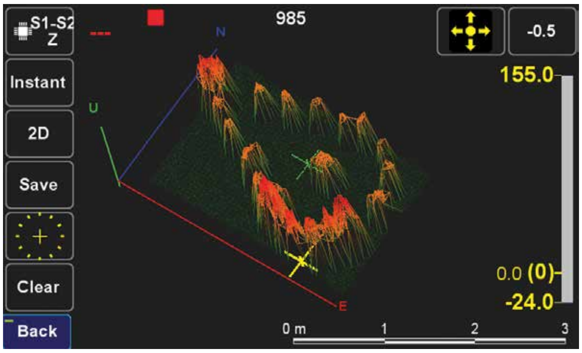


The Mag View focuses only on the mag object with the highest mag value.

The audio and graphical bar on the right side show the magnitude of the magnetic object.

In "Setup" you can select the cell size and the size of the field you want to scan.





The J-Tip has far exceeded my expectations. It is a tool that I have thought about daily my whole career. My thoughts used to be why can't they (whoever they are) make a metal locator that will fit in my pocket. Well, you did it! Yesterday, I was working on a 14 acre boundary survey in steep mountain country. I was able to recover every corner I searched for using the audible tones. I was more effective and efficient than in the past and realized that you have cut the weight and bulk of a metal locator to a fraction of what it was. The J-Tip is lighter than my phone and it fits in my pocket! The locators that I previously used are now collecting dust. They were heavy and cumbersome to tote around. One particular locator that I have used thru the years had a holster and would hang on your side. The back of my knees have taken a beating from that thing slapping the back of them with every step. The J-Tip proved itself to be tough and durable on the mountain survey project. I was also providing topography on a few acres of the site that was covered with green briars, saw briars, kudzu, and very thick. I left the J-Tip on the monopod while working in the brush. Minor scratches are to be expected in that type of environment, so it has a few but the J-Tip took a beating yesterday and worked like a mule. Very impressive!

Adam Plumley, PLS

2D and 3D views of the field show the magnetic objects that have been scanned.

Zooming the 2D and 3D screens can show the shape of the magnetic objects under the ground.

For many sophisticated features of the J-Tip see its Users Manual in www.javad.com