Which antenna is better? Test with WSPR

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How good is the new portable antenna on my motorhome compared to my station antennas on the balcony of the apartment? If you can switch two antennas for the same frequency range at the station, you used to switch the antennas during a QSO and ask the other station how the S-meter reacted to it, or you switched between the antennas yourself in the reception pass and noted the S-meter display. Since the motorhome is a few 100 m away, I can't do it that way. With the introduction of the WSJT-X software /1/ (often used in the FT8 mode), see Figure 1, however, a method has been established with the **Weak Signal Propagation Reporter (WSPR)** mode with which I can answer my question without having to run QSOs. The WSPR mode of operation has been around for almost 20 years and on various websites and other channels you can now also find reports on how WSPR can be used to compare antennas. The company SOTABeams even has a commercial solution on the market with the product WSPRLite /2/ on this basis.

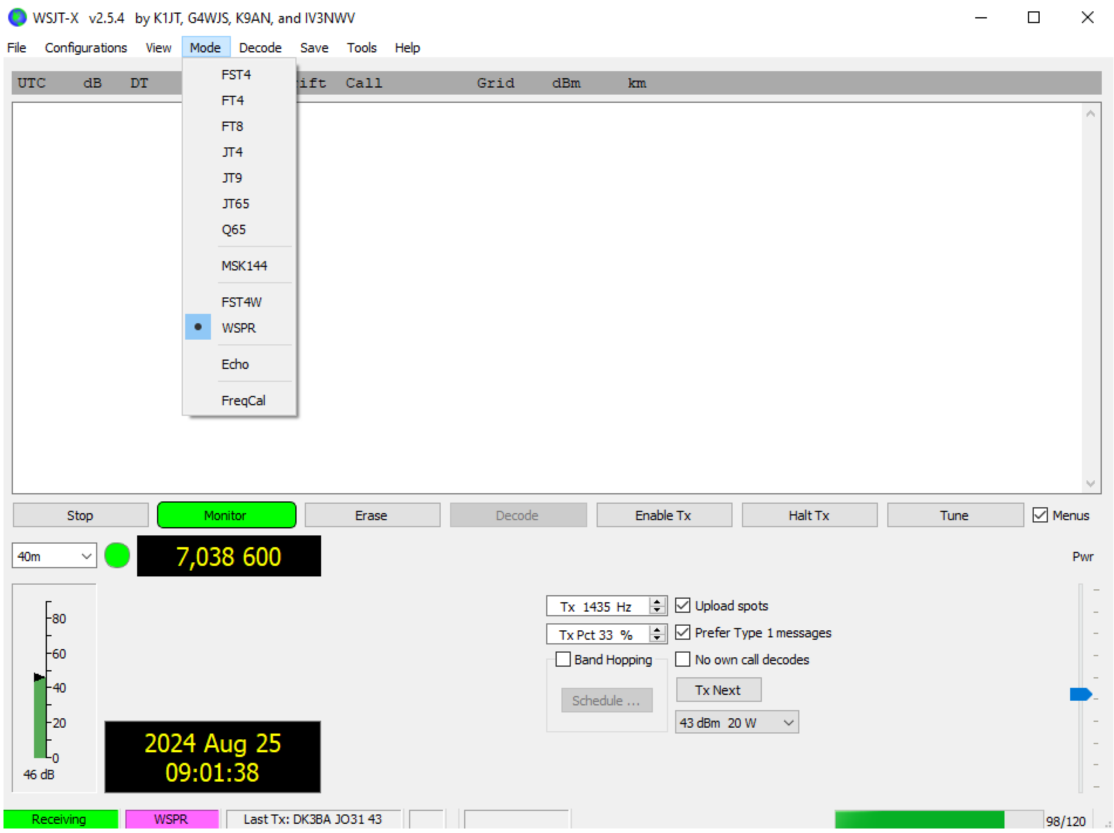

Figure 1: The main window known from the WSJT-X program with the expanded menu for the modes; WSPR was selected here.

Normally, WSPR is only used to test the propagation conditions and the range of a station – the same information from WSPR is also sufficient for testing and comparing antennas. However, the test with WSPR described here is not intended to determine the gain of antennas, radiation diagram or efficiency of antennas. It is "only" a matter of determining which of two antennas generates the higher levels at remote receiving stations, corresponding to higher S-meter readings.

How does the WSPR mode work?

In WSPR mode, my station sends a very narrowband signal in a time slot of 2 minutes, which transmits my call sign, my locator and my transmitting power. Worldwide, many radio amateurs are also in QRV mode, but at any time most of them are only receiving. This is also the case with my own station, which only transmits in an adjustable percentage of the time slots and in between observes and decodes the other signals in the WSPR frequency window of 200 Hz. In Fig. 2 you can see a list of several evaluated receive time slots in the 40-meter band and in between a time slot with my own transmission.

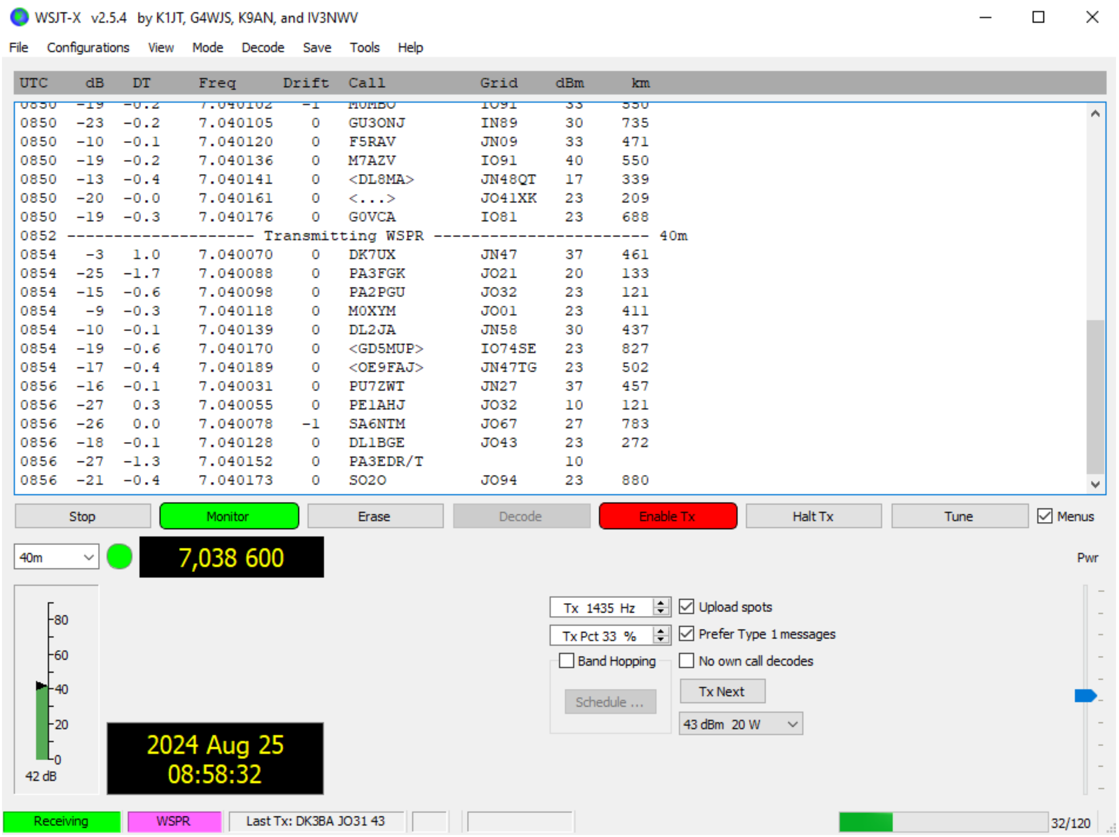

Figure 2: WSJT-X – Mask in WSPR mode with list of received stations in the time slots 08:50, 08:54 and 08:56 UTC as well as a transmitting time slot at 08:52 UTC in between.

The receiving stations that have checked the "Upload Spots" box automatically send a "Reception Report" via the Internet to the central data collection point "WSPRnet"; in this report, all received stations are reported with the signal-to-noise ratio (S/N, second column) measured by the receiver. Shortly after my transmission run, I can see a list of all messages concerning my callsign on the WSPRnet page. In the example, Fig. 3a, the search criteria are first defined, i.e. frequency band, my call sign and the time range, and after clicking on "Update", the list, Fig. 3b, is transferred.

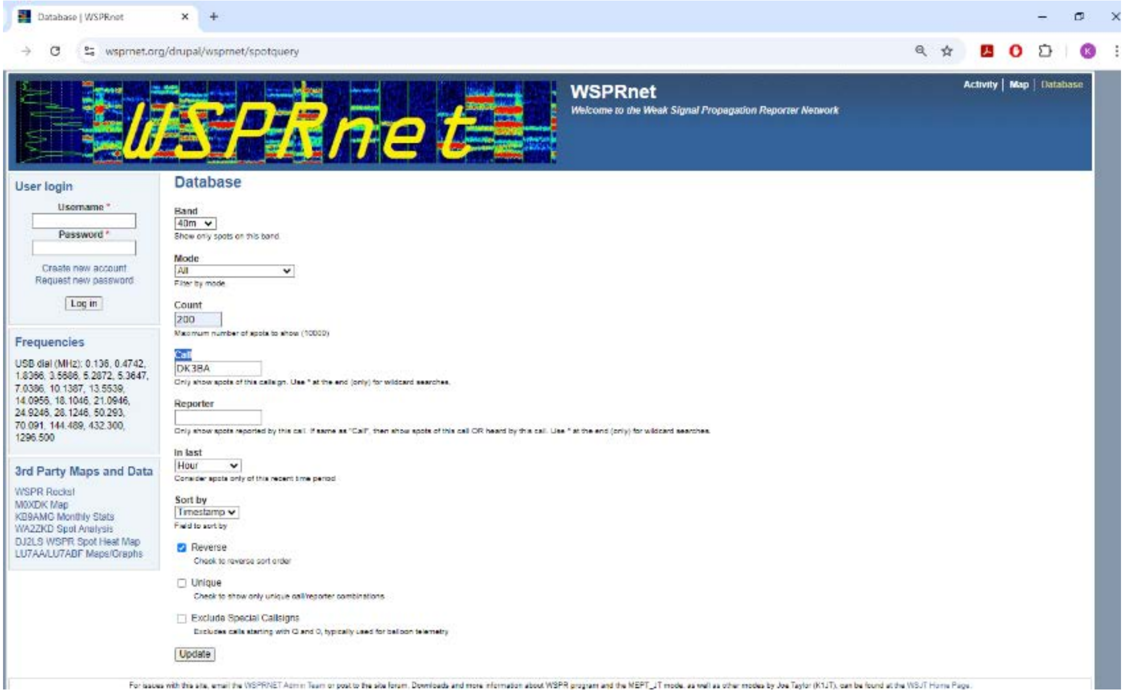

Figure 3a: Setting of the search criteria for the compilation of the reception reports.

A critical look at the reception reports shows: The S/N values reported by a receiving station for my transmission can fluctuate greatly from one time slot to the next due to fading (QSB), as e.g. with the station OH6BG (highlighted in yellow) in the lower list with S/N values between -5 and -18 dB. And something amazing: Although the field strength of my signal should be about the same at two closely adjacent stations (at the same **Az** angle and at about the same **km** distance), very different values of the S/N can be measured. In the list below, the two stations OH6BG and OH1LSQ (highlighted in blue) show differences in the S/N values of up to 16 dB in the same time slots and while

Spot Database

Specify query parameters

200 spots:

Timestamp	Call	MHz	SNR	Drift	Grid	Pwr	Reporter	RGrid	km	az	Mode
2024-08-25 09:00	DK3BA	7.040039	-8	0	JO31lk	20	DK8JP	JO31gk	29	270	W-2
2024-08-25 09:00	DK3BA	7.040036	-11	0	JO31lk	20	PD0JEW	JO22pe	142	307	W-2
2024-08-25 09:00	DK3BA	7.040036	-9	0	JO31lk	20	OE3GBB/Q	JN87aq	776	119	W-2
2024-08-25 09:00	DK3BA	7.040036	+1	1	JO31lk	20	HB9VQQ/RE	JN47kh	479	162	W-2
2024-08-25 09:00	DK3BA	7.040036	-17	0	JO31lk	20	DC7TO	JO62qk	454	73	W-2
2024-08-25 09:00	DK3BA	7.040055	-3	0	JO31lk	20	G6UQZ	JO02gb	447	281	W-2
2024-08-25 09:00	DK3BA	7.040109	-5	0	JO31lk	20	PD1V	JO21pi	116	266	W-2
2024-08-25 09:00	DK3BA	7.040036	0	0	JO31lk	20	G3VPW	IO91gp	582	276	W-2
2024-08-25 09:00	DK3BA	7.040034	+14	0	JO31lk	20	ON5KQ	JO10os	272	256	W-2
2024-08-25 09:00	DK3BA	7.040042	+4	0	JO31lk	20	DH2RAL	JO41lu	146	71	W-2
2024-08-25 09:00	DK3BA	7.040039	-20	0	JO31lk	20	M7EXT	JO02ag	484	284	W-2
2024-08-25 09:00	DK3BA	7.040036	-12	0	JO31lk	20	DL2ZZ	JO31lo	19	0	W-2
2024-08-25 09:00	DK3BA	7.040029	-16	0	JO31lk	20	2E0DSS	IO82xl	627	284	W-2
2024-08-25 09:00	DK3BA	7.040030	-26	0	JO31lk	20	DL8YCA	JO31pl	24	79	W-2
2024-08-25 09:00	DK3BA	7.040036	+2	0	JO31lk	20	HB9VQQ	JN47kh	479	162	W-2

Spot Database

Specify query parameters

200 spots:

Timestamp	Call	MHz	SNR	Drift	Grid	Pwr	Reporter	RGrid	km	az	Mode
2024-08-25 08:52	DK3BA	7.040042	-21	0	JO31lk	20	OH2T	KP30hw	1600	41	W-2
2024-08-25 08:46	DK3BA	7.040043	-18	0	JO31lk	20	OH2T	KP30hw	1600	41	W-2
2024-08-25 08:46	DK3BA	7.040039	-20	0	JO31lk	20	OH6AC	KP12lx	1595	30	W-2
2024-08-25 08:52	DK3BA	7.040039	-21	0	JO31lk	20	OH6AC	KP12lx	1595	30	W-2
2024-08-25 09:00	DK3BA	7.040052	-18	0	JO31lk	20	OH2BUA	KP30bx	1580	40	W-2
2024-08-25 08:46	DK3BA	7.040048	-21	0	JO31lk	20	OH6AH	KP12kr	1573	31	W-2
2024-08-25 09:00	DK3BA	7.040048	-23	0	JO31lk	20	OH6AH	KP12kr	1573	31	W-2
2024-08-25 08:52	DK3BA	7.040048	-23	0	JO31lk	20	OH6AH	KP12kr	1573	31	W-2
2024-08-25 08:46	DK3BA	7.040004	-21	0	JO31lk	20	OH1LSQ	KP03sd	1561	28	W-2
2024-08-25 09:00	DK3BA	7.040004	-21	0	JO31lk	20	OH1LSQ	KP03sd	1561	28	W-2
2024-08-25 08:52	DK3BA	7.040004	-22	0	JO31lk	20	OH1LSQ	KP03sd	1561	28	W-2
2024-08-25 08:46	DK3BA	7.040036	-5	0	JO31lk	20	OH6BG	KP03qa	1545	28	W-2
2024-08-25 09:00	DK3BA	7.040036	-12	1	JO31lk	20	OH6BG	KP03qa	1545	28	W-2
2024-08-25 08:52	DK3BA	7.040036	-8	0	JO31lk	20	OH6BG	KP03qa	1545	28	W-2
2024-08-25 09:00	DK3BA	7.040038	-18	0	JO31lk	20	OH3FR	KP20	1496	41	W-2

Figure 3b: Excerpt of the list of reception reports of my transmission at 09:00 UTC (top) and another list (bottom) with reception reports from several transmission time slots, but with a sorting by distance of the receiving stations.

OH6BG shows strong QSB, the level of OH1LSQ is significantly lower, but practically without QSB. Such behaviour can occur if the local noise level is significantly different, and the antennas used are completely different in their directivity and polarization. The example shows that the S/N values in themselves cannot be a measure of the quality of my transmitting antenna, e.g. the antenna gain, but only provide a picture of the current propagation conditions towards the individual receiving stations. If you look at the whole list of reception reports, however, you can see in which directions and at what distances your own broadcast "carries" at that time and in the band you are currently using. All S/N values would be increased by increasing the transmission power by x dB – this increases the field strength at all receiving stations in the same way, which would also improve the reception reports by x dB. The signal processing in WSJT-X is "linear" over a wide level range (before compression kicks in), so it faithfully reproduces level differences in the received signals as dB differences, unlike many S-meters in our transceivers.

Comparison of antennas

I can use this feature to actually make a quantitative statement about the characteristics of my own antennas: I want to know how many dB my new portable antenna is "better" than my proven station antenna on the balcony of the house. I benefit from the fact that the portable station in the motorhome is already capable of digital mode with a notebook and USB digimode interface from xggcomms (G8XGG).

The idea is to send WSPR signals from both antennas with the same power level and at the same time (with the home station and the portable station under different call signs!) and to compare the results of all reception reports, i.e. to determine the dB differences in the S/N values. Then the difference in level at the many receiving stations is exactly the difference in the S/N values that the receiving stations report for the two call signs. Due to the simultaneity, the fading should have the same effect on both transmissions. Only with a new transmission to a later time slot should the reception levels change due to fading, but the difference between the S/N reports (in dB) should remain the same — so much for the ideal.

However, the propagation of waves through the ionosphere is apparently not quite as easy as thought – this is shown by the examples in the table with selected results for two consecutive time slots from a test on the 40-meter band. Results for my AMA82 Magloop antenna (1.7 m Ø) on the balcony are in column **S/N-b** and results for my new 10 m high vertical antenna /3/ on the mobile home at a distance of 300 m away in column **S/N-a**: The level differences in column **Δ dB** are always pronounced in favour of the vertical antenna, but not the same at all receivers; in the examples in the table between 3 and 12 dB. If, as is the case with most stations in the table, strong fading determines the transmission at that time, the level differences can even jump from one time slot to the other, in the examples in the table we see jumps between 1 dB (SQ9 and OK2) and 5 dB (G4).

Call	**UTC**	**S/N - a**	**S/N - b**	**D dB**
SQ9	08:56	- 5	-13	8
	09:00	-13	-22	9
SA6	08:56	-7	-12	5
	09:00	-11	-14	3
OZ7	08:56	+6	+1	5
	09:00	+10	+2	8
G4	08:56	-8	-14	6
	09:00	+6	-5	11
OE3	08:56	-8	-20	12
	09:00	-14	-23	9
OK2	08:56	-6	-10	4
	09:00	-4	-7	3

Table: Reception reports of some stations after test broadcasts in the 40-meter band.

This behaviour is likely to be caused by the simultaneous propagation of our signals through the ionosphere via different paths and their superposition at the receiving antenna. Fluctuations in the ionosphere generate temporally fluctuating signal levels and phases at the receiver location on these paths, so that the resulting (sum) receive signal has fading, i.e. fluctuates in level. However, due to different radiation patterns in the elevation and different close-up surroundings of my antennas, the different paths are excited to different degrees, which can lead to different compositions of the signal components at the receiving location, with different time variation of fading. It is therefore not possible to name a single number in the reception reports for the advantage of one of the two antennas – this advantage apparently depends to a large extent on the random instantaneous state of the ionosphere, and this also depends on the direction and distance to the receiving station. An evaluation of the measured level differences only makes sense here if they are averaged over many reception reports. In Fig. 4, the results of more than 80 reception reports from Europe with distances between 250 km and 3000 km are shown as points with their respective **Az** angle and the **Δ dB** value. You can see the strong dispersion of the difference levels as well as directions under which a strong accumulation of reception reports occurs. From the distribution of the dots, no preferred direction can be seen, both antennas seem to radiate about "omnidirectional"; on average, the distribution of the difference levels results in an advantage of the vertical antenna over the AMA82 Magloop of about 7 dB.

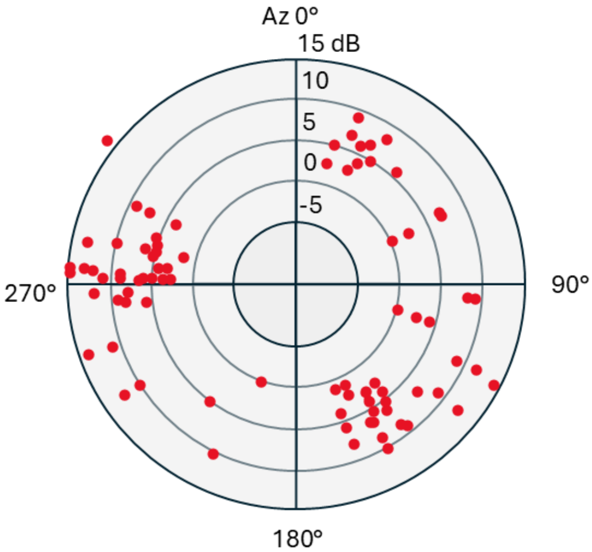

Figure 4: Distribution of reception reports by azimuth angle **Az** and difference level **Δ dB**

The situation is somewhat different if only nearby receiving stations are taken into account that are reached exclusively via the ground wave; in the example, at distances of up to 150 km. The corresponding reception reports show no fading, i.e. show almost constant S/N values over a long period of time. One would expect that the S/N values reported by the stations would decrease steadily with distance, since the power density of the transmitted ground wave decreases by at least $1/R^2$ (reciprocal of the square of the distance R) – i.e. 6 dB descent of the signal level with twice the distance. However, this is hardly recognizable, as S/N values always appear that can be up to 20 dB above or below – the receiving stations are very different in their antennas used, local noise level and the settings of the receivers and evaluation software. Apart from that, it is also clear that the advantage of one antenna over another for the ground wave can differ greatly from the result for the space wave propagation at higher elevation angles in the direction of the ionosphere. In the case of ground waves, differences in polarization and differences in the polar pattern of the antennas exclusively in the horizontal direction (elevation 0°) may be decisive. Vertical radiators generally form stronger ground waves than horizontally polarized antennas.

As far as the antennas to be compared show pronounced differences in the vertical radiation patterns, the reception reports must be sorted by distance ranges in order to obtain a fair result. For example, an antenna with pronounced steep radiation (typical for low dipole) will be superior to an antenna with pronounced flat radiation (typical vertical radiator) in European traffic (e.g. up to 3,000 km distance), but inferior at DX distances – which antenna is better then?

If, as shown, even the transmissions of the two antennas at the same time slot do not completely eliminate the effects of strong fading and an averaging over many reception reports is necessary, one can also accept the level fluctuation between different transmission time slots: Then one can switch between antennas to be compared one after the other at the station and the reception reports can be accounted according to the time slots of the switched antennas. This was simulated once with the available data: An evaluation of the reception reports over four time slots with 88 differences of the S/N values from the previous or subsequent time slot showed a much stronger statistical dispersion (fluctuation range) of the difference values **Δ dB** but they also led to an average value of about 7 dB. This evaluation was carried out "manually", which is much more time-consuming than the evaluation of exclusively simultaneous transmissions – automated data processing could have increased the fun. This would also be quite possible, since you can download formatted lists of reception reports at WSPRnet and that's how the WSPRlite software does it.

It should not go unmentioned that there is an alternative to WSPR with the **Reverse Beacon Network**. So if you don't have the possibility to install WSJT-X (or even detest the digital operating modes operated with it – FT8 etc.), you can use reception reports, so-called "RBN spots", which come in at *reversebeacon.net* after several CQ calls in CW on the Internet site /4/. Compared to WSPR, however, a significantly lower yield can be assumed, because there are usually many more WSPR users active than RBN spotters and also because the range of WSPR transmissions is considerably greater due to the higher sensitivity on the receiving side.

<u>References</u>

/1/ WSJT-X download: https://sourceforge.net/projects/wsjt/files/

/2/ WSPRlite Classic Antenna Performance Analysis System: https://www.sotabeams.co.uk/wsprlite-classic

/3/ Klaus Solbach, Operating from a Motor Home: Antenna for 40 – 10 Meter, https://www.uni-due.de/hft/amateurfunk_en.php

/4/ Reverse Beacon Network: https://reversebeacon.net/index.php