FT8 Reports - What we can learn from

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When operating with FT8, many QSOs can be logged in a short time. It quickly becomes apparent that some reports differ extremely between "Sent" and "Rcvd", sometimes in favor of your own station and sometimes vice versa. This article attempts an explanation and examines whether something can be learned from the reports.

In the analog operating modes (CW and SSB), a radio connection usually works if I receive the other station well above the noise - in the 80-meter band at higher noise levels than at 10-meter. Local QRN plays the decisive role in my situation with, depending on the time of day, up to over S7 level for 3 kHz bandwidth in the 40-meter band (over S6 in the 30-meter band), received with a magnetic loop antenna on my balcony of the apartment building. With FT8 and other digimodes, the S/N shows exactly this ratio of signal strength to noise power in the receiver bandwidth, both for your own station and for the other station.

As a newcomer to the FT8 operating mode with WSJT-X /1/, I immediately noticed that there were always very unequal reports, up to a 30 dB difference between the S/N in my receiver and the S/N reported by the other station, sometimes in favor of the other station, sometimes vice versa. This is actually already known from the analog operating modes, e.g., when a station comes in with S9, but it doesn't hear my signal even though no other station is calling.

But why is that, what should we actually expect based on physics?

In communications technology, a simple mathematical model is used for point-to-point radio transmission with a "line of sight" between transmitter and receiver (Line Of Sight, LOS).

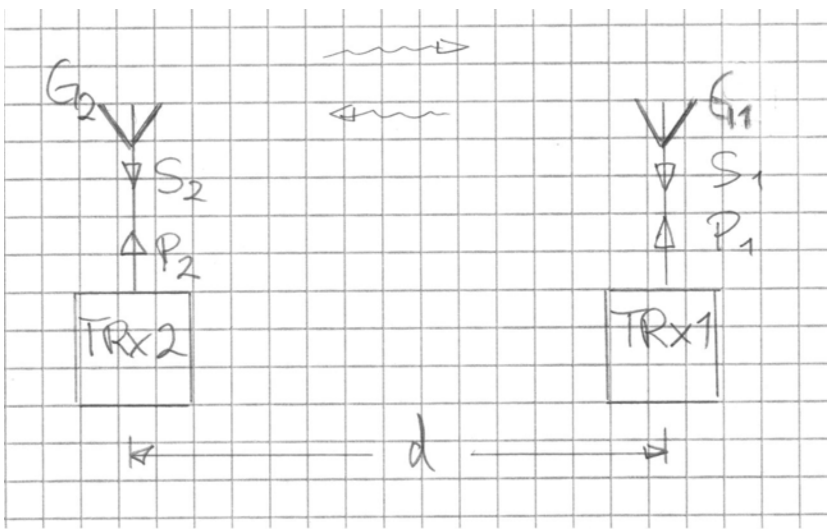

Figure 1 The model of a line-of-sight radio transmission

Figure 1 shows the situation of two radio stations, each of which connects an antenna directly (without loss) to a transceiver (TRx) and is located at a distance *d* in free space. The received signal power S_2 on the TRx_2 is "proportional" to the transmit power P_1 of the TRx_1 with a proportionality factor (the expression in brackets) which includes the product of the two antenna gain numbers G_1 and G_2, the used wavelength λ and the square of the distance *d*:

$$\frac{S_2}{P_1} = \left(\frac{G_1 G_2 \lambda^2}{(4\pi)^2 d^2}\right) = \frac{S_1}{P_2} \qquad \text{Eq. 1}$$

Proportional means that if P_1 is doubled, the received power S_2 also doubles - no surprise there. If the antennas used do not contain amplifiers (such as "active antennas"), the gain of antennas for transmission is equal to the gain in receive. Therefore, the transmission between the two transceivers is "reciprocal", i.e. the factor for the transmission from TRx_1 to TRx_2 also applies to the reverse transmission direction. The received power on TRx_2 is therefore exactly the same as the received power on TRx_1, as long as the same transmission power is used in both cases. It doesn't matter whether the same antennas are used on both sides or whether they are completely different in design, orientation, efficiency, gain and polarization. So even if there is a beam with 10 dB gain on one side and a magnetic loop antenna with -7 dB gain on the other side, the received signal on both transceivers is equally strong. However, the level of received power itself depends very much on these factors: The gain numbers of the two antennas are in the numerator of the factor, i.e. the higher the gain of one or both antennas, the higher the reception level, i.e. the S in the reports. Many of my DX connections with my magnetic loop were only made possible by the high gain of a large beam on the opposite side increasing the signal levels.

However, for radio operation in the shortwave range, the LOS model does not entirely reflect reality: Wave propagation over the earth generates ground reflections that change the proportionality factor, **but not the reciprocity** of the radio transmission! It is different with wave diffraction in the ionosphere: Wave propagation in the ionosphere is in principle direction-dependent, i.e. the proportionality factor can be different for the two transmission directions. In particular, the polarization of the radio waves can be rotated differently as they pass through the ionosphere fore and back and therefore the radio transmission is no longer reciprocal. In addition, the interaction of ionospheric diffraction and ground reflections can create a superposition that leads to QSB, i.e. the proportionality factor can also fluctuate over a short time. Even in analogue operating modes, these two effects often lead to large differences in the signal strength reports of the own station and the other station, even if both stations have approximately the same transmission power.

In FT8 operation, another variable comes into play: The noise power *N*, which is simultaneously measured in the receiver bandwidth. The noise power of each radio station is received by its antenna and measured in the receiver. In the shortwave range, we can assume that we pick-up a large part of the noise power from the environment. Depending on the time of day we receive it from distant sources but mostly from the closer environment (local QRN), while the receiver's own noise is usually negligible. Especially with regard to the local QRN, one can assume that the two noise powers N_1 and N_2 of any two stations can be very different; the balcony antenna certainly performs worse than a beam on a tower 50 m away from the house.

What does this mean for the S/N reports in FT8 QSOs?

We look at this using various special cases.

(a) Assuming the far station is transmitting at the same power and we both suffer from the same receive noise level, then my TRx should rate the far station's signal with an S_1/N_1 (shown in WSJT-X as "Rpt Sent"), which is exactly same as the S_2/N_2 is reported as “Rpt Rcvd” by the other station, no matter which antenna I use:

S/N (Sent)= *S/N*(Rcvd)

(b) If the receive noise of my station is higher than that of the other station with the same transmission power, I send a worse report (Sent) than the other station sends me (Rcvd):

S/N (Sent)< *S/N*(Rcvd)

This is a paradoxical result and no reason for me to be happy, since this apparent “advantage” is based on an actual disadvantage of the higher interference level of my station. Conversely, of course, a low noise level at my station makes the other station “look” better.

(c) However, if I use a lower transmission power than the other station, with the same noise conditions, my station rightly appears to be at a disadvantage:

S/N(Sent)>*S/N*(Rcvd)

And vice versa, a higher output power leads to a beneficial result.

(d) First of all, an astonishing observation: If I insert an attenuator at the receiver or switch off the preamplifier, i.e. reduce the receive gain, the S-meter report drops, but the reports of the decoded remote stations displayed in WSJT-X do not change. As long as the “external noise” still dominates, the ratio of received signal and received noise does not change because both are reduced equally. Therefore, this does not change the comparison of the reports. But of course, in these cases the weakest received signals can fall below the decoding threshold and remain invisible to me. E.g., under appropriate propagation conditions I can then see the European stations that call the DX station, but I do not “see” the DX station itself because it is below the decoding threshold.

(e) The last special case is more complicated: We start from case (a) with any two antennas that are operated with the same transmission powers and pick-up the same noise levels. However, a long cable with considerable attenuation is connected between the antenna and TRx_1, which reduces both the received powers S_1 and N_1 at my receiver as well as the transmit power P_1 arriving at the antenna. In this case, the expression in brackets in the equation must be expanded to include an attenuation factor in the numerator. This also reduces the signal power at both stations by this factor, e.g. by a factor of 1/2 if the cable loss corresponds to 3 dB. However, the ratio S_1/N_1 remains constant because the receive noise and the signal from the other station are reduced equally, while at the other station the S_2/N_2 drops by the factor of the cable loss. This means that your own station looks worse in terms of the reports by the factor of cable loss. In order to get the reports back to parity, unsurprisingly, only the transmission power P_1 has to be increased in accordance with the loss factor.

For most radio stations, the cable attenuation is likely to be of little importance, but there are antennas that already have considerable attenuation "built in". For example, a magnetic loop antenna with 20% efficiency in this view corresponds to a lossless antenna with a built-in 7 dB attenuator. In this case too, the S_1/N_1 does not suffer from the attenuation losses of the antenna as long as the external noise still dominates the receiver's own noise. On the other hand, the other station “sees” the lower signal level due to the reduced transmit power actually radiated by my antenna. Because of the poor efficiency of my antenna, the comparison of the reports is in favor of the other station with a difference that corresponds to the antenna efficiency, in the example 7 dB. Compensation is provided by increasing the transmission power, but this can hardly compensate for the low efficiency in standard magnetic loop designs (no kW power amplifiers!). On the other hand, magnetic loop antennas tend to be positioned close to residential buildings, where they are exposed to increased man-made interference levels, which can significantly worsen the S_1/N_1 reports, see the results of my evaluations in the next section.

Unfortunately, the FT8 protocol does not transmit any information about the stations' noise levels and their transmission powers. You can encounter stations with much higher or lower noise levels or with much higher transmission powers but also much lower (QRP). The non-linear detector characteristic in WSJT-X creates a certain compensation, which evaluates very strong signals lower than their real amplitude (as measured, e.g., at 100 Hz bandwidth with the S-meter). As a result, the S/N reports are kept within narrower limits than would correspond to the real situation. In addition, there are fluctuations due to the non-reciprocal ionospheric propagation and with fast QSB, errors arise due to the time-shifted “reading” of the signal levels in successive runs.

So, it's all just a coincidence and the reports say nothing about your own station?

It is clear that comparing the reports from “Sent” and “Rcvd” cannot actually say anything about the gain of your own antenna. However, we can gain something from comparing reports if we make a few plausible assumptions: First, we can assess the noise situation at our own station. With my antenna close to the residential building, I probably see a higher than average local QRN level because most radio amateurs' outdoor antennas are likely to be further away from the sources of interference in buildings. In my opinion, this results in a disadvantage for my station in terms of noise level of about one S level (in the 40- and 30-meter band) compared to an assumed “average” QRN receive level. There is no comprehensive data on the receive noise levels of radio amateur stations worldwide (yet), but the ITU publication /2/ provides an indication. In its graph *FIGURE 10,* the magnitude of the additional noise figure of a lossless isotropic antenna in an urban environment is shown for system planning purposes. In Figure 2, this data is shown converted to the corresponding receive noise power at 2.7 kHz bandwidth. You can see an idealized steady decrease in noise power with increasing frequency and a level from S9 +4 dB in the 160-meter band down to just above S4 in the 10 meter band. In comparison to, e.g., the first results of the DARC /3/ measurement campaign and the VERON /3/ measurement campaign and individual reports from radio amateurs, these values actually appear to describe relatively unfavorable antenna conditions, but are still too low. In rural surrounding areas, however, you can expect two or more S levels lower noise levels. Accordingly, the ITU publication sets noise levels that are more than 3 S levels lower for a “quiet” rural reception situation. It would therefore perhaps make sense to assume noise levels for the “average” antenna situation of radio amateurs that are one S level lower than those in the ITU publication in Figure 2.

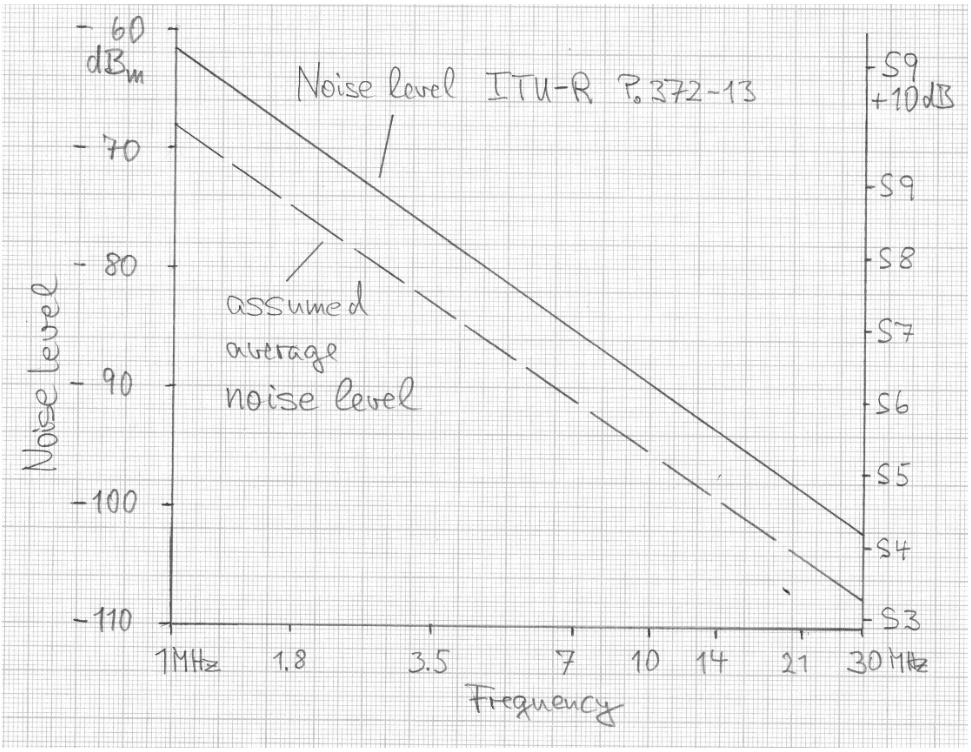

Figure 2 Mean (local) noise levels in an urban environment (median city area man-made noise, adaptation of FIGURE 10 in reference /2/) with a scale in S level steps of 6 dB.

With regard to the transmission power, many radio amateurs find it sensible and necessary not to increase the transmission power unnecessarily in FT8. After looking through many forum posts on this topic, one can get the impression that in the shortwave bands a power level of around 25 W at the antenna is considered sufficient and practical. Consideration of the thermal load on power amplifiers of typical 100 W transceivers due to the relatively long TX passes often also plays a role. Conversely, in difficult propagation conditions or when hunting for rare call signs, people like to go up to full power; with some DX stations one has the impression that they even run a kilowatt power amplifier. There is also a tendency towards higher transmission power if the antenna has low efficiency, such as my magnetic loop or mobile antennas. It therefore seems plausible that the average transmission power of all FT8 stations should be in the range of 20 - 50 W.

Speaking of “average”: The large fluctuations in signal strengths caused by QSB and polarization rotation in the ionosphere are caused by an inhomogeneously distributed and constantly changing ionosphere in the atmosphere above the earth, so that from the perspective of each individual radio station, no systematic pattern in the fluctuations can be seen: they seem purely coincidental. Their effect on the reports is sometimes barely noticeable and sometimes “positive”, that is to say in favor, sometimes “negative”, i.e. in favor of the opposite station. Therefore, if you look at a lot of QSOs on different days and hours, in any number of different directions, at very different distances, then there should be about an equal number of positive and negative effects; the random effects should average out!

The “trick” is therefore not to look at individual QSOs, but rather to average the difference between the “Rcvd” and “Sent” reports from many QSOs, i.e. adding up the differences between the reports from 100 QSOs (on the same band with the same transmission power) and divide the result by 100. Theoretically, if you transmit with a power that corresponds to the average of all the remote stations worked and receive a noise level that corresponds to the average of the noise levels of the remote stations, you should notice a difference of about 0 dB as an average after hundreds of QSOs. Then the effects of non-reciprocal wave propagation through the ionosphere and the QSB effects would be approximately balanced out by statistical averaging and the reciprocal model of the LOS radio connection would come into play again. The number of QSOs used for averaging should be at least one hundred due to the large spread of the rapport differences, whereby more QSOs should result in a smaller deviation from the true value.

In concrete terms, this means: A greater transmission power from my station results in a better report (“Rcvd”) for the other stations, while a larger QRN at my station increases the report for the other stations (“Sent”); both together increase the difference in reports in my favor. In the graph, Figure 3, you can read the average difference Δ(S/N) of the reports, which results from the ratio (in dB) of your own transmission power level (power) based on the assumed average transmission power level of the remote stations and from the ratio (in dB) of your own noise level relative to the assumed average noise level of all remote stations. In the example shown, a transmission power that is twice as high (3 dB) and a noise level that is 5 dB higher results in an average “advantage” of +8 dB in the reports.

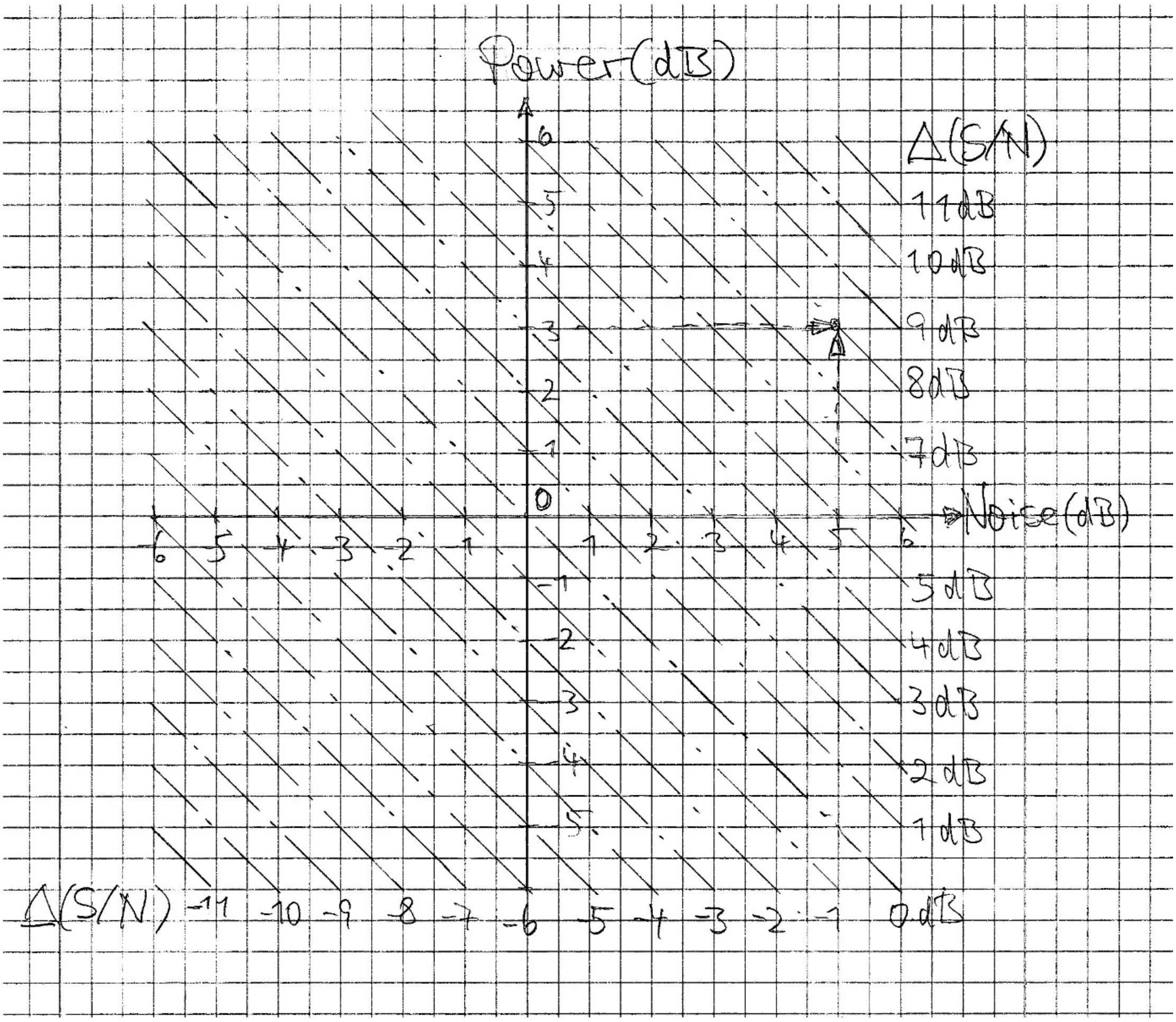

Figure 3 Graph to determine the expected mean difference between the “Rcvd” and “Sent” reports.

My own evaluation of a few hundred QSOs with mainly European contacts on average showed about 5 dB better reports for me on the 40- and 30-meter bands than for the other stations. This is probably due to the antenna on the balcony, which picks up the local QRN significantly higher than most remote stations with antennas typically at a greater distance from local sources of interference. The 50W transmit power used could also have contributed to this result if the average FT8 transmit power in these bands was actually slightly lower.

For the 15-meter band, an end-fed vertical half-wave radiator was used, which is also mounted on the balcony. However, despite the proximity to the house, the noise level in this band at only S3 is significantly lower than in the lower frequency ranges and is probably not far above the level at most remote stations. The evaluation of my QSOs in this band showed an average difference in the reports of around +1 dB when operating with 50 W transmit power. With half the transmit power, this value should decrease by 3 dB: For comparison, almost 100 QSOs were worked with 25 W and the evaluation actually showed an average difference in reports of -2.5 dB. When evaluating the 15-meter band, however, it was noticeable that there were often particularly large differences in the reports from "Rcvd" to "Sent" in the log, especially for DX connections compared to European connections. There is reason to suspect that in these cases DX remote stations worked with significantly higher transmit power levels than my 25 W or 50 W.

Summary:

With the FT8 operating mode we can log many QSOs in a short time with S/N reports, which can be extremely different in individual cases. We cannot make a statement about the status of our own station based on individual reports, but only through a statistical evaluation, averaging the difference between the reports "Rcvd" and "Sent" over many QSOs. Stations with a particularly high local interference level will receive a paradoxical result, namely, on average, they will see better "Rcvd" reports than "Sent", while stations with QRP transmission power will of course see a worse "Rcvd" rating on average. For a station with a typical transceiver in the 100-watt class and an outdoor antenna without a particularly high local QRN, the average difference in the reports should be close to 0 dB. However, this could also apply to a station with an indoor antenna and a correspondingly reduced transmit power, since the indoor antenna receives a particularly high local QRN and this "advantage" in the S/N evaluation is canceled out by the disadvantage of the lower transmission power. Knowing the mean difference can only provide an indication of problems with your own station against the background of the local QRN and the transmit power used. The noise level and transmit power do not have to be evaluated in absolute terms, but rather in relation to the average values given by all remote stations - here, unfortunately, one has to rely on a rough estimate as long as the FT8 protocol does not contain the transmission power used and the measured noise level. In any case, after evaluating our QSOs according to band and transmission power, we can better assess the chances of a successful call using the average report difference obtained.

References

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/3/ Presentation at Amateurfunk-Tagung München 2020, https://www.darc.de/der-club/referate/emv/enams/

/4/ Measurement Methodology and Results of Measurements of the Man-made Noise Floor on HF in The Netherlands, 2019, Koos (T. W. H.) Fockens, Peter (A. P. M.) Zwamborn, Frank Leferink, https://vienna.iaru-r1.org/wp-content/uploads/2019/03/VIE19-C7-007-VERON-Noise-Floor-Measurements.pdf