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RECEPTION QUALITY INDICATOR (RQI) IN FT8

1. Goal of the RQI and description of the calculation method

As announced performances of Ham antennas are often a bit subjective or optimistic, it is proposed an indicator able to compare HF antennas more objectively using reception in FT8.

Indeed, there are a very big number of FT8 transmissions in HF, and for a subset of them, they carry the Locator of the transmission station. If the position of the user station is known (by the Locator in general), it is possible to determine the distance between the transmission and reception stations. Moreover, taking into account the Signal to Noise ratio for these FT8 transmissions, and considering that the distributions of the transmission powers (Pt), transmission antennas gains (Gt) are supposed random around fixed mean values, it is possible to statically determine the probable « gain » of the reception set « Antenna + Noise environment » compared with a reference set « Antenna + Noise environment ». Note that the reference chosen in this paper is the Twente station, useful for the region around Twente, but this reference is modifiable for any region (see §3).

Note: strictly speaking, it is the set « Antenna + Obstacles around the antenna limiting the reception + Noise environment + Receiver noise » which is evaluated by the RQI. However, in HF, the receiver noise is negligible compared to the noise from the environment, for the quality receivers used by SWLs and HAMs. Now for a low-end receiver, the receiver noise is not negligible. Obstacles, as buildings, around the antenna will make decrease the RQI. This mainly concerns antennas on balcony and indoor antennas.

As the calculation is statistical, the uncertainty of the « gain » determination decreases when the number of FT8 receptions increases (it is, in fact, proportional to the square root of this number). In HF, it is estimated a maximum uncertainty of +/- 2 dB, for a station equipped with an omnidirectional antenna as a vertical one and located in the same region as the reference station.

Note about the directional antennas
The RQI of a directional antenna (Yagi for example) will depend on the direction targeted by the antenna relatively to the propagation direction of the moment. If both directions are aligned the RQI will be very positive and reversely. Consequently, for a directional antenna the RQI will vary from a minimum to a maximum.

So the RQI applies to omnidirectional antennas (ground-plane, etc).

Determination of the RQI

Under idealized conditions, on free space, the Friis transmission formula gives:

$$\frac{Pr}{Pt} = Gt \times Gr \times \left(\frac{\lambda}{4 \times \pi \times d} \right)^2$$

Pr is the reception power (W). Pt is the transmission power (W). Gt is the transmission antenna gain (with respect to an isotropic radiator). Gr is the reception antenna gain. λ is the wavelength in m. Note that λ=3E8/f with f the frequency in Hz. d is the distance between antennas in m.

Now, about Pr/Pt in HF:

- In short waves, due to the ionospheric reflection of radio waves, the transmission depends on some complex relationship with λ. Let's call r(λ) this function.
- Independently, the antennas gains Gr and Gt depend also on the wavelength λ.
  In the horizontal plane, the antennas are supposed omnidirectional.
- Pr/Pt depends on the time of the day (t), with t between 0 and 24 h, the main difference on the propagation being due to the degree of illumination (day/night).
  So the previous r(λ) function must be extended to the time t, i.e. r(λ,t).
- Pr/Pt depends on the season and on the solar cycle, but these long periods will not be considered. Now note that the reception references (see page 5) has been taken in Europe in November 2024, so with a good propagation in regards to the solar cycle.
- Pr/Pt is supposed to depend on $1/d^2$ (the same dependency as on free space).
  Moreover, it is supposed that the location of the reception station is known (the longitude/latitude or more commonly the Locator). A subset of the FT8 decodes gives a Locator which permits to determine the distance d between the reception station and the transmission station.
  Note: in fact the path loss exponent of d (supposed here equal to 2) is probably between 2 and 4, depending on the degree and type of ionospheric reflection and hence on the frequency used. However, the author does not have available loss exponent models for SW.
- The position (latitude + longitude) of the user station compared to the position of the reference monitoring station (for example the Twente station in Netherlands, as chosen below) has a sure influence. For a station far away from the reference station (Twente here), it is difficult to estimate the additional uncertainty.
  Note 1: the obvious solution, for a given region, is to have a reference monitoring station, using an omnidirectional developed antenna in a rural quiet zone. For this, refer to the reference tables below.
  Note 2: this does not prevent the comparison of two antennas, in the same time, at the same location, which is the main goal of the RQI (see §4).

So it can be written: $\frac{Pr}{Pt} = Gt(\lambda) \times Gr(\lambda) \times \left(\frac{1}{4 \times \pi \times d} \right)^2 \times r(\lambda, t)$

The SNR (signal to noise ratio) determined by the FT8 decoding program is equal to

$SNR = \frac{Pr}{Pnoise}$ so $Pr = Pnoise \times SNR$

Pnoise is the noise power received in a normalized bandwidth, i.e. 2.5 KHz for the FT8 mode. It is composed of:

- the atmospheric noise (due to lightning), which is variable with the HF frequency,
- the galactic background noise which is also variable with the HF frequency,
- the man-made noise, which decreases with the frequency and depends on the location L,
- and the receiver noise which can be neglected, for quality receivers on HF, in front of the three previous noises.
  Note: in case of doubt on a receiver quality, the RQI can be used, with the same antenna, to compare two receivers (a reference one and the one to test).

So $Pnoise = n(\lambda, L)$

Pnoise is minimum for a quiet rural location and maximum for the city centers.
It can be deduced that:

$$Pr = Pnoise \times SNR = n(\lambda, L) \times SNR = Pt \times Gt(\lambda) \times Gr(\lambda) \times \left(\frac{1}{4 \times \pi \times d} \right)^2 \times r(\lambda, t)$$

The dependency of n and r on λ being unknown, it will be supposed a given wavelength λ0 (for example 80 m or 40 m). Consequently for a given λ0, n depends only on L and it is noted $n_{\lambda 0}(L)$. In the same way, r depends only on t and it is noted $r_{\lambda 0}(t)$. $Gr_{\lambda 0}$ and $Gt_{\lambda 0}$ are the gains of the antennas at λ0. The previous expression writes now:

$$n_{\lambda 0}(L) \times SNR = Pt \times Gt_{\lambda 0} \times Gr_{\lambda 0} \times \left(\frac{1}{4 \times \pi \times d} \right)^2 \times r_{\lambda 0}(t)$$

So $\frac{Gr_{\lambda 0}}{n_{\lambda 0}(L)} = \frac{SNR \times (4 \times \pi \times d)^2}{Pt \times Gt_{\lambda 0} \times r_{\lambda 0}(t)} = K \times \frac{SNR \times d^2}{Pt \times Gt_{\lambda 0} \times r_{\lambda 0}(t)}$ with $K = (4 \times \pi)^2$

Let's suppose N receptions between t=0 to t=24 h, still for the wavelength λ0, with N very large (let's say N≥10,000). $\frac{Gr_{\lambda 0}}{n_{\lambda 0}(L)}$ being considered as a random variable, the average $\overline{\frac{Gr_{\lambda 0}}{n_{\lambda 0}(L)}}$, over a day, tends to the expected "true" value, independent of the time, according to the central limit theorem. Let's note "i" a FT8 reception giving the Locator, so it can be written: $\overline{\frac{Gr_{\lambda 0}}{n_{\lambda 0}(L)}} = \frac{K}{N} \times \sum_{i=1}^{N} \frac{SNRi \times di^2}{Pti \times Gt_{\lambda 0} i \times r_{\lambda 0}(ti)}$

$SNRi \times di^2$ is calculated by the decoding program (Multipsk for example). Pti x $Gt_{\lambda 0}i$ depends on each transmission station i. It will be considered that the average $\overline{Pt \times Gt_{\lambda 0}}$ always tends to the same value $PG_{\lambda 0}$ when averaging a lot of stations. Moreover as the average is done on 24 hours $\overline{r_{\lambda 0}(t)}$ is supposed to tend to a stable average value $R_{\lambda 0}$.
So, the previous expression will be simplified supposing that:

$$\sum_{i=1}^{N} \frac{SNRi \times di^2}{Pti \times Gt_{\lambda 0}i \times r_{\lambda 0}(ti)} \approx \frac{1}{PG_{\lambda 0} \times R_{\lambda 0}} \sum_{i=1}^{N} SNRi \times di^2 = K' \times \sum_{i=1}^{N} SNRi \times di^2 \text{ with } K' = \frac{1}{PG_{\lambda 0} \times R_{\lambda 0}}$$

Consequently, it can be written: $\overline{\frac{Gr_{\lambda 0}}{n_{\lambda 0}(L)}} = K \times K' \times \frac{1}{N} \times \sum_{i=1}^{N} (SNRi \times di^2)$

Let's suppose a reception reference given by some monitoring station $\overline{\frac{Gr_{\lambda 0}}{n_{\lambda 0}(L)}}_{reference}$

The ratio between the reception on a given station $\overline{\frac{Gr_{\lambda 0}}{n_{\lambda 0}(L)}}$ and the reference RX station reception $\overline{\frac{Gr_{\lambda 0}}{n_{\lambda 0}(L)}}_{reference}$ will be called RQI (for Reception Quality Indicator) and will be equal to:

$$RQI = \frac{\overline{\frac{Gr_{\lambda 0}}{n_{\lambda 0}(L)}}}{\overline{\frac{Gr_{\lambda 0}}{n_{\lambda 0}(L)}}_{reference}} = \frac{K \times K' \times \frac{1}{N} \times \sum_{i=1}^{N} (SNRi \times di^2)}{K \times K' \times \frac{1}{N'} \times \sum_{i=1}^{N'} (SNRi \times di^2) reference} = \frac{\frac{1}{N} \times \sum_{i=1}^{N} (SNRi \times di^2)}{\frac{1}{N'} \times \sum_{i=1}^{N'} (SNRi \times di^2) reference}$$

It will be indicated the RQI in dB with $RQI_{dB} = 10 \times Log_{10}(RQI / 10)$

Let's determinate $\frac{1}{N'} \times \sum_{i=1}^{N'} (SNRi \times di^2) reference$, called "Rref" hereafter, for the reference RX station.
Let's take, for example, as reference the WebSDR station of the amateur radio club ETGD at the university of Twente (http://websdr.ewi.utwente.nl:8901/) in Netherlands, Locator JO32KF. The antenna of this station is a PA0RDT Mini-Whip installed at 20 m over a metal roof, which is used as ground reference. The antenna is supposed free of obstacles and it is omnidirectional. The receiver is a homebuilt SDR. This very small active antenna works, surprisingly, very well. Its performance in reception, in term of Signal to Noise ratio, seems, a priori, comparable to a standard developed antenna (dipole in λ/2, "ground plane", etc). Now, the antenna being at 20 m above a metal roof, the man-made noise level is minimum as in a rural environment. And this despite the university of Twente location which is at the edge of the city of Enschede (160,000 inhabitants).

The main results on $Rref = \frac{1}{N'} \times \sum_{i=1}^{N'} (SNRi \times di^2) reference$ for the WebSDR Twente station are given below. The reference acquisition time must be at least 2 days (48 hours), to be higher than the measurement done by the user on exactly one day (24 hours). The maximum uncertainty of this measurement is roughly estimated to +/- 2 dB for a station equipped with an omnidirectional antenna as a vertical one, and located not too far away from the reference station (Twente here).

> Note that normally a reference measurement might be one order (i.e. 10 times) better than the user measurement. In this particular case, the uncertainty decreases as $\sqrt{N'}$ (and proportionally to the standard deviation). So to be 10 times more accurate, an acquisition time of 100 days would be necessary, which is not realistic.

The results for Twente are:

Band	Rref	N’	Acquisition time
80 m (3573 kHz)	1.8505E6	37462	2 days
60 m (5357 kHz)	4.0489E6	64917	4 days
40 m (7074 kHz)	3.1124E6	128727	4 days
30 m (10136 kHz)	7.3621E6	43171	2 days
20 m (14074 kHz)	9.1692E6	69981	3 days
17 m (18100 kHz)	1.3072E7	32670	2 days
15 m (21074 kHz)	1.1451E7	29571	2 days
12 m (24915 kHz)	1.4786E7	27515	2 days
10 m (28074 kHz)	1.1942E7	28769	2 days

Note : theoretically FT8 and FT4 receptions would give the same result as the SNR is calculated in the same way, except that FT8 will detect weaker signals compared to FT4 . The author tests also FT4 in 40 m. The result is coherent with FT8 (i.e. 3.8853E6 against 3.1124E6 but with only N’=5101 on one day). Now as the rate of receptions N’ per day is much lower in FT4 than in FT8, the uncertainty is much bigger. Consequently, the FT4 is not considered.

2. Specific reference table to take into account a reference reception station other than Twente

A RQI reference table, carried in the "RQI_references.txt" file inside the Multipsk directory, lists the results for the reference reception station Twente. Now, as Multipsk displays the Rref value (« Rref » button to push), it is possible, for any reception station, to determine the different Rref exactly as they have been determined above for Twente. Once all the Rref determined, it is enough to carry these values in a new "RQI_references.txt" file and to propose this new file to users of the same region. This new file installed in the Multipsk directory and replacing the Twente one, will be taken into account by Multipsk.

Below is given the content of this "RQI_references.txt" file :

```
// This table, relative to the RQI in FT8, gives the results on Rref obtained with Multipsk, this one monitoring the
// amateur radio club ETGD at the university of Twente in Netherlands, Locator JO32KF (http://websdr.ewi.utwente.nl:8901/).
// Antenna: PA0RDT Mini-Whip installed at 20 m over a metal roof, which is used as ground reference. This very small active
// omnidirectional antenna works very well. Its performance in reception is comparable to a standard developed antenna.
// Noise environment: the noise level is minimum as in a rural environment.
//
// Each user can build his/her own Rref table based on another reception station.
// Each Rref is obtained after at least 2 days (48 h), but the more the number of days, the more accurate the results.
// Of course, before spreading his/her Rref table, the reception conditions (station, location (+ Locator), antenna and
// type of noise environment) must be specified by the user, as shown above.
//
// About this table, the columns, separated by tabulations, are given below. Only the two first columns are compulsory.
// However, if the second column is empty, it simply means that there is no data for this band.
// Notes:
//  1) The 13 Ham bands where FT8 can be received
are:'160M','80M','60M','40M','30M','20M','17M','15M','12M','10M','6M','4M','2M'.
//     Note that Multipsk expects the Ham band labels in this form ("160M" for example), and not "160" or "160m" or "160 M".
//  2) The Rref value, as given by Multipsk, i.e. in scientific notation with "E" for "X10^".
//
// Note that the 160M is not filled because there is no much traffic on this band and 6m, 4m and 2m are not received by
// the Twente station. Moreover, on these bands, the traffic is weak.
//
// The three last columns are for information:
//  1) The number of receptions N', as given by Multipsk. It must be elevated to increase the diversity and so the accuracy.
//  2) The number of days (necessarily integer). Two days is the minimum time.
//  3) The RX FT8 frequency (in kHz and in USB) on which the test has been done.
//
// Note that the 160M is not filled because there is no much traffic on this band and 6m, 4m and 2m are not received by
// the Twente station. Moreover, on these bands, the traffic is weak.
160M
80M	1.8505E6	37462	2	3573
60M	4.0489E6	64917	4	5357
40M	3.1124E6	128727	4	7074
30M	7.3621E6	43171	2	10136
20M	9.1692E6	69981	3	14074
17M	1.3072E7	32670	2	18100
15M	1.1451E7	29571	2	21074
12M	1.4786E7	27515	2	24915
10M	1.1942E7	28769	2	28074
6M
4M
2M
```

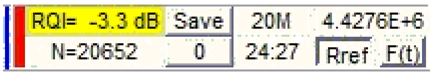
3. Use of the RQI indicator

The RQI indicator is useful to compare the user set “Omnidirectional antenna + Noise environment” with a reference set “Omnidirectional antenna + Quiet noise environment” (as the Twente set for example). A reception station located, around the reference station, having a good omnidirectional antenna (i.e. ground plane, etc) in a rural environment will see a RQI indicator around 0 dB, and perhaps slightly positive. Reversely, a reception station, around the reference station, having a reduced vertical antenna in an urban environment will see a RQI indicator strongly negative (down to -10 dB, see less), and, correlatively, much less receptions compared to the number of receptions of the reference station (i.e. N’/Acquisition time as given above). So a station can be compared with the reference station, taking into account the estimated maximum uncertainty (+/-2 dB).

But the main RQI use is to compare, in the same time and in the same location, two antennas, one being the reference one and the other one being the antenna to test.

Note: for about directional antennas (Yagi for example), the RQI is variable as it depends on the direction targeted by the antenna relatively to the propagation direction of the moment. If both directions are aligned the RQI will be very positive and reversely. However, if the propagation direction is known, the RQI can be possibly used to determine the gain of the antenna, compared to an omnidirectional antenna in the vicinity.

Here is an example of what appears sometime after the 24 hours measurement (the result being here: RQI=-3.3 dB):



Once the "**Save**" button pushed, the content of the RQI_date_time.TXT file (in the RQI sub-directory) is given below. These are the results after 24 hours. Note that it is also given the number of FT8 decodes and the RQI (in dB) for each hour, for the 24 hours of measurement. These pieces of data can give a rough idea of the propagation according to the time, for example to know when it is interesting to monitor FT8 on the considered band. Note that it is ideal to start the measurement at 0h30 local time, so that the displayed hours "1h", "2h"... "24h" correspond to the local times.

"Local time measurement start: 02 Dec 2024 at 19h 20m 13s
RQI results: HF band=20M RQI= -3.3 dB N=20387 Rref=4.3320E+6

1h: N=953 / RQI=-0.2 dB
2h: N=765 / RQI=-0.4 dB
3h: N=614 / RQI=0.2 dB
4h: N=70 / RQI=2.0 dB
5h: N=50 / RQI=-0.0 dB
6h: N=76 / RQI=-0.3 dB
7h: N=29 / RQI=2.7 dB
8h: N=7 / RQI=-11.1 dB
9h: N=12 / RQI=-3.7 dB
10h: N=72 / RQI=-5.9 dB
11h: N=219 / RQI=-2.9 dB
12h: N=718 / RQI=-1.2 dB
13h: N=1200 / RQI=-4.7 dB
14h: N=1640 / RQI=-7.7 dB
15h: N=1501 / RQI=-9.8 dB
16h: N=1731 / RQI=-9.2 dB
17h: N=1619 / RQI=-7.9 dB
18h: N=1085 / RQI=-7.3 dB

19h: N=1433 / RQI=-8.0 dB
20h: N=1401 / RQI=-8.3 dB
21h: N=1241 / RQI=3.4 dB
22h: N=1814 / RQI=-9.7 dB
23h: N=1550 / RQI=-5.6 dB
24h: N=586 / RQI=2.9 dB“

4. Relationship with NCDXF stations

A way to estimate the propagation towards a country (and so towards a certain direction) is given by the NCDXF stations. For example, look at: http://f6cte.free.fr/The_NCDXF_beacons_with_Multipsk.pdf

The advantage of the NCDXF stations is the possibility to determine the propagation on a given direction, according to the time. So for example, it is possible to expect a phone transmission to a country for a certain interval of time. The advantage of the RQI is to give a global appreciation of the set “antenna + noise environment”. So both data complete each other: once the RQI of the antenna correct on at least one Ham band, the NCDXF will give the best schedule (if any) for a communication with a given country, in this Ham band.