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How Much Receiver Performance Does a Contester *Need*? — Part 1

This is the first of a three-part series on receiver performance for contesters by accomplished RF engineer and contester Peter E Chadwick, G3RZP. I ran across an older version of this series, aimed at DX-ers, a couple of years ago in the Chiltern DX Club newsletter. Peter has updated the series for contesters, and we are honored to publish them in NCJ *with his permission. — Scott Wright, KØMD*

In the 1950s, the principal figure of excellence for a receiver always seemed to be *sensitivity*. For VHF/UHF types, it got more technical as *noise figure*, while for marketing people, it was always a number to give the hottest receiver. So what *is* sensitivity? It is defined as the input signal required for a given output signal: That can be the AF power output, commonly used for broadcast receivers; the output signal-to-noise ratio (S/N); the output signal plus noise-to-noise ratio ([S + N]/N), which, when large, is almost equal to the signal-to-noise ratio, or the SINAD — **SI**gnal plus **N**oise plus **D**istortion to Noise plus Distortion ([S + N + D]/[N + D]) ratio. Yet another measure is minimum discernible signal (MDS) — where the signal is equal to the noise, giving a S/N ratio of 1 (0 dB) or a [S + N]/N of 2 (3 dB). For very low noise work, such as moonbounce, the noise temperature in Kelvins may be used.

Giving all these possible measurements, there was confusion as to what was really meant: Professional specifications in the UK tended to work in term of EMF (voltage) while the US used a PD (potential difference) approach. See Figure 1.

The *generator* in the real world — the antenna — has an EMF generated, e.g., it has an internal impedance R_g, and the receiver looks like a resistance (in theory) R_r. From Thevenin's theorem, maximum power is transferred when $R_r = R_g$, and the voltage across R_r will be one-half of E_g. Referring to receiver sensitivity defined as the voltage across its input terminal gives a lower number than simple EMF, and so it looks better in marketing terms.

So why use EMF at all? The answer to this is that antennas frequently do not look like a pure resistance, and even more so in marine or mobile radio installations, where the antenna is generally short in terms of wavelength (see Figure 2).

Years ago, this situation would have applied to many amateur 160-meter stations, with a random length of wire switched between a transmitter with a pi network with a wide matching range and a receiver with a nominal input impedance of perhaps 400 Ω, such as the venerable HRO. In general, losses didn't matter, because sensitivity was limited by external noise. For services where the field strength was known, then system performance was best predicated on the EMF voltage.

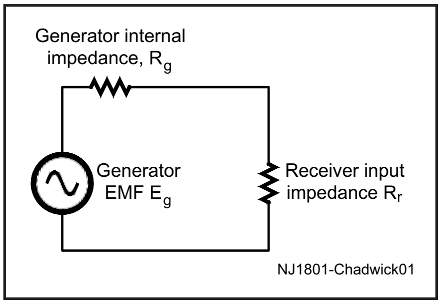

Figure 1 — EMF and PD.

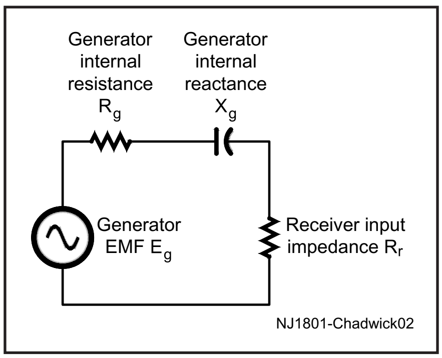

Figure 2 — The equivalent circuit of a typical 2-MHz antenna consisting of an inverted L about 50 or 60 feet long. The R_g in this case is around 10 Ω, and the X_g is around 300 Ω, typically represented by 10 Ω in series with 250 pF.

So, in what units do we measure the input voltage? Historically, it was in microvolts (µV) — either PD or EMF, or dB microvolts (dB µV), often using a defined dummy antenna in the frequency range 0.15 to 30 MHz (See Figure 3).

During the Cold War era, with increased emphasis on electronic warfare, systems design looked at the power received and reflected by aircraft and their antennas, so it became more usual to work in terms of dBm, or decibels referred to 1 milliwatt (mW). So, dBm supposedly means the power absorbed by the receiver relative to 1 mW, and almost universally within a 50 Ω system. Not many receivers have a very good input SWR, and indeed, for the lowest noise this may be purposely mismatched to get a *noise match*, which gives the best noise figure by presenting the first stage with an optimum source impedance for lowest noise. So, receiver sensitivity in dBm really means, "If the receiver input impedance was really 50 Ω resistive, this would be the power absorbed by the receiver from a 50 Ω source that produces the defined output, whatever that is."

All of this is long way from the PD measurement of the voltage — typically microvolts or nanovolts — across the antenna connector. In a 50 Ω system, 0 dBm corresponds to 223.6 mV. The 50-µV PD usually used for S-9 is –73 dBm.

So, what determines the sensitivity of the receiver? It should be — and typically

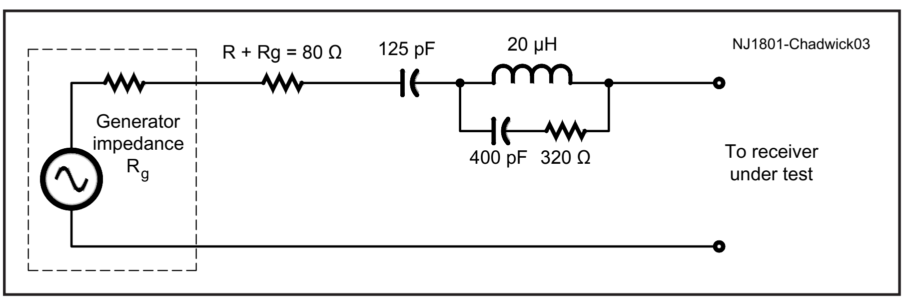

Figure 3 — This dummy antenna looks like a high impedance at low frequencies and tapers off to about 400 Ω resistive above about 10 MHz. For receivers intended to be used in a 50-Ω system, this is a needless complication

is these days — the noise of the first stage and any signal losses in filters, switches, or relays before the first stage. Any resistor — and, for that matter, any conductor (even a piece of silver wire is resistive) — produces noise proportional to its temperature above absolute zero (approximately –273° C), measured in Kelvins. The amount of this noise is given by the equation $P = kTB$, where P is the noise power in watts, k is Boltzman's constant (1.372×10^{-23}), T is the temperature in Kelvins (usually taken as 290), and B is the bandwidth in hertz. This power is –204 dBW or –174 dBm in a 1-Hz bandwidth.

The amount of excess noise over and above this is determined by the receiver noise figure (NF) and the noise bandwidth: With modern filters having steep sides, the 6-dB bandwidth reasonably approximates the noise bandwidth, and this bandwidth can be expressed in dB/Hz, i.e., $\log_{10}(B)$, where B is in Hz.

The noise figure, expressed in dB, measures how much greater the receiver's internal noise is than the kTB noise. For example, a receiver with a 10 dB noise figure will have a noise level of $-164 + \log_{10}(B)$ dBm. Or you can look at it as a perfect noiseless receiver with an added noise input of $(-174 + NF + \log_{10}[B])$ dBm.

This is where the use of dBm rather than microvolts simplifies calculations.

So how much sensitivity does an HF receiver need to have? This depends on the location and the antenna. A half-wave dipole in the clear will produce an EMF of $V = E\lambda/\pi$ volts, where E is the field strength in volts/meter.

ITU-R Recommendation P.372-11 provides a number of curves and formulas from which some predictions can be made: These are used to produce the data in Table 1, with an assumed noise bandwidth of 3 kHz.

Table 1 — Predicted noise levels from a half-wave dipole in the clear in various locations. All figures are rounded. Dipole µV is the PD delivered to a 75-Ω load. S meter readings based on S-9 = 50 µV. These numbers represent the median: 80% will lie within a window between 4 and 11 dB wide, depending on time, and a further 6 to 8.4 dB depending on location within the categories specified. This suggests a worst-case spread of as much as19.4 dB.

Band	Location	dBµV/m	µV/m	Dipole µV	S Meter
160	City	10	3	76	9 + 3 dB
	Suburban	7	2	51	9 + 1 dB
	Rural	0	1	25	8
	Quiet Rural	–13	0.2	5	6
80	City	10	3	41	9
	Suburban	5	2	27	8
	Rural	0	1	14	7
	Quiet Rural	–15	0.2	3	5
40	City	7	2	14	7
	Suburban	2	1.3	9	6
	Rural	-5	0.6	4	5
	Quiet Rural*	–12	0.25	2	4
10	City	1	1.1	2	5
	Suburban	–4	0.6	1	4
	Rural	–10	0.3	0.5	3
	Quiet Rural*	–16	0.2	0.3	2

* = primarily galactic noise.

From Table 1, it can be seen that in a quiet rural location, a dipole on 10 meters at the quietest end of all the spreads could produce as little as 0.1 µV of noise, while in an urban environment, at the other end of the spread, the dipole could be producing 6 µV. Assuming a noise bandwidth of 3 kHz, if we allow the receiver to degrade a signal at the MDS by 0.4 dB, then the receiver noise floor would need to be 10 dB below the incoming noise, or in the best case, –137 dBm, and the receiver noise figure would need to be 2.2 dB. In an urban area, however, the same degradation would be found with a receiver noise figure of 39 dB. Some complication can occur when directional antennas are used. If the plane of the ecliptic intersects the beam, then the galactic noise can increase by the gain of the beam, while in an urban environment, it may be possible to use the directional characteristics to reduce the noise picked up.

For the majority of people, a noise figure of 10 to 15 dB is adequate when antennas having the gain of a dipole are used. This gives a receiver noise floor of between –124 and –129 dBm or around 140 to 80 nV. A good test is to switch the receiver between the antenna and a dummy load with the AGC switched off. If the output drops by 3 dB or more, little improvement is needed in the receiver. This should be measured with a meter, however; 3 dB doesn't sound as big a change as you might expect. However, in a quiet location on 10, 12, and even 15 meters, a 5 or 6-dB noise figure can offer the advantage of another 5 to 10 or so dB (S+N)/N (usually abbreviated to SNR), and that can make the difference between hearing DX and not hearing it. Of course, if the signal is down at that level, it does not necessarily mean that you can work the station.

On 40 meters, the spread means that the dipole providing a nominal 2 µV to a 75-Ω load in a quiet rural area can see a spread of 0.65 to 6.1 µV. A 50-Ω load will see 0.8 of this, representing a power spread of –113 to –93 dBm (numbers been have rounded for convenience). So, in the best case, a better noise figure than $174 - \log_{10}(B) - 123 = 16$ dB is not needed, while the average requirement is for a 26 dB noise figure. The prevalence of large signals both in and adjacent to the 40-meter band means that an attenuator can usefully be provided ahead of a 15 dB NF receiver. At G3RZP, the average noise level from a half-wave 40-meter east-sloping dipole is 1 µV (–107 dBm) in a 3-kHz noise bandwidth.

Where the antenna has a lower gain than a dipole, then sensitivity can become more important, and the use, for example, of a 1-meter diameter magnetic loop on 10 meters might provide a requirement for a lower noise figure than 10 dB.

To sum up, only in relatively few cases — those lucky enough to live in an electrically quiet area — will find the full sensitivity of the majority of receivers built since 1970 or so be less than adequate. In many urban and suburban areas, the ITU-R Recommendation P372-11 numbers [superseded by P.372-13, dated September 2016 — *Ed.*] are now out of date, being much lower than the reality of an HF spectrum highly polluted by so many non-radio electronic devices.