Analysis of received RF noise

A look at what's happening in the spectrum from 1 to 30MHz

PHOTO 1: A poor noise floor of -111dBm at 70.450MHz, as indicated on a Simoco MA-9030 PMR radio.

INTRODUCTION. Listening around the HF bands over many years, we all hear comments such as "my noise level is 5 over S9 here", or "you're a good readable signal but you are not moving my S meter" or "I live in a quiet location and I've got zero noise level here on 80m". Really!! All this is symptomatic of the great area of confusion related to poor receiver signal displays and the lack of understanding of noise sources and levels that afflict all HF reception.

NOISE IN THE HF SPECTRUM. The Noise Factor *fa* in any receiving system is the sum of both internal (hardware generate) and external noise. It is a function of Boltzmann's Constant, absolute temperature in Kelvin, the bandwidth in Hz and the power in dBW from the receiving antenna, ie the received external noise [1]. For a practical Earth-based system set up to receive SSB signals, it is assumed all components are at a temperature *ta* of 290K, ie 17°C. Note that 290K = -140dBm, close to the noise floor of a modern receiver. The bandwidth is typical SSB, 2.7kHz. The antenna is an elevated resonant dipole or similar doublet of unity gain at the measuring frequency and with negligible feeder loss. For a receiver connected to a 50Ω termination, the measured noise level would be the noise floor of the receiver. When connected to the antenna, external noise is added. Noise is normally expressed as Noise Figure, $Fa = 10\log fa$.

SOURCES OF RF NOISE. The radio frequency noise arriving at an elevated antenna comes from three sources:

(1) Galactic noise from space [2]. This is much lower in signal strength than sources 2 & 3 below but, in quiet locations and when the atmospheric noise is low, Galactic noise can be detected, particularly above 12MHz (see **Figure 1**). Noise due to enhanced solar activity also occurs and, along with Galactic noise, will be ignored for this discussion.

(2) Atmospheric noise. The lowest part of the atmosphere is the troposphere where most weather phenomena occur and most radio noise is generated here primarily by lightning discharges [3] in thunderstorms in the troposphere. It is mainly caused by cloud-to-ground flashes, as the current is much stronger than for cloud-to-cloud flashes. On a worldwide scale, around eight million lightning flashes occur daily. This is about 100 lightning flashes per second. The sum of all these lightning flashes results in continuous atmospheric noise. It can be observed with a radio receiver in the form of a combination of continuous white noise coming from distant thunderstorms via ionospheric propagation plus impulsive noise coming from nearby thunderstorms, directly or via ground wave and short skip. The power-sum varies hourly, diurnally, with seasons, nearness of thunderstorm centres and with all the variations associated with ionospheric propagation. Atmospheric noise is thus subject to the huge variations in received signal strength. Although lightning from electrical storms in the troposphere covers a broad spectrum, its noise power increases with decreasing frequency. Therefore, at VLF, LF & MF, atmospheric noise dominates, decreasing with increasing frequency.

(3) Man made noise comes from electronic systems, power distribution and electro-mechanical devices. These sources are the least predictable and, at any location, can have the largest range of signal strength. This noise can be wide band, narrow band, impulsive, unstable, random or white noise, with time-variant levels. Its level can range between extremely high near a noise source to zero is a remote location, such as at sea remote from land. In other words, it's extremely unpredictable.

The ITU has defined a number of locations by their expected noise level. These are:

Quiet Rural/Remote – locations many km from any habitation or electrical installations, eg mountainous regions, deserts, large forests, the tundra, polar regions, oceans etc.

Rural – locations with a few houses dotted around, or in small groups, occasional farms, small commercial sites. Power lines may be present.

Urban – houses in roads and estates, variable density, with normal domestic electrical equipment and with commercial premises scattered around.

Industrial – retail, commercial and

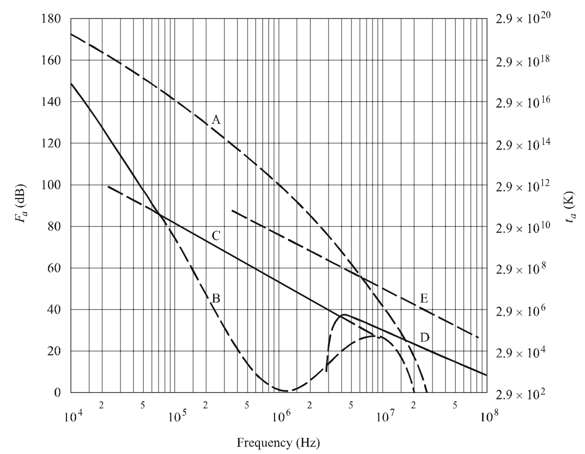

FIGURE 1: Noise Figure in dB above the reference noise temperature, 290K (17°C). A – atmospheric noise, value exceeded 0.5% of the time. B - atmospheric noise, value exceeded 99.5% of the time. C – man-made noise, quiet receiving site. D – Galactic noise. E – median city area man-made noise. The solid line indicates the minimum noise level expected. (Source: ITU-R Recommendation P.372-10 (10/2009), used with permission).

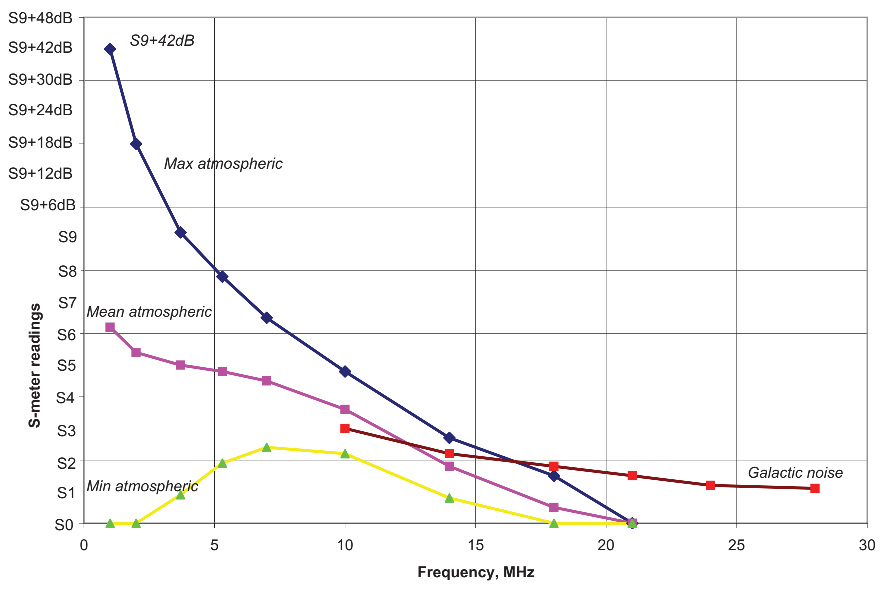

FIGURE 2: S-meter readings of natural noise level.

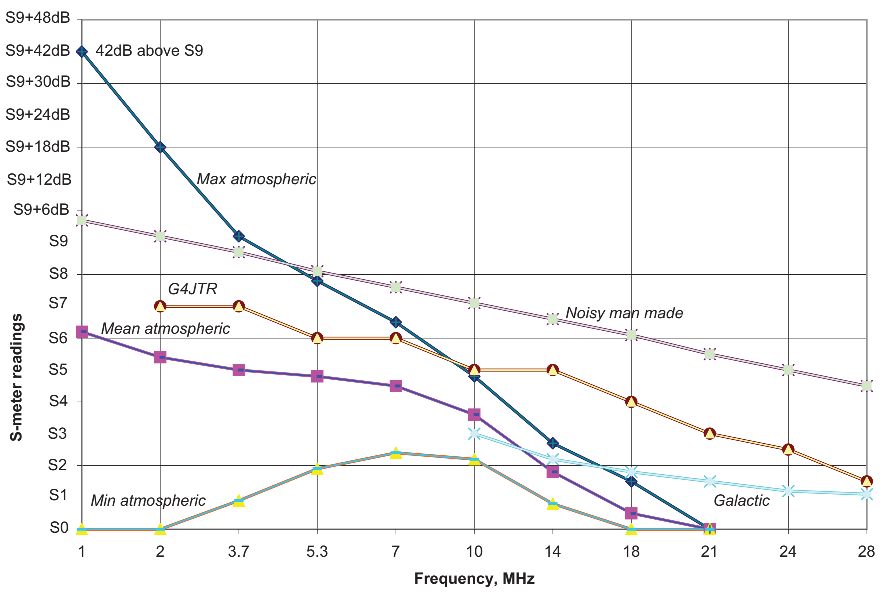

FIGURE 3: S-meter readings of natural noise level plus man made noise.

Industrial areas, with railways, manufacturing, power generation and distribution.

MEASURING NOISE. Figure 1 shows variation in Noise Factor *fa* (expressed as Noise Figure *Fa* in dB above a reference level at a temperature *ta* of 290K (17°C)) versus frequency from 10kHz to 100MHz. (See [1] for the complete analysis). Note the huge variation of atmospheric noise within the minimum (B) and maximum (A) envelope at 1MHz (10^6Hz). This variation decreases rapidly towards 20MHz, where Galactic noise dominates. In theory, and for less than 0.5% of the time, at mid day at a remote location, well out of ground wave range of any MF broadcast stations or local thunderstorms, there could be a near zero noise level as there would be no Ionospheric propagation of distance lightning discharges, whereas at higher frequencies these discharges would be propagated. This explains the dip in the minimum curve (B) around 1MHz, with Ionospheric F2 Layer propagation increasing above 2MHz propagating noise over long distances when a path is present and decreasing again above 10MHz. Line C-D represents the average noise level; very few will be lucky enough to experience a level lower than this. For comparison, (E) shows the likely median level of man made noise in a business / commercial environment. The worst case can be much higher than this.

Let's now look at translating these curves to meaningful receiver signal levels.

ELECTRIC FIELD INTENSITY OR FIELD STRENGTH. All of the external noise sources generate an electric field intensity, En, at the antenna, commonly quoted as Field Strength in µV/m. This is independent of frequency and receiving antenna characteristics and can therefore be used as an absolute measure of field strength of a signal or noise. Traditionally, this is measured using a reference half wave dipole at each frequency of interest. Without going into the theory or sequence of formulae involved [1, 3, **5**], it is sufficient to say that from the Noise Figure (dB) in Figure 1, we can calculate the following sequence using a series of formulae:

1. From the Noise Figure, find the field strength in dBµV/metre, ie µV in dB above 1µV/metre, as received on a dipole antenna (2.15dB gain over isotropic)
2. Calculate the signal level in µV across 50Ω
3. Using **Table 1**, calculate the Received Signal Strength Indication (RSSI) in dBm, ie dB below 1 milliwatt, down to the -140dBm noise floor
4. Read off S-meter reading in S points (IARU scale)

These results can be used to measure and compare noise level at different locations. Unfortunately, this is where the whole operation frequently goes awry.

S-METER CALIBRATION. The IARU recommended S-meter calibration for HF receivers **[6]** is shown in Table 1. Sadly, many manufacturers of amateur radio equipment do not adhere to this IARU standard, even on very costly radios. Measuring various receivers myself and looking at the many reviews in *RadCom* reveals that whilst most S-meters are not too far out at S9, usually within 20 to 100µV (roughly ±1 S-point), most have very non-linear scales below S9. Worse still, some have a very rough 3dB per S-point scale, which means a 2.5µV signal would be S0. This is quite a strong signal, actually S4.5 on the correct scale. It has been shown that even in quiet locations the natural noise level below 15MHz is often around this level, so there might be some logic in setting S0 around this level of noise. But this is unscientific and inconsistent. It is a confidence trick to make receivers look as though they are in a low noise environment and designed so that elevated noise levels do not dominate the S meter reading. Having paid anything up to £8K for a transceiver, I think we should expect a very high quality signal strength indication system based on quantitative science and an agreed calibration instead of the very poor S-meters we have to tolerate. An outstanding exception is the Winradio Excelsior G39DDC SDR, which has on screen signal level in IARU S units, µV (into 50Ω) and Received Signal Strength Indication (RSSI) in dBm down to -140dBm.

Some professional PMR VHF/UHF

TABLE 1: S-meter conversion chart, dBm to microvolts (μV) in a 50Ω system.

Input dBm	μV equivalent	IARU S-meter	dB over S0
0	224,000 (0.224V)		
-13	50,100 (50.1mV)	S9+60dB	114
-33	5,010 (5.1mV)	S9+40dB	94
-53	501	S9+20dB	74
-73	50.1	S9	54
-79	25	S8	48
-85	12.5	S7	42
-91	6.3	S6	36
-97	3.2	S5	30
-103	1.6	S4	24
-107	1.0 (1μV reference)		
-109	0.8	S3	18
-115	0.4	S2	12
-121	0.200	S1	6
-127	0.100	S0	0
-140	0.0224 (noise floor at 290K)		

radios can be programmed to display a digital readout of RSSI in -dBm, like the one in **Photo 1**. Elecraft radios are calibrated to the IARU standard, but most other radios are not. Elecraft even offers their XG3 signal source for setting up S-meters **[7]**. Note also that many radios now have one or two switchable RF stages in front of the first mixer plus an RF attenuator, just to confuse us. Normally the first RF amp should be switched out, as these are used mainly for 50MHz. The main RF amp should be on and, obviously, there should be no attenuation. This is normally the gain set up for the factory S-meter calibration, but this is not always explained in the manual. An SSB bandwidth of 2.4 to 2.7kHz should be used, a centred IF shift and a fast AGC. Unless the operator has set the radio like this and the S-meter is correctly calibrated, on-air signal reports are almost useless!

Fortunately, many radios can be recalibrated manually to give 50μV = S9, often using a software menu item, thus making them a valid signal strength measuring instrument. Note however, linearity is not guaranteed. The XG3 Signal Source is ideal for testing this. Once a calibration is achieved, we can start to measure noise level in various situations using Table 1.

DISPLAYED RESULTS FROM PUBLISHED DATA. By converting Noise Figure in Figure 1 to the signal level figure in Table 1, it is possible to display the noise level data in the way it would be displayed on a well calibrated HF receiver. The Figure 1 data were entered onto an Excel spreadsheet and the cells were used to calculate and derive results.

Figure 2 shows the basic display of the range natural noise level in S-units in the HF spectrum from 1 to 30MHz. The mean curve is the arithmetic mean of the maximum and minimum derived from Figure 1. It should be close to (but not exactly the same as) the 'average' noise level, but it will do for this analysis. This mean curve will be used as the expected average base line noise level in a 'quiet' location. Remember, it is assumed the antenna is an elevated resonant dipole or resonated doublet of similar gain at the measuring frequency, with negligible feeder loss and a receiver bandwidth of 2.7kHz (it won't make much difference if 2.4kHz is used). The constant Galactic noise dominates above about 12MHz for mean noise level or above 17MHz for maximum level. This does not vary much unless you point an HF beam antenna at the Sun!

Even in a quiet rural location, away from man made electrical noise, we can expect S5 to S6 noise levels on the lower HF bands and much higher levels occasionally. Above 14MHz, S2 should be normal, decreasing to S1 at 28MHz. If only we all had this situation!

Figure 3 shows the median case industrial level. It is derived from line E in Figure 1, added to the natural noise level curves. To avoid confusion of lines, I have not added the lines for man made noise in urban, rural and quiet rural. The approximate differences are as follows. Urban: 2 S-points (12dB) lower, Rural: 3 S-points (18dB) lower, Quiet rural: 4 to 5 S-points (24 to 30dB) lower, or roughly line C on Figure 1.

I have also added a 'one-off' measurement at G4JTR (outer edge of an urban area), taken mid-morning on a day in early winter 2011 when no local electrical storms were present, using the calibrated S-meter on a K3 transceiver and a selection of resonated elevated doublets of gain very similar to a dipole (ie unity gain antennas) on a clear frequency in or near each amateur band (2.4kHz bandwidth, centred IF shift, fast AGC). It was interesting to note that 'static' pulses were observed around 7MHz, indicating storms at a modest range, heard via Ionospheric F2 Layer propagation. This line varies on an hourly, diurnal and seasonal basis but seems typical of my location over a period of a few weeks and it appears to be acceptably quiet. Several months later at the equinox, noise levels were on average 1 S-point higher below 14MHz.

CONCLUSIONS. Natural noise level in the spectrum 1 – 30MHz varies considerably, but very quiet conditions can persist at the lower frequencies at times when only ground wave propagation is dominant. Between 2 and 10MHz, natural noise levels from S4 to S6 are normal. Natural noise can be considerably higher when Ionospheric propagation is good and also in those part of the world within range of increased local thunderstorm activity.

Man made noise is a hugely variable phenomenon. In some case, however, rural and even urban areas can be acceptably quiet where there happens to be no serious man made noise generation. Such a situation can be ruined at any time by the arrival locally of a single very poor electrical item, eg a rogue TV, switcher PSU, arcing contacts, PLA device, poorly suppressed machinery etc.

Until radio amateurs demand calibrated S-meters and some manufactures take a much more professional approach to S-meter electronics and calibration, the discussion on noise levels will always be degraded by poor data, poor S-meters and a poor understanding of receiver settings. With the PLT/PLA challenges being very topical and a constant barrage of new electronic devices, it is very important that we all understand the measurements of, and boundaries between, man made and natural noise.

This article is food for thought in the light of my proposed project concerning noise measurements, described in last month's *RadCom*. The main difference is that the measuring project is concerned with trends and not absolute measurements. For more information on the project, please email me via g4fkh@btinternet.com.

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WEBSEARCH

[1] ITU Recommendation ITU-R P.372-10, (10/2009), Radio noise – www.itu.int/rec/R-REC-P.372/en
[2] http://en.wikipedia.org/wiki/Cosmic_noise
[3] http://en.wikipedia.org/wiki/Atmospheric_noise
[4] Field intensity units – http://tinyurl.com/rc8808noise-4 or ww.softwright.com/faq/engineering/FIELD%20INTENSITY%20UNITS.html
[5] http://tinyurl.com/rc8808noise-5 or www.rsgb.org/emc/docs/pdf/archive/backgroundnoiseonhf.pdf
[6] http://en.wikipedia.org/wiki/S_meter
[7] www.elecraft.com/XG3/xg3.htm