

## **1.0 DEFINING THE PROBLEM**

### **1.1 Basics and Terminology**

Whenever two or more transceivers are used in close proximity there is some level of interference involved. This level can vary from practically no problem to actually burning up components in the receiving radio. The purpose of this book is to identify and quantify the various parameters that create the interference and to show methods that will reduce or eliminate it.

To understand the problem it is necessary to learn about the imperfections in modern transmitters and receivers. Transmitters produce substantial output at multiples of the operating frequency. There are noise sources in them that will be radiated along with the desired signal. Receivers can tolerate signals only below certain levels that will create nonlinearities which make reception difficult or impossible, or that will physically damage them.

It's also necessary to understand something about the use of dB, dBm, dBm/Hz, etc., in order to discuss the problem intelligently. This is where we begin.

#### **1.1.1 Understanding the various forms of dB that the RF engineer uses**

Using dB allows us to talk about very large differences in power or Voltage levels with numbers that are easy to comprehend. For example: the maximum power output of a legal transmitter in the USA is 1500 Watts and the noise floor of a modern receiver is 0.04 microVolts. The received power at this Voltage level into 50 ohms is 0.00000000000000003 Watts or  $3 \times 10^{-17}$  Watts. These numbers are not easy to deal with. RF engineers refer to power levels as dB above or below 1 milliWatt in a 50 ohm system and call the result dBm. Thus, 1 milliWatt is 0 dBm. If we convert the above power levels to dBm, we obtain +62 dBm for transmitter output and -135 dBm for receiver noise floor. The equations:

$$1500 \text{ Watts in dBm} = 10 \log (1500 / .001) = +62$$

$$3 \times 10^{-17} \text{ Watts in dBm} = 10 \log (3 \times 10^{-17} / .001) = -135$$

For narrow band signals such as CW, these numbers are easy to calculate from the amount of power read on a Wattmeter. For example:

*How many dBm is a 100 Watt transmitter producing?*

$$100 \text{ Watts in dBm} = 10 \log (100/0.001) = 10 \log( 100,000) = 10 \times 5 = +50\text{dBm}$$

When considering wideband noise an additional factor must be added. The level of noise introduced into a receiver output will depend upon the noise power and the bandwidth of the receiver. The noise may exist over a large bandwidth, but

we are interested only in the noise power within our receiver bandwidth. By taking a standard very narrow slice of noise, we can obtain a number that is useful in predicting interference effects. The common bandwidth reference is 1 Hz. Noise power then is defined as noise density in terms of dBm/Hz. If we measure -50 dBm of noise out of a receiver that has 500 Hz bandwidth the power in dBm/Hz would be:

$$\text{Noise power} = -50 \text{ dBm} - 10 \log 500 = -50 \text{ dBm} - 27 \text{ dB} = -77 \text{ dBm/Hz}$$

*Where the -27 dB is due to the ratio of bandwidths from 1 Hz to 500 Hz.*

This measurement can be made with a true rms AC meter and a signal generator used for a reference. The rms meter reading on the noise source is set to a convenient value on the scale by adjusting the radio volume control. The signal generator is then substituted for the receiver input source and is set to the received frequency. The generator output is then adjusted for the same audio output on the rms meter. The noise power is then equal to the signal generator output power.

Another form commonly used is dBC, where C represents carrier. A number expressed in dBC is dB related to the carrier. Sidebands are generally expressed in dBC. Noise around a transmitted carrier would also be expressed in dBC.

## **1.2 Power Levels in the Amateur Station Transmitter**

Even the best transmitters produce undesired products along with a main signal. These products can produce excessive interference in other radios that are being used nearby unless steps are taken to reduce them. Harmonics occur at integer multiples of the transmitted frequency. The 2nd and 3rd harmonics are usually the worst. For example, a 7 MHz transmitter will produce harmonic signals at 14 and 21 MHz with sufficient energy to cause interference while trying to listen on those bands. Two forms of random noise are also generated in a transmitter. These are phase noise and wide band transmitted noise, and are described below.

### **1.2.1 Harmonics**

Transmitters produce harmonics, which can cause interference to receivers monitoring other amateur bands. The FCC regulations require these harmonics to be more than 40 dB down from the transmitted carrier or -40 dBC. When full legal power is being used, harmonics can be radiated at substantial power levels. Forty dB below 1500 Watts is 150 milliWatts or +22 dBm. These numbers can be taken as the worst case. Amplifiers with pi-L output networks may have harmonic levels considerably below -40 dBC.

### 1.2.2 Phase Noise

The frequency generating portion of a transmitter contains one or more oscillators, usually part of a frequency synthesizer. The solid state devices used to produce the oscillators are not noise free, so some random noise is present in the device currents. This noise modulates the generated waveform and creates small amounts of phase shift. These phase perturbations can be seen on a spectrum analyzer as a broadening of the generated waveform, or noise sidebands. These noise sidebands are called phase noise. The sideband level is generally highest close to the transmitted frequency. Further from the carrier frequency the noise is reduced until at some offset it reaches a plateau called the noise floor. Modern radios have a phase noise floor of about  $-140$  dBm/Hz. (See note 1.) At an offset of 10 kHz it's about  $-130$  and at 2 kHz offset it's about  $-115$  to  $-120$  dBm/Hz. The closer to the actual carrier that we tune, the stronger the phase noise becomes. This noise is present only when the transmitter is actually sending. The synthesizer is used in both transmitting and receiving, so phase noise also a receiving problem.

*Note 1. To add realism to the calculations which follow, many of the radio characteristics listed have been taken from laboratory measurements of the FT-1000MP Mark V, performed by the ARRL. The author, on his FT-1000MP, has measured some of the numbers that were not measured by the ARRL.*

### 1.2.3 Wide Band Noise

Solid-state transmitters use wideband amplifiers from the last mixer through the power amplifier at the 100 Watt level. The low level amplifiers in this chain have some internal noise, as does any real amplifier. This noise is amplified up to the power amplifier output. This amplified wide band noise will be present when the transmitter is activated, even before the carrier is turned on. The power amplifier is usually followed by a low pass filter that helps remove harmonics and also reduces the noise output for bands above the band in use.

As an example, assume a clean, noise free signal is heterodyned to the operating frequency by a noise free injection source. The typical output level of the mixer might be  $-10$  dBm. The gain required to produce 100 Watts out of a transceiver would be 60 dB. Let's assume that the amplifier producing the gain has a noise figure of 4 dB. The input noise of such an amplifier is

$$-174 \text{ dBm/Hz} + 4 \text{ dB} = -170 \text{ dBm/Hz.}$$

*Where  $-174$  dBm/Hz is the noise in a 50 ohm resistor at 300 degrees Kelvin.*

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At the transceiver output this becomes  $-110$  dBm/Hz. This level will increase by 27 dB for a receiver bandwidth of 500 Hz. Now the noise level becomes  $-83$  dBm and related to the 100 Watt carrier power it is

$$-83 - (+50) = -133 \text{ dBC.}$$

### **1.3 Maximum Receiver Levels**

If a large enough signal is presented at a receiver input, damage to internal components will result. There are limits to how large a signal can be inputted to a receiver before it refuses to allow simultaneous reception of normal signals. Transmitter harmonics and noise can interfere with reception if their levels are high enough. Let's examine these various problem areas and assign specific levels below which normal reception can take place.

#### **1.3.1 Receiver Damage**

Examining the components that make up receiver input circuits will show what power levels are safe. Input attenuators commonly use resistors rated at 0.1 Watt. Switching diodes used to select input filters are usually rated at 0.2 Watts. To apply a safety factor of 2 to the resistor ratings would result in 0.05 Watts, or 50 milliWatts, or  $+17$  dBm, being the maximum safe power. This is very safe, because it is highly unlikely that any one component will absorb most or all of the received power at the antenna input of the radio. The worst case would be in the attenuator resistors when the attenuation is set at maximum. Receiving under these signal conditions is impossible.

#### **1.3.2 Receiver Blocking**

When high level signals are applied to a receiver input there is a level, somewhat lower than the damage point, which disables or blocks reception. This level is a function of receiver design and varies depending upon the manufacturer and model. A top of the line modern receiver has a blocking level around  $+5$  dBm for a signal offset of 50 kHz and 0 dBm for 20 kHz spacing. Receiving is useless, but no damage results.

#### **1.3.3 Intermodulation Distortion**

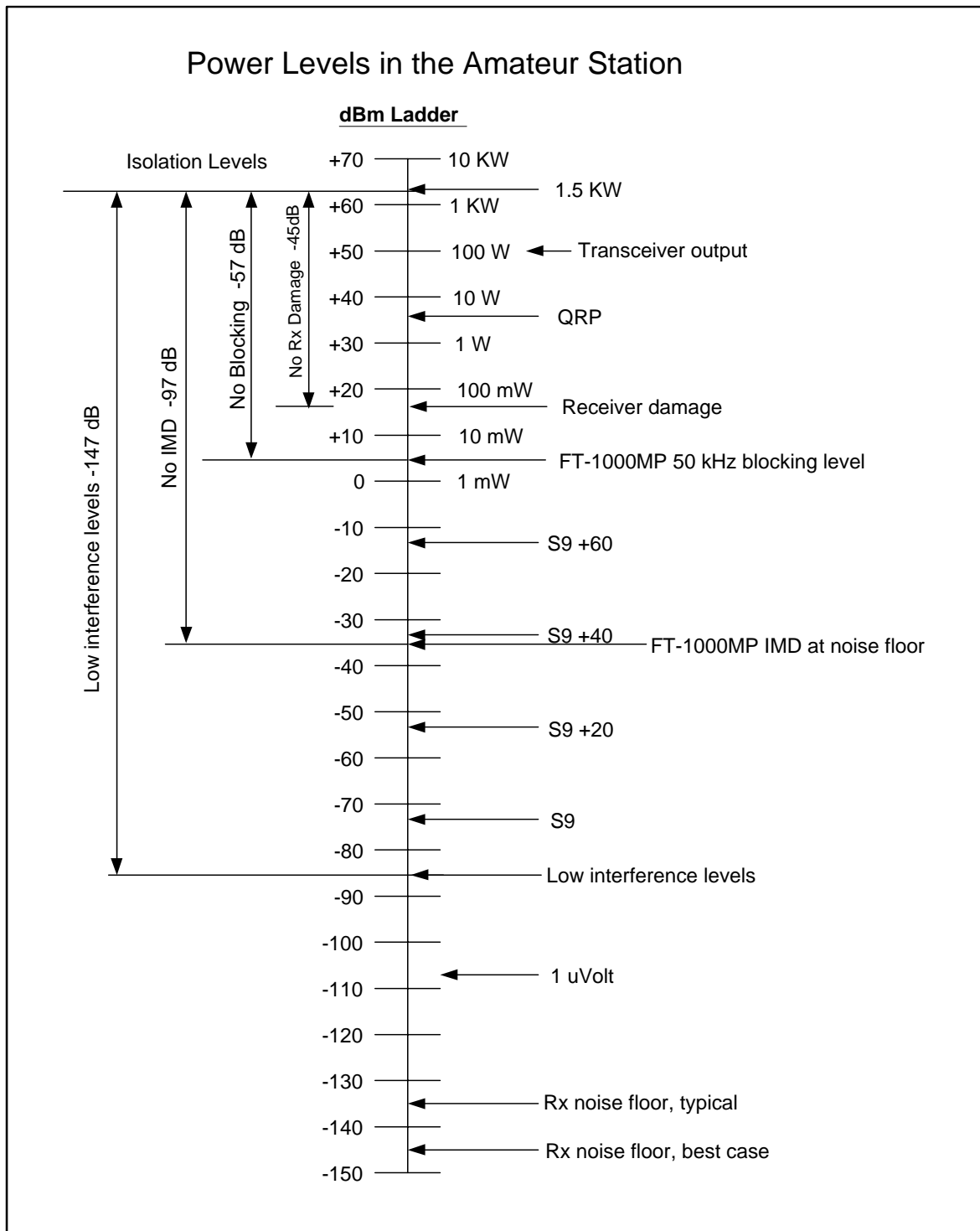
Intermodulation occurs when mixing action takes place between two or more signals to create new signals. Usually these are third order products of the type  $2F1 - F2$  and  $2F2 - F1$ . For example: F1 at 7020 mixes with F2 at 7030 to form intermod products at 7040 and 7010. The level at which this happens in a modern radio is about  $-35$  dBm. This is only 4 milliVolts and would read just under S9 +40 on an S meter. Receiving is possible with lots of interference from cross products.

### **1.3.4 Noise Floor**

All transistors and integrated circuits used in the manufacture of receiver amplifiers and mixers have internal noise sources. This internal noise creates a limit, or floor, in signal level that can be received. The typical noise floor in today's radios is about  $-135$  dBm.

## **1.4 The Power Level Chart**

Figure 1 shows the various power levels of importance for analyzing interference problems in the amateur station. The dBm scale from  $+70$  to  $-150$  represents power levels from above maximum legal to below the best receiver sensitivity. Along the right side of the scale various important power levels are indicated. By taking the difference between two dBm levels of interest, the isolation in dB can be determined. For example: to reduce the  $+62$  dBm transmitter output to that level which will not damage a receiver,  $45$  dB of isolation is required. To reduce the transmitted level to  $10$  dB below S9 that will minimize interference,  $147$  dB of isolation is needed. We will look into the various methods for obtaining isolation in later sections.



**Figure 1 The dBm ladder.**