OPERATING EUROVISION AND EURORADIO

# TR 060

# INTERFERENCE MECHANISMS IN AN AM RECEIVER

TECHNICAL REPORT

Geneva
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## Abstract

This document is intended to introduce the subject of interference mechanisms in AM broadcast receivers. It gives an overview of the subject to those without specialised knowledge of AM radio systems. Much more detailed treatment can be found in various texts on the subject, among them References [1] and [2] and in ITU-R Reports and Recommendations.

# Contents

# Interference mechanisms in an AM receiver

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**Keywords:** Amplitude Modulation, Modulation Depth, Noise, Interference, Masking Effect.

## 1. The AM Receiver

Figure 1 shows a schematic diagram of an elementary AM radio receiver, a crystal set. A receiver of this design – with only 4 components – would actually work, and in the early days of radio broadcasting, over a century ago, a large part of the audience would be listening on such a device.

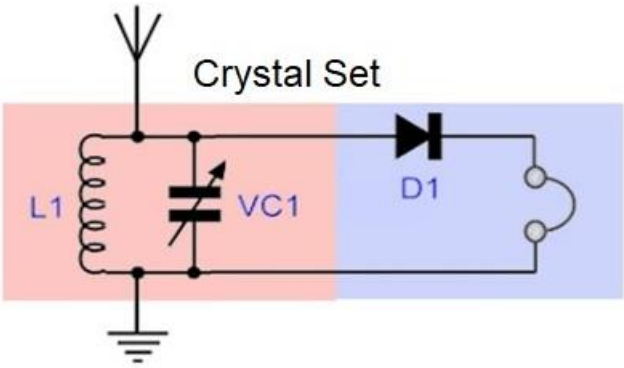


**Figure 1: Schematic diagram of an elementary AM radio receiver**

The receiver consists of two basic 'blocks'. To the left, shaded pink, there is a tuned circuit acting as band pass, RF filter (inductance L1 and variable capacitor VC1 in parallel) to isolate the wanted station (frequency) and to the right, shaded blue, an envelope detector or half wave rectifier[1].

In a standard half wave rectifier, the diode (D1) connects to a capacitor, but in this circuit the job of the capacitor is done by the headphone.

Such a receiver does not need a power supply of any kind, the small amount of power needed to drive the headphone being taken from the incoming radio signal.

In the early days, the antenna usually consisted of a long wire that was sensitive to the electric field component of any incoming signal. The circuit needed a good connection to earth to ensure correct operation.

Over the course of the last 100 years, elements of refinement such as amplification, heterodyne tuning (in the 1930s), internal ferrite (magnetic sensitive) antennas and digital tuning (in the 1980s)

[1] Historically the rectifier consisted of a piece of crystalline mineral, usually lead sulphide, with a fine wire touching its surface and it was referred to as a 'crystal' or 'cat's whisker'.

have been introduced, but the basic circuit and operating principle of a modern AM receiver remains exactly the same as the 'crystal set'[2].

A block diagram of a modern receiver is shown in Figure 2. The blocks shown in black, are functionally identical to those in the crystal set.

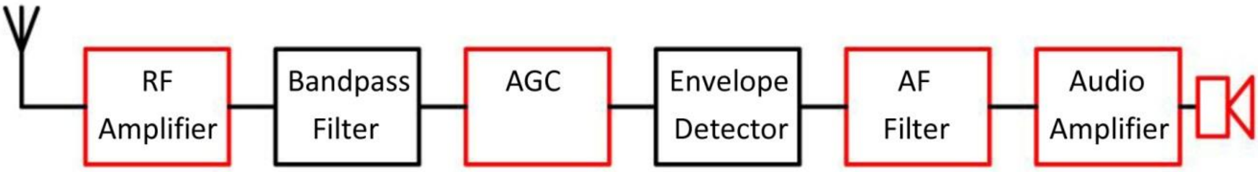


**Figure 2: Receiver Block Diagram - Simplified**

The RF amplifier boosts the incoming signal to make it more tractable but, also, introduces some additional noise. The RF filters in modern receivers are much more sophisticated than the parallel tuned circuit in the crystal set, providing a flatter 'in band' response and better selectivity. If anything, this could make the impact of interference worse rather than better because the wider bandwidth will, potentially, pass more unwanted 'signals'.

The automatic gain control (AGC) is a convenience for the listener. It has the effect of 'boosting' a weak signal and attenuating a strong signal so that the 'volume' at the receiver output remains the same for both. Audio amplification allows the use of a loudspeaker instead of a headphone and audio filtering aids selectivity; it is easier to make a filter with a sharp cut off at audio frequencies that at radio frequencies.

Clearly, blocks involving amplification will require a power supply (a battery in a typical portable) but this is not shown. Crystal set users usually relied on a 'long wire' antenna which was sensitive to the electrical component of the incoming radio signal while modern receivers almost universally use magnetically sensitive (and much more compact) ferrite rod antennas.

[2] Some professional receivers use a synchronous detector, which behaves in a slightly different way from the envelope detector, but such detectors are virtually unknown in commercial, domestic receivers.

## 2. Modulation and Modulation Depth

As the name “Amplitude Modulation” (AM) implies, a sinusoidal carrier wave has its amplitude modulated (or varied) by the audio signal[3] that is being transmitted. Figures 3a and 3b show a plain sinusoid (or carrier wave) of frequency $f_c$ with no modulation. Figures 4a and 4b show the same sinusoid but this time being fully modulated by another sinusoid at a lower frequency $f_m$.

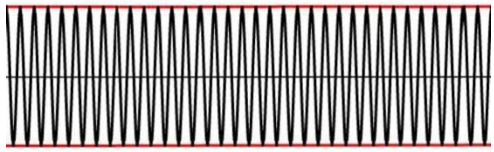

**Figure 3a: Plain Sinusoid No Modulation**

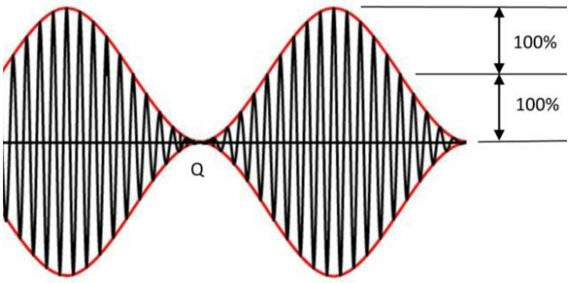


**Figure 4a: Sinusoid with 100% Modulation**

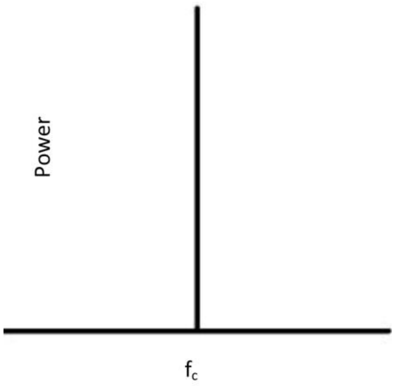


**Figure 3b. Spectrum of plain Sinusoid No Modulation**

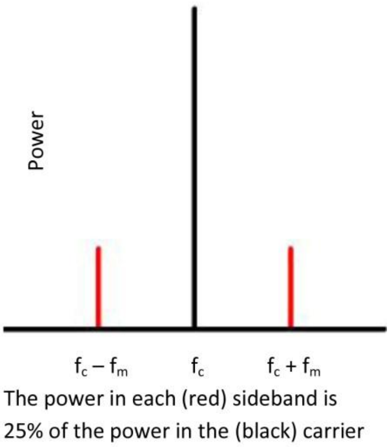


**Figure 4b Spectrum of Sinusoid with 100% Modulation**

Conventionally, the level of modulation shown in Figure 4 is called 100%; the peaks of the modulating sine wave modulate the carrier to its fullest extent[4]. Spectrally this appears as a delta function at the carrier frequency flanked by two smaller delta functions or sidebands at the sum and difference frequencies of the carrier and the modulating signal ($f_c + f_m$ and $f_c - f_m$).

The frequency of the modulating signal ($f_m$) must be sufficiently low to allow all three components to be passed by the RF filter. In this instance, 100% modulation, the energy in each sideband would be a quarter of (6 dB below) the energy in the carrier. It is the sidebands that carry the information, and which need to be protected from noise and interference.

Returning to Figure 3, this situation could be described as 0% modulation; there will be no energy in the sidebands (there will be no sidebands) and it is representative of the AM radio signal during periods of audio silence.

[3] In the case of an AM broadcast.

[4] It would not be possible to modulate the carrier any further because there is no more ‘dynamic range’; the carrier wave has already been reduced to zero in the modulation troughs at position ‘Q’ and to go beyond this would introduce distortion.

Audio silences are the most critical periods from the interference point of view even if they are relatively short breaks in speech, etc. As the level of the wanted audio increases it will tend to mask the effect of any interference.

The red lines in Figures 3, 4, 5 and 6 show the modulation; one of them (upper or lower depending on the polarity of the diode) will be the output of the envelope detector. Fairly obviously if such a signal is input to the crystal set in Figure 1, one of the red lines represents the output from the headphone.

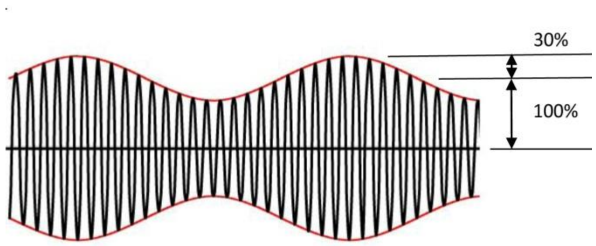


**Figure 5a: Sinusoid with 30% Modulation**

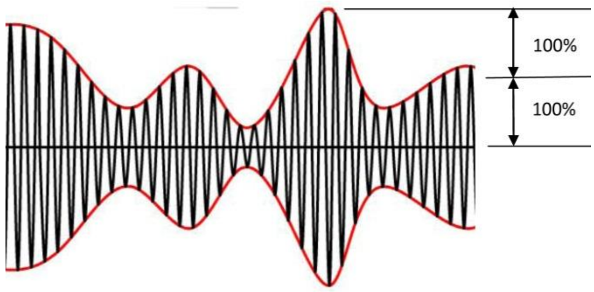


**Figure 6a: Sinusoid with audio Modulation**

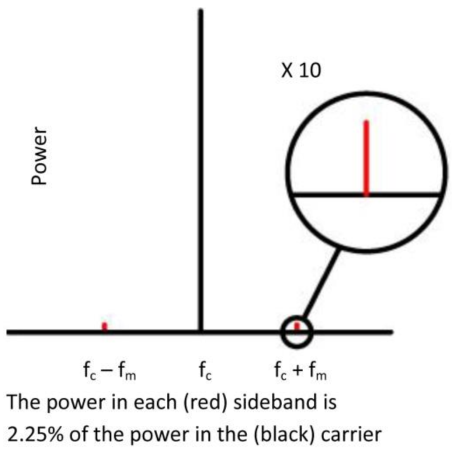


**Figure 5b: Spectrum Sinusoid with 30% Modulation**

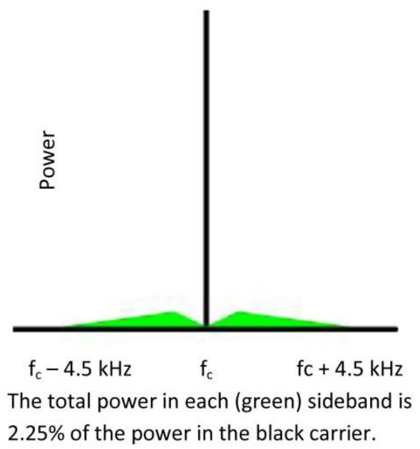


**Figure 6b: Spectrum Sinusoid with audio Modulation**

Figure 5 shows the situation where the modulating sine wave is only modulating the carrier to 30% of the available dynamic range; 30% modulation. In this case, the total energy in the sidebands is 4.5% of that in the carrier (13.5 dB down). 30% modulation is chosen here because this is frequently the benchmark used in ITU-R Reports and Recommendations when assessing the impact of noise (signal to noise ratio) and interference on the audio output from an AM receiver.

Figure 6 shows the more realistic situation where the carrier is being modulated by a speech or music signal. The definition of modulation depth using sinusoidal modulation breaks down here because the broadcaster will always try to maximise the modulation depth (100% in the instantaneous peaks) but the average energy in the sidebands will be very much less than 25% of the carrier energy as it would be for 100% sine wave modulation[5]. The modulation depth of a random signal is often expressed as that of an equivalent sinusoidal signal with the same sideband energy. Using this convention, the sideband energy in Figure 6 would be the same as that in Figure 5 but the energy would be distributed across the (representative) green triangles.

[5] The mean to peak ratio of a typical transmitted speech signal is around 20% while that of sine wave is roundly 70.7%.

While the sideband components in Figures 4 and 5 are drawn to scale, those in Figure 6 are not because they would be too small to be visible at a sensible size on the page. The width of an AM channel in ITU-R Regions 1 and 3 is 9 kHz so the green triangles will not extend more than 4.5 kHz either side of the carrier. In ITU-R Region 2, the width of an AM channel is 10 kHz.

Very clearly, nearly all (95%) of the energy in Figures 5 and 6 is concentrated in the carrier component. During periods of audio silence, 100% of the energy is in the carrier. This means that in many instances, the broadcast signal appears as a sine wave with only a small perturbation.

Conversely, any sinusoidal interference (with or without modulation / perturbation) will appear to the receivers in Figures 1 and 2 to be identical to a broadcast signal; the receiver is unable to differentiate between a wanted broadcast signal and one or more sinusoidal interferers.

The bandwidth of the RF filter is small in comparison with its centre frequency[6] (around 1% in the case of MF[7] and 5% in the case of LF[8]). Any distortion or harmonic components present in an interferer will be rejected. If the interferer is unmodulated it will appear to the envelope detector as a plain sinusoid as in Figure 3. If it is modulated it will appear as an amplitude modulated sinusoid as in Figures 4, 5, or 6.

In an AM radio transmission system, the carrier itself is merely a 'vector'. It is not a part of the 'audio information' being transmitted and is there primarily to facilitate simple demodulation[9]. The 'useful' audio component of the transmitted signal is in the sidebands which represent only 4.5% of the energy therein; 13.5 dB smaller than the carrier component. The power of an AM transmission is usually specified as the size of the carrier component. From an interference point of view this is misleading as it is the smaller audio component that needs to be protected.

In a domestic receiver (based on the Figure 1 concept) any unmodulated sinusoid, regardless of its actual frequency, but provided it is within the pass band of the RF filter, will, if there are no other signals present in the passband, demodulate to silence.

## 3. Noise and Interference

The human ear has different tolerance levels to perturbation of an audio signal caused by different types of interference and by noise. Human hearing is typically much more tolerant of random noise than it is of the interference likely to be encountered by an AM radio receiver. In addition to random noise there are two probable sources of interference that might be encountered by an AM broadcast receiver. An intelligible signal (speech, music, etc.) from another broadcast transmitter or (typically) unmodulated sinusoidal radio interference from a manmade source; WPT for example.

Random noise is likely to come from three sources; naturally occurring noise, man-made noise and noise inherent in the receiver itself[10]; the sum of these three components is total system noise. In setting a minimum signal level for good quality, noise limited AM reception, Recommendation ITU-R BS.703 *Characteristics of AM Sound Broadcasting receivers for planning purposes* [3], seeks audio signal to total system noise ratio of 26 dB referred to a modulation depth 30% (equivalent sine

[6] To achieve adequate selectivity.

[7] An MF channel is 9 or 10 kHz wide on a carrier frequency around 1 MHz.

[8] An LF channel is roughly 9 kHz wide on a carrier frequency of around 200 kHz.

[9] More sophisticated systems suppress the carrier (and often suppress one of the symmetrical sidebands as well) so that all the transmission energy is concentrated in the 'useful' part of the signal. However, such systems need very much more elaborate receivers.

[10] The principal source of internal noise is the very sensitive first stage of RF amplification; the leftmost block in Figure 2. This stage does not exist in the 'crystal set' receiver.

wave peak). The Recommendation also prescribes a minimum usable field strength for the MF broadcast carrier of 8.5 dB(μA/m) (60.0 dB(μV/m)).

In this situation, the anticipated total system noise will therefore be:

8.5 –13.5 (modulation depth[11]) – 26.0 (signal to noise ratio) + 3.0 (correlation gain[12]) = -28.0 dB(μA/m)

Report ITU-R BS.2433 *Assessment of modulation depth for AM sound broadcasting transmissions* [4], reveals that for current, speech-based AM programming, the actual, measured modulation depth is closer to 28% (equivalent sine wave peak) worsening the signal to noise ratio by 0.6 dB.

With reference to the equation above, it is important to note that, as stated earlier, the level of the wanted signal component i.e., the sideband level is 13.5 dB below that of the carrier giving an effective minimum usable field strength of -5.0 dB(μA/m) and it is this that must be used as the benchmark for assessing the effects of noise and interference. Despite the fact that most ITU-R Recommendations and Reports (see next paragraph) typically reference the higher power carrier, this is merely a 'vector' used to facilitate simple demodulation in the receiver.

Fortunately, the tools for assessing the impact of different types of interference are very well established and enshrined in Recommendation ITU-R BS.560 *Radio Frequency Protection ratios in LF, MF and HF broadcasting* [5]. The Recommendation was formulated on the basis of extensive theoretical and experimental studies and it has been used successfully as a guide to spectrum planning and management in the LF, MF and HF broadcast bands ever since. It was used as the basis of the Geneva 1975 (GE75) and Rio de Janeiro 1981 (RJ81) LF and MF Regional planning agreements which between them govern LF and MF broadcasting across the world.

The Recommendation states that the level of an interfering broadcast signal at the receiver should be at least 40 dB below that of the wanted signal. Assuming that the interfering and wanted carriers are precisely aligned in frequency this means that the sideband components of the two signals will add in the receiver and that the unwanted audio signal will also appear at the receiver output 40 dB below that of the wanted audio signal. Effectively this means that where the interfering signal is speech or music, the unwanted audio component should be at least 40 dB below the wanted audio. If the carrier frequencies of the wanted and unwanted signals are not precisely aligned an intermodulation product (IP) will be generated. Provided that the frequency difference is less than about 50 Hz[13] this IP will be inaudible. It will be below the range of human hearing and quite likely will not get past the audio filtering or the loudspeaker in the receiver.

Once the frequency offset between the wanted and unwanted signals gets above about 50 Hz, the IP between the wanted and unwanted carriers rapidly becomes the dominant factor. This is because a) the human ear is rather more sensitive to 'whistles' than other forms of background noise and b) because the sinusoidal carrier is so much bigger (more than 20 times) than the audio in the sidebands. Listening tests have recorded that most annoyance will result from frequency differences between 1 and 2 kHz. The level of an IP in the audio passband will be a function of the signal strengths of the carriers received and subsequent mixing in the receiver. The effect of frequency offset is shown in Figure 1 of Recommendation ITU-R BS.560, which is reproduced here.

[11] For 30% modulation, the sideband energy will be 4.5% of the carrier energy and hence 13.5 dB smaller.

[12] For the wanted signal the sidebands will be correlated (the contributions from the two sidebands will add as 'voltages') while the noise in the sidebands will not (the noise contributions will add as 'powers') giving a 3 dB advantage in the wanted signal to noise ratio.

[13] The GE75 frequency plan stipulates that all AM broadcasting stations in ITU-R Regions 1 and 2 operated with carrier frequencies that are multiples of 9 kHz. All the carriers (and any harmonics) will therefore be aligned on a 9 kHz raster. The RJ81 plan similarly stipulates that all carrier frequencies should be multiples of 10 kHz.

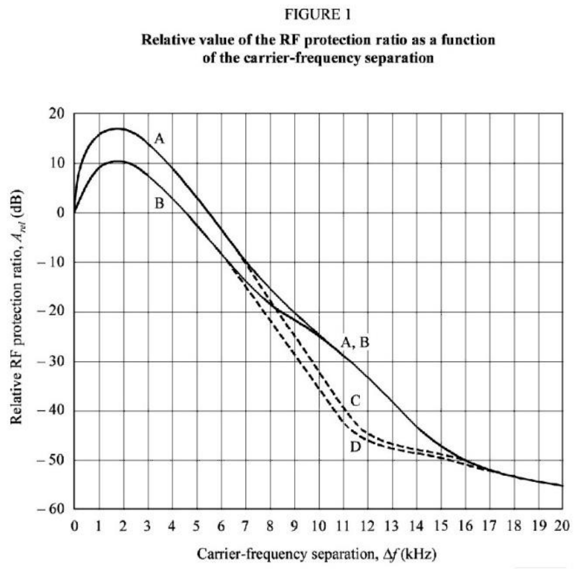


**Figure 7: Reproduction of Figure 1 from Recommendation ITU-R BS.560**

The relevant curve is A blending onto C for a standard receiver. The curve shows the relative protection required for different frequency offsets and so the wanted signal to interferer ratio with zero offset (40 dB) should be mapped onto the curve at the zero point on the ordinate axis. This means that the peak value of the signal to interference ratio occurs at about 2 kHz offset where an additional 16 dB of protection (40 + 16 = 56 dB) is called for. Curve B applies only when a high degree of compression is applied to the audio signal. This is only relevant to music or other continuous audio streams; speech is characterised by short periods of silence and gaps which are the most vulnerable to interference. Above about 7 kHz, Curves A and B are applicable to signals with a 10 kHz audio bandwidth while curves C and D apply when the audio bandwidth is 4.5 kHz.

The Broadcasting service has a primary allocation in the LF, MF and HF broadcasting bands and when the Recommendation was written that assumption was that any interfering signal will be another broadcast station. Nevertheless, the criteria are equally appropriate to any sinusoid-like interferer unless it is within ±50 Hz of the wanted carrier.

The values in Recommendation ITU-R BS.560 should be used for all compatibility analyses to AM Broadcasting except in the situation where the interferer is an unmodulated sinewave that is within ±50 Hz of the wanted carrier.

When the interferer is an unmodulated carrier within 50 Hz of the wanted carrier a protection ratio of 18 dB applies.

## 4. Impact of Interference

The impact of interference and the application of Recommendation ITU-R BS.560 can best be understood through some example scenarios. In each of the following four scenarios, it is easy to see how the elementary radio circuit in Figure 1 would react:

1) *Single unmodulated sinusoidal interferer in the absence of a wanted broadcast station*. The domestic receiver will interpret this as an incoming broadcast signal with no modulation and so will generate silence at the receiver output. Depending on the strength of the interferer the AGC circuitry in the receiver will suppress any system noise.

2) *Wanted modulated broadcast signal with interference from another modulated broadcast signal on the same (± < 50 Hz) carrier frequency*[14]. The two signals will be present at the input to the receiver and at the envelope detector. Unless the two carriers are locked to a common reference, a very low frequency beat is likely to occur between them. Provided that the unwanted signal is sufficiently weak compared with the wanted signal this will be negligible, but the envelope detector will demodulate the sum of the (much weaker) unwanted audio signal and the wanted audio signal. Recommendation ITU-R BS.560 calls for the ratio of the wanted to unwanted carriers to be 40 dB, effectively making the ratio of the wanted to unwanted audio 40 dB as well. If the ratio between the wanted and unwanted signals is less than 40 dB the wanted audio to unwanted audio ratio will be commensurately less. If the ratio between the signals becomes even worse, to about 18 dB, the interaction / intermodulation between the carriers becomes significant and further impairment or fading and distortion will occur. If the carriers are locked to a common reference[15], the unwanted carrier will give a constant slight increase or reduction in the effective level of the wanted carrier (depending on the phase difference at the location of the receiver), an increase effectively reducing the modulation depth of both signals and a decrease effectively increasing it.

3) *Wanted modulated broadcast signal with interference from an unmodulated sinusoidal interferer on nominally the same frequency*. This is a very similar situation to 2) above except that there is no likelihood of the wanted carrier and the interferer being phase locked, and as there is no modulation on the unwanted interferer, an audio protection requirement is not appropriate. In this case if the ratio between the signals gets to be less than about 18 dB, the interaction / intermodulation between the carriers becomes significant and will give rise to fading and distortion.

4) *Wanted modulated broadcast signal with interference from an unmodulated sinusoidal interferer or another modulated broadcast signal on different frequencies where the frequency offset is within the audio pass band*. As explained earlier, in a typical speech-based AM broadcast transmission, 96% of the energy is in the sinusoidal carrier. So, the sinusoidal component dominates and for all practical purposes the broadcast interferer can be considered as a sine wave. In this instance, Recommendation ITU-R BS.560 calls for the ratio of the wanted to unwanted carriers to be up to 56 dB depending on the frequency offset between the wanted carrier and the interfering sinusoid[16].

# 5. Masking Effect of System Noise

Recommendation ITU-R BS.560 is formulated for an environment where system noise is an insignificant factor. In areas of low (but still quite usable) signal, system noise (environmental, man-made and inherent receiver noise) will play a part, effectively masking the effects of low-level interference. As already stated, the human ear is more tolerant of random noise that it is of intelligible or sinusoidal interference. Very little data is available on this subject, but studies carried out by the BBC in 2018 and reported in Annex 2.9 of ECC Report 289 suggest that for the minimum signal levels predicated in Recommendation ITU-R BS.703 a relaxation of about 8 dB can be applied to the maximum tolerable interference level.

[14] Within an ITU-R Region, all broadcasting stations operate on a fixed frequency raster or grid. The effective RF and AF filtering in the receiver is narrower than the raster separation and so any interfering broadcast station that falls within the RF filter will necessarily be on the same frequency as the wanted station. Transmitter frequencies are typically specified and maintained to an accuracy of better than 1 Hz.

[15] Many AM transmitters are frequency locked to the common GPS standard.

[16] It is likely that an unmodulated sinusoid, or carrier as an interferer will need slightly less protection (3 or 4 dB perhaps) than a modulated signal because the modulation will add to the subjective degradation of the wanted signal. However, this is likely to be insignificant compared with the potential masking effect of system noise. See *Masking Effect of System Noise*.

# 6. Conclusions

Despite being relatively inexpensive, AM broadcast receivers are very sensitive devices. They must be sensitive to detect signals from transmitters that might be several tens or even hundreds of kilometres away from the receiving site. Clearly this sensitivity extends to interference and so even in quite strong signal areas their susceptibility to interference is high. They have no way of differentiating between a wanted signal and an interfering signal. Where the interfering signal is another broadcast station, which it often is, factors such as geographical and spectral separation in planning broadcast stations ensure that interference is kept to acceptable levels. Allocation of transmitter frequencies to particular geographical locations is carefully administered by the ITU-R to obviate interference issues. With unlicensed sources of interference this is not possible, and so protection of broadcast receivers relies on emissions from such devices being kept within acceptable limits. It has been the intention of this report to describe how and why these limits should be derived and specified.

Taking scenario 4), above, as an example for AM services in the MF band, the tolerable level for a single <u>unmodulated</u> sinusoid present in an AM channel (and hence in the passband of the receiver's RF filter) on the fringe of the protected service area can be calculated for the best and worst cases as follows:

Best case – interferer frequency (fundamental of harmonic) within 50 Hz of the wanted carrier:

> Tolerable magnetic field-strength level = 8.5 – 18 = **-9.5 dB(μA/m)**
>
> (or in electric field strength 60 – 18 = **42 dB(μV/m)**)
>
> Where 8.5 dB(μA/m) is the minimum usable field strength specified in Recommendation ITU-R BS.703
>
> 18 dB is the relaxation from raster alignment between the wanted and unwanted signals. See Ref [6]

Worst case – interferer frequency (fundamental or harmonic) 2 kHz offset from wanted carrier frequency:

> Tolerable magnetic field-strength level = 8.5 – 40 - 16 = **-47.5 dB(μA/m)**
>
> (or in electric field strength 60 - 40 -16 = **4 dB(μV/m)**)
>
> Where 8.5 dB(μA/m) / 60 dB**(μV/m)** is the minimum usable field strength specified in Recommendation ITU-R BS.703.
>
> 40 dB is the baseline protection ratio taken from Recommendation ITU-R BS.560 and16 dB is the worst-case relative protection ratio from Figure 1 of Recommendation ITU-R BS.560 (shown here as Figure 7 above).

# 7. References

[1] Modulation, Noise and Spectral Analysis (Applied to Information Transmission) - Phillip F Panter McGraw Hill 1965 ISBN 07-048446-4

[2] Modern Communication Systems - Rodney F W Coates MacMillan 1975 ISBN 0 333 15024 4

[3] Recommendation ITU-R BS.703 *Characteristics of AM Sound Broadcasting receivers for planning purposes*

[4] Report ITU-R BS.2433 *Assessment of modulation depth for AM sound broadcasting transmissions*

[5] Recommendation ITU-R BS.560 *Radio Frequency Protection ratios in LF, MF and HF broadcasting*

[6] https://www.bbc.co.uk/rd/publications/wireless-power-transfer-plain-carrier-interference-to-am-reception (WHP332 December 2017)