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Compatibility Measurements

FMeXtra interfering with Aeronautical Radionavigation

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0 Executive Summary

FMeXtra is a system much like DARC where digital information is added to the multiplex signal and modulated together with the AF onto the main FM broadcast carrier.

These measurements were made to assess the interference potential of FMeXtra with the aeronautical radionavigation systems VOR and ILS.

The main results is that the FMeXtra has only a slightly higher interference potential for frequency separations from 150 to 500 kHz (max. 3 dB at 200 kHz) to ILS, and an equal interference potential to VOR, compared to a standard FM broadcast signal.

1 Introduction, aim of measurements

The planned test transmissions of several new digital audio broadcast systems in the frequency range 87.6 to 108 MHz raised the question about their compatibility with other radio applications especially to services in adjacent bands.

One of the most sensitive radio services is the aeronautical radionavigation which starts at 108.0 MHz, directly above the FM broadcast band.

Systems like HD-Radio and DRM+ have already been measured against FM broadcast reception, narrowband FM (BOS) and aeronautical radionavigation. For results see measurement report G531/00329/07.

The FMeXtra system was not included in those measurements due to time constraints. This documentation presents the results of the compatibility measurements for FMeXtra interfering with aeronautical radionavigation only and can be seen as a supplement to the above mentioned comprehensive report for other digital broadcast systems.

The main purpose of these compatibility measurements was to assess the difference in interference potential of FMeXtra compared to that of a standard FM broadcast signal.

The measurements took place in the laboratories of Deutsche Flugsicherung (DFS) in Langen, Germany on August 22nd and August 23rd, 2007.

Active participants:

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Tab. 1: Participants list

The main body of this document provides a description of the measurement process and a result summary. Detailed information as well as every single measurement result can be found in the annexes.

2 Receiver selection

The frequency range directly above the FM broadcast band is used for ILS localizer (108.1 to 111.95 MHz) and VOR (108.0 to 117.95 MHz).

Since the extension of the FM broadcast band to 108 MHz, all aeronautical navigation receivers have to fulfil special requirements concerning the FM immunity that are set by ICAO. For the present compatibility measurements, only one ILS and one VOR receiver were available. It is important to note that the results presented here are only valid for the investigated receiver and can not easily be generalized. To determine the average or worst case protection ratios against VOR and ILS reception, a representative set of receivers has to be measured.

The measured receiver was a “Collins ILS/VOR/MB-900”. It has separate RF frontends for VOR and ILS reception and uses digital signal processing. Course data from the receiver was displayed by a “DPU-86N (EFIS)”.

Because aeronautical communication frequencies are above 118 MHz, this service was not investigated during these measurements because no harmful interference potential beyond that of normal analogue FM broadcast emissions can be expected.

3 Wanted signals

3.1 Description

Aeronautical radionavigation in the frequency bands directly starting at 108 MHz consist of two different systems: VOR and ILS localizer.

VOR uses a combination of AM and FM with one fixed and one rotating antenna (the rotation is simulated electronically): The main carrier is AM modulated with a 30 Hz variable signal, and a 9960 Hz subcarrier that is frequency modulated by a 30 Hz reference signal. This reference signal is emitted from the onmidirectional part of the antenna whereas the AM signal is emitted from the part of the antenna that rotates at 30 Hz per second. Comparison of the phase between this rotating part and the reference signal allows the airborne receiver to determine its horizontal position (in degrees) relative to the direction of the ground antenna. VOR frequencies are the even hundreds of kilohertz starting at 108.0 MHz.

Recommendation ITU-R IS.1140 describes the nominal modulation parameters for the VOR signal during compatibility tests which were used during the measurements: The modulation degree is set to 30%, phase offset is set to 0 which corresponds to a course of 0° relative to the VOR.

The instrument landing system ILS consists of two parts: One part delivers the horizontal offset from the ideal glidepath (“localizer”), the second part gives the vertical offset (“glideslope”). Both carriers are amplitude modulated with two sinusoidal tones, one with 90 Hz and one with 150 Hz. The transmitter antenna patterns are different for both tones. The aircraft receiver compares the signal strength from the components modulated with 90 and 150 Hz. If the aircraft is exactly on the glidepath, both tones will be received equally strong. From the difference in receiving strength between the two components the receiver can determine the vertical and horizontal offset relative to the ideal glidepath.

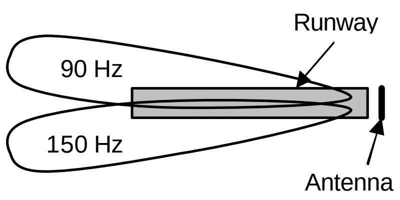

Fig. 1a: ILS localizer emissions

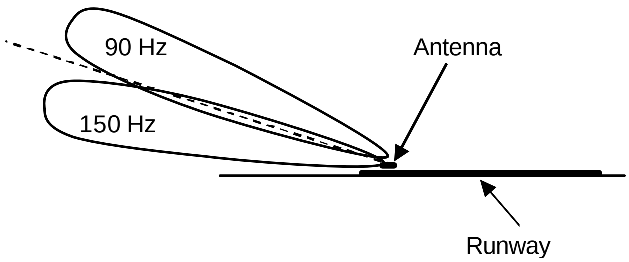

Fig. 1b: ILS glideslope emissions

Localizer and glideslope frequencies are paired but reside in different bands. While the localizer frequencies are the uneven hundreds of kilohertz starting at 108.1 MHz, glideslope frequencies are in the UHF range, starting at 329.15 MHz. Due to this, only the localizer part of ILS was investigated here.

Recommendation ITU-R IS.1140 describes the nominal modulation parameters for the ILS signal during compatibility tests which were used during the measurements: Both 90 and 150 Hz tones were modulated with a degree of 20%. The nominal offset from the ideal glidepath (DDM) was set to 0.093.

3.2 Failure criteria

Failure criteria for analogue aeronautical radionavigation receivers are defined in recommendation ITU-R IS.1009. According to this recommendation, the maximum allowable error in course display for VOR is 0.5°. For the ILS course component the error is defined as 7.5 µA in the analogue course indicator display which is equal to 7% of the total scale, measured at a nominal course deflection of 2/3 of the total scale.

Most modern receivers, like the one used here, are digital. Their output is data telegrams with course information that is passed to the board computer to be shown on a (multifunction) display. To have a similar interference criterion, ITU-R IS.1140 states a statistical method for determining the maximum on-course errors of ILS localizer receivers based on a 95% probability and limits centring error to 5% of the standard deflection. Five per cent of the standard localizer deflection is given by (0.05 * 0.093 DDM) or 4.5 µA (0.00465 DDM) and a 95% probability may be achieved by utilizing plus or minus two standard deviations, 2s, of the normal distribution. An equivalent deflection of 4.5 µA for the VOR is 0.3° change in bearing indication.

Reaching these criteria due to the interfering signal being present was called “course interference”.

In addition to this, the so-called “flag signal” was monitored. Whenever the received wanted signal is too weak or too heavily distorted for the receiver to decode properly, this is indicated to the pilot by a red flag that is lowered over the instrument indicating that the current reading is unreliable. Although this situation usually occurs long after the criteria for course interference, this “flag interference” was also recorded during the measurements.

3.3 Signal generation

Both VOR and ILS wanted signals could be derived directly from the signal generator R&S SME03 (No. 11 in Annex 1).

4 Unwanted signals

4.1 Documentation of spectra

The limits for unwanted emissions outside the used channel are defined as a spectrum mask in ETSI 302 018 that is normalized to a measurement bandwidth of 1 kHz. Because the level of unwanted out of band emissions has significant influence on the adjacent channel protection ratio, much effort was made to carefully document the emitted spectra. To measure the sideband emissions even far below the wanted signal level, it is necessary to enhance the measurement dynamics beyond the normal capabilities of a spectrum analyzer. Therefore, all spectrum plots of the unwanted signals were recorded with the following setup:

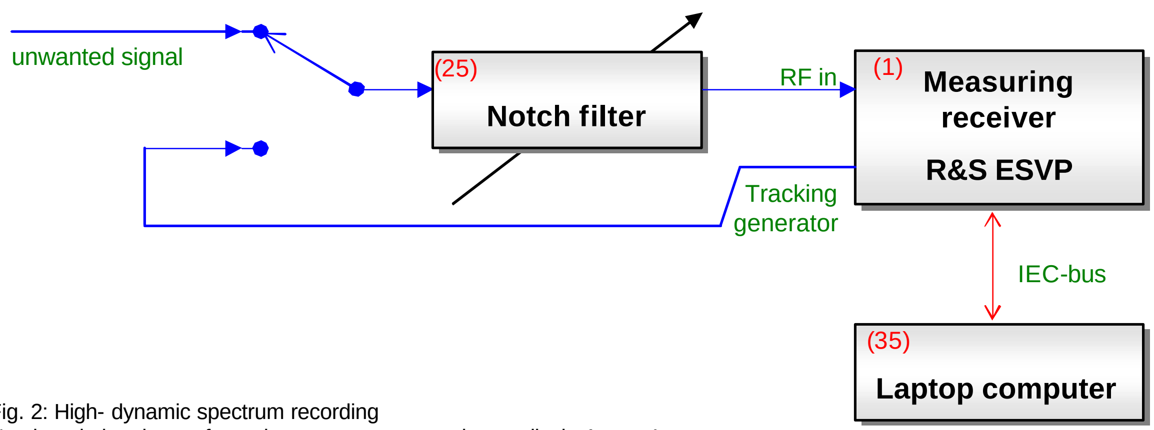

Fig. 2: High- dynamic spectrum recording
Numbers in brackets refer to the measurement equipment list in Annex 1

The notch filter used to attenuate the main signal so that the receiver is not overloaded while still passing the interesting range of sideband emissions with little attenuation. The measurement receiver is controlled by a laptop computer to perform a frequency scan with narrow bandwidth (7.5 kHz) and store the measured level results. First, the filter curve for the frequency range concerned is measured, then the filtered signal is gradually scanned. The sum of the two level/frequency curves is equal to the actual emitted spectrum with a dynamic range of more than 100 dB (corrected for a 1 kHz measurement bandwidth). Sideband spectra of the unwanted FM broadcast and FMeXtra signals can be found in Annex 2.

4.2 Signal Description

4.2.1 FM broadcast

The deviation of FM broadcast signals and hence their interference potential into adjacent channels depends on the deviation which under normal operating conditions varies constantly. Although ETSI EN 302 018-1 defines a transmitter mask for FM broadcast signals, in this case one cannot generate a signal that constantly follows this mask as this would place an unrealistic interference potential to neighbouring channels in terms of time. Instead, the unwanted signal consists of a carrier which is FM modulated with a coloured noise and a deviation that should result in an average bandwidth of the signal comparable to a normal programme modulation. Recommendation ITU-R IS.1140 describes the settings for the unwanted FM signal: The transmitter is operated in stereo mode and the coloured noise is modulated on both audio channels with a fixed level ratio of ½. This signal was used for the protection ratio measurements against ILS and VOR reception.

4.2.2 FMeXtra

The FMeXtra system adds additional digital information to the baseband multiplex (MPX) signal which is modulated on to the main FM carrier together with the audio and RDS signals. In the MPX baseband spectrum, FMeXtra uses the frequency range from 62 to 99 kHz:

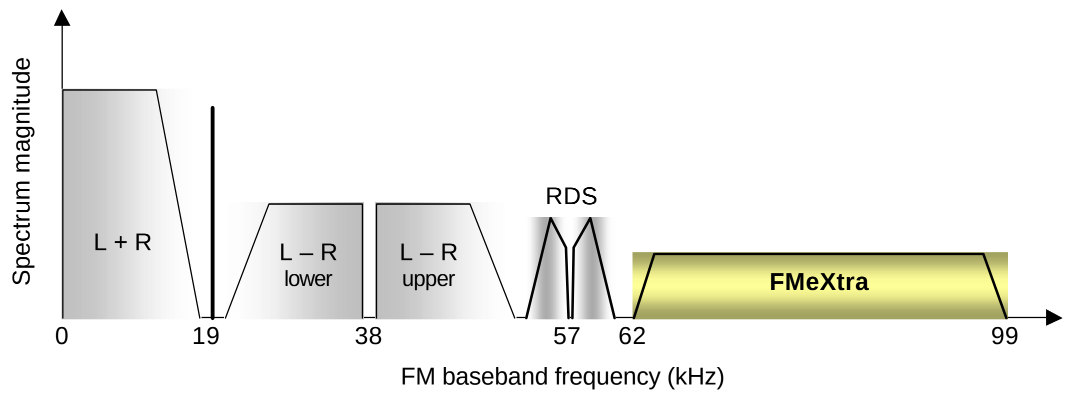

Fig. 3: schematic spectrum of the FM baseband (MPX)

The level of the FMeXtra is well below the level of the audio signals and even 8 dB below the level of the RDS signal.

The net data rate of FMeXtra is about 40 to 48 kbit/s allowing the transmission of supplemental data and/or a separate audio programme.

4.3 Signal generation

To directly allow the assessment of the influence of the FMeXtra signal on the protection ratios, both signals (standard FM broadcast and FMeXtra) were generated by the same modulator and transmitter:

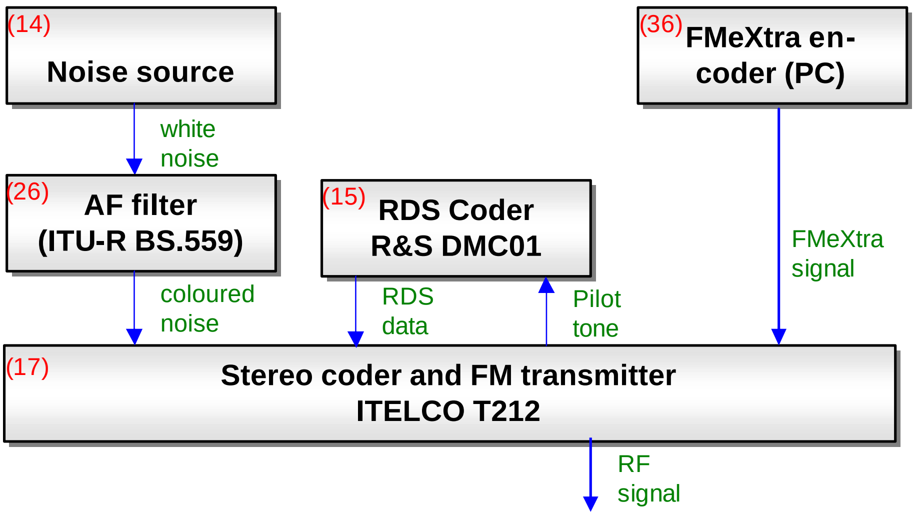

Fig. 4: Block diagram of the unwanted FM broadcast and FMeXtra signal generation.
Numbers in brackets refer to the measurement equipment list in Annex 1

<u>Modulation settings:</u>

The settings are taken out of Recommendation ITU-R IS.1140. The transmitter is operated in stereo mode. Both audio channels are modulated with coloured noise, but the level of the signal modulating the left channel is 6 dB lower (half the voltage) than the level that modulates the right channel. The deviation of the resulting signal was adjusted to +/- 32 kHz with the preemphasis switched on.

There was no measurable difference in the total deviation when the FMeXtra signal was switched on.

The spectrum of the FM broadcast signal can be seen in Annex 2. The following figure shows the upper half of the FM broadcast and FMeXtra spectra in comparison.

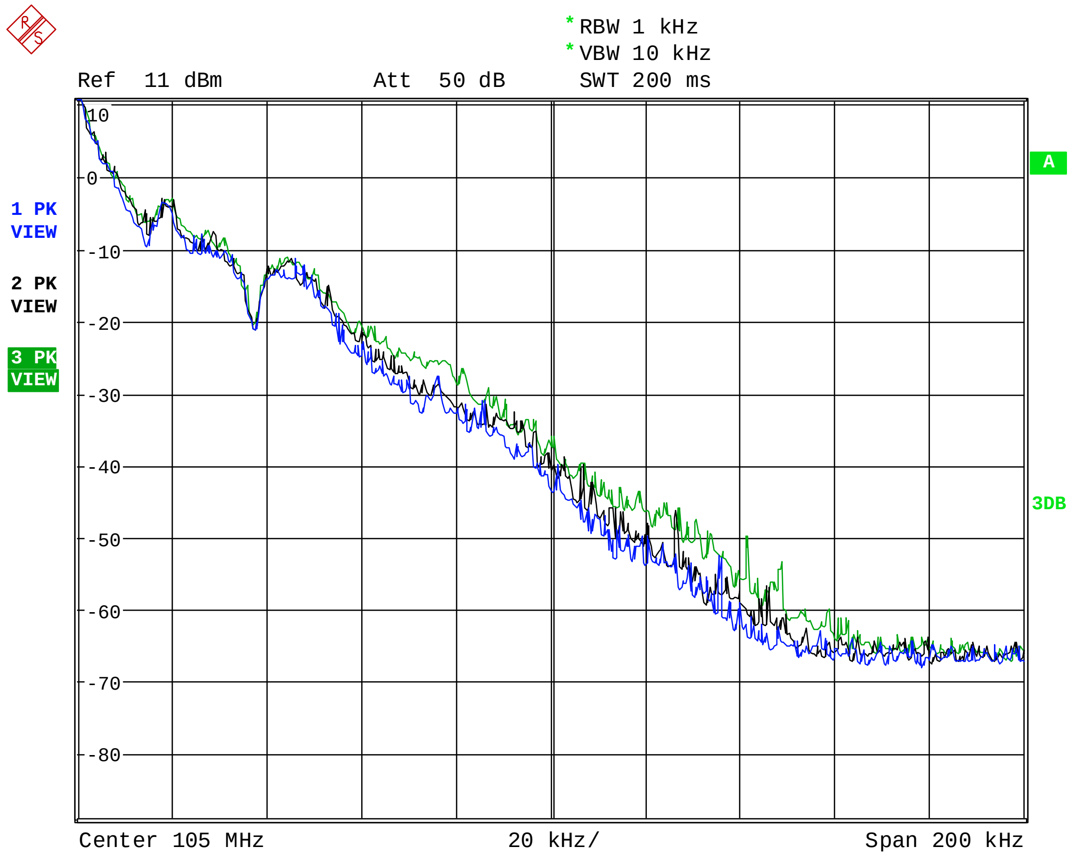

Fig. 5: MaxHold spectrum of the FM broadcast and unwanted signal modulated according to ITU-R IS.1140.
Upper (green) trace: Coloured noise, RDS and FMeXtra
Middle (black) trace: Coloured noise and RDS only, without FMeXtra
Lower (blue) trace): Coloured noise only, without RDS and FMeXtra

It can be seen that the FMeXtra signal slightly lifts the resulting RF spectral density in frequency ranges from 50 to 80 and 110 to 160 kHz from the main carrier.

The current transmitter mask for FM broadcast signals is met also with the FMeXtra signal switched on.

5 Protection ratio measurements

5.1 Measurement setup

The following setup was used to measure the VOR and ILS protection ratios:

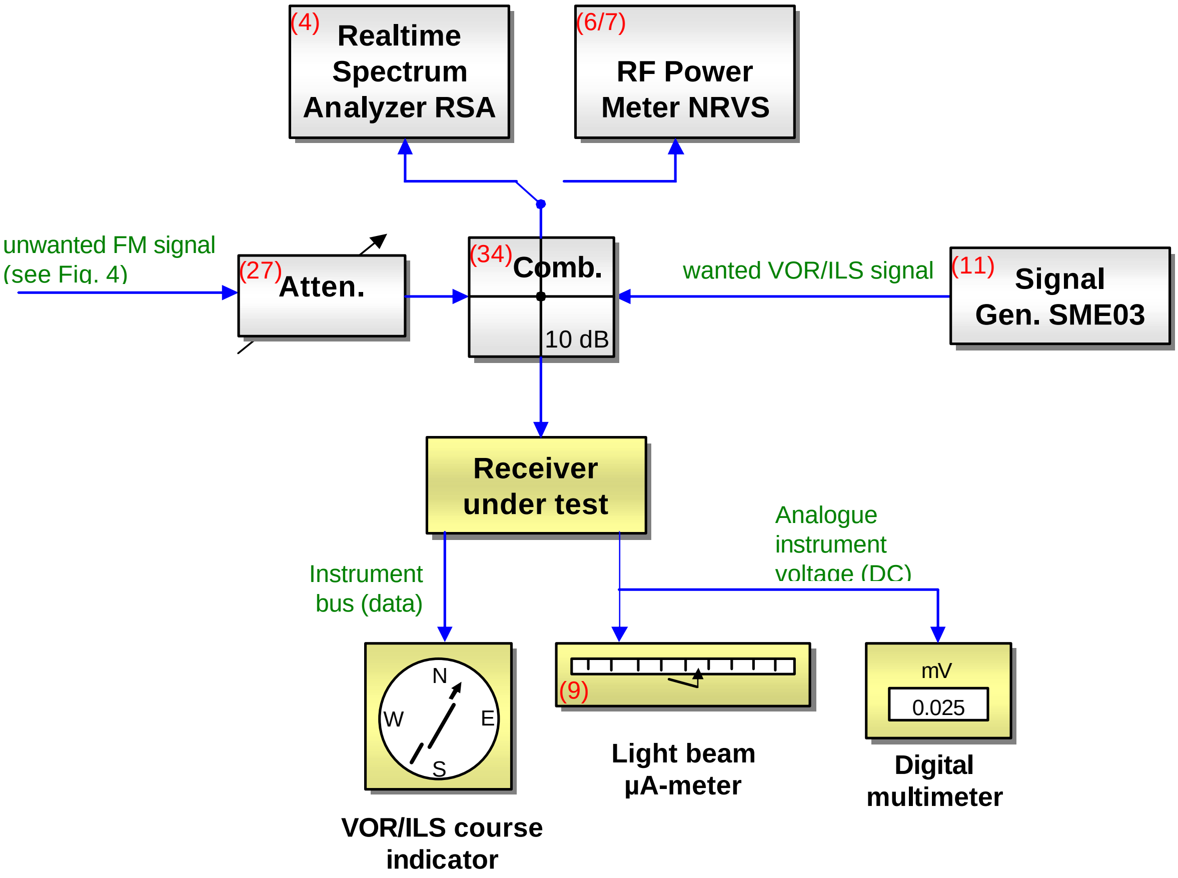

Fig. 6: Setup for protection ratio measurements
Numbers in brackets refer to the measurement equipment list in Annex 1

5.2 Measurement procedure

The general procedure followed for the protection ratio measurements was to supply sufficient wanted signal level to the receiver and then increase the unwanted signal level until the failure criteria occurs. The difference between wanted and unwanted signal levels is the protection ratio. This measurement is repeated for various offsets between wanted and unwanted signal frequencies.

For VOR and ILS, ITU-R IS.1140 describes a set of levels at which protection ratios are to be made: The minimum level listed for VOR where the tested receiver works is -79 dBm, for ILS this level was -86 dBm. To assess the linearity of the receiver, some measurements have been repeated with the next higher signal level listed in the recommendation, which was -63 dBm for VOR and -70 dBm for ILS.

The level of the unwanted signal was always adjusted by means of an external attenuator to ensure that the ratio of main signal to sideband emissions remained unchanged.

The lowest VOR frequency is 108.0 MHz, the lowest ILS frequency is 108.1 MHz. The highest FM broadcast frequency is 107.9 MHz. Starting from this constellation (Offset = -100 kHz and -200 kHz respectively), the FM broadcast signal was shifted down in frequency while the VOR / ILS receiver frequency was kept.

All signal levels throughout this report are given in RMS over the whole signal bandwidth.

5.3 Measurement results

The following figures show the result summary for the most critical criterion, the “course interference”. The detailed results of all protection ratio measurements can be found in Annex 3.

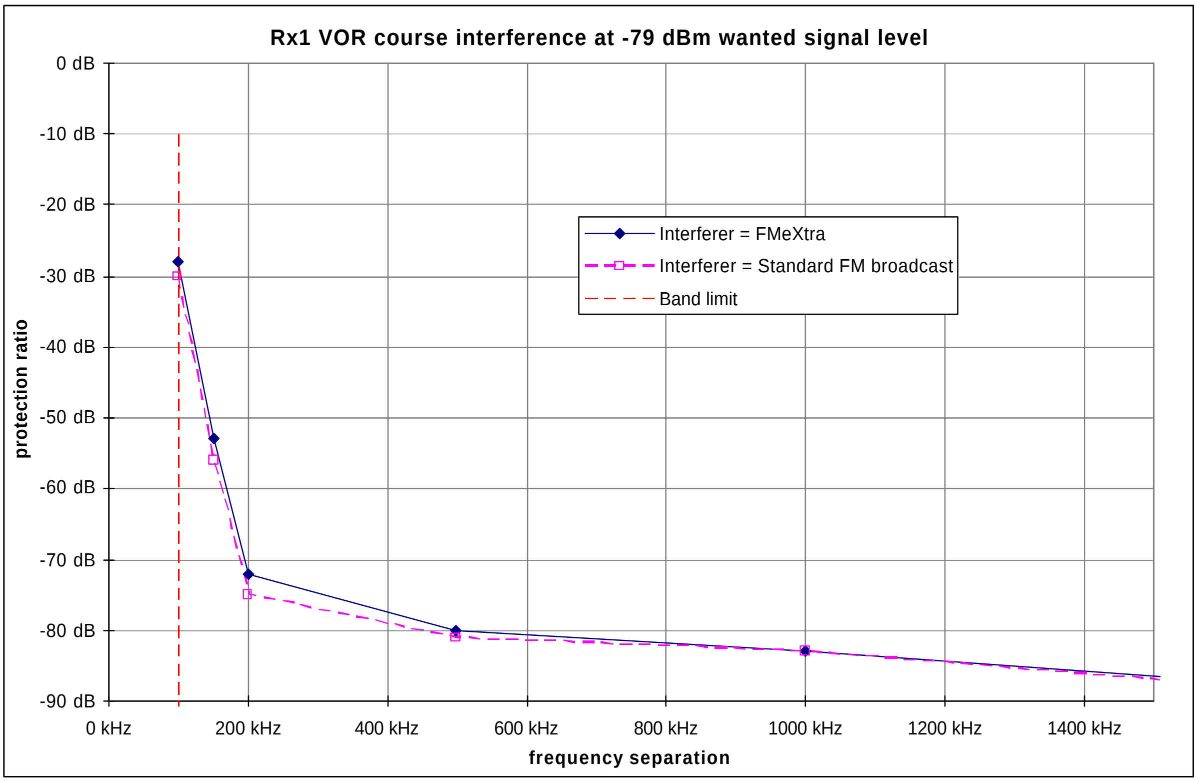

Fig. 7: Protection ratios for VOR interfered by standard FM broadcast and FMeXtra signals

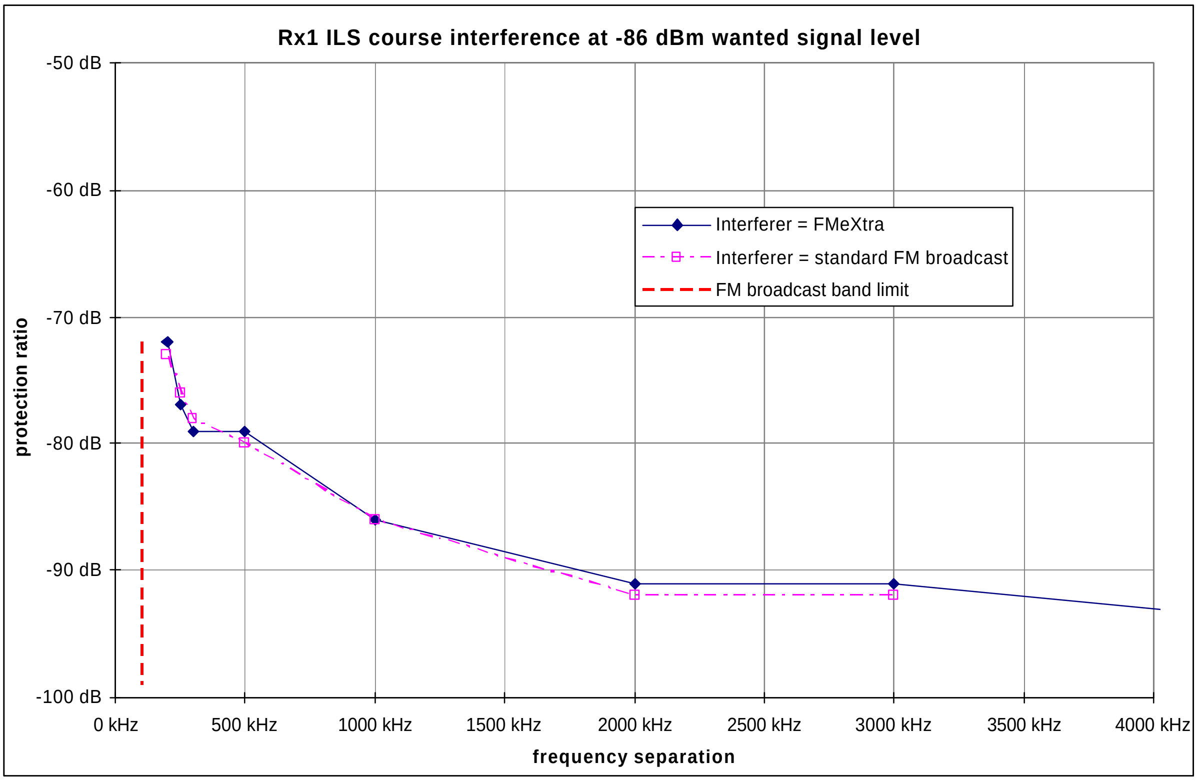

Fig. 8: Protection ratios for ILS interfered by standard FM broadcast and FMeXtra signals

It can be seen that the interference potential of the FMeXtra signal on VOR reception is slightly higher for frequency offsets between 150 and 500 kHz and on ILS reception nearly the same as that of a standard FM broadcast signal.

Care should be taken when comparing the protection ratio results with those given for FM broadcast interfering with VOR / ILS from report G531/00329/97. Especially for higher frequency separations, the actual protection ratio largely depends on the spectral shape of the sideband emissions of the unwanted FM signal. In the earlier measurements, different FM transmitters were used with other sideband emission roll-off. This may result in different protection ratios.

6 Intermodulation measurements

6.1 General

High-level emissions in the FM broadcast band can overload the input stage of an aeronautical receiver and cause intermodulation products to rise inside the aeronautical band and interfere with the reception of the wanted ILS or VOR signal. The performance of an aeronautical receiver under these conditions is called “FM immunity”. The frequencies of these intermodulation products can be calculated from the transmitter frequencies in the FM broadcast band. The most critical cases here are the 3rd order intermodulation products caused by three transmitters inside the FM broadcast band. In ITU-R IS.1009, this To assess the influence of digital systems compared with analogue FM broadcast systems, several measurements of the FM immunity have been made.

6.2 Measurement setup and procedure

The measurement procedure and setup is described in ITU-R IS.1140. The investigated interference mechanism is called “B1 interference”. The following setup was used:

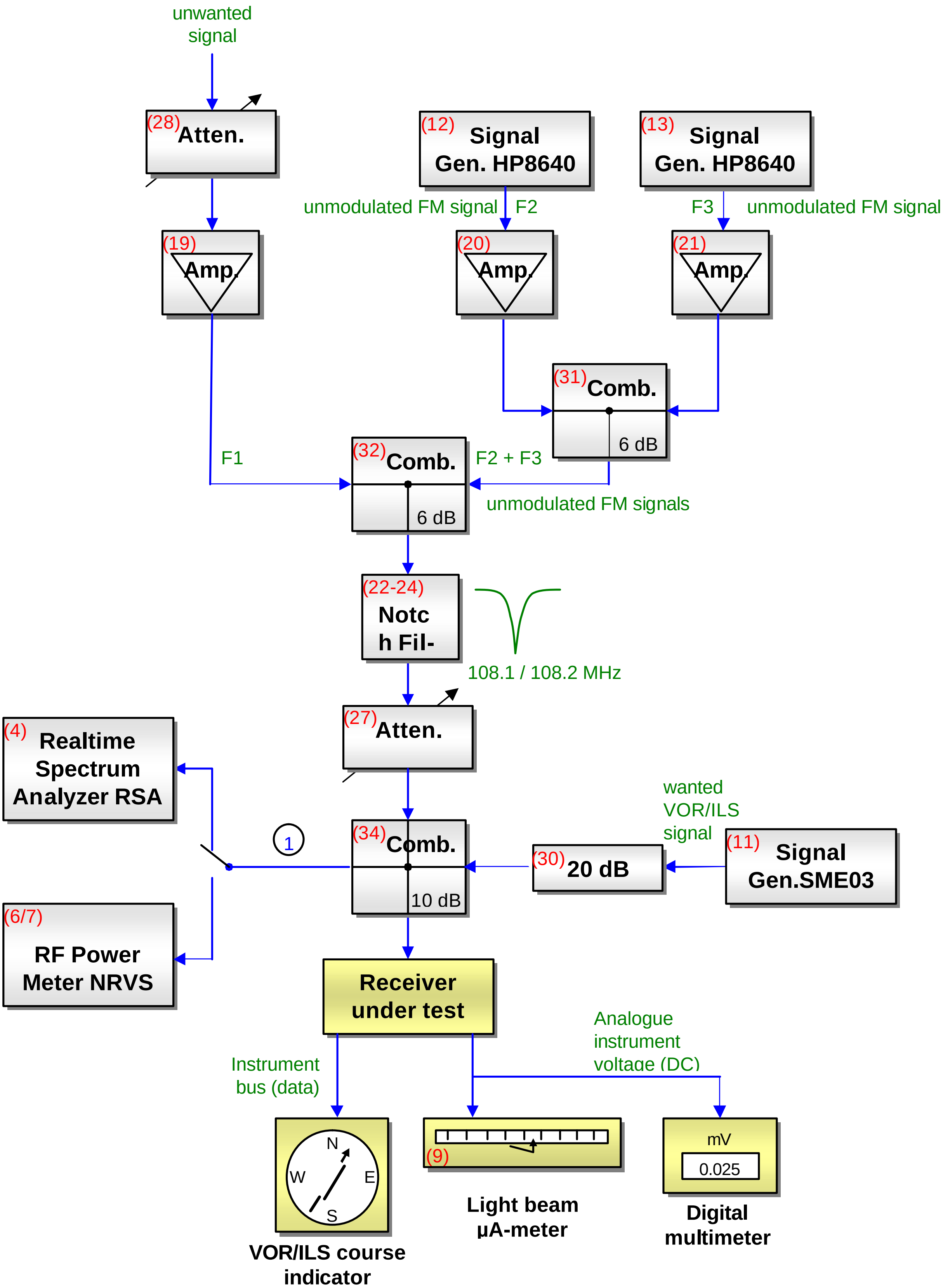

Fig. 9: Setup for FM immunity measurements according to ITU-R IS.1140 Fig. 1a and 1b

The frequencies in the FM broadcast band are called F1, F2 and F3. The most critical case occurs when F2 and F3 are unmodulated carriers, and only F1 is modulated. In our case, F1 is the interfering signal under investigation, which is either the standard FM broadcast (for comparison) or FMeXtra signal.

Four possible frequency combinations for F1, F2 and F3 are given in ITU-R IS.1140. Only the most critical combinations with involved frequencies closest to 108.0 MHz were taken for these measurements, and only those combinations that produce intermodulation on these frequencies (108.1 or 108.2 MHz respectively). However, additional measurements were made where the unwanted frequency F1 was shifted in steps of 30 kHz (roughly the receiver bandwidth) to see whether the bandwidth of the intermodulation product is affected by FMeXtra.

The level of the wanted VOR / ILS signal is again adjusted to the lowest level mentioned in ITU-R IS.1140 where the receiver is capable of performing above the interference criteria. This level is -79 dBm for VOR and -86 dBm for ILS.

By means of the signal generators (12) and (13) and the variable attenuator (28), the levels of the unwanted signal F1 and the unmodulated carriers on F2 and F3 are set to be equal at the output of the combiner (32) in Fig. 9.

The notch filter (22-24) blocks any sideband emissions and transmitter intermodulation on the VOR / ILS frequency under investigation.

Then the total level of the unwanted signals is increased with attenuator (27) until the failure criterion is reached (see 3.2). The difference between the unwanted and wanted signal level at this point is noted as the protection ratio.

6.3 VOR as the victim

The wanted VOR frequency was set to 108.2 MHz as this is the lowest usable channel given in Recommendation ITU-R IS.1140.The following figure contains the results for the FM immunity measurements for VOR reception (B1 interference). Only the course interference is shown as this is the more critical criterion.

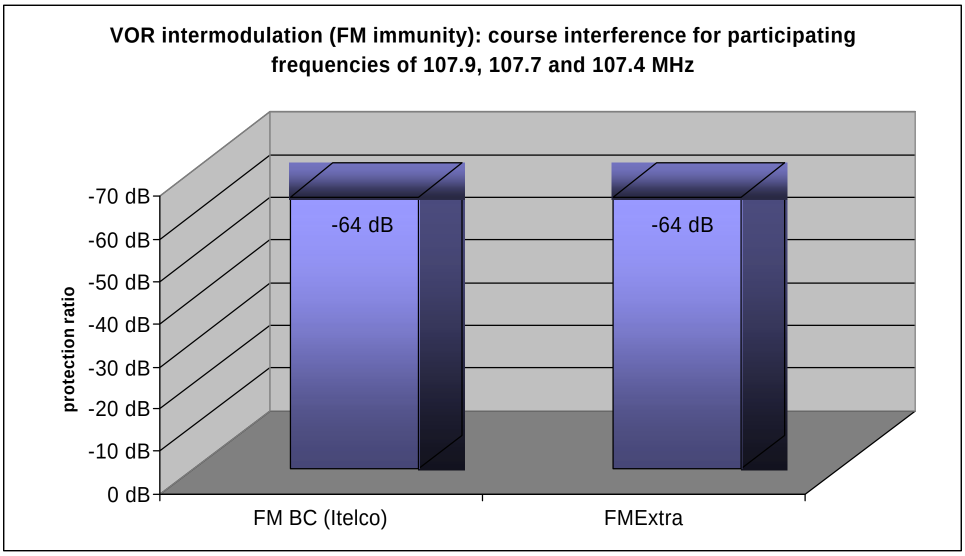

Fig. 10: „FM immunity“ of VOR in the presence of strong analogue and digital broadcast signals

It can be seen that the FMeXtra signal has no influence on the FM immunity for the B1 interference to VOR.

The detailed measurement results are shown in Annex 4.

6.4 ILS as the victim

The wanted ILS frequency was set to 108.1 MHz as this is the lowest usable channel given in Recommendation ITU-R IS.1140.The following figure contains the results for the FM immunity measurements for ILS localizer reception. Only the course interference is shown as this is the more critical criterion.

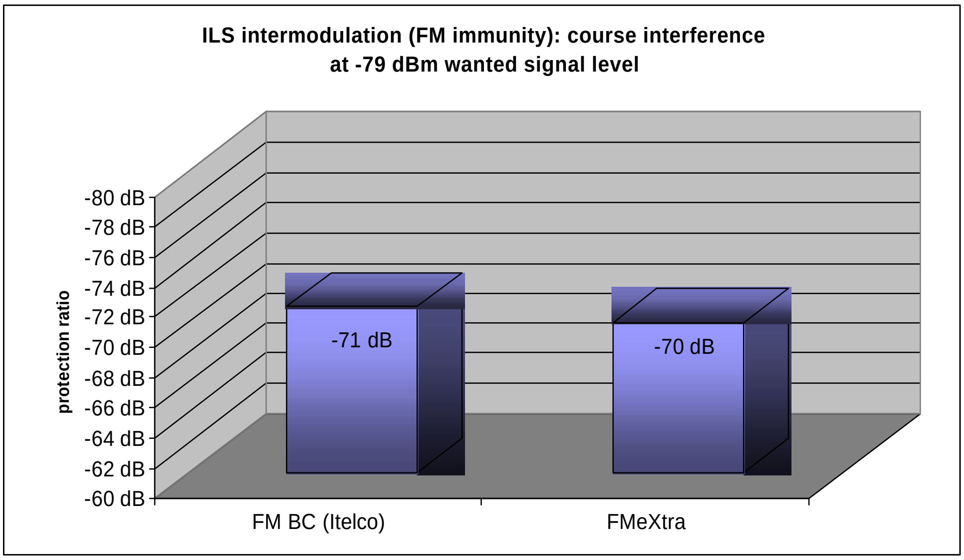

Fig. 11: „FM immunity“ of the ILS localizer in the presence of strong analogue and digital broadcast signals

As with VOR, the FMeXtra signal has no influence on the FM immunity (B1 interference) to ILS reception. The measured difference of 1 dB lies within the measurement uncertainty.

The detailed measurement results are shown in Annex 4.

7 Conclusion

The measurements have shown that in principle the FMeXtra signal has no significantly higher interference potential on aeronautical radionavigation than a standard FM broadcast signal. Considering the fact that the FMeXtra signal has only little effect on the RF spectrum, this result is not surprising.

It should be noted, however, that the protection ratio measurements against ILS and VOR reception made here are only valid for one certified aeronautical receiver. In so far, the results may give indication about the differences in interference potentials between FMeXtra and standard FM broadcast signals, but to determine these protection ratios for general use, a more comprehensive measurement series has to be performed including a large range of aeronautical receivers.

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