npr labs

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FM Modulator Usage and Emission Levels in the United States

NABA, in its contribution (Document 6E/381) entitled "Proposed Draft New Recommendation concerning interference to FM broadcast service from short-range FM modulators," recommends precautions to be taken by administrations and manufacturers of such equipment to ensure protection of FM broadcasting stations. NABA has continued studying the issue and has prepared the following report to illustrate the numbers of FM modulators on roadways in or near Washington, DC, and their measured levels of emissions.

1. Introduction

Increasingly, broadcasters in the U.S. are receiving complaints from listeners that their FM receivers are intercepting unwanted transmissions from nearby FM modulator devices. These devices operate on standard FM broadcast channels without need for licensing under the U.S. Federal Communications Commission Rules, provided they cause no interference to licensed stations.[1] In particular, these unwanted transmissions are being found on roadways of all sizes, where users are linking their satellite radio or personal audio player to the FM receivers installed in their vehicles.

Commercial market data on FM modulators is limited. However, the Consumer Electronics Association reports that FM modulators and FM modulator/car chargers accounted for approximately 16 percent and 7 percent, respectively, of the US $750 million personal audio player accessory market, or a total of US $172 million. Assuming an average cost of US $50 per unit a total of approximately 3.4 million modulators were sold in 2005. This does not include a significant number of modulators sold with portable satellite radios to connect to vehicle radios.

In an effort to investigate some of these concerns, NPR Labs recently conducted a study to measure the field strength of signals emitted from a variety of highways in the Washington, DC area representing a total of 28,510 measured vehicles during the times of measurement. Measurements were confined to 88.1 MHz and 87.9 MHz, which appear to be the two most commonly-supplied frequencies for personal FM modulators. The results indicate that nearly one percent of vehicles were found to have operating modulators on these two channels alone. Of these, approximately one-third are operating with emissions that exceed the regulatory limit. As discussed further below, this results in a high probability that a listener to 88.1 MHz or other FM channels will encounter objectionable interference in a matter of minutes of driving, or perhaps multiple occurrences per minute on high-traffic routes.

2. Measurement Technique

An objective of the study was to measure the number of vehicles with active (radiating) FM modulators along selected roadways. Additionally, the study was to determine the percentage of

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[1] Part 15 of Title 47 of the Code of Federal Regulations governs the technical performance of license-exempt FM modulators, such as RF emission limits. These devices may be used by consumers in homes and offices as well as in vehicles.

vehicles that exceed the FCC emission limits or are expected to cause objectionable interference to reception of broadcast FM signals. Thus, it was preferable to measure the field strength of each detected modulator signal so that an amplitude distribution was available for analysis from the recorded data.

To collect emission data a directional antenna with known gain was directed across the roadway, as shown in Figure 1. The antenna was connected through shielded coaxial cable to a bandpass filter to remove strong out-of-band signals, which was then connected to the spectrum analyzer. The spectrum analyzer was controlled by software running on a laptop computer.

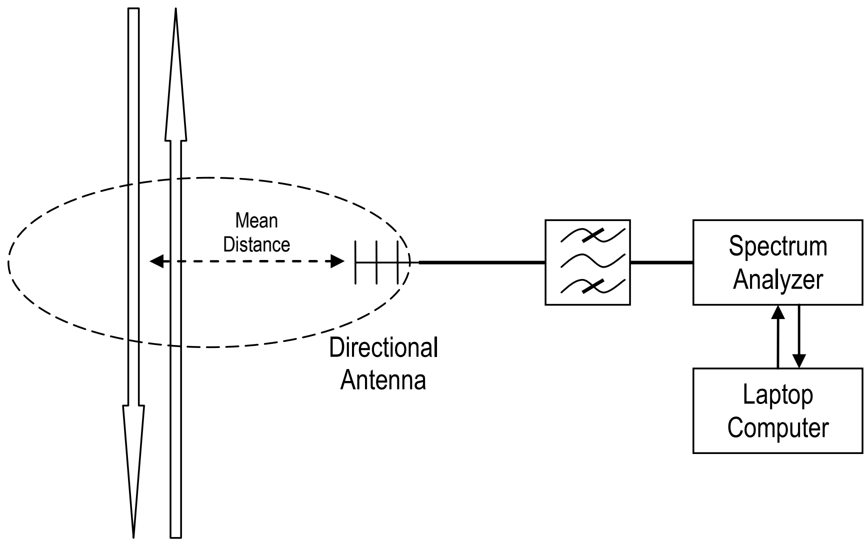

Figure 1 - Diagram of signal collection system

The directional antenna is a 6-element FM Log-Yagi with three driven elements having a gain of 6 dBd. The antenna was operated with vertical polarization to better match the polarization of vehicular antennas (should they be the source of radiation). This also widened the antenna's 3 dB horizontal beam width to approximately 70 degrees to ensure that fast-moving vehicles would persist in the beam long enough to accurately measure. The antenna was elevated approximately 3 m above ground on a non-conductive mast. The coaxial cable was extended approximately one meter behind the rear elements to avoid pattern distortion, as shown in Figure 2.

The spectrum analyzer is an Anritsu MS2721A, with an internal preamplifier giving a system noise figure of 11 dB. The analyzer was operated with RMS detection and a resolution bandwidth of 30 kHz (narrow enough to avoid false detection of FM modulators on adjacent channels). A 3-section bandpass filter (Microwave Filter Co. model 3328RF) was used to pass 87.0 to 88.5 MHz and avoid overload effects from strong out-of-band FM signals. The analyzer was controlled through an Ethernet cable to the laptop computer running a custom Visual Basic program. Signal power measurements were recorded approximately three times per second to ensure that peak values from moving vehicles were accurately captured.

Measurements were collected on 88.1 MHz, which was determined by sampling of a large number of frequency-agile FM modulators as the most common default frequency setting. Some units are shipped with settings of 88.3 MHz or higher, but are a relatively small proportion compared to 88.1 MHz. The operation of WAMU-FM on 88.5 MHz in Washington, DC prevented regional measurement on these higher channels. However, potential interference from WAMU to FM modulators on 88.3, 88.5 and 88.7 MHz is likely to deter local operation on these channels.

Although the FCC's Part 15 regulations stipulate 88 to 108 MHz for license-exempt FM modulators, a significant number of FM modulators available at retail were found on 87.9 MHz. Consequently, we included 87.9 MHz (FM Channel 200) in the measurements, which is reserved for low-power FM stations in special cases but is receivable on standard FM radios.

Figure 2 - Antenna monitoring setup; US Route 50 is seen in distance

A difference in distance from the traffic lanes to the measurement antenna was anticipated, which introduces uncertainty in calculating the radiated fields from vehicles. To moderate this effect at each monitoring site, the mean distance D_m was chosen so that maximum signal variability would be no more than ±3 dB across all traffic lanes.

Measurement data included the current time for each sample and the instantaneous signal power indicated by the spectrum analyzer. To convert the received signal power into field intensity the following expression was used:

$$E = \left(\pi / \lambda\right)\sqrt{P_i \cdot 480}\ ,$$

where E is in V/m and P_i *is* in watts.

Simplifying this expression and introducing adjustments for antenna gain and line and filter losses, the field strength E_m in dBμV at the measurement antenna is:

$$E_m = P_R + 20\log(F) + 105.1 - 30 - G_A + L\ ,$$

where P_R is the received power in dBmW,
F is the frequency in MHz,
G_A is the antenna gain in dBd, and
L is the combined filter and cable losses (-4.5 dB).

The above conversion results in a field strength at the measurement antenna. However, compliance with an emission standard is usually specified as a maximum field at a given number of meters from the radiating source. (The FCC Part 15 limit for unlicensed FM modulators in the frequency range of 88-108 MHz is 250 μV/m at 3 meters.) It was therefore necessary to normalize the measured field strength to the reference distance to determine compliance of the measured vehicles. Since the measurement antenna was elevated above the roadway and intervening obstructions it was assumed that signal variation with distance was essentially inverse-distance, as prescribed by free-space propagation between the vehicles and the antenna. Thus, the field strength of the FM modulators at the reference distance is determined by the ratio of the reference distance to the actual measurement distance:

$$E_r = E_m - 20 \cdot \log(3/D_m)$$

Where E_r is the estimated field strength at the compliance reference distance, and
D_m is the mean distance from the measurement antenna to the traffic lanes.

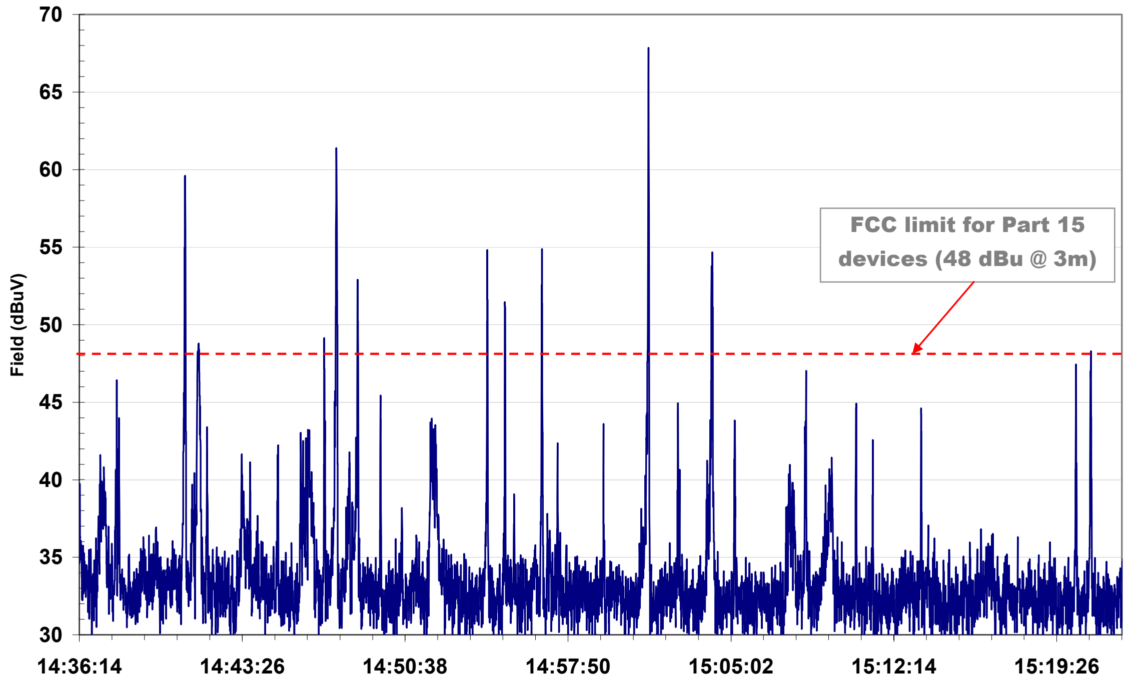

Figure 3 - Measurement of signals at 88.1 MHz on I-395 in Washington, DC

Processing the measured signal powers as described allows one to view the emissions for compliance with the FCC or other regulatory standard. Figure 3 shows a 45-minute measurement sample collected alongside the north-bound lanes of Interstate-395 at Potomac Park in Washington, DC.[2] The estimated field strength in dBμV at 3m is shown along the vertical axis and the local time in HH:MM:SS is shown along the bottom. For comparison, the FCC limit, converted from μV/m to dBμV is shown as a dashed red line. It is readily apparent that at least 9 of the 34 detected modulators exceed the FCC emission limit; some by 20 dB or more. This includes the aperture loss introduced by signals escaping through the vehicle windows.[3]

Measurements were collected at three sites in the Washington DC area, as detailed in Table 1. The first site listed is a major highway entering Washington, DC; these southbound lanes are geographically separated from the measured northbound lanes and are below line-of-sight,

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[2] The frequency of 88.1 MHz is assigned to WYPR-FM, Baltimore, located approximately 50 miles north of the measurement site. The signal from this station contributed to the elevated noise level on this measurement frequency. Noise level on 87.9 MHz was typically 8-12 dB lower than 88.1 MHz at each measurement site.

[3] The study, *A Report To The National Association of Broadcasters Regarding Study and Measurements of Part 15 Devices Operating in the FM Band*, found 13 of 17 FM modulators exceeded the Part 15 emission limit, and measured a vehicle loss of 11.2 dB.

providing good signal isolation. During the measurement intervals, an hourly traffic flow of approximately 5600 vehicles was determined for this four-lane roadway. The second site, Branch Avenue, is a high-volume undivided four-lane arterial through a mixed commercial and residential area outside of Washington, DC. The hourly traffic flow was 5383 vehicles during the 88.1 MHz measurement and 6374 vehicles during the 87.9 MHz measurement. The third site was on US-50, a six-lane undivided highway in a suburban area of Arlington, Virginia, approximately 5 km west of Washington. The traffic volume was approximately 3600 vehicles per hour during the measurements. All of the measurements were conducted in mid-day, when traffic was not congested and flow was relatively constant.

Table 1 - Measurement data of FM modulators from three sites

	Frequency (MHz)	Vehicles Per Hr.	Measurement Period (min)	Detected Modulators (#)	Vehicles with Modulators (%)	Non-Compliant Modulators (#)	Non-Compliant Modulators (%)
I-395, Washington DC	88.1	5520	49	35	0.77	10	0.22
	87.9	5610	53	7	0.14	4	0.08
					0.91		0.30
Branch Avenue, Clinton MD	88.1	5383	53	16	0.14	11	0.20
	87.9	6374	63	9	0.30	1	0.02
					0.44		0.22
US Route 50 Arlington VA	88.1	3497	58	18	0.51	7	0.20
	87.9	3769	58	14	0.37	7	0.19
					0.89		0.39

3. Prevalence of FM modulators

As summarized in Table 1, the data indicate that up to 0.91 percent of vehicles were operating detectable modulators on only *two* FM channels. Usage appeared to correlate with the class of route; the high-speed interstate and US highways having the highest usage and the high-volume arterial having lower usage. This may be related to the length of travel time that drivers anticipate using FM modulators with their audio devices.

Figure 4 - View of US Route 50 at the measurement site

Most significant is the proportion of modulators that were estimated to exceed the regulatory emission limit of 250 µV/m at 3 meters, ranging from 0.22 to 0.39 percent of vehicles or 30 percent to 50 percent of detected modulators. While this may seem a small percentage of all vehicles, the actual number of encounters on the roadway would be high: for example, assuming an average of 3600 vehicles per hour on US Route 50, a driver in the opposite direction could pass approximately 28 non-compliant modulators an hour ($0.0039 \times 3600 \times 2 = 28$).

On a undivided highway, the distance between traffic lanes in the opposite direction is between 2 to perhaps 7 meters. Considering that the estimated field strengths at 3 meters of the measured FM modulators, as illustrated in Figure 3, range from 48 dBμV to 68 dBμV, the probability of objectionable interference is quite high to FM broadcast signals at the 60 dBμV service contour. (Public radio broadcasters, who often occupy these lower-frequency FM channels, know that a significant listener base extends beyond the 60 dBμV contour. ITU-R Recommendation BS.412-9, for example, to suggests a minimum of 54 dBμV for rural service. Lower signal strengths further increase the extent of FM modulator interference to broadcast service.)

The above illustration neglects the traffic travelling *with* the listener, where the probability of interference occurrences is far lower, but far longer. Many of the complaints NPR has received involve public radio listeners who slow in traffic or stop at an intersection and are exposed to interference for long periods of time. These interference cases cannot be prevented – short of turning off their radio.

4. Summary and Conclusions

Market data suggests that FM modulator sales may be in the millions per year in the US alone. The results of direct measurement of FM modulators on roadways in the Washington, DC area find operation in nearly one percent of vehicles on just two FM channels. Since the average U.S. driver spends 55 minutes per day travelling 29 miles,[4] the opportunity exists to pass thousands of vehicles, and dozens of FM modulators, in a daily commute. This study found that approximately 40 percent of these devices are producing signal levels in excess of FCC limits, potentially resulting in objectionable interference to broadcast services. These findings indicate the need for the precautions against interference to FM broadcast service proposed in the ITU Draft Recommendation (Document ITU-R 6E/381).

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[4] *Highlights of the 2001 National Household Travel Survey*, US Department of Commerce, Bureau of Transportation Statistics (http://www.bts.gov/publications/highlights_of_the_2001_national_household_travel_survey/html/section_02.html).