REPORT ITU-R BS.2104*

FM modulator interference to broadcast services

(2007)

Foreword

This Report has been prepared by the Radiocommunication Study Group 6 and the Radiocommunication Working Party (WP) 6E and contains information gathered from a number of external sources as well as from Radiocommunication WP 6E. This Report retains the original text provided by the various Appendices.

1 Introduction

Recent growth in a variety of personal audio and satellite devices on a global basis, such as flash-players and various other consumer electronic devices has led to an extraordinary international proliferation of short-range FM modulators for home and mobile use. These devices are used in the broadcasting channels in the VHF frequency band allocated for sound broadcasting in the Radio Regulations. Although the RF emission levels of these devices may be compliant with regulatory standards as manufactured, the growing number of complaints by radio listeners tuned to FM radio stations raises serious concerns about interference. Unwanted radiation and emissions from these devices can cause objectionable interference to licensed FM broadcast stations. Broadcast systems are designed to take into account intrinsic receiver noise and external radio noise including atmospheric, man-made and galactic noise. The radiation from these short-range devices increases the level of other man-made radio noise, causing an increase in the total external radio noise. The increase of external radio noise results in an increase in the minimum usable field strength and in the degradation of the reception quality of the broadcasting services. The reception environment of broadcasting services needs to be protected from this interference.

2 Summary

The increasing proliferation of short-range FM modulators for consumer use with automobile and personal audio devices has led to the studies described in this report. Four Appendices are provided that address the concerns for interference.

Appendix 1: This text studies the emissions from various FM modulators currently available to the consumer. These modulators are intended to be connected to consumer audio devices for subsequent transmission into the FM radio band from 88 to 108 MHz. At 3 m from the FM modulator, the majority of the modulators tested exceeded the recommended minimum usable field strength for rural environments and many for urban and large city environments expected at 10 m based upon Recommendation ITU-R BS.412-9 – Planning standards for terrestrial FM sound broadcasting at VHF.

Considering that the automobile antenna is located 1.5 m above ground, it is expected that automobile receivers must operate with minimum usable field strengths at least 10 dB below the values measured at 10 m. The consequence is that automobile FM radios may be more susceptible to interference from FM modulators especially when these FM modulators are used within a nearby vehicle.

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* This Report should be brought to the attention of Radiocommunication Working Parties 1A and 1B.

Appendix 2: This text studies further the emissions from FM modulators that are wired devices. These supplemental measurements were conducted to determine the compliance of devices commonly used in automobiles for modulating the audio from satellite radio receivers and MP3 or personal audio players onto frequencies that can be received on a standard automobile FM receiver. The measurements show that the use of a “Y” cable with a “Wired” device yield field strengths at 3 m that are in excess of the prescribed FCC Part 15 limits.

Appendix 3: This text reports on a study to measure the field strength of signals emitted from a variety of highways in the Washington, DC area. The results indicate that nearly one percent of vehicles were found to have operating modulators on one of two broadcasting channels. Of these, approximately one-third are operating with emissions exceeding the regulatory limit that could result in objectionable co-channel interference to broadcast services

Appendix 4: This text addresses concerns in Europe for interference from FM modulators. The European Broadcast Union (EBU) recommends guidelines for countries intending to allow the use of low-power FM modulators. The guidelines include strict enforcement of minimum radiated power limits, limited frequency modulation, full range tuning, and a prohibition on direct connection to external antennas.

3 Conclusions

Broadcasting services are particularly susceptible to interference emanating in the vicinity of the receive antenna under low signal conditions. The increase in FM modulators has brought about a need for further protection to the FM sound broadcasting service.

1 The results of field strength measurements of various FM modulators support the need for recommendations on the use of FM modulators.

2 Since FM sound receivers are vulnerable to co-channel interference, it is possible to avoid the interference by assigning a default FM modulator frequency of operation to a frequency typically receivable on commercial VHF radio receivers, but where possible, one not generally assigned.

3 Where short-range FM modulators are allowed, emission limits need to be restricted to a minimum that avoids interference in FM receivers.

4 In addition, the FM modulators should be capable of full band frequency selection to avoid interference to stations on channel, or on an adjacent channel to, the frequency of modulator operation.

5 Administrations should encourage manufacturers of FM modulators, for automotive installations with direct connections to automobile antenna systems, to provide permanent connectors that avoid the possibility of inadvertent reverse connection to the external antenna.

6 Where direct connection of short-range FM modulators to automotive radios and antenna systems is permitted by administrations, administrations should provide enforcement safeguards to avoid retransmission and disruption to licensed FM broadcasting stations.

Appendix 1

Regarding study and measurement of FM modulator devices operating in the FM broadcast band[1]

1 Introduction

A series of measurements were conducted on 17 “wireless” devices as well as 4 “wired” devices. Measurements of the field strength of the FM Broadcast Band signal transmitted by these devices were made. In addition, verification of the required FCC ID numbers and verification of the compliance with the antenna rules was also performed. This report describes recent measurements of measured field strengths from the devices and outlines the compliance of these devices with other Part 15 requirements.

2 FCC Part 15 operation

The FCC’s Office of Engineering and Technology (OET) issued a Bulletin Number 63 in October 1993, which provides the correct method for calculation of the Maximum Emission Limit or Maximum Field Strength that is permissible from the subject Part 15 device. For frequencies in the FM Broadcast Band (88-108 MHz) there are four limits depending upon the type of emission that the device transmits.

Intermittent Control Signals that do not have high duty cycles are allowed higher emission limits than those devices that are used to continuously transmit (such as an FM audio transmitter). For the devices under study the limit is 250 µV/m at a distance of 3 m from the device. The FCC limit can also be expressed as follows:

$$20 \log (250\ \mu V/m) = 47.95\ dB\mu V/m$$

For comparison purposes in the charts of the report we have rounded the FCC Part 15 limit to 48 dBµV/m. This limit is applied to devices that are equal to or less than 200 kHz in bandwidth. This is detailed in 47 C.F.R. § 15.239 of the FCC Rules.

For devices with bandwidths in excess of 200 kHz, or as the Rules describe “Any” bandwidth, the limit is 150 µV/m (43.5 dBµV/m) at a distance of 3 m from the device (47 C.F.R. § 15.209).

It is also noted that devices that operate pursuant to the Part 15 rules are required to provide to the FCC a “Certification” that the device complies with the requirements of Part of the FCC Rules. This certification is to include data from measurements conducted on the device as well as documentation regarding the measurement facilities, test procedures, and test results of the measurements. This data will be reviewed by the FCC and an appropriate FCC ID number assigned to the device by the FCC OET.

3 Part 15 label requirements

The FCC Rules require that these devices have two labels attached to them. The first label required is the FCC ID number as described previously. Once certification is granted by the FCC this assigned ID number must be marked on the device. However, there is also the requirement that the device must have a “Compliance” label. The “Compliance” label serves as an indication to

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[1] National Association of Broadcasters, The original text can be found at http://www.nab.org/xert/corpcomm/NAB_Part15_Study.pdf)

consumers that the device has been authorized by the FCC. As noted later in this Report, the majority of these devices did not have a “Compliance” label affixed to them.

4 Antenna requirements of Part 15

Another requirement of devices that operate pursuant to Part 15 of the rules is the restriction on the type of antennas that may be provided with the device. In §15.203 of the FCC Rules, the Commission requires that the device be certified with the antenna that is to be provided with the device. And, the Commission adopts restrictions on the types of connectors that can be used for antenna connections to prevent consumers from using antennas other than those provided with the unit. The intent of these requirements is to prevent the use of an antenna that may allow the device to exceed the emission limits of the rules. (Antennas other than those used during the Certification Measurements for the device.) Essentially, the requirement is that these devices should have permanently attached antennas, or “unique connectors” that is not of a “standard” type found at an electronics store.

In the case of the devices that were studied there appear to be three devices that do not comply with these requirements. Device No. 9 is provided with a “rod” antenna with a standard “threaded” end for connection. But, more disturbing is that this device also has a standard “F” connector output for connection to an external antenna (or power amplifier). Devices No. 15 and No. 16 are provided with standard 2.5 mm audio connectors for connection to the supplied external antenna. The supplied antenna is simply a piece of No. 20 gauge wire approximately 12 inches in length. This connector would also not comply with the Commission’s requirements for using “unique” connectors as 2.5 mm audio plugs are standard connectors that can be found in any electronics store.

5 Devices under test

The Devices under Test (DUT) are listed in the Tables 1 and 2. These devices were obtained in the standard commercial marketplace and are generally available to all consumers. The devices were chosen to represent a variety of manufacturers, device type, price, and features. These devices are believed to be fairly representative of the Part 15 FM devices that are commonly available to consumers and are representative of devices in general use by consumers.

The devices are broken into two different categories to allow a better comparison of various FM devices. The first group is called “Wireless” devices. These devices are wireless in nature and do not connect to the FM receiver being used to listen to the audio transmission other than by mutual RF coupling to the receiver from the transmitter. The second group of devices is called “Wired” devices. These units are designed to be inserted between the antenna input on an automobile radio receiver and the automobile antenna. Hence, they are directly “wired” to the automobile radio receiver.

The FCC Rules at 47 C.F.R. § 2.925 and § 15.19 require that the FCC ID number as well as a “Compliance” label be permanently marked on the device. An inspection of each device was conducted to determine the FCC ID number marked on each device as the FCC Rules require. In two cases of the “wireless” devices, no such FCC ID was marked on the device. In the case of the “wired” devices none of them were marked with an FCC ID number. Only a few of the devices were marked with the appropriate “Compliance” label as required.

TABLE 1

“Wireless” devices under test

Device No.	Manufacturer	Model No.	FCC ID #
1	Akron	SF-150a	ME2-SF150
2	Akron	SF-250	ME2-SF250
3	Belkin	Tune Cast F8V367-APL	K7SF8V367
4	Belkin	Tune Cast II F8V3080	K7SF8V3080
5	C Crane Co.	FMT	BYG006
6	Dynex	DX-AC101	POSEF6208
7	Dynex	DX-MP3FM	POSEF6215
8	Griffin Technology	iTrip 9500 TRIPDA	PAV4026
9	Hobbytron	FM25B	NO FCC ID # On Case
10	iRiver	AFT-100	RKVATB350
11	iRock	450FM	QDNDGT201
12	Lenmar	AI-MODAM	NO FCC ID # On Case
13	Monster iCar Play	AI IP FM-CH	RJE160732-00
14	RCA	MM70FM	POSPC-7207
15	Sirius	S50	O6ZS50-C1
16	Sirius	Sportster SP-TK2	P3HSP-R2
17	Starvision	FT-07	RJX93FMT07

TABLE 2

“Wired” devices under test

Device No.	Manufacturer	Model No.	FCC ID #
18	Delphi	SA10003	NO FCC ID # On Case
19	Pyle	PLMD2	NO FCC ID # On Case
20	Scosche	FM-MOD01	NO FCC ID # On Case
21	Starvision	FM-07	NO FCC ID # On Case

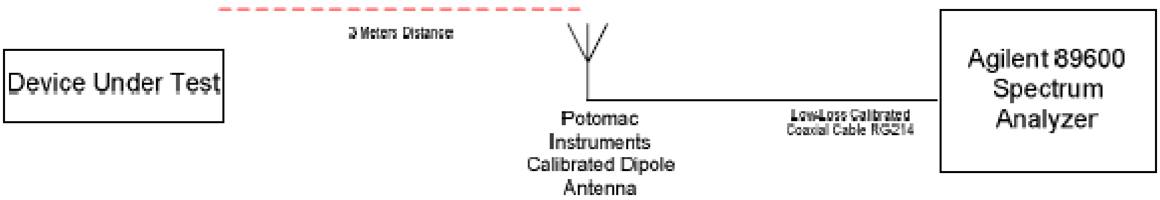
6 Description of test setup

The FCC outlines the specific measurement procedures to be used for Part 15 Compliance measurements in both the FCC Rules and in a document authored by the FCC OET in Bulletin No. 63. Further, the FCC released a Public Notice on October 1993, further clarifying the applicable rules to these devices.

The tests conducted for this study utilized the methods described in these documents. A test location was chosen that was free from discernable co-channel FM Broadcast Stations to allow accurate measurements of the signals from the Device under Test (DUT). The test setup included the use of a NIST-Traceable Calibrated VHF Dipole Antenna (Potomac ANT-71) mounted on a tri-pod and connected via low-loss coaxial cable to an Agilent 89600 series spectrum analyzer (see Fig. 1).

FIGURE 1

Test setup



For the first series of tests, the Device under Test (DUT) was placed on a wooden stand at a distance of 3 m from the calibrated dipole antenna (see Fig. 2). The antenna element lengths were set to the corresponding frequencies based upon the chart supplied with the antenna (see Appendix A).

A series of measurements were made with the spectrum analyzer on the FM carrier emitted by the DUT. First, a measurement of the un-modulated FM carrier was made and a plot of the corresponding spectrum was made. Next, the device was modulated with audio and an additional measurement and spectrum plot were made. Finally, with the audio modulating the FM Carrier, a spectrum plot was made with the spectrum analyzer in the "peak-hold" mode, to establish the approximate deviation (occupied bandwidth) of the device when operating.

FIGURE 2

Test location

7 Measurement results

The measurements summarized in this Report were conducted during the time period 14 May-2 June 2006. In Fig. 3, based on Table 3, a graph of the measured field strength emitted from the device at the prescribed distance of 3 m is shown. *You'll note that 76.5% of the devices exceed the 48 dBμV/m limits of Part 15 operation. Only four devices were found to be compliant with the emission limits. (Only 24.5% were compliant).*

The devices that were found to be compliant with the emission limits were device No. 5, 6, 8, and 13. All the other "wireless" devices were found to be above the limits. The worst offender was device No. 9 with the highest field strength of 99.9 dBμV/m. If we ignore this as a statistical "outlier" and use the other field strength for this device of 86.9 dBμV/m and 88.5 dBμV/m, the device exceeds the Part 15 limit by approximately 40 dB. The average of all the measurements was 62 dBμV/m (1,259 μV/m) which exceeds the Part 15 limit by 14 dB (5 times the limit).

FIGURE 3

"Wireless" device field strength at 3 m
(measured values shown with the FCC limit of 48 dBμV/m)

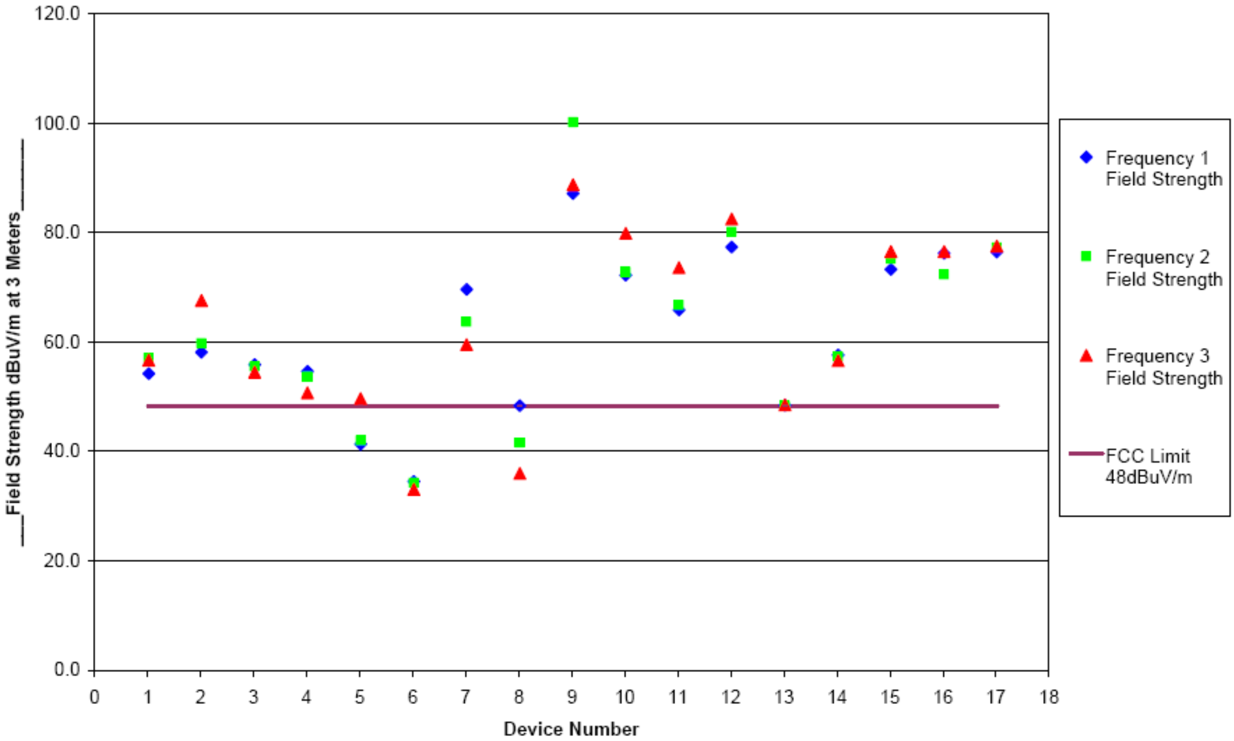


TABLE 3

“Wireless” devices measurement results (devices highlighted in yellow are above limits, compliant devices highlighted in green)

Device	**Frequency 1**	**Field strength w/*K* factor (dBµV/m)**	**Frequency 2**	**Field strength w/*K* factor (dBµV/m)**	**Frequency 3**	**Field strength w/*K* factor (dBµV/m)**
1	88.3	54.0	93.5	56.8	95.1	56.4
2	88.3	57.9	88.7	59.5	107.7	67.3
3	88.3	55.5	88.5	55.2	88.7	54.2
4	88.3	54.4	98.5	53.4	107.7	50.5
5	88.3	41.1	98.5	41.7	107.7	49.4
6	88.1	34.2	88.3	34.0	88.5	32.8
7	88.3	69.4	98.5	63.4	107.7	59.3
8	88.3	48.1	98.5	41.3	107.7	35.7
9	88.3	86.9	98.5	99.9	107.7	88.5
10	88.3	72.0	98.5	72.5	107.7	79.6
11	88.3	65.6	98.5	66.5	107.7	73.4
12	88.3	77.1	100.5	79.8	106.5	82.2
13	88.3	48.2	88.7	48.1	89.1	48.2
14	88.1	57.4	88.3	57.1	88.5	56.3
15	88.1	73.0	98.5	74.9	107.7	76.3
16	88.3	76.0	98.5	72.0	107.7	76.3
17	87.9	76.1	88.3	77.0	88.7	77.2

For the “Wired” devices, the tests indicate that the devices are generally compliant with the Part 15 limits (see Table 4 and Fig. 4). The highest measured field strength of these devices was No. 18 with a field strength of 49.1 dBµV/m which is within 1dB of the prescribed limit. For the purposes here, it was determined that these devices were compliant. It is noted that the average field strength for these devices was 46.96 dBµV/m, well within 1 dB of the limit.

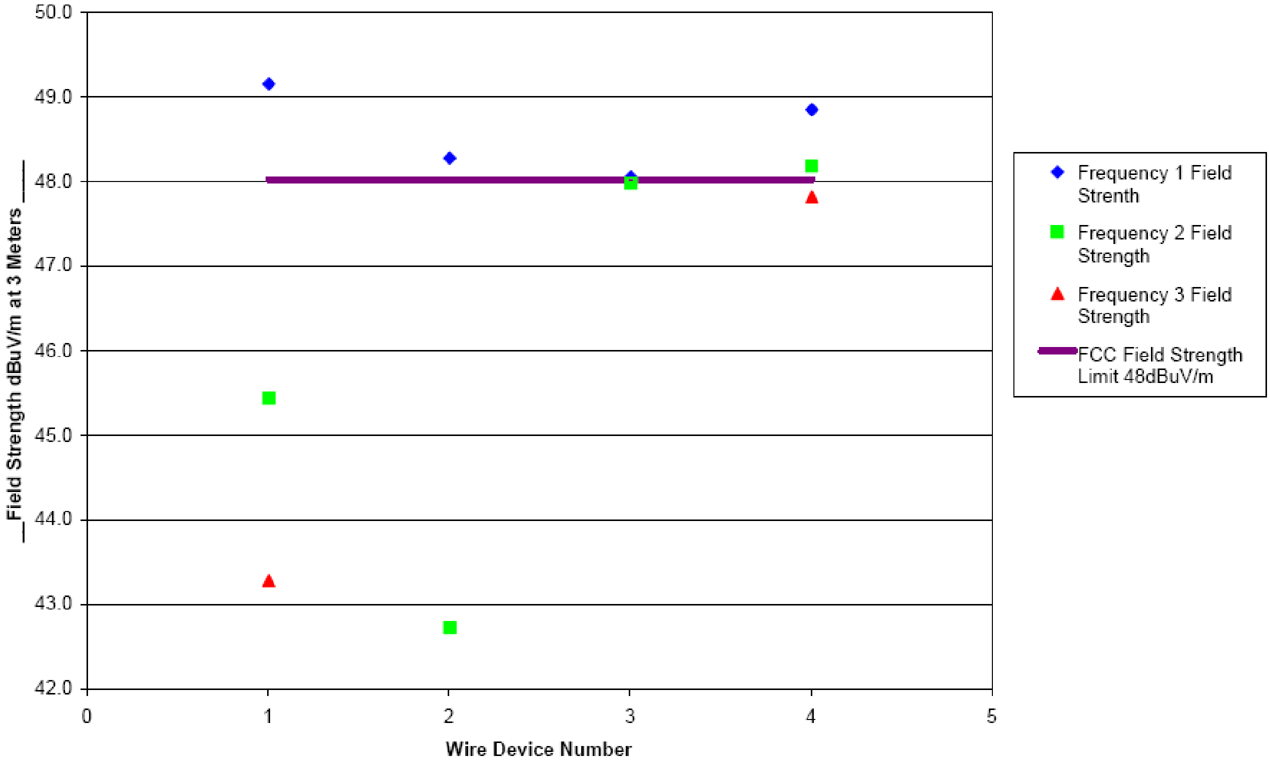
TABLE 4

“Wired” devices measurement results

Device	**Frequency 1**	**Field strength w/*K* factor (dBµV/m)**	**Frequency 2**	**Field strength w/*K* factor (dBµV/m)**	**Frequency 3**	**Field strength w/*K* factor (dBµV/m)**
18	87.9	49.1	88.1	45.4	88.5	43.3
19	88.5	48.3	88.9	42.7	NA	NA
20	87.9	48.0	88.3	48.0	NA	NA
21	87.9	48.8	88.3	48.2	88.7	47.8

FIGURE 4

“Wired” device field strength at 3 m
(measured values compared with FCC limit of 48 dBµV/m)



8 Additional measurements

Additional tests were conducted on a sub-set of devices to determine the field strength of these devices when they are operated in a vehicle. For this test, the device was installed as per normal operation in a vehicle. Then measurements were made of the field strength from the device at a distance of 3 m from the vehicle’s antenna (see Figs. 5 and 6). For this test, three “Wireless” devices were tested and two “Wired” devices were tested. The combined test results are shown in Table 5 and Fig. 7.

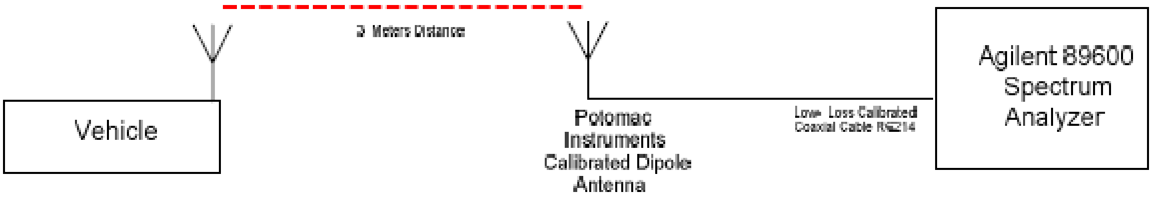
TABLE 5

“Car test” devices measurement results

Device	Frequency 1	Field strength w/*K* factor (dBµV/m)	Frequency 2	Field strength w/*K* factor (dBµV/m)	Frequency 3	Field strength w/*K* factor (dBµV/m)
9	88.3	65.0	98.5	76.2	107.7	77.2
12	88.3	66.8	100.5	67.4	106.5	60.6
15	88.1	55.8	98.5	55.3	107.7	59.0
20	87.9	50.4	88.3	49.8	NA	NA
21	87.9	42.0	88.3	42.1	88.7	43.6

FIGURE 5

Setup for "Car test"



The results indicate that for the three "wireless" devices (No. 9, 12 and 15); they generally exceeded the prescribed 48 dBμV/m limit. Thus, the "attenuation" of the vehicle does reduce the field strength outside the vehicle by an average of approximately 11.2 dB. However, the devices are still well beyond the maximum permissible emissions.

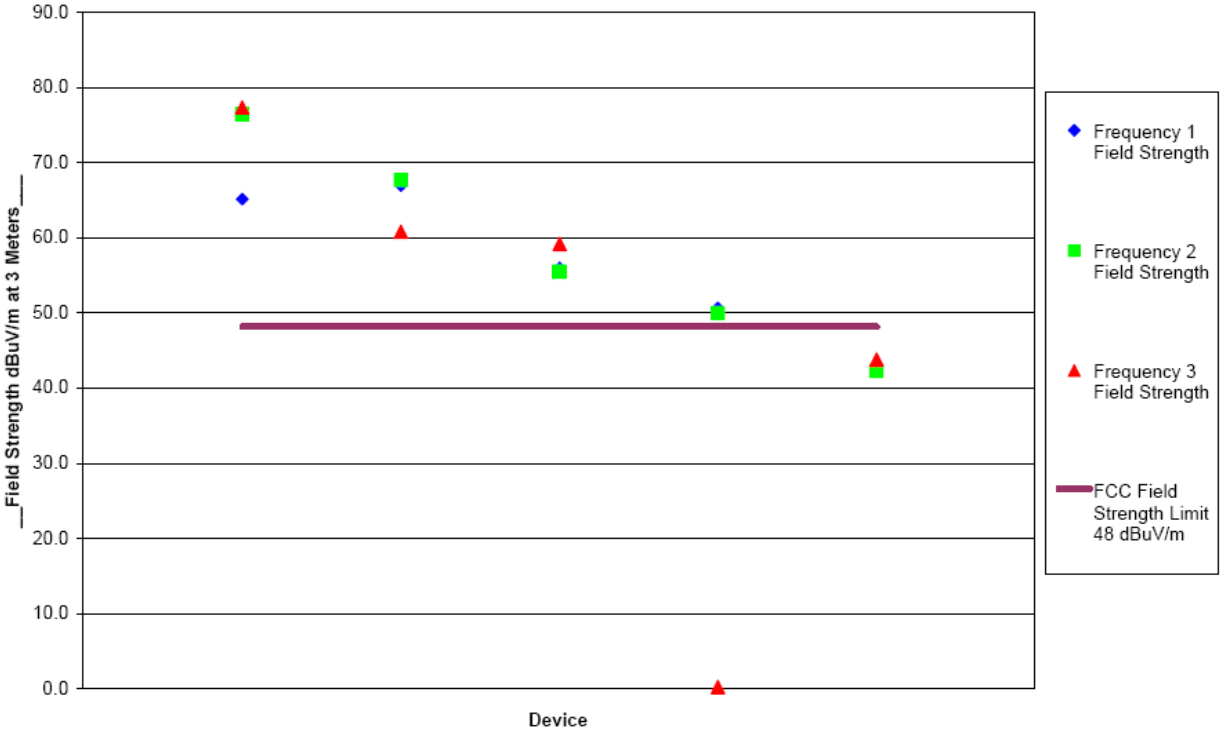
The "wired" devices (20 and 21) were generally compliant (within a tolerance value of 1-2 dB), although the "attenuation" of the vehicle was not as significant of a factor, as leakage through the vehicle antenna was the main radiator. In this case, the "average" attenuation was 2.6 dB.

FIGURE 6

"Car test" setup

FIGURE 7

Car test results – Field strength at 3 m from car



9 Modulation capability

As noted in the description of the measurements, the devices were operated with audio to deviate the FM carrier of the transmitter. During the tests, we noted the deviation of the FM carrier. It was noted that the majority of devices were modulating beyond the standard 200 kHz bandwidth of an FM Broadcast Station. For most of the devices, it appears that no audio limiting circuitry is present. This allows the FM Carrier to be modulated such that it actually occupies more than one standard FM Broadcast Channel. In FM Broadcast Stations, limiters are employed to keep stations from over-modulating. However, in these devices, there are no limiters to prevent the user from modulating the device up to 800 kHz. The only limit appears to be the audio amplifier driving the device.

This is a cause for concern since the users may not know that they are occupying more than one broadcast channel. It may that a user would choose an un-occupied channel that is adjacent to a FM Broadcast Station. The users may believe that they are avoiding interference by operating on the adjacent channel. However, if the unit is modulated heavily (by turning up the volume control) it may well become co-channel and interfere with the licensed operation. To illustrate this point, this spectrum plot shows the deviation of device No. 2. As can be seen from the plot in Fig. 8, it occupies 800 kHz (4 channels).

By contrast, Fig. 9 shows the deviation from Device No. 11, which is well within the 200 kHz channel. It is also noted that the Commission’s Part 15 limit of 48 dBμV/m applies to signals with bandwidths of equal to 200 kHz or less. In the case of most of the devices tested, the bandwidths are in excess of 200 kHz, in which case, the more stringent Part 15 limit of 43.5 dBμV/m applies. Clearly, compliance with this value is also an issue.

FIGURE 8

Peak hold – Deviation device No. 2 – 800 kHz

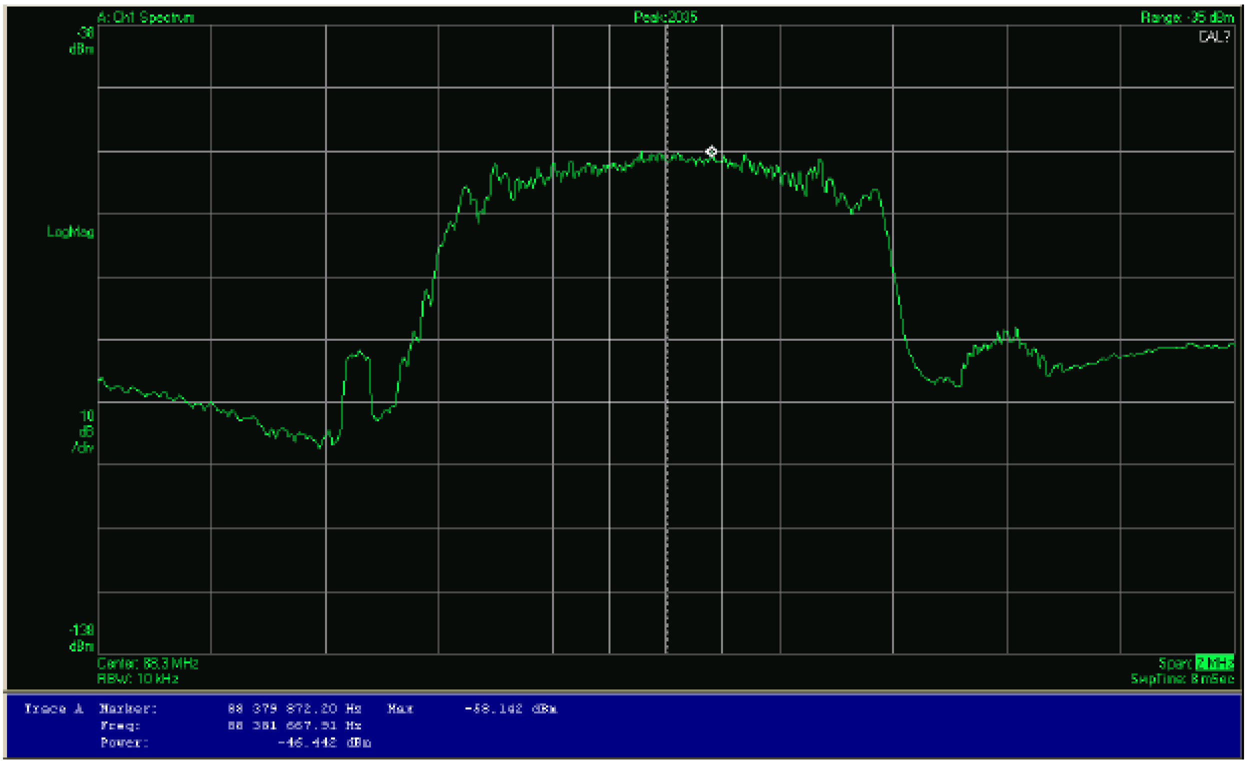
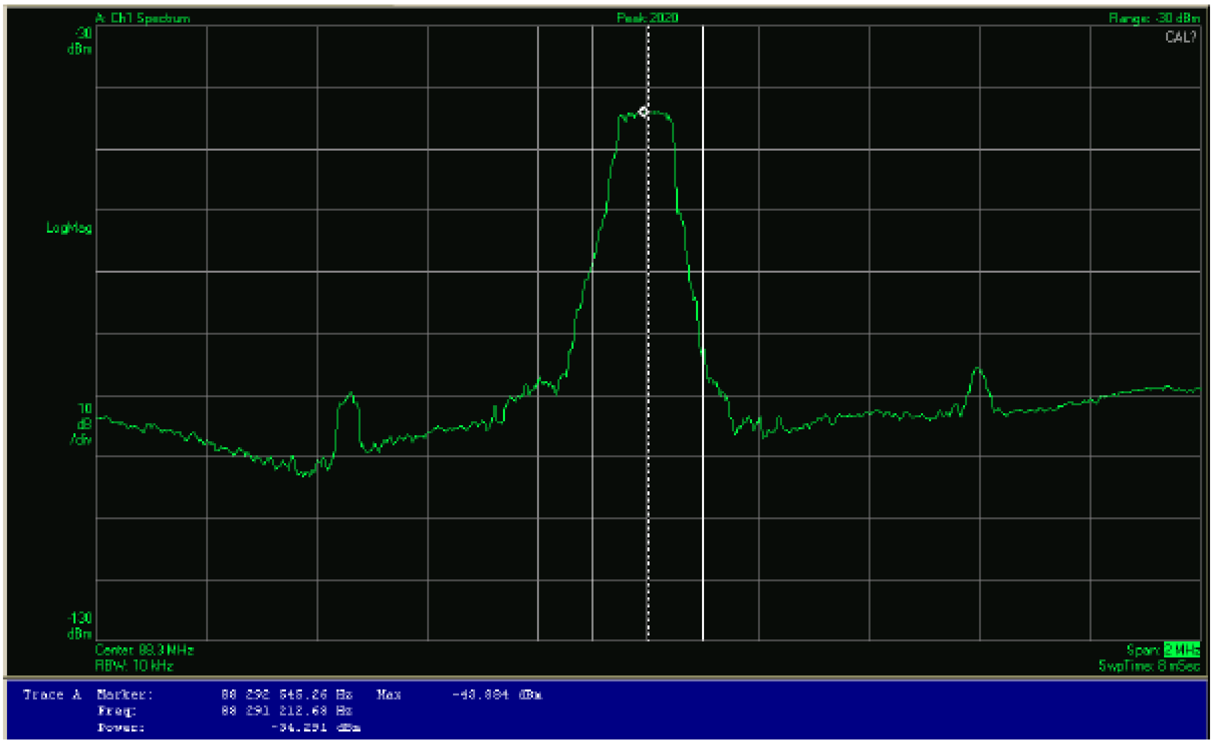


FIGURE 9

Peak hold – Deviation device No. 11 – 150 kHz



10 Digital (HD) radio impact

Based upon the discussion above regarding the very wide deviation of the FM carrier in most of these devices, it is possible that these devices could become a significant problem with digital HD Radio receivers. Since the IBOC signals are occupying “vacant” adjacent channels, it is likely that these are the exact channels a user would choose upon which to operate one of these devices. To the user, the “noise” like HD Radio carrier appears to be a vacant channel. However, with the wide modulation capability and the strong signal levels emitted by these devices, it is likely that significant interference to the much lower power HD Radio signals would be caused. The spectrum plots in Figs. 10 and 11 shows an HD Radio carrier with the Part 15 device off and on, respectively.

FIGURE 10

Part 15 Device OFF – HD radio carrier can be seen in the “vacant” channel

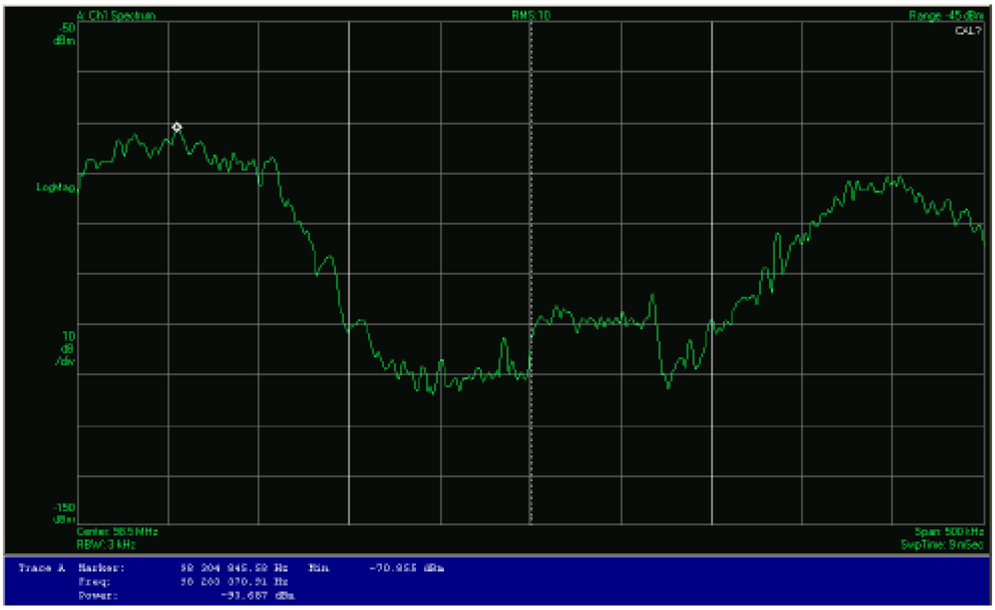
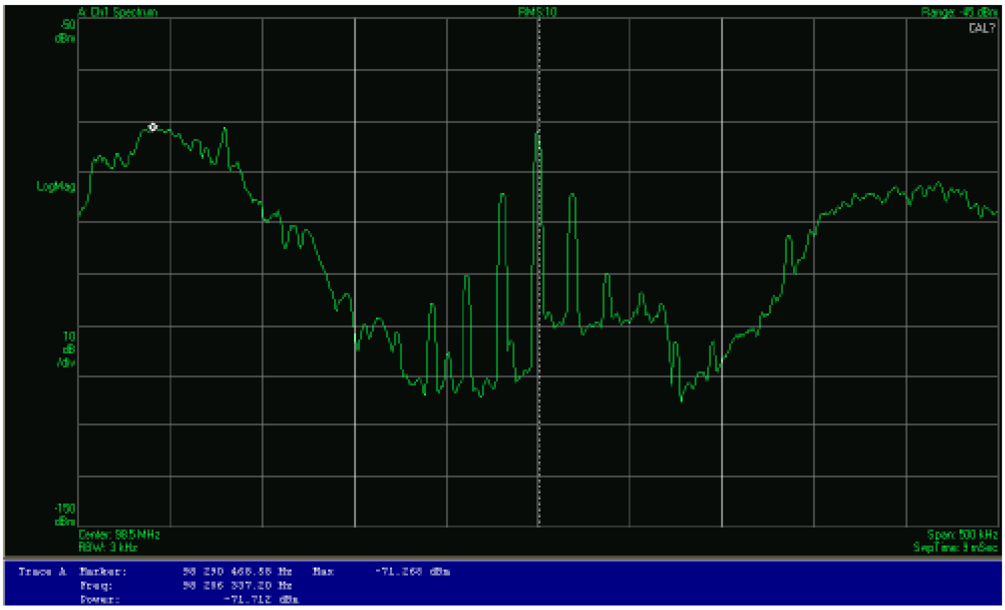


FIGURE 11

Part 15 Device ON – Co-channel interference to HD radio carrier



11 Conclusions

The measurements summarized above show that many of the devices currently on the market that are required to be compliant with Part 15 of the FCC rules, are in fact, not meeting these requirements. Less than 25% of the devices tested met the field strength criteria of the Part 15 rules. Further, some of the devices did not meet the antenna, FCC ID label, and compliance labeling requirements of Part 15. From the sample of devices tested here, it is clear that a majority of devices on the market are violating the FCC rules.

Based upon these tests, it is reasonable to conclude that significant interference to licensed FM broadcast stations exists from these devices. The modulation capabilities of the devices allow them to occupy more than one FM channel simultaneously and may hinder the roll-out of HD Radio services. The strong field strengths emitted by some of these devices will exceed the co-channel and adjacent channel interference ratios (D/U ratios) at which consumer receivers will operate.

Appendix 2

Supplemental tests of FM modulator devices operating in the FM broadcast band

1 Introduction

This Report will provide the results of supplemental tests that were conducted on four “Wired” devices (described in Annex 1) to determine the compliance of Part 15 devices operating in the FM broadcast bands. These supplemental measurements were conducted to determine the compliance of devices commonly used in automobiles for modulating the audio from satellite radio receivers and MP3 or iPod players onto frequencies that can be received on a standard automobile FM receiver.

These additional supplemental tests were to investigate the field strength at 3 m from these devices when hooked to automobile’s antenna and the vehicle receiver via a “Y” cable. This coaxial “Y” cable is simply a three connector unit designed to connect the vehicle antenna and the external FM modulator to the automobile receiver. However, given the design of these devices, they provide no directivity or isolation from the modulator to the vehicle antenna. Thus, the RF signals generated by the modulator are subsequently emitted or “broadcast” by the vehicle antenna.

Measurements of the field strength of the FM Broadcast Band signal transmitted by these devices were made using the procedures and methods prescribed by the FCC for Part 15 devices. A determination of the Part 15 emission compliance is provided herein.

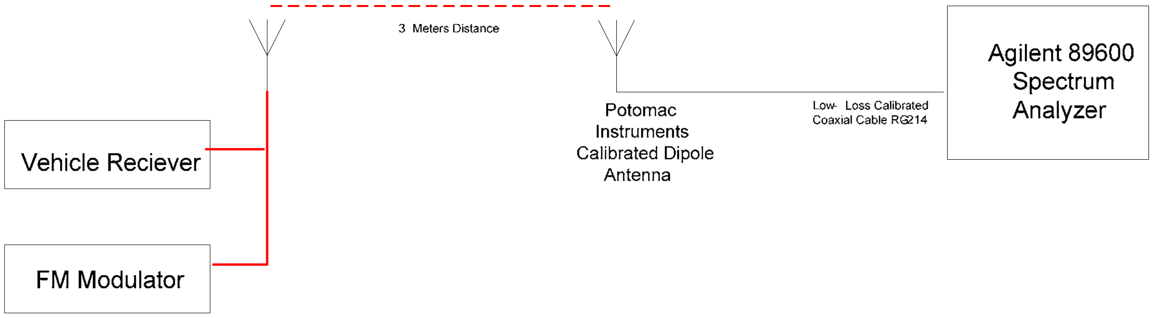
2 Description of test setup

The FCC outlines the specific measurement procedures to be used for Part 15 Compliance measurements in both the FCC Rules and in a document authored by the FCC OET in Bulletin No. 63. Further, the FCC released a Public Notice on October 1993, further clarifying the applicable rules to these devices.

The tests conducted for this study utilized the methods described in these documents. A test location was chosen that was free from discernable co-channel FM Broadcast Stations to allow accurate measurements of the signals from the Device under Test (DUT). The test setup included the use of a NIST-Traceable Calibrated VHF Dipole Antenna (Potomac ANT-71) mounted on a tri-pod and connected via low-loss coaxial cable to an Agilent 89600 series spectrum analyzer (see Fig. 12).

FIGURE 12

Supplemental test setup – "Y" cable



A series of measurements were made with the spectrum analyzer on the FM carrier emitted by the DUT. First, a measurement of the un-modulated FM carrier was made and a plot of the corresponding spectrum was made. Next, the device was modulated with audio and an additional measurement and spectrum plot were made. Finally, with the audio modulating the FM carrier, a spectrum plot was made with the spectrum analyzer in the "peak-hold" mode, to establish the approximate deviation (occupied bandwidth) of the device when operating.

3 Measurement results

The measurements summarized in this report were conducted on 6 June 2006. In the Table 6, the measured field strength emitted from the device at the prescribed distance of 3 m is shown. You'll note that most of the devices are above the 48 dBµV/m limit prescribed by Part 15. The worst-case was device No. 18 that was approximately 8-10 dB above the Part 15 emission limit.

TABLE 6

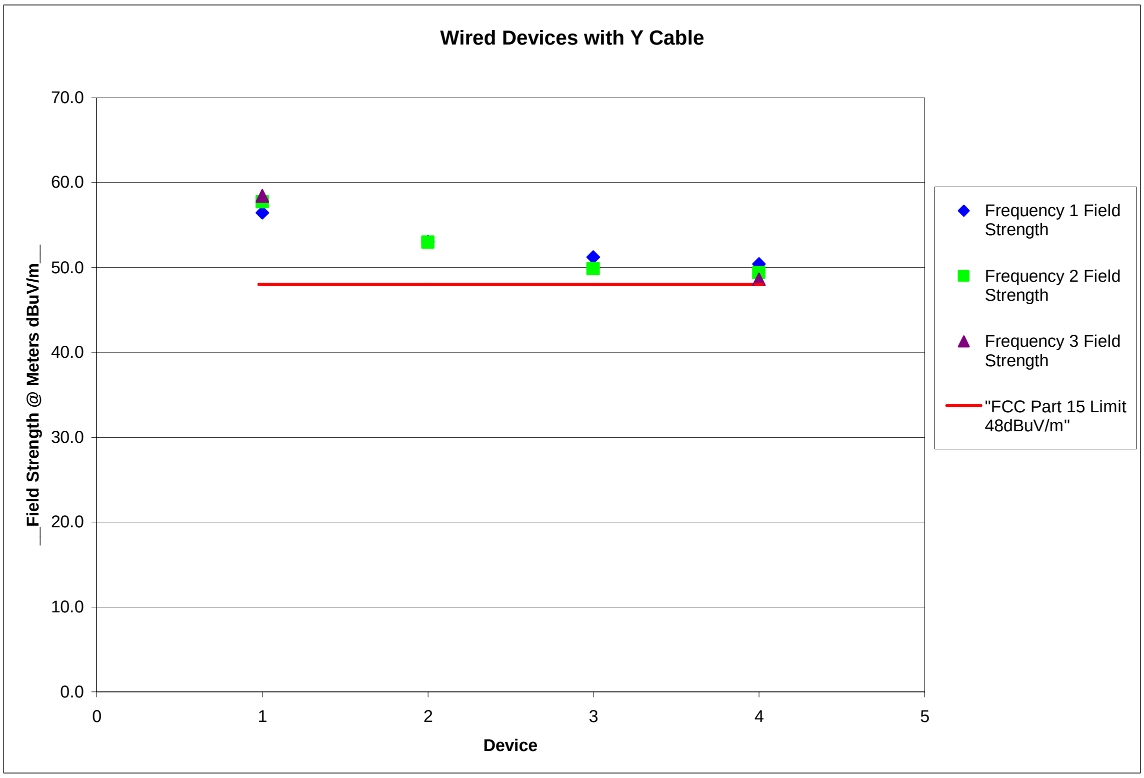
"Wired" devices measurement results – Supplemental tests Y cable

Device	**Frequency 1**	**Field strength w/*K* factor (dBµV/m)**	**Frequency 2**	**Field strength w/*K* factor (dBµV/m)**	**Frequency 3**	**Field strength w/*K* factor (dBµV/m)**
18	87.9	**56.4**	88.1	**57.7**	88.5	**58.5**
19	88.5	**53.1**	88.9	**53.0**	NA	**NA**
20	87.9	**51.2**	88.3	**49.9**	NA	**NA**
21	87.9	**50.4**	88.3	**49.4**	88.7	**48.6**

In order to better illustrate the results, Fig. 13 provides the measured values for each device and shows the FCC limit of 48 dBµV/m.

FIGURE 13

Wired devices with Y cable – Field strength at 3 m



4 Conclusions

The measurements summarized above show that the use of a "Y" cable with a "Wired" device yield field strengths at 3 m that are in excess of the prescribed FCC Part 15 limits. The performance of device No. 4 was within 1 dB of the limits and may be within measurement error, however, the performance of device No. 1 is clearly above the prescribed limits and would be considered violating the FCC rules.

Appendix 3

FM modulator usage and emission levels in the United States[2]

1 Introduction

Increasingly, broadcasters in the United States of America. are receiving spontaneous 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 US Federal Communications Commission Rules, provided they cause no

[2] National Public Radio: (The original text can be found at http://www.nprlabs.org/reports/FMModulatorUsage.pdf)

interference to licensed stations.[3] 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% and 7%, respectively, of the annual 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 incorporated in portable satellite radios to operate in vehicles.

In an effort to investigate some of these concerns, NPR Labs 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 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 Fig. 14. 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.

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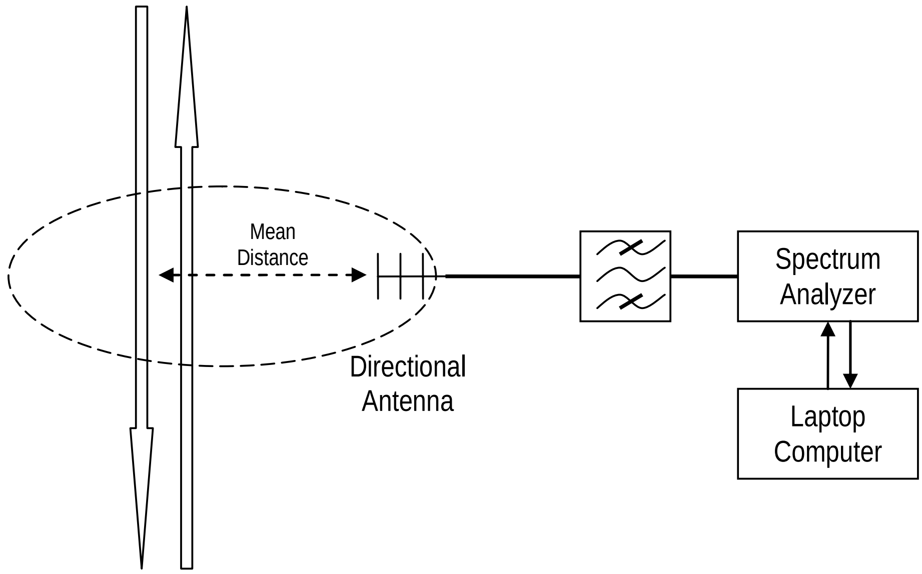
[3] Part 15 of Title 47 of the Code of Federal Regulations governs the technical performance of license-exempt FM modulators, such as RF emission limits. These devices may be used by consumers in homes and offices as well as in vehicles.

FIGURE 14

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° 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 Fig. 15.

FIGURE 15

Antenna monitoring setup; US Route 50 is seen in distance

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 connected through an Ethernet cable to the laptop computer running a custom Visual Basic program to control the analyzer and collect data. 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.

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 (dBµV) at the measurement antenna is:

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

where:

- P_R: received power (dBmW)
- F: frequency (MHz)
- G_A: antenna gain (dBd)
- L: 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 m.) 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:

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

where:

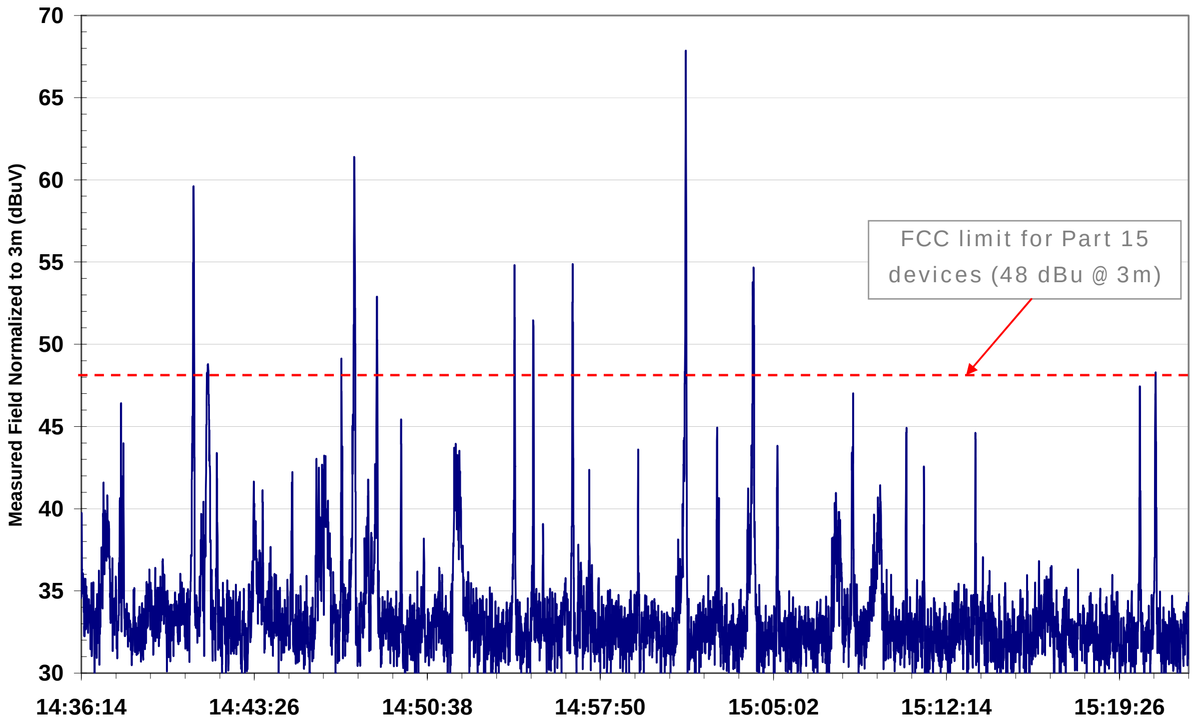
E: estimated field strength at the compliance reference distance

D_m: mean distance from the measurement antenna to the traffic lanes.

Processing the measured signal powers as described allows one to view the emissions for compliance with the FCC or other regulatory standard. Fig. 16 shows a 45-minute measurement sample collected alongside the north-bound lanes of Interstate-395 at Potomac Park in Washington, DC.[4] The estimated field strength in dBμV at 3 m 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.[5]

FIGURE 16

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



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4 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.

5 The study in Annex 1 found 13 of 17 FM modulators exceeded the Part 15 emission limit, and measured a vehicle loss of 11.2 dB.

Measurements were collected at three sites in the Washington DC area, as detailed in Table 7. 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, providing good signal isolation. During the measurement intervals, an hourly traffic flow of approximately 5 600 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 5 383 vehicles during the 88.1 MHz measurement and 6 374 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 3 600 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 7

Measurement data of FM modulators at three Washington, DC roadway sites

	Frequency (MHz)	**Vehicles per hr.**	**Measurement period (min)**	**Detected modulators (No.)**	**Vehicles with modulators (%)**	**Non-compliant modulators (No.)**	**Vehicles with non-compliant modulators (%)**
I-395, Washington DC	88.1	5 520	49	35	0.77	10	0.22
	87.9	5 610	53	7	0.14	4	0.08
					0.91		0.30
Branch Avenue, Clinton MD	88.1	5 383	53	16	0.14	11	0.20
	87.9	6 374	63	9	0.30	1	0.02
					0.44		0.22
US Route 50 Arlington VA	88.1	3 497	58	18	0.51	7	0.20
	87.9	3 769	58	14	0.37	7	0.19
					0.89		0.39

3 Prevalence of FM modulators

As summarized in Table 7, the data indicate that up to 0.91% 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.

Most significant is the proportion of modulators that were estimated to exceed the regulatory emission limit of 250 μV/m at 3 m, ranging from 0.22 to 0.39% of vehicles or 30% to 50% 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 3 600 vehicles per hour on US Route 50, a driver travelling in the opposite direction could pass approximately 14 non-compliant modulators ($0.002 \times 3\,600 \times 2 = 14$) on 88.1 MHz in one hour.

On an undivided highway, the distance between traffic lanes in the opposite direction is between 2 to perhaps 7 m. Considering that the estimated field strengths at 3 m of the measured FM modulators, as illustrated in Fig. 16, 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. Recommendation ITU-R 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.)

Figure 17 neglects the traffic travelling *with* the listener, where the probability of interference occurrences is far lower, but far greater length of exposure. 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.

FIGURE 17

View of US Route 50 at the measurement site

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 of the FM channels. Furthermore, a significant number of these devices are producing levels of emission that could result in objectionable co-channel interference to broadcast services.

Appendix 4

Low-power FM modulators in Europe

The need for efficient enforcement of the European Standard and Recommendation. Status: Statement & Recommendations EBU – R120-2007

The EBU, considering that:

1 Low-power FM modulators are Short Range Devices (SRD) typically used for the purpose of listening to MP3/CD players on a home or car Band II (FM) radio receiver. As these devices transmit signals within a frequency band used for FM broadcasting (Band II, from 87.5 MHz to 108 MHz), they may cause interference to the reception of the FM broadcast signals. Further

explanation on the risk of such interference is given in the Annex on the basis of studies and trials made in Europe and in the USA.

2 The work carried out on this subject by CEPT[6] has resulted in the specification of limits for the RF parameters of these devices. Consequently, an ERP[7] limit of 50 nW for such devices is now part of the ETSI[8] harmonised standard EN 301357, published in July 2006. The deadline for its transposition into National Standards has been set for April 2007. In the meanwhile, European National Regulatory Bodies should be examining the authorisation of the use of these devices in their countries.

3 A major concern is that such devices often do not comply with their corresponding product standard (see Annex 1). This is already the case in the USA and it could occur in Europe when the use of these devices becomes authorized in some European countries.

Recommends that guidelines should be produced for Regulatory and Trading Standards Bodies and for Market Surveillance Authorities in countries intending to allow the use of low-power FM modulators.

Suggested Guidelines

1 The radiated emission levels of the low-power FM modulators should be limited to the minimum necessary for the normal use of these devices (transmission to close proximity receivers) and in no case should they exceed the limit set by EN 301357 (50 nW ERP).

2 The enforcement of the emission limit should be strict enough to avoid the arrival on the market of devices exceeding the limit set by EN 301357.

3 The frequency modulation of the transmitter output of these devices should be limited to a deviation of ±75 kHz, as applied to regular FM broadcast signals. Thus the devices must be equipped with an appropriate limiter.

4 Low-power FM modulators should have a full band tuning range (87.5-108 MHz) in order to prevent a concentration of the interference in some frequencies[9].

5 The direct connection of low-power FM modulators to external antennas, other than the antenna provided with the device, in a home or a car environment, should not be possible.

6 Low-power FM modulators without a CE Mark should be removed from the market immediately; in this case, no testing is required[10].

Annex 1: Risk of interference to broadcasting from low-power FM modulators.

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6 European Conference of Postal and Telecommunications Administrations.

7 Effective Radiated Power.

8 European Telecommunication Standards Institute.

9 One model of such a modulator has been found to use a unique carrier fixed at 107.7 MHz; this is particularly unfortunate in France as this is the frequency used across the country for a synchronous FM network covering highways for the purposes of providing traffic information.

10 Many devices are designed for use in other markets that have different frequency bands allocated to broadcasting than those in Europe. These devices should not be allowed within the European Union.

Annex 1
to Appendix 4

Risk of interference to broadcasting from low-power FM modulators

Two cases of interference to the FM Broadcasting service by low-power FM modulators may be identified. The first corresponds to “normal use” of these low-power FM modulators. The second corresponds to “misuse” or faulty application of the devices when they are linked directly by cable to the radio’s antenna input.

The interference caused by "normal" use of low-power FM modulators

Several tests and simulations have been carried out on the subject of interference from low-power FM modulators to regular FM reception. The details and the results are given in ECC[11] report 73 by a CEPT working group when the subject of the power limits of these devices was considered.

During discussions in the CEPT group, broadcasters pushed hard to set the power limit of these devices to 15 nW ERP. This is close to the limit set by the FCC[12] in the USA (the FCC limit is expressed as a field-strength of 250 µV/m at 3 m, which corresponds to an ERP of about 11 nW). Manufacturers argued that such a level was insufficient for normal operation of the devices. The final decision of the ECC was to set the maximum ERP level to 50 nW (effectively 5 dB higher than that requested by broadcasters). A compromise proposal of a 30 nW ERP limit was rejected.

According to trials led by a broadcasting operator:

– For in-car use of low-power FM modulators, co-channel interference may occur to FM broadcast reception in other vehicles located within a 10 m radius of the modulator. The interference was observed with ERPs as low as 15 nW. More interference cases were observed with higher ERPs such as 50 nW. The worst case scenarios correspond to interference between stationary cars (e.g., traffic jam, traffic lights);

– At least 200 kHz frequency separation of the low-power FM modulator from the wanted FM broadcast signal is required to prevent co-channel interference;

– With a 50 nW ERP, the FM modulator is usually correctly received inside a moving vehicle, even in the presence of a co-channel FM broadcast signal in the area. The reception of the FM modulator would be disturbed only in the presence of a high-level co-channel FM broadcast signal, thus prompting the user to retune the modulator to a different channel. FM broadcast signals at low levels will not prompt the user to retune the modulator to a different channel but interference to the reception of the broadcast signal by nearby vehicles is more likely.

The 50 nW ERP limit is now part of **ERC[13] Recommendation 70-03** and of the harmonised ETSI standard EN 301357, published in July 2006, with a deadline for its transposition into national standards set for April 2007. Some European countries, including Switzerland and Germany, have already implemented the ERC Recommendation. The European national regulatory bodies should now be considering this subject.

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[11] Electronic Communications Committee.

[12] Federal Communications Commission.

[13] European Radiocommunications Committee.

They have several options:

– Prohibiting the use of the devices in their countries.

– Authorizing the devices with the ERP limit proposed in the ETSI standard.

– Authorizing the devices with a lower ERP limit.

In the USA, where low-power FM modulators are authorized and regulated, it appears that the majority of commercially available devices are not compliant with the applicable FCC ERP limit.

A study ordered by the NAB[14] showed that 13 out of 17 devices tested (76%) were not compliant and that on average the limit was exceeded by 14 dB. One device exceeded the limit by 40 dB (10 000 times higher).

Another study made by NPR[15] labs showed that the proportion of non-compliant FM modulators actually used (by direct measurement of field strengths along roadways in Washington, DC) was around 40%. The excess in the signal level with regard to the FCC limit reached 20 dB (100 times higher) in some cases, despite the attenuation due to the car shielding estimated at 11 dB (the difference between the signal level generated inside the car and its level measured outside).

Such excessive ERPs are also very likely to be encountered in Europe. The tests carried out in the beginning of 2005 and reported in ECC report 73 showed that some devices were already in use throughout Europe (despite there being no national regulation at the time in many countries) and that they had ERP levels greater than the 50 nW limit. Out of 8 devices tested, 3 had an ERP lower than 50 nW and 5 had a higher ERP, some of these exceeding the 50 nW limit by 27 dB (500 times higher).

Whilst the regulatory ERP limit of 50 nW is itself of concern, the poor compliance with this limit by manufacturers and the inadequate checking of this compliance by regulators must be a major concern.

Another type of interference can occur with low-power FM modulators as a result of excessive deviation of the frequency modulation in these devices. Deviations up to 243 kHz (instead of the 75 kHz maximum deviation normally used in broadcast transmissions) were measured in some devices. Spectrum occupation of up to 800 kHz was also measured, which is four times the channel bandwidth for a broadcast FM signal. This would cause simultaneous co-channel interference to numerous adjacent broadcast channels.

Some low-power FM modulators have a single or a small number of pre-selected frequencies whereas others offer a tuning range throughout the FM Band II. Limiting the number of tuning frequencies may create a situation where interference is concentrated over a portion of the broadcast band and may therefore affect specific programmes, as is the case in the USA. There, the most commonly used frequencies for low-power FM modulators are in the lower part of the FM Band, which is used mainly by the Public Service Radio stations. A wide tuning range for these devices may be preferable in order to prevent a concentration of the interference.

The interference caused by a possible "misuse" of low-power FM modulators

A specific type of “wired” low-power FM modulator is also available. These devices are inserted between the car antenna and the antenna input of the car radio.

[14] National Association of Broadcasters: (Annexes 1 and 2 or http://www.nab.org/xert/corpcomm/NAB_Part15_Study.pdf)

[15] National Public Radio: (Annex 3 or http://www.nprlabs.org/reports/FMModulatorUsage.pdf)

In some cases, these devices are badly installed, resulting in the locally modulated FM signal being fed directly to the car antenna, which makes the car a mobile FM transmitter. This is explained in the following text adapted from an article published in the 'Radio World' journal[16]:

"In mobile settings, switching devices are commonly provided to disconnect the external FM receiving aerial when the short-range FM modulator is in use. Improper connection or omission of these switches can result in direct radiation of the short-range FM modulator emission through the vehicle's antenna system. This can result in audible detection or interference effects of the short-range modulator on nearby receivers for up to 100 meters or more."

"The switch box, said Dave Wilson, director of technology and standards for the Consumer Electronics Association, is usually installed behind the car radio and has one output and two inputs: the car antenna and the audio output from an XM satellite tuner. If XM is turned on, for example, it will take the signal and modulate it onto a FM frequency; that signal is fed into the radio's FM antenna input. When the XM receiver is turned off, a switch in the box disconnects the FM circuit and reconnects the car antenna.

NPR Vice President and Chief Technology Officer Mike Starling believes some consumers are installing the devices improperly and taking the output of the satellite receiver directly to the antenna input of the car. The problem with that, said Wilson, is when you turn on the FM radio, the satellite signal is fed into the car, but it's also sent back up the antenna and radiated out of the car antenna so the car is acting like a station. This situation doesn't mean the products themselves are not compliant with FCC's Part 15 rules specifying a power limit of 250 microvolts per meter."

The number of interference cases caused by this misuse of low-power FM modulators in the USA is not known.

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[16] The original text may be found at: http://www.rwonline.com/reference-room/special-report/ 2006.07.19-04_rw_RF_mods_2.shtml