
EMI/RFI Regulations and Compliance



Electronic Show and Convention
September 11, 12, 13/Dallas, Texas



EMI: THE FCC CLOSES IN
ON COMPUTER MANUFACTURERS

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The FCC, more than any other federal agency, is involved in closely regulating electronic hardware. Its EMI regulations cover virtually all devices from video games to mainframes. Here's how the agency intends to enforce those rules and how they will test your equipment if competitors' or end user's complaints trigger an agency response.

October 13, 1982 was a grim day for Coleco Industries. Just 75 days before Christmas the FCC had taken the unusual step of notifying customers - Toys R Us, J. C. Penney, Montgomery Ward, and Zayre - to stop selling 50,000 Colecovision units because those units were illegal to sell under federal law.

What had gone wrong: Coleco may have been unaware of the new FCC rules that made some of their product illegal to sell unless certain tests and procedures were performed, and, according to the FCC's Field Operations Bureau (FOB), they were not alone. FOB recent studies have shown that fully one quarter to one third of the regulated electronics industry may be unaware that they could share Coleco's fate. Who are these people? If your company makes any kind of hardware, unless you fall into very narrow exceptions, it could be your company too.

How can this be avoided? The rules themselves can be found in the Code of Federal Regulations, the central repository of all federal-agency-made law. But to avoid Coleco's fate, you really have to know rules that are not written in those regulations. These rules, known to only a handful of commercially minded EMI engineers, can be found by a close examination of the procedures now in use at the FCC's Laurel, Maryland laboratory. Those procedures and the means by which the FCC intends to enforce the rules are the subject of this article.

EMI LIMITS

The FCC's rules on electromagnetic interference were recently expanded to cover all equipment that "generates timing signals or pulses at rates in excess of 10,000 per second and uses digital techniques"--thus encompassing devices ranging from digital watches to mainframe computers. The basic regulations appear in Title 47 of the Code of Federal Regulations Part 0-19, which is available from the U.S. Government Printing Office.

The FCC's EMI rules establish technical standards, informational and procedural requirements and dates for compliance. The two device classifications are:

- 1) Class A--Computing devices intended for use in commercial, industrial or business environments.
- 2) Class B--Computing devices marketed for use in homes, including personal computers and peripherals, all types of electronic games, calculators and digital watches.

Both classes of devices must meet two technical standards.

- 1) Radiated emissions limits--Maximum field strength radiated from a device and its associated equipment and cabling.
- 2) Line conducted emissions limits--Maximum voltage fed back to utility power lines.

Furthermore, the devices must also meet:

- 1) Labelling requirements.
- 2) Instruction manual requirements.

To comply with these rules, you must follow one of two procedures, depending on the device classifications. You must verify the performance of all Class A devices and those Class B devices considered to present a mini-

mal interference potential and certify the remaining Class B devices. Verification and certification have definite meanings in FCC rules.

For devices needing verification, you must check and record performance and keep test records on file, making them available to the FCC if requested. Certification is a more involved process. Class B devices requiring certification include personal computers and peripherals.

The FCC considers personal computers those marketed through a retail outlet or direct-mail catalog, advertised to hobbyists and the general public and operable from 120V or batteries. The most important factor is the price. According to the FCC's Knapp, "If someone comes out with an under \$2,000 computer and says they're aiming at a business environment, it's pretty clear that anyone could buy it, and we would be fairly adamant that it's B."

The certification process results in keeping test data for each certified instrument on file at the FCC. The Commission reserves the right to call in all equipment to check its performance, and it has been exercising this right extensively. The waiting time at the FCC from device submission to test time is on the order of eight weeks. You must thus allow for this delay in your design and marketing cycle; you can't sell units until your product meets the requirements.

All Class A units verified for compliance must bear a label. Class B units not specifically mentioned as requiring certification should be verified. Several labelling and instructional subclassifications exist.

All certified devices must bear a label in a definite format, always containing an FCC-assigned identifier that uniquely identifies the equipment's certification applicant, manufacturer, and model number. (The FCC will assign this number on request at any time and requires that it be assigned before processing a certification application.) The label must also show the seller of the equipment and the country of manufacture (if not the U.S.) and contain a statement that the unit's been certified. All Class B devices, verified and certified,

must inform users via the instruction manual about possible interference from the device and list some steps to reduce such interference if necessary. The FCC also requires additional language for personal computers.

Several types of equipment are handled differently from those discussed so far. The following types are temporarily exempted from the EMI regulations, pending the development of standards:

- 1) Test equipment.
- 2) Industrial control systems.
- 3) Automotive electronics.
- 4) Home appliances.

Also exempted from the FCC computing device rules are most medical equipment but not those mass marketed for home use. Equipment directly utilizing radio frequency energy is already covered by other rules. Adding computing functions to a communications receiver or transmitter, for example, wouldn't bring that device under the scope of the computing device EMI rules.

Devices that connect to a TV, such as some electronic games and personal computers, are subject to a different procedure. These are classified as Class I TV devices, and are regulated under Part 15, Subpart H, not Subpart J (computing devices). Although similar, these rules require more tests to be performed than the computing device rules.

How the FCC Intends to Enforce Its Rules

It was concern about interference to broadcasting that triggered the FCC's new EMI rules in 1979. Police in Oregon and Nevada noted interference to highway patrol operations on their 42 Mhz radios, and aircraft and control towers complained of interference in the 113 Mhz aeronautical band. In another case, a land mobile user operating on a frequency of 31.2 Mhz complained of interference caused by a computer operated by a travel agency across the street. However, the FCC was unprepared for the rash of complaints that would come in over the next few years. Paralleling the growth of the personal computer industry, the number of FCC complaints related to interference has grown exponentially. In 1982 alone, the FCC received 65,000

complaints of interference, and of these nearly 6500 were caused by devices regulated under Part 15, the regulations which govern computers and their peripherals along with such other "incidental radiation devices" as handheld walkie-talkies and video games. The resulting growth of interference complaints has left agency officials with the feeling of being overwhelmed. Said Mr. Charles Cobbs, Chief of the Equipment Authorization Branch of the FCC at Laurel, Maryland, "I am so afraid of an interference epidemic."

Up until this year, the brunt of the FCC's regulatory efforts has been focused on makers of Class B equipment. These are devices which are intended for use in the home, such as video games, personal computers and their peripherals. Unlike Class A gear, which only requires testing by the manufacturer to insure compliance, a process known as "verification", Class B devices have to be certified, which means that the manufacturer must file data with the Commission detailing the interference potential of the device. The Commission has the right in these cases to ask for a sample of the unit and has been exercising that right extensively. If you are planning to sell a personal computer or peripheral capable of being used for a personal computer, you will have to go through the certification process, and you should be prepared to send a sample of your product to the FCC's laboratory.

Originally, the FCC had planned to drop its own laboratory testing of Class B product. Unfortunately, so many of these products failed to meet the FCC's EMI specs that they have chosen to continue the testing program. Of all personal computers, peripherals and video games submitted to the Commission, fully 15 to 20 percent fail to comply with the FCC rules. Furthermore, the failure rate of personal computers and printers is much higher, approaching 50 percent. Therefore, until the industry shows more competence in performing EMI tests, the agency intends to continue testing Class B gear when applications for certification are filed. According to one engineer at the laboratory, "The industry as a whole ought to be on their own, but if they can't take care of interference problems, we're going to have to take care of it for them."

Equally troubling to the Commission is the fact that many makers of Class B equipment have not yet filed for certification. Two years ago, the FCC issued informal letters to over 100 manufacturers of Class B equipment requesting that they proceed with applications for certification. (Finding the manufacturers of Class B equipment was simple, since all the agency had to do was look in current hobbyist magazines.) Last year, the FCC stepped up its enforcement by issuing "Marketing Citations" to scores of companies and individuals, thus beginning the formal process of sanctions. Cited were Class B equipment manufacturers, Class A manufacturers, retailers, and end users, including stores and individuals. Thus, the pattern of the FCC's enforcement to date indicates that its focus is not solely on the manufacturers. Rather, sellers and users of equipment which violate the rules can be cited too, and they have been.

This year, the FCC plans to begin looking to see if Class A equipment manufacturers are complying, and plans are underway at the Commission to step up enforcement of the Class A specifications. In doing so, the FCC does not intend to spend much time in seeking out an inadvertent violator but rather be responsive to complaints from end users and competitors. The object of the verification program for Class A gear was to allow the industry to police itself, but according to Mr. Joe Casey, Chief of Field Operations Bureau of the FCC, "If we do show up at the door, we expect the rules to be complied with." The FCC has already requested some Class A manufacturers to supply the Commission with test data on their units, and the next step will likely be a test of those units at the Laurel, Maryland laboratory.

Two situations can be expected to trigger an FCC examination of Class A computer gear. First, if an end user complains that the gear is causing interference, the FCC will likely respond. Second, if a competitor complains that he's been put at a competitive disadvantage by complying with FCC rules, the FCC will also take action. According to Casey, "We will respond in situations where someone is gaining a competitive advantage by a violation. If Company A expends capital and complies with our rules, and Company B cuts the price because

they thought they could sneak away with it, then we would go find Company B and make them stop." According to officials at the FCC's Laurel, Maryland laboratory, competitors' complaints have already triggered action by the Commission against computer makers.

If the FCC takes action, it will be through a two-step process. First, they will issue a "Marketing Citation". This is a letter informing the company that they are apparently violating FCC rules and may request a sample to be sent to the FCC laboratories. If the violations continue or if the gear is found to be in technical violation of the rules, then a "Notice of Apparent Liability" will be issued. This letter is roughly equivalent to the Internal Revenue Service's audit letter. It will assess a fine and request that company officials come in to talk to the Commission. The FCC takes this process very seriously; in Coleco's case, a Notice of Apparent Liability was hand carried by Joe Casey to Mr. Charles Ferris, the former FCC chief whom Coleco hired to represent them in the Colecovision matter.

Keep in mind that the FCC is not the only one who can enforce the rules. Units that violate FCC rules are illegal to sell in the United States. Because of that, competitors can directly sue to suppress the sale of such goods under federal law. Furthermore, a corporation may find that it's selling its products under consignment to its users. Despite any contracts which may be signed, a unit which fails to comply with the rules can be returned by the customer for a full refund. In 1976, for example, makers of CB gear were surprised to find that retailers who could not sell the equipment due to a drop in demand were returning it to the companies demanding a full refund on the grounds that the equipment did not comply. Much of this gear did not comply with the FCC rules which governed CB radios, and the manufacturers were obliged to accept the returned goods.

The only real protection a manufacturer has against the possibility of FCC sanctions is to test his hardware properly. Unfortunately, the procedures used by the FCC's Laurel, Maryland laboratory are not fully documented in the rules, and this has caused considerable confusion. A review of the FCC's procedures will show that a good

test set up is both inexpensive and fairly reliable.

USE INDEPENDENT LABORATORIES WITH GREAT CAUTION

In responding to inquiries by the FCC, Coleco claimed that its device had been tested by an independent EMI laboratory and was found to be in compliance. The FCC was unpersuaded by that argument and proceeded to levy against Coleco the maximum fine permissible under law without extensive agency actions. With so many computers failing to pass in the FCC's laboratories, the Commission has grown quite skeptical of the performance of independent testing firms.

The FCC rules do not merely require that your unit be tested--they require that your unit meet the FCC rules. Testing alone does not give you any protection. No laboratory, not even one that is staffed by the most experienced and competent personnel, can speak for your product. If the FCC decides to test your product, it will speak for itself. Reams of laboratory data are often ignored by the Commission.

Some laboratories have claimed that they are "FCC Approved". If a laboratory tells you that, you may want to find another. Although the FCC will accept data describing laboratory facilities under Part 15.38 of its rules, they only do that to act as a central repository for public access to information on these various laboratories; they do not approve the facilities. In choosing a laboratory, choose one which closely follows the procedures actually used by the FCC in Laurel, Maryland. In this way, you'll have the greatest assurance that should the Commission test your unit it will pass.

HOW THE FCC PERFORMS RADIATED EMISSIONS TESTS

The purpose of radiated emissions tests is to detect how much signal is being broadcast from a piece of hardware to a receiving antenna placed some distance away. The theory behind the test procedures is quite simple. Take an antenna and hook it to a receiving instrument, such as a spectrum analyzer or receiver, and measure the emissions from the device in the frequency range from 30-1000 Mhz.

The FCC performs its tests in a two step process. First, all units requested by the Commission are tested in a simple indoor facility. If they are substantially under the emission limits, they are considered to be in compliance. However, devices which cause problems are retested in an open field site before the Commission fails them. This procedure saves considerable time and expense.

Figure 1

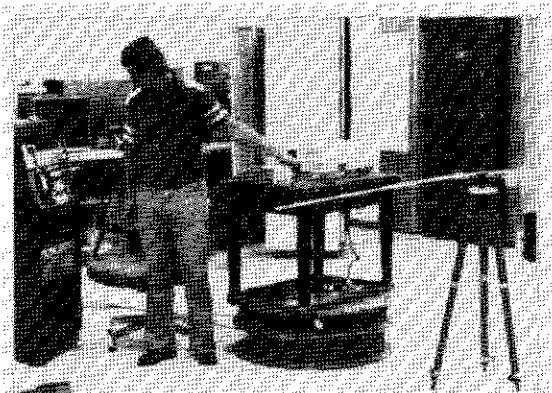


Fig 1--A test engineer checks a Class B printer mounted on a portable wooden table in the FCC's indoor test site. The engineer carefully moves the printer's attached FCC cables and watches the spectrum analyzer for excessive radiated emission readings. The custom built horizontally polarized antenna is located far away from the printer at a fixed 10' height.

The photo in Figure 1 shows tests by the FCC being performed on a printer which was submitted to the FCC for certification. The tests are being performed at the FCC's informal indoor laboratory. Mr. Richard Fabina of the FCC, who is shown in the photo, performs most of the computing equipment EMI tests for the FCC and uses a Hewlett-Packard 141T mainframe spectrum analyzer with 8554L and 8552B plug ins to observe the signals. The antenna he is using was custom built for the Commission by Mr. Glenn Stephens and Mr. Willmar Roberts, former Commission members who have since left the Commission.¹ Originally, the FCC used commercially available antennas in their laboratories, but inadequacies in the design have forced them to customize. To improve the signal to noise ratio, Mr. Fabina also uses an 8447D preamplifier.

A good test begins with the dipoles tuned to a frequency between 30 and 40 Mhz. The spectrum analyzer is then set

up to cover that same range. With its IF bandwidth set to 100 KHz or greater and the post-detection (video) filter turned off, the device to be tested is mounted on a one meter high, one meter wide table, capable of turning to change its orientation.

Then comes the most crucial part of the test. Keeping the antenna at its fixed location and horizontal polarization, begin moving around the cables which are attached to the device. These cables should be draped in every configuration likely to be found by the end user. Special care is taken by the Commission to run the cables along the sides of the unit to pick up any emissions from internal logic which may be coupled onto the cable. Spend approximately five minutes moving the cables around, looking for the highest emission readings. If significant problems are found in this frequency range, spend more time to insure that the worst case is found. Once the worst case emissions readings are found, the antenna should be returned to the exact frequency of these emissions, and the data is taken down. After spending some time in this frequency region, move up to the region between 40 and 50 Mhz and repeat the process. At this point in the test procedure, only peak readings are taken.

Since most emissions from computing equipment are at frequencies below 150 Mhz, the FCC will take considerable care in performing measurements at these frequencies, spending considerable time moving the cables to check for maximum emissions. Since an average of about five minutes is taken at each 10 Mhz interval between 30 and 150 Mhz, this portion of the measurement procedure will take approximately two hours. At higher frequencies, less problems are customarily found. According to Mr. Fabina, "I have found a few problems above 200 Mhz but very rarely are they strong enough to keep someone from passing." Nonetheless, he emphasizes that it is important to continue the radiated tests up to 100 Mhz. At these frequencies, however, the scan width can be widened to examine a wider portion of the spectrum at one time and to make signals easier to see. You may want to widen the IF bandwidth somewhat. All in all, a good radiated test will take about three hours to perform.

Up until this time, the FCC has

primarily concentrated on testing Class B equipment. However, Commission officials intend to use the same procedure to test Class A gear. Of course, large units will not be able to be placed on the one meter high table but should be placed on a rotatable table which is closer to the ground. Despite these minor changes, FCC officials emphasize that the same procedures should be employed to get emission readings which will truly represent the interference potential of the device.

SHOULD CABLES BE ATTACHED IN PERFORMING FCC TESTS?

Most emission problems from computing equipment are due to radiation off cables attached to the unit. As digital logic changes state, RF current pulses appear which radiate off of PC traces and wires connected to the PC board. Since I/O cables are the longest of these wires, they are the most efficient antennas attached to the unit at frequencies below 100 Mhz. Therefore, a piece of hardware can be fairly accurately modeled as a source of RF energy, like a transmitter, and the cables attached to it can be modeled as radiators of that energy, or antennas.

Just as it doesn't make much sense to test a transmitter for range without cables attached, it doesn't make a great deal of sense to test computer equipment without the cables attached. "Obviously, you should attach the cables when you perform the tests," says Mr. Cobbs. However, the industry has been more reluctant to comply. According to Mr. Julius Knapp of the FCC's Office of Science and Technology, "The intent when the test procedures were adopted was that everything would be tested fully exercised with all the cables attached." Some computer manufacturers have strongly resisted such efforts, however.

When the original version of the rules was drafted, certain loopholes became evident. Specifically, the rules seemed to allow computers to be tested in a standalone configuration--that is, without cables being attached. These devices were capable of functioning without any external input other than the AC power. Therefore, since they could function normally standalone, the rules seemed to allow testing in this fashion. Peripherals, however, were a different matter. These devices are

normally used only in conjunction with a cable attached to another device, and here the rules were clear. A peripheral had to be tested with a cable attached and had to be stimulated with an outside source. Therefore, the rules as they then stood permitted CPU manufacturers to test without cables attached but require peripheral manufacturers to test with cables and require the cables to be driven from an active source, such as another computer.

The results of those rules had been to place an apparent unfair burden on peripheral manufacturers. Some peripheral manufacturers found that their devices did not emit significantly but that EMI hazards resulted when they attached to a previously approved computer. Since that computer has been tested without any cables attached, it apparently complied with the FCC rules even though it would have failed the tests with a cable attached to it, since that cable would be an effective antenna for the logic noise generated by the computer. The resulting situation set up by the loophole made it very difficult, or impossible, for some peripheral manufacturers to meet the requirements.

In order to remedy the situation, the FCC's Office of Science and Technology developed new regulations to close the loopholes. The regulations embodied in FCC Measurement Procedure MP-4 require that all computer equipment be tested with cables attached and that the cables be moved to find the configuration which causes the maximum radiation. Basically, the rules to be followed in moving the cables are those currently used by the FCC's laboratory in Laurel, Maryland. Cables have to be draped in every configuration likely to be found in practice, with special care taken to run the cables close to the sides of the unit. However, placing the cable either above or below the unit under test is not required.

The new rules will also sharply cut back on the use of "simulators". When the current EMI compliance rules were proposed in 1979, the government had indicated that a simulator could be used in place of a computer in order to facilitate testing peripherals. This simulator usually consists of a small box which randomly generates data to be transmitted to the peripheral and greatly eased the compliance process since a

simulator could be made which could not cause the cables attached to it to radiate. The intent of these rules, according to Mr. Knapp, was to allow testing with a simulator when an input device was not available. Now, he says, "We'll be very careful in what we accept for simulators" and that "the direction that we are looking at is that everything is going to have to be hooked up to a cable one way or another if it's going to be used that way." Of course, this rule would apply whether or not the manufacturer sells the cables along with the hardware.

LOCAL INTERFERENCE
NOT A PROBLEM

In performing radiated emissions tests, the FCC has to deal with local broadcast stations which produce signals that exceed the limits allowed for computing equipment. Most of these signals come from VHF TV stations and FM broadcasters. In most areas of the country companies attempting to set up sites like the one at Laurel, Maryland will experience the same problem.

Fortunately, interference from local broadcasters doesn't present impossible obstacles to performing the tests. "It's a little bit of a problem, but not too much," says Mr. Cobbs. "It does, however, make testing more of a meticulous process," echoes Mr. Fabina. "The FM band here is as bad as anywhere in the country, but I can live with it."

The reason that Mr. Fabina can live with the interference, as can most testing firms around the country, is because broadcast signals are easily distinguished from those generated by computing equipment. On close examination, FM signals exhibit observable frequency deviation which will not be present in most of the interference from computing gear. Therefore, these signals can be distinguished without turning the equipment on and off. In cases where doubt exists, the gear can be powered down to determine if the computer is the source of the interference. TV stations do not even present as much of a problem as FM stations do, since their aural and video carriers occupy a relatively small portion of the allocated channel. Unless the signal from the computing equipment is within a few tens of Khz from either carrier, TV stations will not present a problem in performing the measurements

Some manufacturers may have different problems in setting up their site, however. If a manufacturing plant is operating a large number of computers on the premises (which is fairly likely), it may be more difficult to separate interference from these computers from signals from the device tested. In this situation, there is only one ready cure--that is, to move the testing location farther away from the plant. Other solutions have been proposed for this problem, including the use of screen rooms or anechoic chambers. However, as we will describe later, screen room use for radiated emissions is not acceptable to the Commission, and the Commission has never seen an anechoic chamber suitable for taking radiated emissions measurements below 100 Mhz.

IF YOU FAIL THE INDOOR TESTS,
THE FCC TESTS ON AN OPEN FIELD
TEST SITE

The informal test procedure described above is not the only way the FCC performs radiated emissions measurements. They would not, under any circumstances, cite a company for failure to meet the FCC rules based on data from the indoor laboratory shown in Figure 1 alone. Rather, if emissions tests in the indoor scan show the device to be close to the FCC limits, they will retest the device outdoors, as shown in Figure 2.

Figure 2

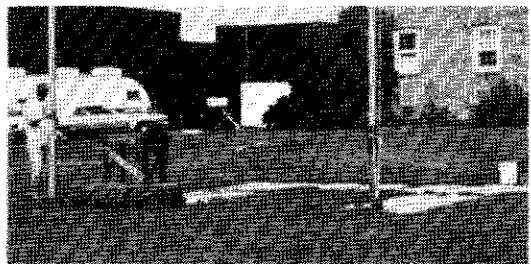


Fig 2—The FCC's simple but highly accurate outdoor test site finds extensive use in final checking of computing equipment that fails indoor radiated-emission tests. Note the wooden mounting table and the two wooden antenna masts located exactly 1 and 3m from the table.

The simplicity of the site shown should not be considered to undermine its accuracy. The site shown in Figure 2 has site attenuation characteristics which are as good as any site in the United States. Over the last six years, the Commission has found that tests performed at the site have been accurate and repeatable.

In order to perform radiated emissions, you will have to either find a testing firm which has a site like the one at Laurel, Maryland or build your own. Setting up a site is a simple and straightforward process. Keep in mind that simplicity is the key and that spending more money on the site does not make it a better site in terms of accuracy or repeatability. For those purposes, it is better to keep the site simple.

The FCC only uses the outdoor test site in cases where it is found that the emission characteristics of a device are questionable. In this case, the device is moved from the indoor laboratory to the outdoor site and is set up in the identical configuration. Cables are placed exactly as they were in the indoor test set up, and a mast one meter away from the rotatable table is used to verify that the readings are the same. Then an antenna is placed on the three meter mast and is moved up and down and changed from vertical to horizontal polarization. Using this process, the FCC confirms that at three meters in an open field site, the device is either over or under the limit. In performing this final set of tests, a receiver with a quasi peak detector is used, since this is required by the rules. Note, however, that the FCC only uses a receiver in this final set of measurements. For all its other tests, the FCC uses a spectrum analyzer in peak mode, due to the fact that a computer often radiates at hundreds of different frequencies. If a receiver were used to do the initial tests, the operator would only look at one frequency at a time. Since the cables have to be adjusted to find the configuration of maximum radiation, use of a receiver alone could take hours or days to perform accurate measurements. For this reason, a receiver is only used by the Commission in this final testing phase. If a computer is clearly below the limit in the indoor scan, it is not taken to the outdoor site at all.

The lesson to be learned by manu-

facturers is that a simple, straightforward facility is the best for performing FCC radiated test measurements. What is needed is a facility which allows the operator to move cables around to find the configuration of maximum emissions. A spectrum analyzer should be used for efficiency. If a simple site, such as the indoor site which the FCC uses, shows that the device, after cable maximization, is more than 6 dB below the limit, then outdoor tests are probably not necessary. In cases where a manufacturer is unsure, a site such as that used by the FCC in the open field should also be used. What a manufacturer should not do is to build a large, complicated and expensive facility since complexity is never a substitute for care in cable placement.

SETTING UP AN OPEN FIELD TEST SITE

Setting up an open field test site which closely resembles that used by the Commission is not an expensive or burdensome task provided that a few simple steps are followed. While the physical layout of the site is not critical, there are a number of difficulties which can arise which could prove costly to your company. Among these, the most expensive mistakes to make are:

- 1) Choosing the wrong set of antennas.
- 2) Laying out the site in such a manner that making the adjustments to cable placement needed for taking accurate emissions measurements becomes impossible.

Keeping these two problem areas in mind, most of what you have to know is laid out in a document available from the Commission known as OST-55. Currently, the American National Standards Institute (ANSI) is proposing an updated standard which is intended to be more comprehensive than the FCC proposed using in OST-55. Until that standard is complete, you can use OST-55.

Basically, to verify your site's performance, a simple test known as site attenuation can be performed. The theory behind the site attenuation test is quite simple. A transmitting antenna is set up at a fixed location at one end of the site with a receiving antenna set up at the other end. If a certain amount of signal is put into the trans-

mitting antenna, a lesser amount of signal ought to be measured at the terminals on the receive antenna. The loss in the signal is known as the site attenuation and should follow a predicted curve (see Figure 3). If it doesn't, there is something wrong with either the equipment used or the physical characteristics of the site.

Figure 3

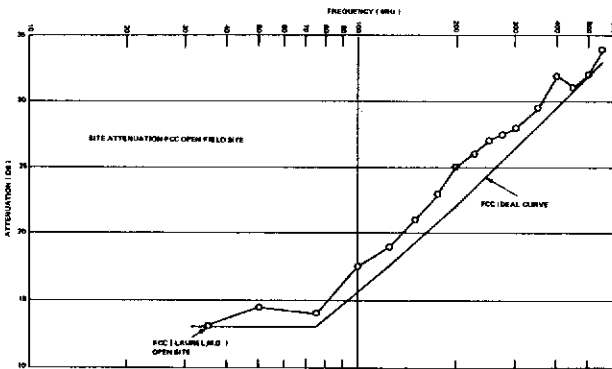
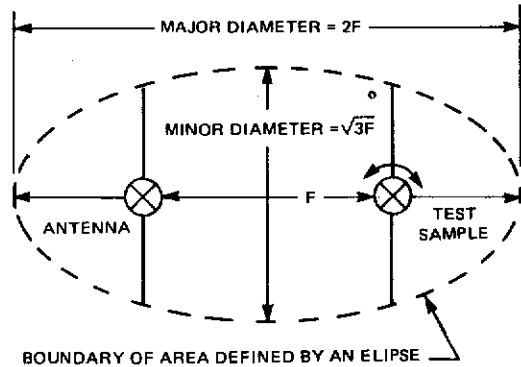


Figure 4



If these factors create a problem, as you can ascertain by using the site attenuation test described below, you can install a ground screen. An inexpensive ground screen can be made of 1/4" galvanized steel mesh, often called hardware cloth. The hardware cloth should be connected to the utility ground and earth ground if outdoors for safety. As a rough guideline, use a mesh carpet roughly 5 meters square for a 3 meter site.

The Physical Characteristics of a Good Test Site

The best test site that you can build is like the one used by the FCC, shown in Figure 2. A mast is set up three meters from a rotating table, and the mast is used to raise and lower the antenna. The basic requirements for an open field site are that it be clear of reflecting objects, such as metal fences, trees, buildings and unburied conduits, for the distance shown in Figure 4. The ground itself should be of uniform and reasonably high conductivity, which will be the case if it is reasonably moist and not subject to drastic seasonal variations and moisture content, and free of interruptions, such as pavement or shallow buried cables, pipes and power lines, other than those needed to run the equipment.

Electrical Characteristics of the Site

The amount of loss between a transmit antenna set up and a receive antenna should follow the predicted curve. For dipoles, the amount of attenuation you should get between a transmit and receive antenna, set up as shown in Figure 5, should be:

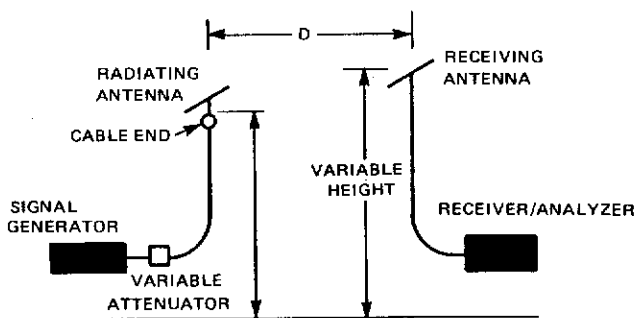
$$\text{Attenuation (dB)} = 20 \log D + 20 \log F + \text{cable attenuation} - 36.6.$$

The equation above assumes 4.7 dB of ground reflection and is only valid for frequencies above 80 Mhz. Below that, near field considerations apply, and the FCC assumes that the curve flattens out. For a good site, deviation from this curve should be less than ± 3 dB.

As shown in Figure 3, the FCC's own site lies within 3 dB of the ideal curve.

In performing the site attenuation tests, set your equipment up as shown in Figure 5. A straightforward test procedure requires a signal generator, attenuator, two tunable dipoles (care must be exercised in selecting these), a receiver or spectrum analyzer and non-conductive antenna support. To perform the tests, connect the signal generator and the analyzer to the transmitting and receiving antennas and adjust the transmitting height as shown in the figure. The antennas should be left in horizontal polarization. Find the maximum value of received field strength of the horizontal component by raising and lowering the antenna. Measurements should be made at 10 Mhz intervals between 25 and 100 Mhz, at 25 Mhz intervals from 100 to 300 Mhz and at 50 Mhz intervals from 30 to 1000 Mhz. Once the data for each measurement has been recorded, the signal generator should be directly hooked to the receiver or spectrum analyzer via a variable attenuator. The attenuator is then used to attenuate the generator signal to yield the same reading. The site attenuation at that frequency can then be read off the attenuator. Note that this test measures the total path loss from the signal generator to the receive instrument and, therefore, includes loss from free space transmission and cable attenuation.

Figure 5



D (m)	H (m)	VARIABLE HEIGHT (m)
3	2	1 TO 4
10	2	1 TO 4
30	2	2 TO 6

Common Causes of Error in Site Attenuation

If you're like most manufacturers, you will find that reproducing the results the Commission has achieved at their site is quite difficult. Companies have reported errors in measurement as high as 8 dB off the theoretical curve for no apparent reason. Furthermore, these problems have arisen after companies have expended great sums in building their sites and have caused alarm to the electronics industry and considerable comment in the trade press.

According to former Assistant Chief of the Laboratory Division of the Commission, Willmar K. Roberts, a major cause of these errors is the antennas used by these companies. Some commercially available antennas may not be suitable for performing FCC tests. Initially, the FCC itself had great problems in getting site attenuation characteristics which approached the ideal curve. After careful study of the situation, they turned to the antennas as the source of error.

In a 1956-1957 study, the FCC plotted the balun losses and the voltage standing wave ratio (VSWR) of the Empire DM-105 series antennas. The results of this study showed that the antennas were not suitable for performing emissions measurements, and in many frequencies had VSWRs of greater than 3:1. This kind of mismatch can cause measurement errors of up to 6 dB or more. Furthermore, these errors will vary depending on the length of cable used in performing the tests.

Roberts' solution was to design and build his own antennas, and since 1957 the Commission has used antennas of Roberts' design. Roberts, who has since left the Commission, is currently a consultant and consults for Compliance Design Inc. which now sells antennas which are identical to those used by the FCC. These antennas have far better VSWR characteristics, as shown in Figure 6, and at all frequencies between 30 and 1000 Mhz, they have VSWRs of less than 1.6:1.

Personnel at the laboratory warned manufacturers to be careful in selecting their antennas. "Just don't take the manufacturers' curves at face value," says Mr. Cobbs. "Do your own homework

and generate your own data." The homework that Mr. Cobbs is referring to is a back-to-back balun test described in Figure 7. Here, the antenna rods are removed from the antennas and the balun loss is measured by using two identical baluns back-to-back. The connection should be reversed, and the attenuation is the average of the two connections. One half of this attenuation factor is the loss for a single antenna balun. Loss characteristics for the Empiretm DM-105 antennas and for the Robertstm antennas are shown in the figure. This data was from the 1956-1957 study. An acceptable set of antennas should have less than .6 dB of loss per balun.

Figure 6

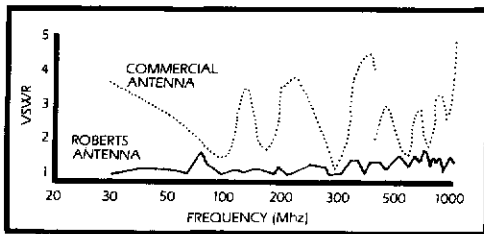
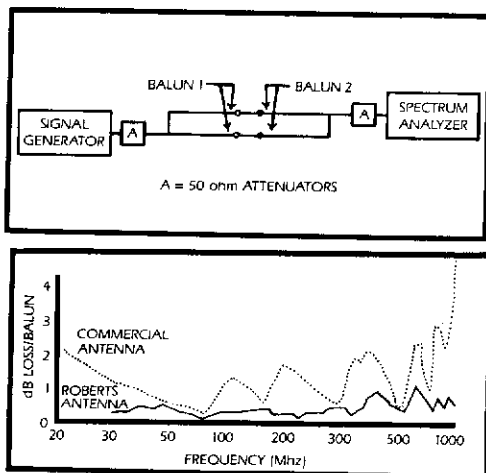


Figure 7



METHODS FOR MAKING RADIATED EMISSIONS TESTS WHICH ARE NOT ACCEPTABLE TO THE FCC

There are certain procedures for taking radiated emissions readings that are not acceptable to the FCC. Foremost of these is performing radiated emissions tests in a screen room. Reflections off the wall of the screen room make such data unacceptable to the Commission. According to the FCC's Cobbs, "The data you get is just not valid stuff. It's nice and quiet, but you just won't get good answers." As for radiated measurements inside a screen room, another FCC engineer said, "Forget it. I just don't think it's going to work."

Anechoic chambers are also viewed by the Commission with skepticism. According to Mr. Cobbs, he has seen only two chambers which might be correlatable to open field tests, and in those cases only for measurements above 100 Mhz. Both of the chambers were also quite large. For example, one of these chambers used reflecting cones 6' high and had an interior open space of almost 1600 square feet. Such chambers are extremely expensive. Some companies have proposed using small chambers with two to four foot high reflecting cones for radiated tests, but almost always with disastrous results. Although work in the field continues, these cones are seen by most EMI engineers as too small to allow the chamber to remain anechoic at frequencies below 100 Mhz. Since an anechoic chamber is generally mounted inside a metallic shell, if the material used to make the chamber anechoic is in fact transparent to electromagnetic radiation at frequencies below 100 Mhz, then the chamber reduces to a shielded room. Resonances in a shield room will give highly inaccurate data and will likely cause a computer manufacturer to fail a product below 100 Mhz when in fact an open field test would show that the device would pass. Furthermore, sharp peaks and nulls in the chamber will make repeatability difficult.

Another area to pursue with caution is automation of the test techniques. Several computer manufacturers have opted for automated techniques in performing measurements. It should always be kept in mind that automation is simply a faster way of producing data. It is not a more accurate way of producing data, and in fact, some companies have

fallen into the trap of substituting automation for care. For example, there is no way to automate cable placement. An operator has to sit with the gear, moving cables around to find the configuration that gives the worst case. This only takes a few minutes to do, and no machine can do it for you.

One highly inaccurate method of taking data is to have an automated set up which rotates the table and moves the antenna up and down but in which the operators do not move cable placement. This type of set up is not acceptable to the Commission. Mr. Fabina reports, "I have seen a lot more failures from people who use automated equipment than people who take the time and the care to move cables by hand." Furthermore, manufacturers relying entirely on an automated set up may find a great deal of difficulty in getting repeatable results. Since cables could be placed in one place on one day and a second configuration the next day, the emission readings will be quite different. A movement of a single cable just a few inches can result in dramatically different emission results. Failure to move the cables is the single largest contributor to error in radiated emissions tests.

PERFORMING LINE CONDUCTED EMISSIONS TESTS

In contrast to radiated emissions tests, line conducted emissions tests are quite simple to perform. Furthermore, since conducted emissions readings vary less with cable placement, automated measurement can play a larger role.

Figure 8

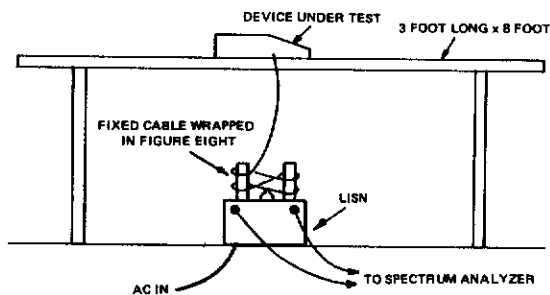
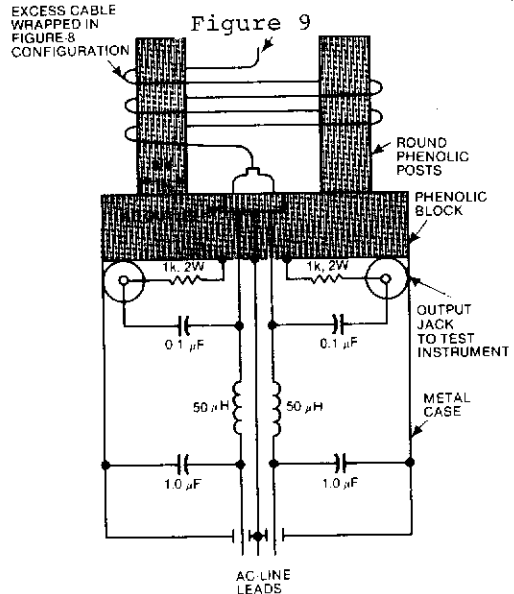


Figure 8 shows the FCC's test set up for performing line conducted measurements. A device to be tested is placed on a 3' x 8' wooden table and its line cord is run down to a line impedance stabilization network (LISN) (Figure 9). Two wooden pegs sit on top of the LISN which allow the slack in the line cord to be taken up. And to avoid inductance, the cord should be looped in a figure-eight pattern around the pegs. The rest of the space on the table is used to drape cables which exit the device under test. Again, these cables should be moved around to find the configuration which results in the worst emissions readings.



Conducted emissions signals come from two sources. First, signals are conducted from the logic through the power supply and back down the AC cord to the LISN. A second effect, which is dominant in frequencies above 15 Mhz, results from emissions from the computer and the cables being picked up by the line cord, which acts as a receiver antenna. Because of this, cable placement readings can vary at frequencies above 15 Mhz. While I/O cables are moved in performing the tests, the AC line cord is not moved but rather is kept in a rigid position, as shown in Figure 8.

In performing conducted emissions tests, the spectrum analyzer is once again the measurement instrument of choice. Below 1 Mhz, you may find emissions readings due to noise produced by

rectifiers or the switching supply. Above 1 Mhz, signals result from the logic itself and from radiation off the cables. Once the worst case configuration is found, receivers can be employed and a quasi peak detector may result in lower readings. If a spectrum analyzer is used as a receiving instrument, a pad should be put on its input to protect it from transients. Although a shielded room is not necessary for performing conducted measurements (the FCC doesn't use one), it may prove a convenience. Resonances off the walls are not as problematic here as they are for radiated emissions tests.

SUMMARY

The FCC's emissions rules should not be treated by manufacturers as a mere formality. The level of interference in the last year has shown that the fears which they had in the late 1970s have come to pass. It is now up to the industry to be responsible in handling the problems that they cause to users

of the radio spectrum.

The burden is on the manufacturers themselves. The FCC doesn't care if you have your unit tested. They only care if your unit complies. No laboratory can give you a ticket which will buy you peace with the Commission. Because of that, performing tests the way the Commission performs tests is extremely important. As shown in this article, a test set up like the FCC uses is highly accurate, repeatable and not excessively long period of time. Furthermore, work at Dash, Straus & Goodhue, Inc. has shown that EMI compliance for most computer equipment will add less than 1 percent to the cost of the hardware if it is done skillfully. If EMI compliance is kept in mind early in the design phase of the project, even less incremental costs may be incurred. In that way, the industry will not be burdened by these regulations, and the radio spectrum will remain free to be used by broadcasters, business and amateur radio operators.

1,2 Antennas identical to those used by the FCC are available from Compliance Design Inc., Boxboro, MA 01719, 617-264-4668