INTRODUCTION

General Information

Users are advised to read through these instructions so that all functions are understood. Immediately after unpacking, the instrument should be checked for mechanical damage and loose parts in the interior. If there is transport damage, the supplier must be informed immediately. The probes must then not be put into operation.

Electromagnetic compatibility continues to be an important issue in the electronics industry worldwide. The main goal of design engineers is to meet ever more demanding specifications, while also making circuitry quieter and more robust to meet tough EMC regulations. The design of microcontroller-based products which fully comply with present and imminent EMC regulations isn't an easy task to undertake with the use of current technologies. Even with the best PCB layout techniques and the most substantial decoupling, at the speeds of today's designs, radiation from boards and the consequent noise impinging on PCBs is becoming a growing problem that will not go away.

By the date of January 1, 1996, every electronic instrument or device which can be imported to the European community must meet the EMC regulations according to EN 55011 to 22 , EN 50081-1 and CISPR-Publications 11 to 22. The EMC directive refers to both electromagnetic emissions and electromagnetic immunity. The manufacturer of electronic equipment or devices declares the conformity of his product with the above regulations by the placement of the CE-sign on the device or equipment. By doing so the manufacturer is liable for all violations of the above regulations. Goods without the CE-sign are not allowed to be sold in the European Community.

In order to be sure that the manufactured equipment meets all specifications according to the EMC regulations, extensive test during the design phase of every electronic device must be done. One of the methods of CE certification is to use the services of a professional testing lab that specializes in the compliance certification process. The lab will have precise test equipment and a shielded, screen room within which the inspection is performed. Since many products being certified will require modification and redesign, the customer is charged on an hourly basis for test time used. Quite often, many trips are made between the test lab and the design/development facility. In order to minimize the cost of the test, it is recommended that a "Pre-Compliance" phase in product development first be conducted. This phase would use a spectrum analyzer such as the **B+K Precision** 2600 Series in conjunction with PR-261 close field sniffer probes, to inspect for emission and leakage; isolate the source, design and correct the problem and then retest. Once the product appears electromagnetically "quiet", it is submitted to the compliance certification laboratory. This should save the expense for much of the test time, since the submitted unit has already been pretested. Typically, the test time and money saved should represent many times the purchase price of the spectrum analyzer.

Operating Conditions

The probes have been designed for indoor use. The permissible ambient temperature range during operation is +10°C (+50°F) ... +40°C (+104°F). It may occasionally be subjected to temperatures between +10°C (+50°F) and -10°C (+14°F) without degrading its safety. The permissible ambient temperature range for storage or transportation is –40°C (+14°F) ... +70°C (+158°F).

The maximum relative humidity is up to 80%.

If condensed water exists in a probe it should be acclimatized before switching on. In some cases (e.g. probe extremely cold) two hours should be allowed before the probe is put into operation.

The PR-261 is the ideal toolkit for the investigation of **RF electromagnetic fields**. It is indispensable for **EMI pre-compliance testing** during product development, **prior to third party** testing. The set **includes three hand-held probes** with a built-in pre-amplifier covering the frequency range from **100kHz** to over **1000 MHz**.

The probes - one **magnetic field** probe, one **electric field** probe, and one **high impedance** probe - are all matched to the 50Ohm inputs of **spectrum analyzers or RF-receivers**. The power can be supplied either from batteries, Ni-Cads or through a power cord directly connected to a Model 2625 or 2630 spectrum analyzer.

Signal feed is via a 1.5m BNC-cable. When used in conjuction with a spectrum analyzer or a measuring receiver, the probes can be used to locate and **qualify EMI sources**, as well as evaluate EMC problems at the **breadboard** and **prototype level**. They enable the user to evaluate radiated fields and perform **shield effectiveness comparisons**. Mechanical screening performance and immunity tests on cables and components are easily performed.

H-Field Probe

The **magnetic probe** incorporates a high degree of rejection of both stray and direct electric fields, and provides far greater repeatability than with conventional field probes. Measurements can be made on the **very near field area** that is close to components or radiation sources. It is especially suited to locate **emission "hot spots"** on PCBs and cables.

E-Field Probe

The electric field (mono-pole) probe has the **highest sensitivity** of all three probes. It can be used to check screening and **perform pre-compliance** testing on a comparative basis.

High Impedance Probe

The high impedance probe is used to measure **directly on the components** under test or at the conductive trace of a PC board. It has an **input capacitance** of only 2pF and supplies **virtually no electrical charge** to the device under test.

SPECIFICATIONS

Frequency range: 0.1 MHz to 1000 MHz (lower frequency limit depends on probe type)

Output impedance: 50 Ohm

Output connector: BNC-jack

Input capacitance: 2pF (high imped. probe)

Max. Input Level: +10 dBm (without destruction)

1dB-compression point: –2 dBm (frequency range dependent)

DC-input voltage: 20 V max.

Supply Voltage: 6 V DC
4 AA size batteries or power from
Model 2625 or 2630 Spectrum Analyzer

Supply Current: 8 mA (H-Field Probe)
15 mA (E-FieldProbe)
24 mA(High imp.Probe)

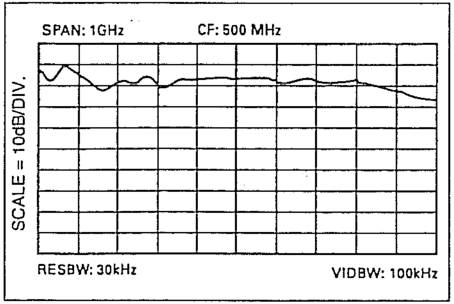
Probe Dimensions: 40x19x195mm (WxDxL)

Housing: Plastic; (electrically shielded internally)

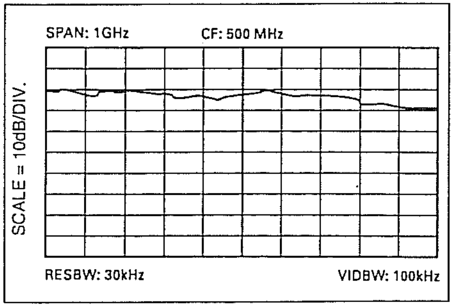
Package contents: Carrying case
1 H-Field Probe
1 E-Field Probe
1 High Impedance Probe
1 BNC cable (1.5m)
1 Power Supply Cable

(Batteries or Ni-Cads are not included)

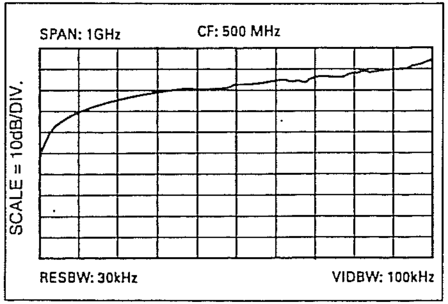
Values without tolerances are typical for an average instrument.



Frequency Response E-Field Probe (typical)



Frequency Response High-impedance Probe (typical)



Frequency Response H-Field Probe (typical)

OPERATION OF THE PROBES

Before performing measurements with two of the PR-261 probes, the High Impedance (Hi-Z) Probe and the E-Field Probe, they must be configured for testing. The 0.8 mm diameter wires which are used as antennas are located in the plastic bag that is in the case for the probes. The wires are plugged into the probe by use of pliers and a light force. The opening for the antenna is located on the narrower front of the probes. The short wire is intended as a contact for the Hi-Z probe. The two longer antennas are to be used on the E-field probe. Depending on the frequency range either the short antenna (6.5 cm) or the long antenna (9.5 cm) is used.

Battery Operation

Next, power must be provided to the probes. If a **B+K Precision** Model 2625 or 2630 spectrum analyzer is used, the necessary voltage is obtained from the instrument by use of a provided special cable. In this case, batteries are not required. If another spectrum analyzer, oscilloscope or RFI measurement set is used for the measurement, the supply must be provided via 4 AA-Cells either NiCad or rechargeable batteries.

Prior to each measurement the switch needs to be actuated. This switch is located adjacent to the BNC connector. This switch must be turned on when either the battery or spectrum analyzer supply are used. However, when not in use, the switch must be turned off to save the batteries which have a life of 20 - 30 hours when turned on.

Output Impedance Matching

The connection of the probe to the spectrum analyzer, oscilloscope or measurement receiver is made via a supplied BNC cable of approximately 1.5 meters length. This length is generally sufficient for most measurements. If for special reasons a longer cable is used, the insertion loss of this cable must be added to the output values at the higher frequencies.

For the normal measurements, the probes are connected to a spectrum analyzer. These instruments generally have an input impedance of 50 ohms. This impedance is the normal termination impedance for the probes. If an oscilloscope or measurement receiver with a different impedance is used, the correct (50 ohm) termination impedance must be used. If the 50 ohm termination impedance is not used, the probe output is not calibrated.

Use of different probe types

The different probes are used for different tests since their electrical characteristics are quite different. The E-field probe is normally used at a distance of 0.5 to 1.5 meters from the RFI source. The thereby observed frequencies are then further localized near the source by use of the H-field probe. The high impedance (Hi-Z) probe makes further localization possible by directly contacting the source and to judge the effectiveness of suppression measures.

Because of its electrical characteristics, the E-field probe is not intended to perform measurements within an equipment or directly on parts that are live. Electrical contact of the antenna with live parts exceeding 20 VDC or + 10 dBm at RF may cause damage to the built-in pre-amplifier. These limits also apply to the Hi-Z probe; however, electrical contact to parts that are below 20 VDC or + 10 dBm are permitted.

Accuracy Notice

The probes may not be used to perform accurate quantitative measurements. It is not possible to relate the probe measurements directly to final values of field strength in V/m necessary for certification tests. The probe kit is intended as an aid for developmental tests to obtain a qualitative amplitude as a function of frequency. These values are strongly influenced by the limiting conditions of the measurement which may change as a function of frequency.

BASIS FOR NEAR-FIELD PROBE MEASUREMENTS

The H-Field Near-Field Probe

The H-Field probe provides a voltage to the connected measurement system which is proportional to the magnetic radio frequency (RF) field strength existing at the probe location. With this probe, circuit RF sources may be localized in close proximity of each other. This effect is caused by the interference sources which in modern electronic circuits are of low resistance (relatively small changes in voltage cause large changes in current). The sources of radiated interference begin as a primarily magnetic radio frequency field (H-Field) directly at its origin. Since in the transition from the near- to the far-field, the relationship between the magnetic- to the far-field must reach the free-space impedance of 377 ohms, the H-field will decrease as the cube of the distance from the source. A doubling of the distance will reduce the H-field by a factor of eight ($H = 1/d3$); where d is the distance.

In the actual use of the H-field sensor one observes therefore a rapid increase of the probe's output voltage as the interference source is approached. While investigating a circuit board, the sources are immediately obvious. It is easily noticed which (e.g.) IC causes interference and which does not. In addition, by use of a spectrum analyzer, the maximum amplitude as a function of frequency is easily identified. Therefore one can eliminate early in the development components which are not suitable for EMC reasons. The effectiveness of countermeasures can be judged easily. One can investigate shields for "leaking" areas and cables or wires for conducted interference.

The High-Impedance Probe

The high-impedance probe (Hi-Z) permits the determination of the radio frequency interference (RFI) on individual contacts or printed circuit traces. It is a direct-contact probe. The probe is of very high impedance (near the insulation resistance of the printed circuit material) and is loading the test point with only 2 pF (80 ohm at 1 GHz). Thereby one can measure directly in a circuit without significantly influencing the relationships in the circuit with the probe.

One can, for example, measure the quantitative effectiveness of filters or other blocking measures. Individual pins of IC's can be identified as RFI sources. On printed circuit boards, individual problem tracks can be identified. With this Hi-Z probe individual test points of a circuit can be connected to the 50 ohm impedance of a spectrum analyzer.

The E-Field Monopole Probe

The E-field monopole probe has the highest sensitivity of the three probes. It is sensitive enough to be used for use as an antenna for radio or TV reception. With this probe the entire radiation from a circuit or an equipment can be measured.

It is used, for example, to determine the effectiveness of shielding measures. With this probe, the entire effectiveness of filters can be measured by measuring the RFI which are conducted along cables that leave the equipment and may influence the total radiation. In addition, the E-field probe may be used to perform relative measurements for certification tests. This makes it possible to apply remedial suppression measures so that any re-qualification results will be positive. In addition, pre-testing for certification tests may be performed so that no surprises are encountered during the certification tests.

Practical Selection of Signal-Line Filters

The steadily increasing operating speed of modern digital logic causes significantly greater concerns with EMC problems. This has become more noticed by all manufacturers of electrical and electronic devices since January 1, 1996, the effective compliance date for the European Union EMC Directive. The EMC Directive does not cause the radiated interference problems, but it causes conflict with the requirements of compliance for each manufacturer.

The times are long gone when the EMC problems could be left to the EMC department or a non-compliant product was not noticed and could be sold anyhow. Every circuit designer must at the beginning of a development be aware of potential EMC problems to even allow the successful certification of a product. Printed circuit boards must be built differently than was possible several years ago. A reasonable broadband decoupling of the supply voltages is the present state-of-the-art.

But also the design of signal lines must be considered and can not be left to chance. Digital signals have a spectrum with a bandwidth, B, that is related by:

$$B = 1 / (3.14tr), \quad \text{where } \mathbf{tr} \text{ is the risetime.}$$

Consequently, the risetime of a digital signal transition is the determinant. The shorter the risetime, the wider the frequency range. However, the calculated bandwidth is not as important as the one that actually exists which can be significantly different than the calculated one. The reason for this is that the calculated value is referenced to a capacitive total load. For most practical cases this does not occur. An approximate calculation shows that one half of the capacitive load means a twice faster risetime; e.g. a microprocessor has a specified risetime of 2 x 10E-9 s (2 ns). The capacitive load is supposed to be 150 pF. If a signal from this processor is loaded only with a CMOS gate of 12.5 pF, the risetime will be 12 times faster and a value of 200 x 10E-12 s (200 ps) must be expected. In the frequency domain, 200 ps is equivalent to a bandwidth of 1.6 GHz. Even in practical circuits, where additional capacitance can be expected, actual bandwidths of over 1 GHz are measurable.

From an EMC point of view, this is naturally very damaging. The actual risetime in CMOS circuits is not easily measurable in most digital labs. To measure the actual risetimes, oscilloscopes with the ability to measure 100 ps (10E-10 s) must be used. Such oscilloscopes are available but at a significant price.

Such fast oscilloscopes are not really necessary to observe the digital system operation. This is the reason that these fast oscilloscopes are not used in digital laboratories and slower oscilloscopes are used. However, slow scopes simulate a risetime which in reality do not exist because they measure only the internal risetimes of the oscilloscope.

This exposes a measurement problem: The relevant EMC characteristics cannot be measured with existing equipment in many cases and the necessary oscilloscope is very expensive.

A practical solution is to perform the measurements in the frequency domain: The digital function is observed with a slower and economical oscilloscope and the relevant EMC characteristics are measured with a spectrum analyzer. Since the spectrum analysis of corresponding frequency ranges is technically simpler than the measurement of the equivalent risetimes, basic spectrum equipment can be obtained which is relatively more economical. Spectrum analyzers with a bandwidth of 1,000 MHz are already suitable for analyzing CMOS circuits. The corresponding oscilloscopes are still very expensive.

Spectrum analyzers are high frequency equipment and have therefore an input impedance of 50 ohms. They are therefore not suitable to measure directly in digital circuits because of this impedance which will influence the circuit behavior. As a minimum the measurement results are false. Consequently, for the measurement in digital circuits a high impedance probe is required which does not load the circuit and convert the signal to a 50 ohm system over a wide frequency range.

The following measurement results were measured with the High Impedance Probe PR-261 connected to a Spectrum Analyzer and with a digital scope.

In principle, it is easy to assume that it is possible to select signal-line filters from catalog values. Well-known manufacturers offer filters with measurement data in the time- and frequency- domain. Unfortunately, the filter data is performed with an entirely resistive load and therefore the data looks very good. However, in practice an entirely resistive circuit seldom exists. Therefore, the filters must be evaluated when installed in a practical circuit. It is then observed that the performance of the filters is not as promised in the catalog. This shall be demonstrated with a series of illustrative examples which are measured in circuits of the 74 ACT family. The gates are always operated with a 5 MHz frequency.

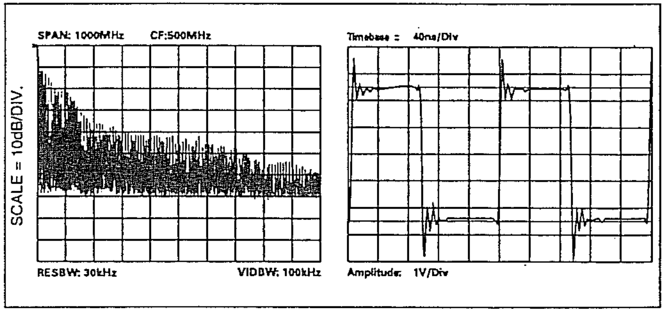


Fig. 1.

Figure 1 shows the time and frequency domain outputs of such a gate which is mounted on a printed circuit and is not loaded. The frequency spectrum is measurable to 1,000 MHz. In fact, it extends even above 1,000 MHz, but for comparison purposes all measurements are scaled only to 1,000 MHz. In the time domain relatively strong over and under shoot and fast risetimes are observable. This signal is very poor relative to the EMC characteristics. The excessive bandwidth permits radiation to take place on relatively small printed circuit boards. When this signal is conducted to other parts, it is especially important to limit the spectrum to avoid excessive shielding structures.

As a first measure to limit the spectrum, a resistor is recommended between the gate output and the conductor connection. The conductor is simulated by an individual gate input to obtain a realistic circuit. The connection and the conductor length must correspond to the actual relationship to make the measurements of signal line filter evaluation meaningful. The effectiveness of line filters is strongly influenced by their termination.

Figure 2 shows the results when a 47 ohm resistor is used. In the time domain a significant improvement occurs. The overshoot is reduced and the risetimes are somewhat slower. The linear dynamic range of an oscilloscope can not demonstrate adequately the EMC characteristics of the signal. The frequency spectrum shows only a slight decrease of the upper frequencies.

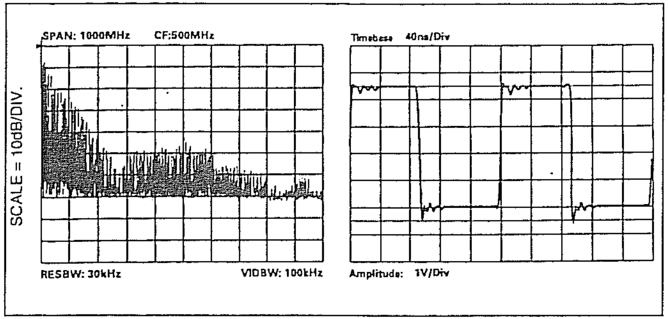


Fig. 2.

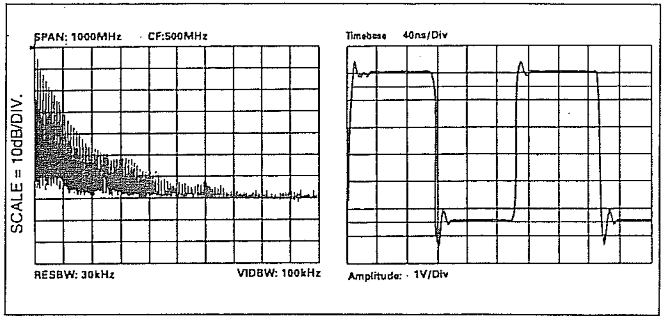


Fig. 3.

The oscilloscope probe is partially responsible for this error since the probe has a capacitance of 6 pF. The Hi-Z probe has only a load capacitance of 2 pF. By selecting specific values of resistors the EMC characteristics may be slightly improved, but an EMC success can not be scored with only the insertion of a resistor. Another improvement can be made by inserting a capacitor to form an RC filter.

Figure 3 shows the results when 100 pF is added to the 47 ohm resistor. The load continues to be the printed circuit track and another gate input. In the time domain, the difference appears negligible. In the frequency domain, the middle and upper frequency range is significantly improved. If a slower oscilloscope is used, any improvement would no longer be recognizable in the time domain. The limitation of using an oscilloscope and using only time domain measurements is easily recognizable: The EMC relevance of a suppression measure is not noticeable.

The next step is to insert a 47ohm, 100 pF, 47ohm T-filter.

Figure 4 shows that the change is quite noticeable when compared to Figure 3. The frequency range is now practically reduced to 200 MHz. At the same time the risetime is significantly slowed down. The approach may be questionable if this slow risetime influences the digital operation. In this case, the component values may be varied to find a compromise between desired EMC characteristics and digital functionality. This suitable example demonstrates the effectiveness of the measurement procedures recommended here.

Several complete signal-line filters are commercially available. The effectiveness of these filters can be evaluated using the same procedures.

Figure 5 shows the use of a three-pole capacitor used as a signal-line filter in the same circuit as used in the previous examples. The results are disappointing: Even though the risetime is significantly reduced, the fre-

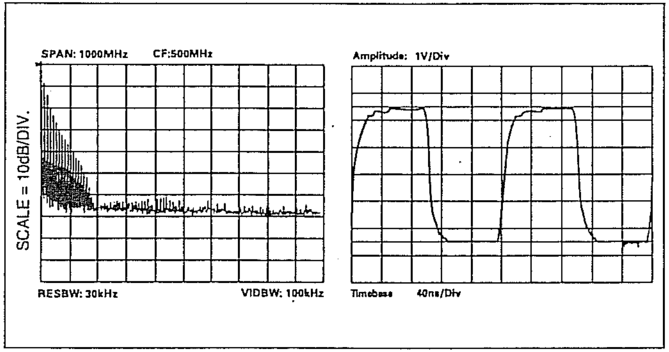


Fig. 4.

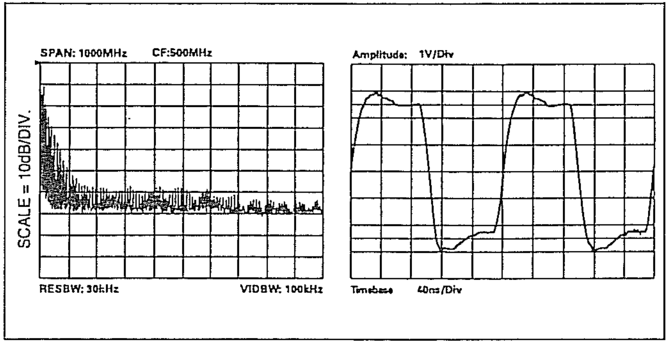


Fig. 5.

quency spectrum is only marginally reduced. This results from the generally poor ground connection of a three-pole capacitor which is relatively high in inductance compared to a R-C-R combination in surface mount technology (SMT). Some offered three-pole capacitors are poor high frequency filters.

Another example is a wideband choke used as a signal line filter.

Figure 6 shows the results. The frequency spectrum is poorly suppressed, but the risetimes are significantly slowed down. It should be noticed here that a time domain analysis only will lead to poor EMC performance and the wrong conclusions. This is an expensive measure that will influence the digital function with disappointing EMC suppression.

As a final example a modern SMT chip filter consisting of two ferrite beads and a feed-through capacitor is shown.

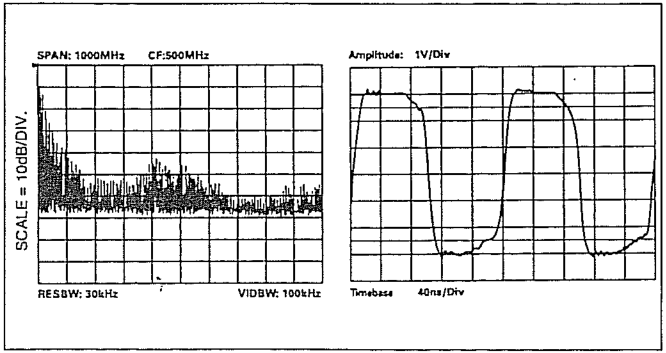


Fig. 6.

Figure 7 shows the results which are relatively good. The spectrum is limited and the risetime is surprisingly fast. The over- and under-shoot is somewhat disappointing. This occurs in filters which consist of only inductance and capacitance.

In conclusion, it is observed that the digital circuit designer who is aware of EMC problems, must look at the frequency domain and not only at the time domain or a false picture may result. Theoretically, everything is contained in the time domain which is only differently presented in the frequency domain. The problem rests with the linear presentation and the resolution of the oscilloscope. Using a generally poor oscilloscope will not lead to a theoretically optimal solution.

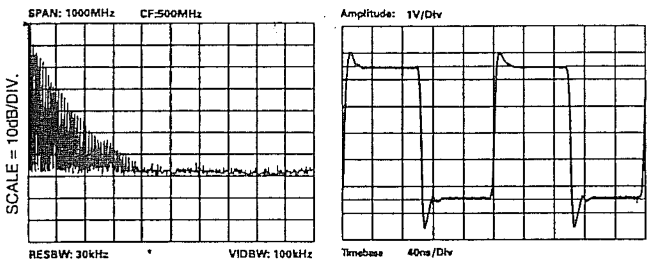


Fig. 7.

Measurement of the Shielding Attenuation of Shielded Housings with the E-Field Probe

What are the results if I surround the entire equipment in a shielded housing? This question will be asked if I fail the CE-Mark EMC test. Unfortunately, this question can not be answered in general because a metallic housing is not always a good shield. No one wants to wait until the next full-scale EMC test for the results. What if the unit under test fails again? What is needed is a simple measurement procedure to determine the relative improvement of the radiated RFI. For this purpose the highly sensitive E-Field probe is used, which is used as broad bandwidth measurement antennas to help answer the above questions.

First, before the E-field probe is used, determination must be made if the probe has sufficient sensitivity and bandwidth. In general, all passive probes are not usable since they have insufficient sensitivity. The simplest solution to determine the sensitivity and bandwidth is to measure the existing ambient field in the practitioner's laboratory that is generated by the surrounding transmitters from 0 to 1,000 MHz. **Figure 8** shows the result of such a measurement which was made with the active E-field probe from the PR-261 probe kit connected to a spectrum analyzer. From 0 to 50 MHz, Figure 8 shows relative high levels which originate from transmitters in the broadcast band and shortwave region. In the frequency range near 100 MHz signals from FM stations are noticeable. Since in the particular case measured, there were no nearby FM transmitters, the amplitudes are relatively low. The strongest signal observed was a UHF TV transmitter at 474 MHz which was located only 15 km from the laboratory. Then up to 800 MHz are several weaker (more distant) UHF TV transmitters. The final signals occur above 900 MHz which are related to cellular telephones. This data shows that the probe is wideband and has sufficient sensitivity. From the AM band around 1 MHz to the cellular telephone band there are spectrum

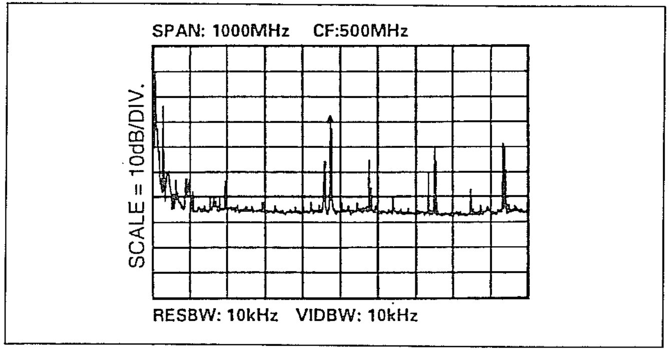


Fig. 8. Measurement of the Ambient Spectrum

lines which are significantly above the noise level. Of course, the spectrum display will be different at each location depending on the relative distance of transmitters. Even in rural areas cellular telephone frequencies must show. Absence of these frequencies show that the probe has insufficient sensitivity at the higher frequencies.

The measurement of the ambient spectrum serves not only to determine probe sensitivity. If the measurements are not performed in a shielded room, the ambient signals can also serve as a reference to recognize the most important frequencies which do not originate from the unit under test.

To perform the measurements, the unit under test is set up, without the additional shield, at a minimum distance of 0.5 meter from the probe. Then the unit under test is rotated in azimuth to find the maximum of the radiation. At this point the data is recorded as shown in **Figure 9**.

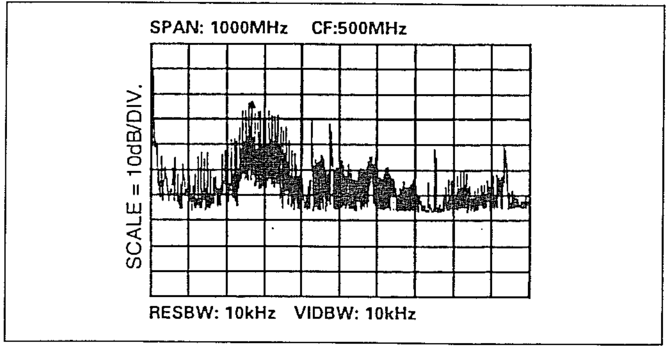


Fig. 9. RFI Characteristics without Additional Shield

Comparison of Figure 9 with Figure 8 shows that RFI is radiated up to a frequency of 1 GHz. The maximum of the radiated power occurs at frequencies between 250 to 350 MHz. The strongest signal is at the marker frequency of 275 MHz at a level of 42.8 dBm.

Next, the same measurement is performed with the additional shielding around the unit under test. Again the unit under test must be rotated in azimuth until the maximum RFI is observed. The direction may be different than in the non-shielded equipment.

Figure 10 shows the data with the additional shield. By comparing Figure 10 with Figure 9, it is observed that the entire spectrum is lower. The shielding attenuation can be determined from these two figures. For the marker frequency of 275 MHz a signal of -55.9 dBm gives a shielding effectiveness of [-42.8(-)-55.9 dBm] of 13.1 dB. For the frequency of

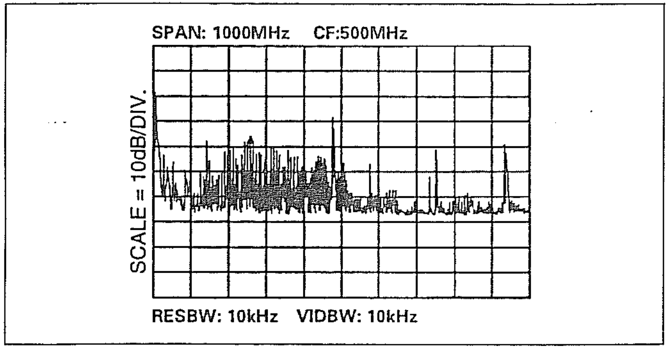


Fig. 10. RFI Characteristics with the Additional Shield

800 MHz, the shielding effectiveness is only 9 dB. Shielding effectiveness of this magnitude are hardly worth the additional sheet metal. But such results are quite common. These measurements were performed on a low-price frequency counter. There is other equipment where similar results are obtained because the radiation may also occur from windows and other openings in the housing or cables connected to the unit under test. However, it is cost-effective to measure before spending money for sheet metal.