EMI Debugging with the R&S®RTO and R&S®RTE Oscilloscopes

Application Note

Products:

- R&S®RTO
- R&S®RTE

This application note offers a straightforward description of how to analyze EMI problems using the R&S®RTO and R&S®RTE. The discussion begins by covering the basic mechanisms that can result in unwanted RF emissions and then describes how to proceed in analyzing EMI problems. Finally, a practical example is given to illustrate the analysis process.

Application Note

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1 Introduction

To some extent, all electric as well as electronic devices emit unwanted electromagnetic fields and transmit unwanted disturbance voltages and currents via their connection lines. In order to prevent such electromagnetic interference affecting the operation or radio reception of other devices, legal limits for emissions are stipulated by law in every economic region.

EMC conformity tests are used to verify compliance with required limits. Time-consuming debugging is typically required in case of noncompliance. Prompt analysis of EMI problems starting in development is a key success factor for products that need to be launched onto the market in due time.

The powerful FFT function in the R&S®RTO and R&S®RTE digital oscilloscopes from Rohde & Schwarz allows analysis of EMI problems right at the developer's own workplace. With their 1 mV/div sensitivity, up to 4 GHz bandwidth and very low input noise, these oscilloscopes are a very useful tool in this application. Developers can use near-field probes as well as current probes to localize and analyze unwanted radiated emissions and disturbance currents and develop efficient solutions to reduce them.

This application note provides a simple guideline to help hardware developers analyze EMI problems using near-field probes in conjunction with digital oscilloscopes. The actual analysis process is demonstrated based on a practical example using the R&S®RTO.

2 Basic Principles of Radiated Emissions

As a basic rule, radiated emissions can occur only when the following conditions are fulfilled:

a) An interference source exists that generates a sufficiently high disturbance level in a frequency range that is relevant for RF emissions (e.g. fast switching edges)

b) There is a coupling mechanism that transmits the generated disturbance signals from the interference source to the emitting element

c) There is some emitting element that is capable of radiating the energy produced by the source into the far field (e.g. a connected cable, slots in the enclosure or a printed circuit board that acts as an antenna)

We will consider all three of these elements in the following section.

2.1 Interference Sources

Modern digital circuits use square-wave signals at high frequencies with steep rise and fall times in order to transmit digital information. Single-ended (asymmetrical) signal transmission (e.g. parallel address or data buses) is typically used between the different components, although differential (symmetrical) transmission is also used in case of very high clock speeds (e.g. differential clock lines). Such devices generate electromagnetic energy with a high-frequency spectrum that is capable of being radiated. Due to the technology used, the circuit components have low supply voltages and are therefore at the same time sensitive to electromagnetic disturbance affecting the system from outside, e.g. via the power supply network.

Parts of a circuit, such as switched mode voltage converters that rely on switching operations with steep edges, can also act as an interference source with a number of high-frequency harmonics.

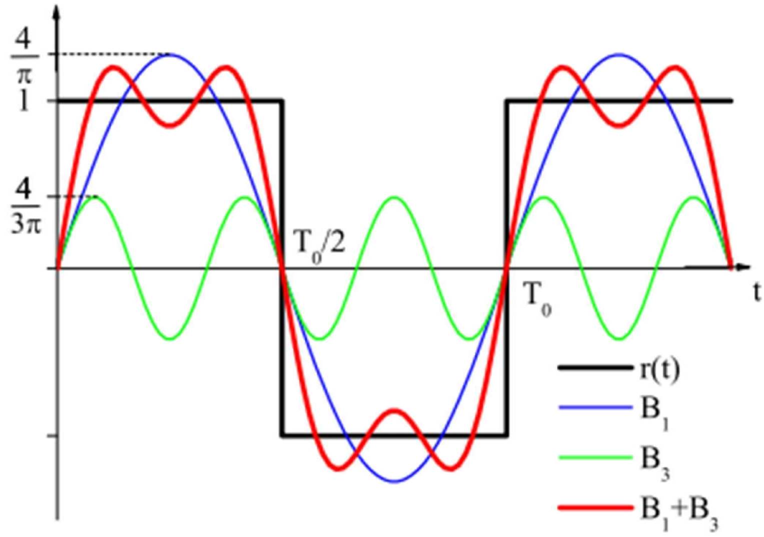


Fig. 2-1: Square-wave signal with odd harmonics.

Although the amplitude of the harmonics decreases with frequency (20 dB per decade for square-wave signals, 40 dB per decade above a certain cutoff frequency for signals with a finite rise time), harmonics play an important role in unwanted radiated emissions. At higher frequencies, disturbance signals are radiated more efficiently because the conductor structures used in electronic systems begin to reach the order of the wavelength of the disturbance signals (see section 2.1.2). For this reason, when using switched mode power supplies, it is typical to first see the high harmonics as a disturbance spectrum in the far field, for example.

In the case of unshielded systems, the actual emission of the interference into the far field occurs, for example, directly via the tracks or components on the printed circuit board. In the case of shielded systems, unwanted RF emissions can occur due to openings in the shielded enclosure or due to an RFI current that is coupled onto a connected cable.

2.1.1 Differential-Mode RF Emissions

Differential-mode RF emissions from printed circuit boards occur due to the flow of current (I_{DM}) via signal paths in which the forward and return conductors are not routed together, thereby forming a conductor loop. In this case, the interference source is a result of the circuit's primary function, i.e. transferring data between two components of the circuit. The EMI problem is caused by inappropriate arrangement of the tracks. The resulting magnetic field from the conductor loop is proportional to the current I_{DM}, the area of the loop and the square of the frequency of the RFI current.

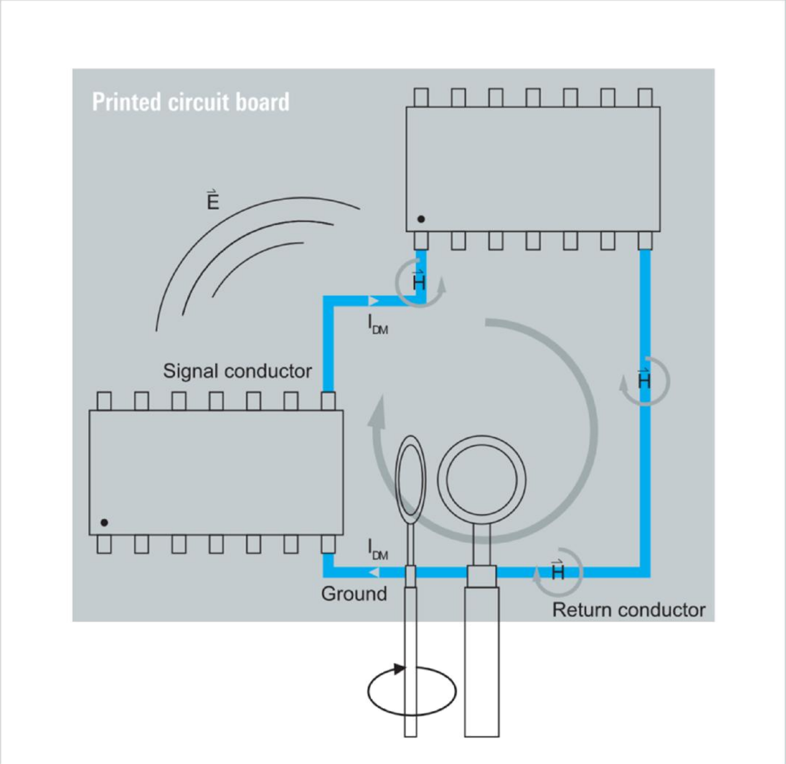


Fig. 2-2: Differential-mode RF emissions from printed circuit boards and positioning of loop near-field probes for measuring such emissions.

Near-field test equipment can be used to detect sources of differential-mode RF emissions. Here, we use loop antennas with appropriate directivity, and the loop antenna must be rotated during the measurement in order to find the maximum value of the RF emissions. This is especially important for comparison measurements after taking corrective measures to eliminate the interference since the radiation pattern can be affected by such measures. Furthermore, the magnetic near field drops off sharply with distance. This makes it important to record the measured values at the exact same location.

Steps that can reduce differential-mode RF emissions include reduction of the loop area (i.e. closer routing of the forward and return conductors) as well as reduction of the current in the conductor loop if this is possible without impacting the circuit's operation. Another alternative, for example, is to reduce the rise/fall times for the transmitted data signals or use filtering to eliminate higher-frequency signal components and thus limit the disturbance spectrum.

2.1.2 Common-Mode RF Emissions

Common-mode RF emissions occur due to undesired parasitic effects, e.g. due to inductances in the current return path or unsymmetries during signal transmission. This problem is very common with multilayer printed circuit boards in cases where slots or other discontinuities in the ground plane prevent the return current for transmitted signals from flowing close to the signal line. This leads to an undesired inductance in the path of the return signal and thus to unwanted voltage differences between different points in the ground plane. If we connect a cable to a printed circuit board of this type, it will function like an antenna and allow a common-mode current I_{CM} to flow. In the frequency range relevant for RF emissions, signal and power supply lines can function as very efficient antennas. Here, our rule of thumb is that line lengths that do not exceed λ/10 are uncritical, whereas longer lines (e.g. λ/6) must be treated as potential sources of RF emissions.

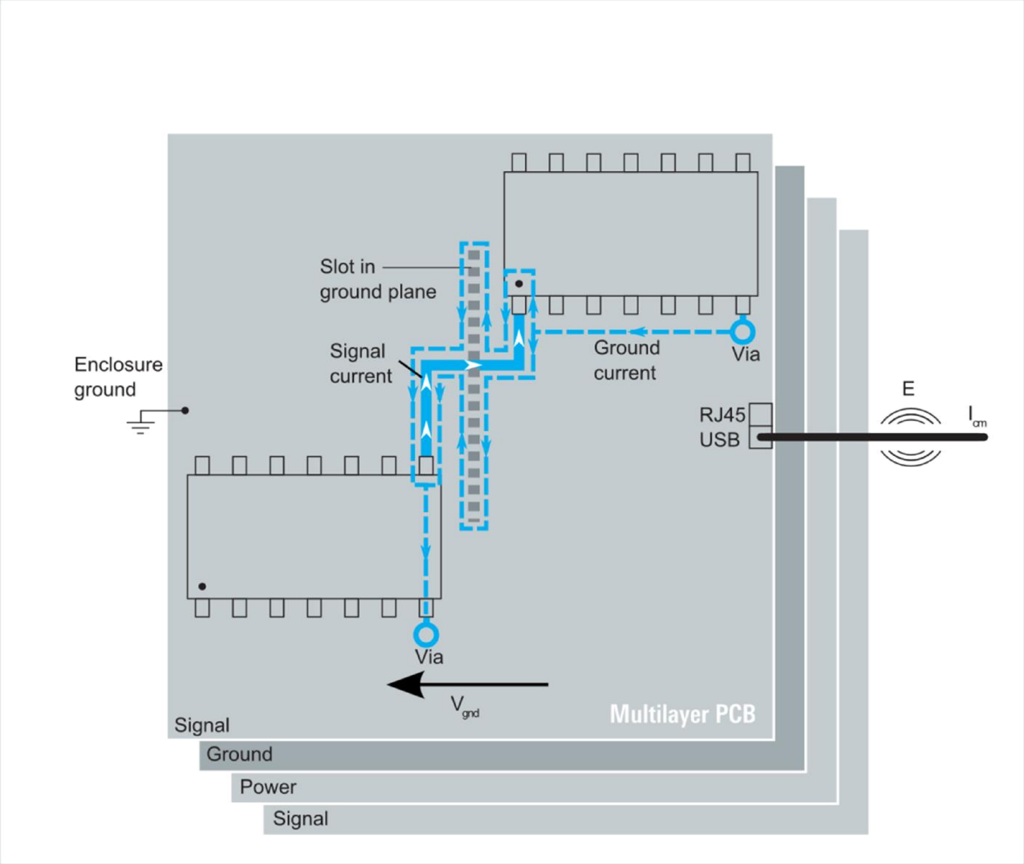


Fig. 2-3: Common-mode RF emissions from a printed circuit board. The source is a slot in the ground plane which causes a parasitic inductance in the return conductor. This causes a voltage drop between different points in the ground plane.

The magnitude of the voltage drop on the ground plane and thus the magnitude of the common-mode current coupled into the connected line are determined by the parasitic inductance and the slope steepness of the signal. Common-mode RF emissions can therefore be reduced by limiting the rise and fall times (i.e. the frequency spectrum) and reducing the impedance in the ground plane. Since we are typically unable to sufficiently reduce the slope steepness for high-speed digital signals without incurring a loss of functionality, the handling of the return current (path with lowest possible inductance) is a critical element in the design process.

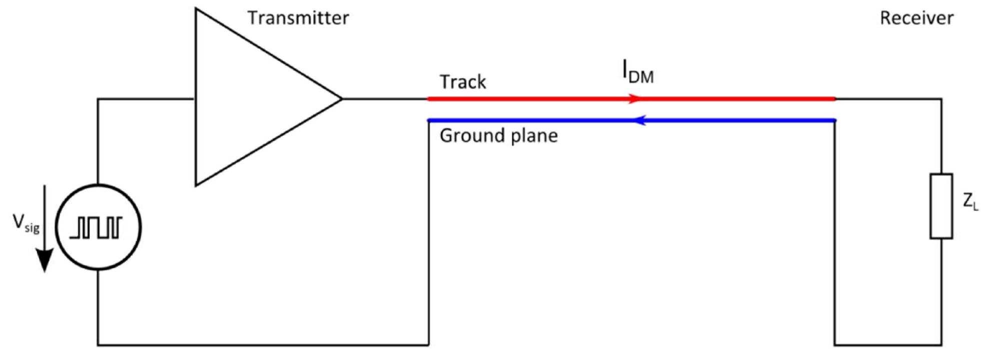


Fig. 2-4: Ideal differential-mode transmission: The forward and return conductors are arranged close to one another while the generated magnetic field is almost entirely canceled out in the far field.

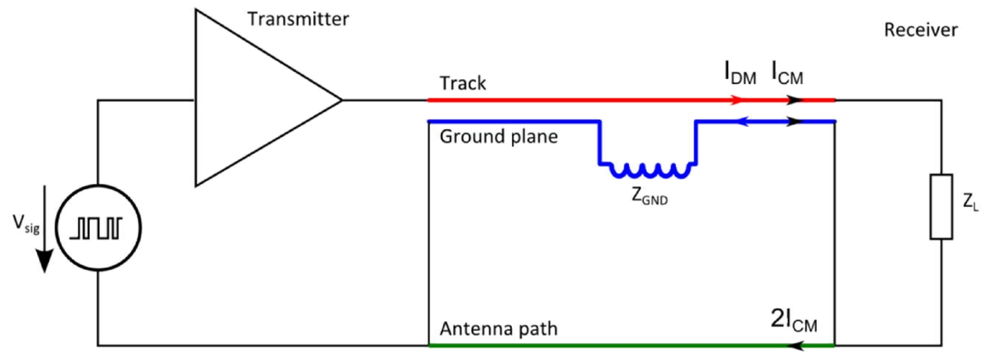


Fig. 2-5: Formation of a common-mode return current via the antenna path due to undesired parasitic inductance in the ground plane. Here, the "antenna path" is typically an external line that functions as an antenna, e.g. a power supply cable.

In actual practice, common-mode RF emissions can also occur due to differential-mode signal transmission. If the parasitic terminating impedances of a differential-mode transmission path differ substantially, in addition to the desired differential-mode current I_{DM} a common-mode current I_{CM} will also flow via the ground plane that connects the transmitter and receiver modules. This unwanted ground current I_{CM} can then also be coupled into lines connected to the board and cause emissions in the far field.

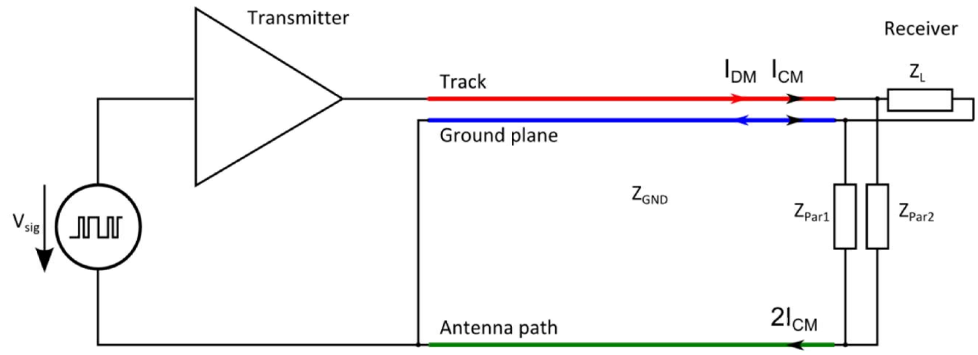


Fig. 2-6: Unbalanced (parasitic) terminating impedances of a differential-mode signal line that causes an unwanted common-mode current I_{CM}. A line connected to the ground plane can thus function as an antenna if it is capable of carrying a part of the common-mode current I_{CM}.

In practice, common-mode currents are one of the main causes of undesired RF emissions. Near-field test equipment can be used to detect sources of common-mode RF emissions. Magnetic near-field probes that are capable of detecting common-mode current (or the resulting field) are suitable for this task. Using compact near-field probes such as the RS-H 2.5-2 included in the R&S®HZ-15 near-field probe set (see section 3.3.3) for determining the current in individual tracks, it is possible to calculate the actual common-mode RFI current using a conversion factor. Of course, the near-field measurements must be supplemented with measurements of the common-mode current along the connected lines.

General steps to help reduce common-mode RF emissions:

- Reduce the RFI current I_{CM} by optimizing the layout, reducing the ground plane impedances or rearranging components
- Reduce higher-frequency signal components through filtering or by reducing the rise and fall times of digital signals
- Use shielding (lines, enclosures, etc.)
- Optimize the signal integrity to reduce unwanted overshoots (ringing), see also section 2.1.4

2.1.3 Conducted Emissions

The lines connected to a device are often the primary source of RF emissions. Electromagnetic waves in the frequency range from 30 MHz to 1 GHz have wavelengths from 10 m to 30 cm. Cables can thus efficiently radiate an RFI current (see section 2.1.2) since their length is in the range of these wavelengths in standard test setups required for far-field measurements.

Radiation of common-mode currents is especially efficient. Although the fields that arise along the cable due to differential-mode currents cancel out partially, this is not the case for common-mode currents. The radiated field strength is directly proportional to the common-mode current.

Near-field measurements can be used to detect the interference sources. By measuring the RFI current on the lines connected to the DUT, we can ascertain whether a connected line is causing RF emissions into the far field.

RF current probes are used to measure the common-mode current and are available in different versions (for different cable diameters and frequency ranges). During these measurements, it should be taken into account that the RFI current varies as a function of its position on the line.

2.1.4 Signal Integrity Problems as an Interference Source

When transmitting signals with high slope steepness, it is no longer reasonable to neglect the propagation velocity, i.e. the time required for the signal to travel from the transmitter to the receiver. Impedance mismatches on the transmission path cause reflections, where part of the signal wavefront returns to the source and is superimposed on the original signal.

When digital signals are transmitted, this effect leads to ringing artifacts and thus to the formation of disturbance signals which can be emitted. All of the components along the transmission path (e.g. transmitter, track, cable, connector, receiver) must be matched to the relevant characteristic impedance in order to ensure proper signal integrity as an essential prerequisite to achieving EMC compliance.

If the signal integrity is inadequate, we can analyze the problem by measuring the signals, e.g. at the transmitter output or the receiver input. After conversion to the frequency domain by means of an FFT, the spectrum of the interference source can be compared to the result of a far-field measurement in order to determine the corresponding source.

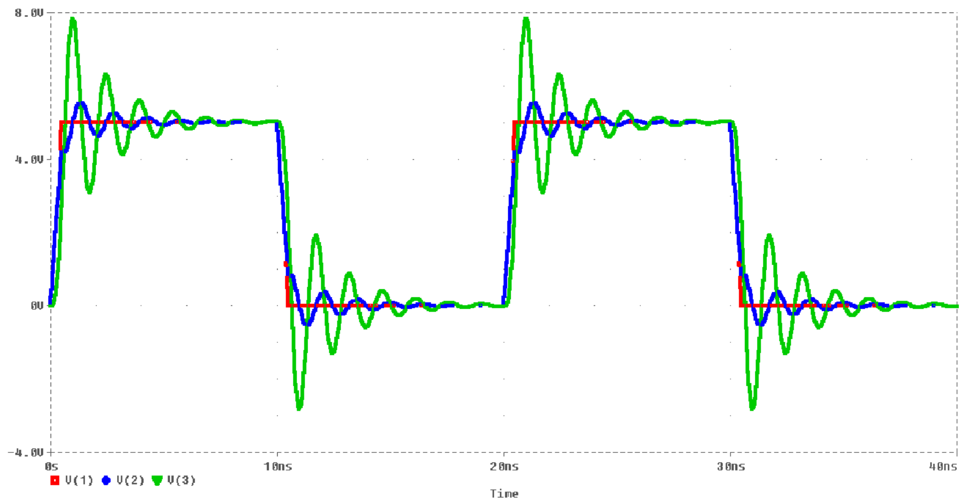


Fig. 2-7: PSpice simulation of ringing: transmission of a clock signal with 0.5 ns rise time/fall time and 20 ns pulse width via a 100 Ω unterminated line; propagation time on the line: 0.1 ns; source impedance of transmitter: 10 Ω. (Red) transmitted clock signal; (blue) signal at transmitter output; (green) signal at receiver.

2.2 Coupling Mechanisms

For interference generated on a printed circuit board to be emitted, the RFI power must be transferred from the source to the emitting element. This is known as the "coupling path" and the transmission type is referred to as "coupling mechanism".

We basically distinguish between the following coupling paths:

1. Direct RF emissions from the source, e.g. from a track or an individual component
2. RF emissions via connected power supply, data or signal lines
3. Conducted emission via connected power supply, data or signal lines

Potential coupling mechanisms are as follows:

1. Coupling via a common impedance

   In this case, the interference source and emitting element are connected via a common impedance.

   This situation occurs frequently since a direct connection usually exists in electronic systems between an interference source and an emitting element (e.g. the common ground of an affected digital circuit (interference source) and the cable screen or ground conductor of a connected signal cable (antenna)).

2. Coupling via fields

   a. Electric field

   In this case, an electric near field is generated emitted by the interference source. This field is coupled into an adjacent circuit or an emitting element (e.g. heat sink) and then radiated into the far field or emitted in a conducted manner. The parasitic coupling capacitance between the interference source and sink influences the energy transfer as a function of frequency.

   b. Magnetic field

   In this case, an electric circuit produces a magnetic near field, which couples into an adjacent conductor loop or a magnetically sensitive component. The resulting energy transfer is determined by the coupling coefficient between the circuits and the current in the interference source.

   c. Electromagnetic field

   In this case, the interference source and sink are far apart, i.e. at least one λ or a multiple thereof. Both an electric field and a magnetic field are generated. The source emits the interference directly into the far field.

2.3 Emitting Elements (Antennas)

The emitting elements that are relevant in EMI applications are basically unintentional antennas.

The efficiency of such antennas (radiation resistance, antenna factor) depends on the geometry of the antenna. The main factor is the length of the antenna with respect to the wavelength of the interference.

Antennas with lengths of only a fraction of the interference wavelength, e.g. $\lambda/6$, can be efficient radiators. The rule of thumb here is that antennas with a length less than $\lambda/10$ are not critical.

The following are the main types of unintentional antennas in electronic equipment:

- Connected lines (power supply, data/signal/control lines)
- Printed circuit board tracks and planes
- Internal cables between system components
- Components and heat sinks
- Slots and openings in enclosures

3 Measurement Methods for Use in EMI Debugging

3.1 Introduction – Near Field and Far Field

In EMC compliance testing, we really only care about the DUT's emissions into the far field. We use the term "far field" if the electric and magnetic field components are in phase and oriented perpendicular to the direction of propagation and a plane wavefront has formed. The electromagnetic wave has separated from the antenna and is now dependent on the propagation conditions in the medium (as opposed to the characteristics of the source). For radiators that are small with respect to wavelength, the far field begins at a distance of about $\lambda / 2\pi$, while for antennas that are large with respect to wavelength, it does not begin until $2 \cdot D^2 / \lambda$. Here, D is the diameter of the antenna structure.

The far-field measurements required in regulatory compliance testing are feasible only in specialized EMC test labs (test chambers or open-area test sites) and tend to be costly and time-consuming. When problems occur with EMC compliance, cost and time limitations typically prevent multiple visits to the test lab in order to develop and analyze improvements. However, other measurement methods do exist that can be used to analyze EMI problems. For applications in development labs, near-field and RFI current measurements are an attractive alternative.

The near field comprises electric and magnetic field components that drop off by a factor of $1 / r^2$ or $1 / r^3$ with distance. In EMC compliance testing, only the far field is relevant; it drops off proportional to $1 / r$ as the distance from the source increases. In the near field, the electric and magnetic field components are not yet tied to the characteristic wave impedance of free space (377 Ω). The wave is not yet disconnected from the transmitter and the field components still depend on the characteristics of the source. For this reason, we cannot draw any conclusion about the far field (and thus EMC compliance) from levels we measure in the near field.

However, the opposite conclusion is possible: If we can measure electromagnetic waves in the far field, then electric as well as magnetic field components must be present in the near field. For example, if we determine during an EMC compliance test that the DUT is producing unacceptable levels of radiation, we can use near-field probes to locate the source of such emissions.

When interpreting results delivered by a near-field probe, we must always take into account whether relevant antenna structures (e.g. connected cables or long tracks) are present that radiate into the far field. Near-field emissions with high amplitudes need not necessarily lead to strong far-field emissions.

In addition to near-field measurements, it is also important to measure the RFI currents that flow, for example, on connected signal or power supply cables of the DUT in order to analyze the cause of RF emissions.

As a general rule, it is recommended to perform a far-field measurement in order to identify the critical frequencies prior to analysis with near-field probes. The actual interference sources can then be localized with a near-field measurement. Once the coupling mechanism into the far field has been identified, suitable corrective action can be taken to eliminate the problem.

3.2 RFI Current and Voltage Measurements

3.2.1 Relationship between RFI Currents on Connected Lines and Emitted Far-Field Components

A typical radiation mechanism involves common-mode RFI currents that flow on the inside conductor or the screen of lines connected to the DUT. Because such lines usually have a length of at least one meter, they represent efficient antennas in the frequency range from 30 MHz to 1 GHz which is highly relevant in EMC compliance. As such, they are often the most critical emitting element. The resulting field strength in the far field is directly proportional to the RFI current; steps to reduce this current thus lead to a direct improvement in radiated emissions. The following formula [1]

$$E[\mu V/m] = 4 \cdot \pi \cdot 10^{-7} \cdot f[Hz] \cdot l[m] \cdot I_{CM}[\mu A] \cdot sin(\Theta) \;/\; r$$

provides a simple estimate of the maximum permissible common-mode RFI current on connected lines (based on the assumption of a dipole antenna). Here, l is the line length, r is the distance between the source and receiving antenna, I_{cm} is the common-mode RFI current and Θ is the angle with respect to the dipole.

For an angle Θ = 90°, a measurement distance of 3 m, a frequency of 100 MHz, a cable length of 1 m and an RFI current of 2.5 µA, an RF emission field strength level of about 100 µV/m (= 40 dBµV/m) is obtained. For example, this corresponds to the Class B limit in line with EN55022. It is thus clear that even RFI currents on the order of 2.5 µA can violate EMC compliance limits.

3.2.2 How to Utilize RFI Current Measurements

By measuring the common-mode current on the lines connected to the DUT, we can determine whether any lines produce emissions present in the far field and if so, what lines. If the RFI currents are negligible on all connected lines, then another mechanism must be responsible for RF emissions (e.g. RF leakage through the enclosure due to insufficient RF shielding).

Moreover, by comparing the spectrum of the RFI current with the measured spectrum in the far field, we can determine the main interference source on the printed circuit board. For example, if a broadband interferer is present in the far field with a maximum value at 100 MHz and an interferer with a similar spectrum is detected in the near field, we have obviously found the source of the interference in the near field. CW interferers can be treated analogously. For example, if harmonics of 25 MHz are present in the far field and an interference source is detected in the near field with a comparable harmonic spectrum, it is most likely the interference source we are seeking.

Due to the direct proportionality between the electromagnetic waves emitted into the far field and the RFI current, proposed improvements are easy to evaluate.

Reproducible measurement conditions are a critical element of such comparison measurements. It is important to pay special attention to the fact that the RFI current varies as a function of its position on the line. Due to reflections on the connected line, standing waves can arise which lead to different RFI currents at different locations on the line. In order to be able to measure the resulting improvement in far-field emissions, a current probe (see section 3.2.4) must be used to measure the maximum RFI current on the line (e.g. a power line). The line length should not be changed during the procedure. In addition, problematic standing waves can be attenuated using absorbing clamps (ferrites) on the end of the line if necessary.

Fig. 3-1: R&S®EZ-24 absorbing clamp for attenuation of standing waves during measurement of the RFI current.

Generally, when measuring radiated emissions in development labs, it is important to pay attention to whether the measured emissions could possibly represent ambient interference. It is thus recommended to make a preliminary measurement with the DUT switched off in order to isolate and measure the ambient interference.

3.2.3 Measurement of RFI Voltages on Power Lines

RFI voltage measurements are also used to determine the RFI current that propagates along connected lines. Such measurements are performed on power lines using line impedance stabilization networks (LISN), e.g. V-LISN on AC/DC power supply lines and T-LISN on telecommunications lines. Line impedance stabilization networks are intended to simulate the impedance of the power supply network or the cable impedance, filter out extraneous interference from the connected power supply network and make the RF interference generated by the DUT available at a measurement output.

Fig. 3-2: R&S®ENV216 two-line V-network for measuring conducted emissions

RFI voltage measurements can be used as a substitute for RFI current measurements as well as for debugging in cases where excessive radiated emissions are occurring. It is important to recall that line impedance stabilization networks are normally used for frequency ranges below that of standard current probes.

3.2.4 Current Probes for Measuring RFI Currents

RF current probes are used to measure RFI currents and are available for different cable diameters and frequency ranges. The following aspects are essential when debugging EMI problems:

- The inner diameter of the current probe should allow good magnetic coupling and therefore needs to be matched to the cable diameter.
- The frequency response should be as flat as possible in the frequency range of interest.
- The current probe's transfer impedance Z should be as high as possible in order to display the measured current as an "amplified" output voltage V. The measured current can then be easily calculated as follows: $\mathrm{I}_{cm}[\mathrm{dB\mu A}] = U[dBuV] - Z[dB\Omega]$.
- The current probe should be designed as a clamp so that it can be easily attached around the line.
- One example of a device suitable for RFI current measurements is the Rohde & Schwarz R&S®EZ-17 current probe with 20 Hz to 100 MHz bandwidth and 10 dBΩ (model 02) or 17 dBΩ transfer impedance (model 03).

Fig. 3-3: The R&S®EZ-17 current probe with 10 dBΩ transfer impedance (model 02) or 17 dBΩ transfer impedance (model 03) and 20 Hz to 100 MHz bandwidth is a good example of a device suitable for measuring RFI currents. The large inner diameter of 30 mm allows measurements on cable bundles.

For current measurements, absorbing clamps such as the R&S®MDS-21 can also be used, or ferrite clamps such as the R&S®EZ-24 without a measurement output in combination with any current probe that has adequate sensitivity and bandwidth along with the appropriate diameter.

3.3 Analysis of EMI Problems Using Near-Field Probes

The main purpose of near-field probes is to measure the electric or magnetic field produced by a DUT in a precisely defined area near the probe with the highest possible sensitivity. Special shielding techniques are used in probes to suppress unwanted fields from other directions. Furthermore, near-field probes are designed to detect either magnetic or electric fields and to suppress the other field component as much as possible. This allows detailed analysis of the relevant near field along with pinpoint detection of interference sources. For example, there exist special near-field probes that can be used to isolate and detect the emissions from individual tracks on a printed circuit board. This allows identification of the track responsible for the radiated emission to be examined. Other types of probes are specially designed to measure currents in IC pins or in decoupling capacitors.

3.3.1 Electric and Magnetic Near-Field Probes

Electric near-field probes suppress the magnetic field component and produce an output signal proportional to the electric field component (E) of the near field. Using a frequency-dependent transducer factor (K_e), we can calculate the electric field strength in the probe's near field as follows:

$$E[dB\mu V/m] = U[dB\mu V] + Ke[dB/m].$$

Magnetic near-field probes suppress the electric field component and produce an output signal proportional to the magnetic field component (H) of the near field. Using a frequency-dependent transducer factor (K_h), we can calculate the magnetic field strength as follows:

$$H[dB\mu A/m] = U[dB\mu V] + Kh[dBA/(Vm)].$$

The magnetic near field is caused by an RF current. Using another transducer factor (K_i) that is likewise frequency-dependent, we can estimate the current causing the field:

$$I[dB\mu A] = U[dB\mu V] + Ki[dBA/V].$$

The transducer factors are normally specified by the probe manufacturer. However, they can also be determined independently based on a constant reference field.

Magnetic near-field probes in particular are typically not isotropic, i.e. the measured field strength is dependent on the direction of the field, the selected position of the probe and naturally the distance to the source. For this reason, the probe should be placed directly on the relevant interference source (e.g. a track) and rotated until the maximum value is measured for the field. This procedure increases the reproducibility of repeat measurements, e.g. after undertaking steps to solve the problem.

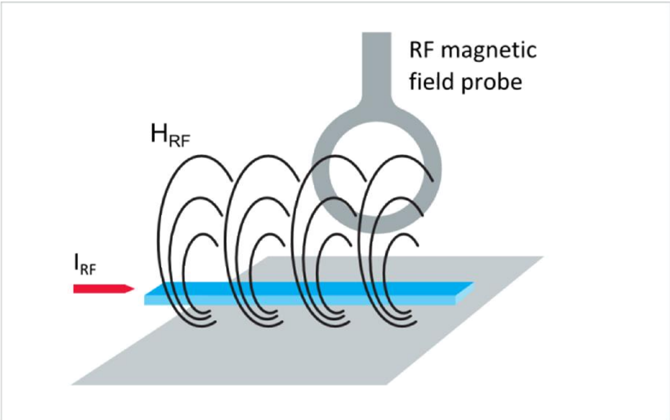


Fig. 3-4: Formation / orientation of a magnetic near field caused by an RF current along a conductor.

In general, magnetic near-field probes have better interference immunity than electric near-field probes, making them easier to use. Furthermore, both differential-mode as well as common-mode RFI currents predominantly cause a magnetic near field and can thus be detected with magnetic near-field probes. For this reason, measurements using magnetic near-field probes represent the preferred diagnostic technique (in addition to RFI current measurements on connected lines).

Electric near-field probes are used to perform comparative measurements of the electric field, analyze and detect coupling mechanisms, and measure switching edges on signal lines and in DC supply systems, to name some examples. They are especially suited to applications where the emission is due primarily to changes in electric potential (as opposed to electric currents). Moreover, they are often helpful when looking for leaks in shielding enclosures.

3.3.2 Applications for Near-Field Probes

Near-field probes are a useful tool for performing detailed analysis of EMI problems on printed circuit boards. The main applications include localization of interference sources and identification of decoupling mechanisms.

- Localization of interference sources on printed circuit boards

  Depending on the actual near-field probe used, the spatial region in which the probe will detect electric or magnetic fields is necessarily small. By moving the near-field probe over the DUT's printed circuit board, it is possible to determine at which position a disturbance spectrum of interest has its maximum value. There, we will often find the source of the interference that is causing a problem in the far field. This can involve individual tracks, bus systems, power supply planes, ICs, heat sinks and even switching transistors.

  A near-field probe can also be used to study the current distribution in a ground plane. In this manner, we can determine whether the return current is flowing via the intended path or is unintentionally distributed due to breaks in the ground plane.

  Probing decoupling capacitors provides a way to assess the effectiveness of power supply decoupling measures. Using a magnetic near-field probe such as the RS-H 2.5 from the R&S®HZ-15 near-field probe set, it is possible to measure the current through the decoupling capacitor and understand how well it suppresses radiated emissions. At higher current levels, the decoupling is generally more effective. By choosing a different type of decoupling capacitor, changing its value and if necessary modifying how it is connected in the layout to the power supply and ground, we can maximize the measured current in the capacitor and thus optimize its decoupling effect.

- Identification of decoupling mechanisms

  In combination with measurement of the RFI current on connected lines, near-field probes can be used to clarify whether the measured near fields are coupled into the far field via the connected lines. If this is not the case, near-field probing can be performed around slots in the enclosure to determine whether inadequate shielding is the cause of unwanted far-field emissions.

Once we have identified the interference sources and the decoupling mechanism, the next step involves finding ways to solve the problem. This includes (for example):

- Testing the signal integrity on critical transmission paths in the DUT. Typical problems here include ringing, e.g. due to inappropriate termination of the transmission lines
- Reducing the slope steepness or filtering transmitted signals in order to reduce the amplitude of the harmonics. Above a certain order, harmonics generally have no substantial influence on the signal integrity but they are emitted more easily due to their higher frequency
- Modifying the layout e.g. optimizing the routing of the return current in cases where single-ended (asymmetrical) signal transmission is used

- Reworking how power is supplied to critical components (power bus design)
- Shielding and filtering lines, e.g. using SMD ferrites, common-mode chokes or cable ferrites
- Improving the shielding of the enclosure

3.3.3 The R&S®HZ-15 Near-Field Probe Set

During analysis of EMI problems, a set of different near-field probes can be very helpful. The R&S®HZ-15 set contains two electric and three magnetic near-field probes of different sizes that are ideal for this application.

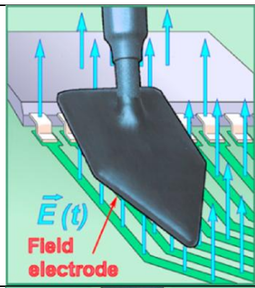
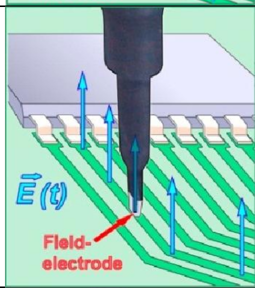
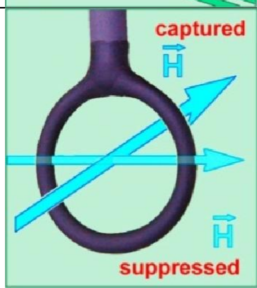
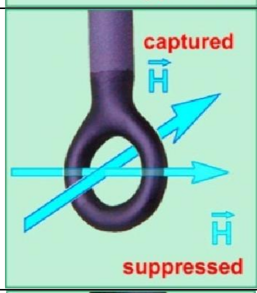
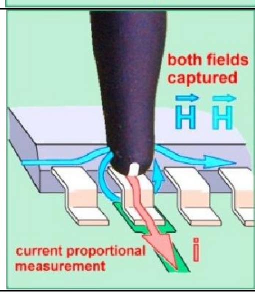
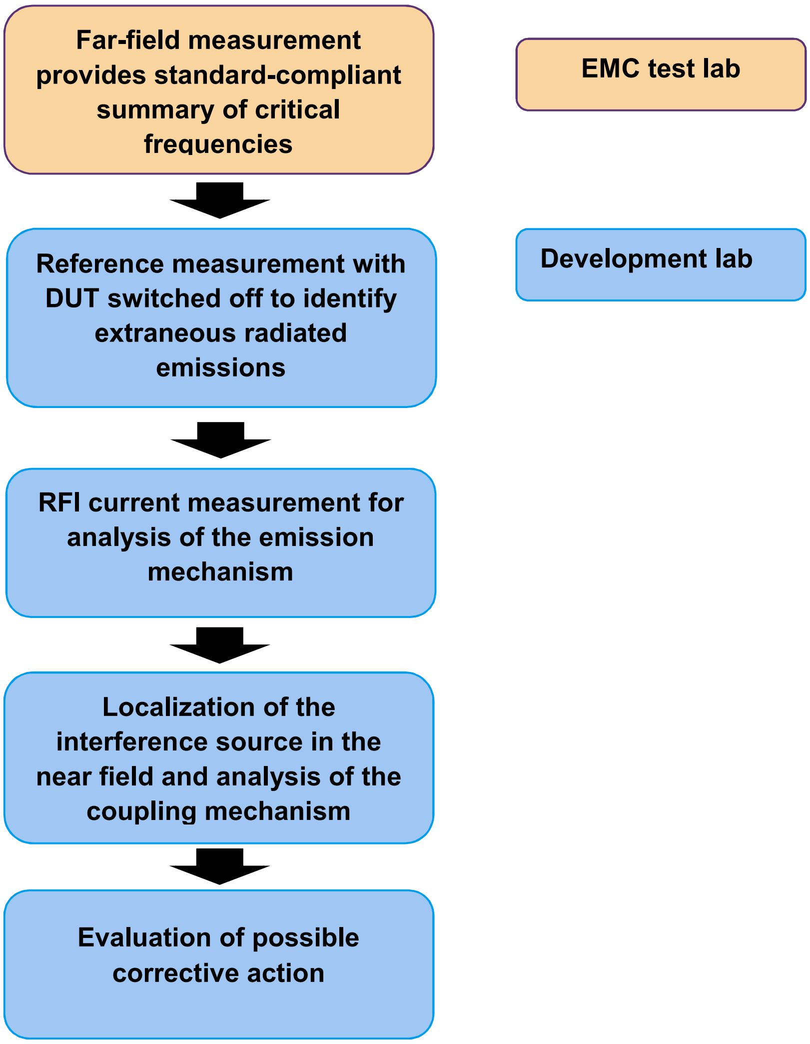
RS-E 02: Large-area near-field probe for measuring electric fields emitted from structures that have a larger surface area (e.g. address or data buses, heat sinks, areas on printed circuit boards). Electric fields are measured with the probe's bottom side; the top side is electrically shielded. If possible, the entire probe should be placed on the DUT. Measurement uncertainties due to an undefined distance between the probe and source (or emitting element) can be reduced in this manner.	
RS-E 10: Near-field probe with very high spatial selectivity for measuring electric fields. The probe's shielding suppresses fields from adjacent structures. Its resolution is approx. 0.2 mm, making it possible to locate the tracks with the highest disturbance level in a group of tracks.	
RS-H 400-1: Magnetic near-field probe with high sensitivity but relatively low spatial selectivity. Very useful for performing an initial analysis in cases requiring coarse measurement and localization of interferers. This probe is directional and must be rotated during the measurement until the maximum value is found.	
RS-H 50-1: Magnetic near-field probe with significantly higher resolution than the RS-H 400-1 but also significantly lower sensitivity. This probe is directional and must be rotated during the measurement until the maximum value is found.	
RS-H 2.5: Magnetic near-field probe with high spatial resolution; especially useful for measurement of RF currents in and along conductor tracks, components and their leads as well as for detection of interferers within bus systems. Can also be used to determine the current on the surface of ICs or through capacitors. Consists of a core with a gap of 0.5 mm. The magnetic field is detected at the gap (white line). The probe is placed with the gap directly on the interference source. This probe is directional and must be rotated during the measurement until the maximum value is found.	

Table 3-1: R&S®HZ-15 near-field probe set.

4 Practical Aspects of EMI Debugging with the R&S®RTO Digital Oscilloscope

4.1 Basic Procedure for EMI Debugging in Development Labs

The following flowchart illustrates the basic procedure for EMI debugging. The process is typically based on the results of a far-field measurement which provides a standard-compliant summary of the critical frequencies.



The actual debugging process begins once the results from the far-field measurement are available. The recommended procedure is as follows:

1. Reference measurement with DUT switched off to identify extraneous RF emissions

   Prior to beginning EMI debugging in the development lab, it is recommended to perform a reference measurement with the DUT switched off. In this manner, we can ensure that any RF emissions from other equipment in the lab or from radio services will not be incorrectly identified as RF emissions from the DUT. This is a crucial step when making measurements with electric near-field probes as well as RFI current measurements on lines. Magnetic near-field probes are often immune to extraneous RF emissions.

2. RFI current measurement if any lines are connected to the device

   In many cases, lines connected to the device turn out to be the emitting elements we are looking for. An RFI current measurement is used to determine which lines are radiating the disturbance signal into the far field. Once the source has been identified on the printed circuit board, the coupling mechanism can be tracked from the interference source on the board to the emitting element. The coupling mechanism is highly relevant when working to reduce the RF emissions.

3. Near-field measurement using different probes for locating the interference source

   The best approach here is to begin with a large magnetic near-field probe such as the RS-H 400-1 loop antenna (R&S®HZ-15) and look for the interference source on the printed circuit board. By then switching to smaller loop antennas such as the RS-H 50-1 and the RS-H 2.5, we can further localize the interference source (see page 22).

   It is best to use magnetic near-field probes since they have better immunity to undesired interference compared to electric near-field probes.

4. Analysis of possible corrective action

   Once the interference sources, coupling mechanisms and emitting elements are known, possible solutions can be implemented and analyzed. Near-field probes or even current probes for RFI current measurements can be easily employed to study the effect of the proposed solutions with respect to the RF emissions. Here, it is important to always make comparison measurements with near-field probes at the same point; the near-field probe must be rotated to detect the maximum value. This is necessary since a potential solution can change the polarization of an RF emission. During RFI current measurements on connected lines, it is likewise important to always check for the local maximum of the RFI current.

4.2 Using the R&S®RTO for EMI Debugging

4.2.1 Basic Oscilloscope Settings

Use the following short steps to configure the R&S®RTO for EMI debugging:

- Press PRESET to obtain a defined setup
- Connect the current probe (for RFI current measurement) or the near-field probe to any input channel
- Select a vertical resolution in the range from 1 mV/div to 5 mV/div for high sensitivity
- Select 50 Ω coupling (for proper matching to the output impedance of the current probe or near-field probe that is used)
- Set a horizontal deflection of about 50 µs/div. This will allow detection of interferers that occur at least once in the signal recording interval of 0.5 ms
- Activate the FFT (select the FFT toolbar symbols and click on the appropriate input signal)
- Enable the color table for spectral display of the FFT (menu: Display – Signal Colors – Enable Color Table)

These basic settings ensure that RF emissions can be easily measured with high sensitivity. At the same time, the overlap FFT function is automatically activated with a large number of individual spectra. Together with the color table, we are then able to easily monitor how the RF emissions in the displayed spectrum vary over time.

4.2.2 Special R&S®RTO Functions for EMI Debugging

High acquisition bandwidth and easy navigation in frequency range

One crucial benefit of using the R&S®RTO to analyze EMI problems is the high acquisition bandwidth with the spectral analysis function. In this manner, it is possible to measure the entire input spectrum at once (limited only by the oscilloscope's bandwidth). Unlike the case when using spectrum analyzers, it is not mandatory when localizing RF emissions on a printed circuit board to activate a max. hold function and wait for the entire spectrum to be processed. The near-field probe can be moved over the board with no delay while always keeping the entire spectrum in view.

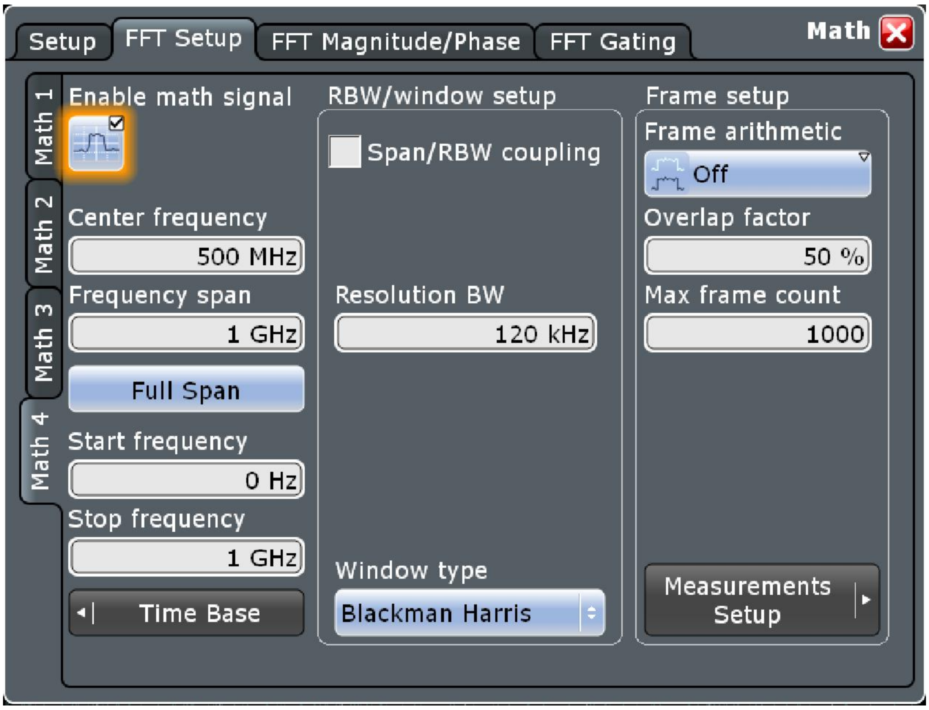


Fig. 4-1: Dialog for setting the FFT parameters: The available settings resemble those of spectrum analyzers.

The R&S®RTO's FFT function is designed to work like that of a spectrum analyzer. This means we can directly set the start and stop frequencies (or center frequency), bandwidth and resolution bandwidth. The time-domain setting (required acquisition length) is automatically adjusted. This makes it very simple to navigate within the frequency range.

When the "Span/RBW coupling" function is activated, a further input box appears for setting a fixed ratio between the span and resolution bandwidth. This ensures that if the span is changed, the resolution bandwidth is always adjusted based on a fixed ratio to the displayed bandwidth in order to ensure a consistent display on the screen at all times.

The "Frame setup" parameter group is used to configure the overlap FFT function (see below).

Overlap FFT with color-coded display of spectral components

Another key feature of the FFT function provided in the R&S®RTO is the overlap FFT. This automatically activated function makes it possible to also view the timing characteristics of the spectrum. The recorded signal is divided into a sequence of segments and the spectrum is calculated for each segment. The number of segments is automatically calculated based on the parameter settings (span and required resolution bandwidth). Here, a smaller resolution bandwidth requires a longer segment length and thus less segments (in case of a fixed record length).

The individual spectra are then overlaid in the spectral display using a color-coding scheme. Commonly occurring frequency components are displayed in a different color to distinguish them from rarer frequency components. In this manner, we can tell at a glance whether a given emission originates in a clock line with constant frequency or is associated with sporadic disturbances.

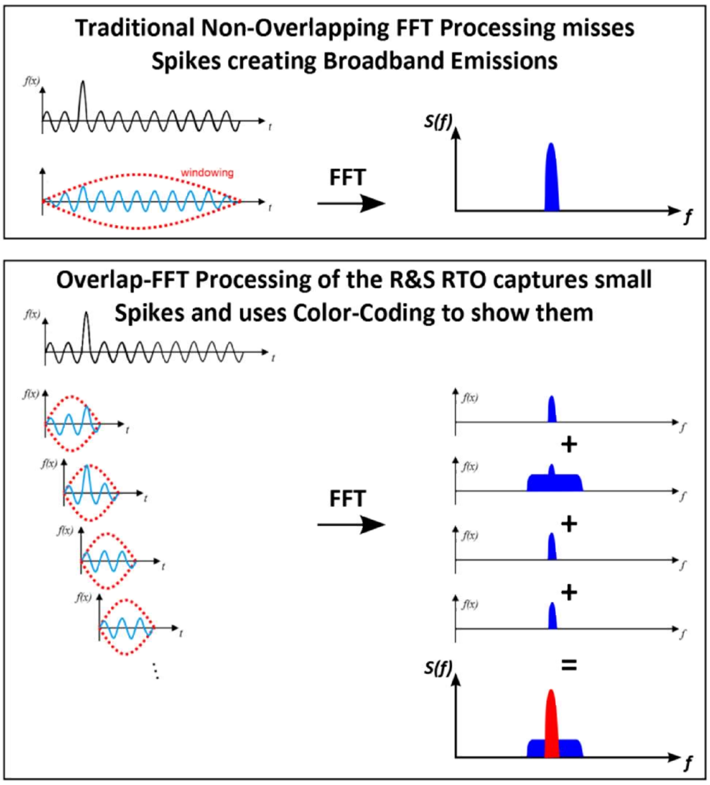


Fig. 4-2: Operation of the overlap FFT: Commonly occurring spectral components are displayed in a different color than spectral components related to sporadic signals.

The "Frame Setup" parameter group (see Fig. Fig. 4-1) is used to set the parameters for the overlap FFT function. The term "Frame" refers to the automatically generated segments of the time function. Using "Frame Arithmetic", we can choose whether all of the spectra for the individual signal segments are displayed simultaneously ("Off" selected) or whether a single average spectrum is displayed. The "overlap factor" determines the extent to which the individual signal segments overlap. A value of 50 % is typically adequate, ensuring that even the spectral components that occur in the overlap region are detected and displayed. However, this parameter can be set to any value between 0 % and 99 % if necessary.

The "maximum frame count" parameter limits the maximum number of segments to be generated. This function ensures that in case of a very large resolution bandwidth (and thus a very small segment length or a very large number of segments), an excessive number of segments to be processed is avoided. The largest possible setting is 10,000 segments in order to ensure fast spectral display. If the number of segments is restricted, the warning ("Maximum frame count reached! Frame coverage 19 %") will appear in the FFT setup dialog. The percentage indicates the part of the measured signal that is still used for spectral calculation (measured from the start of acquisition).

Gated (time-limited) FFT for correlated time-frequency analysis

The "gated FFT" function makes it possible to use only a defined part of the measured signal for spectral analysis. This allows accurate correlation of sporadically occurring spectra with the corresponding time-domain signals. This is controlled via the FFT setup dialog (see below).

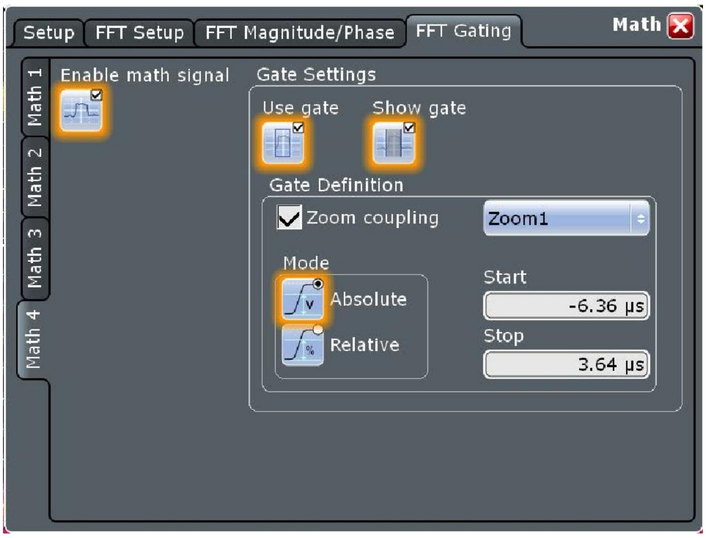


Fig. 4-3: FFT gating function: The settings are handled in the FFT dialog. The "Zoom Coupling" option can be used to automatically couple the gate to a zoom window.

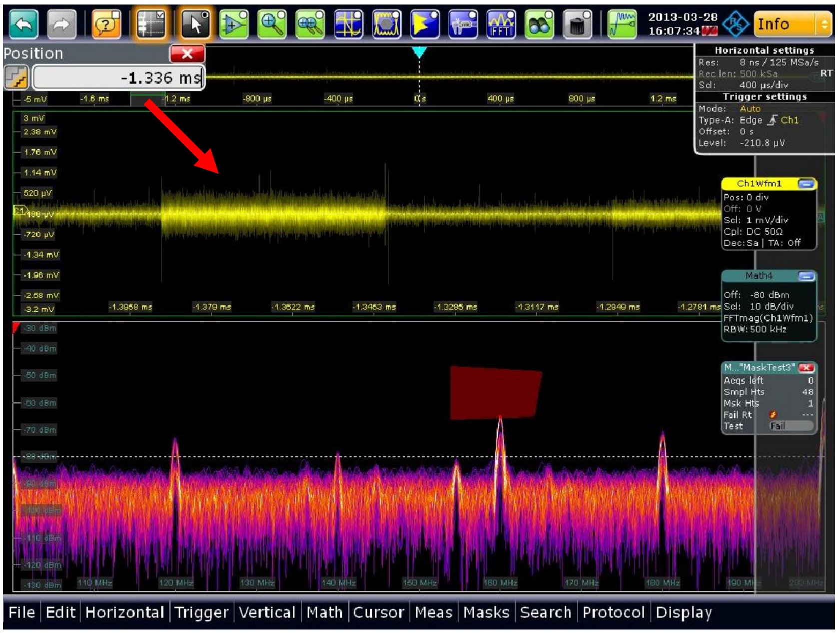


Fig. 4-4: FFT gating with coupled zoom window: The displayed spectrum is automatically limited to the length of the zoom window. By sliding the zoom window, we can accurately determine which spectral components of signals are present in the zoom window.

Frequency masks for triggering detection of sporadic events

The R&S®RTO's mask function can be used in the time domain as well as the frequency domain. Using the "Stop-On-Violation" function which is set in the mask dialog, it is easy to detect sporadically occurring spectral components. The oscilloscope automatically halts acquisition if a spectral component extends into the mask. Hard-to-analyze sporadic emissions can thus be easily captured for subsequent detailed analysis.

Since the spectrum is calculated from the saved time-domain signal by means of FFT, parameters such as the span or resolution bandwidth can be modified even after the acquisition process has completed. The only prerequisite is that in the given case, the settings for the sampling rate and acquisition length must support the desired span and resolution bandwidth.

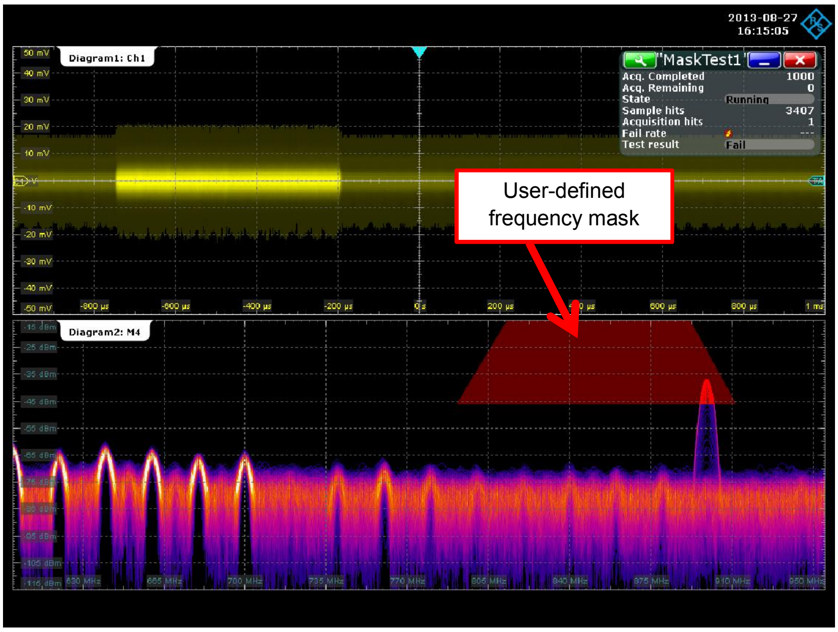


Fig. 4-5: Capturing a sporadically occurring spectral line: The mask violation halts acquisition to allow detailed investigation of the signal.

Increase in maximum record length for FFT display to allow measurement of very long signal sequences

Sometimes it is necessary to increase the maximum record length for the FFT calculation. This involves setting the "Record length limit" parameter in the horizontal setup dialog. By default, it is set to 1 MS (Msample) in order to ensure a fast response by the FFT function. Using an R&S®RTO four-channel instrument with the R&S®RTO-B101 memory expansion, this parameter can be increased up to a value of 25 MS.

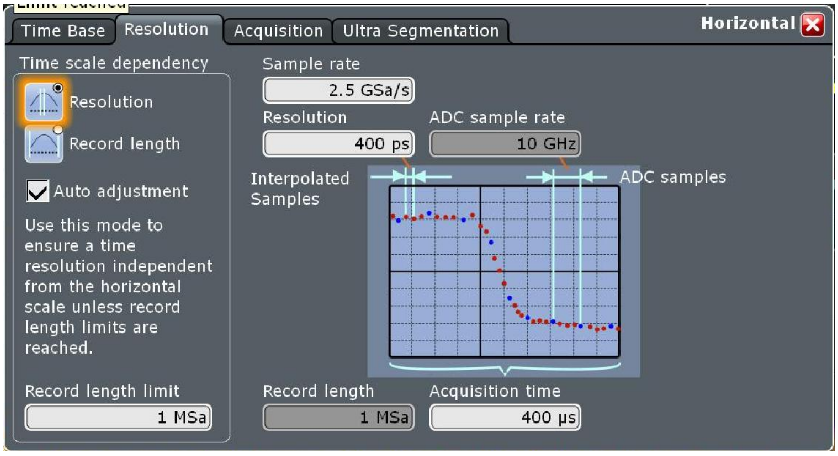


Fig. 4-6: Setting the maximum record length.

Limitations when using oscilloscopes for EMI debugging

An oscilloscope with a powerful spectral analysis function is a very useful tool for solving EMI problems. However, an oscilloscope is no substitute for a test receiver. As such, it is important to keep in mind the limitations that apply when using an oscilloscope. This includes:

- Limited dynamic range

  Oscilloscopes typically use A/D converters with significantly less resolution than test receivers and thus have much less dynamic range. In EMI debugging, this is usually not a limiting factor since in most cases we are interested only in the maximum emissions.

- No preselection

  Oscilloscopes do not have preselection. For this reason, strong interferers outside of the spectral range of interest can lead to unwanted intermodulation products in the frequency band of interest. During EMI debugging using near-field probes, this is typically not a limiting factor since the near-field probe's spatial selectivity ensures that RF emissions are measured only in the immediate vicinity of the location where the probe is placed.

- No standard-compliant detectors

  Although the R&S®RTO has average value and RMS detectors, they do not offer CISPR standard-compliant functionality. However, a CISPR-compliant detector is generally not required for EMI debugging applications.

4.2.3 Tips & Tricks for EMI Debugging with the R&S®RTO

- Avoid overloading

  In order to obtain correct results with the spectral analysis function, it is important to make sure the oscilloscope is not overloaded. Overloading occurs when the measured signal can no longer be fully displayed on the screen. This is very important when working with a near-field probe since large amplitude differences are encountered that can easily cause overloading. Besides false spectral components, false results can also be obtained for the spectral power density in case of overloading.

To avoid such situations, the time-domain signal should always be monitored on the screen in addition to the spectral signal. In case of overloading, the oscilloscope's vertical sensitivity should be reduced.

- The unit of amplitude display in the FFT spectrum can be changed in the spectral analysis dialog to the dBµV unit that is conventional in EMI test and measurement applications.

4.3 Practical Example – EMI Debugging on an IP Telephone

This section explores a practical example illustrating how to use the R&S®RTO to analyze EMI problems. Starting with the results from the EMC compliance test, we demonstrate how to analyze an EMI problem using RFI current measurements combined with near-field probing right on the development bench.

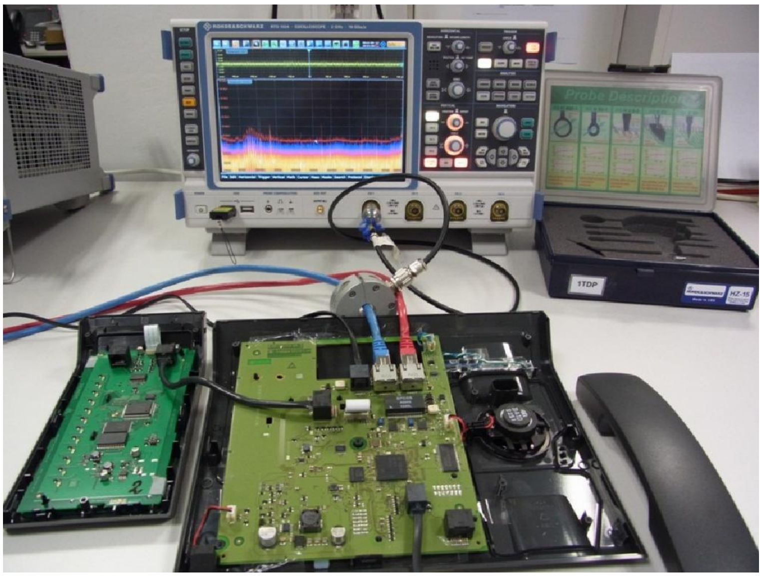


Fig. 4-7: Test setup for EMI debugging on a modern IP telephone. In this example, a current probe is connected to measure the common-mode RFI current on the connected lines.

The DUT is an IP phone consisting of a base unit and an extension unit. Each of these two devices has a control module and a display. The devices are unshielded and are connected to one another via an unshielded line. The base unit is connected to two LAN lines (Gigabit Ethernet, Power-over-Ethernet) as well as an external power supply. In addition, there are cable connections to a display and a handset.

The base unit has a complex processor with DDR2 memory, an Ethernet layer 2 switch, two Gigabit Ethernet PHYs for operating the LAN interfaces, various DC/DC converters, a display interface driver, an SPI interface to the extension unit as well as analog circuits for the loudspeaker and microphone (hands-free mode). The extension unit consists of a display driver, SPI interface module and key decoder.

4.3.1 Results of the Far-Field Analysis

The purpose of the EMC compliance test performed in a test lab (far-field measurement) is to discover the critical frequencies along with the absolute margin with respect to the legally required limits.

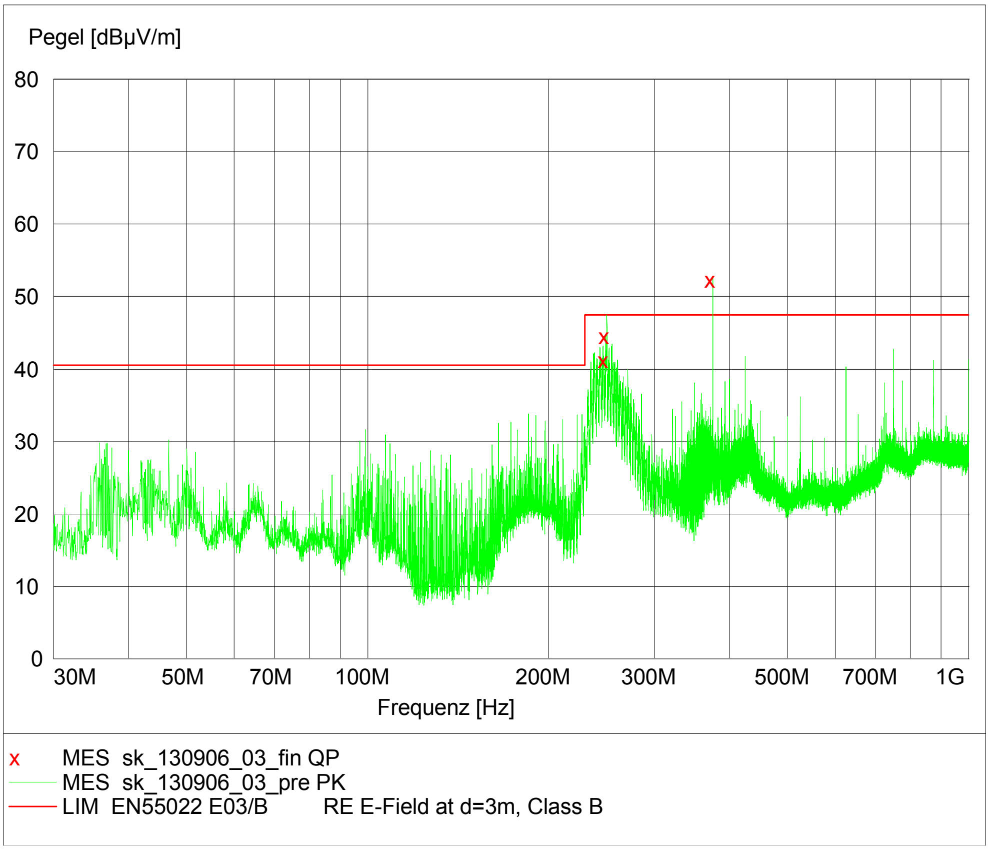


Fig. 4-8: Result of the EMC compliance test.

Frequency	Level	Transd	Limit	Margin	Height	Azimuth	Polarization
MHz	dBµV/m	dB	dBµV/m	dB	cm	deg	
248.68	41.20	17.50	47.50	6.30	0.0	157.00	HORIZONTAL
250.00	44.50	18.00	47.50	3.00	0.0	293.00	HORIZONTAL
375.00	52.30	20.30	47.50	-4.80	0.0	359.00	HORIZONTAL

Table 4-1: Summary of far-field measurement results. There are three critical frequencies. Moreover, there is a broadband disturbance signal at 250 MHz that does not violate the limit but whose emission level is just below the limit.

The results of the EMC test show we must determine the sources of the narrowband interferers at 250 MHz, 375 MHz and the other harmonics of 125 MHz. Moreover, it is also important to analyze the source of the broadband interferer at 250 MHz. Under different conditions, the broadband interferer that is currently under the limits can easily produce emissions that are over the limits during a new far-field measurement in the EMC test lab.

For precise resolution of this problem, it is important to also determine the coupling mechanism into the far field. The following preliminary analysis is useful here:

The wavelength of the highest critical frequency (375 MHz) is equal to 80 cm. At this frequency, efficient antennas require a size of at least λ/6, i.e. about 13.3 cm. Given that such line lengths do not occur on the printed circuit board, we can initially assume that lines connected to the device are causing the RF emissions. However, it is important to also consider other possible emitting elements such as heat sinks and mechanical components. Disturbance signals can be coupled to these elements, causing them to produce RF emissions.

4.3.2 RFI Current Measurement on the Connected Lines

In the first step, we measure the disturbance levels on all of the connected lines and determine the maxima. The highest RFI current is occurring on the blue LAN line (see Fig. 4-9). This line thus represents the critical antenna for decoupling into the far field. A current probe with a transfer impedance of 20 dBΩ was used for the measurement. There was no preamplifier. The level of the RFI current can thus be calculated directly as the voltage level displayed on the oscilloscope (in dBµV) minus 20 dB. In the measurement example below, we calculate a current of 14 dBµA (or 5 µA) from the displayed voltage value of about 34 dBµV at 375 MHz. Based on our estimate in section 3.2.1, this is already a critical level.

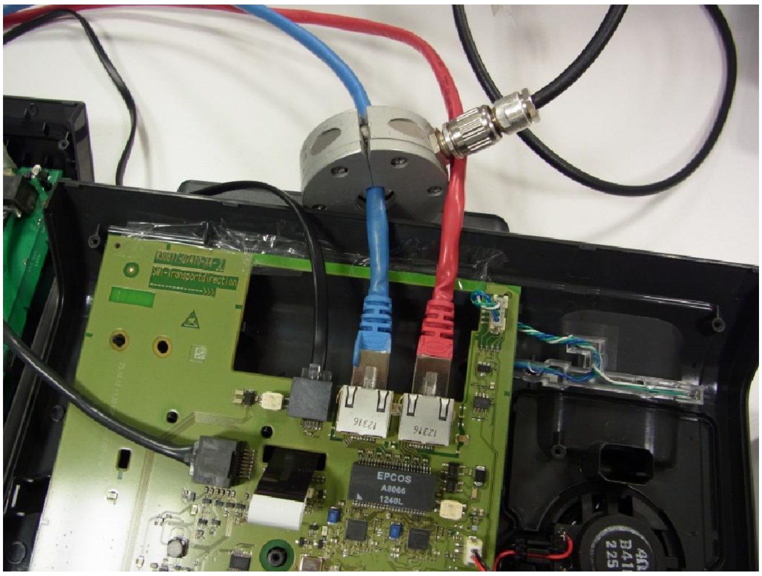


Fig. 4-9: Measurement of the RFI current on a connected LAN line using a special current probe.

Besides the emissions at 250 MHz and 375 MHz that are detectable in the far field, we see other emissions such as the broadband interferer at 360 MHz. However, the latter is not a problem for EMC compliance (see far-field measurement) and therefore does not require further consideration.

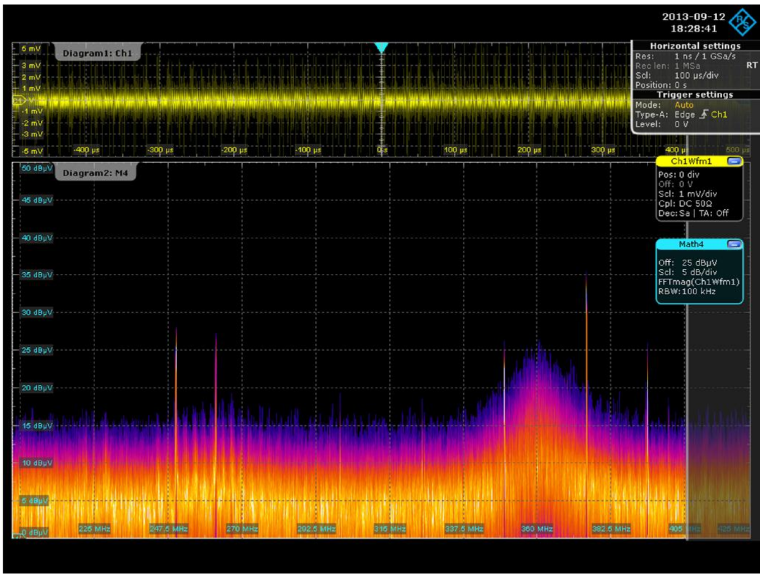


Fig. 4-10: Result of the RFI current measurement on the blue LAN line in the frequency range from 200 MHz to 425 MHz. There are clear maxima at 250 MHz, 262 MHz, 350 MHz, 375 MHz and 400 MHz along with an obvious broadband interferer at 360 MHz.

If we expect to find sporadic as well as constant interferers (or if we detected sporadic interferers during the far-field measurement), we can use the max. hold detector type (see section 4.2) to also measure this type of emission and continuously display it. Because the RFI current is a function of the position on the line, in our example we move the current probe along the line during the measurement; the maximum value is then retained by the max. hold function. For the current DUT, however, we do not obtain any new insights in terms of sporadic interferers using the max. hold function.

However, it is clear that the maximum RFI current (red spectral curve) differs significantly from the measured value at the present position of the current probe (color-coded spectrum).

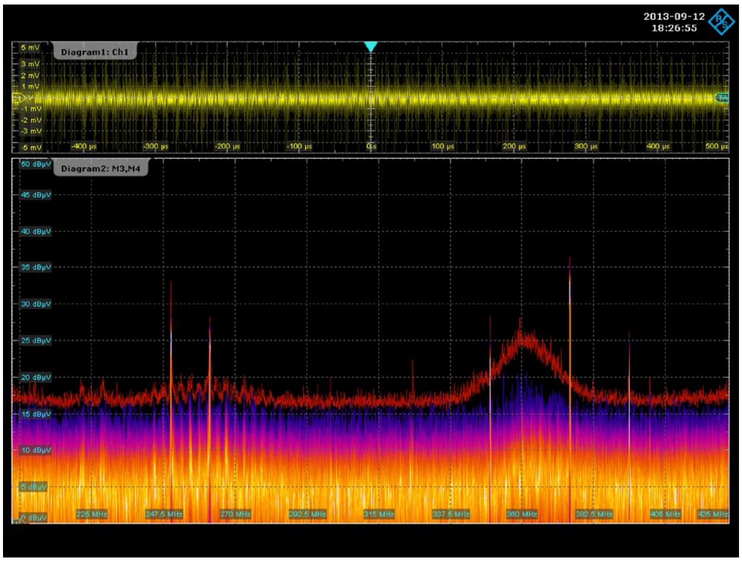


Fig. 4-11: Spectral analysis using the R&S®RTO with two spectra in the same diagram: Currently measured spectrum with color-coded display (yellow-red-blue) along with a spectrum determined using max. hold (red envelope).

We can obtain a clear visual presentation of the distinction between broadband and narrowband interferers by increasing the measurement bandwidth. Based on the color coding, spectra with a constant presence are displayed differently than sporadically occurring spectra. In the example, the white line at 375 MHz represents a constant spectrum that is produced by a clock signal with a constant frequency. Blue spectral components occurred rarely during the analysis interval.

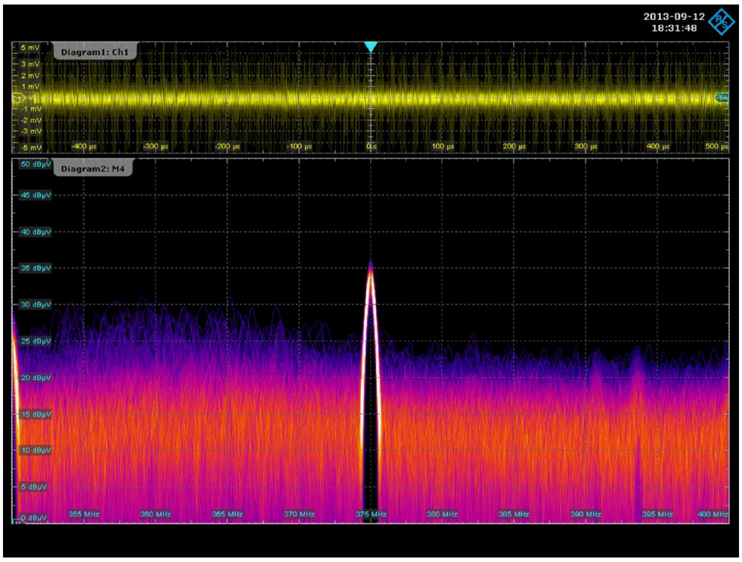


Fig. 4-12: CW interferer at 375 MHz: The white line indicates this spectrum has a constant presence. Harmonics of this type are often due to clock signals.

Fig. 4-13: RFI current measurement on the handset line.

An RFI current measurement on the handset line reveals a high RFI current at 375 MHz; the broadband interferer at 250 MHz is also visible. The handset line is therefore also an important emitting element. Since the broadband interferer at 250 MHz was not visible on any of the other lines, it is obviously radiated primarily via the handset line.

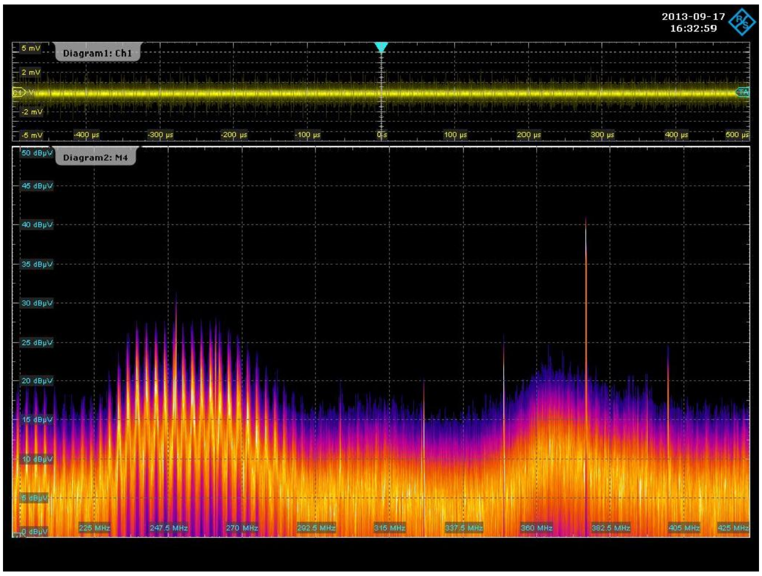


Fig. 4-14: Result of the RFI current measurement on the handset line: Besides the CW interferer at 375 MHz, the broadband interferer at 250 MHz is also clearly visible.

Using these RFI current measurements, we were able to demonstrate that the connected lines are among the major sources causing RF emissions into the far field. This follows from the amplitude of the measured RFI currents (example: Fig. 4-13; the measured voltage at the feedpoint of the current probe at 375 MHz is 40 dBµV; based on the transfer impedance of 20 dBΩ, this implies an RFI current of 20 dBµA or 10 µA).

4.3.3 Near-Field Analysis

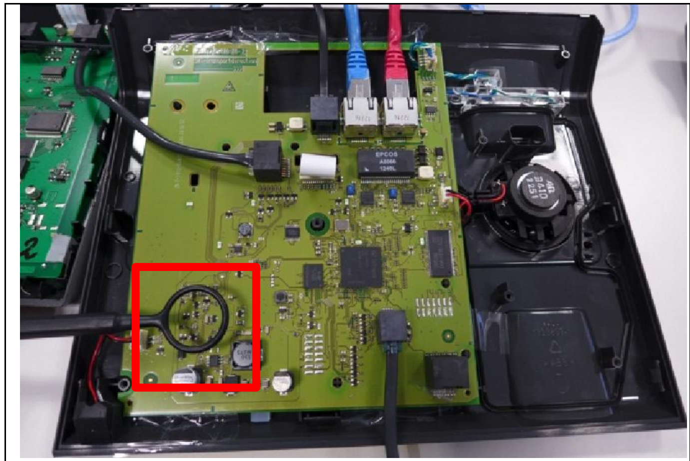
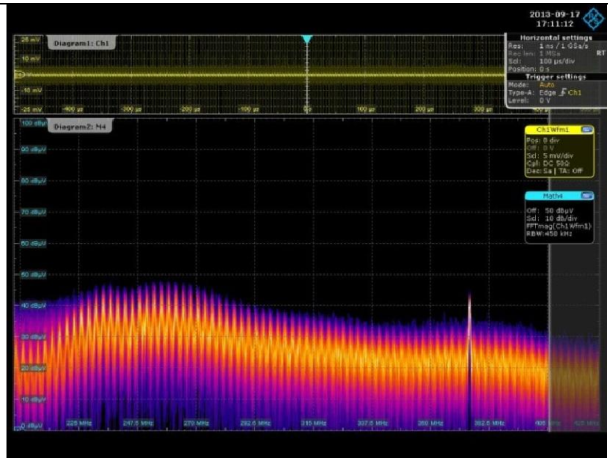
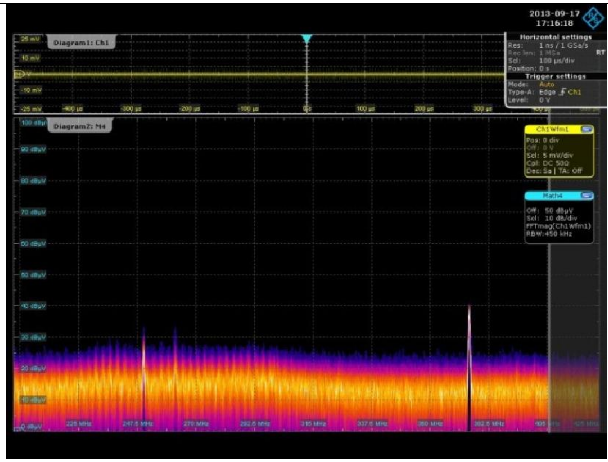
Using near-field probing, we will now localize the interference sources and determine the coupling mechanisms. We slightly modified the oscilloscope settings for this purpose, including especially the following:

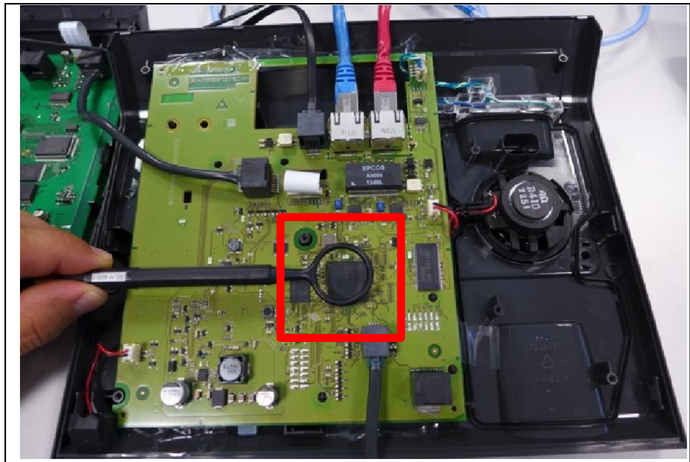
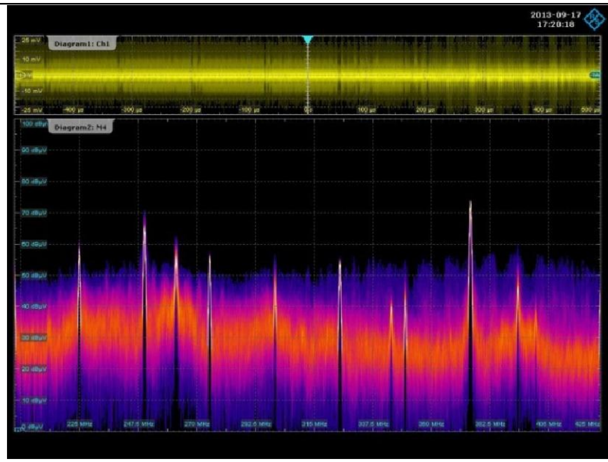
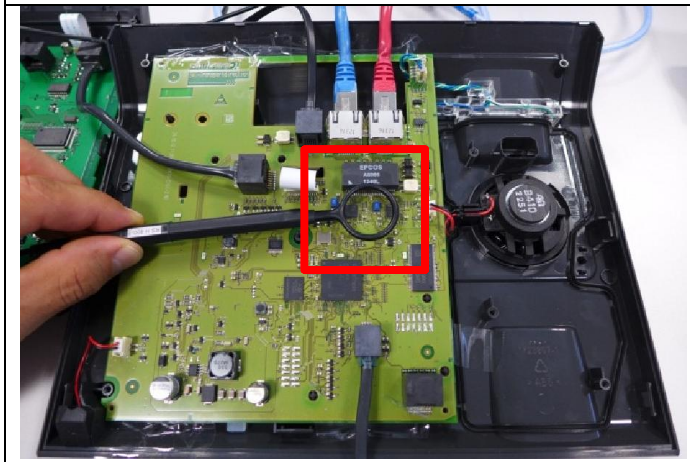
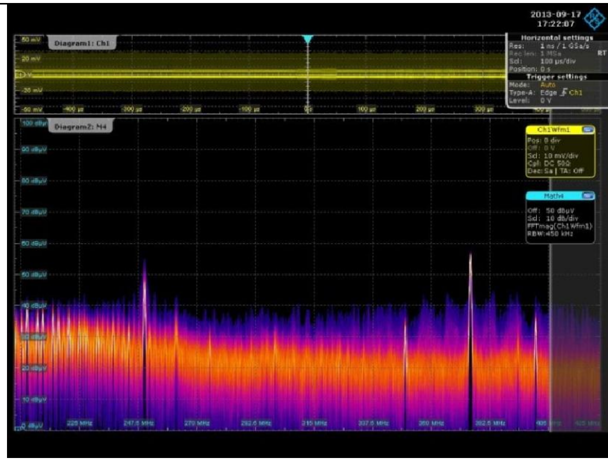
- Reduced sensitivity: 5 mV/div instead of 1 mV/Div. Relatively high levels tend to occur during near-field probing. The sensitivity needs to be reduced to prevent overloading
- Altered vertical scale: In the FFT setup dialog, we modified the vertical scale using the "manual range" option so the FFT spectrum would properly fill the screen and be easier to read

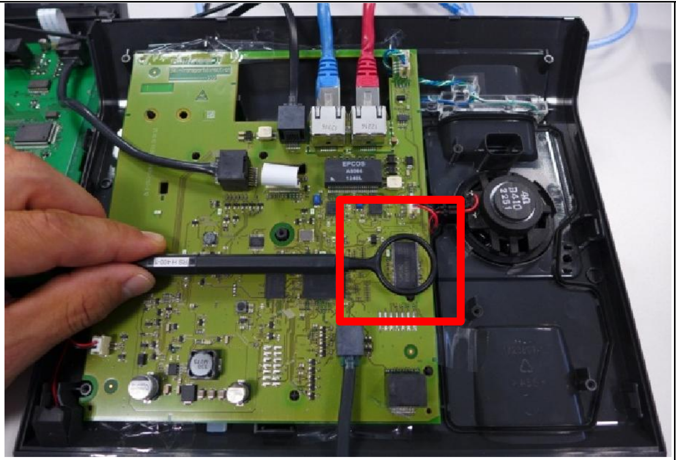
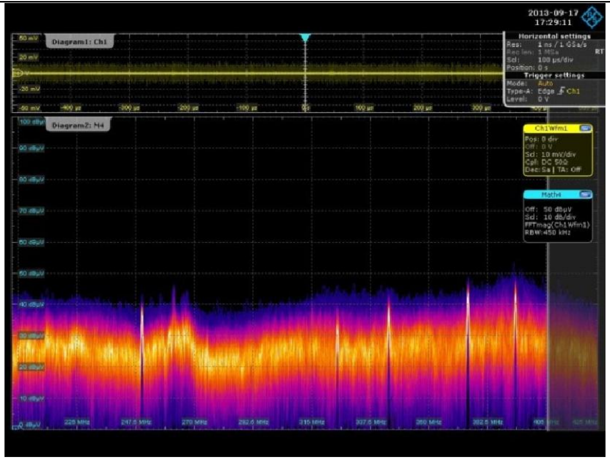
On the following pages, we have compiled photos, screenshots and explanations to show how to work with near-field probes and identify sources of interference.

- **Measurements with the RS H 400-1 large magnetic loop antenna at different positions**

Objective: Identify sources that are producing a near-field spectrum comparable to the disturbance spectrum detected during the far-field measurement or the disturbance spectra on the connected lines.

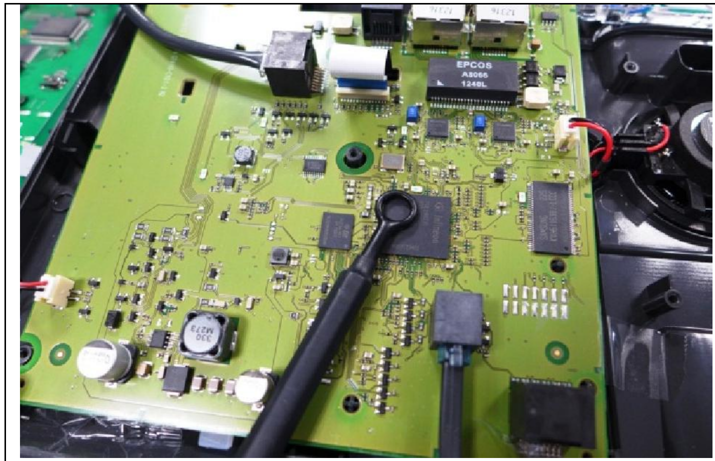
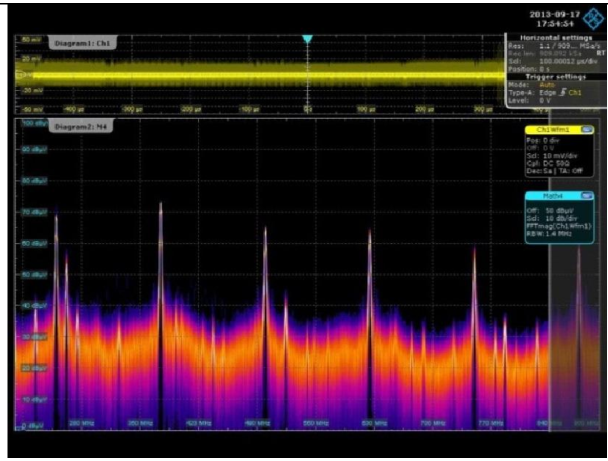
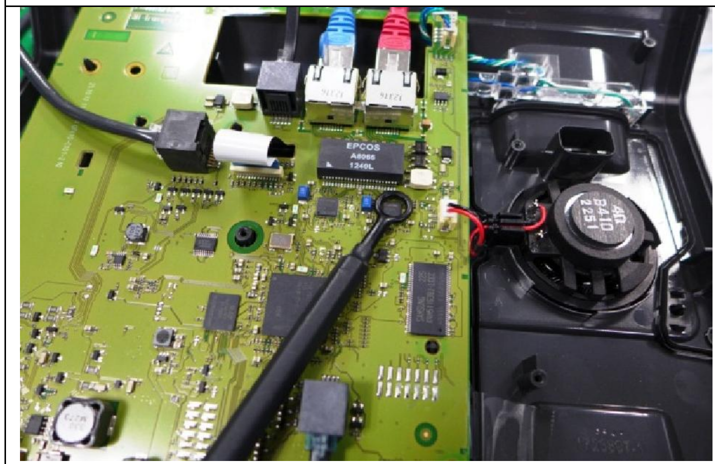
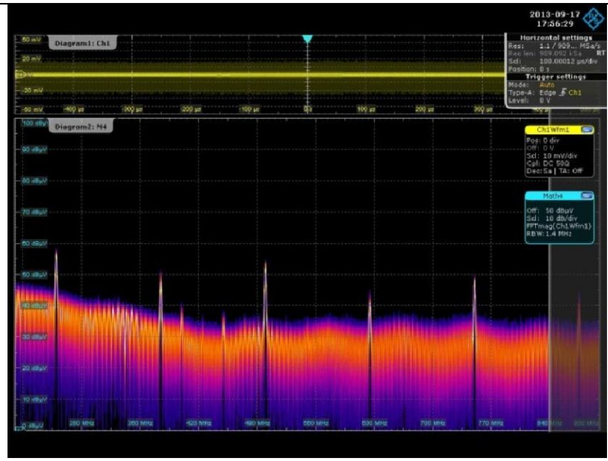
		Near-field spectrum in the region of a DC-DC main converter. We can clearly see the many harmonics produced by the switching converter. These frequencies also occur in the far field (broadband interferer at 250 MHz).
		Near-field spectrum in the region of a further DC-DC converter. Significantly lower levels compared to the measurement on the main converter. This voltage converter is thus uncritical and probably not a source of interference.

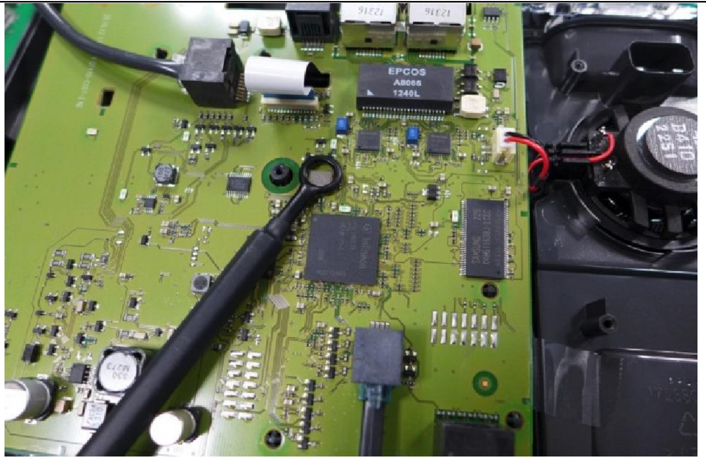
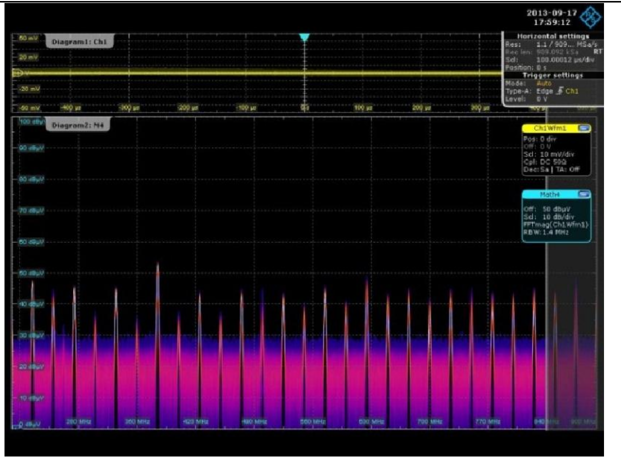
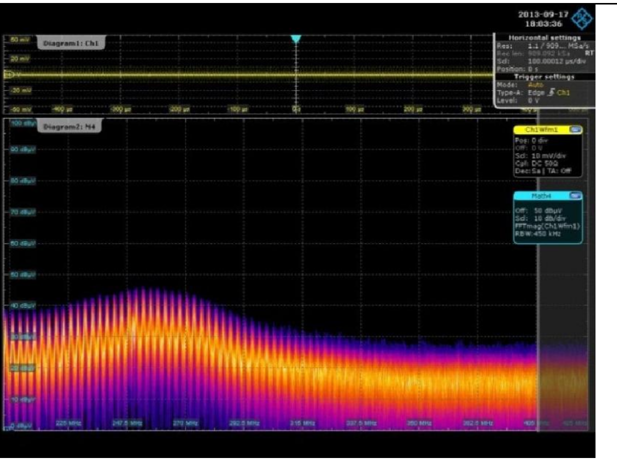
		Near-field spectrum in the region of the processor chip. Significantly heightened level for harmonics of 125 MHz, especially 375 MHz. This module is a possible source of far-field RF emissions.
		Near-field spectrum detected in the region of the Gigabit Ethernet PHY ICs. The individual clock frequencies are clearly visible, especially at 250 MHz and 375 MHz. Although the levels are lower compared to the processor chip, the PHYs directly drive the LAN interface, i.e. they are connected to the LAN cable via a transformer. Since the LAN cable is a key emitting element, we can assume the coupling path is present here.

		Near-field spectrum measured in the region of the memory chip. Here, we find significantly lower levels compared to our other measurement locations (or the disturbance spectra observed in the far field are totally absent). For this reason, this chip is uncritical.

- **Measurements with the RS H 50-1 small magnetic loop antenna**

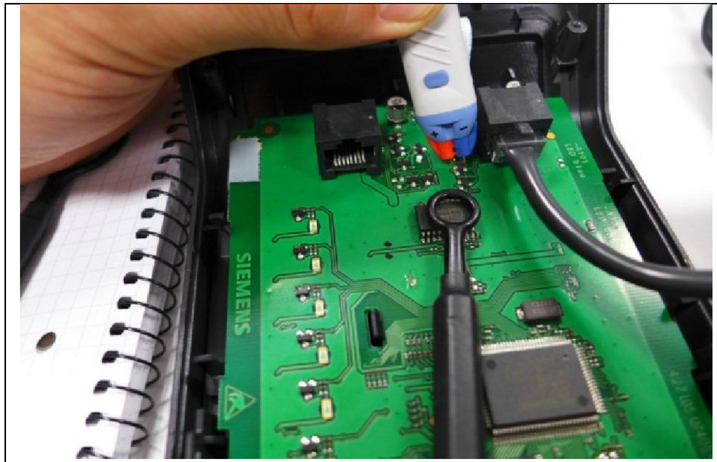
Using the smaller loop antenna, we can now further localize the sources we detected in the first step.

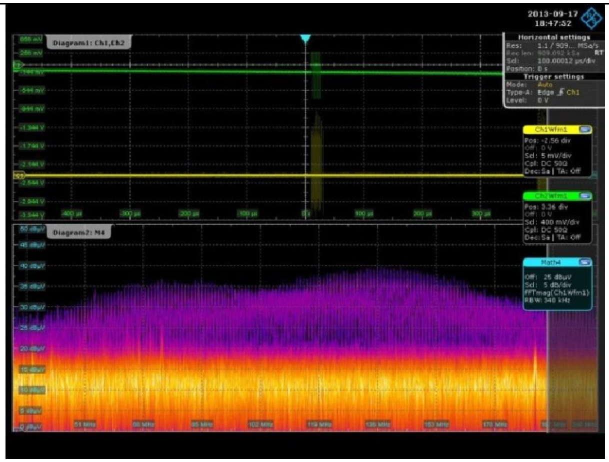
		Measurement on the processor chip: Multiples of 125 MHz are clearly visible. In addition, there is an emission at 262 MHz and its harmonics. The multiples of 125 MHzalso correspond to the frequencies observed in the far field. As a result, these frequencies are critical. In addition, we were able to find the maximum emission at the top left of the processor, i.e. in the Reduced Gigabit Media Independent Interface (RGMII) region of the processor. The interference source was further localized in this manner.
		Measurement on the Gigabit Ethernet PHY: We can clearly see there is a source producing harmonics of 125 MHz. These frequencies also occur in the far field with high levels and are thus critical.

		Measurement on the clock generator (25 MHz): We can clearly see there is a significant source producing harmonics of 25 MHz. However, since harmonics of 125 MHz (and not 25 MHz) are occurring in the far field, the clock generator is not a probable interference source.
		Measurement on the main converter (DC/DC 36 V to 3.3 V); rectifier diode at output: We can clearly see a spectrum consisting of many lines with a maximum at about 250 MHz. This corresponds to the broadband interferer at 250 MHz in the far field. The particular spectral signature indicates this voltage converter is our probable interference source. This is confirmed when we look at the signal in the time domain. In the example, the gated FFT function was used to display the spectrum only at the instant when the switching transistor is activated in order to obtain a timing correlation.

- **Combined time-frequency measurement**

  Using the RS-H 50-1 small magnetic loop antenna and a differential probe, we can display the timing relationship between part of the observed RF emissions and the SPI data transfer between the telephone and extension unit.





Time-domain measurement on the SPI interface (Clk, green curve) + near-field probing on the SPI interface module (yellow curve):

The observed disturbance spectrum coincides with activity on the SPI interface (Clk). We can thus conclude without any doubt that the SPI clock (or this interface) is producing the interference observed in the far field. Again, we used the gated FFT function to display only the disturbance spectrum that occurs when an SPI transfer takes place.

4.3.4 Result of the EMI Debugging

- Based on the results of the far-field measurement, we were able to use near-field and RFI current analysis to determine the interference sources as well as the coupling paths
- We located the following critical interference sources: the processor (RGMII interface), the LAN PHYs and the main converter. Further analysis showed that the common-mode disturbances are coupled via the LAN PHY's supply and also via the LAN converter to the LAN line. The coupling into the handset line is occurring via the processor or as galvanic coupling as a result of the layout
- Based on our analysis, we were able to introduce steps to significantly reduce RF emissions, e.g. by filtering and termination measures, layout changes in the region of the RGMII interface (return path for the common-mode current), improved ground connection for the LAN shielding, improved power bus design (with low impedance) for the LAN PHYs and the processor as well as layout improvements and circuit changes in the region of the main converter

5 Summary

In the past, oscilloscopes were hardly suitable for EMI debugging due to their slow and hard to use FFT function. They also did not have adequate sensitivity to reliably measure RF emissions.

This situation has changed with the introduction of the R&S®RTO digital oscilloscope from Rohde & Schwarz. With 1 mV/div sensitivity, up to 4 GHz bandwidth and very low inherent noise, it is ideal for use with near-field probes or current probes to measure and analyze EMI emissions. Based on the results of EMC compliance testing, the oscilloscope is a valuable lab tool that can be used to quickly understand unwanted emissions and identify their root cause. As a standard developer's tool, the range of applications of oscilloscopes in development labs has now been expanded to include EMI debugging.

Especially the flexible combination of time- and frequency-domain analysis is opening up new possibilities. In addition, the color-coded display helps during debugging by showing how often spectral components are occurring.

This application note discussed the theory and practice of EMI debugging and included a real-world example to illustrate the individual work steps. We hope this document will help developers to analyze EMC compliance problems – especially in their own work environment without any additional test instruments.

6 References

[1] Henry W. Ott, "Noise Reduction Techniques in Electronic Systems", John Wiley & Sons Inc (May 19, 1976)

[2] Henry W. Ott, "Electromagnetic Compatibility Engineering", John Wiley & Sons; 1st edition (September 11, 2009), ISBN-13: 978-0470189306

[3] Clayton R. Paul, "Introduction to Electromagnetic Compatibility", John Wiley & Sons; 2nd edition (February 10, 2006), ISBN-13: 978-0471755005

7 Ordering information

Designation	Type	Order number
Oscilloscopes		
1 GHz, 2 channels, 10 Gsample/s, 20 / 40 Msample per channel	R&S®RTO1012	1316.1000.12
1 GHz, 4 channels, 10 Gsample/s, 20 / 80 Msample per channel	R&S®RTO1014	1316.1000.14
1 GHz, 2 channels, 5 Gsample/s, 10/20 Msample per channel	R&S®RTE1102	1317.2500.02
1 GHz, 4 channels, 5 Gsample/s, 10/40 Msample per channel	R&S®RTE1104	1317.2500.04
Accessories		
Compact Probe Set for E and H Near-Field Measurements, 30 MHz to 3 GHz	R&S®HZ-15	1147.2736.02
Preamplifier 3 GHz, 20 dB, Power Adapter 100 V to 230 V, for R&S®HZ-15	R&S®HZ-16	1147.2720.02
1.5 GHz, active, differential, 1 MΩ || 0.6 pF, R&S®ProbeMeter, micro button	R&S®RT-ZD20	1410.4409.02

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- Energy-efficient products
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Certified Quality System
ISO 9001

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