

On Self-generated RFI at Radio Astronomy Sites

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1 Introduction

Radio Frequency Interference (RFI) is the container into which unwanted emissions – that is, *unwanted* by radio astronomers – are collected when discussing the scientific output capabilities of our radio telescopes.

The mostly, but not always, legitimate radio transmissions that are causing this kind of interference usually are well known to the radio telescope stations, for the frequency bands of interest. These cases of RFI form a first important class of RFI.

A second class is the RFI that is caused by unknown sources, continuously or intermittently, from unknown locations. After thorough investigation some of these interference cases turn out to be members of the first class, but others remain elusive. These latter cases eventually may be tracked down to causes that we don't have easy control of, like emissions from fixed, mobile, airborne, or space sources. Here the efforts of the spectrum regulatory bodies come into play and astronomers are actively participating in the various fora.

But another batch of RFI cases turns out to be emissions that are being generated on-site by the radio astronomy facilities themselves. These self-inflicted troubles are caused by devices, equipment and procedures that cannot be avoided or handled in a better way. The telescope site staff may either be aware of these hazards and take measures to minimise the impact on the observations, or be unaware of the danger and classify the pollution of observations as RFI by 'unknown' causes.

This document is an attempt to raise the level of awareness and gives a limited number of examples where RFI was tracked down to self-generation at the site of the WSRT. Without doubt most radio telescope facilities are already well aware of the hazards and can name numerous examples for this kind of RFI sources.

As time progresses new equipment and technologies are introduced and new insights gained. That is why radio astronomy site staff should stay alert to fight the self generated interference. That is also why this document will be updated over time with new examples of the pitfalls that have been encountered.

2 Overview

The ways in which more or less standard commercial equipment can be an RFI hazard for a radio telescope facility are numerous. In many cases the telescope facilities possess a shielded room, Faraday cage, in which noisy equipment is placed. In general this is the case for the digital part of the receiver chain, consisting of data processing equipment and computers. Outside the cage the 'safe' equipment is situated, like the analog part of the receiver chain. The term 'safe' in this case is relative: on the one hand local oscillator signals may pollute the spectrum and on the other insufficient shielding leaves the circuitry susceptible to interfering signals.

There are exceptions or impossibilities to the principle of situating all noisy equipment in Faraday cages:

- The most obvious one: No Faraday cage present at all. Naturally, this is a situation that limits the possibilities for improvement of the RFI situation.
- Shielded cabinets containing noisy subsystems, with radiating copper cables running between subsystems in unprotected space. A common situation that

can only be remedied by careful selection of cables, shielding, connectors, cabinets and system partitioning and lay-out.

- Workstations in offices located on the telescope site. It is hard to avoid this but attention should be given to quality issues like enclosures and cabling that are designed with EMI reduction in mind. High speed SCSI connections to external disk units are to be avoided. Likewise a RAID system outside a Faraday cage is a serious RFI hazard.
- Working lab instruments located on the site. Analyzers of all kinds (network-, spectrum- and logic-) and signal generators that are switched on while observations are being carried out.
- Network cabling and network equipment. Choose fibre over ScTP (screened twisted pair cable) and the latter over UTP; but take care: UTP to fibre converters can be very noisy.
- Telescope control systems on the telescope in plastic boxes. Unshielded PLC's and cabling.
- Infrastructural equipment in or near buildings on the site. Microwave ovens, mobile telephone (GSM, UMTS or DECT), WiFi, Bluetooth, UWB applications. Even telephone exchange hardware (ISDN) has been found to cause interference.

Most of these hazards have been recognized by responsible staff but slip through the mazes in the prevention of interference during the course of the observations. To illustrate some of these points a number of cases are described in the following section.

3 Examples

The examples below are documented with spectra that have been measured, where not indicated otherwise, with a Rohde&Schwarz FSP-3 spectrum analyzer with a R&S Ultraalog HL562 antenna plus 25 dB pre-amplifier.

Lab instruments

Obviously, any signal generators or lab instruments that contain (micro)processors or high speed digital electronics potentially generate RFI. It is therefore mandatory that instruments are switched off at the end of the day or when not actually in use.

An example is a rather unsuspecting instrument, a Power Analyzer, that turns out to generate particularly much RFI up to about 800 MHz, see section 3.1.

LAN Switch

Standard LAN switches do not receive much attention and many of them may be present in unprotected areas. Usually, a plastic housing with not much shielding metal inside is unable to prevent the high speed digital backplane from radiating. Having a lot of UTP cables connected to the device doesn't help either.

Two examples are presented for two brands 10/100 Mbit switches that do have metal external or internal housings but that nevertheless have been found to radiate during spectrum monitoring sessions, using a Rohde&Schwarz ESMB monitoring receiver. The receiver was connected to a PC either through the switch or via a direct connection. Both models show a comb like signal, that is different for the two. The first figure in section 3.2 shows the spectrogram for a small portion of the spectrum (all plots are 5 minute spectrograms). About halfway the position of the switch relative to the antenna was changed. In the second figure the switch is not used and turned off. In the third figure another brand is used and in the last figure that switch is not used, but is left powered on. During the scans the coupling between switch and

antenna is changed, showing that while not actually in use, the switch still produces interference.

A radio astronomy site using lots of this kind of switches will suffer from an increase of background noise level. The frequency range of this source of interference was not examined.

KVM box

A keyboard, video, mouse box replaces the cabling between the computer and these peripherals by a single fibre connection. The computer can then be placed inside a Faraday cage together with one end of the KVM box (the master). The other end (slave) connects to the keyboard, video screen and the mouse. This seems a good way to avoid having noisy pc's around (both EMI and sound). However, a test to evaluate one particular box showed that a lot of RFI is generated by it, rendering it useless for RFI prevention. Some results are presented in section 3.3. The first figure shows the 2 GHz wide spectrum measured near 2 PC's, one of which is connected to the KVM box and an Allied Telesyn AT-FS705EFC/ST LAN switch (see section 3.2). The forest of interference peaks extends well beyond the 2 GHz measurement limit and polluted the L band significantly. For this reason the KVM box is banned from the site. The reference in the next figure shows the spectrum when all these devices are turned off. To be able to distinguish between interference sources the next figures show the spectrum when the slave part of the master/slave pair of the KVM box is switched off (some reduction in interference but significant RFI remains) and when the KVM box master and slave are turned off. The last figure therefore shows the background RFI as is also seen in the former reference plot, plus the RFI coming from the PC's and the LAN switch. To summarize these composite results: The KVM box master and slave units each generate significant interference peaks up to frequencies well above 2 GHz. The two PC's and the switch generate interference to a degree that is comparable to that seen in other computing equipment (see section 3.5).

LAN UTP/Fibre converter

It is ironic that the devices that are used for interfacing a fibre LAN connection to the UTP input on a computer can be very noisy, as the use of fibre is intended to reduce interference in the first place.

Section 3.4 starts with results found for one particular brand UTP/Fibre converter (Allied Telesyn AT-MC101XL) that is used at the WSRT site for computers (mostly notebooks) that have a UTP jack only (the desktops and workstations all have a fibre LAN interface built-in). The first figure shows the interference up to 1 GHz. The reference figure below that is the spectrum with the power to the converter switched off. Clearly the spectrum is polluted with numerous narrow peaks. The next two figures show the results over a wider spectrum, up to 3 GHz. From these figures the conclusion can be drawn that the interference transgresses into the L band and will be seen in 21 cm observations, as was found during regular WSRT operations. Early 2004 a new type of fibre lan interface intended for notebook computers was tested. The PCMCIA module plugs into a slot in the notebook, allowing a fibre connection to the network. The model that was tested (Microsens PCMCIA Fast Ethernet Card 100Base-FX) showed a lot of interference as is noted in the subsequent plots in Section 3.4. Plots are given for the quiet environment, just the Dell notebook powered on and the fibre module plugged in. These results have led to the decision to reject these modules.

Computing equipment

Personal computers, desktops, workstations, notebooks, can be found anywhere in unprotected space. Many times people are aware of the interference that they produce, but people need them to do their jobs and relocating people into protected

space (Faraday cages) usually is not the answer because of the unpleasant environment for humans. Observatories need a minimum suite of computing equipment to run the telescope, but we make things worse by locating offices and labs on the site. In doing so we allow the noise background to increase on the radio telescope site just by allowing personnel access to the site in excess of the strict minimum to maintain observation operations. It is the aggregate of computers of differing brands, speeds and quality standards that raises the level of the background noise.

Computer speeds are ever increasing. Internal CPU speeds reach clock frequencies of several GHz. From these chips not much EMI emanates however, because of the very small radiating structures and relatively small internal voltage swings (dV/dt). Front side bus (FSB) speeds of 400 MHz and more are more damaging, because of the longer leads on the PC's motherboard that carry this frequency. Internal connections to storage devices will also contribute significantly to the overall EMI. Looking at the interference that PC's produce in practice shows a considerable variety, see the examples in section 3.5. Some of the examples given in the figures identify particular computers, while in other cases this was not really possible because the method of switching units off for identification was not an option. These plots are included just to give an idea of the kind and amount of interference one can expect from (aggregates) of standard commercial computing equipment.

Disk units

Ideally, a disk unit doesn't do too much harm because it is housed inside the computer cabinet and if that is of sufficient quality the interference that leaks out stays below a reasonable level. External disk units on workstations are connected through cables carrying high speed digital signals and some are known to generate substantial levels of RFI. Especially the older technology of single ended SCSI, as opposed to differential, has been found to be radiating much interference into the environment. The latest low voltage differential (LVD) connections should be radiating less interference, even for the very high speed connections. Nevertheless external drives should always be regarded with suspicion.

Examples are presented in section 3.6. The plots show the interference coming from both the computer and the external disk, but probing has indicated that a significant part of the interference is radiated through the connection of the disk to the computer.

Computer monitors

CTR screens have been known to be radiating interference. TFT screens were assumed to be less of a problem. This assumption has proven to be incorrect however, possibly due to badly shielded internal microprocessors or digital logic. A case in point is presented in section 3.7, where a seemingly high quality (judging by image quality and price) 17 inch TFT monitor was found to be a source of wideband RFI. Other TFT screens that were examined didn't show this kind of serious interference.

Digital equipment under test

The presence of a lab on the telescope site has to be avoided, but in order to allow rapid repairs and troubleshooting, all radio telescope stations do have basic facilities on the site. The instruments in use as well as the equipment under test are potential sources of interference. A point in case is a unit under test that consists of high speed logic parts and boards and that is used as a prototype RFI mitigation system; see the figures in section 3.8. This is a system that successfully removes RFI from a baseband signal, but in doing so it generates a great deal of interference into the environment. Clearly this test system has to be switched off while observations are going on and eventually the final system has to be located inside a Faraday cage.

One might argue that the mitigation system would remove the interference it generates, but perfect efficiency in doing so is beyond reasonable expectations. Note from the figures that this example of high speed digital equipment in unprotected space presents a real problem to the telescope facility in the form of strong wide band interference that is hard to identify and that raises the background noise.

Monitoring receivers

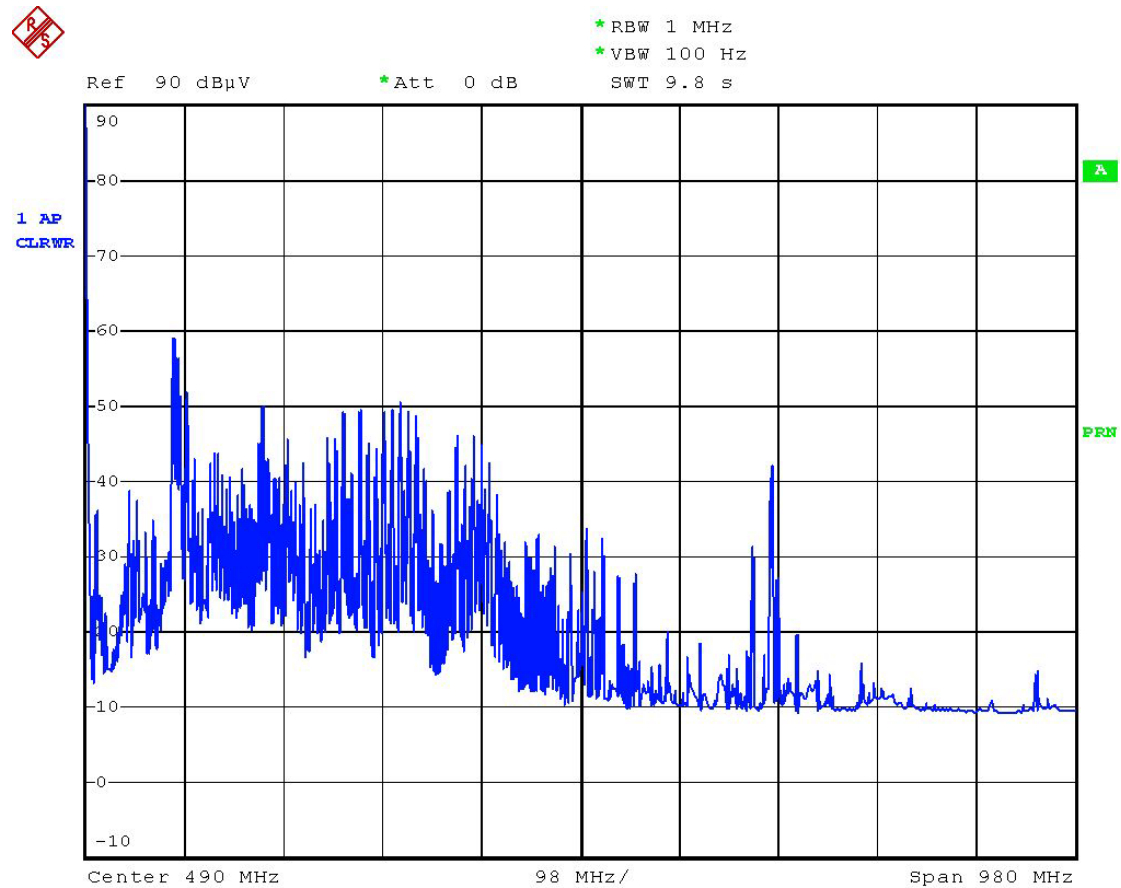
In our efforts to monitor the spectrum to guard the RFI environment a sweeping receiver may be polluting the same environment. This may be going on undetected for a long time, because the RFI may be generated only at specific frequencies while the monitoring receiver sweeps by at another frequency. High quality monitoring receivers have been designed with this potential self-generated interference hazard in mind. Lower cost receivers, like the popular AOR AR5000, do generate strong narrow peak RFI by radiating energy back through the antenna connection, as is demonstrated in section 3.9. Therefore placing the receiver inside a shielded enclosure doesn't help. The generated interference can be related to the internal LO frequencies that it uses.

3.1 Lab instruments

Instrument: Voltech PM300 Three Phase Power Analyzer

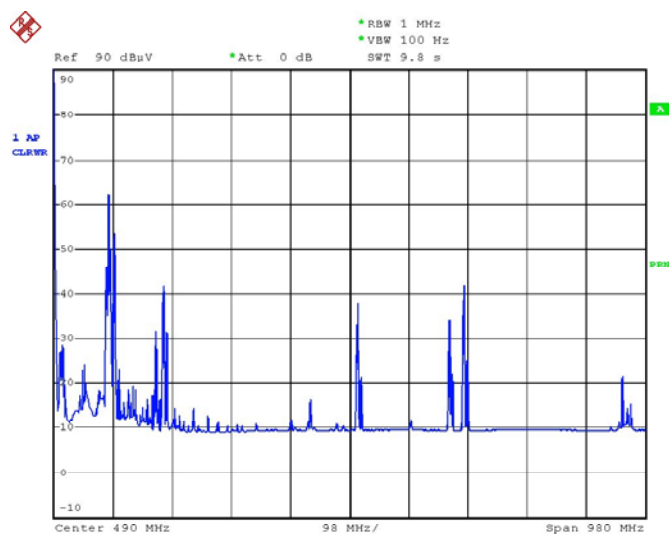
ID: ZWO1674

see: http://www.voltech.com/products/pwr_anl/pm100/pm100.htm



Date: 18.SEP.2003 16:34:17

Reference spectrum
This reference spectrum is taken well away from obvious interferers on the WSRT site. The peaks in the spectrum are all attributed to known radio, TV, telephone (GSM) and mobile transmitters.



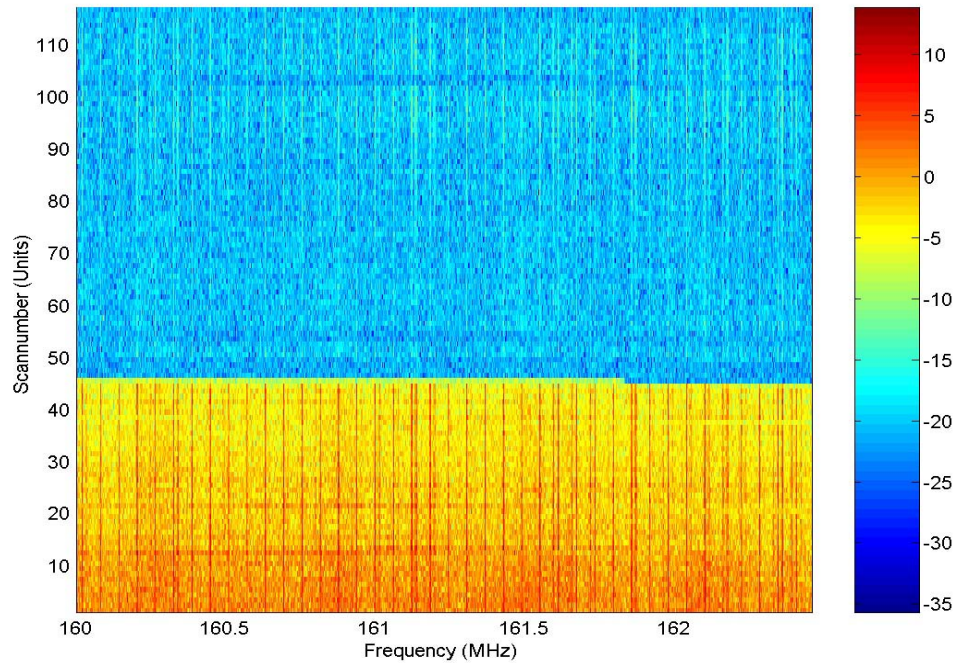
Date: 18.SEP.2003 16:56:05

3.2 Computer Network Infrastructure: LAN Switches

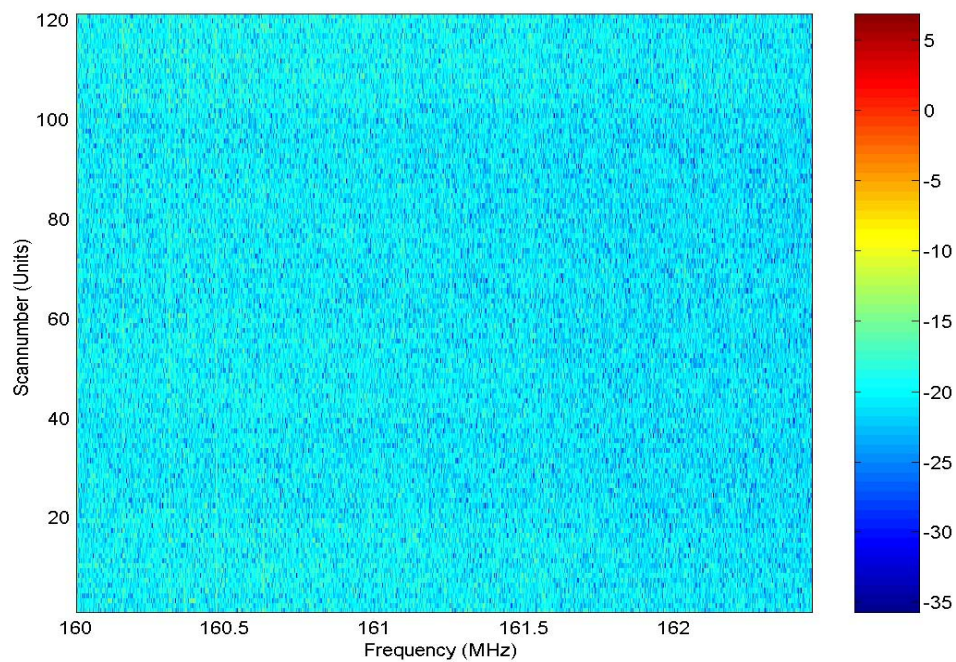
Model: Allied Telesyn AT-FS705EFC/ST

Measured with R&S ESMB monitoring receiver plus HK014 coaxial dipole antenna.

Power on:

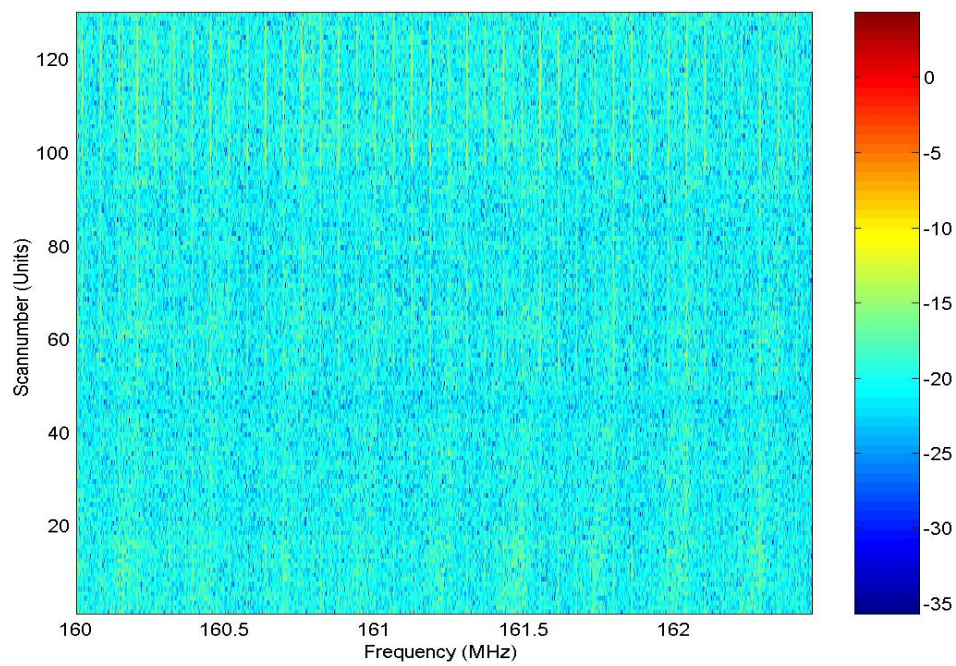


Power off:

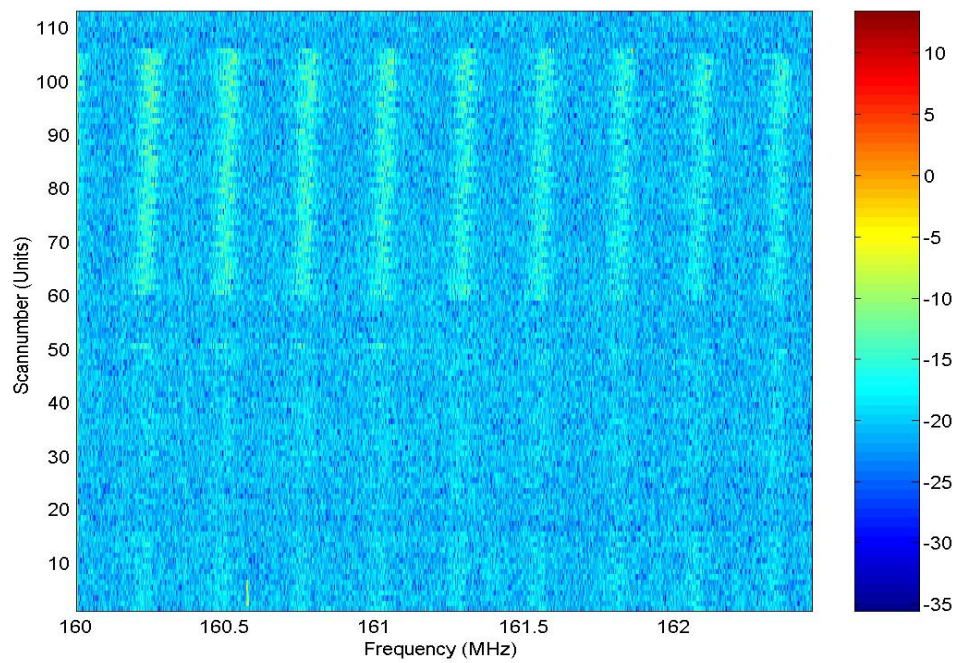


Model: 3Com Office Connect Dual Speed 5 Plus

Power on:



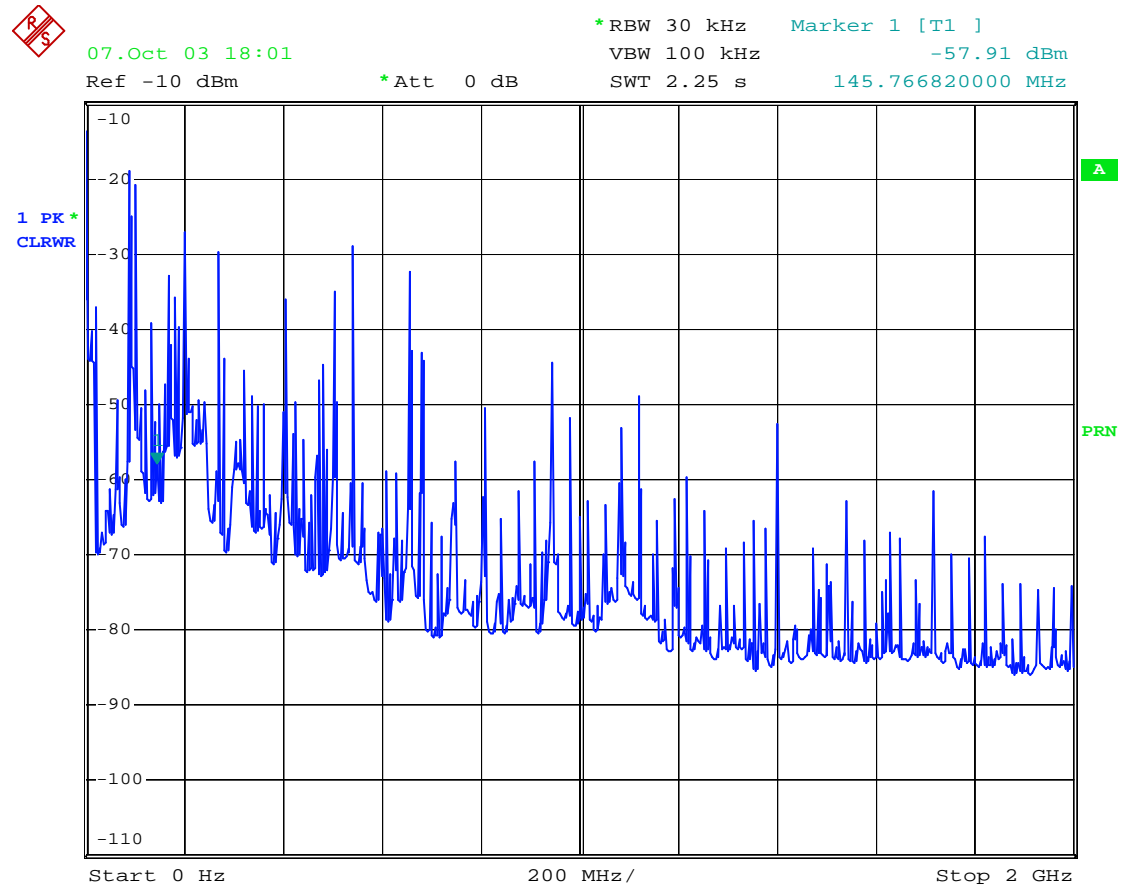
Power on, but not used; close proximity to antenna in scan number 60 to 105:



3.3 Computer Network Infrastructure: KVM box

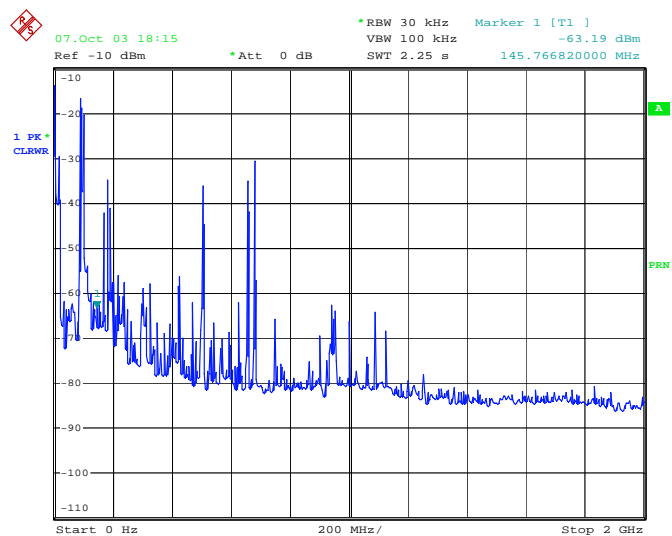
Model: Rose Electronics CrystalViewfiber

KVM box, LAN switch and 2 pc's powered on.



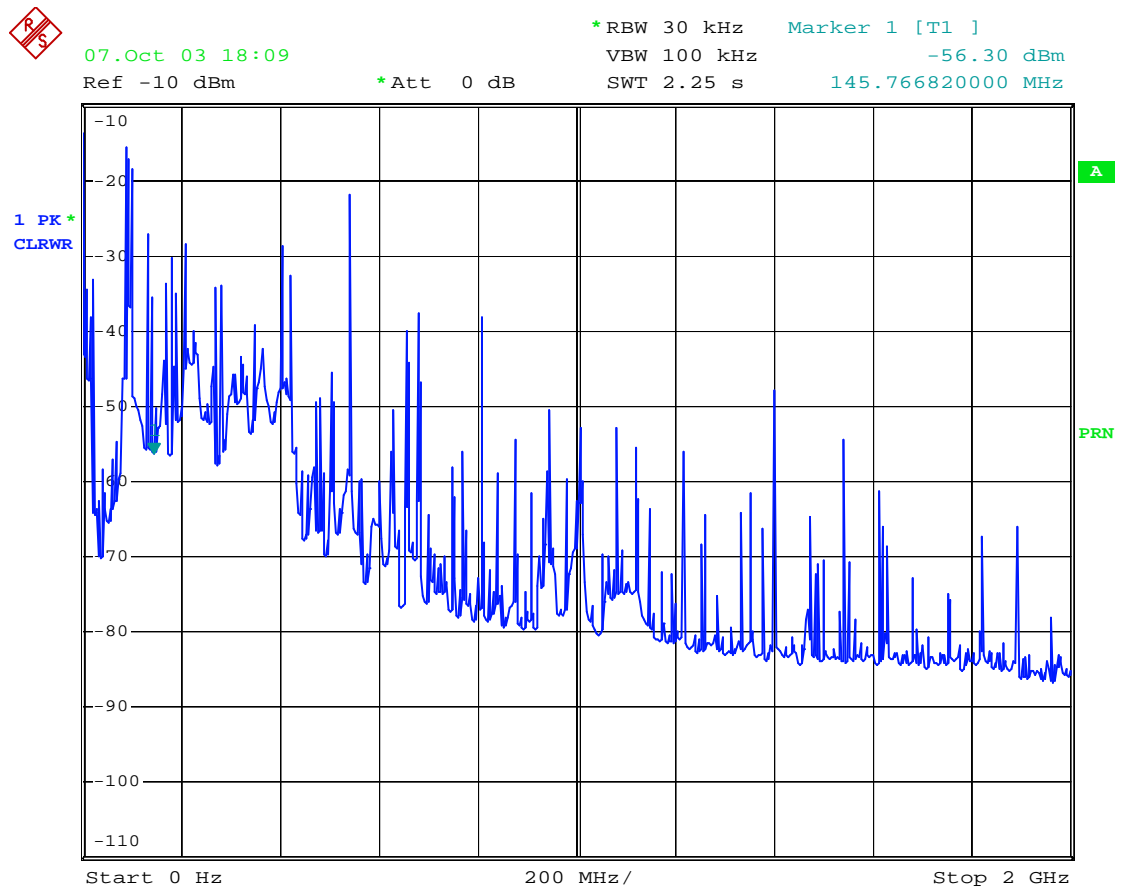
Date: 7.OCT.2003 18:02:04

Reference: KVM box, switch and PC's powered off



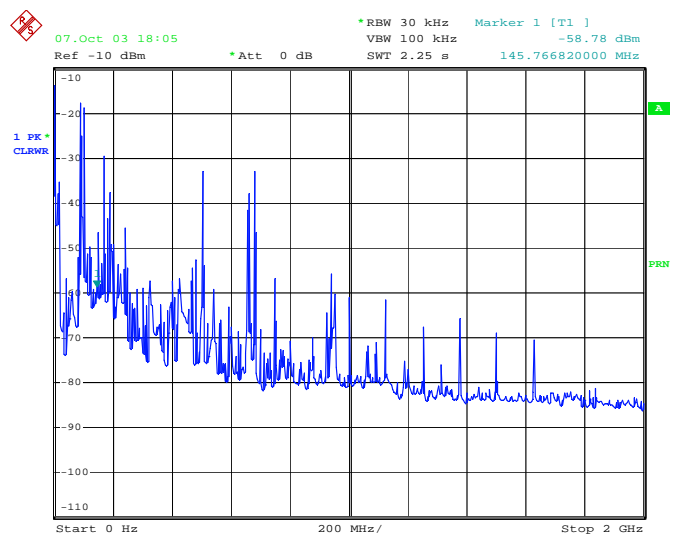
Date: 7.OCT.2003 18:16:02

KVM master on, slave off, LAN switch on, 2 PC's on



Date: 7.OCT.2003 18:09:38

Reference: KVM box off,
LAN switch on, 2 PC's on



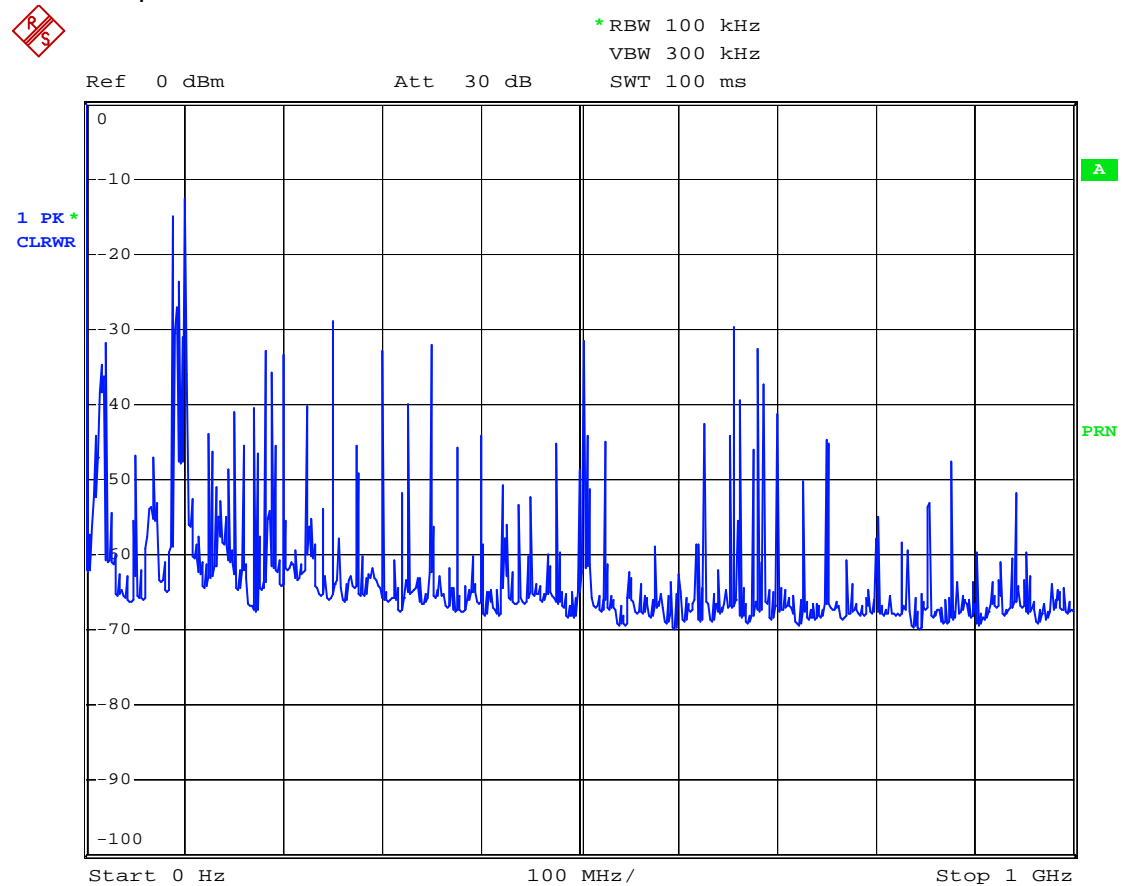
Date: 7.OCT.2003 18:05:28

3.4 LAN UTP/Fibre converter

model: Allied Telesyn AT-MC101XL

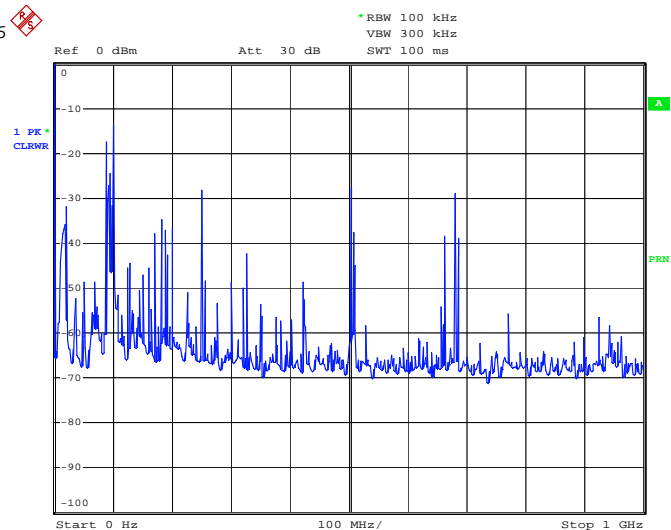
see: <http://www.alliedtelesyn.co.kr/Products/Converter/AT-MC101XL.htm>

0-1 GHz, power on:



Date: 8.OCT.2003 17:17:06

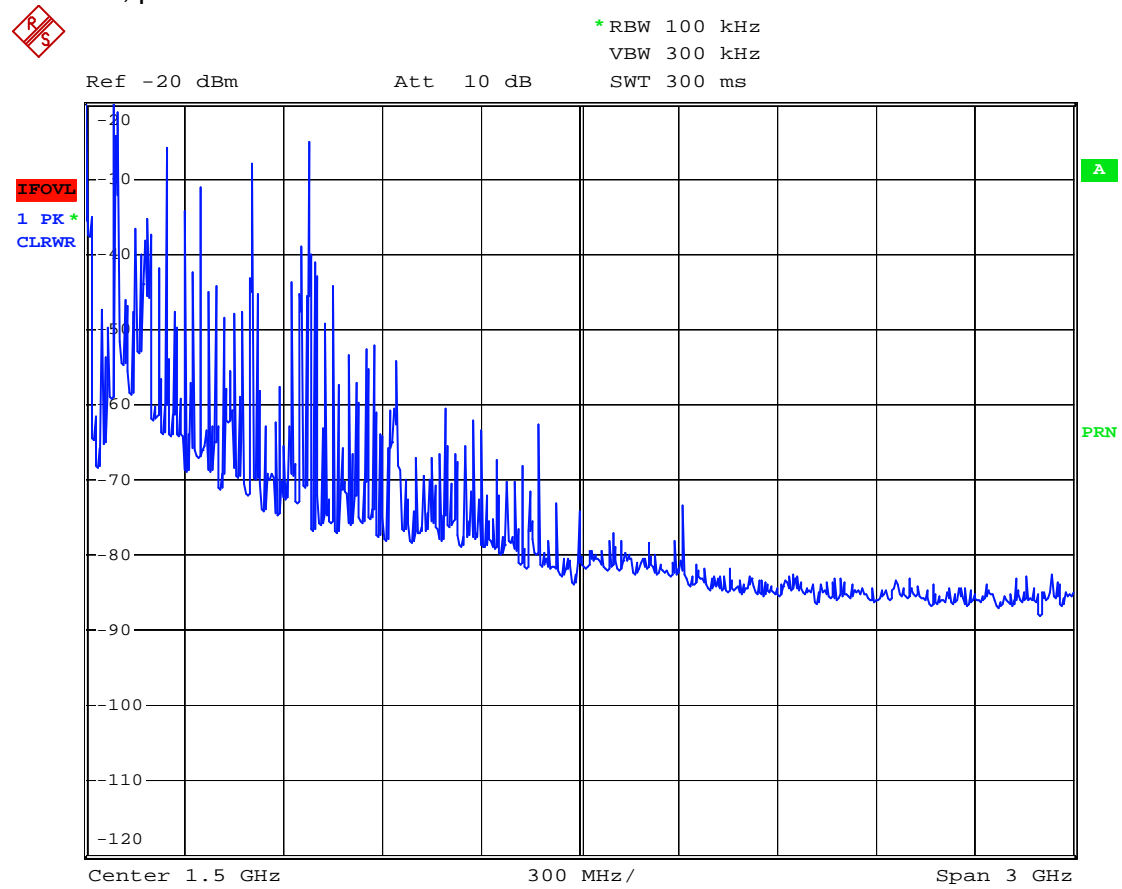
Reference: 0-1GHz, power off



Date: 8.OCT.2003 17:18:06

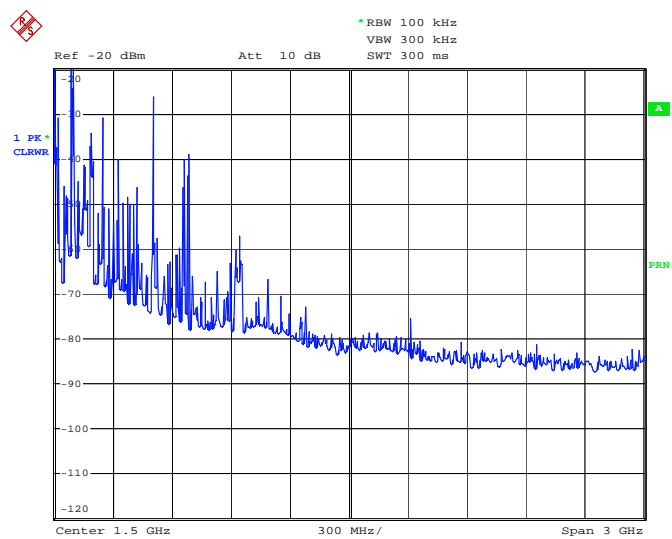
LAN UTP/Fibre converter (cont.)
model: Allied Telesyn AT-MC101XL

0-3 GHz, power on:



Date: 8.OCT.2003 17:15:38

Reference: 0-3 GHz, power off



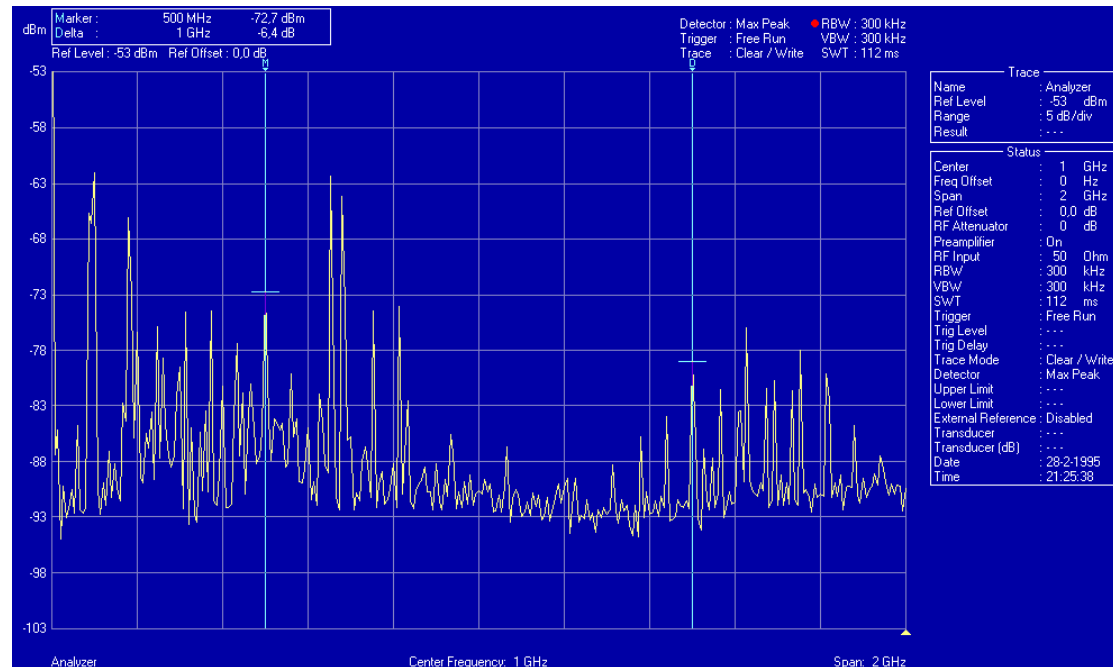
Date: 8.OCT.2003 17:13:36

PCMCIA LAN/Fibre module

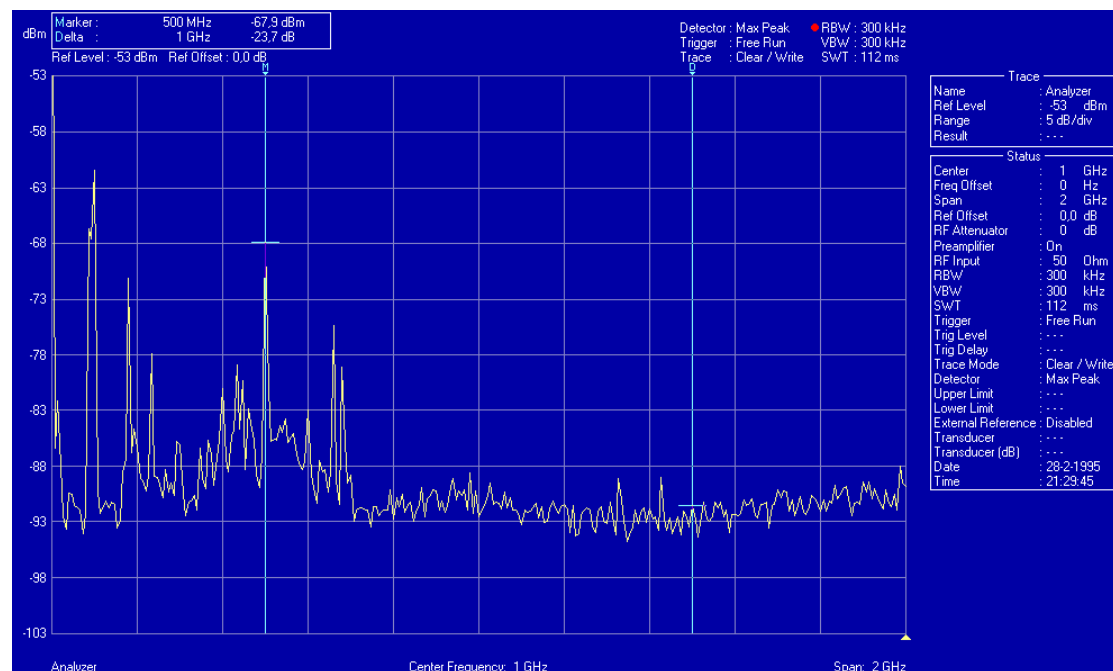
Model: Microsens PCMCIA Fast Ethernet Card 100Base-FX, Multimode 1300nm, SC

<http://www.micosens.de/uk/produkty/PCMCIA.htm>

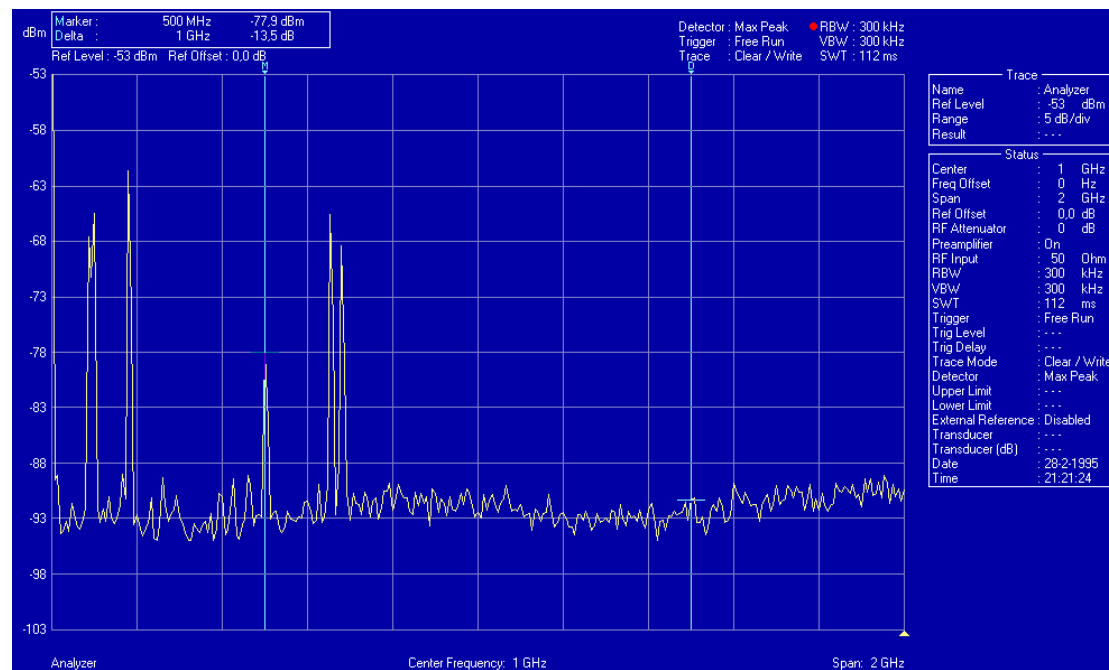
0–2 GHz, Equipment on



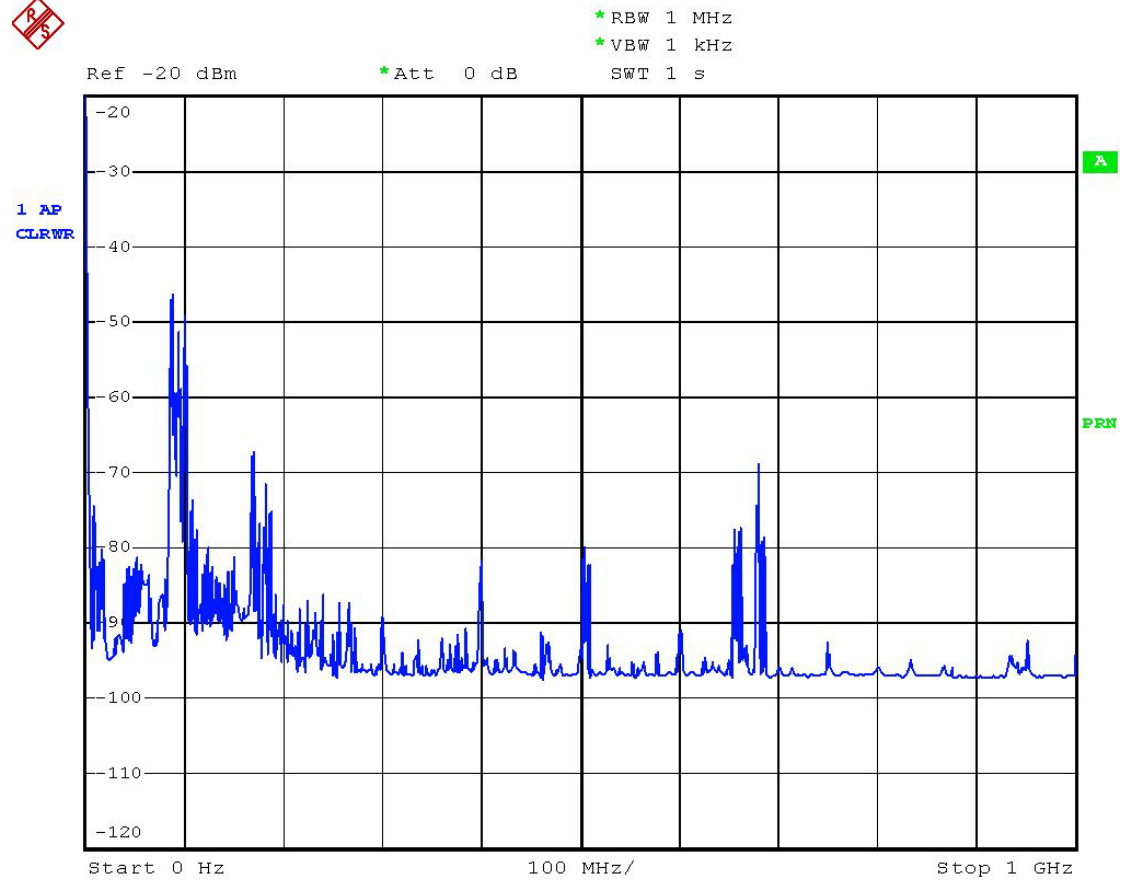
0-2 GHz, Notebook computer without fibre module (Dell Latitude C810), computer is powered on.



PCMCIA LAN/Fibre module (continued)
 0-2 GHz, Reference, Notebook computer off (background).

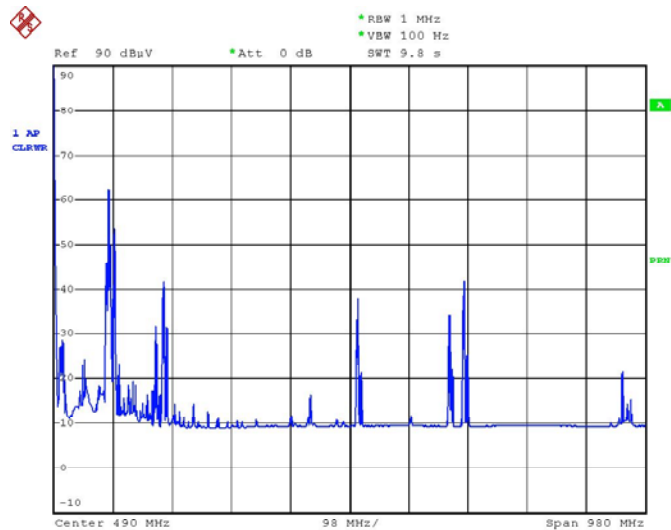


3.5 Computing equipment



Date: 18.SEP.2003 17:12:53

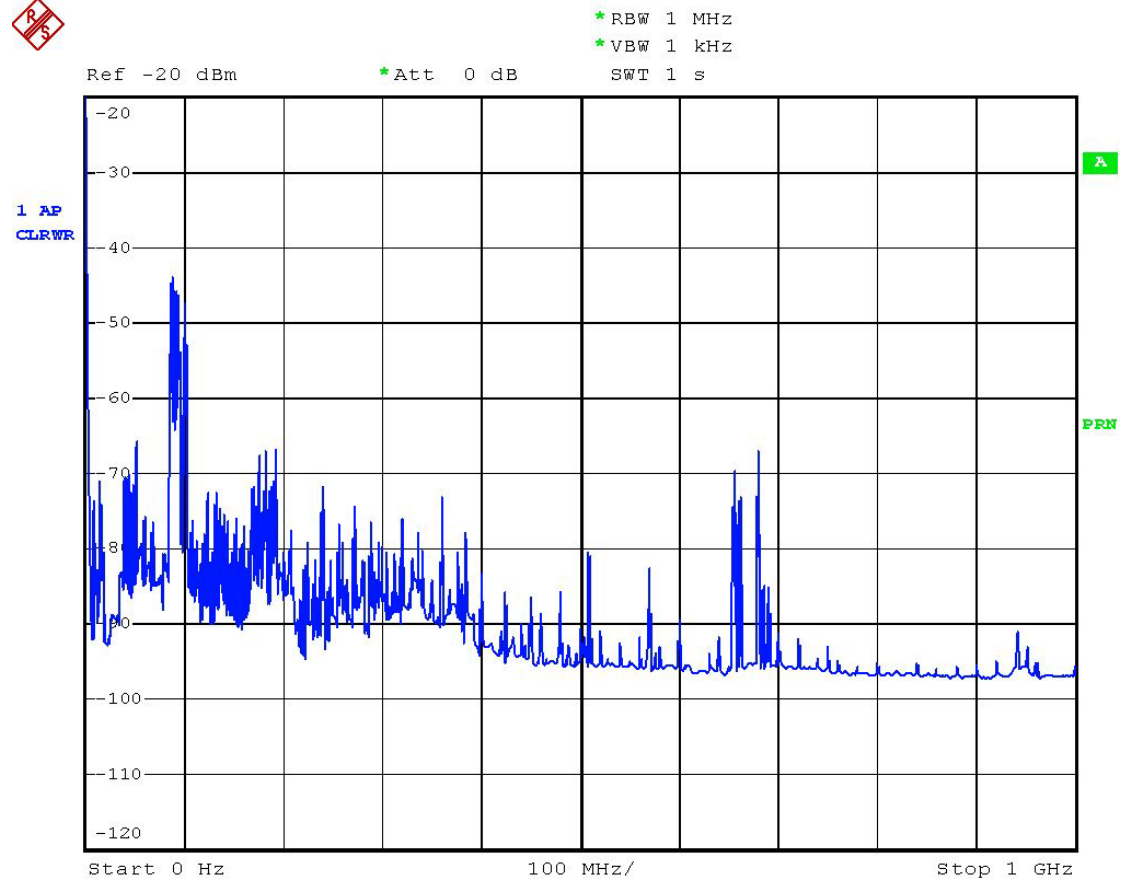
Computer RFI in office with two PC's. These computers happen to be older models with 300 and 733 MHz Pentium II and III CPU's and 100 MHz FSB.



Below: reference spectrum

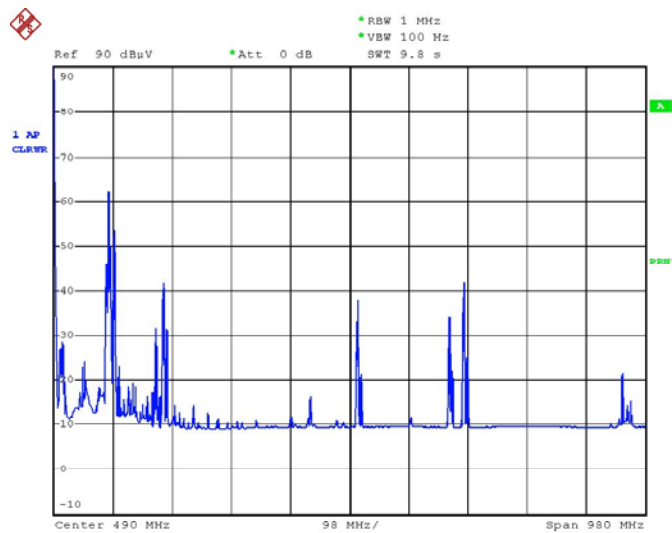
Date: 18.SEP.2003 16:56:05

Computing equipment (cont.)



Date: 18.SEP.2003 17:15:37

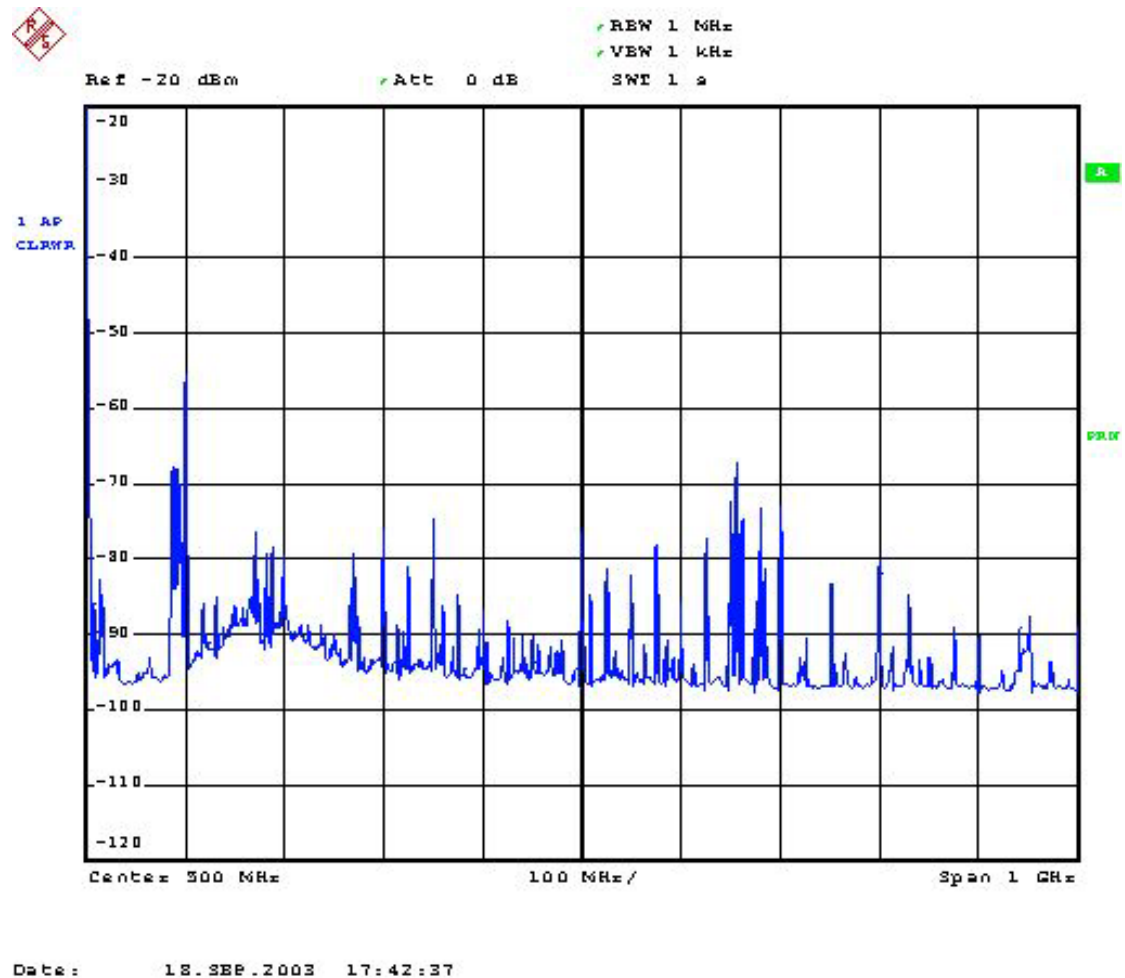
Lab environment, dominated
by interference from PC's.



Date: 18.SEP.2003 16:56:05

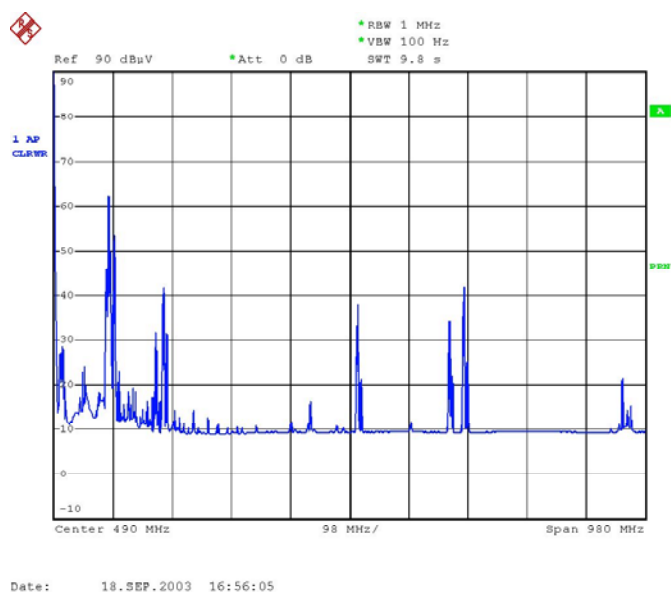
Below: reference spectrum

3.6 Disk units

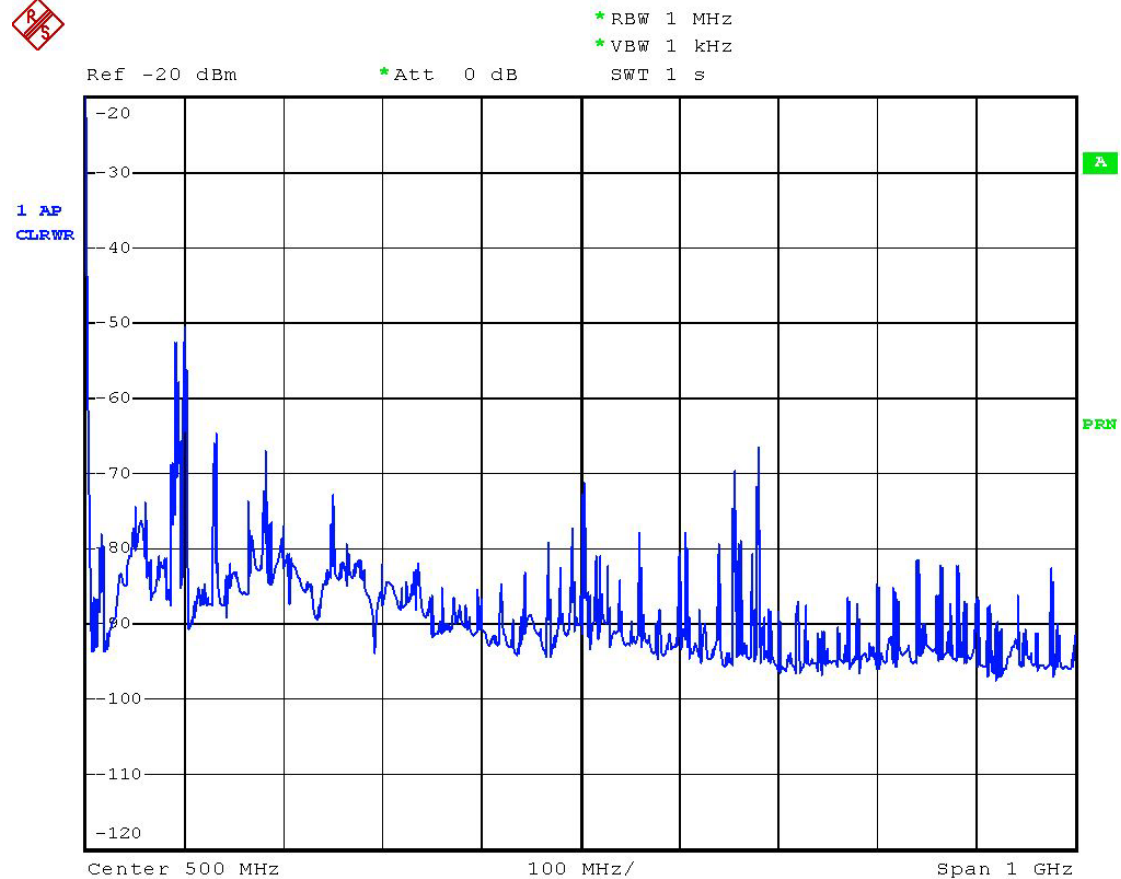


The spectrum above was taken close to a workstation (WAW01) at the WSRT site. This is a HP9000/785/400 MHz C3000 PA8500-RISC-2.0 machine from end of 1999. It has a 80 Mb/s Ultra2 Wide LVD SCSI external disk drive.

Below: reference spectrum



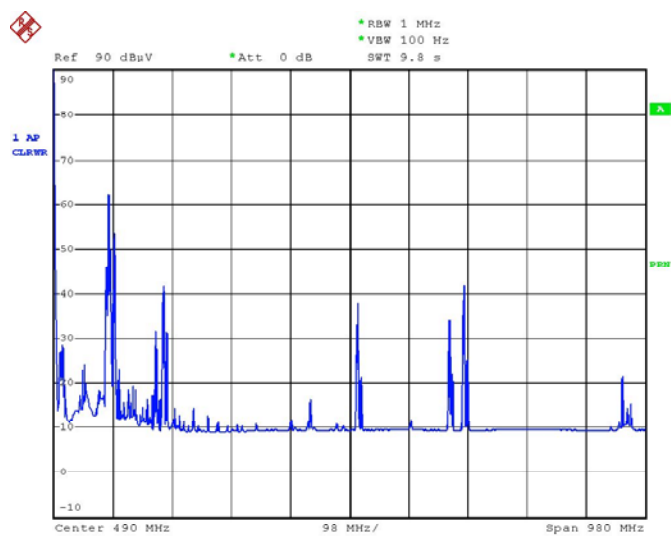
Disk drives (cont.)



Date: 18.SEP.2003 17:38:20

Spectrum close to a HP9000/782 (C200) PA.RISC.2.0 machine (WAW06) from 1998, with FastWide SCSI 20 Mb/s external drive. Note that more high frequency interference emanates from this slower disk system than in the previous example.

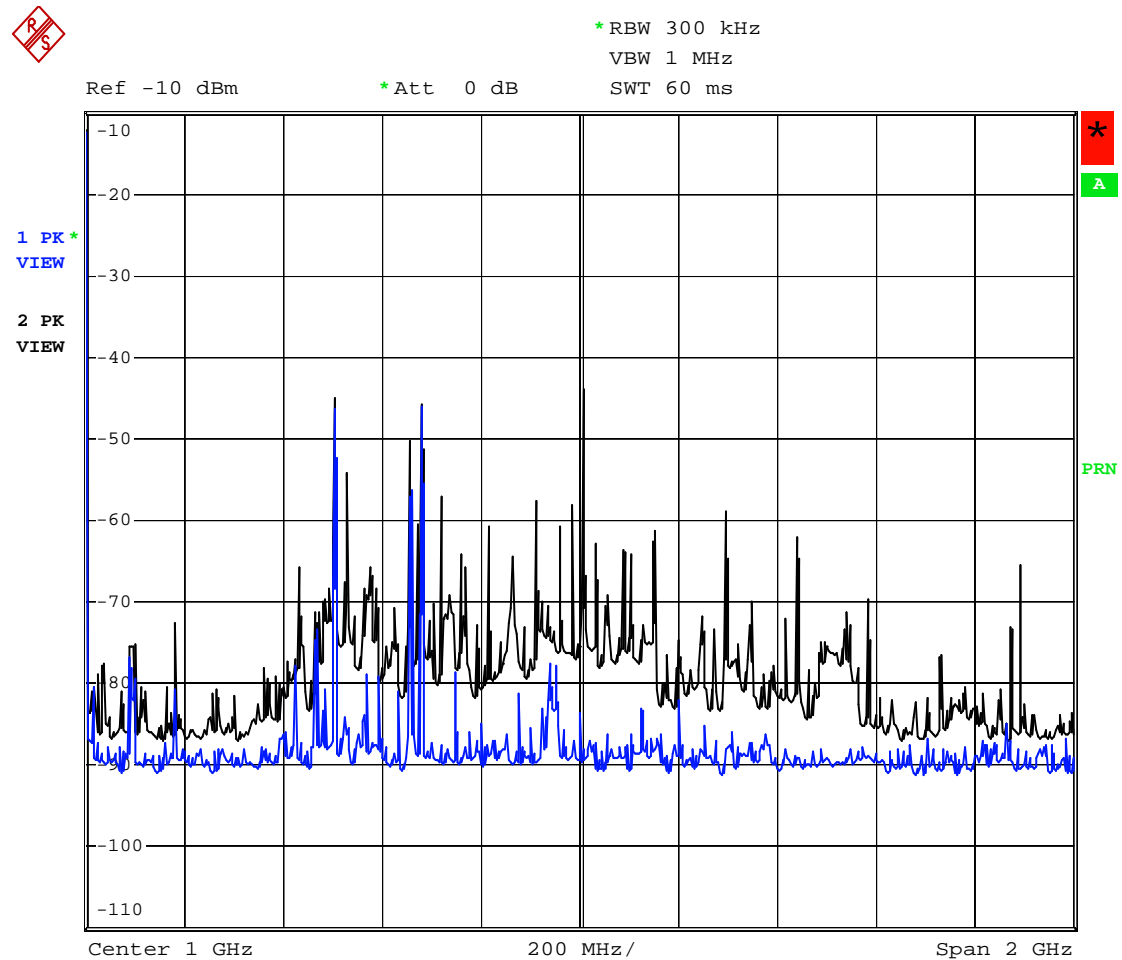
Below: reference spectrum



Date: 18.SEP.2003 16:56:05

3.7 Computer monitors

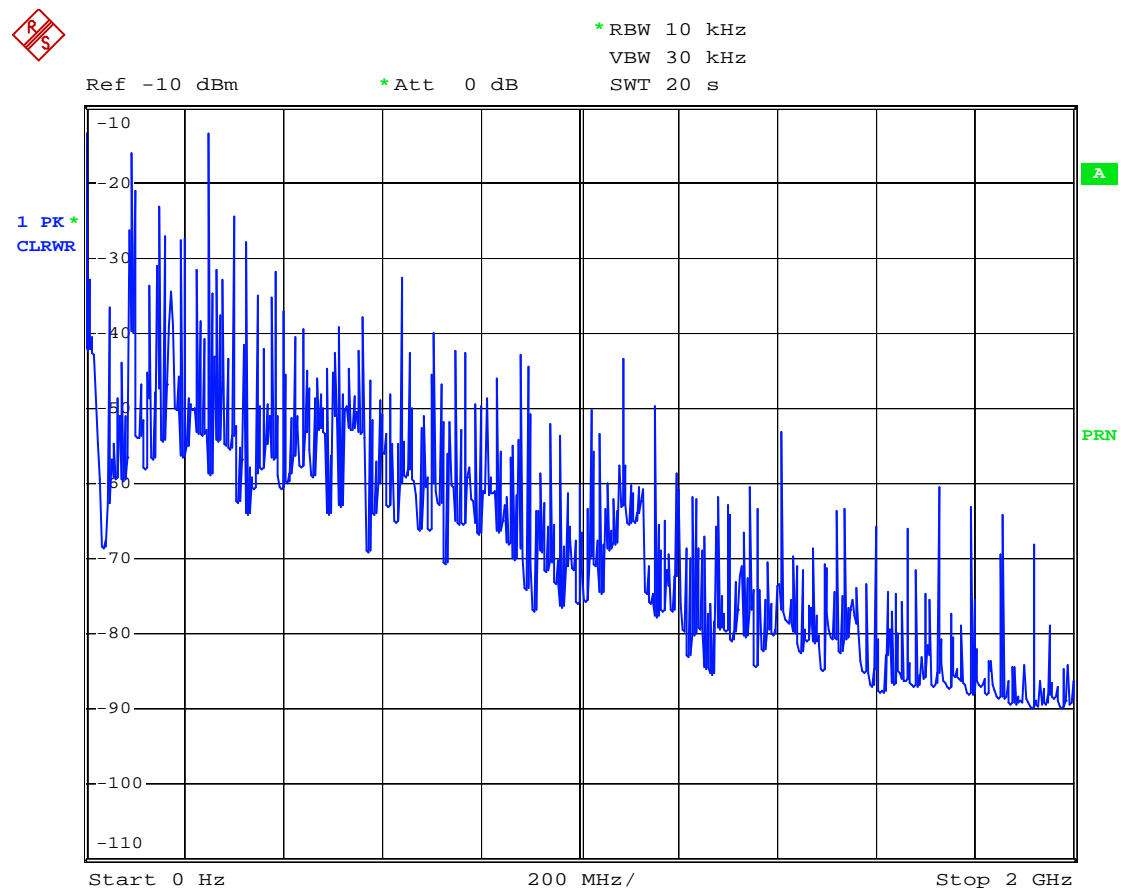
Type: Transtec/STEP17 inch TFT monitor
Model: PixelMaker 17/B Plus MPP760



Date: 13.OCT.2003 18:05:52

The plot shows the spectrum measured near the monitor when it is powered off (the bottom, blue trace) and when it is in operation (upper, black trace). Note the wide band interference that is generated.

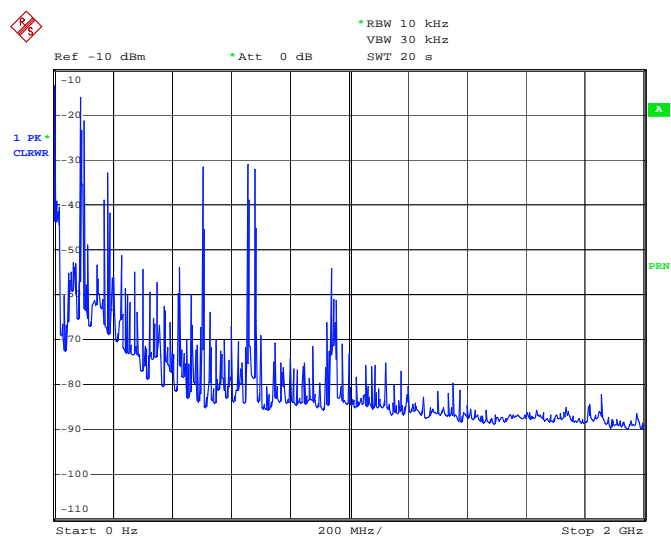
3.8 Digital equipment under test



Date: 8.OCT.2003 17:28:47

Above: High speed digital system and development PC switched on, antenna points directly to the system.

Below: same, antenna points 90 degrees away from system.



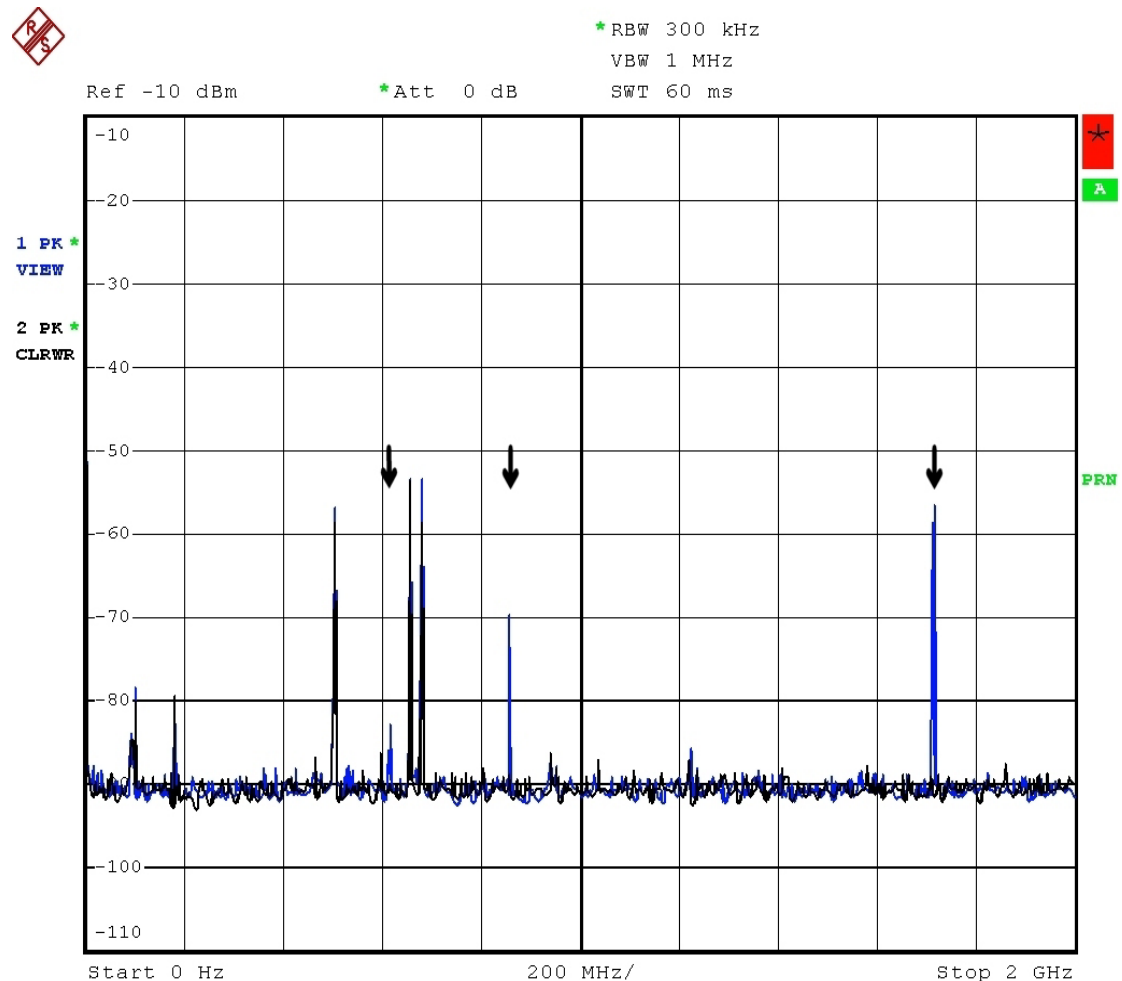
Date: 8.OCT.2003 17:47:01

3.9 Monitoring receivers

Type: AOR monitoring receiver

Model: AR5000

see: <http://www.aoruk.com/ar5000.htm>



Date: 13.OCT.2003 17:51:00

The plot shows two traces: when the receiver is off (black) and when it is switched on and tuned to 1350 MHz (blue). The interference peaks are local oscillator signals and harmonics, and signals of unknown origin. For convenience the strongest ones are indicated with an arrow on the plot.