Helsinki Metropolia University of Applied Sciences
Degree Programme in Electronics Engineering

Tuomo Yli-Taipalus

Video interface card for an HMI device

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Helsinki Metropolia University of Applied Sciences **Abstract**

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This thesis deals with the design procedure of a prototype circuit board that converts analog video to digital video. This video interface card is used to give an additional feature to a current product, Epec 2040 HMI device. Video signal and digital camera theory of operation is also explained in this thesis.

The design procedure started by benchmarking other similar products in the market to see what kind of features are offered in other devices. Next, different video signals were examined in order to set up the system design. After a suitable video decoder chip was found, the schematic designing began. Mentor Graphics software was used for the PCB design, first PADS logic for the schematic and then PADS layout for the actual PCB. Schematic design incorporated video signal filter design, and the calculations for the filters are also a part of this thesis.

The circuit board design was successful, and the video interface card functions as it was designed to. The two different video signal filters on the video interface card were tested with video signal and the frequency responses of those filters were measured. Other filter configurations were also tested, but one of the filters on the video interface card turned out to have the best performance of them all.

The technology tested on this prototype video interface card will work as a reference point for Epec Oy when they consider adding a video input feature to their future revision of Epec 2040 HMI device.

Keywords	video signal, digital camera, low-pass filter, decoder, EMC

Metropolia Ammattikorkeakoulu **Insinöörityön tiivistelmä**

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Insinöörityön tarkoitus oli tutkia tekniikkaa, jolla saataisiin videokameratulo Epec 2040 -näyttöön. Tämän tarpeen toteuttamiseksi suunniteltiin piirilevy videodekooderipiirin ympärille. Tämä dekooderi muuntaa analogisen videosignaalin digitaaliseksi videosignaaliksi. Liittämällä tämä prototyyppipiirilevy Epec 2040:n näyttöön saadaan esimerkiksi peruutuskameran kuva näytölle. Insinöörityössä käsitellään myös erilaisia videosignaaleja ja digitaalisten kameroiden toimintaperiaatetta.

Ennen suunnittelutyön aloittamista selvitettiin markkinatutkimuksen avulla, millaisia ominaisuuksia kilpailevissa tuotteissa on. Kun tiedettiin, millaisia ominaisuuksia lähdetään laitteelta hakemaan, lähempi tutustuminen videosignaaleihin ja dekooderipiireihin oli tarpeen. Kun sopiva videodekooderipiiri oli löydetty, aloitettiin piirisuunnittelu PADS logic –ohjelmalla, josta piirikaavio siirrettiin PADS layout –ohjelmaan, jossa piirilevy sai lopullisen muotonsa. Piirikaavion suunnitteluun kuului myös videosignaalisuodattimien suunnittelu laskelmineen.

Valmis laite toimii niin kuin se on suunniteltu toimimaan, joten siltä osin insinöörityö oli onnistunut. Piirilevylle päätettiin lopulta laittaa kaksi hieman toisistaan poikkeavaa videosignaalisuodatinta testaussyistä. Näiden kahden lisäksi mitattiin 4 muuta suodatinta, mutta parhaan tuloksen antoi piirilevyllä oleva komposiittivideon suodatin.

Tässä työssä testattu tekniikka toimii apuna tai suorana lähtökohtana Epec Oy:lle, kun se suunnittelee videokamerasisääntulon lisäämistä 2040-näyttöön.

Hakusanat	videosignaali, digitaalinen kamera, alipäästösuodatin, dekooderi, EMC

Abbreviations & Acronyms

A/D = Analog to Digital

BLM = Ferrite Bead Inductor

C = Chroma, chrominance

CAN = Controller Area Network

CCD= Charge-Coupled Device

CMOS = Complimentary Metal-Oxide Semiconductor

CRT = Cathode Ray Tube

CVBS = Colour, Video, Blank and Sync / Composite video.

EMC = Electromagnetic Compatibility

FET = Field Effect Transistor

FPC = Flexible Printed Circuit

GPIO = General Purpose Input/Output

HBI = Horizontal Blanking Interval

HID = High Intensity Discharge

HMI = Human Machine Interface

I^2C = Two-Wire Serial Interface

IRE = Institute of Radio Engineers

LCD = Liquid Crystal Display

LVDS = Low Voltage Differential Signal

NTSC = National Television System Committee

PAL = Phase Alternate Line

PC = Personal Computer

PCB = Printed Circuit Board

PIP = Picture In Picture

RGB = Red, Green, Blue

SECAM = Sequential Couleur Avec Memoire

SMD = Surface Mount Device

S-Video = Super Video / Separate Video / Y/C Video

TFT = Thin-Film Transistor

TV = Television

TVS = Transient Voltage Suppressor

VBI = Vertical Blanking Interval

VCR= Video Cassette Recorder

Y = Luma, luminance

1 Preface

Electronics has become a big part of modern machinery control and diagnostics systems. The interface between human and machine consists nowadays of electronic sensors, LCD displays and pushbuttons instead of mechanical levers and analog gauges. Machinery also has some intelligence of its own. Mathematical number-crunching power of microprocessors is used for various calculations to make the drivers work faster, easier and safer. The electronics in control of large physical forces created by hydraulics and engines have to be operationally reliable. Also, because of the harsh conditions where mobile machinery is operated, the electronic control systems have to withstand rough weather conditions and electromagnetic interference coming from various parts of the machine's electrical system.

Epec Oy is a specialist in mobile machinery control and information systems. The company, founded as E-P elektroniikka 1978 in Seinäjoki, concentrated at first on designing and manufacturing customer-oriented electronics. By the end of the 1980's, the first harvester log measuring and optimizing unit, Harvemeter 4000 was established and the focus of business was now in mobile machinery information and control systems. At the beginning of 1990's the name of the company was changed to Epec Oy due to increasing number of international business operations. At the same time, the first generation of modular control systems for forest machines was released. In 1995, Epec expanded its business to mining sector and by the millennium the 3rd generation of modular control system was released. Epec modules were used in crushing stations made by Metso Minerals and a co-operation contract was established with Sandvik Mining & Construction. During 2004 and 2005, one year after the release of the 4th generation modular control system, Ponsse Oyj, a Finnish harvester company acquired 100% of Epec shares. Epec became an independent subsidiary of Ponsse Oyj, and nowadays it takes care of the manufacturing and designing of most of the electronics used in Ponsse harvester machines. [1]

Now 30 year-old Epec has a wide variety of products related to mobile machine control and information systems. One of the main products is the Human-Machine-Interface unit, called 2040 Display. It consists of a 5.7 inch QVGA Colour TFT display and as a hearth it has an ARM9 180 MHz processor. For electronic interfacing with a machine control system, this unit has 2 CAN open buses, two USB 1.1, Ethernet and RS 232/422/485 serial bus. The operating system used in this IP65 protected HMI is Linux 2.6. Typical application platforms for this device could be located in the forest machinery, road maintenance vehicles, construction machines, crushing stations, industrial machinery, agricultural-, automation- or mining applications. [1; 2, p.5]

The 2040 unit described above provides the basis for the system described in this thesis. After carrying out some benchmarking with similar Human-Machine-Interface displays on the market today, it was discovered that several competing devices had an external camera input feature, which is not found in Epec 2040 -HMI device today. Also, there had been a request among present customers for such a function for this specific product. External cameras can be very useful in modern machines. Because of the size of the machines, the driver is not able to see everywhere around the vehicle. Especially rear-view cameras are commonly used in today’s machinery, as well as process cameras in some special applications. These kinds of cameras allow the driver to observe closer what he is doing or what is happening around the machine, so the driver is more in control of the things he is doing. The task was to design a prototype card that works as a camera input feature for 2040 HMI device. The simplified function of this prototype board is to convert composite video signal to digital RGB, which can be fed directly to the display panel.

2 Video signals

2.1 Analog video in general

Analog video image is created to a display by scanning the screen in small lines with electrical signal. The signal amplitude related to time determines the instantaneous brightness of the display. This method comes from the operation principle of a CRT (Cathode Ray Tube). [3, p.1]

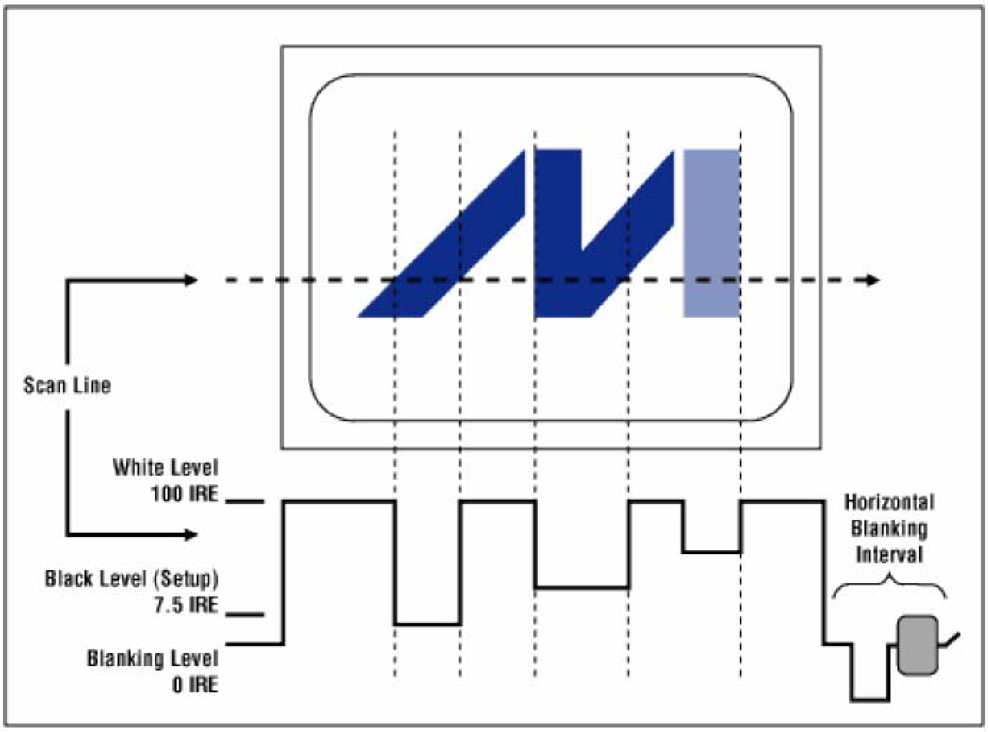


Figure 1.Basic principle of how an image is recreated on a display screen. Note the scanning signal amplitude relationship to picture instantaneous brightness. In the lower right corner there is the Horizontal Blanking Interval. After this synchronization sequence active video portion of signal begins again. [3, p.2]

As the electrical signal sweeps through the screen, the amplitude of the signal changes during this transition. From figure 1 it can be easily seen that the bigger the amplitude of the signal is, the brighter the image will be. The video signal amplitude is expressed in IRE: s (Institute of Radio Engineers). 100 IRE is a level equal to all white signal, and the level of the sync pulse is -40 IRE. Since IREs are expressed as a relative portion of voltage, absolute voltages cannot be determined from figure 1 unless the specific video format is known. For example in composite video level of 100 IRE equals 1 $V_{PP.}$

The actual picture brightness information is followed by Horizontal Blanking Interval (far right in Figure 1). This portion of the waveform tells to the scanning control circuitry to go back to the left side of the screen and start scanning the next line. Scanning normally begins from the upper left corner and works its way down the screen line by line as described above. There are two different scanning techniques in use today, the next chapter will tell more about them; the basic idea of scanning the screen is still the same. Once one complete screen has been scanned from the upper left corner to lower right corner, this picture is called one frame. Between the frames there is a section called the Vertical Blanking Interval (VBI). This pulse guides the scanning circuitry back to the upper left corner in order to start scanning the next frame. Note that both the Horizontal and Vertical Blanking Intervals are so short that they are not visible in the picture. The signal described in this chapter is referred to CVBS and S-video standards as “Y” or Luminance, and it only carries the brightness and synchronization information. So with this signal it is only possible to display a monochrome picture, no colours. [3, p.2; 4]

2.2 Different scanning techniques

Two different scanning techniques are used for video displaying, interlaced and progressive scan. The scanning technique used in a certain application depends on how much bandwidth there is available, and also what kind of display is being used. Different kinds of conversions between analog and digital formats, not to mention conversions between scanning techniques, tend to lose information, increase noise or just make the device more complicated. This is why video signals are meant to be kept in the same format throughout the transmission from source to receiver display controller circuitry. [3, p.2]

Interlacing is a scanning technique where the display area is scanned in two fields. An odd field consists of vertical odd rows and an even field consists of vertical even rows. Both of the fields are scanned simultaneously. For example in PAL based systems, both fields are scanned 25 rows per second. Since the both fields together (25 + 25) make one complete frame, 50 rows are scanned every second. Still, it takes 1/25 of a second to complete one frame, so the frame rate is 25 frames per second. [5]

Interlaced scan comes from the world of CRT, and originally in these vacuum tubes it worked a bit differently. The basic idea is the same but odd and even fields are not scanned simultaneously. The scanning begins from the even field (second row) and once the even field has been scanned, the odd field will be scanned right after that. With this technique it takes twice the time to complete one frame than in modern electronic displays, but it also consumes half of the bandwidth. Even though the fields are not scanned simultaneously, the picture will be visible on the screen because of the phosphorus afterglow on the inside surface of CRT. So for this reason, the only display where interlaced video signal can be displayed without signal deinterlacing is a conventional Cathode Ray Tube. [5]

Progressive scan is a simpler scanning technique than interlacing. In progressive scan, each line is scanned in a chronological order, starting from the upper left corner moving row by row down to the lower right corner. The progressive scan gives higher vertical resolution than interlaced video at the same frame rate. The progressive scan is used in computer displays which require higher resolution and is also the dominating technique in current television displays, including CRT’s. The drawback of the progressive scan is that it requires more bandwidth than interlaced scan. [5, 6]

2.3 Video formats

At the beginning of the design, it was crucial to find out what kind of video signal mobile machinery digital cameras produce and what kind of form the signal has to be converted into. It turned out that the composite video is the common video signal format in these cameras. Since S-video is also supported by the video decoder and S-video output is available in many consumer products today, a decision was made to incorporate it in the design for testing purposes. Digital RGB is the most common signal format that flat display panels accept. Some new panels accept LVDS, which is a parallel digital signal too, like digital RGB.

2.3.1 Composite video

Abbreviation CVBS is commonly used for composite video especially in professional documentation. Abbreviation CVBS stands for Colour, Video, Blank and Sync. The same signal format is used in analog television broadcasts. In television broadcast signal there is an audio signal added to it and the whole signal is modulated through an RF modulator. Composite video is generally used in devices that can be connected to TV set, VCR's, older game consoles, rear-view cameras and other low-end video equipment. However, composite video is still supported by a wide variety of devices; many computer graphic cards still have a composite video connector, and the well-known SCART connector carries RGB, composite video or s-video depending on the application. The standard composite video connector is a RCA jack with a coaxial cable with characteristic impedance of 75 ohms. BNC connectors are also used in some professional applications. In high-end analog video applications, composite video has often been replaced by s-video, RGB or component video. [7, p.4; 8]

Composite video is an analog video signal that consists of three signals called Y, U and V. Y is the base band signal and stands for brightness or Luminance, and it also carries video synchronizing pulses. Y as itself can be displayed as a monochrome picture. U and V carry the colour information between them, and this signal is called hue and saturation. U and V are mixed with two orthogonal phases of colour carrier signal to form Chrominance. So now we have Luminance, synchronizing pulses and Chrominance. To get composite video signal, these three have to be combined. Since signal Y (Luminance and synchronizing pulses) is a base band signal and Chrominance (U and V) is mixed with carrier signal, the combination of these two is called frequency division multiplexing. [8]

There are three main native standards of composite video in use today. These three have various sub standards (refer to table 1) that have some minor differences. Although each standard is used in certain part of the world, most video signal processors and decoder chips support all of the standards. On the other hand, many consumer products are designed so that they only support one native standard.

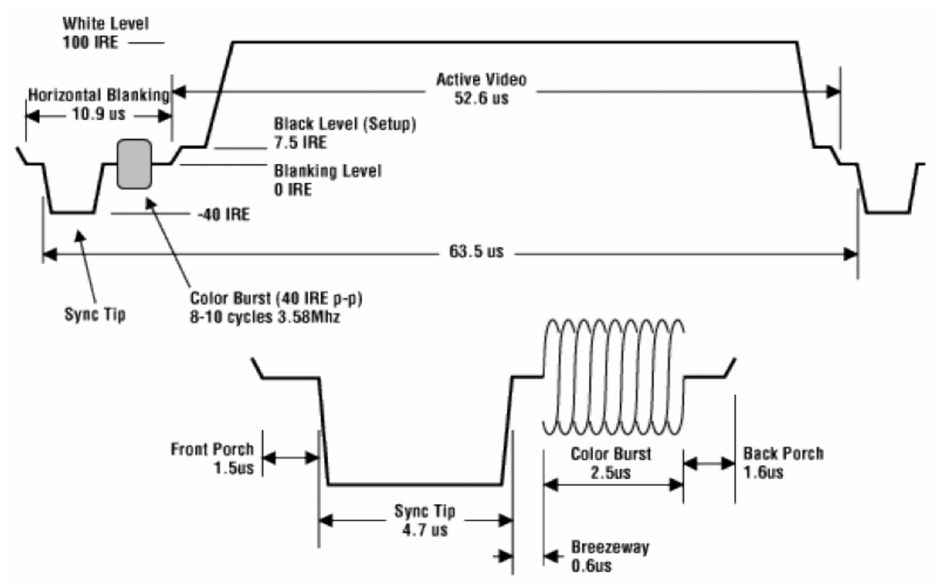


Figure 2. Composite video signal waveform and IRE levels explained. Upper figure represents simplified composite video signal, and the lower one is a magnification of the colour burst and synchronization signals. [3, p.7]

The composite video signal begins with a Horizontal Blanking Interval (HBI). In figure 2, the HBI section is magnified under the CVBS signal. HBI begins with front porch, a time interval between the end of each transmitted line of picture and the beginning of horizontal synchronization signal. After the synchronization signal, there is the colour burst that defines the colours. The colour burst is a sine wave with the frequency of 3.5 MHz to 4.5 MHz. The colour burst completes from 8 to 10 full cycles depending on the exact native format. The phase shift between the colour burst and the active video signal defines the instantaneous colour. For example in NTSC format, the phase shift of yellow colour is 15 degrees, while green colour in the other end of the scale has a phase shift of 315 degrees. Active video is followed by a section called back porch, and it was originally defined as the section between the rising edge of horizontal synchronization and the beginning of active video signal. In colour CVBS signal, the colour burst takes most of the back porch time. After the back porch, there is a small section where there is first a blanking level and then a black level. The voltage offset between these two levels is called “setup” and it is used only in NTSC format. This “setup” helps to separate active video and sync portion from each other. Blanking level and black level are the same in every format except NTSC. Synchronization signals do not interfere with active video because the syncs are below black level and therefore cannot be seen. These “invisible” signals are said to be blanked. [7, p.8; 3, p.7]

As explained in chapter 2.1, the brightness or luma is dependent on the amplitude of the signal. In colour CVBS signal, the amplitude of the signal also defines the amount of colour (saturation) in the active video portion of the signal. The phase shift between colour burst and active video signal defines the colours (hue) displayed at certain instant of time, in other words, certain parts of the screen. This is how the picture is formed on the screen from composite video signal. [3, p.7; 9, p.11]

2.3.2 Composite video native standards

As mentioned previously in the chapter 2.3.1, composite video is a composition of three different signals. Since the signal receiver (TV set or display) cannot form a picture from composite video signal where all information is packed in a single wire, the signal needs to be decoded. Decoding is separating different parts of the signal so that the circuitry driving CRT or display panel can form a picture. There are three main encoding standards for composite video: PAL, NTSC and SECAM. These standards are used in different parts of the world, and they have slight differences in frame rates, subcarrier frequencies and colour modulating techniques (See table 1 for details).

NTSC (National Television Systems Committee) is the video transmission standard used in North and Central America, including Canada and Mexico. Also Japan uses NTSC. The committee established black-and-white television standard in United States in 1941 and colour television standard in 1953. NTSC consists of quadrature-modulated colour-difference signals added to the luma with a colour subcarrier. It consists of 525 lines per frame, and the refresh rate is approximately 30 frames per second (59.94 Hz). [8; 10]

PAL (Phase Alternate Line) is the European counterpart to the NTSC. It is used in Western Europe, in the Middle East and in some parts of Africa and South America. It is similar to NTSC but uses subcarrier phase alternating in order to reduce sensitivity to phase errors that would be displayed as errors in colours. PAL consists of 625 lines per frame but has lower refresh rate than NTSC, 25 frames per second (50 Hz). [8; 10]

SECAM (Sequential Colour with Memory) is very similar to PAL. It is used in France, Russia, some parts of Africa and Eastern Europe. The difference to PAL and NTSC is that chrominance (colour) signal is frequency modulated whereas chrominance is not separately modulated in PAL and NTSC. [11]

So composite video is a composition of different signals and should not be confused with component video which consists of three different signal cables.

Table 1. This table shows the characteristics of PAL, NTSC and SECAM standards. These standards define the form of the analog video signal, and they are used in different parts of the world.

Video signal native format comparison					
Format	**Frames /second**	**vertical lines**	**Scanning**	**Video Bandwidth**	**Colour subcarrier frequency**
NTSC M	60	525	Interlacing	4.2 MHz	3.579545 MHz
PAL B, G, H	50	625	Interlacing	5.0 MHz	4.43361875 MHz
PAL I	50	625	Interlacing	5.5 MHz	4.43361875 MHz
PAL N	50	625	Interlacing	4.2 MHz	3.582056 MHz
PAL M	60	625	Interlacing	4.2 MHz	3.575611 MHz
SECAM B, G, H	50	625		4.2 MHz	-
SECAM D, K, K', L	50	625		6.0 MHz	-

2.3.3 S-video

S-video is an abbreviation of Super Video or Separate Video. This video signal can offer better quality than composite video, and it is also more immune to external noise. S-video consists of Y (luminance) and C (chrominance), and these two are basically the same kind of signals that can be found combined in the composite video. Because of the signaling, sometimes S-video is also called Y/C video. In designated S-video cable, signals travel in two pairs, luminance & luminance ground, and chrominance & chrominance ground respectively. Because luminance and chrominance signals are carried with separate wires, high-frequency luminance does not have to be low-pass filtered like in the composite video. This increases the bandwidth of luminance and chrominance signals, as shown in figure 3. Two separate wires also prevent crosstalk between luminance and chrominance and eliminate dot crawl. Since the chrominance part is formed from U and V just like in the composite video, also

S-video needs to be encoded. These native encoding formats are the same for composite video, NTSC, PAL and SECAM. [12]

The standard connector for S-video interface is 4 pin Mini-DIN with 75 ohm characteristic impedance, but also Mini-DIN connectors with 7 and 9 pins are used. These connectors are commonly used in laptops and video cards, and they contain additional signals to S-video, such as component video and analog RGB.

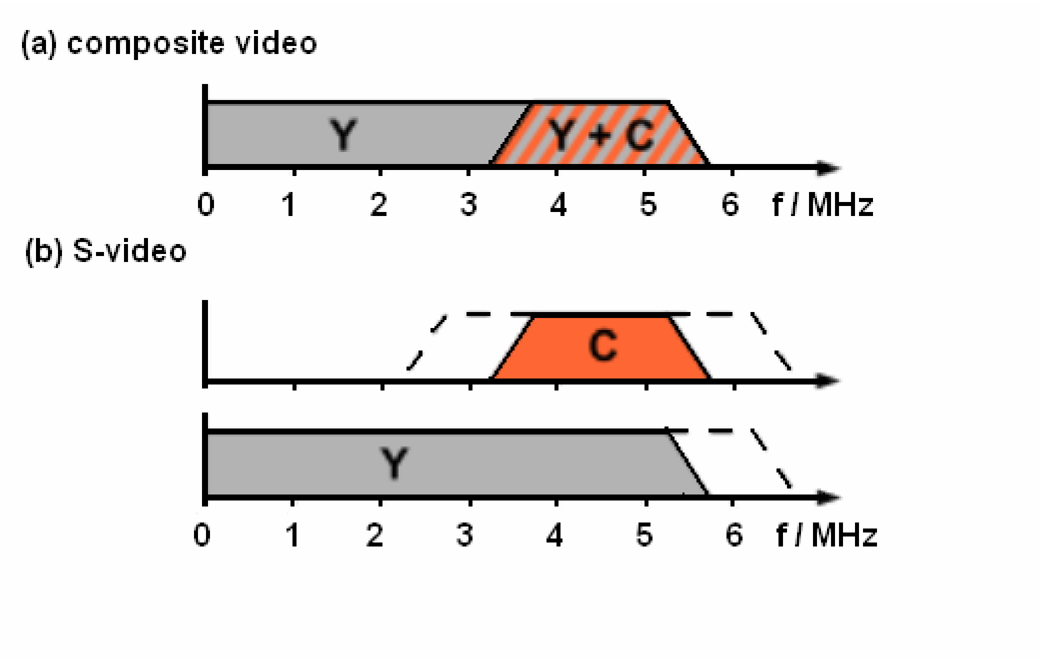


Figure 3. Composite video and S-video Luminance (Y) and chrominance (C) component bandwidths.

Figure 3 demonstrates the difference between S-video and composite video signals. Figure 3 (a) shows a composite video signal where luminance (Y) and chrominance (C) are combined. Figure 3 (b) shows S-video signal where chrominance and luminance are carried in separate wires. The dashed line in the lower picture shows the bigger bandwidth of S-video. From these figures it can be seen that luminance and chrominance are partially in the same frequency spectrum, so crosstalk of these two signals may cause dot crawl in the composite video. Evidently this is not the case in the S-video signal. The bandwidths of these video signals can also be seen from the figure 3. As mentioned earlier in this chapter, S-video chrominance does not have to be low-pass filtered. Figure 3 shows the relationships between the bandwidths of S-video and composite video. S-video has a larger bandwidth for both Y and C. This means that S-video can create more accurate imitation of the original picture, in other words, it has a better quality. [8; 12]

2.3.4 Digital RGB

There are various digital RGB representations, but currently 24-bit Truecolor is the mainstream standard. In this 8 bits per colour representation, a totally black screen is created with (0,0,0) bit values and completely white screen with a bit combination (255,255,255), respectively. In small TFT displays, colours cannot be displayed with high accuracy, so these devices do not require such detailed colour information. As mentioned before, the 5.7 inch TFT accepts 16 bit (5,6,5) digital RGB. Green section has one additional bit since human eye is more sensitive to green colour. The other TFT -display used in this project accepts 18 bit (6,6,6) digital RGB. [13]

3 Digital vehicle cameras

Cameras mounted on mobile machinery must withstand very extreme conditions and still be reliable in every situation. In machinery like harvesters or mining machines, external cameras must be well-protected against rough weather conditions. Taking this into consideration, only professional vehicle cameras would be an option for this project. Most of these robust cameras have a high IP-rating, a heated lens and they output composite video. The viewing angle is an option to choose, many of these cameras have lenses with a viewing angle from 45^o up to 160^o. [14]

3.1 CCD digital camera

CCD is actually a rectangular photoelectric light sensor inside the camera. This part converts light to electric signal. “CCD” stands for Charge-coupled Device, and this name comes from the theory of operation of this array. The CCD array consists of photodiodes and capacitors. Each capacitor-photodiode pair forms one pixel. At the beginning of the exposure, each capacitor is discharged. As light hits the photodiodes, electronic charge generated by the photodiodes goes into the capacitors and the voltage across the capacitors starts to rise. The bigger the intensity of the light hitting into the photodiode, the faster the voltage rises across the capacitors. After the exposure, the voltage across each capacitor is measured. A CCD array works like an analog shift register, and it can transfer small electric charges from place to another without losses. After the exposure, electric charges from capacitors are transferred from the CCD to amplifiers and after that to analog to digital converters. [15, p.27]

There are two main types of these CCD cells. A Full Frame cell always requires an external mechanical shutter. If light hits the photodiode when electric charge from capacitor is being transferred from the CCD, it will mess up the picture.

That is why the mechanical shutter blocks the light away while picture information is being transferred inside CCD. In an Interline transfer cell, every other pixel is shielded from light. So the electric charge from capacitor is transferred to this covered pixel and the measurement and transfer of electric charge can be done while photons are hitting the array. These kinds of cells are used in video cameras where mechanical shutter cannot be used. The drawback of this cell is that half of the effective array area is lost, and this results in poorer image quality. [15, p.28]

3.2 CMOS digital camera

The basic theory of operation is the same for CMOS as it is for CCD. Photodiodes placed in a rectangular matrix convert light into electronic information. However, the image sensor made out of Complimentary Metal-Oxide Semiconductor material has lots of differences compared to CCD cell.

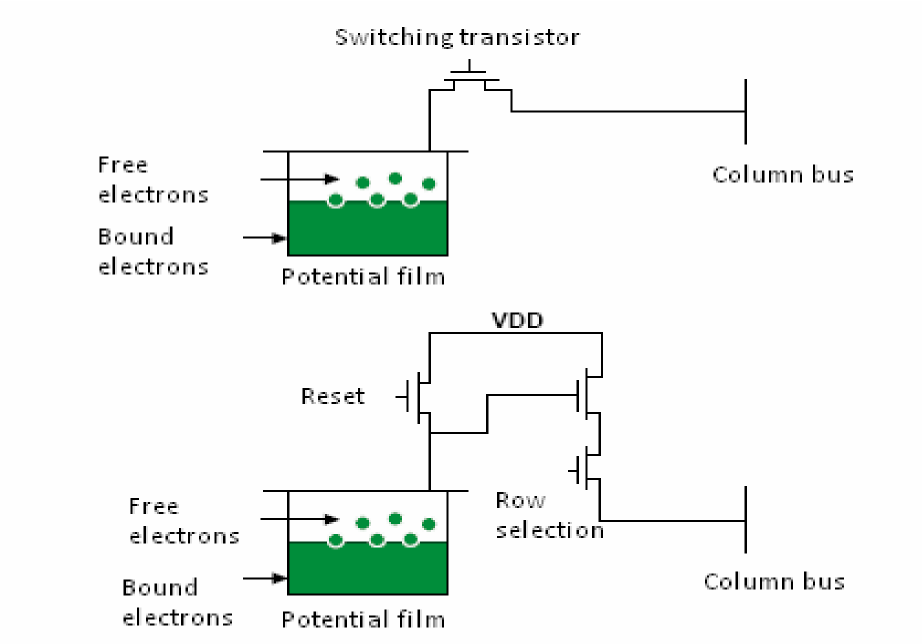


Figure 4. The figure shows the difference between active and passive pixel system in CMOS-array. The upper figure represents the passive pixel system and the lower the active pixel system. [16]

The main difference in CMOS compared to CCD is that because CMOS is made with the same technique as microchips, additional electronics like amplifiers, A/D converters and signal processors can be integrated into this image sensor. The CMOS array consists of horizontal column buses and vertical shift registers. The buses take care of transferring the charges from photodiodes, and shift registers control the exposure, reading and resetting cycles. The charge is fed to column bus via an integrated switching transistor located next to the photodiode. In this passive pixel system shown in the top of figure 4, the signal fed to the capacitance of the column bus is amplified at the end of the bus. After this phase, voltage can be measured and the pixel re-exposed as soon as the transistor has been turned off and bus set to zero.

The efficiency of this kind of pixel system is good, that is, the amount of collected electrons from photodiode is almost the same as the amount of photons hitting the photodiode. However, this passive pixel system has some basic problems, too. Since the charge pulses from the pixel travel different distances depending on where the pixel is located in the array, the pixels furthest from the amplifier may not be able to charge the whole capacitance of the column bus in weak lighting conditions. Also the switching voltages of the transistors vary. Consequently, the charge of the pixels does not enter the bus simultaneously. Both of these disadvantages increase the amount of noise and uneven intensity of pixels. [16, p.41]

To get rid of these problems in the passive pixel system, an active pixel system was developed. As demonstrated in the bottom of figure 4, this system incorporates a small amplifier integrated next to the photodiode. The amplifier consists of three transistors: source monitoring and resetting transistor and a row selection transistor. Since the signal is amplified by the source monitoring transistor, the size of the cell is no longer a problem. The resetting transistor takes care of the exposure time, working as an electronic shutter. With the row selection transistor, each row of pixels can be allocated separately when pixel charges are transported to column amplifiers. [16, p.41]

All additional electronics in the sensor itself take a part of the exposure area. This weakens the picture quality. Interline transfer CCD suffers from the same problem. A solution for both CCD and CMOS is to use a micro lens in front of the pixel to gather the light to a smaller area. A microlens approximately doubles the sensitivity of a pixel. [16, p.41]

3.3 Colour sensing in digital cameras

Both of the arrays described above are only capable of capturing monochrome pictures. In colour video cameras, two techniques are used for colour detecting: a grid of colour filters or individual image sensors for red, green and blue. [17]

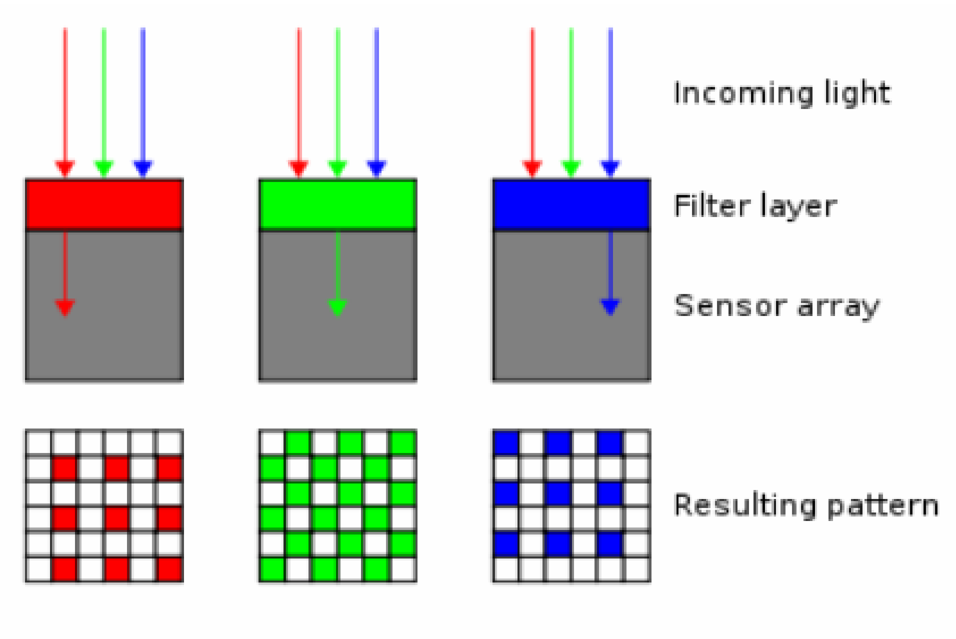


Figure 5. Bayer-pattern RGB colour filtering. This kind of colour filter can be placed over a CCD or CMOS cell in digital camera. [18]

When a colour filter grid is used to sense colours, the so-called Bayer-pattern filter is a common application. In this pattern, the ratio of different colours is following: red 25%, green 50%, and blue 25%. So there are twice as many green pixels as red or blue ones. This ratio between red, green and blue imitates human eye capability of resolving different colours. In figure 5, this colour detecting strategy is described as it can be found in digital cameras, this picture is simplified of course. On the top of the figure 5, the incoming light has passed the camera lens and mechanical shutter if there is any. The filter layer covers the whole CCD or CMOS array which can be anything from a couple of millimeters to a few centimeters in diameter. Each colour square of the filter is dimensioned so that only one photodiode gets exposed through one filter square. As a result, one photodiode only senses the wavelength of red, green or blue light. After amplification, signals from different pixels are converted to digital form and combined with complex digital signal processing to form a picture. [15, p.30; 18]

Another way to create colour pictures with CCD or CMOS sensors is to use multiple cells. Light coming to camera lens is divided into wavelengths of red, green and blue light with prism assembly and guided to three different CCD or CMOS cells. In this way, one cell is exposed with only one colour wavelength. Now more colour information can be stored and the pictures have better quality than the ones exposed with colour filter array described above [17].

4 System description

The device built in this project is a peripheral card designed to work with one of Epec's products. Even though these two devices can operate together as they were meant to, the video interface card described in this thesis will never be a part of any product. It was designed for prototyping purposes only. The goal of this project was to test the technology available for this kind of application and to provide the basis for integrating the technology of the video interface card to a future release of 2040 HMI device. This integration could be a peripheral video input device or a part of 2040 main board.

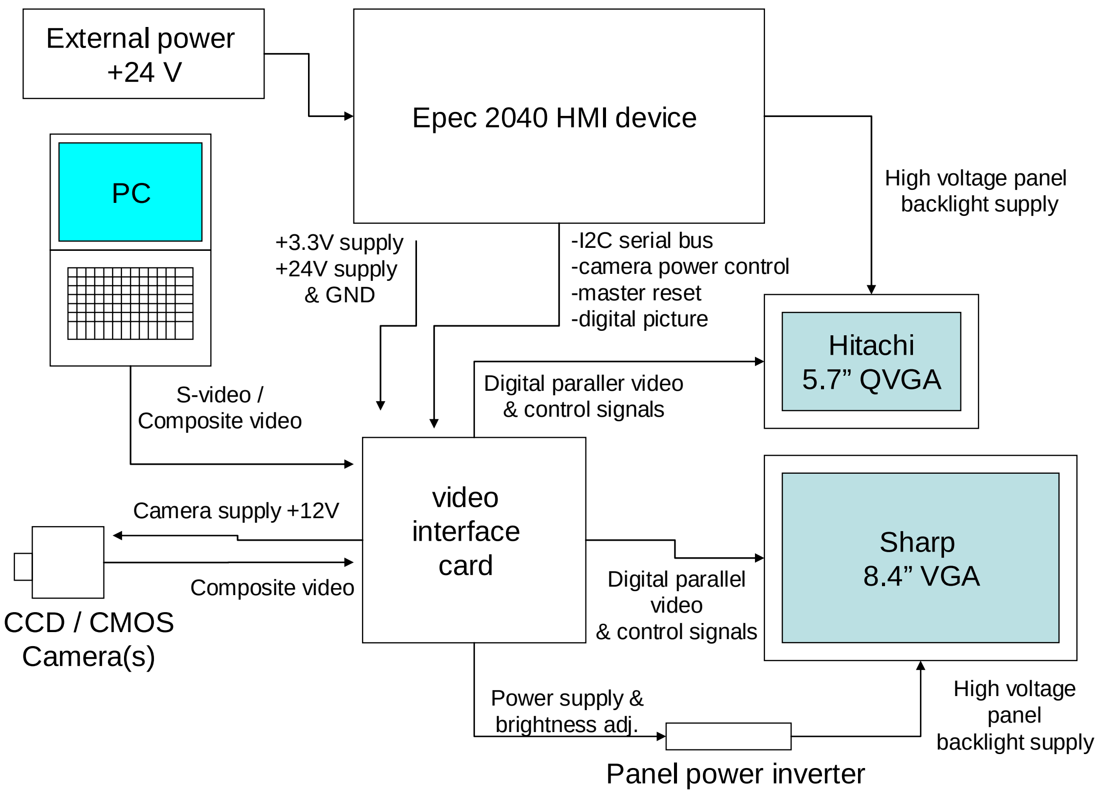


Figure 6. Video interface card with all connections necessary to test the features desired in this project.

The 2040 HMI device, which acts as a motherboard in this system, feeds the picture information in a digital form. This parallel digital signaling consists of 5 bits of red, 6 bits of green and 5 bits of blue colour components. In addition, there are horizontal and vertical synchronization signals, pixel clock, 3.3 volt supply and GND. In this project, this digital RGB from 2040 is fed to the video decoder chip in the video interface card.

4.1 Peripheral devices

Connections shown in figure 6 are not the actual signal wires, the arrows just point out what kind of information is going and where. A single arrow can represent 1 wire or 40 wires, showing the simplified relationships between different devices. In the middle of figure 6 there is the video interface card, which is the main focus of this thesis. Above it, there is the 2040 HMI device, a current product of Epec. Other devices in the figure are quite obvious, 2 different display panels, external power and a PC acting as a source of S-video signal. Hitachi 5.7” display is currently used in 2040 HMI, so its backlight power is provided by 2040. Sharp 8.4” panel is being tested as well, but it has its own backlight power inverter which is powered by the video interface card. The camera unit can be found in far right in figure 6. A 12 V supply for this camera unit is provided by the video interface card. The camera unit feeds composite video signal to the decoder board. This is the main source of the video signal.

4.2 Interface between the video interface card and 2040 HMI device

4.2.1 Decoder board supply power

Two different supply voltages are connected from 2040 board to video interface card. +24 V and ground are drawn straight from the power connector of 2040 HMI device. Another supply, +3.3 V is taken also from 2040 board. Since 2040 has extra capacity in the +3.3 V power, it was considered to be reasonable not to build another +3.3 V source to the video interface card.

4.2.2 Communication and control

I^2C bus is a link between the ARM9 processor in 2040 module and the video decoder chip in the video interface card. This is a two wire serial bus, where the clock signal is fed through one wire and the data through another wire. Through this bus the main processor in 2040 module is able to read and write the video decoder chip’s registers. When 2040 is connected to a PC via Ethernet, registers of the video decoder chip can be programmed.

External camera supply voltage can also be controlled by the ARM9 processor. The camera power supply mounted on the video decoder board has a control pin that can be connected to GPIO (General Purpose Input / Output) in ARM9 and thus switched on and off remotely. Since 2040 module is connected to CAN –bus, it gets the information about what is happening in the vehicle at the moment and the camera can be switched on according to that information. For example, when reverse gear is switched on, the rear-view camera can be powered up automatically. The video interface board has a reset button with which the whole system can be reseted, since it is connected to the master reset of 2040 main board.

4.2.3 Data transfer

2040 module feeds the 18 bit RGB to the video interface card. This information is fed through the very same cable that normally goes from 2040 main board to Hitachi 5.7” TFT. Using this same signal as an input for the decoder chip, no changes to the original product had to be made. So this signal provides the user interface view, normally displayed on the screen of 2040 HMI device. With synchronizing pulses and additional ground and power wires, the 18 bit RGB video signal is transferred through 40 pin FPC cable to the video interface card.

4.3 The desired operation of the video interface card

4.3.1 Initial settings

In the system power-up, ARM9 in 2040 module loads register settings through I^2C bus to the decoder chip. This sets the video input modes, Picture In Picture mode, panel resolution etc. to the decoder chip. In power-up, the panel backlight also lights up powered either from 2040 main board or from the decoder board depending on which panel is used.

4.3.2 Normal mode operation

When external cameras are not used, digital RGB from 2040 is fed to the decoder chip. In this chip it is scaled to fit the resolution of the used panel. This signal is then fed straight to the panel. Now the display shows the application user interface which provides information about the operating conditions of the machine and its engine. This view can also give information about the surroundings, for example the weight of the load or the length of the log. In this mode, cameras can be turned on manually with the pushbuttons found in the 2040 HMI. When the camera is turned on, the operator can select the display mode from the pushbuttons: full screen camera or Picture In Picture mode. In PIP mode, the operator can select multiple cameras or a camera and the instrument cluster on the same screen. When combining two pictures with this video decoder chip, the possibilities are almost endless. However, the basic configuration would be to the instrument cluster essential information and rear-view camera picture on the same screen.

4.3.3 Forced camera control

In forced camera control, CAN -bus proves to be handy. Instead of feeding supply to camera from reversing light and wasting 2040 modules' inputs for backup information, virtually everything that is happening in the machine can be picked up from the CAN -bus. Here is what would happen when reversing: 2040 HMI device's processor gets information from CAN that the reverse gear is engaged. The processor sends a script through I^2C to the decoder chip. This script defines the values of several registers. Video inputs, picture ratio and PIP placement among other things are configured. Forced camera power up control feature in the video interface card is connected to 2040 HMI GPIO. The camera supply is powered up by the command given from GPIO. The end result of this all is two pictures on the screen, video from camera and graphical user interface from the 2040 HMI.

Figure 7. Picture In Picture mode of the video interface card in use. In the upper left corner of the screen there is live video from the camera, and the application user menu on the background.

5 Electromagnetic compatibility aspects

EMC is to be observed from two complementary aspects. There are always sources of interference emissions and a victim which is susceptible to this interference. If one of these is not present, then EMC is not a subject of interest. EMC systems are divided into two different types. “Inter-system” means EMC relationship between two different devices. This means that these devices are not a part of the same system and they have no common electrical functionality, except EMC relationship. An example of this kind of system could be a mobile phone and a radio. Description “Intrasystem” is used for a system where the source and the victim for interference are in the same piece of equipment. Intrasystem interference could occur, for example, between a switched-mode power supply unit and an audio amplifier fitted on same PCB. [19, p.153]

5.1 Interference coupling mechanisms

Electromagnetic interference can couple from source to victim by conducting through common impedance that source and victim share. A common path for conductive interference coupling is a shared ground plane between the source and the victim. This applies to both intrasystem and inter-system coupling. A simple fix for this common impedance coupling is to separate the connections so that there is no common current path. Even though the victim and the source do not have a common impedance, this kind of interference coupling is still possible. All devices, even the ones with floating ground reference, are connected to each other via stray capacitances and impedances. [19, p.153-154]

Interference can also couple through air via electric, magnetic or electromagnetic fields. An electric field is generated between two conductors in different potentials. Changing voltage on one conductor applies an electric field around it. This field may couple to another conductor nearby and induce a voltage on it. This coupling capacitance is a function of distance between the conductors, their effective areas and the presence of any electric screening material. This kind of coupling usually appears between cables that are situated close to each other, and the source cable has big dv / dt, in other words rapidly changing voltage. [19, p.155, 160]

When a conductor has a current with a big di / dt rate flowing through it, a magnetic field forms around it. The relationships in magnetic induction are similar to the electric induction described above. The voltage induced to the victim is a function of di / dt in source conductor and the areas of victim and source current loops and their orientation and distance to each other. Also the presence of any magnetic screening has an effect on induced voltage. This kind of magnetic field is created, for example, by magnetic solenoid valves. These valves have a large area of current loop, a high di / dt rate and they draw a lot of current. [19, p.155]

“Most electronic hardware contains elements which are capable of antenna-like behavior, such as cables, PCB tracks, internal wiring and mechanical structures. These elements can unintentionally transfer energy via electric, magnetic or electromagnetic fields which couple with the circuits.” [19, p.153]

In real-life EMC issues there does not exist purely electric induction or magnetic induction described above. Since these two interact with each other, they cannot be treated separately.

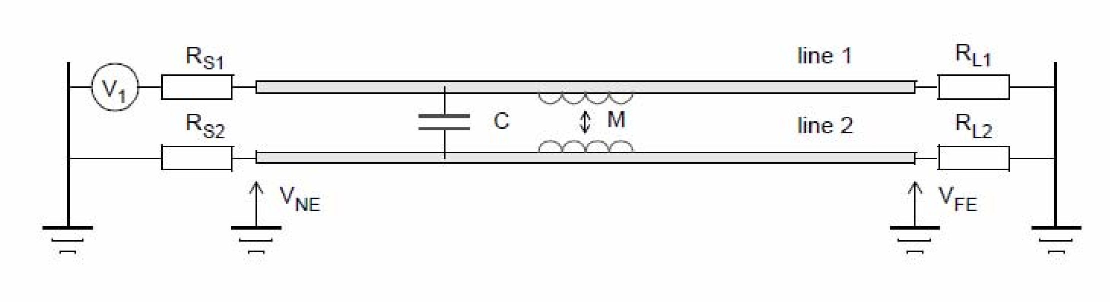


Figure 8. Crosstalk phenomenon. This figure represents equivalent circuit of two wires with stray capacitance and inductance between them. Also source and the load resistances (RS & RL) for each wire can be found in this figure. The voltage at both ends of the wires are Vne (voltage near-end), Vfe (voltage far-end). [19, p.157]

Figure 8 represents cables with two conductors, one at each end. Both of the cables are connected to remote ground planes. The capacitor and inductor symbols in the figure represent the inductive and capacitive connection between these cables; they are not physical components. Capacitive coupling between line 1 and line 2 induces a voltage in line 2. Current in line 2 induces a voltage magnetically to line 1. Since magnetically induced voltage is in series with the conductor, it induces negative voltage to near-end (Vne) and positive voltage to far-end. The total interference at each end is the superposition on both sources. The model described above is only valid at low frequencies. This means that the length of the cables must be much less than the wavelength of the signal. [19, p.157-158]

5.2 Emission environment

When considering EMC aspects in the PCB design, it is helpful to have some kind of idea of the environment where the device will operate. In this environment, is it more a source than a victim? Is there any sensitive equipment at close distance that could receive interference from our device? What are the possible sources / victims in this environment? What kind of power supply our device will be using, battery or mains distribution network? What kinds of other devices are connected to the same power supply? Is there a possibility that interference could conduct through the inputs of our device?

These are the kind of things that should be considered in product design from EMC point of view.

The video interface card is designed as though it would be a part of Epec 2040 HMI display. 2040 HMI display is usually used in heavy machinery cockpits. So nearby there can be switches, relays, electronic hydraulics controlling units, electronic engine controlling unit, a diesel or petrol engine, halogen or xenon lights, magnetic valves for air and hydraulics and electric motors.

5.3 Emission sources in machinery environment

Table 2. Usual EMC emission sources in mobile machinery environment. Most of the emission sources are engine auxiliary devices or solenoid valves of the hydraulic system.

Emission sources	Cause for emissions	Coupling mechanism
Starter motor	large current in coils, solenoid coil	inductive, electromagnetic & conductive
Alternator	large AC voltage, ripple	electromagnetic, conductive
Coils (petrol engine)	very high AC voltage, coils	electromagnetic
Distributor	very high AC voltage, sparks	electromagnetic
Spark plug wires & caps	very high AC voltage	electromagnetic
Xenon lights	High DC voltage	capacitive
Magnetic valves	large current in coils, changing fast	inductive
Electric motors	large current in coils, changing fast	inductive
Battery	alternator, other equipment drawing current	conductive, voltage spikes, undervoltage

Table 2 shows some of the emission sources found, for example, in the harvester machinery. When the starter motor is used, it usually lowers the battery voltage and therefore the whole system voltage comprehensively, since the alternator is not working yet at this point. If the battery voltage level drops too low, it might interfere other electronic devices in the machine. Also the coils in the motor electric magnets and the solenoid coil in the starter motor create a magnetic field around them.

AC voltage created in the alternator is run through a rectifier and used to charge the battery. However, this voltage still has some ripple in it. This can have an effect on some sensitive electronic equipment. The alternator also creates an electric field and a magnetic field around it.

Petrol engine coils create voltages up to 30 kV. This voltage is discharged to engine ground plane several times in a second. So the fast changing high voltage in coils and coil wires & spark plug caps create a significant electromagnetic field around them. The distributor is also one potential source of emissions, since the voltage of several kilovolts jumps through a tiny air gap in there. This happens at the same frequency as the coil discharging, which is dependent on the engine rpm.

Even though the engine auxiliary devices are often considered to be among the worst emission sources, also other potential sources can be found in mobile machinery. High Intensity Discharge (HID) lights are commonly used in machinery today. These lighting systems can be a source of electromagnetic emissions as well. HID system consists of the bulb and ballast for each bulb. The bulb needs as much as 25 kV in the startup and this voltage is generated by the ballast. The ballasts are usually properly sealed, so emissions coming from there are not a thing to be concerned about. But unshielded wires going to the bulbs create quite significant electromagnetic field around them. Also the current drawn from the battery to create such voltage will drop battery voltage at the moment when the lights are switched on.

One special group of components found in the machinery is solenoid valves. These valves can be a part of a hydraulic or a pneumatic system. Either way, these valves always incorporate powerful coils. Since the solenoid valves can be working at a quite frequent pace, the supply cables for the valve coils are delivering currents with high di / dt rates. So the magnetic field is present near these valves and their supply cables.

EMC issues between the video interface card and devices described in table 2 are called inter-system coupling. Intrasystem coupling issues in this video interface system are limited between two PCBs; 2040 main board and the video interface card itself.

6 EMC considerations in the circuit and PCB design

The biggest concern in this device from EMC point of view is that emissions coming from the surrounding devices distort the analog video signal. Also intrasystem EMC issues had to be taken into account since there are analog and digital signals on the same PCB.

6.1 PCB layers

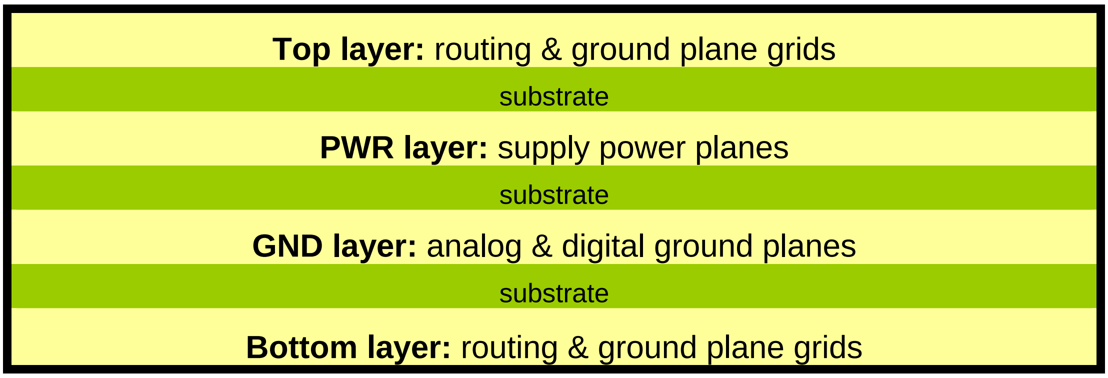


Figure 9. 4 PCB layers of the video interface card. This order of layers is said to be a good general purpose configuration for a 4-layer PCB. [19, p.208]

The video decoder card has 4 layers, as figure 9 demonstrates. The top and bottom layers are reserved for signaling, so there are as few power supply tracks as possible. The second layer is the PWR layer on which are all the supply voltages. It is divided into 4 planes, 1.8, 3.3, 12 and 24 volts. This layer does not contain any tracks. The 3rd layer is the GND plane, which is divided into digital and analog ground, quite evenly half and half. There are no tracks on this layer either, only solid copper. The bottom side of the board is reserved for signaling as well as the top layer. The good thing about this kind of layer arrangement is that all the signal tracks are always adjacent to the ground or power plane. Also, since the power and ground layers are adjacent to each other, interlayer capacitance works as decoupling capacitance at high frequencies. It is also preferred that critical signal should be adjacent to ground plane rather than power plane because the effect of the ground plane is to reduce the common ground impedance. So in this design, the intention was to route the most critical signals on the bottom layer, since it is adjacent to the ground plane. [19, p.207-208]

6.2 PCB partitions

6.2.1 Ground plane division

Both top and bottom layers have copper grids on their unrouted sections. These grids are connected to digital and analog ground planes and separated following the same line as ground planes on the GND layer. Figure 10 demonstrates this plane division.

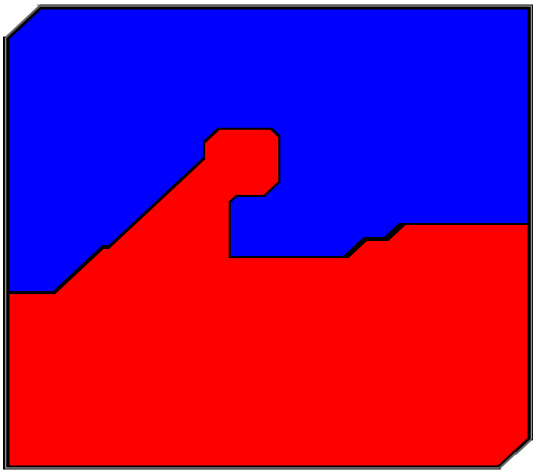


Figure 10. Analog and digital ground planes. Analog section of this PCB is blue and the digital ground plane is red. A ferrite bead inductor (BLM) is connecting these two planes.

Figure 10 shows how the video interface card is divided into analog and digital ground plane. On the top and bottom layer, these planes are copper grids and in the GND layer they are solid copper. The copper grid's task on the board is to reduce common ground impedance and act as a shield for EMC emissions. This grid also ensures good copper balance on the board, so the heat will spread evenly and the board is easier to manufacture.

This ground division also divides the whole PCB to analog and digital sections. On the digital side, there are only digital signals and digital circuitry, whereas the analog side has only analog signals and analog circuitry. The reason for this ground plane division is to keep the analog ground plane as "clean" as possible. Fast di / dt signals on the digital side have an effect on the ground plane as well. However, these ground planes are not completely separated. Since the ground reference voltage was desired to be kept at the same level on both sides, these planes are connected to each other from one point with a BLM ferrite bead inductor. A BLM inductor has a very low resistance on DC voltage, but when the frequency builds up, inductance, resistance and impedance increase in proportion to the frequency. So a BLM inductor keeps the ground planes electrically connected but prevents any high-frequency interference transfer between the analog and digital ground plane. [20, p.2]

6.2.2 Power plane division

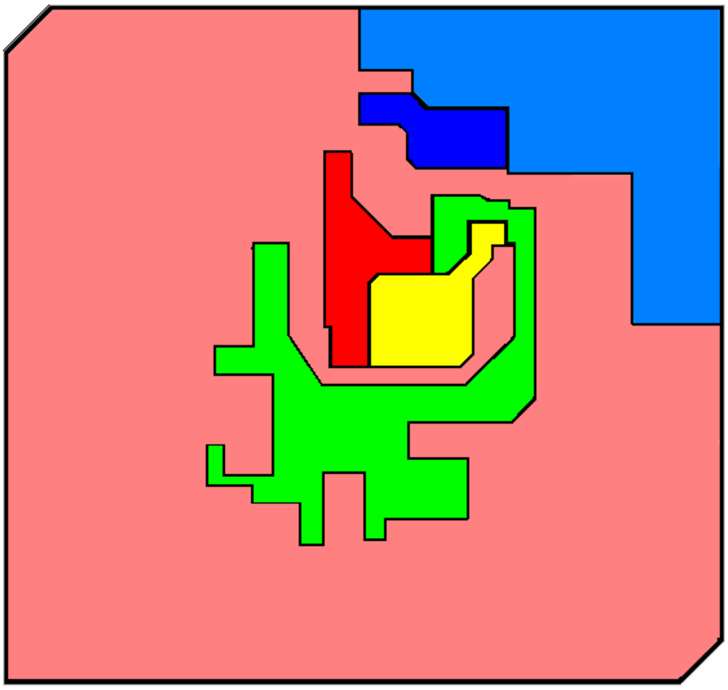


Figure 11. PWR layer in the video interface card is divided into 6 different sections; 3.3 V (pink), 3.3 V_{ANALOG} (red), 1.8 V (green), 1.8 V_{ANALOG} (yellow), 12 V (light blue) & 24 V (blue).The 3.3 V & 1.8 V analog and digital planes are connected to each other with ferrite bead inductors. Other planes on this layer are not connected to each other.

The biggest PWR layer section is a 3.3 V digital supply. This can be seen in figure 11 as pink coloured field. The layout of this layer is realized so that all the other power sections are exactly where they are needed and the digital 3.3 V power supply fills the rest of the layer. The digital supply is not as sensitive to interference as the analog supply and this kind of arrangement suited component placing best. In the center of the board there is the green section of 1.8 V digital supply voltage. This power plane is used mostly by the core of the processor. Next to this is the yellow section. This section is 1.8 V analog supply. It is connected to digital 1.8 V supply via a BLM inductor. The function of BLM here is to maintain the same voltage level in both planes, but to prevent interferences from transferring in between these planes. The function of BLM was explained in more detail in chapter 6.2.1. The dark red section next to the yellow section is the analog 3.3 V supply area. It is also connected to the digital 3.3 V supply via a BLM.

Last, the two sections in the top right corner are a part of the PCB's external power unit. The red section is 24 V supply and the brown section is 12 V supply. 24 volts is used to make 12 volts for peripheral devices. The camera and the TFT display backlight inverter get their supply from here.

6.3 Other design considerations concerning EMC

6.3.1 Digital circuit decoupling

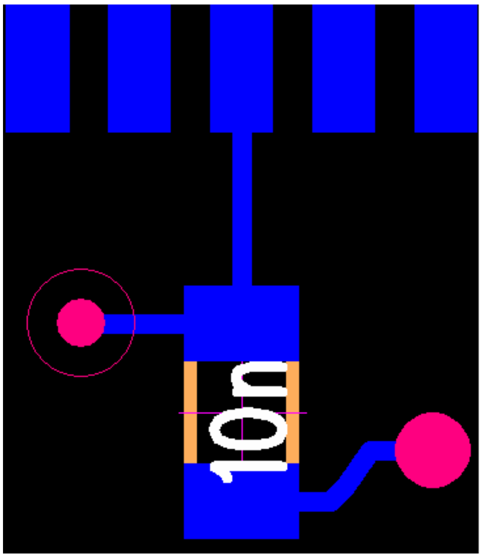


Figure 12.Decoupling capacitors are placed as near to the circuit supply pin as possible in the video interface card. Note also the short ground and supply leads from capacitor.

In digital circuit supply, decoupling is really important. When the states of digital circuitry change rapidly, they will create switching noise from the transient currents taken from voltage supply pins. This means that digital circuitry supply pins should have decoupling capacitors to even up the high di / dt rate in the supply pin. [19, p.226] These capacitors should be as close to the supply pin as possible, so that the impedance between the supply and the pin would be the smallest possible. Figure 12 is taken from the video interface card, and it shows a typical arrangement of a decoupling capacitor on this PCB. On the left side there is a via going to the PWR layer directly to the supply, and on the right side the via is going straight to the ground plane. This kind of arrangement is commonly regarded as a good way to decouple digital circuitry.

In addition to these 10 nF capacitors, the video interface card has larger capacitors in parallel to ensure good supply for digital circuitry at all times. One 10 μF electrolyte capacitor per one group of supply pins is used. One group of supply pins varies on this board from 3 up to 8 supply pins. Pins in the same group supply the same circuit. Figure 13 is taken from the circuit diagram of the video interface card and it gives an example of digital circuitry supply on this board.

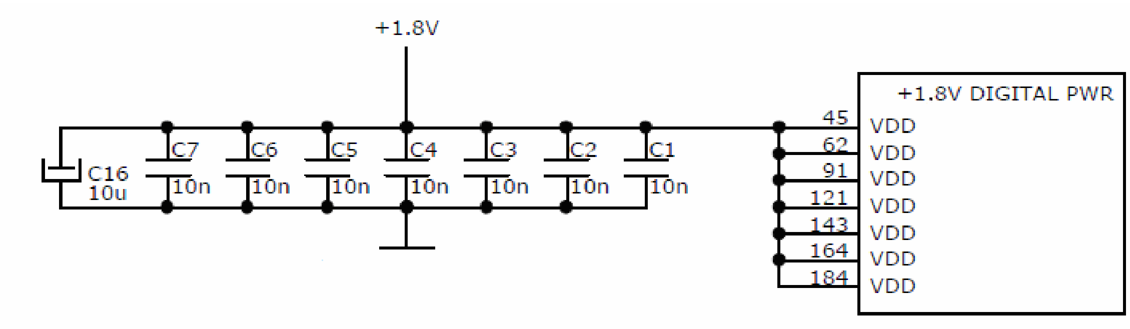


Figure 13. Decoupling capacitors and a bulk capacitor. This 1.8 V digital power section is one of the supply voltage sections of the video decoder chip. All the 10 nF capacitors are placed near the supply pins, and the bigger 10 μF capacitor acts as energy storage for these smaller capacitors.

6.3.2 Over-voltage protection

Over-voltage protection in the video interface card is applied to analog inputs and supply voltage inputs. It is done by using Transient Voltage Suppression (TVS) Arrays. These arrays consist of Transient Voltage Suppression Diodes. These diodes are connected to the ground plane from the transmission or supply line that is protected. Figure 14 shows the principle of this connection and how the TVS is represented in schematic. [21]

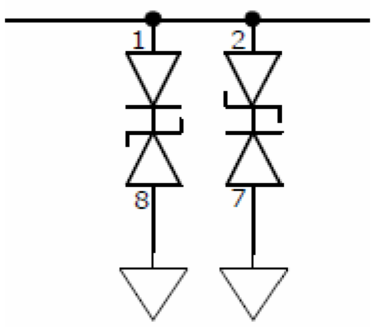


Figure 14. Transient Voltage Suppressor (TVS) on a transmission line. The TVS consists of special voltage suppressor diodes and it is used in analog inputs on the video interface card.

A Transient Voltage Suppressor Diode is very similar to a Zener diode in its theory of operation. The difference is that a TVS Diode is designed to protect electronics against over-voltages, so it can handle large currents and voltages. The theory of TVS operation is simple: once the avalanche breakdown voltage of the diode is exceeded, it will conduct and therefore shunt the excess current on the ground. [21] Figure 14 shows a bidirectional TVS, which is capable of suppressing positive and negative voltages exceeding the component protection rating. In the video interface card, 5 volt suppressors are used in analog video inputs and in 3.3 V supply. The 24 volt supply, on the other hand, has 24-volt suppressor protecting it. [21]

7 Video interface card functions & electrical description

This video interface card was designed to work together with Epec 2040 HMI device. The system these two devices form is described in chapter 4. In this chapter the focus is purely on the video interface card.

7.1 Different functional partitions

As figure 15 demonstrates, the video interface card is divided into different functional sections. The earlier described ground and supply layer divisions are related to this functional division as well. But dividing circuit board in different blocks is reasonable for many different reasons.

Putting the components related to the same task in the same place clarifies the whole device and makes it easier to understand what each component does in the design.

Most devices work better and faster if the components are arranged according to the signal path. This means that those components that are close to each other in the schematic are also close on the PCB. A short distance means low parasite inductance, so the device will work as it was meant to.

There is also an EMC aspect to this system partitioning. From the EMC point of view, the partitions with emission sources and the partitions vulnerable to emissions should be placed as far away from each other as possible. This is also related to keeping analog and digital partitions in the same groups. In this way, more sensitive analog signals will not be interfered by the noisy digital ground or the power plane. [19, p.190-191]

Thermal issues are one thing that has to be considered in partitioning as well. Especially FETs that control large currents create a lot of heat. Also some power supplies and microprocessors generate a lot of heat. These kinds of partitions should be placed on the PCB so that the heat would distribute evenly on the circuit board.

Copper distribution on the circuit board is an important thing for two reasons. First of all, even copper distribution will help the heat coming from components spread evenly on the PCB. Secondly, when there is approximately the same amount of copper all over the board, it is easier to manufacture so the manufacturing process will be more reliable.

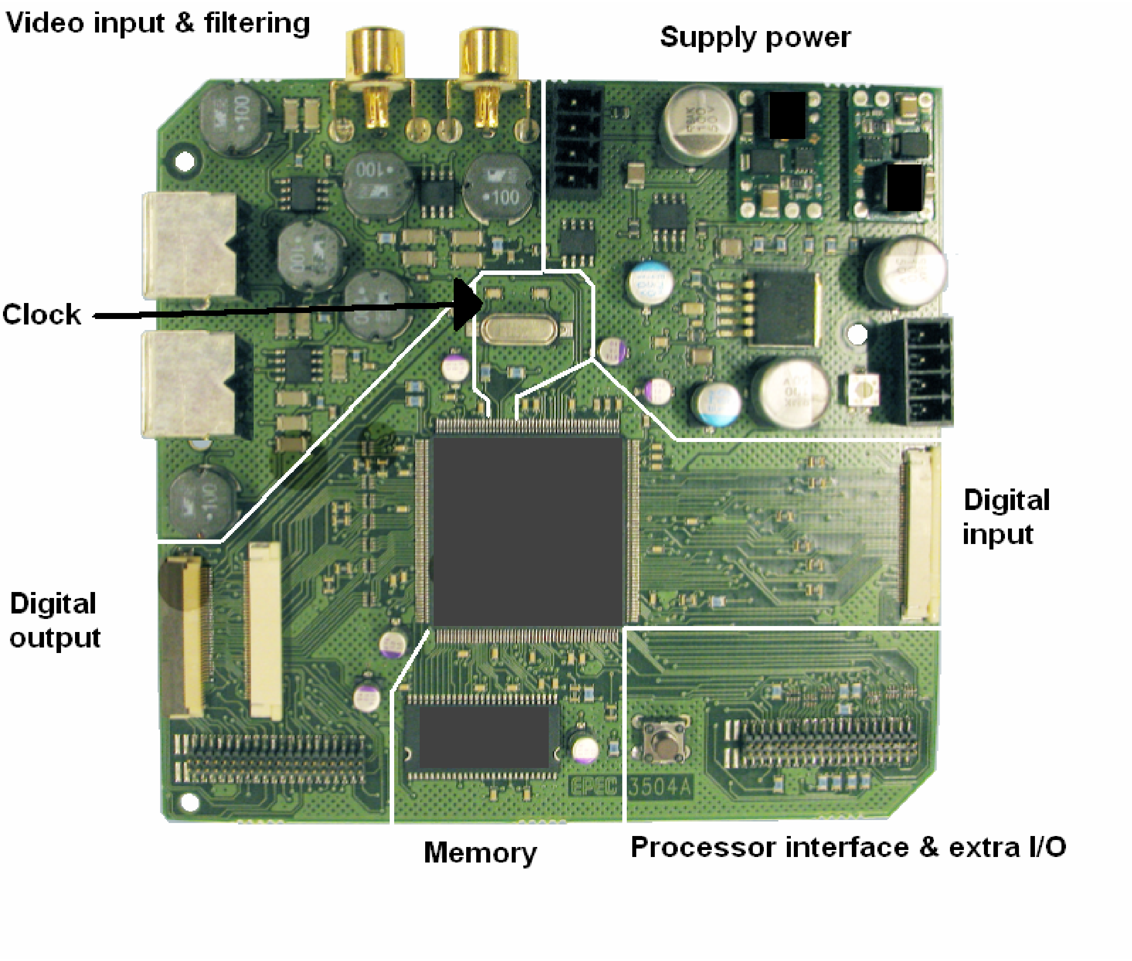


Figure 15. Video interface card viewed from the top side. Different functional partitions are marked on the picture.

7.2 Supply power partition

This partition is located in the upper right corner of the board in figure 15. In this partition, supply voltages for peripheral devices as well as to the board circuitry are created. There are two 4 -pin connectors in this partition. The upper connector, X11, is the mains supply connector for this board. 24 V supply, 3.3 V supply and GND are fed to the card through this connector. The fourth pin in this connector is the supply voltage for an external camera. 24-volt supply goes to the two switched-mode power supply units. 12 volts for the camera supply and the panel backlight inverter is created in these units. 3.3 volts is used directly as the digital supply and the analog 3.3 V supply is separated from it with a BLM ferrite bead inductor. This 3.3 V is also a supply for the regulator that drops the voltage down to 1.8 volts. The regulator output acts as a digital supply and an analog supply is separated with a BLM from it. Since the ground is preferred to be as “clean” as possible, it is filtered through two BLMs to create the analog and the digital ground plane.

Another connector in this section is devoted to the external inverter for TFT display backlight tubes. This connector X12 has a 12-volt supply and ground, and a SMD trimmer connected to it. The trimmer is used to adjust the brightness of the backlight.

In figure 15 in the upper right corner two mixed-mode power supply units can be found. These units are placed next to each other and in the very corner of the PCB for a reason. This reason is that since these units operate at a relatively high frequency, there might be some EMC emissions coming from them. So they are as far away from critical signals as possible so that the possible emissions will not cause an intrasystem EMC problem.

7.3 Clock partition

There is nothing special about this partition, only a 27 MHz crystal, resonant capacitors and a couple of resistors. A noteworthy thing about the ground plane distribution is that the digital ground plane makes “a cape” for the crystal. This is done so that the clock signal will not interfere with analog ground and video signals that are quite close to it.

7.4 Digital input and digital output partitions

The purpose of digital input partition is to connect the 18-bit (6,6,6) RGB signal coming from 2040 to the video decoder chip. This digital RGB signal goes normally to 2040 display panel. So from this input the user interface screen is fed to the TFT panel.

The digital output section has two different FPC (Flexible printed circuit) connectors and a 2-row 40-pin spike row connector on it. The FPC connectors are for the two TFT display panels, and these connectors output 18-bit RGB video. Since the signaling and the FPC used in the displays differ slightly from each other, two different connectors had to be used. However, two displays cannot be connected here simultaneously since the signal levels are not adequate for that. The spike row connector is for testing purposes and it also acts as additional display panel connector. The spike row has the same signals connected as the FPCs, with 2 bits additional per colour. So via this connector, it is possible to connect any display that requires up to 24-bit RGB video.

In this section some resistor grids and single resistors can be found as well. These are 33 ohm resistors and they are connected in series to each outgoing line. The reason for these resistors is to limit current in case of misconnection or some other hazard. So they protect the video decoder chip from current spikes.

Since the resistance is so small, no notable voltage drop will occur over these resistors.

7.4.1 Interface and control partition

The spike row connector in this partition features processor control and interfacing related connections. I^2C two wire serial bus, master reset and camera power supply control are connected via this connector. I^2C is used to program and control the video decoder chip. Master reset is connected to the pushbutton on the left side of this connector. When connected to 2040 HMI device reset, this pushbutton will reset both systems simultaneously. The camera power control pin is connected directly to the camera power supply in the supply power partition. Applying 0 V or 5 V to this pin will switch the camera supply on or off.

Other pins in this connector are connected to the video decoder chip, and some additional features can be used through them. However, these features are not being used in this project.

7.4.2 Video inputs and filtering

This PCB section consists of analog video inputs and video signal filtering circuits. The two RCA connectors are dedicated for external camera inputs. Also, two S-video connectors are mounted in this section. Since there are very few or no rear-view cameras on the market that provide S-video signal, this connection is used to input S-video signal from a PC. These S-video inputs are used for testing purposes.

The filtering section consists of a TVS (described in chapter 6.3.2), a low-pass filter and a DC block capacitor. The function of TVS (Transient Voltage

Suppressor) is to protect the device from over-voltage pulses and prevent injury in the device if this input is connected incorrectly. The TVS used here is rated for 5 volts, so it will suppress any voltage exceeding this rating. As explained in chapter 2, composite video signal amplitude is well under 5 volts, so TVS will not interfere with the video signal.

8 Filter design

The design of the video signal filter was started by defining the characteristics of the filter. The desired filter type would be a low-pass filter with about 5 MHz cut-off frequency. After determining these filter properties, a decision was made to use a third order Butterworth low-pass filter in this design.

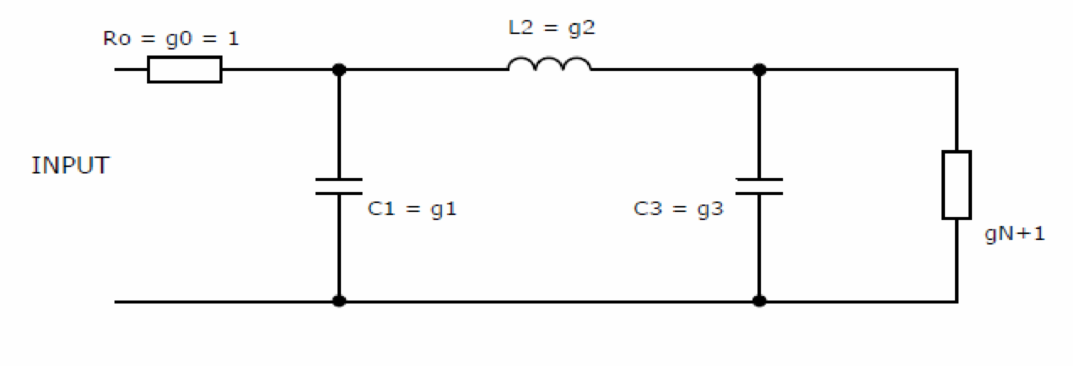


Figure 16. Normalized low-pass filter [22, p.120]

In the equivalent circuit of a low-pass filter in figure 16, the input impedance R_0 = 1Ω. The cut-off frequency ω of this normalized filter is 1. The filter order N is defined by the amount of reactive components, so this filter is of third order. From the equivalent circuit of a low-pass filter in figure 16, it is possible to calculate the component values that will give the desired frequency response for the filter. [22, p.120]

$$g_k = 2\sin\left[\frac{(2k-1)\pi}{2N}\right] \tag{1}$$

$g_k = component\ impedance$

$k = 1 \ldots N$

Equation 1 is used to calculate the component values for a normalized low-pass filter with minimum ripple on the pass-band. For this minimum ripple filter $g_0 = 1$ and $g_{N+1} = 1$. [22, p.120]

The calculated component values are:

$$g_1 = 1$$
$$g_2 = 2$$
$$g_3 = 1$$

Next, the normalization of the filter was removed. At this point, the input impedance R_0 was set to 75Ω, since it is the characteristic impedance of the composite video.

$$L_k^{'} = R_0 L_k \tag{2}$$

$$C_k^{'} = \frac{C_k}{R_0} \tag{3}$$

$$R_L^{'} = R_0 R_L \tag{4}$$

$L_k, C_k, R_L =$ *prototype filter component values*

$L_k^{'}, C_k^{'}, R_L^{'} =$ *scaled element values*

Scaled element values calculated from the equations 2, 3 and 4:

$$L_k^{'} = 75 \cdot 2 = 150$$
$$C_k^{'} = \frac{1}{75} = 0.0133$$
$$R_L^{'} = 75 \cdot 1 = 75$$

Finally, since the cut-off frequency $\omega = 1$, it was scaled up to 5 MHz using the equation 7. This cut-off frequency was selected on the basis of composite video signal frequencies. Colour burst, which is the part of this video signal with the highest frequency, has a frequency of around 5 MHz. The scaled component values were derived from the equations 5 and 6 [22, p.121].

$$C_k^{'} = \frac{1}{\omega_c L_k} \quad (5)$$

$$L_k^{'} = \frac{1}{\omega_c C_k} \quad (6)$$

$$\omega = 2\pi f \quad (7)$$

Final component values for this filter are:

$$R_1 = 75\Omega$$
$$R_2 = 75\Omega$$
$$C_{1,2} = 212\rho F$$
$$L = 2.4\mu H$$

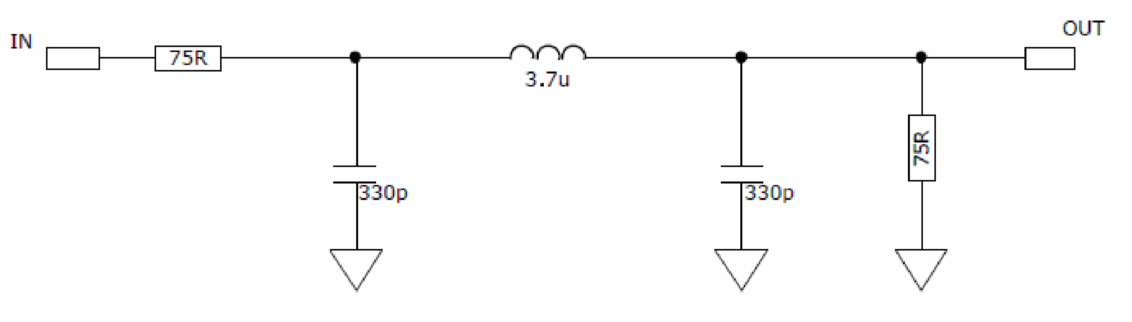


Figure 17. Third order Butterworth low-pass filter with a cut-off frequency of 5 MHz. The component values for this filter 1 were calculated above.

Simulated Bode diagrams for filter 1 can be found from appendix 1. From the phase diagram in appendix 1, it can be seen that the phase shift is quite rapid in this filter. The filters used in this video interface card are based on the filter in figure 16, but some changes to this filter were made. First, the component values had to be matched to those already used in Epec. In addition to that, a decision was made to add a $100nF$ DC block capacitor in the output of this filter. Two different pull-down resistor values (50 and 100 ohm) can be found from the filters in the video interface card and one more value (75 ohm) was tried out during the testing. The filter testing is described in more detail in chapter 9.

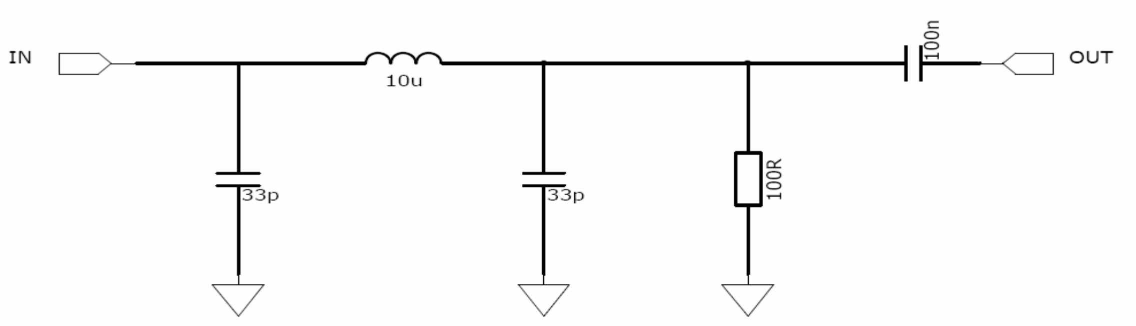


Figure 18. Filter 2. This third order Butterworth low-pass filter is used as the composite video filter on the video interface card. In the output filter 2 has a series capacitor which acts as a DC block that removes all excess voltage offset from the video signal.

The simulated Bode diagrams for the filter 2 in figure 18 can be found from appendix 2. Note the smoothness of the phase shift in filter 2 compared to the results of the filter 1 in appendix 1. Different values for the parallel resistor in this filter were tried out during the testing, but the 100-ohm resistor gave the best results in terms of frequency response and minimal video signal distortion.

8.1 Composite video filter analysis

After changing the component values of filter 1, the frequency response of the filter 2 had to be calculated to see if it meets the desired specifications. The analysis was made by means of basic circuit analysis:

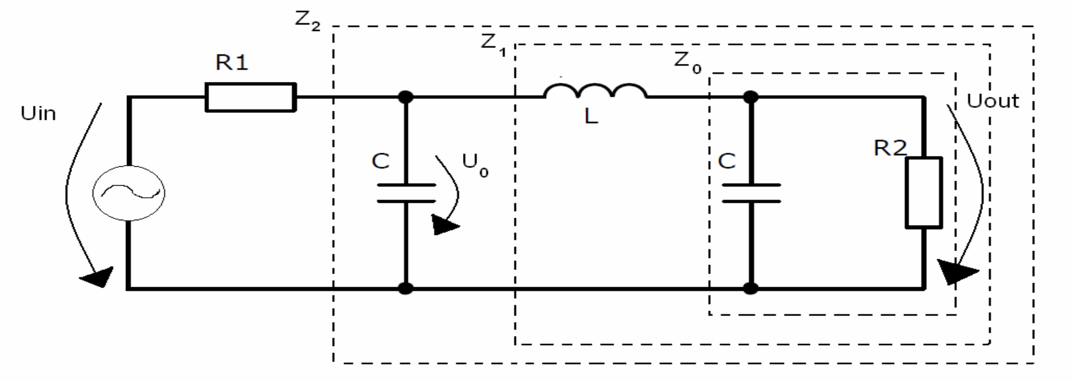


Figure 19. On the basis of this circuit diagram the transfer function below was calculated.

$$ZC = \frac{1}{j\omega C} \tag{8}$$

$$ZL = j\omega L \tag{9}$$

$$Z_0 = \frac{R_2}{1 + j\omega R_2 C} \tag{10}$$

$$Z_1 = ZL + Z_0 \tag{11}$$

$$Z_2 = \frac{ZC \cdot Z_1}{ZC + Z_1} \tag{12}$$

$$U_0 = \frac{Z_2}{Z_2 + R_1} \cdot U_{in} \tag{13}$$

$$\frac{U_{out}}{U_{in}} = \frac{Z_0}{ZL + Z_0} \cdot \frac{Z_2}{Z_2 + R_1} \tag{14}$$

$$\frac{U_{out}}{U_{in}} = \frac{\dfrac{R_2}{1 + j\omega R_2 C}}{j\omega L + \dfrac{R_2}{1 + j\omega R_2 C}} \cdot \frac{\dfrac{j\omega L + \dfrac{R_2}{1 + j\omega R_2 C}}{1 - \omega^2 LC + \dfrac{j\omega R_2 C}{1 + j\omega R_2 C}}}{\dfrac{j\omega L + \dfrac{R_2}{1 + j\omega R_2 C}}{1 - \omega^2 LC + \dfrac{j\omega R_2 C}{1 + j\omega R_2 C}} + R_1} \tag{15}$$

Equation 15 represents the transfer function of filter 2. This equation was used to calculate the frequency response presented in figure 20.

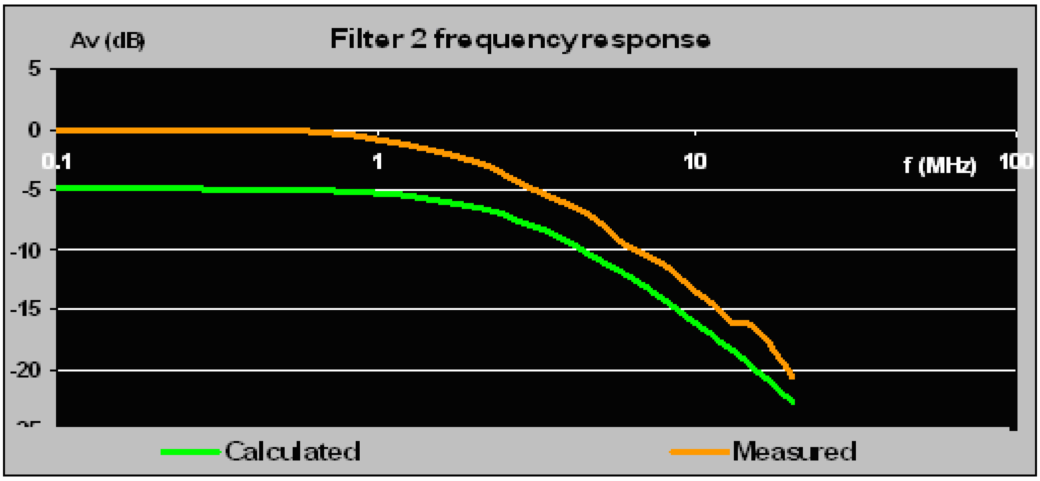


Figure 20. Filter 2 frequency response. On the x-axis frequency on a logarithmic scale, and on the y-axis filter gain in decibels.

Figure 20 represents the measured and calculated frequency response of filter 2. The green line is the frequency response calculated from equation 15. The amber line represents the actual measurement results for filter 2. The shape of the graphs is uniform, but the calculated curve has 5dB attenuation from the beginning whereas the measured graph does not have any attenuation at the lower frequencies. One reason for this could be that the input signal used in the measurements did not have characteristic impedance of 75 ohms.

9 Testing

Filters were the main focus of testing in this project. In addition to filter calculations, the goal was to observe how video signal is affected by these filters. It was also important to make sure that these filters would not distort or attenuate the actual video signal. In total, 6 different filter configurations were tested. Here only the filter that had the best performance in the tests is presented, as well as some cases where a filter caused significant video signal distortion.

9.1 Test setups

Two kinds of tests were performed for the filters. First, composite video signal from a rear-view camera was fed to the filter and three different test points were connected to a digital oscilloscope. Test point 1 was located in the input of the filter, test point 2 after the Butterworth low-pass filter, and test point 3 in the output. In this way it was possible to observe what happened to the video signal in different stages of the filter. With this information it was easier to see which part of the filter had to be changed to achieve optimal filter performance.

After testing the filters with video signal, a sine wave from a function generator was fed through the filter. The function generator output impedance was set to 75 ohms. This sine wave frequency was increased from 500 kHz up to 20 MHz. Peak to peak voltage of this sine wave was approximately 1.25 V, which was quite close to composite video peak to peak values. Again, an oscilloscope was connected to the filter test points and the measurements of peak to peak values were taken at 1 MHz intervals. From these measurements it was possible to sketch the frequency response of the filter.

9.2 Error factors in measurements

Although the measurements that were made are relatively simple, some components of the test setup might have interfered with the results. When carrying out measurements at Megahertz frequencies, the cables between devices have to be of the right kind. Reflections in the transmission lines are possible. In these measurements there was no information available about the impedance of the camera output, neither the impedance of the function generator cable. It is possible that the camera cable has affected the matching of the filter. According to the composite video signal standard the impedance of the cable should be 75 ohms. The composite video signal was fed through a multicore cable along with other signals. On the other hand, this cable is commonly used in commercial rear-view cameras.

9.3 Measurement results

In total six different filter configurations were tested but here is presented only the filter that performed best in these measurements.

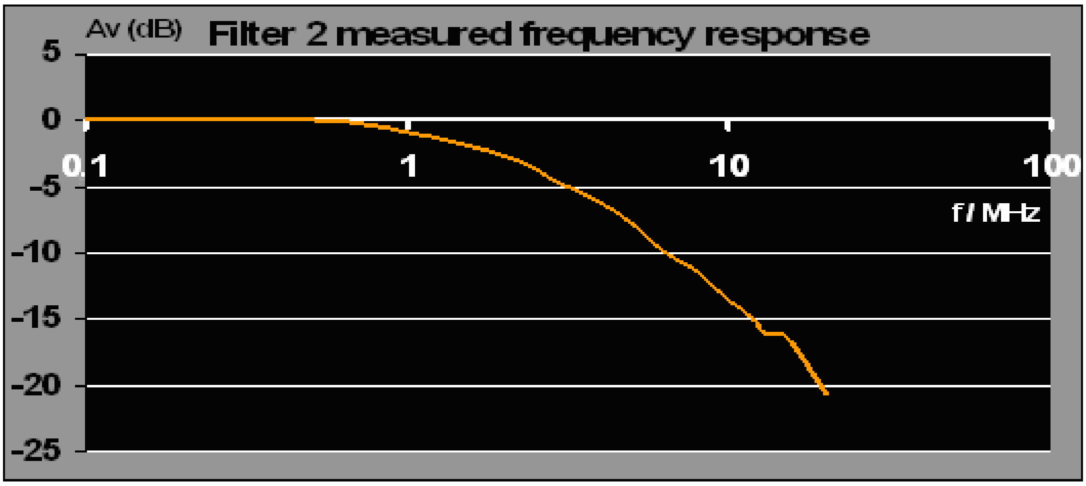


Figure 21. Filter 2 frequency response. On the X-axis of the graph is the frequency on logarithmic scale. Y-axis represents the filter gain in decibels. The -3bB corner frequency is somewhere around 5 MHz, which is just above all composite video signal frequencies. This filter had the best performance of all measured filters.

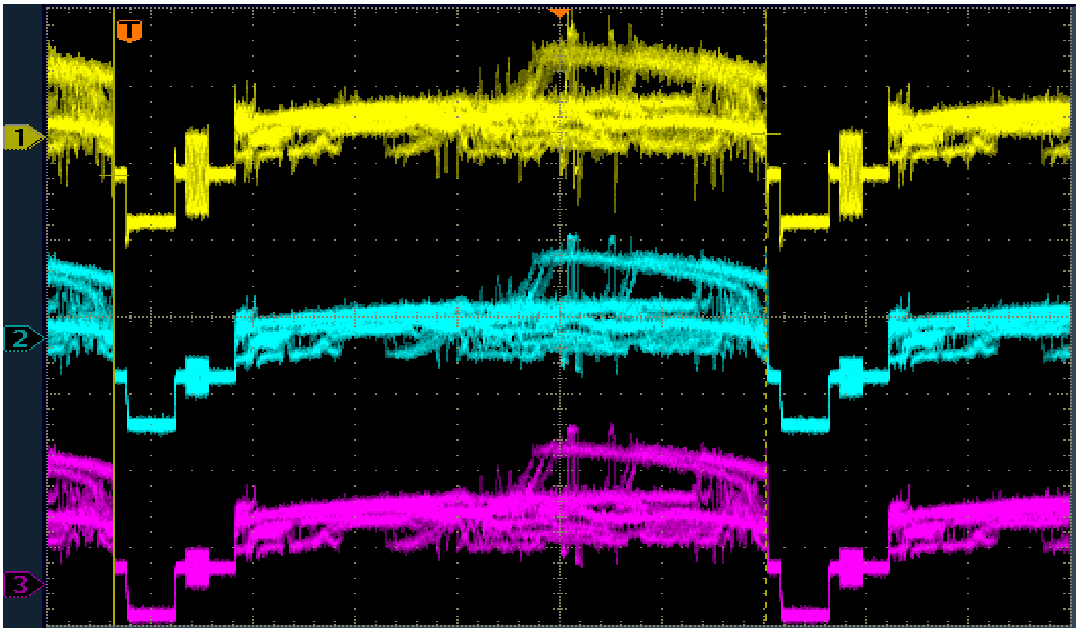
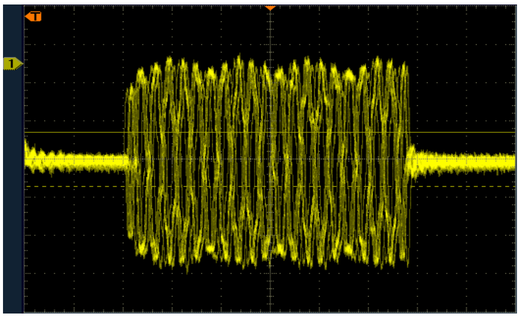
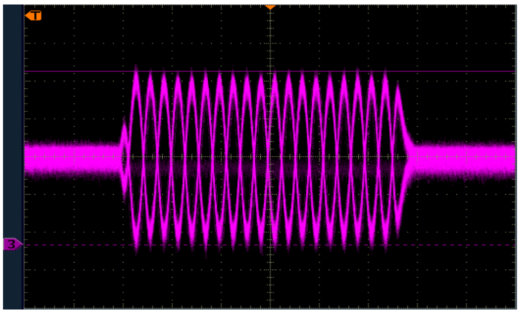


Figure 22 shows composite video signal in different stages of filter 2. This picture is taken from oscilloscope in special video triggering mode. Y-axis scale on all the signals is 500 mV. In far left corner, small arrows with numbers 1, 2 and 3 on them represent the zero DC levels of the signals. From top to bottom the filter stages are: input, after Butterworth and output. In the yellow input signal it can be seen that there are some transients in the edges of the sync, but the filter removes them. Note how the block capacitor removes negative DC offset from the output signal.

Figures 23 and 24. Colour burst section of composite video in the input and output.The input is marked yellow and output is marked pink. This picture is taken from oscilloscope in special video triggering mode. Y-axis scale in the yellow input signal is 100 mV and 50 mV in the pink output signal. Different scale on the pictures is used so that it would be easier to spot the details in both of them. In the far left corners of the pictures small arrows with numbers 1 and 3 on them represent the zero DC level.

In figure 24, the colour burst section looks really clean compared to figure 23 input stage signal. Even though this output stage has smaller amplitude, the quality of the output stage is clearly better. Also note how the DC offset is negative in the input and positive in the output. The output stage offset is now really close to the composite video standard.

9.4 Signal distortion caused by filters

Some cases are presented here from the measurements where signal was distorted because of the filter. In most cases distortion was a symptom of insufficient filter matching or completely missing parallel resistor.

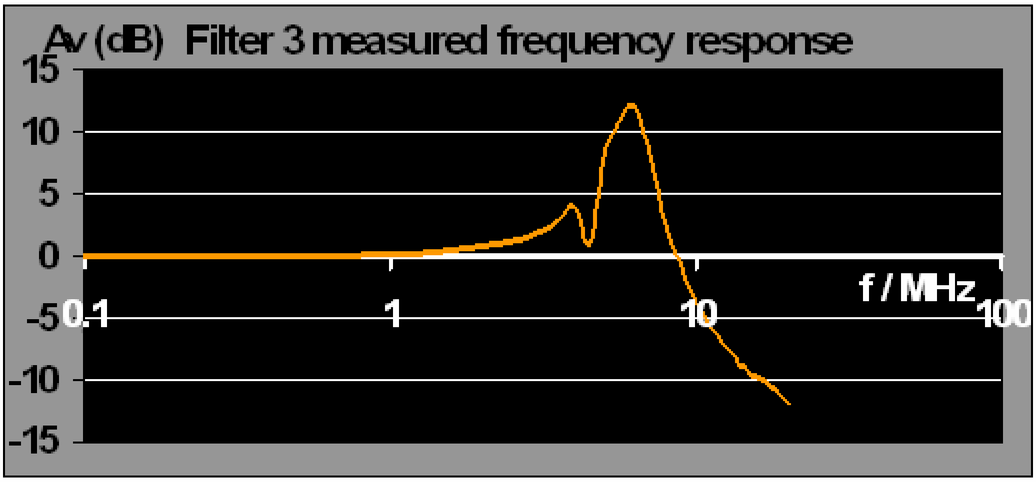


Figure 25. This is a frequency response of a filter with no parallel resistor. On the X-axis of the graph is the frequency on logarithmic scale. Y-axis represents the filter gain in decibels. In around 8 MHz this filter has a lot of gain, but since this gain is not within the right frequency range and the frequency response of the filter is nothing but smooth, this kind of filter will only cause distortion to the video signal.

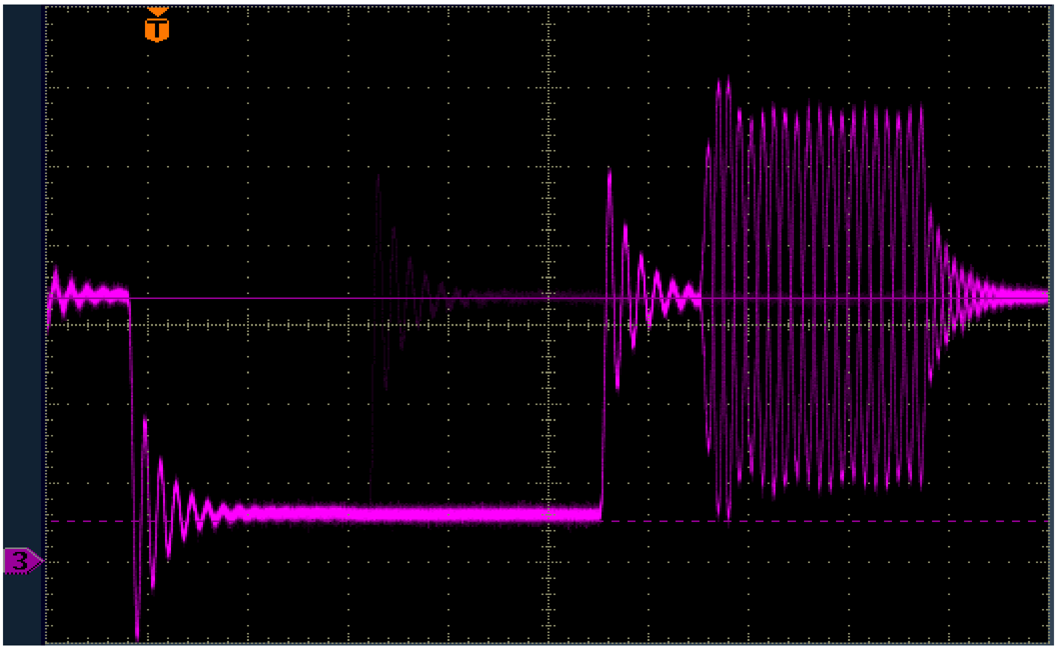
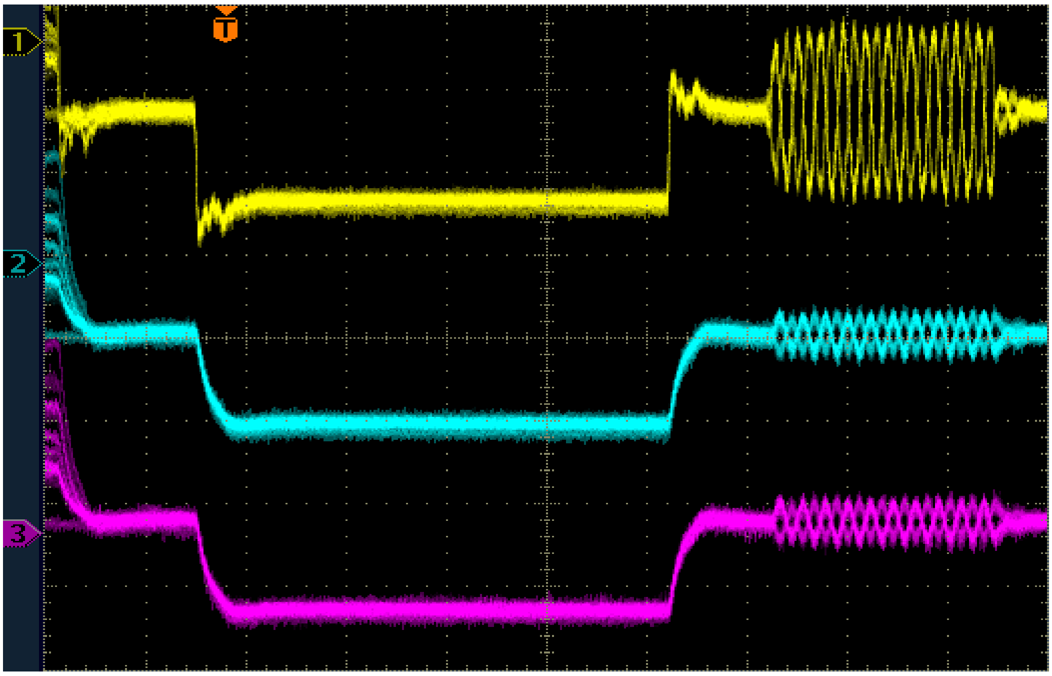


Figure 26. Composite video signal syncs and colour burst in the output of filter 3. This figure is taken from oscilloscope in special video triggering mode. Y-axis scale in this figure is 200 mV. In far left corner, a small arrow with number 3 on it represents the zero DC level of the signal. Note how the edges of the synchronization sections experience ringing instead of being straight edges.

The phenomenon in figure 26 is called ringing. In most cases it is caused by wrong or missing matching. [23, p.41] The frequency response graph in figure 25 does not look good for this application either. The filter amplifies some parts of the signal, while other parts remain unamplified. Peak to peak value of the colour burst section is about 2 to 3 times bigger than in the input signal. This value is also well over composite video signal standard, so this kind of amplification is not needed here.



Figures 27. Figure 27 is taken from oscilloscope in special video triggering mode. Y-axis scale in this figure is 200 mV for all three signals. In the far left corner a small arrow with numbers 1, 2 and 3 on it represents the zero DC level of the signals. Note how the negative DC offset in test points 1 and 2 is corrected to the right level in test point 3.

Filter measured in figure 27 is the same filter as filter 2; the only difference is that it has a 50 ohm parallel resistor instead of 100 ohms. The filter with 100 ohm parallel resistor was the best performer of these measurements, but clearly the attenuation of this filter with 50 ohm load resistance is too big. Also, as can be seen from the edges of the sync signal, the matching is not the best possible for this application here either. One more thing to note from this figure is the negative DC offset in the output. The input video signal has a negative DC offset, but the filter removes the negative DC offset so that the signal is on a correct level according to composite video standard.

10 Conclusions

The goal of this project was to design a prototype card that makes it possible to connect at least two rear-view cameras to Epec 2040 HMI device. The end result of the design was the video interface card that is described in this thesis. The video interface card meets all the demands that were set in the beginning, and has some additional features too. From the designer's point of view, this project was successful since everything on the PCB works as it was designed to work. Having said that, in order to get every feature of the board working, it was necessary to do some hardware modifications afterwards. Some of these modifications are just normal for a prototype card, but others could have been avoided with a careful PCB design. These avoidable mistakes are physical dimension measurement errors and wrong pin arrangements in some connectors. Luckily, it was possible to modify all of these afterwards so that the device works as it should work.

The testing of the video interface card was the most interesting part of the project. During the filter testing, it became very clear what kind of filter works with these video signals and what kind of does not. During the PCB design, the decision was made to put 2 different kinds of filters on the PCB to make it possible to test which one of them performs best. As mentioned earlier, a few other filters were measured in addition to those found in the video interface card.

The main interest for Epec Oy in this project was to examine the technology that could be used in a future revision of 2040 HMI device. In my opinion, if the technology used in the video interface card will be used as a part of future 2040 HMI, the video capabilities of that product will have quite competitive features compared to other HMI devices available today.

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Filter 1

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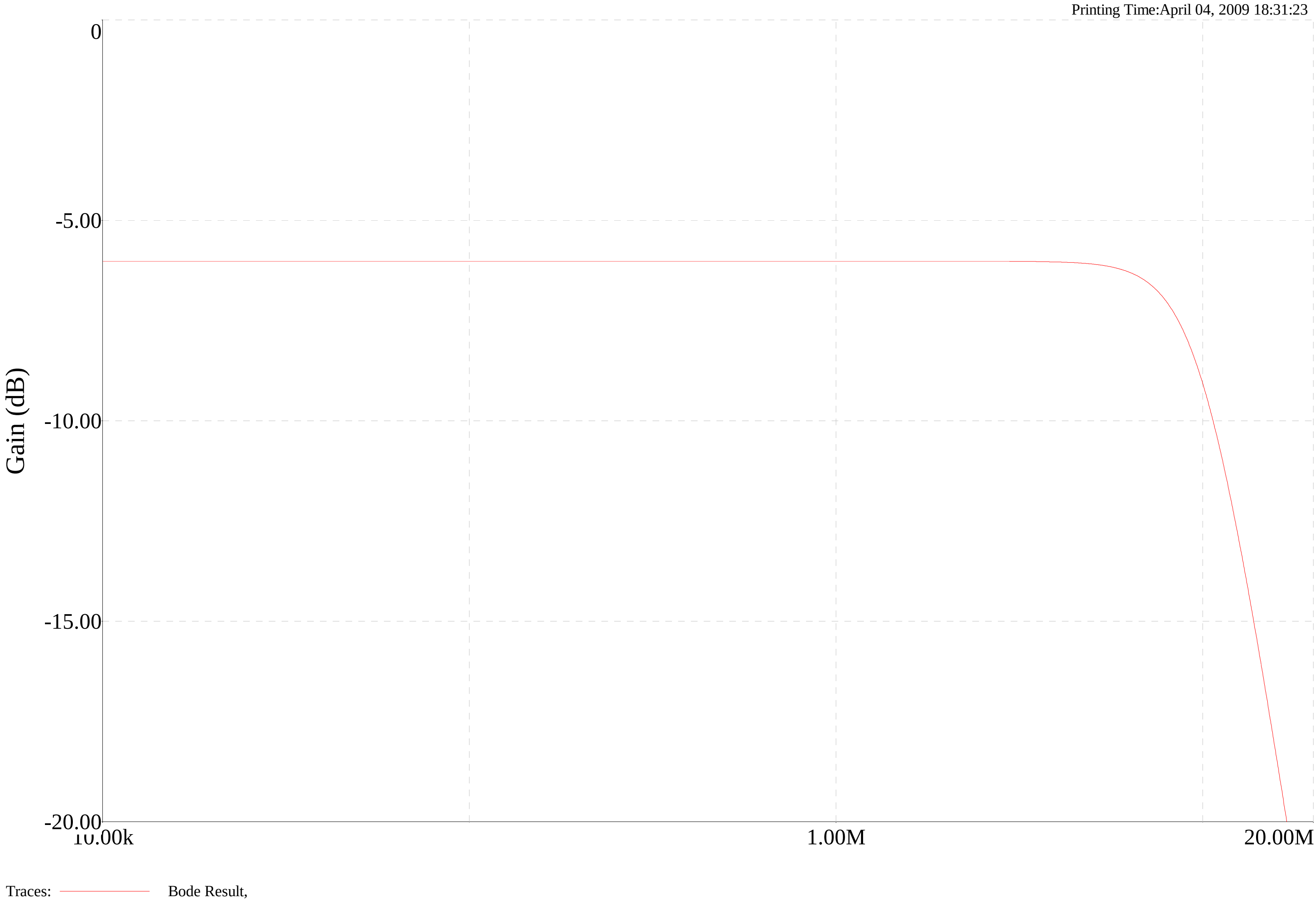

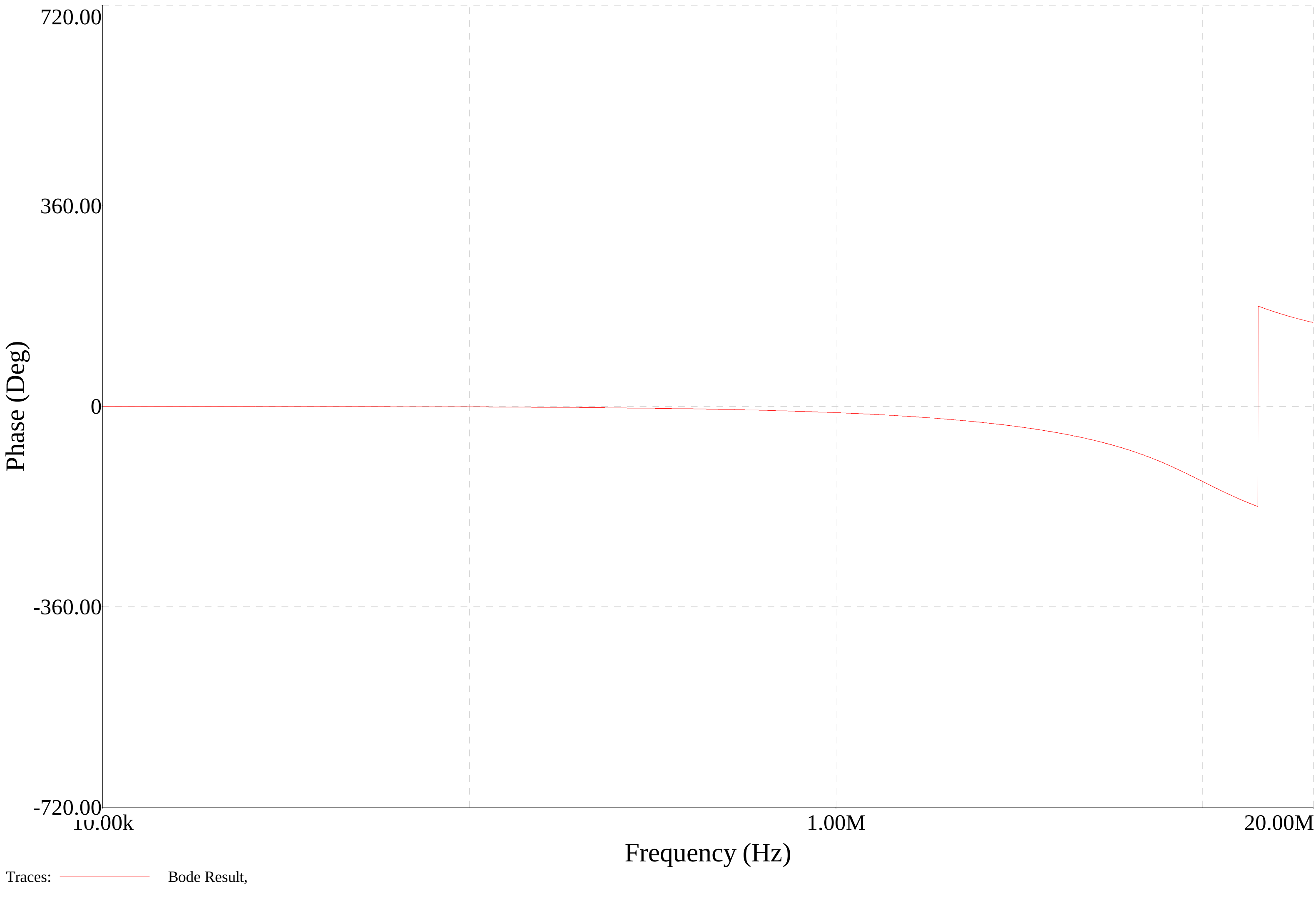

Filter 2

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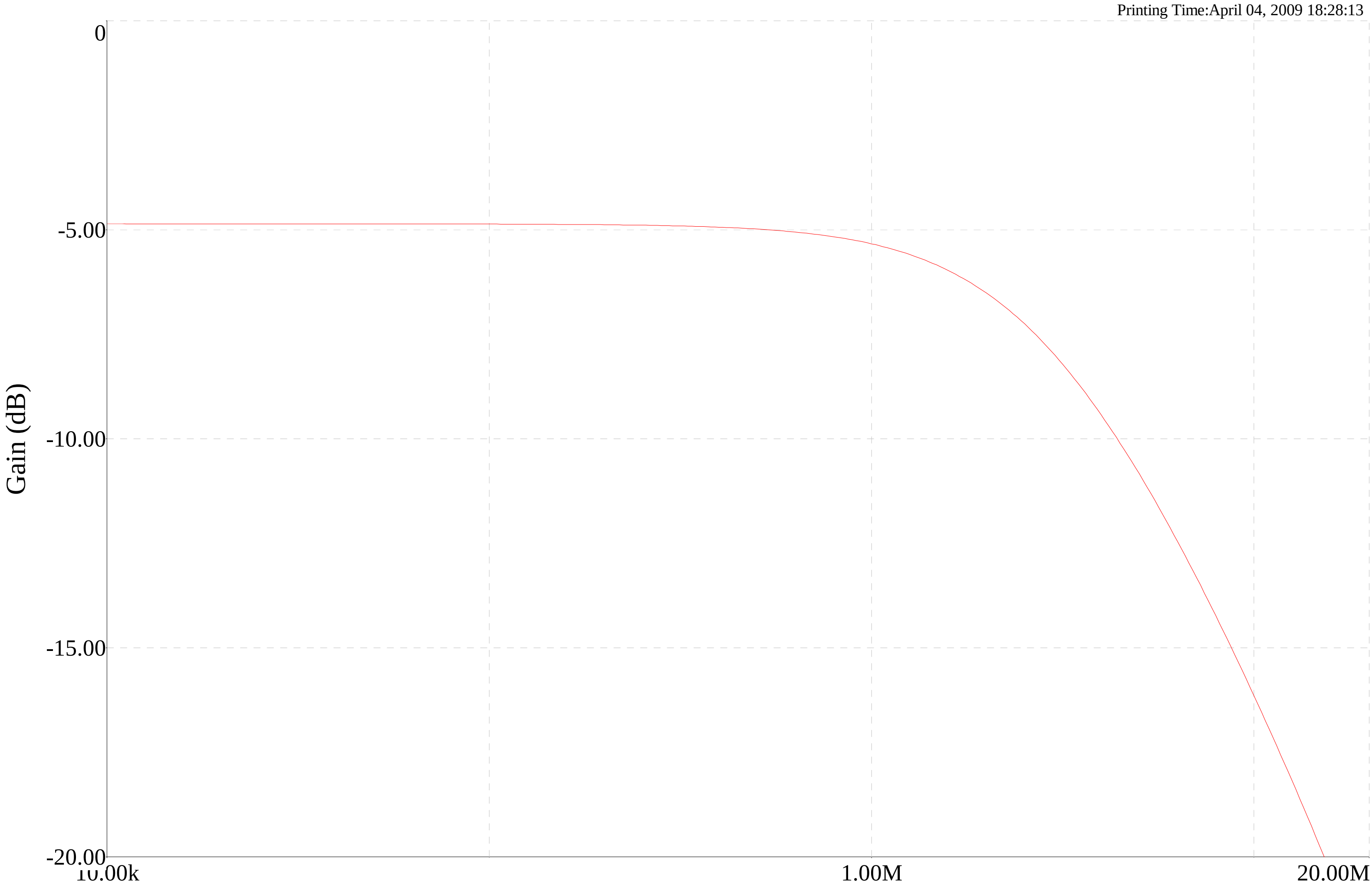

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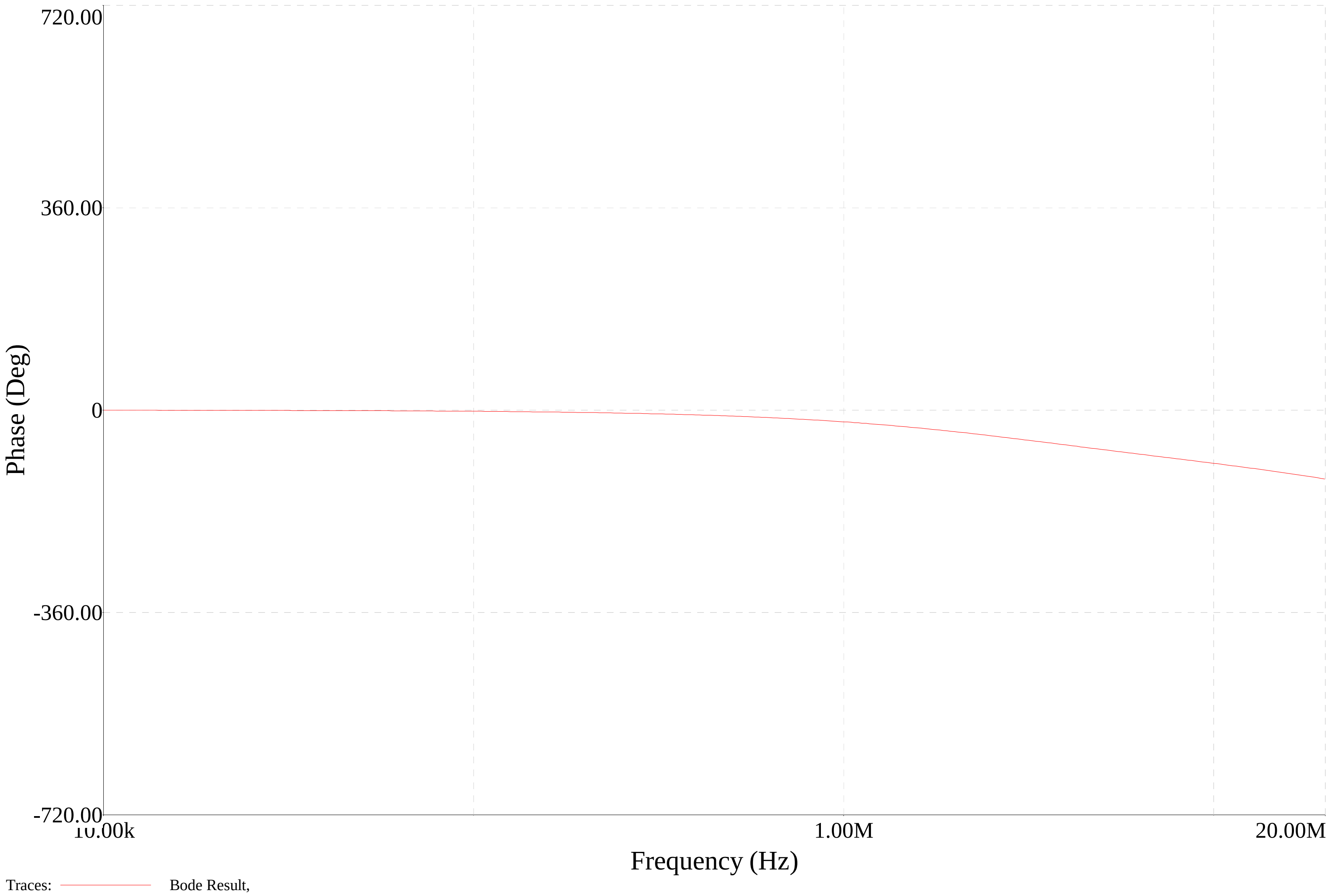

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