Electromagnetic Radiation from Video Display Units: An Eavesdropping Risk?

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This paper describes the results of research into the possibility of "eavesdropping' on video display units. by picking up and decoding the electromagnetic interference produced by this type of equipment. During the research project. which started in January. 1983. it became more and more clear that this type of information theft can be committed very easily using a normal TV receiver.

Keywords: Electromagnetic radiation, eavesdropping, data security, privacy, Electromagnetic compatibility.

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North-Holland
Computers & Security 4 (1985) 269-286

1. **Introduction**

It is well known that electronic equipment produces electromagnetic fields which may cause interference to radio and television reception. The phenomena underlying this have been thoroughly studied over the past few decades. These studies have resulted in internationally agreed methods for measuring the interference produced by equipment. These are needed because the maximum interference levels which equipment may generate have been laid down by law in most countries.

However, interference is not the only problem caused by electromagnetic radiation. It is possible in some cases to obtain information on the signals used inside the equipment when the radiation is picked up and the received signals are decoded. Especially in the case of digital equipment this possibility constitutes a problem, because remote reconstruction of signals inside the equipment may enable reconstruction of the data the equipment is processing

This problem is not a new one; defence specialists have been aware of it for over twenty years. Information on the way in which this kind of "eavesdropping" can be prevented is not freely available. Equipment designed to protect military information will probably be three or four times more expensive than the equipment likely to be used for processing of non-military information.

Until recently it was considered very difficult to reconstruct the data hidden in the radiated field, and it was therefore believed that eavesdropping on digital equipment could only be performed by professionals with access to very sophisticated detection and decoding equipment. As a result, digital equipment for processing information requiring medium or low level protection, such as private and business information, is not protected against eavesdropping of this kind.

This report gives the results of a research programme carried out by the dr. Neher Laboratories of the Netherlands PTT. These results prove that the above assumptions are wrong. Although the studies were restricted to the possibility of eavesdropping on video display units, the results clearly show that it can, in some cases, be done using equipment which is generally available on the market. In the case of eavesdropping on a video display unit, this can be a normal TV broadcast receiver. With some minor alterations to this receiver it is easy to extend the number of types of video display units which can be eavesdropped on.

The object of the research programme was not only to study the problem itself, but also to find ways of preventing this kind of information theft. An additional aim was the definition of a measurement method which could be used to check the severeness of the problem with individual video display units [VDUs '] (possibly for type-approval purposes). The solutions found are described later.

2. Cause and Effects in Brief

2.1. Phenomenon

The application of square wave signals and high switching frequencies in digital equipment leads to the radiation of electromagnetic fields containing frequency components up into the UHF region. Although the power spectral density of these signals decreases with increasing frequency, this is compensated for in the radiated field, because the radiation effectiveness of the electronic circuits inside the equipment increases with frequency. This means that the radiation level produced by digital equipment may be constant up to several hundred MHz.

In some cases, resonances in circuits may lead to higher radiation levels at some frequencies in the radiated spectrum. Even circuits not designed to carry a certain signal may radiate part of this signal due to cross-talk and because the circuits are resonant for some of the signal's frequency components. A striking example of such a radiating circuit is the main power cable of a piece of equipment.

2.2. Video Display Units

If we limit ourselves to video display units, it can be easily recognized that the field radiated by such

' **In the United States, the reference is a VDT or video display terminal.**

a piece of digital equipment will consist of two distinguishable parts:

- narrowband harmonics of the digital clock sig nals, and
- broadband harmonics of the various 'random' digital signals such as the video signal.

Contrary to other broadband signals inside a video display unit, the video signal is amplified from transistor-transistor logic unit (TTL) level to several hundred volts before it is fed into the cathode ray tube (CRT). The radiation originating from the video signal will therefore be the dominant component of the broadband field generated by the video display unit in most cases.

Each (radiated) harmonic of the video signal shows a remarkable resemblance to a broadcast TV signal, as is shown in the technical appendix of this paper. It is therefore possible to reconstruct the picture displayed on the video display unit from the radiated emission by means of a normal television receiver.

2. 3. Decoding A ids

The signal received by the TV receiver does not contain synchronization information. This means that the picture displayed on the TV screen while 'receiving' radiation from a video display unit will be moving over the screen in both the horizontal and vertical directions, unless the synchronization frequencies in the video display unit and the TC receiver are the same. Although the latter is true for many types of video display units, the picture received will not be very stable and therefore not easily readable. The quality of reception can be improved by externally generating the necessary synchronization signals and feeding them into the TV receiver.

With this extension to the normal TV receiver (the costs are approximately $15), almost any type or make of video display unit can be easvesdropped on, provided it generates a sufficiently high radiation level. The extension can be designed and constructed by any electronic amateur within a few days.

2.4. Implications

If no preventive measures are taken, eavesdropping on a video display unit is possible at several hundreds of metres distance, using only a normal black-and-white TV receiver, a directional antenna and an antenna amplifier. It is even possible to pick up information from some types of video display units at a distance of over 1 kilometre If more sophisticated receiving and decoding equipment is used, the maximum distance can be much greater.

It is evident that this possibility has implications with regard to the protection of information. This is especially relevant to cases where protective measures have already been taken, such as encryption and/or physical protection. In any chain of measures taken to protect information, the weakest link may well be the video display unit radiating information around. And as everybody knows, a chain is never stronger than its weakest link.

As it is relatively easy to reconstruct information from the field radiated by video display units, the phenomenon may have consequences for information security even where a low or medium level of data protection is required. It should be borne in mind that the eavesdropping possibility may affect telebanking and other activities carried out with the aid of a personal computer. It is possible for a neighbor to copy information displayed during these activities (e.g. data on the financial situation) using his own TV receiver.

In some cases reception of private information of neighbours may even happen accidentally. Information can be displayed on the receiving television set during normal operation. This is not an imaginary occurrence: The Radio Control Service of the Netherlands PTT - which is in charge of spectrum management - has had several complaints from persons who were receiving information from a nearby travel agency.

All this means that this eavesdropping problem necessitates measures over the entire range of information security levels, ranging from 'top secret' to 'privacy-sensitive.'

3. **Electromagnetic Eavesdropping**

Many video display units or terminals are based on the same principles as black-and-white television. The free-running synchronization oscillators in a TV receiver can therefore sometimes generate nearly the same frequency as the one used in the VDU. If this happens the displayed information can easily be reproduced on the TV screen, and this can even occur accidentally.

The problem cannot be solved by using only types of video display units of terminals with synchronization frequencies out of the *normal* television range, since a malefactor who is determined to copy the information on his TV screen has several ways at his disposal of adjusting the synchronization frequencies in his TV receiver to those in the video display unit or terminal. All it takes to do so is a little knowledge of the principles of TV reception and an investment of about $5.

3.1. Reconstructing Synchronization

3.1.1. The External Oscillator Solution

The easiest and cheapest way of reconstructing the synchronization in the TV receiver is the use of a device containing two oscillators:

- one adjustable oscillator for the frequency range 15-20 kHz to generate the horizontal synchro nization signal (line synchronization), and
- one adjustable oscillator for the frequency range 40-80 Hz to generate the vertical synchroniza tion signal (picture synchronization).

Both signals can be combined and fed into the synchronization separator (Fig. 2) of the TV receiver. It is rather difficult to adjust both oscillators to the video display units or terminals synchronization frequencies because both have to be adjusted constantly during reception.

It is well known that the vertical and horizontal synchronization frequencies are related according to:

$$f_{\text{hor}} = k \; f_{\text{vert}},$$

where k *is* the number of display lines on the CRT or screen. It is therefore practical to generate only the horizontal synchronization frequency, and to obtain the vertical synchronization frequency through division of f_{hor} by k. A programmable digital frequency divider which can be used for this purpose can be bought for about $10. Once the number of screen lines has been determined, the synchronization can be restored by adjusting only one oscillator.

Fig. 1 shows an eavesdropping set-up in which this type of synchronization recovery is used.

3.1.2. Recovery from the Received Signal

The horizontal and the vertical synchronization frequencies are available in the spectrum of the

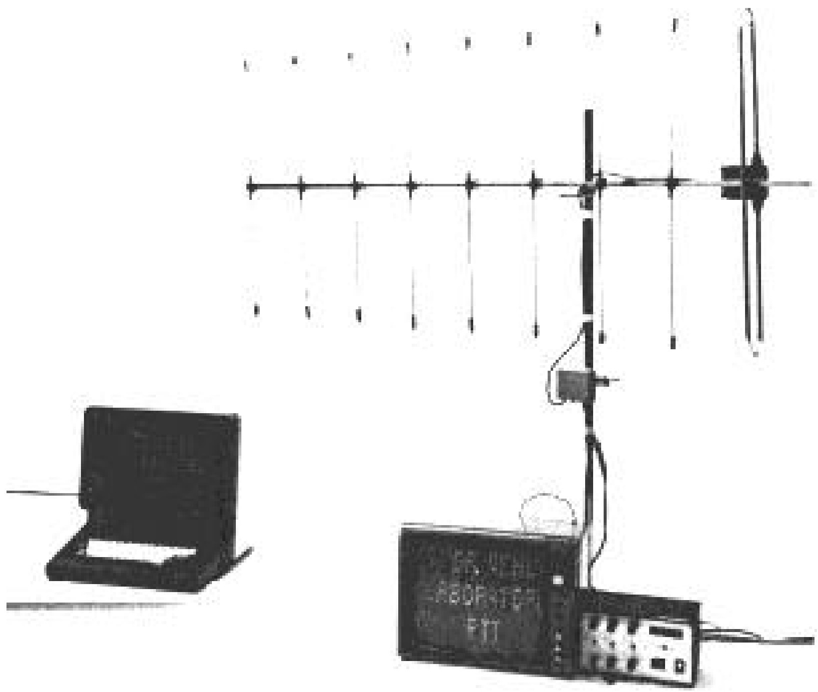

Fig. 1. Eavesdropping eel-up using a variable oscillator and a frequency divider to restore synchronization. The picture on the TV is picked up from the radiation of the VDU in the background.

video signal in the video display unit or terminal because the video signal is made equal to zero during horizontal and vertical flyback of the electron beam in the CRT[2]. As the frequency components are not available in the 'format' expected by a TV receiver, it is necessary to design a synchronization recovery circuit. A straightforward approach in this respect is extraction of the horizontal synchronization frequency from the line feed [LF] signal, using a narrow bandpass filter. The signal obtained is a sinusoidal wave of 15-20 kHz with a fair amount of phase noise. This noise can be easily removed using a very slow phase locked circuit. A pulse shaping circuit can turn the sinusoid into a square wave (synchronization signal) and the vertical synchronization frequency can easily be obtained again by division of this frequency by the number of screen lines. In order to obtain a stable synchronization signal it is necessary to have either a high signal-to-noise ratio in the received signal or to include a narrow bandpass filter in the circuit. In the latter case it is necessary to use a tunable filter to obtain a generally usable circuit for synchronization recovery.

3.2. Site Measurements

The first measurements of the electromagnetic field strength generated by various types of VDUs were carried out on a measuring site as described in *CISPR Publication 16* [3]. Fields strength measurements according to the forthcoming CISPR recommendation on data processing and office equipment (DP/OE) showed that none of the VDUs under test produced electromagnetic interference beyond the proposed limits.

In spite of this, it was still possible to obtain a clear picture of the displayed information on a normal TV receiver at a distance of about 50 metres from the video display unit or terminal. For video display units or terminals in metal covering the maximum reception distance was about 10 metres.

These measurements were carried out within

2 This is in contrast to the assumption in the Appendix that the video signal is a random digital signal but it does not affect the usability of the theoretical model for this purpose.

3 CISPR is the special International Committee on Radio Interference and is one of the committees of the IEC.

the TV broadcast bands; field strength measurements, however, showed that the maximum radiation level produced by a video display unit or terminal was always located between the TY broadcast bands. Consequently, the maximum reception distance may be expected to be larger than the distances mentioned in the aforegoing [4]. Also, since measurements were carried out using a dipole antenna for reception, the use of a directional antenna may provide at least 10 dB extra gain, thus leading to another increase in maximum reception distance. Sometimes a video display unit or terminal is placed near reflecting objects. This may in the worst case lead to a transmission gain of about 3 dB.

Taking account of all these factors, it seems justified to estimate the maximum reception distance using only a normal TV receiver at about 1 km for a video display unit or terminal in plastic covering and around 200 m for one in metal covering.

3.3. Experimental Eavesdropping

To prove that eavesdropping is feasible in a practical situation using this simple set-up, the following experiment was carried out. The equipment (dipole antenna, TV receiver, and synchronization oscillators) was put in a car, which was placed in the car park of a building in which a word processor was being used. An attempt was then made to copy the information from this word processor's video unit by taking photographs of the screen of the receiving television set. The photographs convinced even the most skeptical people in our organization of the threat of this possibility to information security.

3.4. Further Experiments

In February, 1985, we carried out an eavesdropping experiment in London, in cooperation with the British Broadcasting Corporation. Part of the results were shown in the programme "Tomorrow's World."

A small van was equipped with a 10 metre high pump mast to which a VHF band III antenna was clamped (10 dB gain). The received signal was fed through an antenna, amplified (18 dB) and displayed on a television screen inside the van. For obvious reasons we cannot give information on the data picked up during the experiment. The results can be summarized as follows:

- It is possible to eavesdrop on the video display units or terminals in buildings from a large distance, using a car fitted up for the purpose.
- Although the experiment was carried out in broad daylight and many people watched us, nobody asked what we were doing.

4 In the future. TV receivers will be able to receive signals at frequencies between the TV broadcast bands since these frequencies will be used for cable television.

4. Solutions

4.1. Decrease Radiation Level

There are various techniques for decreasing the amount of radiation from electronic circuits. They include:

- Do not use a family of digital components which switches faster than necessary for the operation of the circuits. This limits the high cut-off frequency of the radiated spectral intensity.
- Keep the radiating area of an electric circuit loop as small as possible. This can e.g. be done by providing a return lead as near as possible to each signal lead on the printed circuit board.
- Keep interconnecting leads as short as possible.

More details and additional techniques can be found in the various publications on electromagnetic compatibility design, such as [5] and [6].

The above measures will decrease the total amount of radiation from the printed circuit boards in the equipment. They cannot decrease the radiation from the electron beam in the CRT. Thus additional measures are required.

If the entire video display unit or terminal system is electromagnetically shielded, the radiation can be almost eliminated. A metal shield will keep the electromagnetic energy inside the unit or terminal. The shielding effectiveness (in dB) of a metal shield is almost proportional to the thickness of the shield in the frequency range from several hundred kHz up to several hundred MHz (depending on the size of the video display unit or terminal).

If a metal shield could be constructed round the video display unit or terminal, the radiation level outside the equipment would be determined by the thickness of the shield and the radiation level before the shield was installed. Unfortunately, the construction of such a shield is not feasible because.

• part of the shield would have to be optically transparent to be able to see the screen;
• cables would have to penetrate the shield to link the unit or terminal to the outside world (interfacing, power supply);
• the keyboard would have to be reachable for the operator; and
• in most cases ventilation openings would be needed.

To allow all the functions mentioned above, a vast range of shielding materials and aids are available on the market, including:

• metal (gold) coated CRT screens;
• wire mesh nettings to be placed before a CRT screen
• honey comb gratings for ventilation;
• shielded cables for interconnection of VDU and keyboard;
• electric filters to prevent radiation from penetrating cables; and
• special material to join the different parts of the shield, etc.

The total of measures which can be taken to reduce the radiation level is rather expensive, and may double or even triple the price of a video display unit or terminal depending on the final radiation level accepted.

4.2. Increase Noise Level

From a radio-interference point of view, this type of solution is the worst imaginable, but it is a possibility. Manufacturers already have many problems in complying with statutory radio interference limits, and it is therefore virtually impossible to equip a unit or terminal with such a noise source.

The only solution one might think of to prevent eavesdropping in this way is to place a lot of equipment in one room, e.g. a large number of terminals. Experiments have shown that this is not a real solution. As noted earlier, the radiation pattern of a terminal is largely determined by resonances at some frequencies. These resonances occur at different frequencies, even if two units of the same type are chosen. This means that eavesdropping on a cluster of video display units or terminals is possible, because each unit has different (resonance) frequencies at which the radiation is dominant.

4.3. Cryptographic Display

The basic factor leading to the detection of the information displayed on a video display unit or terminal by means of a normal TV receiver is the similarity between the two systems as regards image build-up. Therefore, a simple and adequate solution to this problem is to change the sequence in which the successive display lines are written on the screen. A TV receiver expects the picture build-up to start at the top line and to end at the bottom line in a natural sequence (1, 2, 3, 4, . . ., k).

It is comparatively easy to change the sequence of the pattern of the digital image build-up of the video display unit into a semi-random one. The sequence obtained can be made dependent on a code key which can be fed into the units circuitry. If the radiated signal is now picked up by a TV receiver, the information is not readable, and it is very difficult to ascertain whether information is being received at all. The information can only be obtained from the received signal when the sequence is known or when sophisticated decoding equipment is used. In order to prevent detection of the information by "trial and error" (with k display lines there are only $k!$ possibilities), the code key can be made to change semi-randomly after a preset time interval. The design of a video display unit or terminal with such a cryptographic display is relatively simple and the total costs are estimated at about $20 extra per terminal.

This system does not provide full protection against eavesdropping but it is adequate in most cases. This is especially true where a low or medium security level or privacy is required, such as in home applications and in most office applications. The costs of the system are realistic in relation to the required security level. This solution was found as a result of our studies in this field. Patents on this method are pending.

5. Measuring Methods and Requirements

5.1. Existing Standards

It can be safely assumed that equipment for military and government applications (security services) is tested according to stringent standards. Apparently two types of standards exist:

- the NACSIM 5100A . Tempest Standard (U.S.A.), and
- the AMSG 720B Compromising Emanations Laboratory Test Standard (NATO).

Both standards are applicable to all types of equipment, not only to video display units or terminals. Measurement methods and requirements in the NACSIM standard are unknown to non-Americans. According to the scarce information available [7] equipment is tested under the surveillance of a special committee (TQSC). If approved, the equipment may be placed on the "Tempest preferred product list" (PPL). Once listed on the PPL, the equipment may not be exported or sold to the public without U.S. governmental approval.

Not long ago (1982), NATO defined its own "Tempest" standard. This AMSG standard is in special cases used for both military and governmental applications in NATO countries. As documents relating to the standard are classified, the information is not freely available. It is unknown how this AMSG standard relates to the NACSIM standard but the measurement procedures and requirements defined in the former are known to be mainly of U.S. origin.

5.2. Usability

The aforementioned standards are clearly not very suitable for non-military and non-government applications, especially in cases where a low or medium security level is required. This is not only the case because the methods and requirements are not freely available, but also because the requirements are probably too stringent for these applications, resulting in unacceptable costs. We have therefore developed a simple method for testing video display units or terminals in this respect.

5.3. Simple Measuring Set-Up

The aim of the measurement set-up is to check the reconstructability of information displayed on a unit or terminal by means of a normal TV receiver. Since various sources of radiation occur, this reconstructability is not determined only by the radiation level produced [1]. Therefore a normal TV receiver should be used as a measuring instrument. The measuring distance from the unit or terminal under test will in that case be the variable which determines the stringency of testing: the information on the screen is required not to be reconstructable on a normal TV receiver at a distance larger than d metres, where d is de

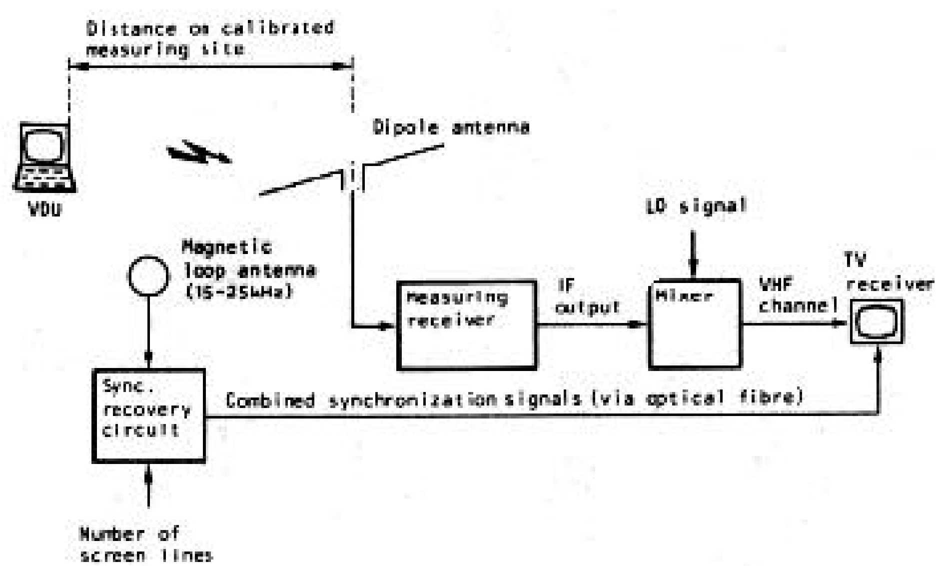

Fig. 2. Measurement set-up

termined by the tester. This type of measurement set-up has disadvantages, including:

- reconstruction (reception) is only possible within the TV broadcast bands, and
- the measurement sensitivity is dependent on the type of TV receiver used.

Therefore a measurement set-up according to Fig. 2 was used.

The video display unit or terminal under test is placed I metre above the earthed conductive ground plane of a measuring site according to *CISPR Publication 16.* The antenna signal from a calibrated measuring antenna (e.g. a dipole) is fed into a receiver suitable for measurements in the range of 30 to 1000 MHz. The IF signal of the measuring receiver is used as an input to the TV receiver, thus using the former as a frequency convertor. If the TV receiver is tuned to this IF frequency it is possible to observe whether reconstruction of information from the received signal is possible. If the IF frequency is located outside the TV broadcast bonds, it must be converted to an arbitrary VHF channel as shown in Fig. 2. This cascading of two receivers has several advantages:

- measurements can be carried out over the entire frequency range 30-1000 MHz because the mea suring receiver determines the measuring frequency;
- the measuring receiver determines the sensitivity of the entire set-up; and
- field strength measurements can be carried out simultaneously, thus enabling comparison between picture reception quality and ambient field strength.

Since the IF signal is filtered at the detection bandwidth of the receiver, a detection bandwidth of at least 1 MHz should be selected. In order to obtain a clear picture on the TV screen, the bandwidth of the measuring receiver should be at least 4 MHz. With a 1 MHz bandwidth, a page of text is not clearly readable but will be recognized as such. At bandwidths smaller than 1 MHz the picture on the TV screen will hardly be recognizable as a page of text.

In contrast to the eavesdropping situation, the video display unit or terminal is available during measurements, thus enabling the pick-up of synchronization signals directly. This can be done easily by picking up the magnetic field from the high voltage transformer, close to the unit. This transformer in most cases is driven at the horizontal synchronization frequency of the display unit or terminal as in a normal TV receiver.

As described in the Technical Appendix, the signal is picked up and filtered, and stabilized in a phase locked loop. The vertical synchronization frequency is obtained from the horizontal synchronization frequency by division through the number of screen lines on the video unit or terminal. Both signals are combined and fed into the synchronization separator of the TV receiver. The signal is transmitted via an optical fibre to prevent disturbance of the radiated high frequency field of the video unit or terminal during measurements

6 Conclusions

1. Video display units or terminals generate electromagnetic fields with frequency components up into the UHF region which contain the harmonics of the video signal.
2. A normal TV receiver made suitable for this purpose will in some cases be able to restore the information displayed on a video display unit or terminal on its own screen, when this field is picked up. Depending on the type of video display unit or terminal, this reconstruction may under optimum conditions be feasible from distances of up to 1 km.
3. The information in video display units or terminals will not be detectable at such distances if an electromagnetic shield is applied. Adequate shielding of the electromagnetic fields generated may double or even triple the price of a video display unit or terminal.
4. If the writing sequence of screen lines of the video display unit or terminal screen is changed into a random sequence, reconstructio is made impossible. The costs of this type of video display unit or terminal data protection are estimated to be much lower than those of electromagnetic shielding.
5. The measurement method developed can be used to obtain information on the reconstructability of the data displayed on a video display unit or terminal, at a predetermined measuring distance. The set-up is simple and measurements do not take an unreasonably long time to be carried out.

Technical Appendix

Principles of Television

Picture Build-Up

The picture on a television screen is built up sequentially. The moving picture is the result of 50 frames (European standard) being displayed per second. Each picture consists of a number of horizontal lines which are so close together that individual lines cannot be recognized when looking at the TV screen from a reasonable distance. These horizontal lines are written on the TV screen in a predetermined sequence: the first line is written at the top of the screen and the last line at the bottom. The individual lines are written from left to right on the screen.
Each TV picture is built up as illustrated in Fig. 3. The device used to build up the TV picture is called a Cathode Ray Tube (CRT) (see Fig. 4).
If a high voltage is applied between the (heated) electrode (cathode, negative voltage) and the conductive layer on the inside of the screen (anode, positive voltage), electrons will start flowing from the cathode to the anode.
As a result of the application of a magnetic field around the 'foot' of the CRT the electron flow is guided into a very narrow beam. If the voltage is high enough, the kinetic energy of the electrons is so large when reaching the screen that the screen will emit photons of visible light. Thus by controlling the voltage applied between the cathode and the anode, the light intensity of a given a spot on the screen can be controlled. Since electrons are charged particles, applications of a magnetic or electric field perpendicular to the direction of flow will change that direction. If a field is generated in both the horizontal and the vertical direction by applying voltages between the steering electrodes, the place of the lighted spot on the screen can be changed. It is easy to see that the application of sawtooth-voltages with different frequencies leads to the movements of the spot over the screen as shown in Fig. 3. Thus, the picture on a television screen is built up by modulating the light intensity of a spot moving over the screen in the predetermined manner.

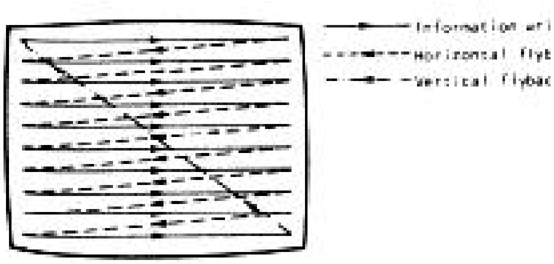

Fig 3 Sequential frame build-up in screen lines.

Video Signal

The signal required to modulate the light intensity of the moving spot is called the video signal. A TV broadcast receiver receives this video signal from the transmitter. To enable the TV receiver to decode the received video signal into a readable picture it has to 'know' at what moment in the received signal the information on each line starts As the picture is built up according to a predetermined scheme, information on the starting moment of each first line of a frame and all the following lines has to be transmitted as well The signal used to feed this information to the TV receiver is called the synchronization signal. For practical reasons the video signal and the synchronization signal are combined into one signal, the line feed [LF] signal. The LF signal in a TV receiver consists of:

- a positive part, the video signal, and
- a negative part, the synchronization signal (pulse train).

The signals can be combined into one signal, because the synchronization signals can be transmitted in between separate lines and frames. A small part of an LF signal in a TV receiver is shown in Fig. 5.

Video Display Units

Picture Build-Up

The build-up of the picture on a video display unit is much the same as in a TV broadcast receiver.

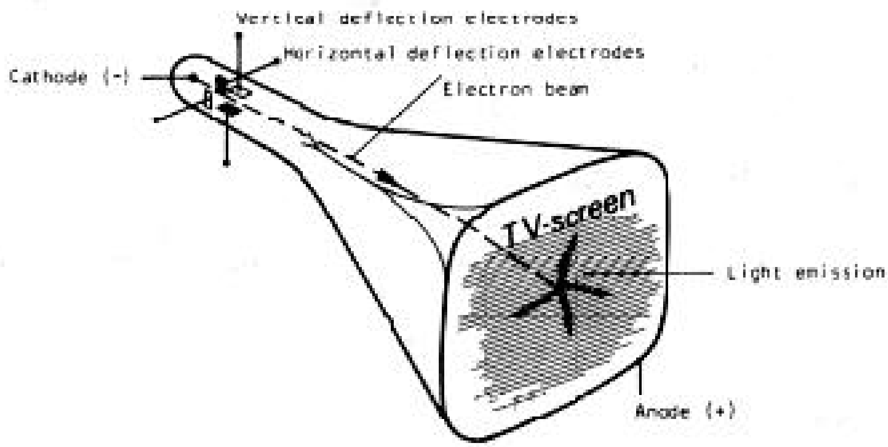

Fig. 4. Cathode ray tube.

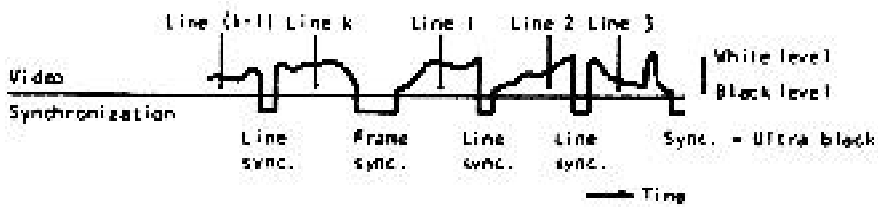

Fig. 5. Line feed [LF] signal in a TV receiver.

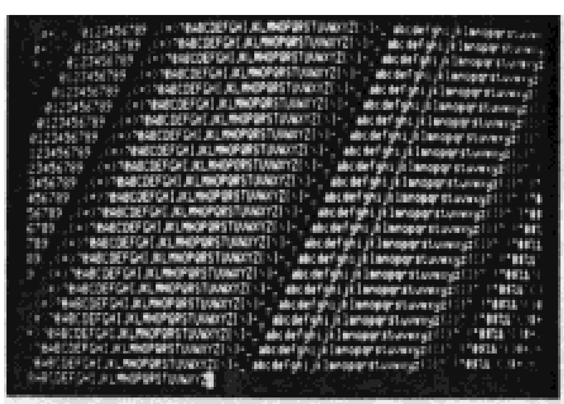

Fig. 6. VDU screen with text.

Fig. 7. Detail of Fig. 6.

Fig. 6 shows the image displayed on a video display unit. Fig. 7 is a close-up photograph of the screen which shows that the symbols displayed consist of small dots. These dots (pixels) are arranged in horizontal lines, just as in a normal TV receiver.

Video Signal

A graphic representation of the shape of the video signal needed for a picture is shown in Fig. 8. To build up the display in pixels, the current of the electron beam is on-off modulated. Thus, the video signal in a VDU is a digital signal, a logical "one" producing a " white" spot on the screen and a logical zero preventing this spot from appearing. The initial video signal is shown in Fig. 8b,, corresponding to the shaded screen line in Fig. 8a.

To obtain the required resolution on the VDU screen, the bit duration in the video signal should be short. If the bit duration were to be as long as shown in Fig. 8b,, the pixels on the screen would be distorted into ovals instead of circles, because of the scanning speed of the electron beam. Therefore the bit duration is decreased through modulation of the initial video signal 8b on a square wave (the video-dot-clock) with the same period as the bit duration in the initial video signal. In this way the bit duration is decreased to 50 per cent of the original value, as shown in Fig. 8c.

The modulation process is easily performed by applying both signals to a logical AND, since the signals can only have the values 0 and 1. Evidently, a number of adjacent pixels in a horizontal row are written on the screen as individual pixels. However, the optical size of the pixels is so large that this is not noticed when looking at the screen from a reasonable distance. The fact that horizontal lines are also displayed as a row of individual pixels is important for the detectability of the information by means of a TV receiver, as will be shown in the section on detection of information.

Spectral Contents

If the text displayed on the VDU screen is nonrepetitive, the signal may on a first approximation be considered as a random digital signal. The power spectral density of this signal is given by:

$$s_{xx}(f) = A\left(\frac{\sin \pi f T_b}{\pi f T_b}\right)^2 \qquad \{V^2/\text{Hz}\}$$

where T_b is the duration of one bit in the final video signal, and A is a function of the number of pixels displayed on the screen and the signal amplitude in volts [2]. A part of $S_{XX}(f)$ is given in Fig. 9.

As the video signal in a VDU can only be realised with finite transition times, T_t, the real

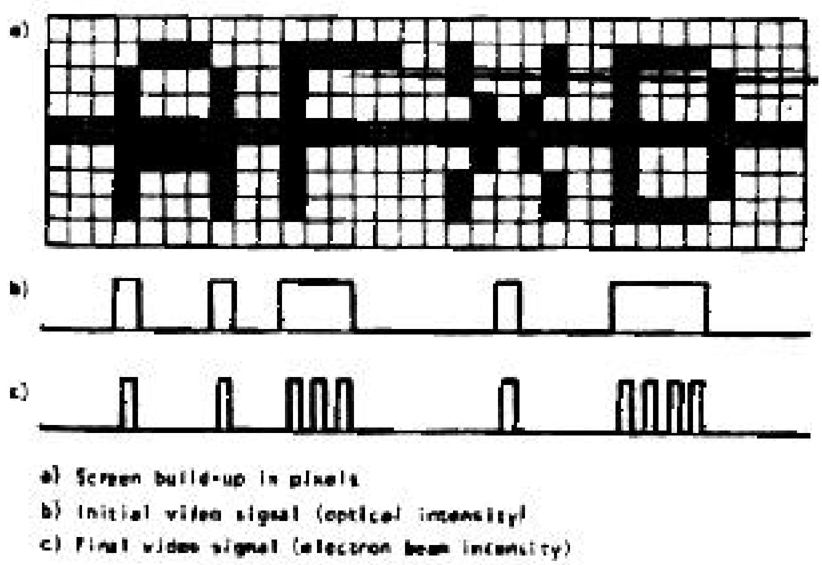

Fig. 8. Build-up of the video signal in a VDU.

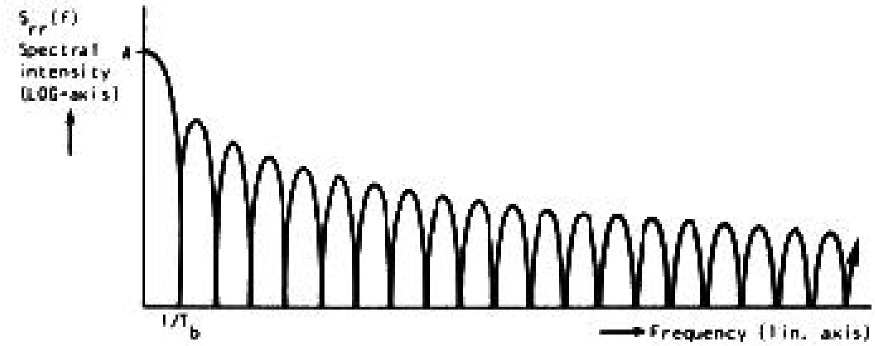

Fig. 9. Power spectral density of the video signal.

power spectral density of the video signal is described more appropriately by:

$$S'_{xx}(f) = S_{xx}(f) \cdot \frac{1}{(\pi f T_r)^2 + 1} \qquad \{V^2/\mathrm{Hz}\}$$

thus:

$$S'_{xx}(f) = A \cdot \left(\frac{\sin \pi f T_b}{\pi f T_b} \right)^2 \cdot \frac{1}{(\pi f T_r)^2 + 1} \{V^2/\mathrm{Hz}\}$$

In the above expression the last factor denotes a first order low pass filter characteristic with cut-off frequency f_2= 1/9T[b- It is readily seen that the envelope of the power spectral density of the signal is fairly constant up to the frequency f_1= 1/πTb, from which frequency it will be decreasing at a rate of - 20 dB per decade down to f_2 = 1/πTt. At frequencies higher than f_2 the spectral density decreases at a rate of - 40 dB per decade.

Generally, the frequency f~ is in the range 20 to 50 MHz, and f_2 is in the range 200-500 MHz, depending on the type of components and circuits used.

Other Signals

The video signal is not the only signal in a VDU. It will be shown in the next section that the video signal is the most powerful broadband contribution to the radiated emission. This is because it is the only signal in a VDU that is amplified to far above TTL level. It is therefore unnecessary to go into the nature of other broadband signals in a VDU for this analysis. Because clock signals are repetitive, their power spectrum consists of individual spectral lines at the add harmonics of the clock frequency. Because the spectral lines are far apart, each of the lines may be looked upon as an independent narrowband source for our purposes. The intensity of these narrowband components decreases with increasing frequency. as is the case with the video signal's power spectrum. Because the power spectral density of the clock signals is concentrated in individual spectral lines, rather than spread over the entire frequency axis, the power in each of those lines can be fairly high compared with the power density in the video signal (depending on the measuring bandwidth).

What is even more important, the clock signals are often obtained by frequency division of the video-dot-clock. This means that many spectrum lines will coincide with the centre of a lobe in the video signal. This phenonnenon has a great impact on the detection of information with a TV receiver.

Electromagnetic Radiation

Principles

It can be derived from Maxwell's equations that the acceleration of electric charges results in the generation of an electromagnetic field. This phenomenon is well known, and it is used to our advantage in radio communications. A current is forced to flow through a conductive wire (antenna). This current will generate an electromagnetic field which can be picked up at a large distance from the transmitting antenna using another conductive wire in which the field will generate a current. It can be proved that the current generated is similar to that in the transmitting antenna.

This means that any conductor carrying a current with varying strength (alternating current) can regarded as a transmitting antenna. Digital equipment will therefore generate electromagnetic lds containing all frequency components of all ,nals inside the equipment. Since the electro- magtic field is generated by the acceleration of charges, its strength is related to the derivative of the current in a circuit, rather than to the current itself.

Radiation of the Video Signal

It is obvious that the video signal in a VDU is dieted into the surroundings of the equipment ~ the video processing circuitry, and by the elecon beam in the CRT. On a first -rough- approximation, the radiation effectiveness of a circuit increases monotonously with frequency at a rte of + 20 dB per decade, up to a frequency (of several hundred MHz) which is determined by the hysical size of the circuits used for video signal processing [3].

If it is assumed that this cut-off frequency is higher than f_2, the radiated power spectral density $S_{rr}(f)$ can be estimated by:

$S_{rr}(f)$: : $\sin_2(\pi f T_h)$ $\{V^2/m^2Hz\}$

where $f_1 > f > f_2$. A part of this spectrum is shown Fig. 10.

It can be derived from communication theory that if the receiver is tuned to one of the lobes of the spectrum, the entire video signal can be retored. This can be made plausible if each of the radiated lobes of the power spectral density is regarded as an AM-modulated version of the line feed portion of the video signal up to the Nyqvist frequency $f_N = 1/2T_b$ [4]

Emission Measurements

Measurements were made in respect of the interference produced by a VDU. The video-dot-clock of the VDU chosen was 11.004 MHz. The system clock frequency was 1.57 MHz, so narrowband components could be expected to occur in the radiated spectrum at 1.57 MHz intervals. Two types of measurement were carried out:

- The maximum available interference power on the mains power cord was measured using the CISPR absorbing clamp.
- The electric field radiated by the VDU in the direction of maximum radiation was measured with a biconical antenna according to MILSTD-461/462 at a distance of 1 metre. In this set-up the main power cord was shielded.

Measurements were made with an HP 8586A spectrum analyser in the frequency range 30-300 MHz, at a detection bandwidth of 10 kHz and the function 'MAX HOLD' having been selected. The results are given in Fig. 11 and Fig. 12. The upper portions of Fig. 11 and Fig. 12 illustrate the measurement results for a full screen of text of a VDU. The lower portions of Fig. 11 and Fig. 12 illustrate the VDU screen on which only the cursor is displayed. These results show that:

- the level of broadband interference is largely dependent on the number of characters displayed on the screen;
- the level of narrowband interference is independent of the contents of the display, and individual narrowband components are determined by the VDU system clock and the video-dot-clock.

It can thus be concluded that the video signal is the most powerful source of broadband emission, and that the clock signals are the most powerful

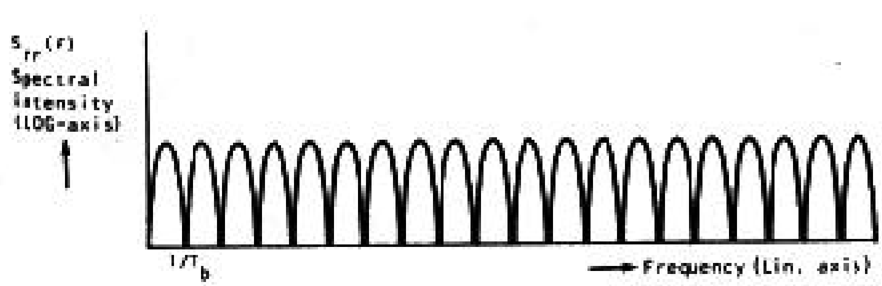

Fig 10. Power spectral density $S_{rr}(f)$ of the radiated field $(f < f_2)$.

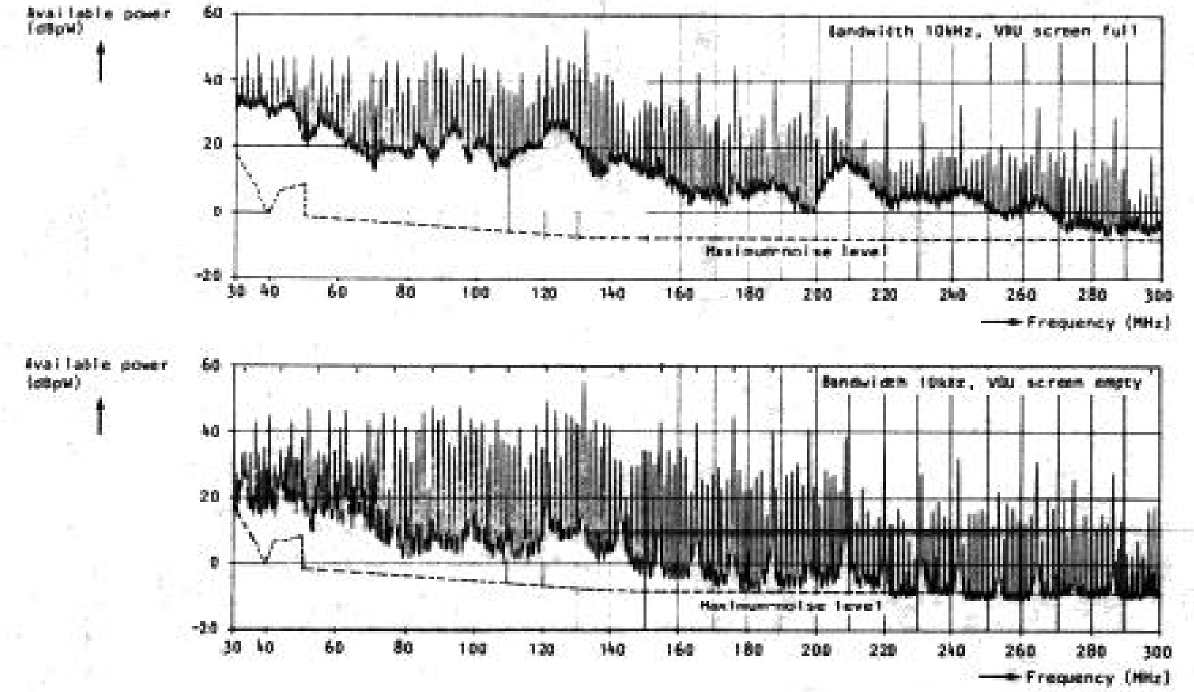

Fig. 11. Maximum interference power available on the main power cord.

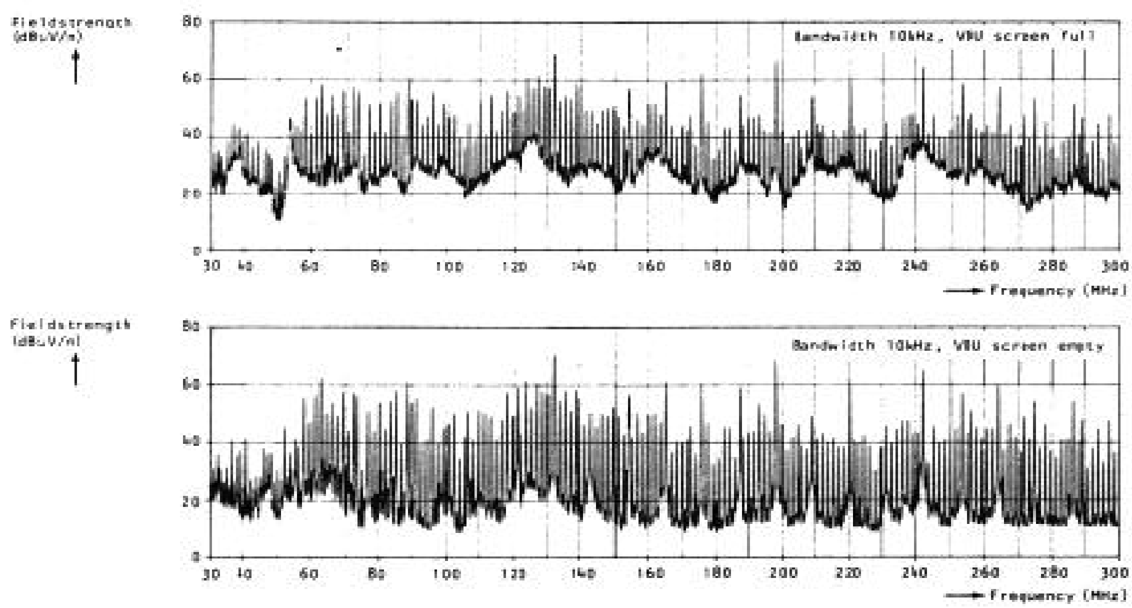

Fig. 12. Field strength in the direction of maximum radiation at I meter distance (horizontal polarization)

sources of narrowband emission. The measurements clearly show that the emitted broadband spectrum does not follow the assumed sin2(,r~,) function. Especially in Fig 11 it is clear that at some frequencies (e.g. around 125 and 210 MHz) resonances occur which cause the emission to increase to 15 dB above the emission level at adjacent frequencies.

Radio Interference Limits

Measurements of the electromagnetic field strength generated by various types of VDUs were carried out on a measuring site as described in *CISPR Publication 16.* Field strength measurements according to the forthcoming CISPR recommendation on data processing and office equipment (DP/OE) showed that none of the VDUs we tested produced electromagnetic interference beyond the proposed limits. In these measurements the observed frequency range was 30-600 MHz.

Reconstruction of Information

Signal Processing in TV Receiver

In its simplest form a TV receiver can be described according to the block diagram of Fig. 13. As can be seen in this block diagram, the TV receiver can only see a very small part of the spectrum radiated by the VDU, with a bandwidth of approximately 8 MHz[5], at an arbitrary frequency somewhere in the VHF or the UHF region

[5] Normally a TV receiver is equipped with a VSB demodulator and a detection bandwidth of approximately 4.5 MHz. This is effectively equal to an AM detector and 8 MHz detection bandwidth

Fig. 14 shows that the TV receiver will not notice the difference between the radiated signal (solid line) and the video signal which has the same spectral density at the reception frequency of the TV receiver (dotted line). The band filtered out by the detection filter of the TV receiver is displayed as a shaded block in the same Figure.

The response of the TV receiver to the radiated signal can thus be computed using the entire video signal as an input signal to a TV receiver. The amplitude of this signal is chosen at such a value that the power spectral intensity of the signal is equal to that of the radiated signal at the reception frequency. The signal processing in the TV receiver is visually represented in the time domain in Fig 15.

Fig. 15a shows the input video signal.

Fig. 15b shows the IF signal in the TV receiver in response to this video signal.

In Fig. 15c the LF signal in the TV receiver is shown; due to the AM detector this is the envelope of the IF signal.

Fig. 15d displays the video signal in the TV receiver with optimum adjustment of the brigthness and contrast levels.

The amplification of the LF signal around the threshold, determined by the brightness level, is determined by the contrast level. On a first approximation the contrast level determines the steepness of the flanks in the final video signal in the TV receiver. In contrast to the screen build-up in a VDU, the maximum of the video signal determines the black level, whereas the minimum determines the white level. The picture on the TV screen is therefore a copy of the picture on the VDU screen and is composed of a white (or gray) background with black letters.

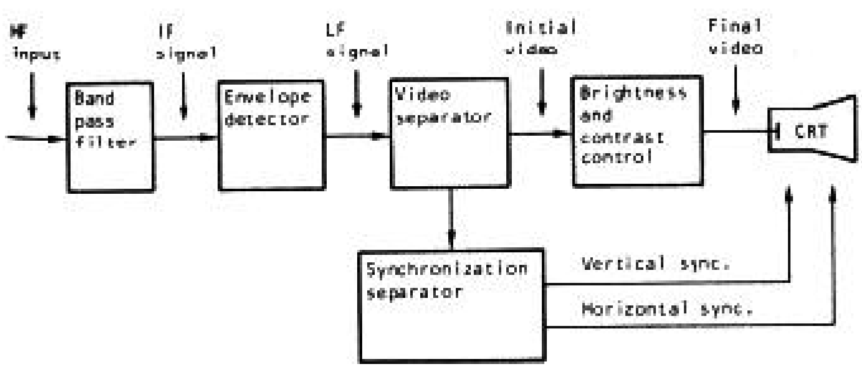

Fig. 13. **Simplified block diagram of a TV receiver.**

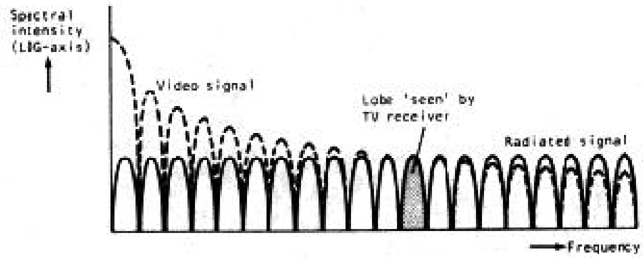

Fig. 14. Video signal and radiated electromagnetic field. with equal amplitudes at the reception frequency of a TV receiver.

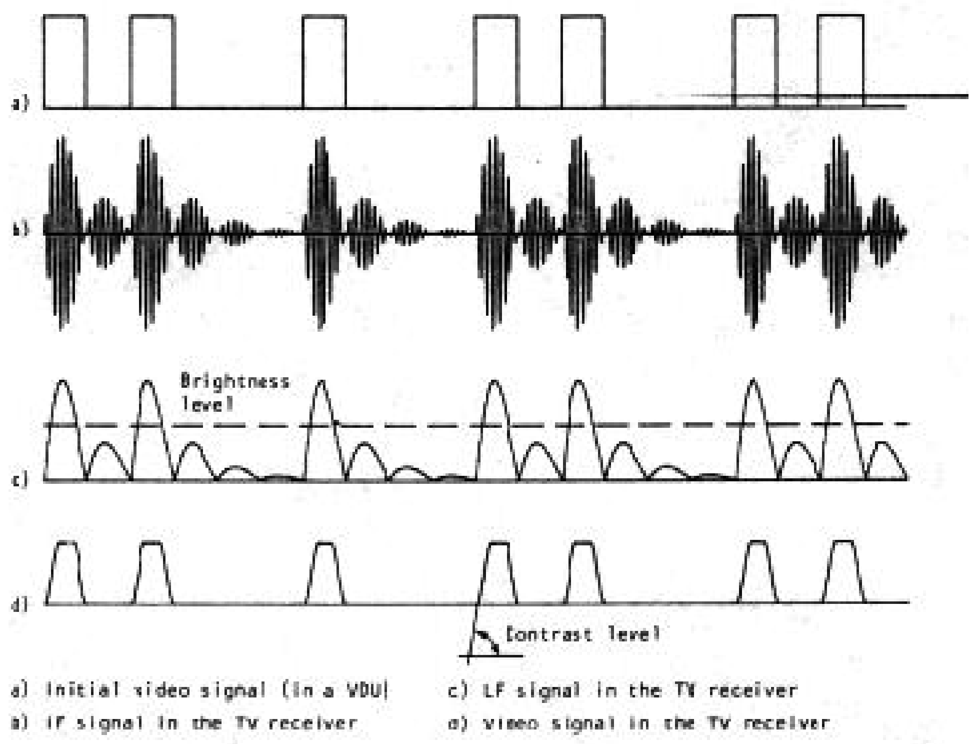

Fig. 15. Signal processing in a TV receiver.

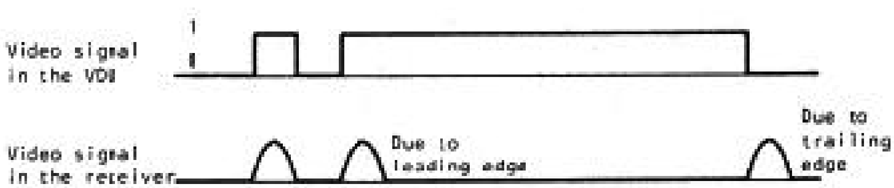

Fig. 16. Reconstruction of line elements.

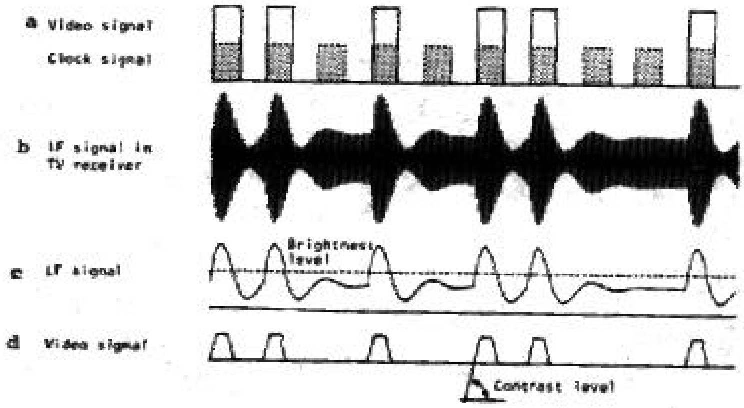

Fig. 17. Signal processing in a TV receiver with coherent narrowband component available.

Fig. 15 shows that a horizontal line element on the screen of the VDU is composed of a number of adjacent pixels which leads to reconstruction of the video signal for line elements. Since the electromagnetic field generated is related to the derivative of the video signal, only the leading edge and the trailing edge of a */long* pixel would be displayed on the TV receiver as a dot. The effect is shown in Fig. 16.

Influence of Narrowband Components

The IF signal in the TV receiver as illustrated in Fig. lSb can be quantified as:

$$V(t) = a(t) \cdot \cos(W_c t),$$

where Wc is the frequency of modulation, which is equal to the centre frequency of the receiving filter. If the received narrowband signal is an odd harmonic of the video-dot-clock, its frequency under optimum reception will be Wc. The received signal can then be described as:

$$V'(t) = a(t)\cos(W_c t) + B\cos(W_c t + \phi),$$

with B and ϕ being constants.

Or, assuming $\phi = 0$:

$$V'(t) = [a(t) + B]\cos(W_c t).$$

Envelope detection in the TV receiver now leads to:

$$e(t) = |a(t) + B|$$

Assuming $|a(t)| > B$, we obtain:

$$e(t) = a(t) + B$$

Demodulation of this type of signal is shown in Fig. 17. In comparison with reception under absence of the narrowband component, there are two advantages:

1. The total signal power received by the TV set *is* determined by the sum of *ai(t)* and B.
2. The signal can be better reconstructed because the dynamic range of *e(t)* has increased relatively.

First Measurements

First measurements during the experimentation showed that a TV receiver will indeed restore the video signal of the VDU, although the image does not appear on the screen because of the lack of synchronization information in the received signal. This is evident if Fig. 17d and Fig. 15d are compared with Fig. S.

The synchronization signals are separated from the video signal in the video separator. When the TV receiver is tuned to a broadcast station, the synchronization signals are explicitly transmitted; thus the receiver is able to restore the synchronization of the received information. Normally a VDU does not radiate such a *smart* signal. The TV receiver picking up the signal radiated by the VDU is thus unable to synchronize on the signal received.

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