ABSTRACT

Advances in VLSI technology will continue to enable almost all of the major electronics-related scientific and technological achievements to eventually be introduced into, and blossom in, the home electronics market for the benefit of all consumers. Current electronics trends suggest that computers and communications equipment will gradually diffuse into the home and be integrated with traditional home electronics products, such as audio and video equipment and home appliances. This will give birth to a new and more advanced information age.

In reviewing the history of the development of electronics, we can clearly see that new electronic technologies and products appear first in the scientific and military fields, are later transferred to the industrial and professional markets, and eventually are introduced in the home and personal markets. At each step in this transfer process, these electronic products are dramatically improved in terms of price, weight, and size, thanks to high volume mass-production.

Outstanding and innovative scientific and technological achievements finally blossom and explode in the home electronics market, providing enormous benefit to the consuming public. In this respect, it can be said that at present the computer business is still in its infancy because computers are not yet that widely used in the home.

The term "home electronics" (HE), as used in this paper, refers to consumer electronics, home appliances, and to a certain subset of information and communications equipment.

Facsimile machines and VCRs, which were once used almost exclusively by newspaper and broadcasting companies, are now widely used by the average consumer. Similarly, the shelves of retail stores will be teeming with lap-top engineering workstations whose high performance exceeds that of a mainframe computer of just 20 years ago.

Fig. 1 shows the price and size reductions for active electronic components during the past fifty years. Prices have gone down to one 100 millionth and size has been reduced to one 1 billionth. And, as long as these price and size reductions continue, the current electronics revolution will continue for at least another decade.

The following are the requisite characteristics for successful HE products:

1. Low cost
2. Small size
3. Ease of use
4. Convenience
5. Comfortableness
6. High level of quality.

Among these, numbers 1 and 2 are physical requisites and numbers 3 to 6 are human-related ones. In the HE market, manufacturers are racing to compete against one another in meeting these requirements. Considering the fact that HE products are used by various segments of the public, including children, the aged, and the handicapped, they require, in a sense, more sophisticated and diversified user-friendly technologies than products designed for industrial use.

2. MARKET OVERVIEW

What follows is a statistical overview of the HE industry.

2.1. World

Fig. 2 shows worldwide production and demand during 1988 for audio and visual (AV) equipment, which was almost equivalent to
the production and demand figures for consumer electronics equipment as a whole. Japanese AV production accounted for 46% of worldwide production valued at 70 billion dollars. The Asian share, including Japan, amounted to nearly two-thirds of the total. Thus, Japan and other Asian nations have come to be looked upon as the world's major source of supply for these products, since half of the production in these nations is exported to the rest of the world.

The United States, once a leading nation in terms of electronic inventions and discoveries, especially as concerned the radio, phonograph, and television technologies, has been steadily yielding its preeminent production position to Asian nations.

For the sake of reference, Fig. 3 shows the 1988 production and demand figures for computers (or information equipment) and communication equipment. Worldwide production of computers and communication equipment during that year was valued at 157 million dollars and 111 billion dollars, respectively. Unlike in the case of AV equipment, the U.S. and European nations still maintain the dominant market share in these areas.

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2.2 Japan

In Japan, the HE industry has enjoyed continuous growth in parallel with the nation's overall economic growth and increased per capita income. As Fig. 4 shows, the HE industry has undergone an economic boom with the introduction of each new generation of electronic equipment, such as black and white TVs, color TVs, and VCRs. However, a rather pessimistic forecast has been made for the next decade. The annual growth rate for HE equipment in the coming years is expected to be as low as 3.5%, or about half of that for computers and communication equipment. "Hi-Vision" TV (HDTV) is thought to be one of the best candidates for high growth among the various kinds of AV equipment.

Fig. 5 shows the level of Japanese electronics production and the breakdowns between Japanese domestic consumption and exports for the three major HE market segments during 1989. The production of AV equipment was equal to 3.9 trillion yen, of which 60% or 2.4 trillion yen, represented domestic consumption and 40% represented exports. And, 2.4 trillion yen worth of home appliances were produced, with almost all of this production being consumed domestically in Japan. Out of a total of 10.7 trillion yen worth of computer and communication equipment production, which was 2.5 times higher than AV equipment production, some 8.2 trillion yen worth was consumed domestically. It is worth noting that 0.6 trillion yen worth of this 8.2 trillion yen figure was purchased for home use and this "home use" portion is expected to grow rapidly in the future.

To sum up, the total value of Japan's home electronics market in 1989 was about 5 trillion yen.

3. PRESENT STATUS OF HOME ELECTRONICS

3.1 Penetration of Information and Communications Equipment into the Home

Recently communications equipment, such as facsimile machines and portable telephones, along with information equipment, such as word processors, PCs, and electronic notebooks, has been introduced into the home, thanks to the smaller size and reduced cost brought about by advances in VLSI technology.

In addition to information and communications equipment, information processing technology has begun to diffuse into HE products. For example, camcorders utilize 11 microcomputers to adjust and control their mechanical functions. Washing machines and vacuum cleaners employ "fuzzy" logic to determine air and water flow rates and the required washing or cleaning time.

The distinction between consumer electronics and industrial electronics in terms of products, application, and technology has gradually become ambiguous. In other words, these two fields seem to be merging into a single integrated market.
Another example of information processing technology at work in an HE product is the voice-activated program-input system for VCRs, which is schematically shown in Fig. 6. Viewers can program in channel numbers, days of the week, and starting and ending times, by giving oral commands to a remote control device. Viewers can confirm their programming instructions on a liquid crystal display. Pre-registration of the viewer's voice is necessary because the viewer's voice can be easily recognized through dual pattern-matching method. This device is capable of recognizing up to 60 words even under relatively noisy conditions.

![Fig.6 BLOCK DIAGRAM OF INTERACTIVE VOICE PROGRAMMING VCR](image)

3.2 Towards Higher Quality and Performance in AV Equipment

In order to increase the quality and performance of AV equipment in the future, reliance on the "digital" technology will be indispensable. It is already being utilized to a large extent in the areas of adjustment and control of AV equipment. However, in the signal processing, very little current video equipment employs this technology, although audio equipment, such as CD and DAT, does so.

As for TV sets, manufacturers have tried in recent years to add such additional functions as multiplex, teletext, facsimile machine capability, picture-in-picture, etc., but these efforts have not led to any significant increase in the level of TV set production.

Also, several efforts at enhancing picture quality are under way. In "Clear Vision", a higher resolution picture is achieved by extending effectively the video signal bandwidth. Unfortunately, to date, this has not met with any great commercial success. "Wide Vision", which has the same 16:9 aspect ratio as HDTV, is also under consideration. Both approaches are based upon the insertion of additional information into the frequency spectrum space of the video signal and are compatible with the current NTSC system. [1], [2]

These days, TV sets containing a built-in BS tuner or large screen (31") CRT are very well accepted by consumers.

In Japan, three channels of NTSC system broadcasting are available via a geostationary satellite. These provide the customer with high quality picture and sound because the broadcasting's electromagnetic wave does not encounter interference from obstacles such as buildings, and sound is transmitted by means of PCM.

The large screen picture gives the viewer a feeling of "presence" and is the biggest attraction to the customer. However, as larger, say 40 inch, screens are demanded by the customer, the weight of the CRT will increase to about 140 kg. For a lighter alternative, LCD projection display systems are being developed. But, lower illumination, poor resolution, and the short life of the light source are problems which must first be overcome.

Recently, the commercial introduction of Hi-Vision TV (HDTV) sets was announced, but the price ranges from 2.5 million yen for the set without a decoder to 4.5 million yen for the one with a decoder. However, it is expected that continued progress in the VLSI technology will lead to a reduction in price and for these sets in the not-too-distant future. The video signal decoder is expected to be as compact as three PC boards, or even less. The problem with this size reduction will be how to manage the heat generation (35W) caused by high component density and the electromagnetic radiation deriving from the high speed logic (48 MHz).

With regard to VCRs, efforts have been made to achieve better sound and picture quality, once again by extending signal bandwidth, but despite these efforts, production rates have tended to fail. On the other hand, the camcorder has registered steep growth in production and sales. Thus, manufacturers are racing to reduce their size and price, to provide a clearer picture, and to add new features, such as a wobble-free mechanism.

The next development targets are an Hi-Vision VCR and a digital VCR.

3.3 Home Appliances Providing Easier Use and Enhanced Comfort

Recently, "Fuzzy" logic technology has been widely employed in Japan in the design of various electric and electronic products. Using this type of logic, maximum output or performance can be obtained by analyzing a mix of ambiguous information, such as "cold", "hot", "long", etc.

For example, "Fuzzy" washing machines can detect the type and degree of dirt which needs to be removed as well as the volume of clothes, and then determine the optimum level of water, water flow, and washing time. This type of logic can find wide application in other household appliances which are mostly used on the basis of human senses as opposed to the application of logical reasoning.

Experience has taught us that, unlike machines, human beings do not generally thrive in constant temperatures and constant air flow. Thus, efforts have been made to incorporate 1/f fluctuation, which widely exists in nature, into electric equipment. And, these efforts are beginning to meet with commercial success. An "1/f fluctuation" electric fan produces powerful slow air flow and weak ripple air flow in alternating but irregular patterns. People experiencing such air movement feel refreshed as if they were standing in an outdoor breeze.

Fig. 7 illustrates the pattern of time variation for the blade revolution speed of the fan and the resulting power-frequency spectrum. The primary electronics for this fan consists of a 4-bit microcomputer with a 2 k byte ROM and a 64 byte RAM. [3] This 1/f fluctuation phenomenon can be expected to find wide

![Fig.7 1/F FLUCTUATION OF AN ELECTRIC FAN](image)

[1991 VLSITSA 3]
application in, for example, lighting fixtures, cooking appliances, air conditioners, and Japanese style "kotatsu" tables which possess a leg warming heat source.

In order to evaluate the degree of comfort offered by an environmental system such as a heating or air conditioning system, neural networks can be employed. For example, with regard to air conditioning systems, the network can determine the relationship between human perception of the comfort level and the physical variables, such as air volume, flow direction, room and outside temperatures, etc. What the network learns is written on a ROM table (several K byte) and then used to control the operation of the system.

4. HOME ELECTRONICS IN THE NEXT DECADE

In order to predict the future of home electronics, it is necessary to consider the role which it plays in everyday human life and the value which it has for people. In doing this, we can see the emergence of three major trends: 1) personalization, 2) networking, and 3) multimedia.

4.1. Personalization

As their standard of living increases, people generally desire to go beyond comfort, convenience, and amusement, and seek creativity and differentiation from others. This has served to create the new market segment of "personal electronics", where an electronic product is owned and used primarily by a single member of a family or other group, as opposed to being used collectively by all of the members of the family.

In addition, this personalization trend has been aided by advances in VLSI technology which have made it possible to make increasingly smaller and cheaper products for individual use, such as headphone stereo sets, LCD TV sets, electronic notebooks, book type word processors, and other PCs.

Also, the pursuit of an individual life style has given rise to the emergence of "interactive" electronic equipment, which allows users to select specific information at will as opposed to merely being a passive listener or viewer.

The video game machine is a typical example of interactive equipment. CD-I and DVI also belong to this category. Because of 2 or 3 powers of 10 times greater storage capability, they can be expected to have a wide array of applications, not just in the area of hobbies, but in the fields of entertainment, education, and business as well.

Fig. 8 provides a CD-I block diagram. It has a microprocessor in the center to control the entire system and a system bus running from the processor to each functional block: input, output, and processing. The architecture is quite similar to that of a computer, which tells us that the merging of computers and consumer electronics is already under way.

Another aspect of personalization which we should keep in mind is that of equipment designed for the handicapped, very young, or the aged. Most of the electronic products in current use are unfriendly to, or too difficult to use by, these groups. However, it is expected that future breakthroughs in cognitive science and artificial intelligence will play an important part in developing a solution to this problem.

4.2. Networking

The same motivation which has propelled people towards personalization has also led towards networking. A person who wishes to work or play in his own style will also need a means to communicate with others. And, another motivation stems from the desire to live a high quality life through networking, which may someday eliminate the need to waste time commuting to the office for many workers.

As to wire networks, as you can see from Fig. 9, we can see a home bus system (HBS) taking shape. Electric cables and wires can be extended to each corner of the house to allow for complete, and even remote, control of all of the home's electronic equipment, environmental equipment, such as air conditioners and light fixtures, security systems, information equipment, such as telephones and facsimile machines, and AV equipment.

Already several experimental homes containing such a HBS have been constructed. The required specifications for home bus systems in Japan were established this past November.

A main bus is comprised of coaxial cables (max. 2 pcs.) and twisted pair wires (4 pcs.) to which a number of information outlets are attached. The main bus is connected to electronic equipment via an interface unit (IFU) or to sub-buses, such as a domestic digital bus (DOB) or power line, via a gateway (GW).

Interfaces and gateways contain a 4 - 8 bit microcomputer and 2K to 6K gates of logic, with volume production prices being estimated at several hundred yen. In the future, we shall see optical fiber cable introduced into the home and connected to the integrated Service Digital Network (ISDN).

As to wireless networks, Japanese manufacturers have been very active in developing and introducing new telephone products ever since the Japanese telephone market was opened up by the Japanese Government. For example, the cordless telephone market has experienced rapid growth. Cordless telephones are now used mostly in the home. There are plans in place to extend their use well beyond the home.

As to portable telephones, there has been intense competition to achieve smaller size, lower power consumption, and lower prices. The most recent development model weighs only 200 grams and is 150 cc in size.
A digital wave of digitalization is beginning to wash into this field as well. At the outset, we can expect to see digitalization introduced in the car phone systems during 1991. NTT plans to introduce a "micro-cellular" portable telephone system in 1995 which will cover the entire country with service zones or "micro-cells" of electromagnetic waves.

This digital "micro-cellular" system will allow for a telephone unit for each individual or a system in which anyone can speak with any other person anywhere anytime. In order to increase the number of channels, the frequency used will range from 800 MHz to 1.5 GHz.

In the future, society will be closely interconnected by information communications networks just like a huge organism in which each cell is interconnected by a central nerve system.

4.3 Multimedia

Since the introduction of "Audio CD" several years ago, various new types of optical disc equipment, such as CD-ROM, CD-I, CDV, and DVI, have been developed. CD-ROM and DVI operate in tandem with computers, whereas CD-I works in the same manner as a conventional phonograph.

All of this equipment contains multiple display media, such as video, graphics, text, and/or data, in addition to audio, and is interactive by nature. Fig. 10 is designed to make the point that audio and video can be seen as representing emotional, or "right brain", media, while graphics, text, and data represent logical, or "left brain" media. This suggests that electronics has begun to have greater affinity with the human beings.

![AV & CC](image)

In addition to entering via optical disc media equipment, information will be transmitted into the home via various other means, such as cable TV, terrestrial and satellite broadcasting, and communication networks.

The combining of multiple display media with various means of transmission will soon give rise to an advanced information age in which people will be able to do almost all of their shopping, banking, work, learning, and even receive medical care from the home.

Fig. 11 shows the core multimedia technologies. In the future, multimedia products will probably possess multi-window capability and will require a higher resolution display as large as 2,000 x 2,000 pixels, etc. In order to achieve real-time processing, a 10-bit A/D converter with 100 Msps of sampling frequency and a CPU with 100 MIPS of performance will be needed.

One of the most important current problems associated with the multimedia field is the absence of a large body of attractive software. Of course, this is a sort of chicken and egg problem since software engineers argue that it is the limited penetration of multimedia hardware which is hindering the development of new and appropriate software.

Thus, we can expect it to take a fairly long time before CD-I will be able to thrive in the market. As a stopgap measure, we shall see the emergence of "CD-I Ready" which has only a limited interactive nature and merely adds still pictures to music, and "Electronic Books" which store book and periodical text in 8 cm mini discs. As we can see, the multimedia business is still in the "trial and error" stage.

Another significant obstacle revolves around image compression technology. Moving pictures require a much larger storage capacity and/or a transmission rate which is about 3 powers of 10 greater than that for speech. Thus, it is necessary to achieve highly efficient compression. For this reason, the recommendations with respect to compression of the MPEG (Moving Picture Expert Group) are under active discussion in Japan.

At present, there are two key groups of technology which are essential to the development of successful HE products: 1) technologies which allow for smaller size and lighter weight, and 2) digital technology. These two groups of technology will be discussed using the camcorder and digital VCR as primary examples.

5.1 Smaller Size and Lighter Weight

As we all know, competition in the HE equipment field is quite intense, especially in the area of portable electronic products, and a great deal of this competition revolves around the achievement of smaller size and lighter weight.

Fig. 12 depicts the reduction in price, weight, and power consumption for camcorders from about 1983 to the present.
Without question, the higher integration brought about by advances in VLSI technology has played an essential role in increasing the performance, and expanding the functions, of electronic equipment without adding to cost. Fig. 13 provides our projection for progress in VLSI performance during the coming decade and a half. As you can see, we estimate that, by the beginning of the next century, VLSI memory capacity will have reached 256M bits, which is equivalent to the amount of information in an average encyclopedia, and microprocessor performance will reach 1,000 MIPS, which is equivalent to that of a current supercomputer.

As a result of this phenomenal progress in the area of semiconductor devices, the home electronics market can be expected to continue to grow to almost unlimited heights. Fig. 14 illustrates the progress which has been made over time with regard to the solid state CCD imager in terms of the number of pixels as a function of the optical system format. At present, the state of the art imager is a 1/2 inch imager but we are gradually seeing a shift towards a 1/3 inch imager without any sacrifice of resolution, sensitivity, or dynamic range.

The processing technology required for a CCD imager is no less complex than that required for memory, because the CCD imager is an analog device while memory is digital. In addition, a CCD imager requires pattern definition just as fine as that required for memory.

In parallel with highly integrated silicon chips, we must not forget about the importance of high density packaging technologies. In camcorders, VLSI devices are packaged in TSOPs (thin small outline package) of 0.3 mm of lead pitch which are mounted on 4-layer wiring PC boards of only 0.3 mm in thickness by means of surface mount technology.

As the pin count increases and device size is reduced, the lead pitches will be narrowed to as little as 0.1 mm or less, and tape automated bonding technology using film barriers will be employed instead. The most recent development efforts have yielded a lead pitch of from 50 micron meters down to 10 micron meters. [4], [5] For even finer dimensions, a multichip module technology using a silicon substrate will have to be employed.

Another factor which must be considered is the size and weight of the battery. One effective solution to the battery problem would be to reduce power consumption by lowering the supply voltage of equipment.

However, a reduction in the power supply leads to a decrease in the speed of VLSI circuits. VLSI speed is roughly proportional to the square of supply voltage value. In order to compensate for a decrease in speed, it is necessary to scale down the dimensions of the device since speed is inversely proportional to the root of scaling factor K.

In other words, as with computers, HE products will be deeply dependent upon state of the art VLSI devices.

5.2 Digital Technology

Digital technology will soon be applied to video equipment in place of traditional analog technology. CD (Compact Disc) is a typical example of digital technology being applied to audio equipment. It realizes the ultimate in fidelity and compaction of the recording disc and, in just the past few years, has overtaken analog recordings which had a history of over 100 years.

This same transition is going to occur in the video world. Digital VCRs possess high picture quality and can maintain it even after several dubbings. Moreover, new image compression technology allows for a high level of compaction of the recording medium.

Fig. 15 shows the relationship between the SNR (Signal to Noise Ratio) and tape consumption for analog and digital VCRs. In order to improve its SNR, an analog VCR must greatly expand its recording-signal bandwidth and thereby consume an extremely large amount of tape. This is because the signal bandwidth must be doubled in order to achieve an increase in the SNR of 3dB. In contrast to this, a digital VCR can attain a high SNR for high picture quality easily and without paying the penalty of large tape consumption. This is due to the fact that the SNR of a digital VCR is determined by resolution bits. An increase in resolution bits does not significantly affect total tape consumption. For example, a 6dB improvement in the SNR of a digital VCR can be achieved with only a one bit increase in resolution.
However, one serious drawback associated with "primitive" digital recording technology is that it requires roughly ten times wider signal bandwidth than that which is required for analog recording. Fortunately, this drawback has been overcome by recent advances in digital technology. Digital error correction allows for higher recording density and digital image compression allows for higher information density in a narrow signal bandwidth.

There are several methods for obtaining image compression. DCT (Discrete Cosine Transform) is one promising compression method which is based upon the transformation of pixel intensity to coefficients of spatial frequency. [6] The spatial frequency spectrum of a normal picture is concentrated in low frequencies where human sensitivity is the highest. Thus, image compression can be achieved via various quantization processes wherein the coefficients of the spatial frequency are quantized more coarsely with higher frequencies. In addition, DCT is capable of high quality image compression, which requires high speed operations and which, until recently, was considered to be too difficult to achieve in the area of consumer products. However, ULSI technology will soon solve this problem.

Fig. 16 shows the basic configuration of a digital VCR. During the recording process, visual signals are converted into analog electric signals by the CCD device and these analog signals are then converted into digital signals by the ADC. The image compressor compresses all visual information and the compressed signals are recorded by the magnetic recording device, along with the error-correction signals, after passing through the channel-encoder. In the playback process, this recording process is simply reversed.

Digital VCRs require 10M bit memory and 150K gate logic LSIs which operate at a clock rate of 20MHz. Of course, the manufacture of such LSIs is within the scope of current LSI technology.

In order to realize a consumer-use digital camcorder, however, further efforts have to be made to develop similar LSIs which also contain CCD, A/D and D/A converters, and other analog components, with a power dissipation of 2.3W which is smaller than that of current development models by a factor of 10.

Some Japanese manufacturers have announced development models of consumer-use digital VCRs. Their technologies used in image compression and error correction coding are different from one another. It will take a few years before such products will come into the market because standardization is not yet established.

The technological strategy in image compression and error correction coding will be different, depending upon whether the equipment is a recording and playback device such as VCR, or a playback-only device such as CD-ROM, CD-I or DVD. It should be noted that in the former case the costs of recording and playback processings should be in balance, while in the latter case the cost of playback processing is to be as low as possible compared to that of recording process.

6. CONCLUSION

In concluding, let us summarize the key points of this discussion:

1) Home electronics products are currently heading in the direction of personalization, networking, and multimedia.
2) Computers and communications equipment will increasingly be integrated with traditional AV equipment and home appliances.
3) Many electronic products will require more sophisticated and diversified technologies in order to penetrate the home market to any significant extent.
4) At present, to be successful, home electronics products must be small in size, lightweight, low-priced, and adopt all image compression.

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