Milestone-Proposal:Vacuum Fluorescent Display, 1967

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Docket #:2024-26

This proposal has been submitted for review.

To the proposer's knowledge, is this achievement subject to litigation? No

Is the achievement you are proposing more than 25 years old? Yes

Is the achievement you are proposing within IEEE's designated fields as defined by IEEE Bylaw I-104.11, namely: Engineering, Computer Sciences and Information Technology, Physical Sciences, Biological and Medical Sciences, Mathematics, Technical Communications, Education, Management, and Law and Policy. Yes

Did the achievement provide a meaningful benefit for humanity? Yes

Was it of at least regional importance? Yes

Has an IEEE Organizational Unit agreed to pay for the milestone plaque(s)? Yes

Has the IEEE Section(s) in which the plaque(s) will be located agreed to arrange the dedication ceremony? Yes

Has the IEEE Section in which the milestone is located agreed to take responsibility for the plaque after it is dedicated? Yes

Has the owner of the site agreed to have it designated as an IEEE Milestone? Yes

Year or range of years in which the achievement occurred:

1967

Title of the proposed milestone:

Vacuum Fluorescent Displays (VFDs), 1967

Plaque citation summarizing the achievement and its significance: ***Text absolutely limited by plaque dimensions to 70 words; 60 is preferable for aesthetic reasons.***

Vacuum Fluorescent Displays (VFDs) were first commercialized in 1967 by Tadashi Nakamura, founder of Ise Electronics Corp. These revolutionized the calculator industry by replacing the large, expensive, and high-voltage Nixie tubes then used for character display. By 1972, VFDs could display various symbols and numbers in a flat panel format. Their exceptional visibility and durability made them popular in home appliances, automobiles, industrial equipment, and consumer electronics through the 1990s.

200-250 word abstract describing the significance of the technical achievement being proposed, the person(s) involved, historical context, humanitarian and social impact, as well as any possible controversies the advocate might need to review.

The Vacuum Fluorescent Display, commercialized by Dr. Tadashi Nakamura in 1967, revolutionized the calculator industry and had a profound impact on various sectors such as home appliances, automobiles, and industrial equipment. Dr. Nakamura, founder of Ise Electronics Corp., developed VFDs as a low-cost, low-voltage solution to replace Nixie tubes. The technological innovation of VFDs offered exceptional visibility and durability, making them popular in numerous applications.

The historical context includes the calculator boom of the 1960s and 1970s, where VFDs were critical in the "calculator wars." By the early 1980s, VFDs were produced in vast quantities to meet the demands of various industries. Dr. Nakamura's collaboration with academic institutions and other corporations, such as the Noritake Group, underscores "Frontier spirits" and "cooperative" in technological advancement.

Dr. Nakamura focused on the necessity of producing more efficient and reliable display technology at a lower cost and operating at a low voltage. However, there are several technical issues, and one of them is solved by viewing the display upside down like the "Egg of Columbus". This inspiration led to the creation of the VFD, not only replacing the older Nixie tubes but also opening up new possibilities for various technological applications. The enduring legacy of VFDs lies in their continued production and relevance, even more than half a century after their development.

IEEE technical societies and technical councils within whose fields of interest the Milestone proposal resides.

IEEE Consumer Technology Society

In what IEEE section(s) does it reside?

IEEE Nagoya Section

Contents

IEEE Organizational Unit(s) which have agreed to sponsor the Milestone:

IEEE Organizational Unit(s) paying for milestone plaque(s):

Unit: IEEE Nagoya Section
Senior Officer Name: Jun Sato

IEEE Organizational Unit(s) arranging the dedication ceremony:

Unit: IEEE Nagoya Section
Senior Officer Name: Jun Sato

IEEE section(s) monitoring the plaque(s):

IEEE Section: IEEE Nagoya Section
IEEE Section Chair name: Jun Sato

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Please note: your email address and contact information will be masked on the website for privacy reasons. Only IEEE History Center Staff will be able to view the email address.

Street address(es) and GPS coordinates in *decimal form* of the intended milestone plaque site(s):

670-5 Uchimi, Taiki-cho, Watarai-gun, Mie 519-2736 JAPAN, GPS coordinates: N 34.410162, E 136.470089

Describe briefly the intended site(s) of the milestone plaque(s). The intended site(s) must have a direct connection with the achievement (e.g. where developed, invented, tested, demonstrated, installed, or operated, etc.). A museum where a device or example of the technology is displayed, or the university where the inventor studied, are not, in themselves, sufficient connection for a milestone plaque.

Please give the address(es) of the plaque site(s) (GPS coordinates if you have them). Also please give the details of the mounting, i.e. on the outside of the building, in the ground floor entrance hall, on a plinth on the grounds, etc. If visitors to the plaque site will need to go through security, or make an appointment, please give the contact information visitors will need.
Noritake Itron Corporation headquarters. Corporate building.

Are the original buildings extant?

No, Since the original building from when Ise Electronics Corp. was founded has already been demolished and no longer exists, the milestone plaque will be placed in the existing head office building. This head office building was constructed in 1969 for the mass production of VFDs and the adjacent building is still the only factory in Japan that manufactures VFDs.

Details of the plaque mounting:

In the ground floor entrance hall of main building.

How is the site protected/secured, and in what ways is it accessible to the public?

The entrance hall is monitored by a security system 24/7. Visitors can come to the entrance hall without security check.

Who is the present owner of the site(s)?

Kazuhiro Shinohara, President of Noritake Itron Corporation.

What is the historical significance of the work (its technological, scientific, or social importance)? If personal names are included in citation, include justification here. (see section 6 of Milestone Guidelines)

Justification of Name in Citation

Dr. Tadashi Nakamura, the founder of Ise Electronics Corp., was born in Ise City in 1923 and studied electronic engineering at Nagoya Higher Technical School, the predecessor of Nagoya Institute of Technology. He joined Kawanishi Machine Manufacturing (later Kobe Industry) and was involved in the research of phototubes and cathode-ray tubes.

After World War II, Dr. Nakamura successfully developed ultra-high frequency cathode-ray tubes at the same company, gaining international recognition. Despite his achievements in the technical field, the merger with Fujitsu threatened to close off his research paths, and the termination of other projects reinforced his determination to establish his own company to develop and bring his technologies to market.

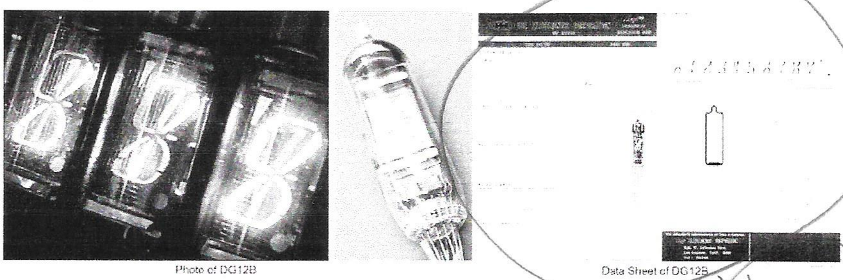

Figure 1 DG12B, the First Commercialized Vacuum Fluorescent Display

At the time when Dr. Nakamura decided to start his own company, the electronic industry in Japan was on the verge of a calculator boom. In 1959, Sharp Corporation and Canon Inc. introduced electronic desktop calculators to the market, but the early calculators were expensive, large, and used Nixie tubes for character display, which operated at high voltage and had visibility issues, Moreover, high patent fees posed a cost-cutting obstacle for Japanese manufacturers.
His former boss at Kobe Industry and in charge of calculator development at Sharp Corporation, suggested and encouraged him to develop a low-cost, low-voltage display tube. Dr. Nakamura, focusing on the luminescence of zinc oxide phosphor at low voltage, decided to pursue the development of display tubes for calculators.
Dr. Nakamura founded Ise Electronics Corp. in 1966, aiming to contribute to local development as well.
The earliest VFDs were based on the idea of combining single-digit CRTs and triode vacuum tubes. At the time, CRTs required voltages of several hundred volts to excite the phosphor.
He knew that zinc oxide phosphor could luminesce at even lower voltages. Furthermore, he knew from experience that viewing the luminescence directly from the side where the electrons hit the phosphor was brighter than viewing the luminescence through the phosphor layer as with CRTs. This led to the "Columbus' egg" idea of a display tube that could be viewed directly through the cathode side, the opposite of a CRT [P1].
He succeeded to make the prototype of Vacuum Fluorescent Display (VFD) in 1966 [O1], then he commercialized the first VFD by starting the mass production of DG12B shown in Figure 1 and some other VFDs in 1967 [M1],[N1],[N2].

The successful development of fluorescent display tubes at the time of establishment involved many technical experts and researchers from academia working together. The network of connections and vacuum tube technology knowledge cultivated at Kobe Industry played a significant role. The gathering of engineers from Kobe Industry, transcending organizational boundaries, led to the technological innovation of fluorescent display tubes. After the company's founding, Nakamura, the company president, stayed at the factory, and all employees worked tirelessly on research and development. As a result, they completed the prototype of the fluorescent display tube in just two months.

Pursuing the founding principle of "cultivating world-class technology through creativity and development" was also a notable feature.

This involved gathering personnel at the Central Research Laboratories during the venture stage and forming a network of joint research with universities and domestic and international partners. Nakamura's collaboration with academic institutions and other corporations, such as the Noritake Group, underscores "Frontier spirits" and "cooperative" in technological advancement.
Nakamura continued to dedicate his life to the development of the electronics industry as both a researcher and a technician, striving to sustain and grow his company [N3].

In recognition of these achievements, Nakamura was awarded the Society for Information Display (SID) Award twice, in 1979 and 1991 [A1], [A2].

Historical Significance

Background

In mid-1960s, the patent fees for Nixie tubes invented overseas were high, and light-emitting diodes (LEDs) were only commercialized as very expensive point-source indicators, with numerical display devices not yet completed.
Therefore, VFDs were adopted and technological advances were made to serve as calculator displays during the calculator wars from the late 1960s to the 1970s. At that time, most displays in household appliances showing lines of characters or numbers in blue-green colors were VFDs rather than LCDs.

VFD Structure and Operation

Overview

In 1966, Tadashi Nakamura established the Ise Electronics Corp. (now Noritake Itron Corp.), and the Vacuum Fluorescent Display (VFD) was invented by him in 1967 [M1],[N1],[N2].
Initially, VFDs were round glass tubes displaying single digits. The first mass-produced VFD by Ise Electronics, the DG12B, was installed in Sharp's CS-16A, the world's first MOS-IC calculator [O2],[O3]. VFDs were also used in the "Casio Mini", known as the world's first personal calculator [O4], which displayed single digits. Subsequently, multi-digit VFDs in a single vacuum tube were developed for cost reduction.
By 1972, flat panel VFDs capable of displaying multiple numbers and symbols were developed, expanding their applications [1].

Key characteristics of VFDs as devices are:

- Self-emissive with high brightness.
- Low operating voltage, directly drivable by LSI, with low power consumption.
- Easy multi-color display due to special phosphors.
- Flexible display patterns.
- Excellent heat and moisture resistance, suitable for various operating environments from high temperatures to extremely low temperatures.

VFD Structure

A VFD is a triode electron tube with a directly heated oxide cathode, a grid, and an anode that emits light, housed in a vacuum container with at least one transparent side shown in Figure 2.
The cathode, a tungsten core wire coated with ternary oxides of Ba, Sr, and Ca, is thin enough not to obstruct the display. The grid, made from a stainless steel thin plate processed into a mesh using photoetching, also does not obstruct the display. The anode, coated with phosphor on a conductor shaped into the desired display pattern, emits light when excited by electrons at low voltage.
As a vacuum tube, the main part of the enclosure is made of glass, similar to other vacuum tubes. By directing electrons from the cathode to the phosphor, the VFD is used as a display device for calculators and household electronic devices.

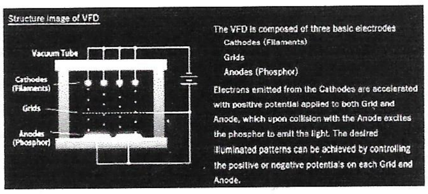

Figure 2 VFD Structure

A similar technology is the cathode-ray tube (CRT), but it differs significantly in structure, such as using magnetic fields to deflect the beam of electrons emitted from an electron gun.

VFD Operating Principle

The cathode, made of tungsten wire coated with alkali metal oxides, emits thermal electrons when heated by an electric current. The grid, a metal mesh, accelerates and spreads electrons from the cathode to the anode by applying a positive voltage or blocks electrons from reaching the anode by applying a negative voltage to erase the display. The anode, coated with phosphor on a patterned conductor, emits light when electrons passed through the grid collide with and excite the phosphor when a positive voltage is applied.
Observing the luminescence from the side where the electrons hit the phosphor makes it brighter than viewing the luminescence through the phosphor layer as with CRTs.

VFD Applications

Overview

VFDs were widely used from the 1980s to the 1990s due to their excellent visibility and durability. They were widely used as display devices in home electronics such as TVs, audio equipment, video decks, and kitchen appliances.
VFDs were adopted in many consumer products due to their relatively low development and manufacturing costs, promoting widespread use. They were also extensively used in industrial equipment, measuring instruments, and medical devices, contributing to increased work efficiency. Bright and clear displays provided accurate information to operators and technicians, improving work precision and safety.
High-density dot matrix VFDs capable of displaying Kanji characters and bitmap images were used in POS registers for displaying item names and change, VTR/VCRs, clocks, 7-segment displays, and custom-designed displays for each device, requiring easy-to-read characters and long display life.

Alphabet and Katakana Display

Initially developed as numeric display elements for calculators, the practical application of flat glass multi-digit tubes allowed the creation of arbitrary display patterns, leading to the development of 14-segment numeric and alphabetic display tubes and 5x7 dot character display tubes shown in Figure 3.
Due to the increased wiring density in the case of multi-line dot character displays, internal wiring using thick film became difficult. To address this, in 1978, Ise Electronics established a technology for wiring using photoetched aluminum thin films [2].

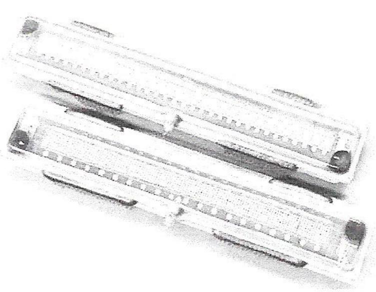

Figure 3 32 Digits 14-Segment VFD and 20 Digits 5x7 Dot Character VFD

Automotive Meters

In the 1980s, this display device was particularly used by automakers for digital meters such as speedometers in onboard equipment, due to its bright, easy-to-read display and wide operating temperature range.
Examples include those installed in high-end Subaru cars in the early 1980s, dubbed "Digi-dash" or "digital dashboards" by Subaru enthusiasts. The bright display made it suitable for electronic displays in automobiles. Until full-color LCDs replaced them, VFDs were used in the meter displays of the Toyota Prius series.

Game Machines

VFDs were also used in electronic game machines (early handheld game machines) from 1979 to the mid-1980s, due to its colorful, bright and clear visibility. These game machines featured bright, clear displays, but since the size of the VFDs manufactured at that time was quite small, Fresnel lenses were used for magnification.
Early game machines achieved multi-color displays by passing the light emitted from the phosphor (typically green) through transparent color films. Subsequently, low-speed excitation phosphors were developed, and game machines were equipped with sophisticated multi-color displays.

Graphic Display

Initially, VFDs developed for displaying numbers, letters, and symbols evolved to meet the demands of the time, allowing the free display of graphics and Kanji with full-dot displays starting around 1977 shown in Figure 4. Initially, these were 20x20 dots with a 4mm pitch, but by 1981, high-density, large-capacity displays capable of displaying 128x128 dots with a 0.4mm pitch TV video image were developed [3],[6].
Early graphic VFDs were passively driven, requiring the number of leads to be at least equal to the number of horizontal plus vertical dots, making the assembly and installation of drive circuits challenging. In 1986, VFDs with built-in drivers were developed, reducing the number of terminals to about 20 for large-capacity displays, leading to wider adoption of graphic display tubes.

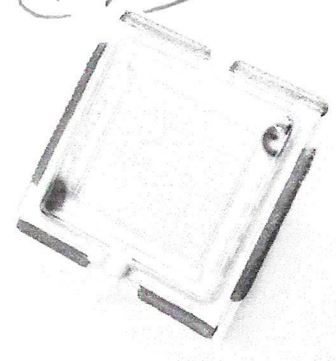

Figure 4 Early 41x40 Dots Graphic VFD

Ultra-Small Image Display

Achieving high-definition displays with dot sizes of about 0.1mm or less with VFDs was nearly impossible with the extension of the structures used for graphic display VFDs.
Applying semiconductor microfabrication technology, an early active matrix fluorescent display tube was announced in 1980, formed by depositing phosphor on switching elements on a silicon chip [4],[P4].
Subsequently, an ultra-small image display tube with 172x108 pixels within an 8x6mm screen was developed in 1983 for use as a viewfinder in video cameras shown in Figure 5 [5].
Although the ultra-small image display tube did not become widely popular due to cost and size issues, the technology of incorporating silicon chips within display tubes significantly contributed to the development of VFDs with built-in drivers.

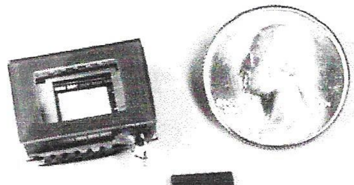

Figure 5 VFD for Camcorder Viewfinder

Digital Signage

VFDs were also used in the development of digital signage and electronic billboards, utilizing their bright and attractive display characteristics. Notably, VFDs were highly valued and utilized in commercial facilities' spatial design, enhancing the aesthetics beyond merely conveying information.
Examples include the use of VFDs for internal guide panels at the Sumida Aquarium shown in Figure 6 and digital signage in Izu Kyuko 8000 series trains.

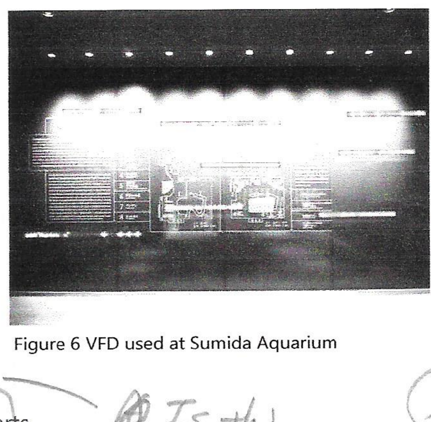

Figure 6 VFD used at Sumida Aquarium

Large Displays

In 1982, Mitsubishi Electric began developing a high-resolution, close-range Aurora Vision using VFDs. However, insufficient merging of light-guide emission elements resulted in image quality issues. The VFD display devices lacked sufficient brightness and longevity, with brightness rapidly decreasing under high brightness due to heat generation.

In response, Mitsubishi Electric began developing a new light-emitting element using VFD manufacturing technology and CRT principles in 1985. By developing the FMCRT, the indoor Aurora Vision Mark II with a brightness of 1,300 cd/m2 was commercialized in June 1986 [7]. Sony Corporation exhibited the JumboTron at the 1985 International Science and Technology Exposition (popularly known as the Science Expo). This ultra-large display device, measuring 40m x 25m, utilized phosphor emission elements made by Futaba for its Trinilite light-emitting elements containing red, blue, and green emission parts.

Industrial Impact of VFDs

As mentioned earlier, the calculator industry, which used problematic Nixie tubes, paid attention to low-voltage fluorescent display tubes. When Sharp released the CS-16A calculator [O1],[O2] with the first installed VFD in December 1967 and after that, many calculator manufacturers proliferated, leading to price smashes and the start of a period known as the "Calculator Wars".

Consequently, Ise Electronics Corp. alone could not meet the demand, so they licensed patents to NEC and signed production consignment agreements with Futaba to handle the rapidly increasing domestic and international demand [N3]. By the mid-1970s, the total annual production of VFDs reached 40 million units.

Subsequently, changes in the calculator industry and the emergence of LEDs and LCDs led VFDs to seek new markets and continue developing new products. As a result, VFDs found applications in clocks, automobiles, information devices, and other new markets, reaching an annual production volume of 90 million units in the early 1980s.

What obstacles (technical, political, geographic) needed to be overcome?

Overcoming Obstacles

VFDs were developed as low-cost, low-voltage numeric display devices for miniaturized and low-priced calculators. Technological innovations in VFDs were carried out in three stages [1],[2],[3],[4],[5],[6], with challenges and solutions at each stage summarized as follows:

Single-Digit Tube Development in 1967

The earliest VFDs were based on the idea of combining single-digit CRTs and triode vacuum tubes. At the time, CRTs required voltages of several hundred volts to excite the phosphor.

Dr. Nakamura knew that zinc oxide phosphor could luminesce at even lower voltages. Furthermore, he knew from experience that viewing the luminescence directly from the side where the electrons hit the phosphor was brighter than viewing the luminescence through the phosphor layer as with CRTs. This led to the "Columbus' egg" idea of a display tube that could be viewed directly through the cathode side, the opposite of a CRT [P1].

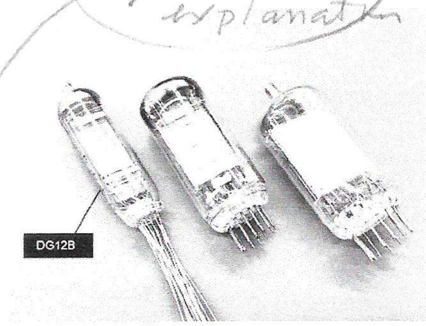

Figure 7 Single-Digit Tubes in 1967

Practical implementation required extremely fine cathode wires that did not obstruct the view and highly efficient phosphors. With the cooperation of many technical experts and researchers from academia, electrode structures and phosphor formation methods were established and single-digit tubes were developped in 1967 shown in Figure 7. This development was announced in the Electronics magazine May 1967 issue [M1], followed by coverage in Japanese industry newspapers [N1],[N2],[N3].
The potential of VFDs was recognized, and production began in September of the same year.

- Lowering the cathode emission voltage: Adoption of zinc oxide phosphor instead of conventional CRT phosphors.
- Increasing brightness: Direct viewing of cathode-side luminescence instead of through the phosphor layer.
- Preventing the cathode from obstructing the view: Development of fine cathode wires by Japan Electronic Materials.
- Improving phosphor efficiency: Development cooperation with Dai Nippon Toryo and guidance from Professor Takagi at Shizuoka University Faculty of Engineering.
- Revising electrode structures: Switching from two-electrode to three-electrode tubes for higher brightness.

Multi-Digit Tube Development in 1971

When using single-digit tubes in calculators, it was necessary to arrange several to twelve tubes, resulting in assembly work, brightness variations, and alignment inconsistencies. To address these issues, Ise Electronics Corp. developed and commercialized a multi-digit metal tube with a flat glass window in 1971 shown in Figure 8 [P2].

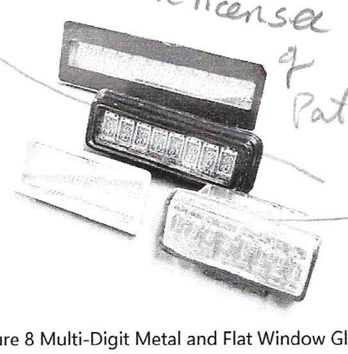

Figure 8 Multi-Digit Metal and Flat Window Glass Tube

By encapsulating multiple digits in a single vacuum tube, the device became cheaper, and assembly work was significantly reduced shown in Figure 9.

NEC, Toshiba, and Futaba also developed multi-digit tubes with multiple elements enclosed in a round glass tube. By 1972, each company shifted to 12mm round glass multi-digit tubes for handheld calculators.

- Assembly work for using many single-digit tubes: Development of multi-digit tubes with flat glass and metal enclosures.
- Inconsistent display performance among single-digit tubes: Minimally noticeable variations by using a single vacuum tube.

Flat Panel Development in 1972

Traditional VFDs used ceramic substrates, which accounted for about 50% of material costs and were a major obstacle to cost reduction. Additionally, large ceramic substrates had issues with warping and dimensional accuracy. To address these problems, the switch from ceramic to glass substrates was attempted [P3]. Despite challenges such as low electron emission from the cathode and low phosphor luminescence efficiency, these were overcome by 1972, and mass production began.
As a result, VFDs became flat panels with glass substrates as part of the enclosure, improving space factor shown in Figure 10.

- Cost reduction: Switching from ceramic to cheaper glass substrates.
- Warping and dimensional accuracy of large substrates: Ensuring flatness and dimensional accuracy with low-temperature-fired glass substrates.
- Low electron emission from the cathode: Solved by improving paste materials and optimizing firing conditions.
- Low phosphor luminescence efficiency: Solved by improving paste materials and optimizing firing conditions.
- Mass production challenges: Introducing new dedicated equipment due to different production processes from conventional products.

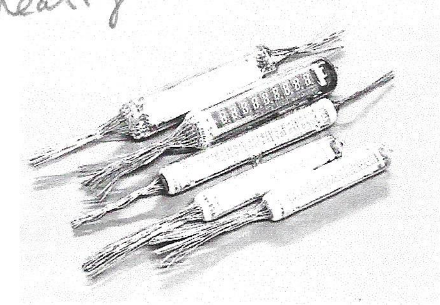
Figure 9 Multi-Digit Single Glass Tube

What features set this work apart from similar achievements?

Features Setting This Work Apart from Similar Achievements

VFD that can be driven at a lower voltage than Nixie Tube

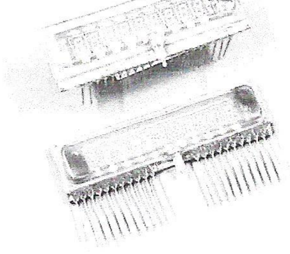
Figure 10 Early Flat Glass Panel VFDs

Before the development of VFDs, calculators used Burroughs's Nixie tubes, which operated on the principle of gas discharge. Nixie tubes required driving voltages of around 200V, making IC driving difficult. Moreover, the numeric display method, which involved stacking metal electrodes, was time-consuming and not flat, resulting in poor visibility.
Additionally, high royalties were a significant issue. Consequently, calculator manufacturers in Japan eagerly sought the development of domestically-produced display tubes that were low-cost, low-voltage, and offered superior display characteristics. VFDs, developed to meet these demands, overcame Nixie tube shortcomings and were widely adopted in the calculator industry.

VFD that is cheaper than Light Emitting Diode

A light emitting diode (LEDs) is a type of diode that emits light when a voltage is applied in the forward direction. The red LEDs was invented by Nick Holonyak in 1962. However, at the time of the development of the fluorescent display tube, commercial LEDs were extremely expensive and limited to indicator point light sources of infrared and red LEDs.
It wasn't until the late 1960s to early 1970s, when computers and watches started using LEDs displays, that LEDs became a significant business. Monsanto introduced the first commercial numeric display, the MAN-1A. HP and other companies also entered the numeric display market, leading to cost competition and a market share battle with fluorescent display tubes. Fluorescent display tubes maintained their market by advancing multi-digit displays and reducing costs.

Self-illuminating VFD that is brighter than reflective Liquid Crystal Display

Liquid crystals are optical materials that possess both liquid and solid properties, and liquid crystal displays (LCDs) utilize the reorientation of liquid crystal molecules under voltage to modulate display images.

The existence of liquid crystals was discovered by Reinitzer in 1888. In 1968, RCA in the United States developed a liquid crystal display device (cholesteric liquid crystal) that becomes opaque when a voltage is applied, scattering incident light; however, it did not reach commercialization.

In 1973, Sharp Corporation adopted LCDs technology for the display of its EL-805 calculator, which used CMOS-LSI technology allowing battery operation.

Following this, LCDs became widely adopted for calculator displays, significantly reducing the use of fluorescent display tubes. However, LCDs of the 1960s to 1970s had several challenges:

- As "reflective" displays, they had poor contrast in low-light conditions.
- Their reliance on polarization limited the viewing angles.
- Low temperatures could cause dimming and slow response times.

In contrast, VFDs, being self-luminous, offered bright and clear displays, and their robustness in various temperature environments made them suitable for industrial and automotive applications.

Multi-color display devices

When LEDs were first developed, they were available only in single-color, either infrared or red. The high-brightness blue LEDs, using gallium nitride and mass-produced today for backlighting and illumination purposes, became practical in 1993. Consequently, LEDs at that time were not full-color.

LCDs were also monochrome displays during the 1960s and 1970s. The development of color LCDs technologies began with a paper on color filter methods for LCDs published by Professor Uchida of Tohoku University in 1981.

Japanese companies adopted this method and advanced the collaborative development between industry and academia, leading to practical applications and progress in color displays.

Initially, VFDs displayed only a single blue-green color. However, as their applications expanded, there was an increasing demand for multicolor displays. While there were many phosphors that could be excited by high-speed electron beams like in CRTs, phosphors other than green zinc oxide scarcely emitted light below 100V.

(8)

Research on phosphors that could emit light when excited by low-speed electron beams began around 1975 at NHK's Science & Technical Research Laboratories, but their lifespan and luminous efficiency were insufficient. Improvements led to the practical application of two-color VFDs displaying green and orange by Futaba and Ise Electronics Corp. in 1978. This advancement preceded LEDs and LCDs in colorization, significantly enhancing display capabilities. Subsequently, phosphors for various colors were developed and commercialized, allowing for mass production of multicolor VFDs.

VFD developed in Japan and still evolving today

While the basic technologies for major displays such as LCDs, plasma displays, LEDs, OLEDs, and CRTs were mostly developed in Europe and the United States, the fundamental principles of VFDs were uniquely developed in Japan. At the time of development, considering the trends of other display devices, the product lifespan of a VFD was initially thought to be about ten years.

However, to meet customer demands, VFDs evolved from single-digit displays to multi-digit displays and flat panel formats capable of showing multiple numbers and symbols. This evolution was driven by unique ideas and technological innovations.

Moreover, leveraging their bright and easily visible characteristics and high reliability, new markets were continuously pioneered. As a result, even more than half a century after their development, VFDs are still being produced today.

Where are they used today?

Fig 6

Why was the achievement successful and impactful?

Compared to Nixie tubes, which were the most commonly used numeric display tubes at the time, VFDs had features such as a low operating voltage and low power consumption, which meant they could be driven directly by ICs, and they were self-illuminating, bright, easy to see, and had a long lifespan.
These features, and the fact that they did not infringe on the Burroughs patent, led to the success of VFDs, as they were able to meet the demand for electronic desktop calculators, which were experiencing rapid growth at the time. (8)
VFDs were also easier to see than reflective liquid crystal display (LCDs), and had evolved to allow multi-digit displays, flat display tubes, alphabet and graphic displays, complex shape displays, and multi-color displays, as well as a wide operating temperature range and long lifespan, so they were used in a variety of applications that were difficult for reflective LCDs and ight emitting diode (LEDs) at the time.

Supporting texts and citations to establish the dates, location, and importance of the achievement: Minimum of five (5), but as many as needed to support the milestone, such as patents, contemporary newspaper articles, journal articles, or chapters in scholarly books. 'Scholarly' is defined as peer-reviewed, with references, and published. **You must supply the texts or excerpts themselves, not just the references**. At least one of the references must be from a scholarly book or journal article. All supporting materials must be in English, or accompanied by an English translation.

References

Paper

[1] K. Kiyozumi et al.; "Flat Panel Multi-Digit Fluorescent Display", SID 1976 Int'l Symp, P130-131, 1976.
[2] K. Kasano et al.; "A 240-Character Vacuum Fluorescent Display and its Driving Ability", SID 1979 Int'l Symp, P58-59, 1979.
[3] M. Iwade et al.; "Vacuum Fluorescent Display for TV Video Images", SID 1981 Int'l Symp, P136-137, 1981.
[4] S. Uemura, K. Kiyozumi; "Flat VFD TV display incorporating MOSFET switching array", IEEE transactions on electron devices ED-28 No.6 P749-755 1981.
[5] S. Uemura et al.; "MOS-Addressed VFD Image Display on a Chip", Proceedings of 3rd International Display Research Conference, P238-241, Japan 1983.
[6] K. Kiyozumi, T. Nakamura; "Vacuum fluorescent displays: from single digits to colour TV Displays", Displays Volume 4, Issue 4, P213-220, October 1983.
[7] S. Iwata et. Al; "A large screen full color display for indoor use", Proceedings of 7th. International Display Research Conference, P196-199, London 1987.

Patent

[P1] PATENT 3508101 1970-04-21, Mikiharu Tanji, Character Indicating Electron Tube - VFD Basic Patent
[P2] PATENT 3723789 1973-03-27, Mikiharu Tanji, Flat Composite Fluorescent Display Tube
[P3] PATENT 3786295 1974-01-15, Heihachi Fujii, Anode Substrates for Multi-Digit Type Fluorescent Display Tubes
[P4] PATENT 4081716 1978-03-28, Sashiro Uemura, Fluorescent Display Elements

Magazine

[M1] Electronics. McGraw-Hill., ISSN:00135070, May 29, 1967, P.212-213

(8)

Short description of SID would be nice.

Society for Information Display (SID) Awards

[A1] Certificate of SID Special Recognition Award in 1979
[Remarks] In May, 1979, The Society for Information Display has presented the Special Recognition Award to Tadashi Nakamura for innovative contributions to Vacuum Fluorescent Displays.
Screenshot SID website SID Special Recognition Awards
Retrieved 25 October 2024: https://www.sid.org/Awards/Individual-Honors-and-Awards/Special-Recognition

[A2] Medal and Certificate of SID Karl Ferdinand Braun Prize in 1991
[Remarks] In May, 1991, The Society for Information Display has awarded the Karl Ferdinand Braun Prize for outstanding contributions to Display Technology to Tadashi Nakamura and Kentaro Kiyozumi for the invention and development of the Vacuum Fluorescent Display.
Screenshot of SID website KARL FERDINAND BRAUN AWARD
Retrieved 25 October 2024: https://www.sid.org/Awards/Individual-Honors-and-Awards/KARL-FERDINAND-BRAUN-AWARD

Short description of K. F. Braun Prize would be nice.

Newspaper

[N1] Dempa Shimbun Daily, July 21, 1967 Issue

[Remarks] This newspaper article has been licensed to use by Dempa Publications Inc. on October 24, 2024.
[Remarks] "Ise Electronics to soon mass-produce new type of numeric display tube "Digitron"
Jointly developed with Hayakawa, driving voltage only 25V
Ise Electronics (President Tadashi Nakamura), in collaboration with Hayakawa Electric, has succeeded in developing a new type of numeric display tube called "Digitron" that can be operated at low voltage, and will soon begin mass production. Digitron can be driven at low voltages from 10V to 25V, and can be driven directly by IC, so Hayakawa Electric will be using it in all MOS type IC electronic desk calculators that it will develop soon. Compared to conventional discharge type numeric display tubes, this Digitron is smaller and less expensive, and as for the problem of lifespan, it has already withstood a lifetime test of more than 3,000 hours, and it is said that Burroughs Corporation of the United States has already approached them about a technical partnership.
While so-called active elements such as vacuum tubes have shown rapid progress and development, numeric display tubes have seen little demand and have shown little progress so far. This has recently come into the spotlight due to the rapid growth of electronic desk calculators and the promotion of digitalization of various measuring instruments.
The most commonly used numeric display tube is the Nixie tube. This discharge type display tube is currently being researched by the most popular users, the desktop calculator manufacturers, mainly for two reasons: 1) the Burroughs patent issue has not yet been resolved, and 2) the driving voltage is high at over 100 V when used with ICs, making it suboptimal.
Canon uses bulbs other than Nixie tubes. The light-point display tubes used by the company have holes corresponding to the numbers drilled into the display plate inside the tube beforehand, and these are illuminated with a 6.3 V bulb. This method does not infringe on the Burroughs patent, but 1) the bulb's life is short, at about 3,000 hours (it is said that Nixie tubes have about 20,000 hours per element), and 2) although the voltage is low at 6.3 V, it requires a current of several tens of milliamperes, making it somewhat difficult to drive it as is with current ICs. Digitrons, on the other hand, have a structure as shown in the figure, and the obvious difference from conventional discharge tubes is that the directly heated cathode is located in front of the anode. This cathode is a direct current type, but it is heated at a low temperature and does not emit light itself, so it does not get in the way even if it is located in front of the characters. The heater voltage is 0.8V and the current is 90mA, but when 25V voltage is applied to the anode side, the heater current is only 7.7mA.
The current flowing through the tube - that is, the anode current - is about 0.7mA per character. Therefore, the power consumption is extremely small, and it can be driven directly by IC, so it is attracting attention as a future numeric display tube. The numbers are displayed as a combination of phosphorus-coated character pieces in a mosaic format. The display method is to pressurize the mesh grid to 25V, and only the necessary parts of the character pieces behind it are also pressurized to 25V, while the other character pieces are kept at 0V, and the space charge from the filament hits the pressurized parts with electrons, causing them to light up, as in the conventional method.
Another feature of phosphorus paint is that it can be made in various colors other than red. It is said to be bright enough. However, some people say that the mosaic format of the characters is a bit of a drawback, as it is not optimal for Japanese people. In the case of export, this method is easily accepted in Europe and the United States and there are few problems.
Digitron is attracting attention as one result of research into numeric display tubes, which began in earnest in anticipation of the huge demand for desktop calculators (an estimated 300,000 tubes were used in Japan last year), and it is quite likely that even newer, cheaper display methods will be developed in the future. Some people are beginning to say that at least Burroughs' patent for discharge-type numeric display tubes may soon become meaningless.

[N2] The Nikkan Kogyo Shimbun, July 17, 1967 Issue, P4
[Remarks] This newspaper article has been licensed to use by the Nikkan Kogyo Shimbun, Ltd. (Authorized No. N-24102401)
[Remarks] "Character display at about 25 volts"
"Ise Electronics develops "Digitron"
Ise Electronics (700 Wada, Ueno-cho, Ise City, Mie Prefecture, President: Nakamura Tadashi) has developed a new numeric display tube, "Digitron" for use in IC-based electronic calculators, with the cooperation of Hayakawa Electric and Nippon Electronic Materials. This is the first in the world to be able to display characters at a low voltage of about 25 volts. The company is planning to start mass production this fall, and it is expected to have a major impact on related industries when it is released.
"Digitron" has the following features: 1) a brightness of over 100 lux at a low voltage of 20 to 25 volts, 2) characters painted with green phosphor are displayed on the same plane, and 3) low power consumption. The low voltage is particularly noteworthy as it can be used immediately with IC-based desktop calculators.
Technically, the principle is that electrons emitted from a directly heated filament are accelerated by a grid and blink in response to the phosphor painted on the character display board and the input signal. The new feature is that the filament is now in front of the dial, which is a 180 degree turn from the previous version where it was at the rear, and the key point is that the filament is not visible even when the letters are displayed.
There are two ways to display the results of calculations on electronic desktop calculators: the light dot type and the vacuum tube type. The light dot type was developed by Canon, while other manufacturers use neon numeral display tubes patented by Burroughs in the United States. Digitron is a vacuum tube type like the neon numeral display tube, but it is said to have eliminated the drawbacks that have been cited up until now. It was successfully developed with the cooperation of Hayakawa Electric in the circuit area and Nippon Electronic Materials in the materials area, in order to be used in IC-based desktop calculators, which are expected to grow in the future. It is currently in the prototype stage, but there are plans to expand the factory to the headquarters factory in Ise City on a site of about 13,000 square meters this fall to mass-produce it, with a monthly production of 100,000 units planned from April next year.

[N3] The Nikkan Kogyo Shimbun, January 25, 1968 Issue, P14
[Remarks] This newspaper article has been licensed to use by the Nikkan Kogyo Shimbun, Ltd. (Authorized No. N-24102801)
[Remarks] "The Struggles of Creating the Top Ten New Products No.3
Ise Electronics "Digitron" fluorescent character display electron tube
Although low voltage and high brightness technologies have been overcome, problems remain in terms of "Life"
The "Digitron" fluorescent character display electron tube developed by Ise Electronics (Wada, Ueno-cho, Ise City, Mie Prefecture, President Tadashi Nakamura) has the major feature of being able to display green fluorescent characters with high brightness (about 800 lux) at low voltage (25 volts), and for this reason it is considered ideal as a numeric display tube for electronic desktop calculators that have been made into ICs (integrated circuits).
Among domestic computer manufacturers, Ise Electronics's Digitron Hayakawa Electric, which cooperated in the development, was one of the first to adopt it as the numeric display tube for its recently released electronic desktop calculator "Compet 16" and interest in the product is rapidly growing, with NEC entering into a technical partnership with Ise Electronics to begin production of Digitrons.
The Digitron is an ultra-high vacuum electron tube with a unique group of electrodes built into the glass tube. It works by accelerating the thermionic electrons emitted from the filament with a grid and striking an anode phosphor element, where this energy is converted into light and emitted as characters.
In addition to being low voltage and high brightness, it emits green light, so your eyes don't get tired. On the same plane It also has

features such as being easy to read and displaying characters, and Professor Eiji Sugata, Dean of the Faculty of Engineering at Osaka University, has praised it for its low voltage and high brightness, saying, "It is an electron tube that goes beyond conventional wisdom and will contribute greatly to the development of the electronics industry."

The company's president, Tadashi Nakamura, worked at the Kobe Industry headquarters until June 1966 in researching cathode ray tubes for televisions, and in May 1964 developed the single-gun color picture tube for transistor color televisions. The development of the Tesitron was initiated when Hayakawa Electric Industries commissioned the company to carry out research into "whether it is possible to create a low-voltage numeric display tube for use in IC-based desktop calculators." So they started development.

Initially, with the cooperation of Nippon Electronic Materials (Kuchidanaka Nogami, Amagasaki City, President Masao Okubo), they borrowed the company's laboratory (Nagaoka-cho, Otokuni-gun, Kyoto Prefecture...now the research laboratory of Ise Electronics) and President Nakamura and several other researchers worked on development.

Technical Section Chief Kanji Tanji, who was involved in this, said, "First, we struggled to break the 50-volt barrier, provide sufficient brightness, and extend the lifespan. In order to emit light at low voltages, we installed a grid (an extremely fine mesh-like control grid) between the filament cathode and the anode phosphor element to control the diffusion and acceleration of thermal electrons, and it became possible to emit light even at 25 volts. However, the brightness was low, so a special material was used for the conductor of the anode phosphor element, and sufficient brightness was obtained. Even so, evaporation from the oxide was absorbed by the phosphor, and the brightness deteriorated and the lifespan was shortened, so a screen grid was installed between the phosphor screen and the grid, which extended the lifespan and finally allowed us to go ahead with commercialization."

President Nakamura also spoke of the difficulties that led to the birth of the new product, saying, "Developing a new product is not something that can be done in an instant; it is an accumulation of well-known principles, and it only becomes successful after a series of logical improvements and repeated efforts."

Thus, with the commercialization of the product in sight, Ise Electronics. was established in September 1966, and at the same time, construction of a factory began in Ueno-cho, Ise City, and sample production of 1,000 units per month began in April 1967.

Around this time, the domestic computer industry was under pressure to resolve the fact that the manufacture and circuitry of neon numeric display tubes infringed on the patents of Burroughs Corporation of the United States, and just as they were hoping for an alternative product to emerge, Digitron was developed and the product suddenly became popular. For this reason, the company plans to complete construction of a new factory by the end of February, and is set to mass-produce 100,000 units per month in order to meet demand. President Nakamura, who brought the product to market in just a year and a half, said, "Because it's an entirely new product, reliability is necessary. For this reason, our next challenge is how to mass-produce it with high quality," and Manufacturing Department Second Manufacturing Section Manager Masuda Mitsuru said, "We will place emphasis on uniform quality and strive to reduce costs and improve yields."

Also, Technical Section Manager Tanji, who is in charge of the technical department, showed his enthusiasm, saying, "We want to develop something with lower voltage and higher brightness and explore new demand," while Kyoto Research Laboratory Chief Matsuda Taizo spoke forcefully, saying, "We will research circuits that can fully utilize Digitron's characteristics as one way to explore new applications."

Others

[O1] National Museum of Nature and Science
Center of the History of Japanese Industrial Technology, Essential Historical Materials for Science and Technology
Retrieved 31 October 2024: https://sts.kahaku.go.jp/english/material/2023.php
Retrieved 31 October 2024: https://sts.kahaku.go.jp/english/material/2023pdf/noe351.pdf
Registration in fiscal year 2023, Number 351, Single-digit Vacuum Fluorescent Display Tube (Prototype) - Bringing Japan's original display devices to the world -

[O2] Milestones: Pioneering Work on Electronic Calculators, 1964-1973
Retrieved 30 October 2024: https://ethw.org/Milestones:Pioneering_Work_on_Electronic_Calculators,_1964-1973

[O3] dentaku-museum.com/Sharp desktop calculator/CS-16A
Retrieved 30 October 2024: http://www.dentaku-museum.com/calc/calc/1-sharp/1-sharpd/sharpd.html
[Remarks] "The CS-16A was an advanced calculator that not only used ICs, but was also the first in the world to use a fluorescent display tube. At the time, most calculators used Nixie tubes, patented by Burroughs in the United States. However, Nixie tubes consumed a lot of power at the time, and the patent fees were high, and Burroughs also required that calculators using Nixie tubes not be exported to the United States. For this reason, Sharp had to make a calculator that did not use Nixie tubes at all costs. At the request of Sharp's Sasaki, Masao Okubo, who was the president of Japan Electronic Materials at the time, invented the fluorescent display tube. Tadashi Nakamura, who worked at Kobe Kogyo, left the company and established Ise Electronics, which succeeded in mass production. The world's first fluorescent tube was thus produced and was installed in the CS-16A. After the appearance of the CS-16A, the combination of MOS and fluorescent display tubes became the basis for calculators, and various calculators followed this line. In that sense, the role played by the CS-16A was very significant."

[O4] dentaku-museum.com/Casio Mini
Retrieved 30 October 2024: http://www.dentaku-museum.com/calc/calc/2-casio/2-casiomini/casiomini.html
[Remarks] Mini. The first Mini was released in August 1972.
With a low price of 12,800 yen, this calculator was the forerunner of the "popular calculators" that were intended for personal use.
Looking at the inside, we can see that it used a separate display tube (single tube).
Mini CM-601, Released in February 1973, six months after the release of the Mini.
Slightly longer and slimmer than the original Mini.
The display tube was changed to a round multi-digit tube (round tube).

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