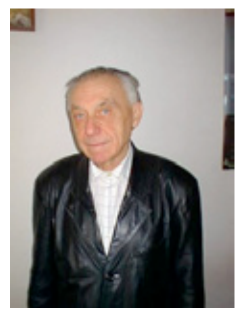
SETUN's reflections

How the SETUN computer was perceived in the "Western" scientific community

"The work day began with 'morning exercises': Each employee of the laboratory, including the project manager, got five ferrite cores of a diameter of 3 millimeter …" (N. P. Brusenzov)[1]

1. Introduction



Img. 1: N.P. Brusenzov (2004)

In 1958 the Russian engineer Nikolai P. Brusenzov and his small team constructed the world's first and still unique ternary computer. The computer that was built at the Research Computing Laboratories of the Moscow State University (MSU) was named after a nearby small river, the SETUN'.

Although the iron curtain divided Eastern from Western scientist, there was a huge interest on both sides to learn about each other's progress in technology.

The following research examines, how scientists of the "Western Block" learned of the existence of the SETUN computer and how the information was reflected in Western scientific publications.

It seems, that the existence of the SETUN in the Soviet Union at least supported and sometimes even triggered the research in the "Western World" in the field of ternary logic, a subset of multi-valued logic. Though its' constructor can not claim to be the first who thought about ternary logic and computing technology,[2] the impact of SETUN's' existence should not be underestimated. In a summary on the development of multi-valued logic and computing technology given in 1977, Epstein/ Frieder/ Rine put it this way: "However, the SETUN computer awakened interest in subsystems such as arithmetic units [Haberlin/ Müller 1970, Yoeli/ Halpern 1968, Vranesic/ Hamacher 1971, Mine et. al. 1971] and numerous electronic modules as cited in an abridgement of the bibliography for Thelliez' doctoral thesis [Thelliez 1973]."

[1] In: Malinovski 1995, [transl. F.H.]

[2] Grosch, H. J. R.: Signed ternary arithmetic. Digital Computer Lab. Memo. M-1496, MIT, Cambridge, Mass., May 1952

The appearance of the SETUN in 1958 and the fact that scientists on the Western side of the iron curtain learned about it in 1959[3] could be seen in the context of the Soviet's launch of the Sputnik Satellite in Oct. 4, 1957.

The Sputnik had a very significant impact on the advancement of scientific research in the United States and other Western countries. Or how the Historian Walter A. McDougall put it: "No event since Pearl Harbor set off such repercussions in public life."[4] The American public was quite surprised that the Russians where the first to launch a rocket and a satellite to successfully reach the earths' orbit. Though the Americans were aware of the importance of a space program and expected to launch their own satellite soon (Project Vanguard - launch planned for November 1957) the American public and with them scientists, military and the government were overwhelmed. "There was a sudden crisis of confidence in American technology, values, politics and in the military. Science, technology, and engineering were totally reworked and massively funded in the shadow of Sputnik."[5]

With the intention to reduce the technological and military gap,[6] the *Men on the Moon Program* was announced by John F. Kennedy in May 25, 1961 before the US Congress with the words: "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish."

In the consequence of this announcement, the technological research in the US was generally boosted.[7] The outcomes of the following basic research eventually lead not just to space travel but also to technologies as the multimedia computer, Internet or the Global Positioning System.

It is obvious that the SETUN didn't make such a big public impression and didn't have such an impact on science. But in the light of what was said about the Sputniks impact to science, it can be assumed, that SETUN's pure existence has triggered or at least supported the research that went on the Western side of the iron curtain.

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[3] Robertson, James in: Carr III, John W. 1959

[4] McDougall, Walter A.: The heavens and the earth – A political history of the space age. (Basic Books, New York, 1985) John Hopkins Paperback Edition, p142

[5] Dickson, 2003, p 4

[6] Walter McDougal argues, that a gap never really existed and that it rather was a successful production of Soviet propaganda in connection with a lucky timing of the Soviet space program. (McDougal 1997)

[7] Paul Dickson describes how the Men on the Moon Program changed the attitute towards science in the US in the 1960's. (Dickson, 2003 p 225 – 231 "Upgrading the three *R*s")

2. Information gathering

To understand, how the information on the SETUN was spread in the "West" (USA, Canada, Great Britain, Israel and Japan), 44 out of 100 scientific documents were examined for direct references to SETUN and/or its constructors. The research spans a period of 20 years from 1958 to 1977 and included documents, which were published in the US from US-American, Canadian, British, Israeli, Japanese, Argentine and Indian authors. The 44 examined documents present the main body of still accessible texts. 66 other documents could not be found or obtained from libraries for various reasons. [8] The examined articles were found via the Columbia University Library[9] and Compendex Catalogue[10] either by cross-references or one of the following keywords:

- three-valued logic
- ternary / trinary
- base-3
- TERNAC
- SETUN
- Brusenzov

While the indirect references where not counted,[11] 13 out of 44 documents where found, that named the SETUN and referred directly to descriptions of the SETUN. These references refer basically to 3 different instances:

1. Two separate groups of American scientist visited the Soviet computing centers in 1958/ 1959 and actually saw the SETUN. Their published reports were widely spread in the US in the following years. (Robertson et. al. 1959, Ware et. al. 1960)
2. A summary on Soviet computing technology by Rudins 1970, drove its information from Robertson 1959 and Ware 1960.
3. Some articles originally published in Soviet or Eastern Block publications in Russian by Brusenzov or his co-developers were eventually obtained and translated into English. Some scientists did translations personally; other translations were reprinted in English in periodicals.

To give the reader an impression on how the SETUN was mirrored in the US academic publishing in 1958-1978, all direct occurrences including the surrounding context are cited below. Additionally comments are given, where found to be necessary.

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[8] For some documents, the references taken from the original articles, were not traceable in catalogues and libraries at all. It can be expected that they exist somewhere but the time limit did not allow to research all potentially accessible reference databases. For other documents the references could be cleared, but lack of time, money or administrative problems circumvented the author to actually get hold of them.

[9] http://www.columbia.edu/cu/lweb/index.html

[10] Compendex is one of the most comprehensive bibliographic databases of engineering research available today, containing over eight million references and abstracts taken from over 5,000 engineering journals, conferences and technical reports. http://www.engineeringvillage2.org

[11] That means someone citing a document that contains a reference to a third document which names the SETUN. From a raw review of the references, it can be assumed, that most of the documents have at least one indirect reference to a text, where SETUN is named.

3. Sources and commentary

The first ever account of the existence of a ternary computer in the USSR was published in June 1959 by Carr III, John W./ Scott, R. Norman/ Perlis, Alan J./ Robertson, James E. in “A Visit to Computation Centers in the Soviet Union.” in the periodical *Communications of the ACM*. Further references show that the gathered material was also used for seminars and public lectures, spreading the information even more.[12]

Author	Affiliation
Carr III, John W.	Research Computation Center, University of Michigan
Scott, R. Norman	University of Michigan
Perlis, Alan J.	Carnegie Institute of Technology
Robertson, James E.	University of Illinois[13]

The visitors saw the SETUN and other Russian computers firsthand but they did not mention Brusenzov at all, so it remains unclear if they actually have met him personally. The article is a technical description and gives just a few ideas, why the SETUN was constructed. The “dissatisfaction with the STRELA”, a vacuum tube based machine that was constructed during the same period at the Moscow State University, was indicated by the author(s) as main motivation for SETUN’s development. Unfortunately no reason for Brusenzovs’ usage of three-valued logic was given.

Img. 2: John Carr (undated)

Three out of the thirteen documents that name the SETUN are referring to this article.

> “The four authors spent a two-weeks period from August 27 through September 10, 1958, visiting Computation Centers in the Soviet Union at Moscow, Kiev, and Leningrad. […] They talked with Russian and Ukrainian computer mathematicians and engineers working on comparable problems and were given very complete guided tours […].
>
> The digital computer SETUN is under construction at Moscow University. More attention was given to miniaturization than elsewhere among places visited, with elements mounted on cards which were in plug-in trays perhaps 2" x 3" x 6" deep. The arithmetic unit, control, console, and input-output control are mounted in one unit approximately 7' high by 11' long, with a separate unit 6' long for the memory cores, the drum, and magnetic tapes. The lower 30" of the units is not used.

[12] The article is often referred as “Carr 1959” pointing to John Carr who was the editor. James Robertson actually gave the description of the SETUN, so the reference is used here as “Robertson 1959”. Robertson 1959 In: Carr III, John W./ Scott, R. Norman/ Perlis, Alan J./ Robertson, James E.: A Visit to Computation Centers in the Soviet Union. Communications of the ACM, v 2, n 6, 1959, p 8-10, p 14; Proceedings of the seminar on the status of digital computer and data processing developments in the Soviet Union. ONR Symposium report ACR-37, Washington USA

[13] Prof. James E. Robertson (1942-1999), an electrical engineer and expert in error-checking systems, pioneers basic techniques of efficient binary division (now known as SRT). At that time the computers IBM 650 and ILLIAC are installed at the University of Illinois.

SETUN is to be a base 3 machine with 18 digits per word, each digit having one of the values -1, 0, or +1. The machine is to be serial, fixed point and with a single address in each of two commands per word. It was described as asynchronous, with a 200 kc. clock. Addition and subtraction will require 180 μsec, multiplication 360 μsec. No division instruction will be provided. A normalization instruction is included in the order code of 27 instructions to facilitate floating point computation. One index register is provided with one digit of a command indicating one of the three alternatives: add index, subtract index, or do not modify.
The memory hierarchy includes an 81-word ferrite core memory and approximately 2000 words of drum storage. The drum rotates at 7000 rpm, with a maximum access time of 14 msec, corresponding to two revolutions, one for waiting, one for transfer of a block of 27 words. The drum is physically small, perhaps 4" in diameter by 6" high, and has 60 tracks. Addition of magnetic-tape units is planned at some later date.
Input and output will be on 5-hole punched paper tape; all transfers are to be in blocks of 27 words. The reader will be photoelectric, reading 400 lines/sec and requiring 15 to 20 lines to stop: A printer is also to be available. Components are to be a "type of magnetic amplifier using ferrite cores," except for 70 vacuum tubes used as "generators" (drivers). The explanation given for base 3 operations was that the hysteresis loop of the cores was not sufficiently square and that compensation was required. Thus, two cores are necessary for each digit and three states can be utilized. The motivation given for construction of the machine was dissatisfaction with STRELA, said to be too complicated for open-shop university use.
A base 3 digit is stored in two cores in the core memory, on two tracks on the drum, and on two holes in the paper tape. A single unit, containing one record tube and a five- transistor read amplifier, can be switched to any one of three tracks of the drum.

[...]

It is the computer mathematics group at Moscow that is constructing the SETUN to provide for simpler and more flexible operation of their center than is possible with the large and relatively unreliable (10-minute mean free error time) STRELA. We were informed that the mathematics group intended to continue research in computer design in the future. Thus, SETUN is a single-address computer and algorithms are being developed which maximize the use of an accumulator during extended calculation of algebraic formulae." (Robertson in Carr 1959)

Just 8 months later in 1959, and after a Soviet scientist group had visited the US; another group of US scientist was invited to see computing machines at several sites in the USSR. Once again the SETUN, which had been finished in December 1958 by Brusenzov and his team, was shown. This time his name got mentioned. It is more than astonishing, that later on nobody who cited this document mentioned Brusenzov as the constructor of the SETUN and as the one, who had the idea to use ternary logic.
The article by Ware, Willis. H. (ed.)./ Alexander, S.N./ Armer, P./ Astrahan, M.M./ Bers, L./ Goode, H.H./ Huskey, H.D./ Rubinoff, M. got published as "Soviet Computer Technology" in the periodical *Communications of the ACM* in March 1959, then in the *IRE Transactions on Electronic*

Img. 3: Willis Ware (ca. 2000)

Computer in Mar 1960, as a report for the RAND Corp as file RM-2541 in March 1960, and in the *Bulletin Provisional International Computation Centre* in July-October 1960.

Author	Affiliation
Ware, Willis. H.	RAND Corp.
Alexander, Samuel N.	National Bureau of Standards, United States
Armer, Paul	RAND Corp.
Astrahan, Morton M.	IBM
Bers, Lipman	Institute of Mathematics, New York University
Goode, H.H	University of Michigan, Bendix System Division
Huskey, H.D.	University of California
Rubinoff, M.	Philco Corp.

“ Thursday, May 21 [1959]

The rest of the group [Astrahan, M. M./ Alexander, S. M./ Armer, P./ Bers, L./ Huskey, H.D./ Ware, W. H.] visited the Lomonosov Campus of the Moscow State University and its computing center. The work of this computing center was discussed and the STRELA and SETUN installations were visited and described. We met or spoke with the following:
Academican S.L. Sobolev, Head, Computing Chair, MSU [...]
N. P. Brusenzov, Chief engineer of the SETUN machine

[...]

SETUN

This base-3 machine being constructed at Moscow State University appeared to be in operation when we saw it (fig. 16). It was explained that the choice of base-3 was made because it can be shown that in some sense a base of 3 provides the most efficient utilization of equipment. [Footnote missing] Since a base-3 electronic technique is not available, they decided to construct a base-4 machine and to utilize only 3 of the 4 possible states. The unused 4th state in each case is available for some form of checking. This machine is regarded as experimental, and as an educational training program for engineers. In part they felt that SETUN was a protest against the huge, complicated machines being built elsewhere. It was thought easier to operate a simple machine at their center. The machine contains 4,000 magnetic cores, 4,000 germanium diodes, approximately 100 transistors, and 40 vacuum tubes. It operates at a 200-kilocycle clock rate. It uses 1 MC transistors, which are rated at 150 milliwatts dissipation at 25 degree centigrade, but can tolerate a maximum of 100 degree centigrade.
SETUN has only 81 words of storage and 27 different instructions. It is a single-address, fixed-point machine, with 18 ternary digits per word. The point is fixed between the second and third digits from the left. It is serial and contains two instructions per word. There is no divide instruction.
The ferrite core store can be regarded as having 162 9-digit words because the half-words can be addressed. The drum store contains 2,268 half words. Number representation of SETUN requires 2 binary digits per base-3 digit; therefore a 9-digit, base-3 word, will require 18 tracks on the drum. There are three such groups of 18 tracks on the drum, or a total of 54 heads. In each band of 18 tracks there are 756 words recorded in parallel; there are thus 756 bits

> around the 13-inch circumference. It is planned to add magnetic tapes to this machine at some later date.
> Addition time is 180 microseconds, including all accesses. Fetching of the next instruction is overlapped with the execution of the previous one. Multiplication time is 335 microseconds, and transfer of control is 100 microseconds. SETUN includes a normalizing instruction (shifting operations to facilitate programming of floating-point), one index register, and teletype input and output. The German type RFT teleprinter is partially base-9 and partially base-3. A 9-digit word is printed as two base-9 digits, then one base-3 digit, then two more base-9 digits. The characters used are:
>
> Base-9: 4, 3, 5, I, 0, 1, 2, 3, 4
> Base-3: i,0,1
>
> Five-level punched paper tape is used for the input and output." (Ware et. al. 1959)

This seems to be even more detailed information than in Robertson 1959 and it can be assumed the Robertson's' account has been used to verify and complete the document by Ware et. al. 1959.[14] Now we get some additional information on SETUN's context: "This machine is regarded as experimental, and as an educational training program for engineers. In part they felt that SETUN was a protest against the huge, complicated machines being built elsewhere." Instead of pointing out the STRELA as in the former article, it was more generally referred to "complicated machines elsewhere" as an argument of distinction for the SETUN. No author was given for this statement. Additionally the question, why ternary logic was used, remained unanswered again.[15]

The next article – published 2 years later, in 1961 – was based on the research of Hallworth, R.P./ Heath, F.G. from the University of Manchester. They researched about "Semiconductor circuits for ternary logic" and don't name the SETUN directly but give a clear reference to Robertson 1959.

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[14] It is worth to mention as well, that Willis H. Ware, the editor of this article, at that time was an employee of the RAND Corporation.
Industrialist Donald Douglas approached the Army Air Force in January 1946 with a plan for joint industry-government coordination – in short, a think tank. Project RAND (coined by Arthur Raymond from *R*esearch *an*d *d*evelopment) was originally founded with Douglas Aviation. In May 14, 1948 Project RAND separated from Douglas and became an independent, nonprofit organization. The think tank established a special field of sciences, called "Soviet Studies" about ten years later, following the Sputnik shock. „In a real sense, Soviet studies were invented at RAND." (Jonathan D. Pollack). This departement collected and examined material from various sources (unclassified documents, news sources, intelligence services etc.) about the social, sociological, political and scientific life of the Soviet Union which was delivered in public or classified publications to a variety of readers in the US and the Western world. The goal was to better understand recent Soviet developments and to enable decion makers to react in a short time.

[15] Brusenzov later argued, that a general advantage of ternary logic was the "most natural number system" (Brusenzov) and also mentioned the demand to reduce the amount of components to achieve a relatively small construction. [Malinovski 1995, Rumjanzev 2004]

Author	Affiliation
Hallworth, R.P.	IBM British Laboratories, former Member of Faculty of Technology, University of Manchester
Heath, F.G.	Faculty of Technology, University of Manchester

> "Interest has increased recently in non-binary switching theory, because certain advantages may be obtained by using a radix higher than 2 in digital computers [Robertson 1959] as well as digital communication systems. [...] Generally in both applications binary circuits and logic have been used because of their simplicity. It can be shown, with certain assumptions, that the most efficient radix for computing is 8, which makes 3 the best integral value." (Hallworth/ Heath, 1961)

R. D. Merrill was one of the most active authors in this field, 7 publications from 1963-1973 on ternary logic were found.[16] Merrill was the first to give another reference to SETUN than Carr 1959 and Robertson 1959. He cited an article on "The order code and an interpretative system for the SETUN computer." from 1962 by E.A. Zhogolev, who was the main programmer in the SETUN team.[17]

Author	Affiliation
Merrill, R. D.	Electronic Sciences Lab, Lockheed Missiles & Space Co., Palo Alto, Calif., USA

> "The SETUN, a Russian stored program computer, incorporates the ternary number system in its arithmetic unit. [Zhogolev 1962] The mechanization was not wholly ternary since the control logic is binary and information is binary encoded for storage in the bulk and random access memories. Evidently the SETUN was so designed to take advantage of the relative ease of representing negative and positive numbers and the simplicity of performing round-off when using the ternary representation." (Merrill 1965)

When Merrill stated: "Evidently the SETUN was so designed to take advantage of the relative ease of representing negative and positive numbers and the simplicity of performing round-off when using the ternary representation.", he was giving for the first time a possible reason for the use of ternary logic. His use of "evidently" shows, that he expressed his point of view, not Zhogolevs.[18] One year later, in 1966, Merrill puts the SETUN in a broader context.

[16] See Appendix A

[17] "I will check my files, but seem to remember that this information came from [Antonin Svoboda] from Czechoslovakia, in this country then, who was famous at that time for his work with the application of the Chinese Remainder Theorem (modular arithmetic) to digital computing and error correcting codes. His work was given to me by Dr. Howard Aiken, then the director of Harvard University's Laboratory for Computing." (Merill 30-Mar-2005), Svoboda built the first Czechoslovakian computer named SAPO in 1957.

[18] Zhogolevs introduction reads: "However developed the order code of a computer may be, it provides the mathematician with a very imperfect tool to describe the computational processes. This tool can be considerably enlarged and improved with the ususal methods for making programming more automatic (standard sub-routines, compiling and interpretive systems, programm generators, etc.) The need for an improvement in the basic programming structure is most acute for small computers with a simple logical structure and, usually, a small set of very elementary operations.

"Moreover there have been several instances reported recently where ternary logic and switching networks have found practical application. For example SETUN, a Russian stored-program computer, incorporates the ternary number system in its arithmetic unit to take advantage of the relative ease of representing negative and positive numbers and the simplicity of performing round-off in the ternary representation [Zhogolev 1962, Merrill 1965]. Also many proposed content addressable memories utilize tristable switching and memory elements to accomplish masking and associated operations [Lewin 1962]. Ternary switching theory has been proposed as a useful means of designing hazard-free binary gating, and series parallel contact networks [Eichelberger 1965, Yoeli/ Rinen 1964]. NASA has actively supported the development of tristable fluid logic devices for hydraulic switching systems [Reader/ Quigley 1963/63]. Still another area is the use of ternary logic redundancy in binary networks to improve operating reliability [Varshavsky 1964]." (Merrill 1966)

This overview given by Merrill shows how the field of research on ternary logic and computation has broadened after 1958. And this was what Yoeli/ Halpern stated as well in their article from 1968: "Only recently, considerable interest in non-binary, and especially ternary, switching circuits has arisen owing to the potential advantages of ternary over binary systems."

Author	Affiliation
Yoeli M.	Faculty of Electrical Engineering, Technion, Haifa, Israel
Halpern, I.	Faculty of Electrical Engineering, Technion, Haifa, Israel

"Only recently, considerable interest in non binary, and especially ternary, switching circuits has arisen owing to the potential advantages of ternary over binary systems. [...]
The Russian computer SETUN [Brusenzov 1962, Brusenzov 1965] is an interesting experiment of a digital computer, which uses a symmetric ternary number representation. This number representation has many advantages, which are discussed in the sequel. However, whereas the SETUN uses magnetic circuitry in its arithmetic unit, this paper proposes a ternary arithmetic unit which supplies present-day diode-transistor circuitry. Detailed circuit realization, and logic diagrams of ternary gates, of a 3-stable element, and of a full adder are developed. From these modules, a complete ternary arithmetic unit can be simply constructed." (Yoeli/ Halpern 1968)

Img. 4: Michael Yoeli (2002)

Yoeli and Halpern are the first to directly cite from articles written by Brusenzov.[19] They see the SETUN as "an interesting experiment" which in the broader context of general computer development was an obvious consideration. Yet, Brusenzov himself stressed the fact that the SETUN was used in 30 installations spread all over the

In this article we consider the first steps towards an improvements of the basic programming of the SETUN unsing an interpretative system which can be a bsasis for the future improvement of this apparatus." [Transl. by R. Feinstein] (Zhogolev 1962)

[19] In an email to the author Michael Yoeli writes: "I don't remember how I came across the references you mention ..." (Yoeli, M. 12-Mar-05) and regarding his knowledge of Russian language: "I did take a beginners' course in Scientific Russian, but did not make much progress." (Yoeli 18-Mar-2005)

USSR and that the users were satisfied with its function and reliability. So in his opinion it was more than just “an interesting experiment”. [Malinovski 1995, Rumjanzev 2004]

D.I. Porat referred in his 1969 article “Three-valued digital systems” to Robertson 1959 without addressing the SETUN directly and rather talking of the existence of a “ternary computer” in general. As in many other articles the reference to the SETUN was given to support the own research.

Author	Affiliation
Porat, D. I.	Stanford University, Calif. USA, former at University of Manchester, UK

> “Digital equipment design is based on the binary-number system because of the availability, low cost and reliability of binary switching and storage elements. Higher radix systems are implemented by use of binary coding; however, at least one ternary computer [Robertson 1959] has been in operation which incorporates 3-valued elements.” (Porat 1969)

Author	Affiliation
Rudins, George	Rand Corp

A short summary on the SETUN was given by George Rudins in his article “Soviet computers: a historical survey.” It was published in RAND’s *Soviet Cybernetics Review* in January 1970. The aim of the journal was “to disseminate to a wide range of specialists information about Soviet publications, activities, and new developments in computing technology, cybernetics and scientific policy.” (p.ii). The research was supported by the United States Air Force under the Project RAND-Contract No. F44620-67-C-0045. What is astonishing is the fact the Rudins, who was the managing editor of *Soviet Cybernetics Review*, didn’t give any references for the complete article. It is most likely that he drew his information from Robertson 1959 or Ware 1959.

> “The first Soviet computer with alphanumeric I/O capabilities, the Setun’, was developed in 1958 as part of a graduate student project at Moscow State university; N. Brusenzov, who worked on the Strela with Basilevskij, was also involved in this project. The Setun’ was capable of performing 4000 opns/sec (1-adress), and had 81-18-bit words of core store. It was the world’s only computer to ever use base-3 logic. According to the Soviets, base-3 logic was supposed to provide the most efficient utilization of hardware. Since base-3 electronic technique is nonexistent, they decided to construct a base-4 machine and to utilize only three of the four possible states. Although the entire project was regarded as an educational training program for engineers, an attempt was made to serially produce it, but it failed miserably – base-3 logic turned out to be highly impractical.” (Rudins 1970)

From nowadays-available information it becomes obvious, that Rudins’ summary contains wrong and incomplete information: Brusenzov never worked with Basilevskij on the STRELA computer, as the article supposes. They rather worked within the same organizational structure at the Moscow State University. The STRELA was produced at the newly established Computational Center at the MSU in the Special

Construction Office SKB-245. Brusenzov's laboratory was also part of the Computational Center but not directly connected to the SKB-245.
Rudins also mentioned that an *attempt* was made to produce the SETUN serially. Obviously his information was not precise as well, when he wrote: “an attempt was made to serially produce it, but it failed miserably” It is true that *mass* production of the SETUN failed. There was for instance the plan to produce some thousand copies a year in the Peoples Republic of Czechoslovakia, which was turned down by the Soviet authorities because they wanted the money to be earned by themselves rather than by the Czechs (Brusenzov in Rjumanzev 2004). But it is not true that the *serial* production, as Rudins claims, failed. There was a serial production of the SETUN at the Kazan Mathematical Machines plant[20] starting in November 1961 and releasing 50 copies which were spread all over the Soviet Union (Malinovski 1995).[21] In this context it becomes obvious, that also Rudins conclusion “base-3 logic turned out to be highly impractical” is shortening if not even wrong.[22]

Img. 5: Gideon Frieder (ca. 2000)

Gideon Frieder started to work on the TERNAC in the early 1970s. His goal was to create a ternary computer for evaluation of ternary logic and arithmetic against binary logic. The TERNAC wasn’t a computer itself but rather an *emulation* of a ternary computer written in FORTRAN-IV.[23] He cites Ware 1959 for his information about the SETUN.

Author	Affiliation
Frieder, Gideon	State University of New York/ Buffalo, USA
Luk, C	State University of New York/ Buffalo, USA

> “There seems to be quite an abundance of hardware units built for ternary computers, including adders, multipliers etc. [Dept. of EE, 1971]. Furthermore, a ternary computer was built in the University of Moscow in the late 50’s [Ware et. al. 1959]. These existing devices illustrate exactly the problem to which we referred in the previous passage; they employ base-3 arithmetic without any reference at to how such arithmetic should be applied. Although ternary systems were known for a while, and in particular balanced ternary was looked into [Knuth, 1969, vol. 2, pp.173-176], there is, to the best of my knowledge, no a priori attempt in those systems to decide if arithmetic should be implemented in balanced or regular ternary.” (Frieder/ Luk, 1972)

[20] Kazansk Mathematical Machines Factory (now: ICL), 34 Sibirsky Trakt, 420029 Kazan, http://www.icl.kazan.ru/eng/activities/production/background/
[21] For comparision: DEC produced 50 copies of the fully transistorized PDP-1 from 1961-1964 (Ceruzzi 1998, p 128)
[22] For further information on the Soviet computer technology industry and the state system of planning and strategy see Klimenko 1999.
[23] “There was also a MIL (Microcode Implementation Language) version for the Burroughs B1700. Inasmuch as the Burroughs limited the availability of MIL to a very small number of laboratories, and the B1700 was not readily available as an emulating machine, the Fortran-IV version seemed to be essential for wide evaluation purposes.” (Frieder 12-Jul-2005)

In 1974 Gideon Frieder gave "A Summary of the Development of Multiple-Valued Logic as related to Computer Science." at the Symposium on Multiple-Valued Logic in Cooperation with G. Epstein and D.C. Rine.[24] They refer to two sources regarding the SETUN. Again 1960[25] is mentioned for the first time as a reference and Zhogolev 1962 to who was first referred by Merrill 1965.[26]

Author	Affiliation
Frieder, Gideon	IBM Israel
Epstein, G.	Indiana University
Rine, D. C.	Department of Statistics and Computer Science, West Virginia University, Morgantown, USA

"The earliest document seriously proposing a full scale ternary computer was written in 1952 by Grosch [Grosch, 1952]. It advocated the implementation of a balanced ternary (digits –1,0,1; radix 3) arithmetic unit for the Whirlwind II computer which was then in design.
The first full scale implementation of a ternary computer called SETUN was completed in 1958 at Moscow State University [Again 1960, Zhogolev 1962]. Restricted by poor hardware reliability and inadequate software, there was no extensive attempt to use SETUN for critical comparison of binary and ternary computers in the area of arithmetic." (Frieder/ Epstein/ Rine 1974)


Img. 6: D.C. Rine (2000)

There is an interesting turn in the context, which they draw for the development of using ternary logic and computing technology. When they mention Grosch and his thoughts about ternary logic for the WHIRLWIND computer in 1952, it shifts the mentioning of the SETUN to be the first ternary computer a little bit toward the fact, that even before1958 someone was at least thinking about ternary computing. On the background of the Sputnik shock in 1957 it is obvious, that at least some importance was given to the question: "Who was the first?"

Frieder/ Epstein/ Rine stated further, that the SETUN was "restricted by poor hardware reliability and inadequate software" which at least if one believes Brusenzov was not the case. He especially stressed the high reliability of the SETUN (90 percent usage time) in comparison to other Soviet computers of that time. (Rjumanzev 2004). Advancing to it from the point of view some 15 years later, comparing Eastern and Western developments and advancing from the own interest in comparing ternary and binary computing – something the SETUN was not intended to be for – the authors somehow blur the reason and the cause when stating: "Restricted by poor hardware reliability and inadequate software, there was no extensive attempt to use SETUN for critical comparison of binary and ternary computers in the area of arithmetic."

[24] "SETUN actually started my interest in MVL [Multiple Valued Logic – F.H.] from a digital systems point of view, and we had read the early works of SETUN in the early 1970's." (Rine 23-Mar-2005)
[25] I've found one article by Again 1960 but it doesn't address SETUN directly.
[26] See also Appendix A.

The author of the following article, Z.G. Vranesic, was one of the most published authors in the field of ternary logic.[27] He researched at that time at the University of Toronto. Although his first traceable article on the subject is dated to 1971, it takes three more years until he refers to the SETUN computer. When he finally referred to SETUN in 1974 he didn't cite from the former known sources but rather reveals a new original Russian article from the *Moscow State Universities Vestnik* (1962).[28]

Author	Affiliation
Vranesic, Z.G.	Department of Electrical Engineering and Computer Science, University of Toronto, Ontario, CA
Smith, K. C.	Department of Electrical Engineering and Computer Science, University of Toronto, Ontario, CA

"Some of the early attempts concentrated on the development of basic devises which were essentially non-binary in nature. Such was the case of the Rutz transistor [Kaniel 1973], the parametron [Schauer/ Steward/ Pohm/ Reid 1960], multi-aperture square loop ferrite devices, etc. [Anderson/ Dietmeyer, 1963]. Magnetic cores received special attention [Ivaskiv 1971,Santos/ Arango/ Pascual/ 1965] and even became a key building block in the SETUN computer [Brusenzov/ Zhogolev/ Verigin/ Maslov/ Tishulina 1962]. Eventually these attempts gave way to the approach of utilizing readily available binary components for construction of circuits which exhibit multi-valued behavior." (Vranesic/ Smith 1974)

Img. 7: Z.G. Vranesic (2000)

It is not clear, where exactly Rath has taken his knowledge of the SETUN. In the general references to his article he named Hallworth/ Heath (1961), Merrill (1966), Porat (1969) and Yoeli/ Halpern (1968) who all refer to the SETUN computer and partly also give a small description of it.

Author	Affiliation
Rath, Shri Sudarsan	Department of Electrical Engineering, Regional Engineering College, Rourkela, Orissa, India

"Ternary means an element of a switching system which will perform 3-valued transmission and 3-valued switching. The Russian computer SETUN is an interesting experiment in digital computation. It uses 3-valued devices and follows a symmetric ternary system of logic states 1,0,-1." (Rath 1975)

In 1977 Epstein/ Frieder/ Rine contributed a chapter on *The development of multiple valued-logic as related to computer science* in the Book *Computer Science and Multiple-Valued logic, theory and applications*, edited by D.C. Rine.

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[27] See Appendix A

[28] "I don't remember where I found the reference to Brusenzov's paper, but I got a copy of it through the University of Toronto library. The paper was in Russian, which I can read because I grew up in Croatia (which was then a part of Yugoslavia) and had to take Russian as a required foreign language. The paper was interesting only as one of the first attempts to build a non-binary computer." (Vranesic 14-Mar-2005)

Author	Affiliation
Frieder, Gideon	IBM Israel
Epstein, G.	Indiana University
Rine, D. C.	Department of Statistics and Computer Science, West Virginia University, Morgantown, USA

"Ternary systems for computation were discussed in 1840 [Cauchy 1840, Lalanne 1840]. By 1950, there were ternary devices widely enough known to be included in a review book [Epstein/ Horn 1974]. However, it was not until 1958 that the first full scale ternary computer was completed at Moscow State University [Again 1960, Brusenzov 1960, Robertson et. al. 1959, Zhogolev 1962] although ternary computers where proposed as early as 1952 [Grosch 1952]. While this encouraged work on subsystems such as arithmetic units in Canada [Vranesic/ Hamacher 1971], Japan [?], Switzerland [Haberlin/ Müller 1970], and Israel [Yoeli/ Halpern 1968], the low-level programming language devised for this Russian computer was so difficult to use that there was little insight into 3-valued logic by users.

[…]

The earliest document seriously proposing a full scale ternary computer was written in 1952 by Grosch. It advocated the implementation of a balanced ternary (digits –1, 0, +1) arithmetic until for the Whirlwind II computer which was then in design. However, there was no discussion in this document of algebraic or logic operations.
In the late 1950's the first full scale implementation of a ternary computer as undertaken by a Russian team at the Computing Centre of Moscow State University. This computer, completed in 1948 and named SETUN, was briefly described by Carr et al. [Robertson/ Carr 1959] in a 1959 survey of Russian computers. It was used for some time but both poor hardware reliability and inadequate software hampered its usage [Zhogolev 1962]. Additional details may be found in [Again 1960, Brusenzov 1960].

The SETUN computer was a fixed-point arithmetic computer with words of 18 ternary units (trits) in length. There were two trits to the left of the fixed-point rather than one. The memory consisted of a core storage unit of 81 words and a magnetic drum unit of 1944 words.
The representation of a trit in flip-flops or the core storage unit was accomplished through the use of two coupled cores, which provided three stable states. The hysteresis loops for these coupled cores did not allow four stable states. The representation of trits on the magnetic drum or input/ output tapes was through binary-coded ternary on two stacks, hence wasting a single binary digit (bit) of information per trit. This waste was compounded through the use of a ternary-decimal (a further waste of 17 bits of information per decimal).
The SETUN was an arithmetic machine. The only logic operation it had was digit-by-digit conjunction (logical multiply). It was therefore completely unsuitable for any evaluation of ternary logical operations. Yet there was no extensive attempt to use it for critical comparison of binary and ternary computers with respect to arithmetic operations.

However, the SETUN computer awakened interest in subsystems such as arithmetic units [Haberlin/ Müller 1970, Yoeli/ Halpern 1968, Vranesic/ Hamacher 1971, Mine et. al. 1971] and numerous electronic modules as cited in an abridgement of the bibliography for Thelliez' doctoral thesis [Thelliez 1973]." (Epstein, G./ Frieder, G./ Rine, D.C. in Rine 1977)

This seems somewhat friendlier towards the SETUN than in their summary given in 1974, maybe also because they put it into an even broader context. Regarding the usage and reliability they stick to their findings, which they made three years before. Remarkable was their understanding, that the SETUN awakened the interest in the further work on ternary computing devices.

It would be interesting to follow the development of the field in the beginning 1980s with the broad access to microchips, which abandoned the use of transistors for computer devices. There were unfortunately not enough resources to do further research. So the chapter by Rine/ Frieder/ Epstein might be taken for the closing chapter of the activities in the 1970s.

4. Why the research in the "West" eventually stopped.

The examination of these sources naturally evocates the question why the research interest on ternary computing slowed down after a period of twenty years. The major authors were contacted by e-mail and asked the questions: "Can you remember where you got the knowledge of SETUN's existence from." And: "Why did you stop researching the field of ternary computing or ternary arithmetic?"

Michael Yoeli who was involved in ternary logic in the 1960s at the Technion in Haifa comments the development in that time and SETUNS influence from his nowadays point of view:

> "We were attracted by the general idea of ternary computing. However, the problem is to design the relevant hardware, in such a way that the ternary computer becomes competitive with available binary computers. SETUN was an effort to deal with this problem, but there is no doubt that this effort failed and the idea of the SETUN was indeed eventually abandoned. At the time the SETUN was built in Moscow, computer hardware technology was just in its beginning. However, even more advanced technologies do not offer a reasonable challenge. Our computing unit was just a design on paper, but no effort was made to implement this idea. From a software viewpoint the idea of ternary computing is indeed attractive, and the SETUN was an important contribution to this idea." (Yoeli 12-Mar-2005)

So Yoeli puts the success of binary memory units as a major reason, which made the effort to actually transfer the theory of ternary logic into real applications, i.e. ternary microchips, unattractive and unaffordable.

Roy D. Merrill who in the 1960 was associated with the Lockheed Missiles and Space Corp Research Lab gives another viewpoint.

> "We [Lockheed Missiles and Space Corp] had a contract with the Air Force to explore a number of areas that might enable the computer designer to devise means of making the computer operate faster and with less complexity. [...] We researched Residue Arithmetic because addition, subtraction and multiplication arithmetic operations could be carried out without waiting for the carry bit. We researched ternary arithmetic because it could possibly have helped ease the complexity of the logical design. Neither proved to be successful for other than very special applications." (Merrill, 26-Apr-2005)

Zvonko Vranesic, who was with the Department of Electrical Engineering and Computer Science at the University of Toronto in the early 1970s, writes about the advantages and disadvantages of ternary logic:

> "Ternary logic has some useful arithmetic properties, such as allowing the balanced representation of numbers. Its main drawback is that there do not exist any practical implementations of ternary storage circuits. Thus, if one has to use binary storage devices, it is clear that it makes more sense to try 4-valued logic circuits which can interface to the binary memory more efficiently." (Vranesic 14-Mar-2005)

And he further explains:

> "The reason why storage devices are binary is that it is easy to use transistors as simple switches that have to states, OPEN and CLOSED, which can be interpreted as 1 and 0. There are no simple elements that can be implemented using the Integrated Circuit technology which would naturally exhibit 3 states." (Vranesic 17-Mar-2005)

This correlates with the account D.C. Rine gives on this question. He researched during the 1970s at the Department of Statistics and Computer Science of the West Virginia University in Morgantown, USA. Rine answers that the interest in multi-valued logic (of which 3-valued logic is a subset) had to do with the general development of microprocessors. In the 1970's companies such as IBM, Motorola, National and others started to explore the combination of 2-state logic with 4-state logic in microprocessors to improve speed and memory capacity. Applying the pure scientific findings in multi-valued logic to the actual engineering process wasn't always easy.

> "As we studied, and invented, the idea of Technology Readiness (TR) models and Technology Maturity (TM), it was discovered that there is a transition for most technologies through 9 different TM/TR stages from research ideas inception through integration into existing systems. So it took the research inception of n-state logic[29] to make its way from purely research (isolated) ideas to a maturity and readiness such that the existing computer systems technology could accept or interface with 4-state VLSI maturing technology. The very important point to observe is that an important point in time much be reached when technologies evolving from reach to more mature/ ready technologies can usefully interface with current existing computer systems wide technologies. If evolving/maturing new technologies do not reach that point in an appropriate time then they will generally never be used in current/existing systems. Many interesting and novel research ideas never go beyond the phases from inception to stand along maturity, and are therefore never used in existing systems." (Rine 23-Mar-2005)

[29] Multi-valued logic

In the case of the 1970's microchip development it turned out, that the merging of 2-state and 4-state logic was successful. But it turned researchers – and among them Rine – away from further research in any n-state logic where n would be an uneven power of 2.

> "I turned my attention to directing PhD research dissertations using interval logics, formal methods proof systems and formal natural logic communication systems which seemed to hold more promise for my own research. And I could not see a way or a path for reaching the higher TM/TR levels with 3-state VLSI[30] logic. More recent dissertations/ papers appeared in those areas." (Rine 23-Mar-2005)

Gideon Frieder who led the development of the TERNAC emulator at the SUNY Buffalo during the 1970s answers the question, why the research eventually stopped:

> "Essentially, we were victims to our own success. In developing the algorithms for the emulation of a balanced ternary machine on a binary host, we found that one can implement both the [ternary] arithmetic and the logic on binary hardware. So if somebody is interested in using a ternary computer, it is easy to implement it as software or microcode. The realities of Moore's law showed us that ternary hardware is not cost effective in the state of affairs in the 80s." (Frieder 15-Jun-2005)

To add a little bit of context to Rines and Frieders answers, the time period, the beginning 1960's in which the SETUN was developed, should be considered as well. When the first talks started about it at the Moscow State University recently founded Computing Research Center started in 1956, the machine that would become the SETUN was still thought of as being a binary computer. But at this time computing technology in the Soviet Union was still in its early phase, which meant it was quite experimental.[31] Not much experience existed and many machines were built "from the scratch". For the SETUN for instance a seminar gathered for a few months, consisting of mathematicians and electrical engineers and would make up a general plan, of how to build such a calculating machine. Brusenzov was a radio engineer by education. Working diverted from others and in parallel to other ongoing projects (e.g. STRELA, BESM) on his own, it was relatively easy to come up with something basically different as ternary logic.

When the research on ternary computing seriously started in the "West" in the 1960s, the situation and context was entirely different. A broad experience in building binary computers and elements existed along a growing industry that was about to switch from using ferrite cores and vacuum tubes towards transistors[32]. So it was much more difficult to not just start a project on ternary computing but to actually finish it in the sense, that a computer based on ternary logic would be build and used.

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[30] Very Large-Scale Integration – Placing thousands of transistors in a small space – the microchip.
[31] This experimental phase of computing was delayed a little bit compared with the US because universities and plants in the Soviet Union had to be rebuilt after World War II and the human losses also affected the sciences. Brusenzov, who was a radio operator during the war, was taken into the Soviet Army in 1943 and finishing his 10th grade was delayed until 1948. Of the 25 young men, who entered the war in 1943 only 5 , including Brusenzov, survived.
[32] Cerruzzi 1998, p 64

The reasons for the research in ternary computing, ternary arithmetic and ternary devices following the given accounts can be summed up as:

- general interest in ternary computing in the early, experimental years of computing
- use of balanced ternary numbering system (-1 | 0 | 1), especially for residue arithmetic
- hope to simplify logical design

The set of reasons for the failure of developing a working ternary computer in the US or Canada is closely connected to technology readiness and technology maturity:

- problem to design the relevant hardware
- problem to translate design on paper into working devices
- competing with existing binary hardware
- research in a complex field of scientific and/or military applications.

It is obvious that technology doesn't become into existence "out of nowhere". There is a historical, political and personal context that has to be considered. The article tried to follow the "carrier" of the Russian SETUN computer through early Western computer science. It could be shown, that the existence of the SETUN computer partly triggered awareness in the "West" or at least supported the ongoing research in form of an argument for own academic research projects and funding.

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Appendix A

List of Authors with more than 3 publications

Amount of Articles (single and co-author)	Author	Affiliation
7	Merrill, R. D.	Electronic Sciences Lab, Lockheed Missiles & Space Co., Palo Alto, Calif., USA
7	Vranesic, Z.G.	University of Toronto, Ontario, CA
6	Frieder, Gideon	State University of New York/ Buffalo, USA
5	Muzio, J.C.	University, Winipeg, CA
5	Mouftah, H.T.	Laval University, Quebec, CA
5	Rine, D. C.	Department of Statistics and Computer Science, West Virginia University, Morgantown, USA
4	Miller, D.M.	University, Winipeg, CA
4	Arango, H.	Department of Electrotecnia, Universidad Nacional del Sur, Bahia Blanca, Buenos Aires, Argentina
4	Santos, J.	Department of Electrotecnia, Universidad Nacional del Sur, Bahia Blanca, Buenos Aires, Argentina
3	Hasegawa	Kyoto University, Japan
3	Mine, H.	Kyoto University, Japan
3	Higuchi, Tatsuo	Department of Electronic Engineering, Tohoku University, Aoba, Aramaki, Sendai, Japan
3	Thelliez, S.	Universite de France Comte (?)
3	Yoeli, M.	Faculty of Electrical Engineering, Technion, Haifa, Israel
3	Varhshavsky, V.I.	Department of Mathematical Inst. of Academy of Science of the USSR, Computer Center of Leningrad, USSR

Appendix B

Examined documents on ternary logic, mathematics and computing

Author	Title	Publisher	SETUN mentioned
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