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Soviet Progress in the Production of Integrated Circuits

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SOVIET PROGRESS IN THE PRODUCTION OF INTEGRATED CIRCUITS

SUMMARY

1. The USSR is running hard, but so far futilely, to catch up with the United States in the field of integrated circuits (ICs). Production is less than 4% of US output, and the USSR lags 5 to 10 years behind the United States in IC production technology.

2. Although Moscow has vigorously pushed the development of ICs since about 1965, large-scale production (10 million or more devices per year) of simple monolithic ICs began only in 1972. Advanced types are at best manufactured only on a pilot basis. Moreover, a large share of Soviet annual IC output—perhaps as much as one-half—does not meet design requirements or quality standards.

3. Production yields are low because Soviet plants

- lack advanced manufacturing and testing machinery and techniques,
- maintain poor environmental standards and quality control procedures, and
- employ backward management techniques.

In most cases, production line equipment is of domestic origin. The most modern and productive Soviet IC production facility, the Mikron Plant in Zelenograd, is equipped mainly with Western machinery acquired illicitly outside embargo channels, or from non-COCOM countries.

4. The Soviet armed forces control the production of integrated circuits. An overwhelming share of ICs goes into military/space equipment such as guidance circuitry of air defense missiles, avionics equipment on fighter aircraft, and computers with special military applications. Because long lead times are needed to redesign military electronics hardware for ICs and to interface new-generation electronics with existing military systems, ICs are used only selectively in these applications. No new generation of military electronics equipment based exclusively on ICs has been identified. The brand new Soviet military hardware captured during the recent Mideast War—surface-to-air missiles, radios, and ground communications equipment—which would be logical candidates for microminiaturization did not incorporate ICs.

5. ICs have been sparingly used in Soviet civilian equipment. Civilian programs for third-generation computers, which potentially would need 75 million units per year, are just getting off the ground. At most, no more than 3 million ICs were needed in 1972 to meet all civilian requirements.

Note: Comments and queries regarding this publication are welcomed. They may be directed to of the Office of Economic Research.

6. The USSR, probably hoping to exploit East European acquisitions of Western IC production know-how, has sought joint IC development and production agreements with East European countries. An agreement with Poland, for example, followed quickly in the wake of Warsaw's successful negotiations with France for a turnkey IC production plant.

7. The USSR for many years has pursued every available means of obtaining IC production equipment and know-how from the West. The reliance on Western equipment acquired through various channels helps to account for both the successes and the failures of the Soviet IC program. Western equipment has filled gaps in the production process, making IC production possible at an earlier date. The piecemeal acquisition of technology, however, without supporting manufacturing know-how probably has reduced yields and the quality of the devices being produced. Substantial growth in the future in the quality and volume of IC output hinges upon the acquisition of Western know-how and equipment. The Soviets, as a consequence, will continue their intensive efforts to acquire Western equipment and technology for the manufacture of integrated circuits.

8. Unless there are substantial reductions in the international embargo of semiconductor production technology and equipment, Soviet progress in the development of a large and technologically advanced semiconductor industry will remain slow. Despite occasional diversions, the embargo has been generally effective in denying the USSR access to the advanced production technology needed to overcome its deficiencies.

DISCUSSION

Introduction

9. The explosion in integrated circuit technology over the last 15 years has revolutionized the electronic industries of the West. This revolution has made it possible to produce equipment of ever-increasing complexity and with size, weight, power consumption, and costs sufficiently small for practical use in a wide variety of applications. In particular, this new technology has permitted the development of military weapons and support systems not previously feasible.

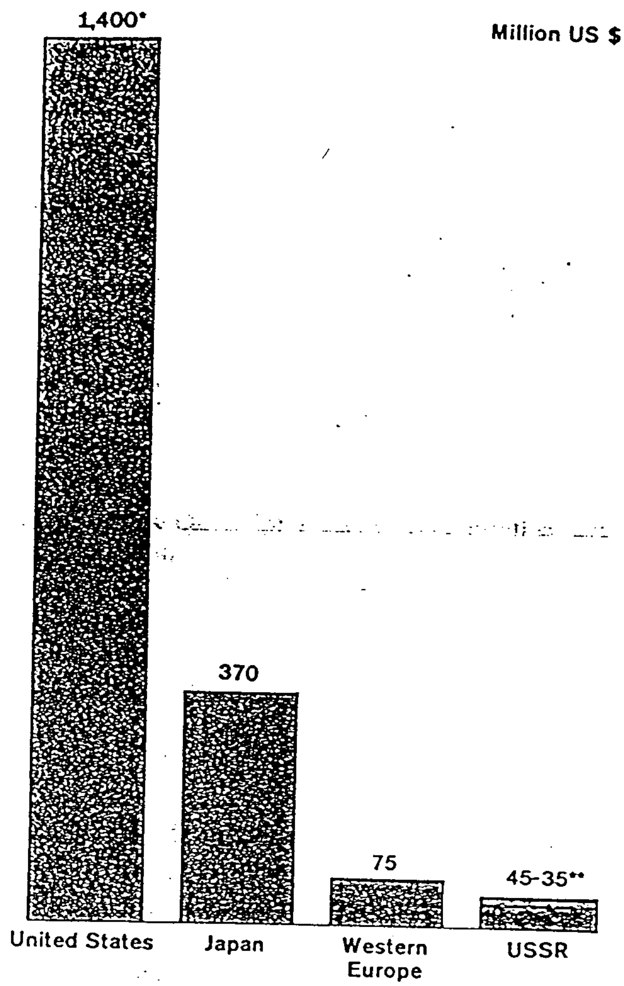
10. Since integrated circuits were first developed in the United States around 1960, the USSR has tried to develop an indigenous technology and to take advantage of the West's superior capabilities. This publication surveys the integrated circuit industry of the USSR in terms of the quantity and value of production, the types and quality of output, and the patterns of consumption. The publication does not discuss scientific issues in any detail and should not be taken as an analysis of Soviet progress in integrated circuit research and development. Appendix A provides a brief discussion of how Soviet IC production was estimated for recent years, and Appendix B contains basic terminology for the nontechnical reader.

Background

11. The United States is the world's major producer of integrated circuits and the world leader in integrated circuit engineering and manufacturing technology. In 1973, US firms, including wholly-owned foreign subsidiaries, produced integrated circuit devices valued at $1.4 billion, about three-fourths of world output, or four times the output of Japan and 19 times the output of Western

Figure 1

Estimated World Output of Integrated Circuits, 1973



*Including output of foreign subsidiaries of US firms.
**Physical output valued at the average world market price of $0.85 per unit.

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Europe (see Figure 1).[1] Output of ICs in the USSR in 1973, valued at the average world market price, amounted to $35 million to $45 million, less than 4% of US output.

12. The United States also is the major exporter of ICs. In 1972, ICs valued at about $140 million were exported, mostly to Western Europe and Japan. US exports and sales abroad by wholly-owned US subsidiaries supply about 70% of West European and one-third of Japanese requirements for ICs. These shares may be increasing; US exports of ICs during the first half of 1973 were up

[1] US output of semiconductors (transistors, diodes, rectifiers, and ICs) amounted to $2.8 billion in 1973, about 60% of world semiconductor output.

dramatically over the corresponding period in 1972. Sales to Western Europe doubled and those to Japan were up by three-fourths. Increased sales to Japan, stimulated by the easing of Japanese import restrictions, could further strengthen US domination of the world integrated circuit market.

13. The United States has pioneered nearly every major advance in IC manufacturing technology. Through sales of patents and licenses and the direct transfer of know-how to wholly-owned subsidiaries, US manufacturing technology has spread to Western Europe and Japan. Nevertheless, because of continued rapid advances in semiconductor technology in the United States, no West European country or Japan has been able to achieve overall technological parity with the United States.

14. Although integrated circuits were initially developed for military application, the share of IC output used for military/space applications has declined steadily in the United States. Rising yields and falling costs have resulted in dramatic reductions in price and a remarkable expansion in commerial applications. The average price of an integrated circuit fell from $8.33 in 1965 to $1.03 in 1972; during this period the military/space share of US output fell from 50% to 16%.

15. The decline in the military/space share of IC output masks the increasing military importance of IC technology. As the reliability and performance of all types of ICs have improved, applications of ICs to military electronics systems have expanded. In the United States, military procurement of ICs grew from FY 1971 to FY 1974 by 22% (from $143 million to $175 million) while the procurement of military electronics hardware declined by 14% (from $4.9 billion to $4.2 billion).

The Soviet IC Program

16. The development of integrated circuits in the USSR has been pushed on a priority basis since about 1965. Although interested in IC technology as early as 1960, the USSR lacked the precision equipment and technical know-how needed to translate known scientific principles into laboratory prototypes. Soviet microelectronics technology was still rudimentary in 1965: technical handbooks and other literature to aid designers were unavailable, and specialized facilities for training technicians and designers were practically non-existent. Also, having opted early for germanium as the basic raw material for the production of semiconductor devices, the USSR failed to exploit the R&D experience in silicon epitaxial and planar processes that had been the basis for major semiconductor developments in non-Communist countries.

17. In the USSR, a decision to push the development of silicon technology may have been made in the early 1960s when construction began on a large new development/production complex for the USSR Ministry of the Electronics Industry at Zelenograd. This complex, which was built at a priority pace and came into operation in 1965-66, has become the leading scientific center in the USSR for the advancement of silicon semiconductor state-of-the-art. Zelenograd produced the first Soviet silicon epitaxial-planar transistor (1965) and the first monolithic IC based on silicon (1965). Subsequently it has carried out major development work on hybrid ICs, bipolar transistor-transistor logic (TTL)

devices, and, most recently, metal-oxide semiconductors (MOS) and emitter-coupled logic (ECL) devices.[2]

18. The USSR has continued vigorous efforts to develop monolithic ICs from germanium,[3] using planar epitaxial processes. In the United States, similar efforts were abandoned by most firms[4] early in the 1960s. In part, the USSR has succeeded where US firms earlier had failed. Germanium ICs were developed in the late 1960s and apparently now are being produced in small quantities. Yields, however, are reported to be very low and quality and reliability unsatisfactory. The highly efficient production techniques that work so well with silicon are not readily adaptable to germanium.

19. By 1968 the Soviet IC program, apparently with high-level backing and priority funding, was in high gear. A large number of institutes and design bureaus had been drawn into the program, and a few new experimental plants had been built to speed the transition from laboratory prototype to series production.[5] Some hybrid ICs already were being produced, although in only small quantities. At the same time, more than 200 prototypes of monolithic ICs had been developed. Moreover, epitaxial-planar transistors had entered series production, indicating that the USSR had assimilated the basic processes for the production of monolithic ICs.

Military versus Civilian Requirements

20. The Soviet IC program has strong military overtones. One source has said that the great majority of all the ICs produced in the USSR were intended for military applications. According to this same source, a senior Soviet official[6] responsible for IC production has stated that "ICs are used almost exclusively for military and space equipment."

21. Most Soviet design bureaus and plants engaged in IC research and development have dual subordination: to the Central Scientific Institute No. 22 of the Ministry of Defense, which approves and monitors defense-oriented IC development projects; and to the Management (Direktsiya) of the Scientific Center, Zelenograd,[7] which plans and finances IC research and development. The activities of the Scientific Center, in turn, are at least partially controlled by the Military-Industrial Commission[8] which, according to the source, "initiates, monitors, and terminates all defense-related IC development and production programs." In addition, the military representatives assigned to practically all development and production facilities apparently have broad powers—even

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[2] For definitions of technical terms, see Appendix B.

[3] Germanium is inherently faster than silicon but more unstable at higher operating temperatures.

[4] A major exception, IBM continued R&D efforts in germanium ICs until at least 1969.

[5] The experimental plants of design bureaus develop the production engineering for factories.

Subordinate to the MEP.

[8] Including ministers of defense-related ministries, high-ranking Party officials, and technical experts from industry.

to interfere, if necessary, in the production process. For example, the transistor production line at the Svetlana Plant in Leningrad reportedly was "frequently shut down by military representatives for not meeting specifications."

22. Because of the extraordinary secrecy surrounding the development, production, and use of ICs in the USSR, information on major military weapons systems that use or are intended to use ICs is scarce. ICs reportedly are produced for use in naval avionics equipment, avionics for military fighter aircraft, navigation instruments for various military systems, and special application military computers. Also, it has been reported that monolithic circuits, nicknamed Logika-2 and developed during 1970-72, are being used in the guidance circuitry of missiles used in the Moscow air defense system. Other reports indicate that ICs, including monolithics, have been used to build a variety of laboratory test and measuring instruments, probably as unique items or on a few-of-a-kind basis for use in the development and production of electronic hardware for military/space purposes.

23. In general, ICs seem to be used only in the highest priority military applications. Many new items of Soviet military hardware—surface-to-air missiles, radars, and communications equipment—were captured during the recent Mideast War and now are under technical exploitation in the United States. The electronic circuitry of this equipment consists mainly of vacuum tubes and germanium transistors (the component technology and design is of the late 1950s), not ICs.

24. The USSR uses a small portion of its ICs in civilian electronics equipment. Major civilian users include Soviet producers of third-generation computers, especially RYAD general-purpose data processing computers patterned after the IBM-360 series, and minicomputers designed for industrial process control applications. Because these programs are far behind schedule, they use only a few million ICs annually. They represent a large potential demand, however—on the order of 75 million units annually. The USSR plans to microminiaturize industrial instrumentation and civil communications equipment using ICs. So far, this kind of equipment has not been produced serially.

Path of Development

25. The development of more complex integrated circuits and new circuit families in the USSR has generally followed the same sequence as in the West,* although with a substantial time lag. Indeed, the Soviet IC development program may be primarily oriented to copying Western products and technology instead of developing native innovations. For example, A. I. Shokin, Minister of the USSR Electronics Industr directed that US (and other foreign) IC and solid-state technology be reproduced at the Mikron facility in Zelenograd. To aid in the assimilation of foreign developments, process technology copied from a major US producer of ICs was introduced in Mikron in about 1971, and vacuumization and climatology conditions described as the best in the USSR were established. Subsequently, Shokin criticized Mikron for being slow to copy Western circuits. By copying Western IC developments, the

* The chronology of development is as follows: hybrids; monolithic small-scale integration (SSI) types—digital, then linear; medium-scale integration (MSI); and large-scale integration (LSI).

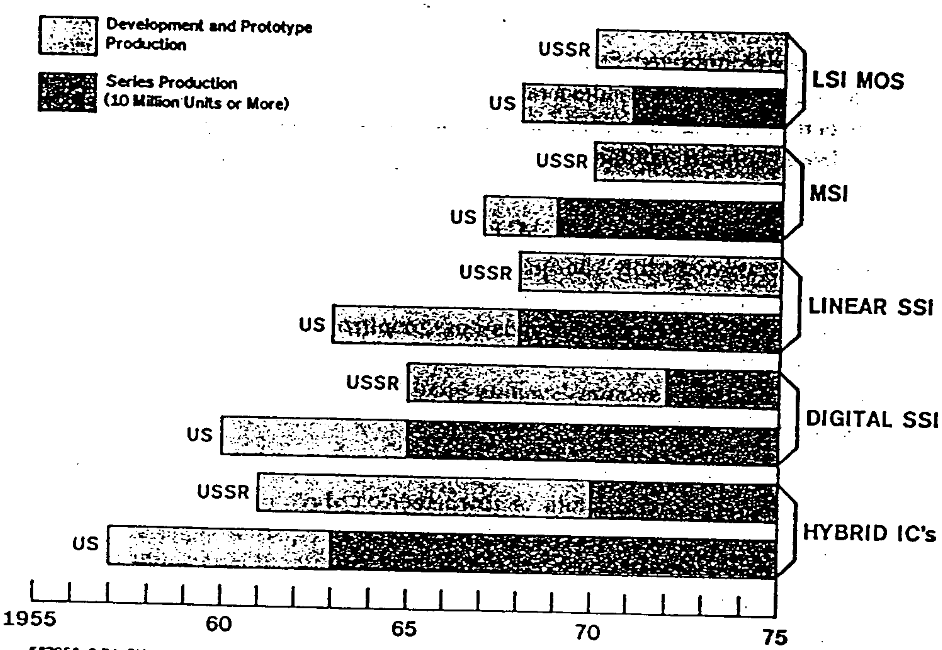
USSR saves on R&D costs and valuable development time. While economical, this strategy condemns the USSR to remain considerably behind the West in IC technology.

State-of-the-Art [10]

26. Currently, the USSR is serially producing hybrid ICs and monolithic digital ICs of SSI complexity, mainly DTLs and TTLs. Linear ICs probably are being produced in pilot-scale quantities. More advanced digital devices—ECLs, TTLs of MSI complexity, and MOS/LSI—have been manufactured as prototypes but are still largely in the development phase (see Figure 2).

USSR and US: Development and Production of Integrated Circuits

Figure 2



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27. Soviet state-of-the-art in both hybrids and monolithics, as reflected in technical evaluations of Soviet ICs by US experts, is at least 5 years behind US technology. Progress has been greatest for TTLs (SSI) and for ECLs, and the Soviet-US technology gap for these devices has been narrowing. For high-density devices—MSI and LSI—progress has been slow, and the gap is widening. MSI and LSI devices have already been under development in the USSR for 4 years, whereas the development cycle in the United States lasted only 2 years

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[10] Soviet ICs of the following types and dates of manufacture have been acquired for evaluation in the United States: hybrids—1969, 1971, 1972, 1973; diode-transistor logic devices—1969 and 1974; resistor-transistor logic devices—1970; transistor-transistor logic devices—1971, 1972, 1973; emitter-coupled logic devices—1972, 1973; and metal-oxide semiconductors—1971, 1973.

and 3 years, respectively. Improvements in the Soviet state-of-the-art for individual types of ICs are discussed below.

28. Series production of a few simple types of *hybrid circuits*, consisting of either thin- or thick-film resistor networks with one or more discrete transistors, began in the USSR around 1968. The technology embodied in these devices resembles that of US devices of the early 1960s; they now are being supplemented by more advanced hybrids, thin-film circuits employing 18 to 30 transistors, and more recently, by several types using up to 10 monolithic IC chips per circuit. These advanced circuits match the performance, although probably not the reliability, of standard hybrid types available in the United States. Soviet state-of-the-art, however, falls far short of many hybrid devices custom-made in the United States to meet extraordinarily complex design requirements. The United States, for example, manufactures multi-layer thick-film ceramic hybrids that use advanced processing techniques [11] and achieve high levels of microminiaturization; the USSR does not.

29. Advances in the design of Soviet hybrids reflect improvements mainly in thin-film preparation techniques. Deficiencies in Soviet thin-flm networks—peeling and blistering were noted in devices produced in 1970 or 1971—seem to have been corrected. The preservation of the contents of the encapsulated package from outside contaminants—hermeticity integrity—may still be a problem.

30. *TTLs* constitute the bulk of *monolithic* IC output in the USSR and have improved considerably during the past three years. Samples of 1973 Soviet TTLs with medium power and speed have propagation delay times [12] (speed) on the order of 10 nanoseconds (ns), compared with 20 ns for the same series of devices manufactured in 1971. In addition, current TTL devices reflect major improvements in key areas such as bonding, mask-alignment, gold doping, and passivation of metalization.[13]

31. The USSR has developed but apparently has not yet produced *monolithic ECL devices* of exceptionally high performance. Laboratory tests on recent Soviet samples demonstrated performance characteristics equal or superior to most ECL devices now available off-the-shelf in the United States. For example, the Soviet ECLs operated at a speed of 1.5 ns (compared with about 2 ns for common US types) but are slower than the most advanced ECLs available on a custom-made basis in the United States (0.7 ns). The reliability of Soviet devices has not been established.

32. ECL devices of the type that have been tested in the United States probably are not yet available for commercial use. We know that a prototype of one model in the RYAD computer series—the ES-1050—was built with ECLs of a much lower state-of-the-art (slower and less dense). Because the ES-1050 depends upon high-speed ECLs to meet its design capabilities, the more advanced type probably would have been used if they had been available.

[11] One of these techniques, the beam lead process, is an advanced bonding technique that overcomes a major cause of low yields in IC production and greatly improves reliability.

[12] Time required to pass an electrical impulse from one circuit to another. In the United States, some more advanced TTLs (schottky) have reached very high speeds of 5 ns and less.

[13] The process of protecting the device from contamination and other damage during critical processing steps by oxidizing the silicon wafer to form an impenetrable surface of silicon dioxide (glass).

33. The development of MSI/LSI monolithic ICs, despite 3 to 4 years of intensive work, is still at an early stage in the USSR. Current Soviet devices are like the pioneering devices produced in the United States in 1968 and are slower and much larger than current US counterparts. Because larger devices use more silicon material, they contain fewer circuits per wafer of silicon, incur lower yields of usable circuits, and involve higher manufacturing costs. Soviet MSI/LSIs are not now competitive with Western-made devices. Unless speeds are increased and wastage reduced, they may even not be competitive with Soviet SSI devices.

34. *Linear devices* have been under development in the USSR since about 1968. Soviet linear devices are still outdated by US standards, being equivalent in design technology to the earliest devices made in the United States in 1967. Work on linear devices may have suffered because of the more urgent requirements for digital devices. In any case, Soviet state-of-the-art in monolithic linear ICs is 1 to 2 years behind Soviet digital IC technology.

Production

The Role of ICs in the USSR

35. Semiconductor production in the USSR still consists overwhelmingly of conventional transistors and diodes. Germanium devices comprise a large share of these, possibly the largest.[14] The production profile is changing; a major shift to silicon is under way, and integrated circuits are beginning to represent a substantial share of total output. Nonetheless, output of conventional semiconductors has not yet peaked and is likely to continue to dominate the product mix, at least through 1975 (Table 1).[15]

Table 1

USSR: Estimated Output of Semiconductors

Million Units

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Total	49	87	130	182	254	355	426	511	613	736	868	999	1,153	1,415–1,425
Conventional semiconductors	49	87	130	182	254	355	426	510	611	729	852	979	1,123	1,375
Transistors	14	27	43	60	85	125	142	203	243	287	347	409	483	575
Diodes	35	60	87	122	169	230	284	307	368	442	505	570	640	800
Integrated circuits	....	....	....	....	Negl.	Negl.	Negl.	0.5	2	7	16	20	30	40–50
Hydrid	....	....	....	....	....	....	....	0.5	1.5	6	12	15	20	20–25
Monolithic	....	....	....	....	....	....	....	Negl.	0.5	1	4	5	10	20–25

36. Continued output of conventional semiconductors is dictated by high demand. Many items of electronics hardware of recent design and manufacture, both civil and military, use conventional transistors, diodes, and even tubes. Designers of conventional military equipment strongly resist change and prefer to design around proved components. Moreover, the redesign of equipment to use ICs can be a protracted process lasting several years.

[14] A list of semiconductors in production in the USSR compiled by the National Bureau of Standards, Department of Commerce, shows that, as of December 1973, germanium types of transistors outnumbered silicon types by 2:1 (*Tabulation of Published Data on Electron Devices of the USSR Through December 1973*, in publication).

[15] For a discussion of the production estimate, see Appendix A.

37. Estimates of total IC production as given in Table 1 seem large relative to known civil and military end-use. For example, no more than 3 million devices would have been needed in 1972 to meet all civilian requirements, leaving 27 million ICs available for military/space use. But we have not been able to identify any military program, or combination of programs, that could account for that number of ICs. In the United States, which makes extensive use of ICs in military electronics equipment, consumption for military/space purposes in 1972 is estimated at only about 100 million units. A recent report covering a Soviet military-related institute, believed to have a high priority, stated that in 1971 and 1972 there was great difficulty in procuring even the minuscule quantities of ICs needed—batches of 20 devices at a time. Estimated Soviet civil and military consumption of ICs for the years 1970 and 1972, is shown in the following tabulation:

	1970	1972
	Million Units	
Total	16	30
Civil	less than 1	3
Military (residual)	15	27
	Percent	
Military as percent of total	95	90

38. The output figures in Table 1 and the tabulation are based conceptually on the number of ICs delivered by producers (see Appendix A) and must therefore, be considered gross output. The discrepancy between output figures and identified requirements almost certainly results from a high rejection rate in users' production facilities. According to one source, as much as 50% of the ICs delivered to computer manufacturers in 1972 were rejected because they failed to meet quality standards. The percentage of rejects by military users also may be high because of the rigorous requirements of military designers for durability and reliability.

39. Other factors affecting the quality of output in the USSR include the lack of adequate IC test equipment and poor quality control procedures. Also, under present incentive systems, managers and workers are more concerned with quantity than quality of output.

The Industry

40. The Soviet IC industry is highly concentrated. Three plants produce the lion's share of the output. Fifteen other plants produce smaller amounts usually at a less advanced level of technology.

IC production may exist in an additional 11 plants (see Figure 3 and Table 2).

41. The Eksiton Plant with 10,000 workers is believed to be the largest Soviet producer of hybrid ICs. The Mikron Plant, the most modern and technologically advanced semiconductor facility in the USSR, is the largest Soviet producer of monolithic devices. Much of the production line machinery and equipment in the plant is almost certainly of Western origin. The Radio Parts Plant is the second largest producer of monolithic ICs, and the first Soviet plant known to have serially produced monolithic devices.

Table 2

USSR: Known Integrated Circuit Plants[1]

LOCATION	PLANT
Major Producers	
Moscow (Zelenograd)	Mikron
Pavloposad	Eksiton
Voronezh	Radio Parts
Other Producers of Unknown Size	
Bryansk	Lenin Electrical Engineering
Fryazino	Semiconductor
Kiev	Tochelektropribor
Kishinev	Mion
Leningrad	Svetlana
L'vov	Electrovacuum Devices
Minsk	Unknown
Moscow	Mosmuzradio
Moscow (Zelenograd)	Angstrem
Moscow (Zelenograd)	Komponent
Novosibirsk	617
Riga	Semiconductor Instruments
Shadrinsk	Telephone Equipment
Siauliai	Nukleon
Tashkent	Tube and Lamp No. 191
Locations of Other Plants Where IC Production May Exist	
Dnepropetrovsk	
Kherson	
Nal'chik	
Rybinsk	
Saransk	
Sverdlovsk	
Tallin	
Tbilisi	
Ul'yanovsk	
Vitebsk	
Yoshkar-Ola	

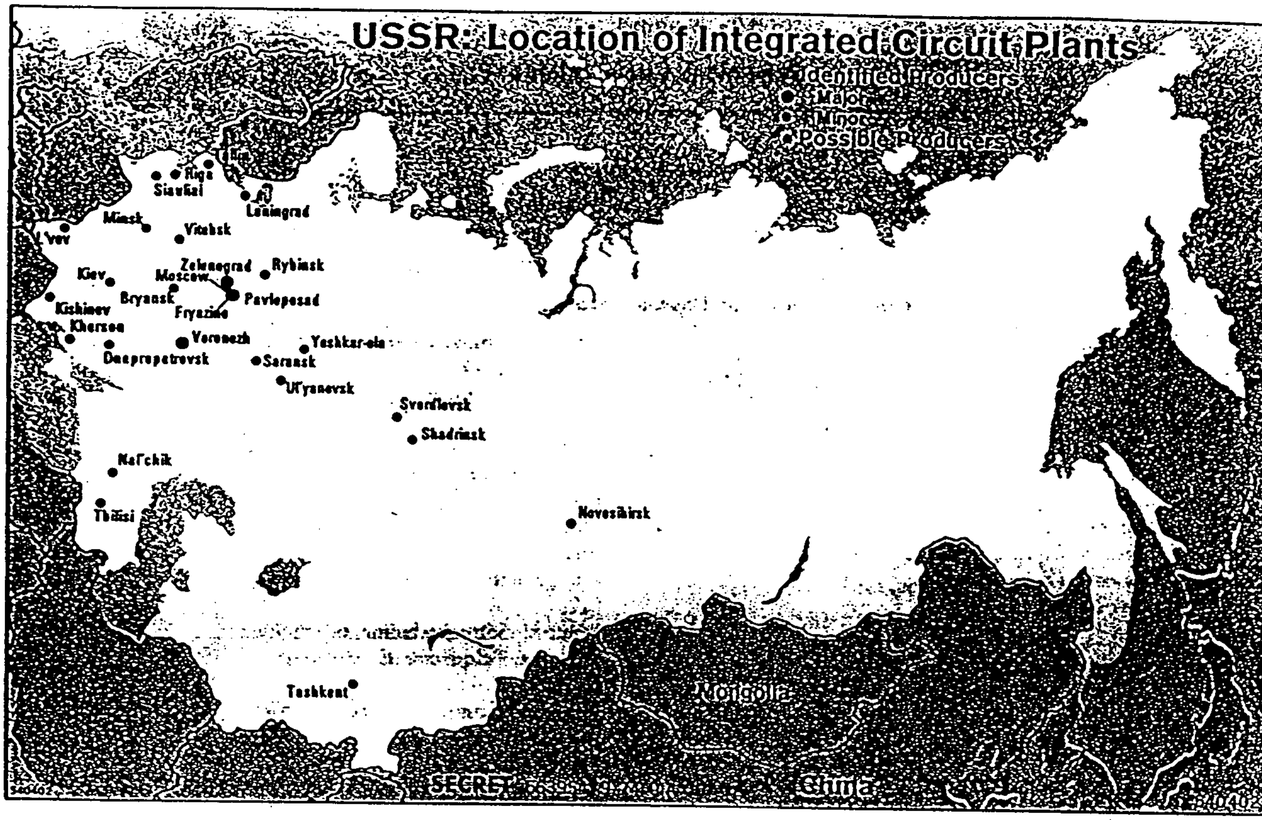
[1] Facilities known to be experimental producers such as the Vilnyus Design Bureau are not included.

42. Most of the remaining facilities have begun production of ICs only since 1971. They are believed to be specialized producers of a limited range of devices for special high-priority applications. A few plants—Komponent in Zelenograd, Nukleon in Siauliai, and Mion in Kishinev—are relatively new facilities devoted exclusively to the production of ICs. They probably will become major producers in the future.

Manufacturing Technology

43. Soviet IC production processes are backward and inefficient by US standards.

- A surprisingly small portion of the production processes are automated;
- Computer-aided design techniques are not used, so far as we know;



USSR: Location of Integrated Circuit Plants

- Quality control procedures and standards, and environmental controls (ventilation, cleanliness) over sources of contamination at crucial processing steps, are poor or non-existent; and
- Production proceeds by rule-of-thumb formulas, with no real program evaluation and review techniques.

44. The technology for quantity production of materials used in manufacturing IC devices also appears to be inadequate. High-quality silicon, ceramics, and special chemicals (e.g., photo resists) are in chronically short supply, even in design bureaus where requirements for these inputs are relatively small.

45. Soviet semiconductor plants operate with outdated equipment—according to some US observers, comparable to equipment in US facilities 5 to 10 years ago.[16] Although the major Soviet plants rely on key Western equipment, most of the machinery in the industry is Soviet-made. Indeed, much of the production line equipment appears to have been fabricated by the user facilities, a factor in the wide variations in the quality of devices produced by different plants. According to recent information, the Soviet semiconductor industry is now under pressure to obtain additional US-made IC manufacturing equipment. The

[16] Soviet brochures describe a variety of production equipment of modern design comparable to recent Western state-of-the-art, including advanced step- and repeat-cameras and pattern generators, multitube diffusion furnaces, and a mechanized packaging system somewhat similar to the US mini-mod system. But none of these items has ever been observed in Soviet production facilities, and it is doubtful that many are in wide use.

Soviets suggested to one US manufacturer that, although such equipment is embargoed, it could be shipped to a third country, "sanitized," and re-shipped to the USSR.

46. A major weakness in Soviet IC manufacturing technology is the absence of computer-controlled test equipment and diagnostic systems. Soviet testers used in both probe and final test stages are simple, manually-operated machines which are greatly inferior to Western-made systems. Soviet-made testers appear to be copies of older Western systems. Some visitors to the USSR have alleged that a large proportion of Soviet test capability consists of illicitly acquired Western machines.

47. As a result of these deficiencies in the production process, yields as a percentage of usable ICs, after full processing, are extremely low in the manufacture of ICs in the Soviet Union. One source

revealed that the best yield on monolithic ICs achieved as of late 1972 was 4%, and that the highest yield claimed by any IC facility producing monolithics was 20% (at the Western-equipped Mikron Plant in Zelenograd). By comparison, yields above 50% are common in the United States in the production of the same class of monolithic devices.

Foreign Assistance

Cooperation with Eastern Europe

48. Aid from abroad has been instrumental in building the Soviet IC industry. Cooperation between the USSR and Eastern Europe in semiconductor technology has been mostly one-sided. The USSR has benefited from the results of R&D in Eastern Europe but has been less free in sharing its own technology. Only Bulgaria and Poland are known to have received any direct Soviet assistance. In 1970-71, Bulgaria received machinery and equipment for the production of discrete semiconductor devices (transistors and diodes); in 1971-72 Poland was given machinery for the production of transistors and certain types of ICs.

49. The more industrialized countries in Eastern Europe had managed by the late 1960s to advance beyond the USSR in selected areas of IC technology. For example, Czechoslovakia had begun pilot-scale production of TTL ICs in 1969, a year before the USSR, and recently Hungary may have achieved a higher level of development than the USSR in ion-implantation technology for MOS/LSI. In 1968, Poland took a major step toward the creation of the largest and most modern IC production capability in Eastern Europe. It contracted with SESCOSEM of France for a complete turnkey facility (machinery and technology) for the production of bipolar TTL devices, linear ICs, and epitaxial planar transistors.

50. The Polish-SESCOSEM contract was quickly followed by a Soviet agreement with Poland for joint development and production of IC devices, reflecting a new Soviet policy of closer and mutual cooperation with Eastern Europe in semiconductor technology. The new Soviet initiatives probably were encouraged by the prospect of gaining access to Western IC technology.

51. The French IC facility was approved by COCOM in 1972—the first time that COCOM approved the sale of Western IC technology to any Communist country—and became operational this year. It will turn out an estimated

7 million ICs annually.[17] In addition, through arrangements (both legal and illegal) with other Western firms, Poland has, or soon will have, the capability to produce high-power silicon controlled rectifiers, thick-film hybrid ICs, poly- and monocrystalline silicon, and double-sided and multi-layer printed circuit boards.

52. The USSR also has cooperative IC development and production agreements with Bulgaria and Hungary. Bulgaria now has a small capability to produce MOS ICs, although current output does not appear to be sufficient to satisfy even domestic requirements. MOS ICs are of intense interest to the USSR. Bulgaria is seeking further Western assistance for MOS production and also wants to purchase MOS/LSI devices. Hungary and the USSR are jointly trying to develop ion-implantation production technology, which is now emerging as a major new process for large-scale production of high-density MOS and bipolar devices. Hungary is looking for Western help in this area and in the expansion of semiconductor production into more advanced areas of IC technology as well.

53. Cooperative agreements in semiconductor technology exist with Czechoslovakia and East Germany, although the specific areas of cooperation are not known. The Soviets may be working with East Germany in the design and manufacture of semiconductor production machinery. East Germany is the only country in Eastern Europe that designs and manufactures a full line of semiconductor production machinery, much of it for export to the USSR. While East German production equipment is markedly inferior to US equipment, improved new products are now at the prototype stage.

54. Levels of output of ICs in Eastern Europe are still too small (at most 10 million devices in 1973) to permit large exports to the USSR. Poland now may be in a position to supply the USSR with small quantities of high-quality, high-reliability devices useful for special-purpose military applications. In the next year or two, as Polish IC production reaches capacity levels provided by the French plant, Poland may be able to supply the USSR with enough ICs to aid substantially in the Soviet production of third-generation computers.

The Special Case of Yugoslavia

55. Yugoslavia probably has given a sizable boost to the Soviet IC program by reexporting semiconductor production machinery of US-origin to the USSR. Under a provision of the Soviet-Yugoslav Trade Agreement for 1971-75, Yugoslavia is to provide to the USSR "special technological equipment for the manufacture of semiconductors and integrated circuits," valued at $5 million. Yugoslavia, however, does not manufacture semiconductor production machinery and lacks the specialized machinery and technology needed to manufacture such equipment. Moreover, by the admission of senior officials of Iskra, one of the largest Yugoslav producers of electronics, Yugoslavia plans to continue to import, rather than produce, semiconductor production machinery.

56. Imports from the United States in 1969-73 amounted to $7 million, including 83 bonders, 15 diffusion furnaces (3-chamber models), and 4 Mann

[17] Calculated by French authorities on the basis of a low yield rate. Much higher output levels—15 million to 20 million units per year—ought to be possible as Polish yields approach Western standards.

step and repeat cameras. Imports from the United States alone would permit Yugoslavia to produce at least 50 million semiconductors of various types annually. Yugoslavia's semiconductor requirements are currently estimated at about 20 million to 30 million units annually.

Western Contributions to the Soviet IC Program

57. Soviet IC manufacturing facilities typically include an eclectic mix of production equipment from Western countries—mainly France, the United Kingdom, West Germany, and Switzerland—and Japan.

58. The cumulative value (or quantity) of Soviet capital purchases in the West is not known, but may be assumed to run into several million dollars. The value of test equipment and other unidentified equipment purchased from Japan alone in 1970-72 exceeded $5 million.

59. The USSR has purchased individual items of production equipment, usually without associated training, maintenance, or production technology. No complete, integrated, Western-manufactured IC production line has been observed in Soviet facilities. however, the USSR has purchased from France a complete plant for the production of semiconductors and ICs.

60. Since about 1970, Soviet efforts to acquire IC manufacturing machinery and technology in Western countries have been extensive and unremitting. The Soviets have sought industrial items across the entire spectrum of IC manufacture—including whole production lines and complete turnkey facilities. In addition, the Soviets are seeking technology for manufacturing all types of ICs including bipolar and MOS and LSI. They are particularly interested in US technology, and in agreements with US firms that will ensure the continuing transfer of future US technology.

61. Although total potential Soviet purchases of US equipment cannot be estimated, many Soviet feelers for individual machinery items have been valued at upwards of $100,000. Three purchase requests were staggering: 1,000 IC test stations, 1,000 diffusion furnaces, and 56,000 tons of silicone molding compound.[19] For some types of equipment, the Soviets expressed a willingness to pay exorbitantly high prices—up to 80% above the market price for high-volume bonders and advanced step and repeat cameras.

Prospects

62. The Soviet IC program is at the crossroads. If, as in the past, the USSR relies mostly on its own efforts, near-term progress along several fronts is likely

[18] Exports of strategic goods from Switzerland, which is not a member of COCOM, are not subject to embargo restrictions.

[19] Used for plastic encapsulation of semiconductors and ICs. Silicone also is used for other applications outside of the electronics industry.

to be moderate at best. First, output can be expanded by adding new production lines at existing IC facilities and by setting up IC production in some of the semiconductor plants that currently do not produce ICs. New plants also may come on stream. Existing facilities in Vilnyus and Siauliai have been scheduled to receive new plant facilities since 1972, and at least one new plant was to be put into operation at Zelenograd during 1972-75. Second, improvements in production yields, especially of low-density devices (DTLs and TTLs) can be expected as managers and workers gain experience with this complex technology. Yields probably will remain low by Western standards and production costs high, unless the Soviets are able to assimilate advanced production technology more rapidly than in the past. Third, Soviet state-of-the-art in advanced serially produced bipolar and MOS/LSI devices is unlikely to reach current US levels by the mid-1970s. By that time the technology gap could be enormous. MOS/LSI ICs in the United States currently have density levels of 4,000 bits per chip; these are expected to rise to 16,000 to 32,000 bits per chip by 1980.

63. If, on the other hand, the USSR could acquire IC technology and equipment from the West, progress in both the development and production of ICs could be rapid, depending upon the nature and extent of Western assistance. The USSR could obtain Western help in three ways:

- Large-scale purchases of IC production and test equipment for the modernization of existing plant facilities. Under this option, production yields and the quality of ICs now in production could be upgraded rapidly though probably not to Western standards unless related know-how also were included.
- Purchase of turnkey plants and technology for the production of advanced types of ICs, especially MOS/LSI.
- Joint R&D programs with private US and other foreign firms.

Implementation of any of these options would require a major relaxation in embargo controls.

64. In the short run, the Soviets are likely to view the first option as their most urgent need. Large-scale production of high-quality, high-reliability ICs of SSI complexity would permit the USSR to design and build complex military electronics hardware to satisfy most, and probably all, military requirements for several years to come, including those of the most advanced Soviet weapons systems. In addition, the USSR probably would be able to initiate mass production of third-generation computers for civil uses.

65. In the longer run, taking up the second option would permit the USSR to close substantially the current technology gap with the United States. The third option would enable the USSR to stay abreast of US advances in the state-of-the-art. In addition, joint R&D programs could help the USSR overcome institutional barriers that currently delay getting new products out of the laboratory and into industrial-scale production. Some joint programs already are provided for in the scientific and technical agreements recently signed with a few large Western electronics producers.[20]

APPENDIX A

Estimate of Soviet IC Production

With the help of new information, Soviet output of ICs can be estimated for 1970 and 1972 (16 million and 30 million units). "Output" refers to the number of units delivered by producers to end-users and, as explained in the text, is subject to a high rejection rate in the users' facilities. The 1970 output figure was given to a Soviet manager of a semiconductor plant by a high-ranking official of the Soviet semiconductor industry and seems reliable. The reliability of the 1972 figure, which is based on fragmentary plant data, is less certain. Output of ICs (hybrids and monolithics) at Voronezh in 1972 under existing 2-shift production conditions is estimated at 5 million units. One source reported that Voronezh was one of three plants having approximately equal levels of output that produced a "majority" of total Soviet IC devices in 1972. Thus, total output of ICs was on the order of 30 million units or less.

Quasi-official data also were provided by the same source for planned Soviet output in 1971 and 1972; the Soviets had hoped to produce 40 million to 50 million ICs in 1971, and 75 million to 100 million devices in 1972. These data are considered an unreliable guide to actual production:

- Accurate planning probably was not possible in the early years of this technologically complex industry. Yields of ICs are especially unpredictable because of their extreme sensitivity to differences in worker skills, production know-how, and the quality of manufacturing equipment. Even very small changes in yields are magnified into large changes in useful output.* Hence, it seems likely that planners grossly overestimated achievable yields in projecting output for 1971 and 1972.

- At levels above 30 million units per year, ICs almost certainly would begin to appear in consumer and commercial end-products. We have seen little evidence of this.

- The production of ICs depends heavily upon the uninterrupted flow of high-quality materials from suppliers outside the industry, over which the industry could exert little, if any, control. In fact, the uneven delivery of materials of varying quality was a major factor impeding production in 1970-72.

Estimating output after 1972 is even more difficult. With nominal improvements in yields and in the efficiency of IC manufacturing generally, Soviet production of ICs would be in the range of 40 million to 50 million units in 1973.

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*For example, an increase in yields from 10% (90% of output is defective) to 15% results in a 50% increase in useful output.

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APPENDIX B

Basic Terminology

Integrated circuits (ICs) are miniaturized assemblies in which both electronic components and their interconnections are formed by diffusion, implantation, or deposition of materials into or onto a common substrate. Electronic components in an integrated circuit normally include both active (transistors and diodes) and passive (resistors, capacitors, and occasionally inductors) types. Most ICs may be classified as *monolithic* and *hybrid*. In monolithic types, active and passive components and interconnections are formed within or upon a semiconductor substrate, usually silicon. Monolithics are classified as SSI, MSI, or LSI (small-, medium-, or large-scale integration) types, in increasing order of circuit complexity and number of components per IC. In hybrid types, passive components are formed as films on an insulating substrate, such as ceramic, and separate active components are attached by bonding.

The monolithic process lends itself to high-volume production and the manufacture of complex structures. The hybrid process tends to be limited to low-volume applications and the production of less complex structures or circuits with special requirements (such as high power output or high operating frequency) beyond the reach of monolithics. Generally, manufacturing techniques for hybrids are simpler than for monolithics, although in some cases individual active components in a hybrid may be high-technology products.

Hybrid ICs are of two types: *thin-film* and *thick-film*. In the thin-film type, passive components and interconnections are deposited as films by sputtering or evaporation. In the thick-film type, passive components and interconnections are formed by a silk screen process. The thin-film process provides a higher degree of precision in dimensional tolerances and tends to be used when small packaging or a microwave frequency capability is required. The thick-film process is more appropriate when small packages, tight dimensional controls, and high-frequency capability are not required.

Monolithic ICs are also of two types, *bipolar* and *MOS*. Bipolar devices are so-called because they use both negative (electrons) and positive (holes) charges as carriers of electrical current. MOS (metal-oxide semiconductor) devices, by contrast, uses either electrons (nMOS) or holes (pMOS). A monolithic IC that incorporates both pMOS and nMOS is called CMOS (complementary MOS). Both bipolar and MOS devices require the same kinds of manufacturing equipment but employ different manufacturing techniques. Bipolar types were the first to be developed; MOS IC technology is of recent origin, since about 1968.

Many families of bipolar ICs, each with variations in circuit design or production technology, have evolved over the years, notably (in order of development): resistor-transistor logic (RTL), diode-transistor logic (DTL), transistor-transistor logic (TTL), and emitter-coupled logic (ECL). Currently, mostly TTL and ECL are used for new equipment design.

ECL, CMOS, and TTL are widely used in general-purpose logic elements. ECL is the fastest, CMOS consumes the least power, and various types of TTL provide a tradeoff between these two key electrical characteristics. TTL and the nMOS and pMOS ICs are widely used in memory or other circuits in which the IC, or major segments of it, is composed of large numbers of identical circuit elements. In general, MOS structures are less complex than bipolar equivalents, permitting denser packaging of components. Hence, when used as memories, they have higher capacity or require less space for the same capacity. Bipolar devices are faster.

Finally, ICs may be classified as *digital* or *linear*. Digital devices operate like a switch; they control the flow of current and thus are widely used to perform logic, storage, and arithmetic operations in digital computers and similar equipment. Linear ICs respond to a continuously varying signal; common uses include amplifiers or voltage regulators. Many ICs have both digital and linear functions included in the same circuit.