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ECONOMIC INTELLIGENCE REPORT

PRODUCTION OF SEMICONDUCTOR DEVICES IN THE USSR

CIA/RR 59-44
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CENTRAL INTELLIGENCE AGENCY

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SECRET

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S-E-C-R-E-T

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FOREWORD

This report represents an initial inquiry into production and utilization of semiconductor devices in the USSR. The report explores the extent and direction of the Soviet effort in semiconductor electronics and provides a comparison of Soviet and US economic capabilities in this new and rapidly expanding sector of electronics technology.

The emphasis in this report is placed on production of audio- and radio-frequency diodes and transistors, the semiconductor devices which are rapidly acquiring great economic and strategic importance as functional substitutes for electron tubes. The report thus provides a broad base for the assessment of future rates of growth in the Soviet electronics industry

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PRODUCTION OF SEMICONDUCTOR DEVICES IN THE USSR*

Summary

In spite of intensive Soviet study of the basic physics of semiconductor devices,** the USSR consistently has lagged at least 2 to 4 years behind the US in production of these devices. This timelag applies not only to quantities produced but also to introduction of progressively more advanced devices. Although the timelag applies most specifically to Soviet production of transistors, available data indicate a similar timelag in production of germanium and silicon diodes.

During 1958 the USSR produced approximately 24.5 million germanium and silicon semiconductor devices*** compared with 132 million produced in the US during that year. Of these totals, transistors accounted for 4.5 million units in the USSR and 47 million in the US. Available information indicates that although US production of germanium and silicon semiconductor devices in 1958 was more than five

* The estimates and conclusions in this report represent the best judgment of this Office as of 1 August 1959.

** The term semiconductor device in relation to electronic components refers to a solid-state device the function of which is based on the electrical properties of materials that fall in the fourth valence group in the periodic table of the elements or of binary alloys that exhibit similar properties. The semiconductor devices most frequently used at present are designed for alternating current (ac) rectification, for electronic switching, and for the detection or amplification of audio-frequency (af) or radio-frequency (rf) energy. In these functions, such devices can accomplish many of the active circuit functions which previously were performed only by electron tubes.

*** In this report, primary emphasis is placed on the af and rf diodes and triodes (transistors) produced from germanium or silicon, the semiconductor devices which have exhibited the most important strategic and economic influence in the past few years. Brief consideration also is given to the more conventional selenium, copper oxide, and magnesium copper sulphide diodes. Semiconductor devices operating on principles of sensitivity to light, heat, infrared, and magnetic fields are not discussed specifically, because of the absence of information on the production schedules for these devices. For a more specific consideration of the use of semiconductor devices and production technology, see Appendixes A and B, respectively.

times that of the USSR in terms of physical units and more than six times that of the USSR in terms of value, the projected rate of growth in production of these devices is about the same. In 1958 the value of production of all types of semiconductor devices was $26.7 million* in the USSR and $228.7 million in the US. Present indications, therefore, are that during the next 5 to 7 years the US will maintain a substantial lead over the USSR in the quantity of production of semiconductor devices. From the start of series production in mid-1956 to the spring of 1959, however, the USSR has achieved relatively significant gains in acquiring the materials, technology, plant facilities, labor skills, and experience needed to produce on an industrial scale some newer types of relatively sophisticated transistors and diodes and undoubtedly will continue to make rapid progress in this field. Nevertheless, as of early 1959 the USSR is believed to have remained materially behind the US in the quality and diversity of the semiconductor devices produced as well as in the volume of production.

The USSR has been slow in incorporating the more important of its semiconductor devices into finished equipment. The relatively unsophisticated germanium diodes have been used widely in television and radio sets designed for entertainment and, at a time when production goals for electron tubes were being underfulfilled consistently, were a valuable supplement to production of electron tubes. Diodes have been used also in electronic computers. In contrast to the use of diodes in the USSR, however, Soviet progress in the application of transistors has been slow and unimpressive. Open literature abounds with descriptions of prototypes of a wide range of end items in which transistors have been used, but actual production of such items has been either nonexistent or negligible. Although the quantity and quality of production of transistors in the USSR in 1958 would have supported moderate levels of production of equipment using transistors alone in place of tubes, these levels were not achieved. Even in 1959, when significant advances in both quantity and quality of production apparently are occurring, there are no indications of the large-scale use of transistors in finished equipment.

Similarly, there is no indication that any significant scale of production has been achieved in specialized auxiliary electronic components required for use with transistors. As a result, it is estimated that at least by the end of 1958 most of the transistors produced in the USSR were being utilized within the Soviet electronics industry itself for purposes of training and for development of prototypes. On the basis of the introduction of silicon transistors and more advanced germanium transistors in late 1958 and the achievement of increased production by 1959, it is estimated that equipment which

* Dollar values are given in current US dollars throughout this report.

contains transistors and is of greater sophistication will be produced on an industrial scale during 1959 and increasingly during the Seven Year Plan (1959-65). Although the highest priority in the use of these devices will be accorded to military applications, the plant production, which inevitably includes a considerable quantity of medium-quality and poor-quality units which do not meet the military specifications, will make significant quantities available for use in less demanding industrial applications and in consumer equipment, such as hearing aids and radio receivers.

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1. Introduction

Basically, production and utilization of semiconductor devices as electronic components have been developed since World War II. In the period before 1940, semiconductor devices were limited to a narrow range of materials and devices used largely as ac rectifiers and as devices sensitive to light and heat. Since the successful development of triode elements capable of operating at audio and radio frequencies, the rate of growth of this component sector of the electronics industry has accelerated sharply in all countries that are major producers of electronics.

So far the capability of the USSR in the development of semiconductor devices has been studied almost exclusively from the purely scientific and technical point of view,* inasmuch as the magnitude of the Soviet production effort has been relatively small. Even in the West, which has maintained a significant lead in production of semiconductor devices, no important aggregate economic effect was noticeable until very recently. Since 1950, however, productive capacity of the Soviet electronics industry has been expanding steadily, and since about 1953 Soviet production capability in semiconductor devices has begun to show vigorous growth. [redacted] 50X1

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The semiconductor devices most frequently used at present in electronic circuits are designed either to rectify, to amplify, or to detect af and rf energy.** In these uses, such devices can accomplish

[redacted] 50X1

** In addition to these functions, devices employing other properties of semiconductor materials are being used increasingly in such applications as the detection of light energy and magnetism, the direct conversion of heat into electricity, and the extraction of heat by electricity.

many of the active circuit functions which previously were performed only by electron tubes. Because of their extremely small size, decreased requirements for power, and higher efficiency, semiconductor devices are frequently greatly superior to electron tubes. Although the degree of substitution of semiconductor devices for electron tubes is far from complete, the range of possibilities for substitution is increasing continually.

The USSR has concerned itself deeply with the basic theory of semiconductors and appears to have developed a high degree of competence in this field. Soviet work in crystallography provides an excellent background for the production of semiconductor devices. The range of Soviet investigations with respect to basic material apparently has been considerably broader in scope than the equivalent work in the West, and the laboratory equipment which has been seen by the Western visitors has been of excellent quality. 2/

In spite of the great emphasis in the USSR on scientific research on semiconductors, present Soviet capabilities for production of transistors and diodes are based primarily on Western technological developments and appear to lag behind Western practice by at least 2 to 4 years. Western production techniques in this field have been described in detail in Western technical journals that are readily available to Soviet workers in the field.

In the USSR as in the West, currently produced af and rf diodes and transistors are made almost entirely from either germanium or silicon. There is no evidence of shortages of basic raw materials in the USSR. Soviet Donets coal contains a relatively high percentage of germanium, and silicon is one of the most abundant of the elements. These basic raw materials, however, must be processed very carefully by the manufacturer of crystal to achieve the desired electrical properties. Unless this process is carried out under very precise temperature and atmosphere controls, a low yield of usable product is obtained, because of the wide spread of the parameters of the crystal. [redacted] 50X1
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There is, nevertheless, some evidence of shortages of sufficiently pure germanium for use by the Soviet producers of semiconductor devices.

Germanium crystals reportedly are supplied to the electronics industry by chemical plants in the USSR, primarily from the Kalinin Coke and Byproducts Plant in Dnepropetrovsk. 4/ Soviet press comments have indicated the need for improvements in both quantity and quality of production. 5/ [redacted] 50X1
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[redacted] No information is available on Soviet capabilities 50X1
in production of silicon crystals. However, inasmuch as the first-production-run silicon transistors were not produced in the USSR until 1958, it is estimated that industrial-scale production of silicon crystals of the required purity for transistors was established only recently.

A good approximate measure of the relative progress of the US and Soviet electronics industries in substituting semiconductor devices for electron tubes is a comparison of production of transistors and receiving tubes, which, of the major categories, are most readily substituted for each other. In 1958 the US produced 397 million receiving tubes and 47 million transistors, whereas the USSR produced 94 million receiving tubes and 4.5 million transistors. Thus the US with a production ratio of transistors to receiving tubes of 1 to 8 is significantly ahead of the USSR, which has achieved a ratio of only 1 to 21.

2. Production

a. Past Production

Although the USSR has placed great emphasis on the basic study of the structure and electrical characteristics of semiconductor materials for a number of years, Soviet initiation of industrial-scale production of the more important types of electronic devices incorporating semiconductor materials has lagged consistently behind the US, and Soviet devices have been based almost entirely on Western technological achievements. A few examples of this timelag in production of individual items are shown in Table 1.* A comparison of production of semiconductor devices in the US and the USSR, in terms of units, is shown in Table 2.** In 1958 the value of Soviet production of all types of semiconductor devices was $26.7 million, whereas the value of US production was $228.7 million.

Although germanium and silicon semiconductor diodes were first produced during World War II in the US and other Western countries, the USSR did not begin to produce these diodes until the late forties. The first Soviet items produced were silicon point contact diodes which were made on a laboratory scale in 1948. 7/ Germanium point contact diodes were not put into series production until 1953. 8/ These dates for Soviet production represent an extremely long timelag compared with Western production. The first germanium junction diodes were put into series production in the USSR in 1955, whereas comparable

* Table 1 follows on p. 6.
** Table 2 follows on p. 6.

Table 1

Approximate Dates of Introduction
of Selected Semiconductor Devices
into Industrial-Scale Production in the US and the USSR

Device	US	USSR
Germanium point contact diodes	World War II	1953
Silicon point contact diodes	World War II	1948
Germanium junction diodes	1951	1955
Silicon junction diodes	1954	1958
Germanium junction transistors	1952	1956
Silicon junction transistors	1954	1958
Germanium power junction transistors (10 amperes)	1954	1958
Silicon power junction transistors	1956	a/
Silicon high-speed switching diodes	1955	a/

a. This semiconductor device is not available at present in the USSR.

Table 2

Quantity of Production of Germanium
and Silicon Semiconductor Devices in the US and the USSR a/
1955-59

Million Units

Date	Type of Semiconductor Device	US	USSR
1955	Transistors	3.6	Negligible
	Diodes	20.0	1.2
1956	Transistors	12.8	0.6
	Diodes	35.0	2.0
1957	Transistors	28.7	2.0
	Diodes	45.0	7.0
1958	Transistors	47.1	4.5
	Diodes	85.1	20.0
1959	Transistors	66.4 b/	7.5
	Diodes	103.1 b/	30.0

a. For methodology, see Appendix C.
b. Projected.

units were in production in the US in 1951. 9/ In production of silicon junction diodes, there was a comparable timelag: US production started in 1954, whereas the first Soviet units appeared only in late 1958. 10/

An important aspect of economic capability in production of semiconductor devices which is not apparent from a simple statement of the time sequence of the initiation of production of various categories of devices is the diversity of types which are available. The large number of companies in the West which produced these devices have developed a large number of different types for which there are no comparable Soviet units. Thus, for example, whereas the USSR produces one type of germanium transistor with a maximum frequency of 400 megacycles per second (mc/s), comparable performance is available from Western producers for a number of different devices.

By choosing among the available types for the specific circuit application, much more efficient results are possible than would obtain if only one type were available in a given frequency or power category. Furthermore, at present there are a number of specific types available in the West which are not produced on an industrial scale in the USSR. High-power silicon transistors, which have been available in the US since 1955, are not produced in the USSR. 11/ There are no high-speed switching devices being made at present in the USSR, but these devices have been available for over 2 years in the US. 12/ High-speed switching diodes are used widely in high-speed digital computers. There is as yet no indication of Soviet production of more advanced specialized diodes such as avalanche types, diodes suitable for parametric amplifiers, and Esaki effect diodes. 13/

b. Quantity and Value

Before 1953 the vast majority of semiconductor devices produced in the USSR consisted of relatively small quantities of low-power ac and af diode elements made from selenium, copper oxide, or magnesium copper sulphide and used primarily in measuring and testing instruments. Small quantities of germanium and silicon point contact units were produced for developmental and limited operational use in rf applications, primarily in radar receivers. Estimates for 1950 through 1959 of quantity and value of production of the basic types of semiconductor devices in the USSR are shown in Tables 3 and 4.*

* Tables 3 and 4 follow on pp. 8 and 9, respectively. (Text continued on p. 10.)

Table 3

Quantity of Production of Semiconductor Devices in the USSR a/
1950-59

Thousand Units

Year	Diodes		Transistors		
	Germanium and Silicon	Other b/	Germanium	Silicon	Total
1950	10	71	Negligible	0	81
1951	15	275	Negligible	0	290
1952	25	1,232	Negligible	0	1,257
1953	250	1,500	Negligible	0	1,750
1954	750	1,616	30	0	2,396
1955	1,250	2,050	60	0	3,360
1956	2,000	3,000	600	0	5,600
1957	7,000	11,000	2,000	Negligible	20,000
1958	20,000	20,500	4,100	400	45,000
1959	30,000	25,500	6,000	1,500	63,000

a. For methodology, see Appendix C.
b. Believed to be composed largely of selenium, copper oxide, and magnesium copper sulphide devices for power rectification, movements of alternating current meters, audio clippers, and similar uses.

Table 4

Value of Production of Semiconductor Devices in the USSR a/
1950-59

Million 1959 Rubles b/

Year	Diodes		Transistors	Total
	Germanium and Silicon	Other c/		
1950	0.1	Negligible	Negligible	0.1
1951	0.1	0.2	Negligible	0.3
1952	0.2	0.8	Negligible	1.0
1953	2.0	1.0	Negligible	3.0
1954	6.1	1.0	0.5	7.6
1955	10.1	1.3	1.1	12.5
1956	16.2	1.9	10.8	28.9
1957	56.7	7.0	36.0	99.7
1958	162.0	13.1	81.0	256.1
1959	243.0	16.3	135.0	394.3

a. For methodology, see Appendix C.
b. Believed to be composed largely of selenium, copper oxide, and magnesium copper sulphide devices for power rectification, movements of alternating current meters, audio clippers, and similar uses.

Beginning in 1953, production of germanium and silicon diode units was expanded rapidly. By 1955, these diodes still only constituted about 37 percent of total semiconductor units produced, whereas production of germanium and silicon diodes represented approximately 81 percent of the total value of production for that year. Between 1955 and 1959 the rapid growth in production of these diodes continued, although after 1955 the relative share of diodes in the total value of production of semiconductor devices began to decline because of the initiation of industrial-scale production of transistors in 1956.

The early emphasis which was placed on production of germanium and silicon diodes occurred at a time when there existed no evidence of a priority requirement for these devices in the quantities produced. It is believed that this production effort in diodes was planned as a form of basic technical training for personnel and for the development of materials and techniques to be used eventually in production of transistors. This development of a production capability for medium-quality diodes in excess of priority requirements is a possible explanation of the Soviet practice, in effect since 1955, of incorporating these diodes into consumer entertainment equipment in instances in which, in the West, economic considerations continue to dictate the use of electron tubes.

It is estimated that germanium and silicon diodes will represent almost two-thirds of the total value of production of germanium and silicon semiconductor devices during 1959. In 1959, Soviet product mix of diodes and transistors is approximating the product mix of the US in 1955-56. In the US the value of production of germanium and silicon diodes had fallen by 1958 to a level of approximately 46 percent of the combined value of diodes and transistors. 14/ This is a possible indication that the Soviet rate of growth in transistors will be expanded during the Seven Year Plan (1959-65) at a rate slightly greater than that of semiconductor devices as a group.

Production of semiconductor devices in the USSR was at a very elementary level when the goals for the Sixth Five Year Plan (1956-60) were announced, and no plans for this type of device were announced. During 1957, however, a production series for selected years between 1950 and 1957 and a plan goal for 1960 was provided. 15/ This goal stipulated production in 1960 of all types of semiconductor devices of 30 million units, a figure approximately 9 times that of 1955. By 1958 it was apparent that production of semiconductor devices was being expanded at an annual rate considerably in excess of that which was required to achieve the original goals for 1960, and information received during 1958 and 1959 indicates that production in 1960 probably will be between two and three times the original goals of the Sixth Five Year Plan (1956-60). 16/

In spite of this degree of success in the past few years and in spite of the apparent priority of support which still is being accorded production of semiconductor devices, the projected rate of growth for the Seven Year Plan is relatively modest. The level of production in 1965 is to be approximately 10 times that of 1958, whereas this same rate of growth had been achieved over the previous 3-year period. 17/ It is estimated that the USSR will easily be able to achieve its goals in terms of units and that, within this growth, production of transistors will grow at a slightly faster rate than the production of other categories of semiconductors. As a result, the value of production in 1965 of this component sector of the electronics industry, in terms of constant prices, will be more than 10 times the value of production in 1958.

The apparent future Soviet rate of growth in production and use of transistors, when compared with actual progress in the US and other countries outside the Sino-Soviet Bloc is surprisingly low. When viewed in relation to any realistic estimate of economically desirable Soviet applications in both the military and civilian sector of the economy, this rate of growth indicates the continuing presence of production problems.

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c. Technology

As in many other instances involving Soviet development and production of modern types of electronic components, the initial efforts were devoted almost exclusively to production of crude copies of Western designs in numbers only sufficient to meet the most urgent Soviet needs. In the instance of germanium and silicon semiconductor devices the top Soviet priority was assigned, in the period shortly after World War II, to production of very high frequency (VHF) point contact diodes for use in radar receivers. The limited quantities of such devices which were required were apparently being produced successfully, probably on a laboratory scale, before 1950; and no difficulties have been observed in production in recent years in either the quantity or the quality of devices for radar receivers. The attempts to initiate industrial-scale production of even a limited number of other types of semiconductor devices were not successful until the latter part of the Fifth Five Year Plan, and the majority of these types were of substandard quality compared with the quality of similar types of devices being produced in a number of Western countries at that time.

Soviet technical literature has frequently contained criticisms of the quality of semiconductor devices being produced. One of the more thorough assessments of the levels of quality reached as of the beginning of 1956 was contained in a statement by V.I. Siforov, a leading Soviet specialist in semiconductor devices. Siforov characterized the existing levels of production of semiconductor devices as inadequate because of the following reasons: (1) wide spread in technical parameters, (2) instability of the technical parameters, (3) high noise characteristics, (4) low cutoff frequency, and (5) limited range of operating temperature. 18/

Samples of a considerable number of Soviet semiconductor devices have been received and tested since 1956. The results of most of these tests have indicated that the general quality of Soviet devices, except for a few types of diodes, remained unsatisfactory at least through 1957. 19/ Soviet devices received and tested during the latter part of 1958 and early 1959 indicate that the USSR has achieved a moderate degree of success in overcoming some of the limitations mentioned by Siforov. These devices, however, are not yet representative of a good broad-front industrial technology in this field and are technically far below the highest US technical levels. The best Soviet samples indicate a capability not far behind the US in the technical quality of low-power germanium VHF transistors. There is no indication of the Soviet rate of production of this type, and the mounting employed is unnecessarily complicated and difficult to put successfully into mass production. 20/ The frequency and power capabilities of the Soviet devices do not match those produced in the US, and in Soviet silicon transistors the capabilities are far below those of the better US varieties.

Tests of other samples of diodes and transistors received in 1958 and 1959 indicate that the present Soviet production technology, although definitely better than technology in 1956, has failed to achieve levels which would place this Soviet industry in any way close to the better of the Western nations. In two of the areas cited by Siforov (noise and frequency characteristics), definite improvements have been made. Improvements probably also have occurred in reducing the wide spread of technical parameters of devices which have been in production for a year or more. Many of the devices tested still suffer from the degradation of electrical characteristics following their exposure to even nominal extremes of temperature and humidity and indicate that the instability of the technical parameters continues to be a problem. 21/ [redacted] 50X1 50X1 50X1 The improvements in Soviet devices which have been noted in the areas of maximum operating

frequency, maximum frequency-power combination, and maximum operating temperatures have been more than offset by Western developments during this period. In addition, a major Soviet timelag at present lies in the relatively small variety of types which are in production. The limitation which results from this limited variety is believed to exert a severe restriction on the use of semiconductor devices in many areas of communications, control, and data processing.

A qualitative timelag in the production technology is indicated also by the absence in the USSR of official standards against which semiconductor devices can be measured. Such standards have not been published for any semiconductor device, although there is an indication that standards for some of the types which have been in production for several years will be forthcoming during 1959. 23/

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One of the primary reasons for the continuing Soviet difficulty in the mass production of high-quality semiconductor devices probably lies in the very low level of mechanization which exists in this field in the USSR.

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In the US some of the more critical operations and processes determining the quality of the finished product are carried out automatically to reduce the variations in tolerances which result from human control. Many of these operations still are carried out manually in the USSR.

From the above discussion it is apparent that, in spite of vigorous Soviet efforts in this field, only moderate achievements have been noted, particularly when Soviet successes are matched by more recent Western gains in this field. Thus, although the Soviet devices of higher quality now being produced indicate that in forthcoming years the electronics industry will begin to incorporate significant numbers of diodes and transistors in operational equipment, additional qualitative achievements must be made by this Soviet industry to enable the USSR to gain the full measure of advantage of semiconductor devices in the more critical weapons systems for which

extremes of temperature, vibration, and shock exist. The limitations of quality of Soviet devices probably will be felt most severely in the next few years in the fields of electronics for missiles and aircraft.

d. Plants

The major Soviet producer of semiconductor devices, particularly transistors, is believed to be the Svetlana Electron Tube Plant in Leningrad. This plant is the only known location of production of transistors in the USSR, although Soviet officials have stated that there is at least one other plant which is producing transistors in 1959 and veiled references in the press as early as 1957 indicated that limited production of transistors may have been taking place outside the Svetlana plant at that time. 27/ It is believed, however, that production of transistors on an industrial scale was limited to the Svetlana plant until at least in the latter part of 1958, when new production facilities may have come into being elsewhere. Expansion of production of transistors is still taking place at the Svetlana plant although the plan goals for that plant are significantly less than the goals for the industry as a whole.*

Soviet facilities for producing other types of semiconductor devices are being rapidly increased at present, both by expanding present plants and by putting new facilities into production. Eventually, production of transistors may take place also in some of these plants. During the latter part of 1958 it was announced that three new plants for semiconductor devices were being built and soon would be put into operation. By December of that year, one of these new plants, in Tallin, Estonia, began the series production of semiconductor photodiodes and varistors. Two additional plants, one located in the Armenian SSR and one in Mordovskaya ASSR, were to begin production in 1958 or 1959. 28/ The Tashkent Electric Bulb Plant began the mass production of semiconductor devices in 1958. One other plant in Uzbek SSR, the Samarkand Cinema Apparatus Plant, is engaged in production of semiconductor devices, although this production may be limited to selenium rectifiers. 29/ The Moscow Equipment Plant was reported to be producing selenium diodes in 1956, but there is no indication that germanium or silicon units have yet been produced in this plant. 30/ The Saransk Electro-Rectifier Plant is reported to be producing germanium diodes. 31/

Although the information above indicates that a substantial effort is taking place in the USSR to improve and expand Soviet capability to produce semiconductor devices, the lack of detailed information on plant facilities precludes the possibility of assessing

* For information on the planned expansion at the Svetlana plant, see Appendix C.

the goals for 1965 on this basis. The fact that the initial goal of the Seven Year Plan for production of semiconductor devices was later revised downward by a substantial margin may be an indication that some of the originally planned investment will not take place.*

3. Use

The theoretically possible uses of Soviet semiconductor devices cover an extremely wide range from the most simple af uses such as hearing aids to extremely complex applications such as computers, pulse circuitry, and telemetering instrumentation. In addition, there is a whole class of special applications, including the Hall effect and parametric amplifiers, that have been mentioned very little in the Soviet literature. 33/ In time, semiconductor devices will have an important effect on the entire Soviet electronics industry. In an increasing number of specialized fields such as those of guided missiles, airborne electronic equipment, scientific research instrumentation, and programs for earth satellite vehicles and in the field of electronic computers the effect of semiconductor devices will be revolutionary. The miniaturization, ruggedization, and economy of semiconductor devices undoubtedly will create a rapidly rising demand in the USSR for production of these items and their use in these programs.

a. Transistors

In spite of the many potential uses for transistors, there is relatively little Soviet equipment using transistors which has been completed through the prototype stage. Of this equipment, none can be identified positively as being in series production. Experimental designs have been developed and discussed in the press for equipment ranging from simple hearing aids and portable radios to some more advanced items such as television sets and computers. In the fall of 1958, however, the literature contained numerous complaints that although transistorized receivers had been developed and widely publicized, they were not available in the stores. 34/ Recent information indicates that virtually all transistors currently produced are allocated to military organizations. The majority of these transistors probably are used in programs of military research and development. There is no evidence of actual use of transistors in military equipment at present. One relatively limited end item which is scheduled to go

* Originally it was announced that production of semiconductor devices in 1965 was to be from 13 to 14 times the production in 1958. Subsequent announcements, plus statements of Soviet industry officials, have indicated that this plan has been revised and that production in 1965 is planned at present to be only 10 times that in 1958. 32/

into series production in the near future is the transistor analog computer model MN-10. 35/ A few transistors can be purchased on the open market of the USSR, but manufactured products containing transistors apparently are not available. 36/ Even as late as November 1958, Soviet experts continued to speak of the "fascinating" prospects offered by the initial introduction of semiconductor devices into industry. 37/ The list of planned uses of transistors in the USSR compared with the theoretical possibilities of the devices is still very unimpressive.

Two possible reasons may be advanced for the lack of Soviet production of equipment utilizing transistors. The first reason is that the volume of transistors required within the industry for research and development and for training engineers in their use has probably been so large that most of the available units were required for this purpose at least through 1958. The second reason is probably the relatively poor quality of Soviet transistors, compared with US units, until the end of 1958. In 1959, Soviet progress in both quality and quantity of transistors probably has resulted in increases in their use in finished equipment. The quantity of production of transistors in the USSR was only about 10 percent as large as corresponding US production in 1958 and is increasing at roughly the same rate as US production. In spite of this quantitative timelag, the USSR apparently is moving rapidly in acquiring technological competence in production of at least limited numbers of VHF germanium units and some silicon transistors. 38/ It is believed, therefore, that the USSR within the next 2 years will initiate production of several types of transistorized end items, including some of the more sophisticated military types, which contain transistors. These end items will incorporate substantial numbers of domestically produced transistors. This development will offset to a limited extent the lagging production of standard electron tubes which has been noticed since 1955.

b. Diodes

The most common of the semiconductor diodes is the germanium point contact diode. This device has a wide range of applications, primarily as rectifying, gating, and clamping devices operating at relatively low currents and voltages. These units are used widely in the USSR in television sets and computers. It has been stated that the instrumentation of Sputnik III contained 4,000 semiconductor devices, and in all probability these were predominantly germanium point contact diodes. 39/ The USSR uses more germanium point contact diodes in consumer radios and television sets than are used in comparable Western designs. Point contact silicon diodes are devices which operate at very low voltages and currents and are used mainly as mixers in the microwave frequency bands -- in radar and microwave relay receivers.

The junction diodes are more recent developments than the point contact diodes, and Soviet applications are still mainly in the developmental stage. Technically, the junction diodes having a large current-handling capacity are limited in use to the lower portion of the frequency spectrum. The reverse conduction characteristics of the silicon diodes is also used as a direct current voltage regulator or ac peak level control device (Zener diode). Soviet production of silicon junction diodes, which began in 1958, should result in their wide use as highly efficient miniature substitutes for electron tube rectifier and regulator tubes. The junction diodes available in quantity in the USSR at present do not yet include either those with capability for very high voltage or those with switching characteristics for very high speed. 40/ Production of the latter type in particular will be necessary for high-speed, compact computers and for advanced devices such as parametric amplifiers.

APPENDIX A

USE OF SEMICONDUCTOR DEVICES IN GENERAL

1. Advantages

The most obvious and best publicized advantage of semiconductor devices in general over conventional circuit elements lies in the size of the semiconductor devices. The typical transistor is approximately two orders of magnitude smaller than the electron tube that it can replace. Transistors are extremely valuable where miniaturization of electronic equipment is a consideration. Because the power requirements are decreased by use of transistors and the efficiency of the circuit is thereby increased, the temperature rise in the equipment containing transistors is significantly less than that of equipment containing electron tubes. There has been insufficient elapsed time to evaluate adequately the life expectancy of semiconductor devices, but there is every indication that the service life of the devices will be at least 10 times that of electron tubes. An additional characteristic of semiconductor devices is their inherent ability to function under conditions of severe shock and vibration. They are thus extremely valuable in mobile, airborne, and missile borne applications. Furthermore, in the case of transistors, the low voltages required for operation make them ideal for the usual mobile or battery installations. The combination of the characteristics noted above also contributes to the suitability of semiconductor devices for use in printed circuit and modular construction.

2. Possibilities and Limitations of Substitution

At the present state of the art in both the US and USSR, one of the widest areas of substitution of semiconductor devices for electron tubes is in uses in which the functions can be accomplished independently of power levels. In such uses, transistors and semiconductor diodes make ideal circuit elements. One obvious illustration of this use is in the field of electronic computers where the functioning of the computer is substantially a process of pulse counting, an operation which can be performed independently of the power level. It is unimportant whether one counts 2-volt pulses, 20-volt pulses, or 100-volt pulses: the basic requirement is that of reliability. This reliability can be achieved at levels of relatively low voltage by transistors and the size of the computer greatly decreased relative to a comparable electron tube computer.

Another large class of functions performed by electron tubes consists basically of linear amplification of signals at low-power levels. Capability of transistors in this function creates favorable possibilities for substitution of transistors for electron tubes in radio receivers and af equipment; low-power transmitters and oscillators; and line communications equipment, including those using various multiplexing techniques. Semiconductor devices are very effective and very efficient also as telecommunications switching elements, direct current (dc) to dc converters, variable motor controls, and units performing functions of voltage regulation. Research within the past year in the US indicates that semiconductor devices soon will be used widely in parametric amplifiers, permitting signal amplification with extremely low noise figures in the VHF and ultrahigh frequency (UHF) region.

The limitations on substitution are discussed in terms of present US development in the field of semiconductor devices. These limitations can be categorized best as temperature, power, frequency, and noise. For example, present technical capabilities of a germanium transistor limit operation and storage to a maximum temperature of approximately 100° centigrade (C), whereas for silicon units the maximum temperature may be increased to approximately 200° C. This relationship to temperature places considerable restrictions on the use of transistors, particularly germanium transistors, in military equipment. Present indications are that other semiconductor materials, such as gallium arsenide, indium phosphide, and silicon carbide will have to be used to attain maximum operating temperatures in the range of from 200° to 700° C.

The second important consideration is that present technology permits operation of relatively high-power levels only in the low-frequency range. Power outputs in the order of 1 kilowatt or more are possible in the af and the supersonic frequency spectra at present, but the power capabilities are much more limited as frequency increases. The present state of the art permits power outputs on the order of 5 watts at 20 mc/s in the high frequency spectra and power outputs on the order of 1 watt at 100 mc/s in the VHF spectra, and the present operational limit of operation of transistors is on the order of 1,000 mc/s. A further limitation is placed on use of a semiconductor device by the internally generated noise of the device. The noise figures obtainable with transistors in the high frequency and VHF regions, when operated as simple amplifying devices, are not as good as those of the better electron tubes, but with the use of semiconductor diodes in parametric amplifiers it is believed that semiconductor devices eventually will be superior to electron tubes and widely used in the VHF and UHF regions.

On the economic side the cost of semiconductor devices is still higher than that of electron tubes, but even where cost is of little importance the basic limitations of the devices are such that electron tubes will remain in wide use. There is every expectation that in time the cost will be competitive and the relative performance characteristics will determine whether semiconductor devices or electron tubes are used. At present in the US the relative costs are such that in a number of uses (particularly uses in which availability of power supply, limitations in size, or problems of reliability must be considered) semiconductor devices are being substituted very widely for electron tubes. For some years now, production of the hearing aid industry has been almost completely converted to models containing transistors, and in the case of personal portable radios the trend has been very strong toward the transistor models. Automobile radios also have tended toward increasing the use of transistors, but the relative costs have prevented complete conversion to transistors. In consumer goods, the decision to use transistors has to a very large extent been determined by relative costs. In the instance of military equipment, however, the advantages in size, service life, reliability, and efficiency have been given the greater weight. In spite of the relatively few military types available and the inadequate data on reliability, there has been a constantly increasing volume of military equipment containing transistors. The beginning of very-large-scale production of military equipment containing transistors is beginning in the US in 1959, and continually increasing quantities of production are planned for 1960-64.

APPENDIX B

PRODUCTION TECHNOLOGY OF SEMICONDUCTORS IN GENERAL

Between the groups of "conductors" and "insulators" in general there are the transitional elements designated the group of the semiconductors. These semiconductors are found in the fourth valence group of the periodic table of the elements. Practical possibilities also exist for production of intermetallic compounds which will exhibit similar physical properties. Such materials would be compounds of elements of either the third and fifth group or the second and sixth group of the periodic table. Almost all semiconductor devices currently being produced are made from the elements germanium and silicon rather than compounds, although considerable research and development currently is taking place on compounds such as gallium arsenide, indium phosphide, and silicon carbide.*

Current technical processes are concentrated on production of germanium and silicon as the primary semiconductors. Both these elements are used in their crystalline form. The technical processes require production of crystals of extremely high purity for use as the basic raw materials for semiconductor devices because the electrical characteristics of the devices are critically dependent on the quality of the raw material.

The basic material germanium normally is obtained as a byproduct of the smelting of zinc or lead or from flue dust of certain coals. The germanium goes through a refining process to purify further the material and to convert it to a crystalline form. This process involves zone refining of the material according to standards of extremely high purity. Precise quantities of other materials then may be added to achieve the desired electrical properties. Neither the US nor the USSR has a basic problem of raw materials. Within the USSR the Donets coal contains a relatively high percentage of germanium. The germanium crystals used by the Soviet transistor plants are obtained from the chemical industry and are grown in the Kalinin Coke and Byproducts Plant in Dnepropetrovsk.

In production of a typical alloy junction transistor the germanium crystal is first sliced into thin wafers, and these wafers then are diced so that the basic unit of the device is a small piece

* One US organization currently is producing a gallium arsenide reference diode for applications at very high temperature (325° C).

of germanium roughly 1/10 of an inch square and less than 20 thousandths of an inch thick. These dice then are lapped and etched to precisely controlled thickness and finish. The junction dots, which supply a rigidly controlled quantity of the appropriate chemical impurities to produce the desired electrical properties of the transistor, then are placed on the centers of the dice and are alloyed to the germanium in a precisely controlled alloying oven. The resulting units then are tested, mounted, cleaned, and sealed. The finished transistors are tested and sorted according to various electrical characteristics.

Although the mounting in a relatively low-power unit is less critical, in high-power units some type of heat sink provisions must be made. In general, the higher the requirements of the finished component in terms of frequency and amplification capability the higher will be the requirements for purity of basic material, careful control of production, and fine tolerances in the mounting and packaging. Even within the field of the relatively common af or medium frequency transistors, it is difficult to keep the characteristics of finished product reasonably close together in most production operations. This problem is avoided to a certain extent by classification of the end items rather than by production control. At the end of a transistor line the producer commonly will obtain transistors which will be labeled with more than one type-designation, depending on the characteristics of the finished product. Initial Soviet production of the P-1 junction transistor resulted in seven different suffixes for units with different parameters. For maximum utility the parameter spread in any of the types must be relatively small, or a significant percentage of the achievable gain must be sacrificed in the circuit design of the stabilization networks. The mounting, protecting, and sealing operations critically affect the ruggedness and reliability of the finished product. Secure mounting, protective coating of high quality, and good hermetic sealing are all necessary for reliability and long life.

The productive process is substantially the same in the case of silicon transistors, but there is at least one difference. Although raw material is abundantly available, the purification of silicon is more difficult than the purification of germanium, and Soviet progress in this field has been relatively slow. Other materials for use in semiconductor devices are at present largely in the research and development stage both in the West and in the USSR.

APPENDIX C

METHODOLOGY

1. Total Production

Estimates of the total quantity of semiconductor devices produced in the USSR through 1957, as shown in Table 3,* were obtained from the production time series officially announced in the Soviet press. 41/ The estimate for 1958 was derived by using the geometric mean between the rate of growth for 1957 and the annual rate of growth implied by the Seven Year Plan (1959-65). The resulting figure indicates production in 1958 which was 2.25 times production in 1957. On the basis of the plan goals most recently announced, it was estimated that production of semiconductor devices in 1965 will be 10 times that in 1958, an estimate which implies an average annual rate of growth of 39 percent. 42/ This rate of growth represents a reduction in the plan goal announced earlier for this industry, for which planned production for 1965 was from 13 to 14 times that in 1958. The rate established by the later information is estimated to be within the capabilities of the USSR. This rate was applied to the estimate for 1958 to obtain the estimate for 1959. The announced series contains information on the aggregate production of semiconductor diodes and transistors, and is estimated to include substantial numbers of the relatively simpler selenium, copper oxide, and magnesium copper sulphide rectifier diodes as well as germanium and silicon diodes and transistors. It is possible that other devices such as solar cells, Hall effect elements, photosensitive elements, and so on also may be included in the announced totals. The quantity of these devices produced up to the present, however, is estimated to be negligible from an economic point of view. The series announced for aggregate production has been published and discussed several times in the Soviet press and by Soviet officials in their discussions with Western specialists. The announced series is believed to be reliable although its value is lessened by the ambiguity of the products covered. A critical consideration of the economic effect of production of semiconductor devices requires that this series be broken down further into estimates of the produced quantities of transistors, germanium and silicon diodes, and other diodes.

For a breakdown of this series into these three basic types of semiconductor devices, there are four indicators which apply in varying degrees to the estimates of transistors and germanium and silicon

* P. 8, above.

diodes. The first of these indicators consists either of plant information or of statements by Soviet officials which indicate the approximate percentage of the total series which represents transistors.

The second general indicator is found in specific announcements in technical journals concerning specifications of devices available to the Soviet engineers. These publications provide information on the technical characteristics of diodes and transistors as they become available and thus provide an excellent indicator of the time sequencing of the important aspects of production of semiconductor devices.

A third indicator of the state of the art in both production and utilization of semiconductors devices, also provided by technical publications, is found in articles concerned with specific applications of various types of devices. Such publications have included both general articles on operation of the semiconductor devices and specific examples of semiconductor device circuitry. The relative sophistication of the articles and the quality of the semiconductor devices necessary for the indicated use provide valuable insights into the state of Soviet production and use of semiconductor devices.

The fourth indicator is particularly important as a measure of progress in production of end items using particular semiconductor devices. This indicator lies in the area of production of auxiliary components for semiconductor device circuitry. Because of the different voltages, power, and impedances at which semiconductor devices operate, the components necessary for use with semiconductor devices must be considerably different from those used in standard electron tube equipment. These components must be available in order to obtain the full measure of advantage in the relative size of these devices compared with electron tubes. At a minimum the efficient use of semiconductor devices requires considerably modified components and ideally calls for a completely new family of miniaturized low-voltage and low-power components. The quantity of production of such components is therefore a strong indicator of the extent to which semiconductor devices, particularly transistors, actually are being incorporated into finished equipment.

The derivation of the estimates of quantity and value for each of the three basic types of semiconductor devices currently produced in the USSR is discussed in greater detail in the following sections of this appendix.

2. Quantity of Production

a. Transistors

Shortly following the announcement of the US invention of the transistor, the USSR published a brief summary of characteristics of transistors, but further data for immediately subsequent years are almost totally lacking. The first indication of series production of transistors, both junction and point contact types, was contained in the publication of detailed data on these types of products in mid-1956. 43/ This indication of initial production was substantiated further by the announcement in June 1956 of the initiation of series production of transistors in the Svetlana Electron Tube Plant in Leningrad. 44/ This announcement marks the first industrial-scale series production of transistors in the USSR. The literature from that time to the present has included articles indicating an increasing sophistication in transistor electronics. During 1957 the development and initiation of production of other types of transistors and the initiation of production of high-frequency transistors occurred. The beginning of series production of semiconductor devices by the experimental-production division of the Ukrainian Academy of Sciences was announced in 1956, but subsequent to this announcement there has been no indication that transistors have been produced at this location. 45/

In view of the announcement mentioned above it is estimated that production of transistors was an extremely nominal portion of the production time series before 1956 and consisted of experimental models produced in laboratory or trial run quantities. Production of transistors in 1956 is estimated to have been approximately 600,000 units. This estimate is based on the estimated capacity of the Svetlana Electron Tube Plant, the only plant believed to have reached industrial-scale production at that time. The 1957 estimate of 2 million transistors was obtained from a Soviet official on a visit to the US during 1957 46/ and was confirmed by another Soviet official during 1958. 47/ This production is believed to have been the approximate capacity of the Svetlana plant during 1957, given a higher level of efficiency than during the initial 6 months of production. This quantity of production represented barely a minimum requirement for use in experiment, research, and development and would not represent a capability to incorporate transistors in any substantial quantities into military, industrial, or civilian end items.

The estimates for production of transistors and product mix of germanium and silicon transistors in the USSR for 1958 and 1959 were based on indications of production of the Svetlana Electron Tube Plant

obtained in April 1959. 48/ This information indicated that production of transistors at the Svetlana plant in the first few months of 1959 was at a rate of approximately 500,000 per month. Because production of transistors at this plant still is expanding rapidly this rate is believed to be somewhat higher than the 1958 average monthly rate but lower than the final average monthly rate which will obtain for this plant in 1959. On the basis of this rate it is estimated that only approximately 4.5 million transistors were produced in 1958 at the Svetlana plant and that production during 1959 will be approximately 7 million. Although the estimate for 1958 applies only to the Svetlana plant it is believed to represent virtually all of the industrial-scale production of transistors in the USSR. Limited production of special types of transistors undoubtedly takes place at research institutes and design bureaus, and it was reported in early 1959 that at least one other plant, unidentified, now is producing transistors. 49/ It is believed that such production is still only on a limited scale and probably will not provide more than an additional 0.5 million units during 1959. Total production in 1959 is therefore estimated at approximately 7.5 million units. Production estimates for years later than 1959 have not been possible from information available at this time. Figures from the Seven Year Plan have been announced only for production of all types of semiconductor devices, specifying a level of production in 1965 which is to be 10 times that of 1958. Since 1954 the rate of growth for transistors has been approximately the same as that for semiconductor devices as a group, but there is no firm basis for estimating that such a correlation will hold in the future. Information exists which implies that production of the Svetlana plant in 1965 will be only three to five times that in 1958. 50/ During this period new plant facilities are expected to come into production, but production to be achieved by these plants cannot be determined as yet.

b. Germanium and Silicon Diodes

The initial years of the Soviet production series for germanium and silicon diodes was estimated on the basis of fragmentary data on the production schedules of plants which produced semiconductor devices. Estimated rates of growth were projected from the earlier data on the basis of indications of the amount of use of these units in Soviet production of end items. There are no indications that germanium and silicon diodes were used to any appreciable extent in the USSR before 1953, except for rf mixer diodes in UHF and VHF military electronic equipment, primarily radar. This lack of use of diodes is reflected in the estimates for 1950 through 1952. After 1953 these devices were used on an increasing scale in various types of military and industrial electronic equipment and in civilian entertainment equipment. 51/ In 1953 the Soviet journal Radio published the first data

on domestically produced germanium diodes in the DG-T1 to DG-T8 series, but it was not until 1954 that there was very wide dissemination of detailed data on the use of these diodes. 52/ These were germanium point contact diodes, and it was not until 1956 that technical data were provided and series production was announced for germanium junction diodes. 53/ Although the point contact silicon types of diodes were the first diodes produced in the USSR it was only in 1958 that reference was made openly in the press to production of silicon junction diodes. This reference was contained in an announcement that the Leningrad Sovnarkhoz (Sovet Narodnogo Khozyaystva -- Council of National Economy) would begin production of silicon diodes in 1958. 54/

Because there is less specific information available on production of germanium and silicon diodes than there is on transistors, the estimates of unit production of these diodes are considered less exact than the estimates for transistors. It should be noted in this connection, however, that production of germanium and silicon diodes often is used as a form of basic technical training for personnel and for the development of materials to be used eventually in production of transistors. It may be expected, therefore, that the rate of increase in production of these diodes in the initial years of development of transistors can be correlated with later production of transistors. Although diodes are used extensively in electronic equipment both with electron tubes and ferrite circuit elements, there is also a wide variety of uses in which they are used in conjunction with transistors. Computers containing transistors provide an excellent example of a combined use of transistors and semiconductor diodes. Semiconductor diodes are thus complementary to transistors in some circuit applications and are used with electron tubes in other circuit applications. In an expanding electronics industry the rate of growth for production of diodes will be somewhat greater than that for transistors. A comparison of the rates of growth of each type of semiconductor device is provided in Table 3.*

c. Other Diodes

Although the majority of germanium and silicon diodes are those which incorporate a relatively less complex production technology and generally are used in less critical applications than the other Soviet semiconductor devices considered in this report, no concrete indication of the quantities produced has become available from either the Soviet press or other sources. Therefore, this series of diodes has been derived as a residual of the official aggregate series after the estimated production of germanium and silicon diodes and triodes was subtracted.

* P. 8, above.

3. Value of Production

Value of Soviet production of semiconductor devices in 1959 rubles, shown in Table 4,* was derived as follows.

a. Transistors

It is estimated that 1956 was the first year in which the scale of production of transistors in the USSR would permit any correlation between the cost of production and the sales price of the unit. Initial production basically constitutes an investment designed to develop technology in both production and use of the devices. Between 1956 and 1959 the average factory cost per unit in current rubles** for Soviet transistors was reduced from 30 rubles to 18 rubles. Soviet officials have stated that unit cost will be reduced to approximately 15 rubles in the near future. 55/ The average factory cost of transistors in 1959, 18 rubles, was applied to the estimate of units produced to obtain the value series in 1959 prices, and a logarithmic projection giving a price in 1958 of 21.3 rubles was used in computing the 1958 value.

b. Germanium and Silicon Diodes

In the absence of data relating to average cost of production for diodes, it was necessary to derive a 1959 ruble-dollar ratio based on cost of production of transistors and to assume that the same relative efficiency of production was applicable also to production of semiconductor diodes. The average factory cost of production of transistors in the US in 1959 is approximately $2.53 per unit. 56/ If this cost is compared with the Soviet average cost (18 rubles per unit) a ruble-dollar ratio of 7.1 to 1 is obtained. The US average 1959 factory cost of production for germanium and silicon diodes is $1.14 per unit. 57/ This cost implies an average ruble cost of approximately 8.1 rubles per unit. This cost was applied to the estimate of units produced to obtain the value series.

c. Other Diodes

To derive the Soviet value of production for selenium, copper oxide, and magnesium copper sulphide cells a procedure was followed similar to that used for germanium and silicon diodes. The US average factory sales price in 1959 for these units was $0.09 per unit. 58/ The implied Soviet average price for these units, calculated from the ruble-dollar ratio for transistors, is approximately 0.64 rubles per unit. This price was applied to the physical unit series to obtain the total value of production for these units.

* P. 9, above.

** Unless otherwise indicated, ruble values are given in current rubles throughout this report.

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