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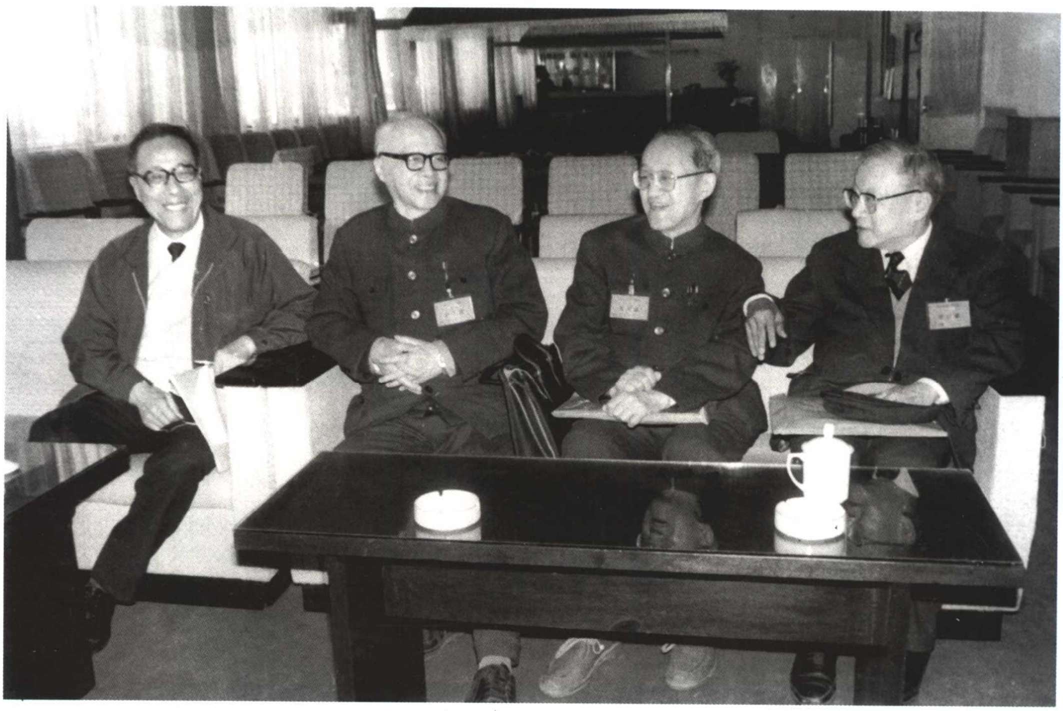
杨嘉墀——1919年出生，江苏省吴江人，1980年加入中国共产党，我国著名自动化和空间技术专家，我国自动化与控制技术、航天技术领域的主要开创者之一，我国《高技术研究发展计划纲要》（简称“863”计划）倡导人之一。

1941年毕业于上海交通大学电机系电信专业，1947年至1949年在美国哈佛大学应用物理系先后获硕士、博士学位。1950年至1955年期间，先后任美国宾夕法尼亚大学研究员和美国洛克菲勒研究所高级工程师。

1956年回国后在中国科学院、中国空间技术研究院等部门长期从事自动化技术、航天技术的研究和发展工作，历任研究所室主任、副所长、所长、研究院副院长、卫星总设计师、航天部总工程师、航空航天部科技委顾问等，现任中国空间技术研究院、中国航天科工集团公司技术顾问，总装备部科技委技术顾问。50年来为国家的航天事业作出了重大贡献，多次立功受奖，1984年被评为航天部劳动模范，1985年获国家科技进步奖特等奖，1987年获国家科技进步奖二等奖，1991年被评为航空航天部有突出贡献的老专家，1995年获中国科学院陈嘉庚信息科学奖，1999年获何梁何利基金科学与技术进步奖，1999年获国家“两弹一星”功勋奖章。

杨嘉墀是中国科学院院士、国际宇航科学院院士，曾任国际宇航联合会副主席，第三届、第四届、第五届全国人大代表。

▲ 1999年9月18日，江泽民亲自向杨嘉墀颁发“两弹一星”功勋奖章及证书



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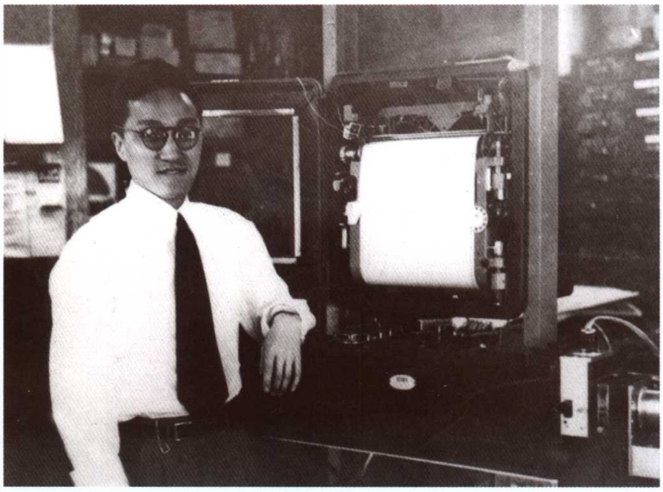
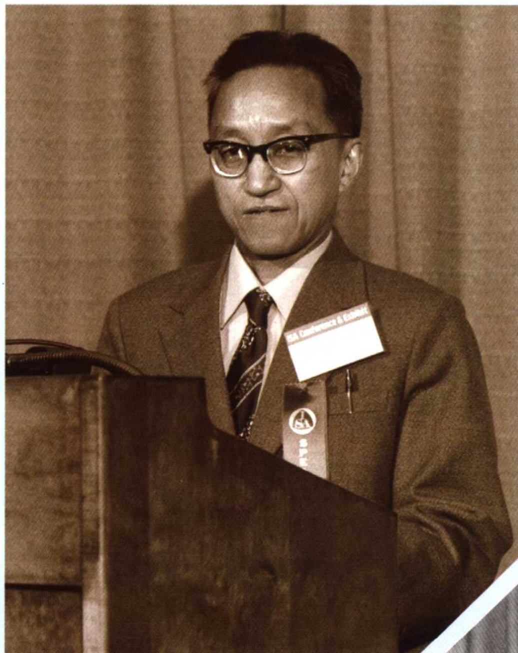
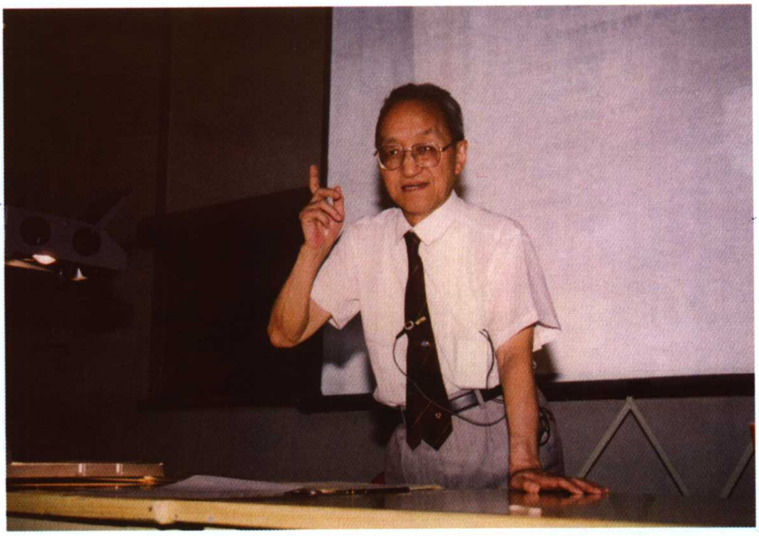


▶ 1953 年，杨嘉墀与他在美国研制的自动快速记录吸收光谱仪合影



◀ 1980 年，杨嘉墀在美国参加仪器仪表学术会议暨展览会

▶1985 年，杨嘉墀在瑞典接受国际宇航科学院院士证书



◀ 1995 年，杨嘉墀在讲学中

◀ 1999 年，杨嘉墀与夫人徐斐重返江苏吴江震泽镇

◀ 2002 年，杨嘉墀在知识产权讲座上

序

杨嘉墀同志1919年出生于江苏省吴江县,1980年加入中国共产党,1941年毕业于上海交通大学电机系电信专业,1949年在美国哈佛大学应用物理系获博士学位,1956年回国后在中国科学院自动化研究所、国防科委五院502所和中国空间技术研究院工作,先后担任室主任、副所长、所长、副院长、航天部总工程师、中国仪器仪表学会和中国自动化学会理事长等职务。中国科学院院士,国际宇航科学院院士,第三届、第四届、第五届全国人大代表。嘉墀同志长期致力于中国自动化技术和航天技术的研究工作,领导和参加了包括中国第一颗卫星在内的多颗卫星的总体及自动控制系统的研制,先后获国家科技进步特等奖、中国科学院陈嘉庚信息科学奖、何梁何利基金科学与技术进步奖以及"两弹一星"功勋奖章等。

我和他共事多年,经常在一起讨论我国科技发展的问题。1986年我们4人(我和王淦昌、杨嘉墀、陈芳允)共同讨论向中央提出了国家发展高技术计划的倡议,得到了中央领导的批准,即现在的"863"计划。

嘉墀同志热爱祖国、为人厚道、平易近人、工作刻苦、求真务实、学识渊博,而且关心年轻科技人才的成长,培养了一批航天控制领域的博士生和中青年专家。他对新事物敏感、高瞻远瞩,时刻关心国内外科技发展的动向,积极为中国自动化技术和航天技术的发展献计献策,积极参与中国空间技术的发展规划。正是由于嘉墀这样的一大批航天战士在党的领导下辛勤耕耘,才使我国航天事业取得如此辉煌的成就,才逐渐形成了"自力更生、艰苦奋斗、大力协同、无私奉献、严谨务实、勇于攀登"的航天精神。

此次出版的《杨嘉墀院士文集》收集了他从1951年到2005年的部分论文和报告,内容包括4个方面:①仪器仪表技术;②自动化技术;③航天技术;④国家科技和空间技术发展规划。特别是1995年他在国际会议上发表的"中国空间计划中智能自主控制技术的发展"为中国航天控制跨越式发展指明了方向。本文集不仅从一个方面反映了他为我国航天事业和国家科技发展做出的突出贡献,而且必将对推动我国科学技术的发展产生很大的影响。如本文集的出版能对广大科技工作者和后继一代对嘉墀同志的光辉成就的了解和学习有所裨益,我相信嘉墀同志和他的同业界及挚友们都将感到非常高兴和欣慰。

王大珩

2005年11月

目　　录

A Quarter-Square Multiplier Using a Segmented Parabolic Characteristic*

Abstract A circuit for multiplying two varying voltages based on the "quarter-square" method has been developed. A segmented nonlinear element is used for squaring, and a time-sharing scheme permits the use of a single squaring element instead of duplicate elements as in previous designs. The circuit has a time delay of less than 40 microseconds (0-67 percent) and has an accuracy of better than ±1 percent. The original circuit was designed to operate only in the first quadrant. Various methods for including the four quadrants are discussed.

1 INTRODUCTION

In the course of the development of a fast analog computer for solving simultaneous nonlinear differential equations representing chemical reactions, the problem of designing a circuit for multiplying two variables was encountered. To suit the type of equations and range of parameters of our problems, the multiplying circuit has to satisfy the following requirements: (1) The error has to be less than one percent of the maximum operating range, (2) it has to be able to handle input variables that go to zero although they are always positive, (3) the time delay introduced by the multiplying circuit should be less than 50 microseconds, and (4) the components used should be insensitive to voltage and ambient temperature variations and reasonably stable with time. The third requirement is very important, because the multiplying circuits are situated in the feedback loop of the various computer setups for solving differential equations. Thus, excessive time delay will cause inaccuracies or even oscillations in the final results.

Most of the existing types of electronic multiplying circuits do not satisfy all these requirements. Multiplying devices using nonlinear circuit elements as in a logarithmic multiplying circuit have a restricted voltage scale which is usually not sufficient for the required accuracy and stability. Such elements usually exhibit the appropriate nonlinearity only at small voltages or currents and usually over a small range. The characteristics of crystal nonlinear devices change rapidly with temperature. Many systems for multiplication require either (1) a carrier system, like the automatic gain control method[1] and the double modulating method,[2] or (2) a feedback system like the crossed field method[3] and other cathode-ray tube methods.[4] These last two systems have a

* Britton Chance, Frederic C. Williams, Chia-Chih Yang, John Busser, and Joseph Higgins, The Review of Scientific Instruments, Vol. 22, No, 9, September, 1951, pp. 683－688. This work has been supported by the ONR, Contract N6－onr－24911.

band-width limitation which slows down the response of the multiplier and raises stabilization problems. The present scheme uses the basic "quarter-square" method of multiplication of Mynall[4] but involves no feedback loop or cathode-ray tubes and permits the use of voltage scales large enough to avoid inaccuracy and instability. After use in the computer for almost a year, we can say that the multiplying circuit suits our purpose quite satisfactorily.

Considerable experimentation was carried out on a method for multiplication in which the slope and time duration of a triangular wave form represent the two variables to be multiplied. The desired product is then the peak amplitude of the wave form. A related method has been described by Hirsch[5] in which exponential wave forms are used. The circuit has an accuracy about equal to that of the method described here for circuit designs of equal complexity. The quarter-square method as developed here has considerable potentialities for extremely rapid operation; whereas the recovery time of the wave form generating circuits, as well as the accurate linearization of a rapid wave form might become serious limitations of the triangular wave form method. The development of this particular circuit was briefly reported in 1950.[6]

2 PRINCIPLE OF OPERATION

The quarter-square method for multiplying two quantities A and B, based on the equation,

$$AB = \frac{1}{4}[(A+B)^2 - (A-B)^2],$$

uses squaring devices as the main nonlinear elements. The squaring devices are called parabolic function generators, because the output against input characteristic has the shape of a parabola. In this multiplying circuit, the parabolic characteristic of the squarer is approximated by segments, which are set by appropriately biased diodes.[7]

Thermionic diodes have been chosen in preference to germanium crystals because the back current of the latter is large and unpredictable. The static characteristic of the parabolic function generator is shown in Figure 1. The dots are plotted to an arbitrary scale by taking the square root of the values of the output currents. They deviate from the straight line by less than 0.4 percent of the maximum output current. By using 15 diodes (6K 4's connected as diodes), the characteristic covers a scale of more than 25 volts which is the maximum voltage all the other components of the computer are capable of handling. Thus the parabolic function generator gives an output current proportional to the square of the input voltage without the use of a feedback loop. The only drawback is that the parabolic function generator cannot handle a negative input voltage. For our applications, the computer will be used only for positive quantities, but their difference $A-B$ will be negative when A is less than B. Since $(A-B)^2=(B-A)^2$, this difficulty is avoided by a quick-acting switching circuit arranged so that $B-A$ is used when A is less than B, and $A-B$ is used when A is greater than B. Therefore, the parabolic function generator is required to accept only positive voltages.

In previous "quarter-square" methods of multiplication, two squares are required and must be

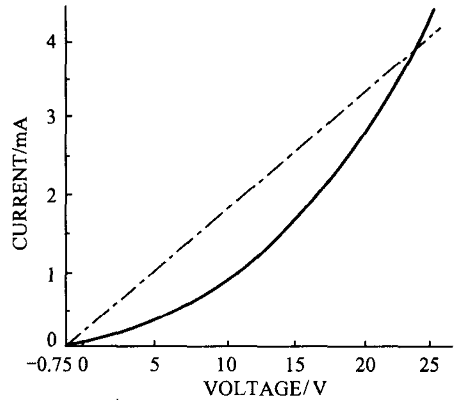


Figure 1 Performance of parabolic function generator

(ac-11)

very nearly identical. The error due to a small discrepancy in their characteristics will be considerable if one of the inputs is large and the other is zero, because here the difference of the square of the two large quantities is involved. To avoid this difficulty, a time sharing scheme of feeding one squarer with the quantities $A+B$ and $|A-B|$ alternately at 50 kilocycles per second is adopted in this method. The alternating or square wave component of the output is then proportional to the difference of the squares of $A+B$ and $A-B$, or to the product $4AB$. This square wave is then clamped and detected by the usual difference detection that employ switches.[8]

The block diagram of the quarter-square method of multiplication is shown in Figure 2. The amplitude discriminator as shown in Figure 3, is a bistable circuit. It consists of two amplifiers with a large common cathode resistor and a positive feedback coupling between the two units to give very nearly infinite gain. In addition, diodes are attached to the plates of the pentodes in order to prevent the plates from rising too high during the switching action. When A is greater than B, the voltages at output terminals T_1 and T_2 will be -50 volts and $+50$ volts, respectively. When

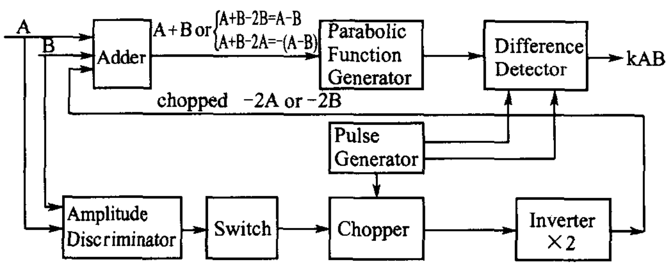


Figure 2 Block diagram of quarter-square multiplier

(ac-9)

B is greater than A, these voltages will be inverted. These output voltages are used to control two balanced diode switches which operate as a single-pole double-throw switch. Thus only the smaller one of A and B will pass the switch. The output is then chopped at 50 kc by a diode switch which short-circuits intermittently the feedback resistor of an amplifier. This chopped A or B rectangular wave is doubled and subtracted from the sum $A+B$ and the values $A+B$ and $|A-B|$ ap-

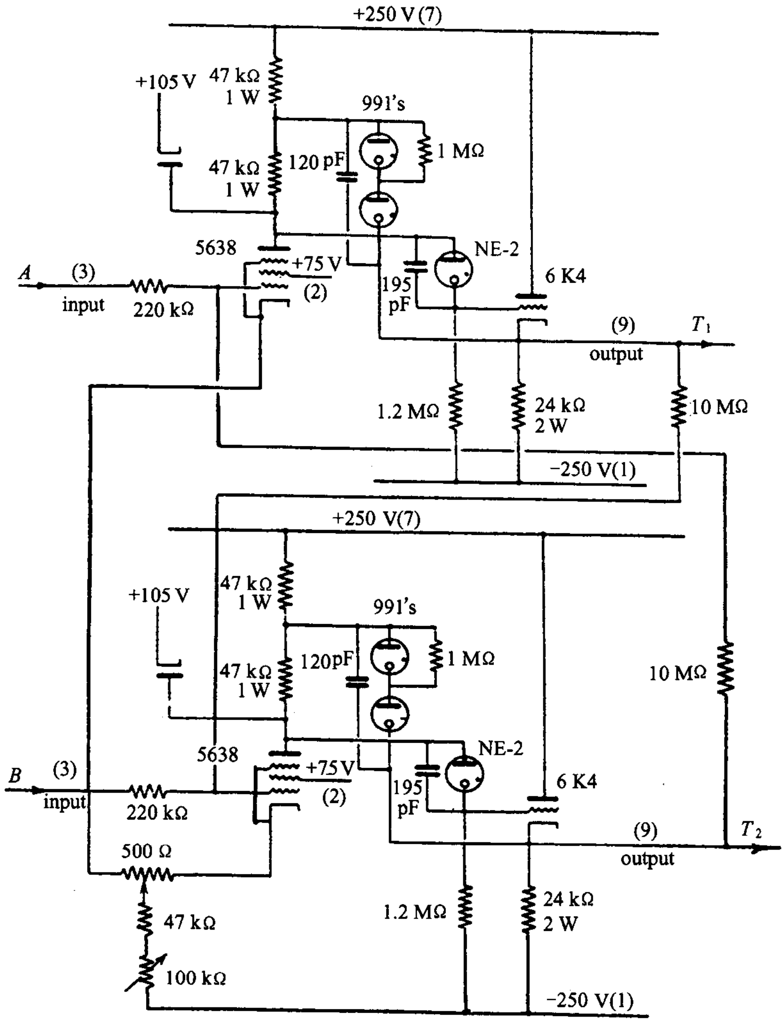


Figure 3　The amplitude discriminator

(ac-40)

pear alternately at the output of the adder. Figure 4 shows the ideal wave forms of voltages before and after the parabolic function generator both for the case $A > B$ and for the case $A < B$ for constant values of A and B. The complete circuit diagram except the pulse generator is shown in Figure 5, where the triangles represent standard dc amplifiers with cathode follower used throughout the computer. They have a gain of about 150 which is large enough to insure accurate adding. Figure 6 shows the construction of the whole multiplying circuit. It is mounted on a single panel seven inches high.

The pulse generator consists of three delay multivibrators[9] with adjustable width and delay. They supply (1) 50 kc rectangular waves to gate the chopper and (2) 50 kc pulses to clamp and detect the square wave output from the parabolic function generator. Figure 7 shows the three wave forms of the gating voltages feeding into the multiplier. Since it is desirable to have a shorter clamping time and a longer detecting time, the duration of the positive half-cycle of the gating wave form (A) is adjusted three times longer than the duration of the negative half-cycle. Thus

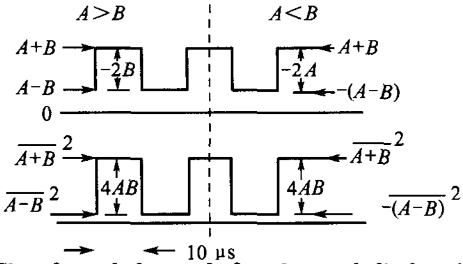


Figure 4 Wave forms before and after the parabolic function generator

(The amplitudes of the lower traces are divided by 3.)(ac-41)

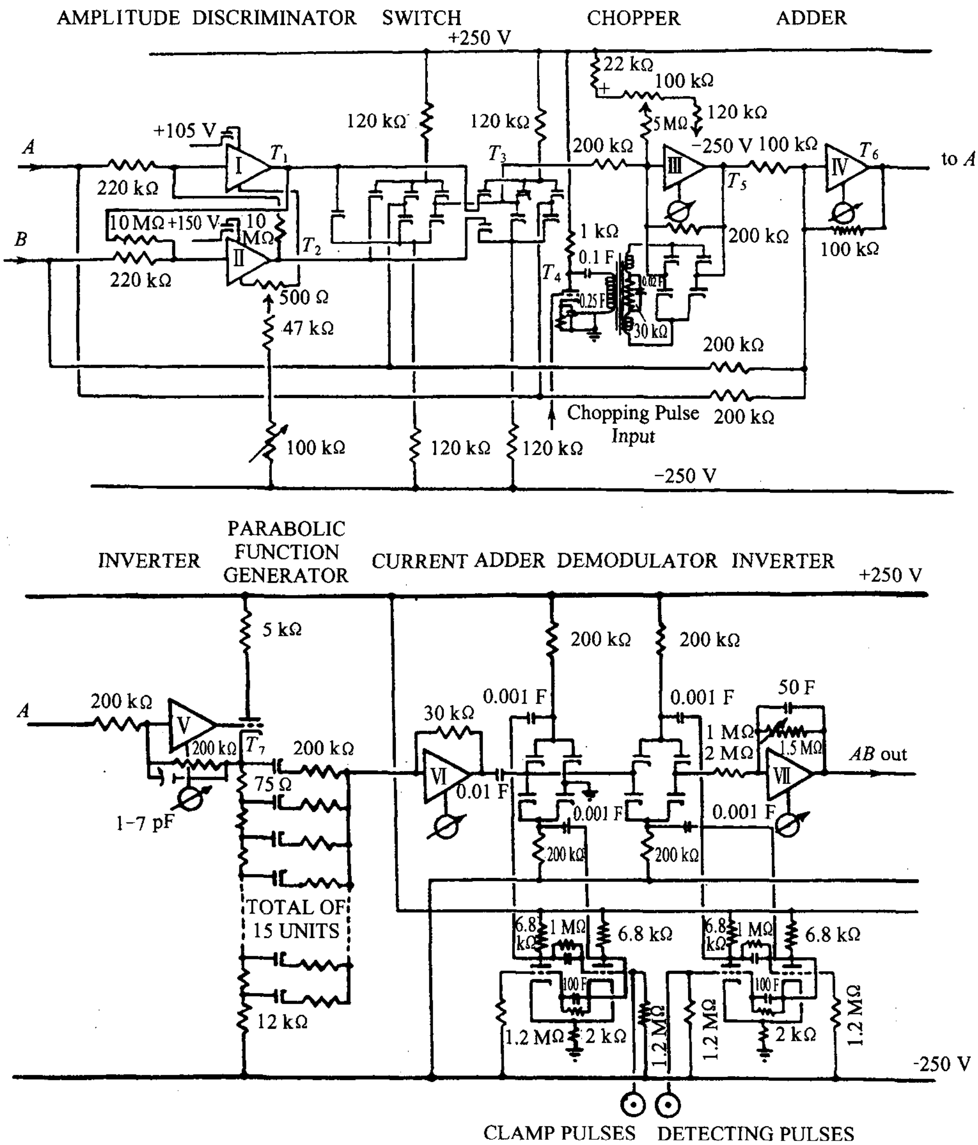


Figure 5 Circuit diagram of the quarter-square multiplier

(∅ denotes bias control.)(ac-20b)

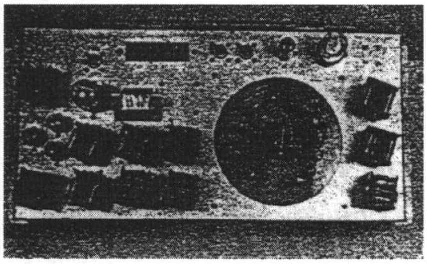


Figure 6　Front view of the multiplier

(ac-21)

the clamping pulses have a width of about 3 μsec while the detecting pulses have a width of about 15 μsec. Since a single pulse generator is used for all the multipliers in the computer, isolating amplifiers or multivibrators are supplied at each multiplier.

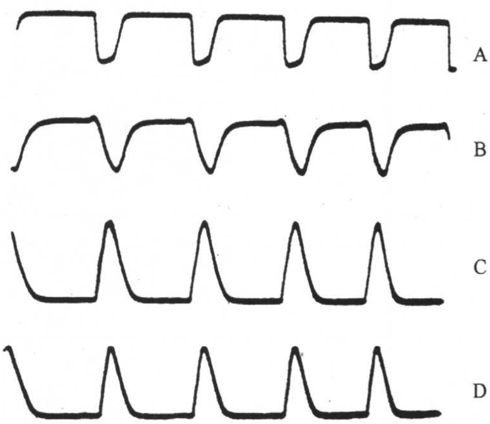


Figure 7　Wave forms generated by the pulse generator

(A) Wave form for gating chopper switch; (B) Wave form at input terminal of squarer; (C) Wave form for clamping switch; (D) Wave form for detecting switch. (ac-42)

Certain scale reduction is necessary in an electronic multiplying circuit in order to reduce the maximum swing of the output to the maximum permissible limit. Here we use a factor 1/25 so that the multiplier will give the output $1/25AB$ with two inputs A and B. Thus with the maximum swings in the inputs of 25 volts, the maximum output will be 25 volts. This constant factor is obtained by adjustment of the gain of the current adder following the parabolic function generator.

3　TEST AND PERFORMANCE

Both the accuracy and response speed of the multiplying circuit have been tested. Tests of the accuracy of the multiplying circuits were made by applying different values of constant voltages (0 volts, 5 volts, 10 volts, 15 volts, and 25 volts, for example) to terminal A and a linearly varying voltage from 0 volts to 25 volts to terminal B. For precision testing, a slowly varying voltage is used and the output is recorded with a Speedomax recorder. The peak errors were found to be less than one percent of the maximum output voltage. For routine tests, sequences of step voltages of different amplitudes are applied to terminal A and a triangular wave form is applied to terminal B and the output is shown on an oscilloscope. Figure 8 shows the two inputs and the output as actually photographed from an oscilloscope with time and voltage scale superposed. One small division of time corresponds to 400 μsec. It is hardly noticeable from these results that the amplitude discriminator has turned the switch once when A is equal to B during each computing cycle. The very small nonlinearity of the trace is partly caused by the cathode-ray tube.

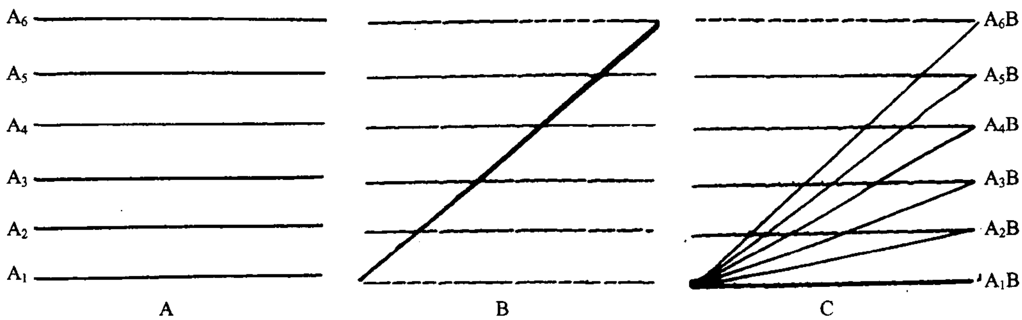


Figure 8 Test patterns

(A) Inputs to terminal A; (B) Inputs to terminal B; (C) Output of multiplier. (ac-43)

The speed of response of the multiplying circuit was tested by applying a constant voltage to one input terminal and a square wave to the other. Figure 9 shows the input and output wave forms. In Figure 9 the smoothing condenser on the final inverter stage was taken out to show the ripples of 50 kilocycles per sec. It is seen that the output rises within two cycles of the chopping wave or 40 μsec. It is obvious that the response time can be further decreased by increasing the chopping frequency.

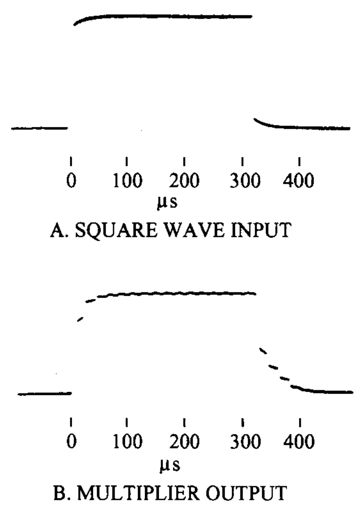


Figure 9 Transient response of the multiplier

(ac-44)