BASIC CHARACTERISTICS AND FUNCTIONS OF TRAFFIC SIGNAL EQUIPMENT

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

June 1977
VHTRC 77-R53

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PREFACE

The traffic signal provides effective control by allocating the right-of-way through an intersection, first to one group of motorists and then to another. Yet the signal, especially if it is improperly timed, not only impairs the movement of traffic at the intersection, but governs the capacity of the entire street system.

There are approximately 3,000 signalized intersections in Virginia, and the communities have traffic control systems consisting of numerous types of equipment from various manufacturers. Not surprisingly, technicians in the field are not always familiar with the controls they must operate and repair. Without a clear understanding of the basic characteristics and functions of the signal equipment, they cannot make the fine timing adjustments and repairs necessary to maintain efficient signal operations.

This report outlines the basic characteristics and functions of the typical traffic signal equipment found in the state of Virginia. It has been prepared to help traffic engineers, signal technicians, and local officials understand the signal equipment in their communities.

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ABSTRACT

A questionnaire survey was conducted to determine the types of traffic signal controls utilized by state and local agencies.

The majority of the equipment was found to be supplied by three manufacturers; however, there are hundreds of different pieces of control equipment in use. Much of the equipment is quite old, and while it is relatively simple to operate, repairs are very difficult because of the unavailability of replacement parts. On the other hand, the newer equipment is very sophisticated and highly trained technicians and electricians are required to operate and maintain it.

Apparently very few efforts have been made to standardize the equipment in the individual communities. Over 70% of the agencies responding to the questionnaire used equipment from two or more manufacturers, and all but two of them used a variety of models.

Information on the characteristics and functions of the typical control equipment used in the state was obtained from the manufacturers and is summarized in the report.

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INTRODUCTION

During the past decade emphasis has been concentrated on freeways as a means of transporting people and goods; however, many states are now encountering difficulty in the planning and construction of new urban highways because of environmental and social concerns. This difficulty will most certainly be magnified by the fuel shortage. Consequently, it appears that arterial streets and highways will have to continue to meet the majority of the traffic demands. Literally hundreds of billions of vehicle miles are traveled annually on city streets.

During the time emphasis was being placed on freeways, the performance of streets and highways — that is, the ability of the system to provide safe and efficient transportation and reduce pollution and congestion — deteriorated. At no time since World War II has top performance been achieved in the highway network, and the situation is getting worse. It is imperative that this trend be reversed.

The majority of urban street and highway systems incorporate signalized intersections and the intersection continues to be the point of minimum capacity. To improve system capacity without sacrificing safety, it is necessary to bring traffic signal operation to the highest possible level of efficiency.

PROBLEM

The function of the traffic signal is simple — it allocates time and space through an intersection, first to one group of motorists and then to another; but the attainment of maximum benefit from the device is not simple. The final timing must be made in the field after the signal has been installed, and the variety and sophistication of equipment, along with intersectional geometry, make the allocation of time and space a very complex operation.

The communities in Virginia have traffic control systems consisting of numerous types of equipment from various manufacturers, and, not surprisingly, technicians in the field are not always familiar with the controls they must operate and repair. Without a clear understanding of the basic characteristics and functions of the signal equipment, they cannot make the fine timing adjustments and repairs necessary to maintain efficient signal operations.

PURPOSE AND SCOPE

The major objective of this research was to provide a document outlining the basic characteristics and functions of typical traffic signal controls found in the state of Virginia.

A great deal of research has been carried out to help the technicians in designing suitable traffic signal schemes and in setting signals to minimize delay. Also much practical experience has been gained by technicians working in the field over the last thirty years or so. Some of the results of research and some information based on experience have been published in a variety of journals, but none of the articles really describe the basic characteristics of signalization in terms that can be understood by traffic technicians and electricians who are new in the field.

ANTICIPATED BENEFITS

It has been estimated that if all existing traffic signals were operated at their potential, the efficiency of intersections could be increased by 40%.(1) In many cases only minor adjustments of the timing dials would be required to bring the operation up to par. This is especially true of the newer sophisticated equipment where a clear understanding of the different timing adjustments and their functions is not always readily apparent.

The following two hypothetical examples are presented in an effort to demonstrate the waste in time and energy resulting from improperly timed traffic signals.

In the first example, assume that only one vehicle is unnecessarily delayed for a total of 5 seconds during each signal cycle at an intersection controlled by a two-phase signal operating on a 90-second cycle. This delay that intuitively seems to be insignificant can produce a total of 487 hours of vehicle delay per year. Assuming an occupancy rate of 1.5 persons per vehicle, 730 passenger hours of delay per year would occur at the intersection. On a statewide basis (3,000 signals) the total annual delay would exceed 2 million passenger hours.

In terms of energy, studies have shown that a typical automobile consumes 0.7 gallon of fuel per hour while idling.(2) Consequently, 1 million gallons of gasoline would be wasted in Virginia each year in the example cited above.

In the second example, assume that the green time remains on the side street an additional 5 seconds after the last vehicle has cleared the intersection before yielding the right-of-way to the traffic on the major street. The major street is a 4-lane arterial facility and 10 vehicles per lane encounter the 5-second delay during the peak hour between 5 and 6 p.m. The cycle length is 90 seconds and the occupancy rate is 1.5 persons per vehicle.

During the peak hour the total vehicular delay is 2.27 hours, or 3.4 passenger hours. Therefore, during a normal 5-day work week when rush hour traffic usually occurs, the passenger delay is 17 hours and the fuel waste is 8 gallons. If this condition exists at the 3,000 signals in Virginia, the annual statistics would be 2.6 million hours of passenger delay and 1.2 million gallons of fuel wasted.

While the two examples cited are hypothetical, similar situations frequently occur in Virginia. It is not uncommon to have vehicles backed up at a signalized intersection for a quarter of a mile, even in small towns. Hopefully this report will help the signal technicians and electricians understand the equipment in their communities and thus enable them to make the fine timing adjustments necessary to maintain efficient signal operations. The final product should be a benefit to all citizens in the form of reduced travel time, energy conservation, fewer accidents, and alleviation of air and noise pollution.

HISTORY

The first traffic signal was installed in London in 1868, near the Houses of Parliament, to provide safety for members of Parliament who had to negotiate the busy traffic streams. It was of the semaphore-arm type with red and green gas lamps for nighttime visibility. The semaphore arms extended in a horizontal position meant stop. When lowered to a 45° angle the message was caution. At night a green light was employed with the caution position and a red light with the stop position. The semaphore was operated by policemen. Unfortunately an explosion occurred that killed one policeman and injured two others, and no further experiments of this nature were tried in England for the next 50 years.(3)

The first mechanical semaphore appeared in the United States about 1913 in Detroit. It consisted of four revolving blades set at right angles atop a light portable stand with the blades displaying the words "stop" and "go" on alternate faces. At night the arms had a signal lantern of the railroad type using red and green lights.(4)

In Richmond, semaphore signals were installed about 1916. They consisted of four arms painted white and red alternately and bearing the words "open" in black letters on the white arms and "closed" in white letters on the red arms. Each arm was equipped with electric lights showing through a red lens in the "closed" arm and a white lens in the "open" arm. The electric current for the lights was furnished by a storage battery located in a shelter under the signal.(4)

In 1914 a signal installed in Cleveland had the basic essentials of a modern signal installation, however it was only a two-color system — red and green. The first three-color system — red, green and yellow — was introduced in Detroit in 1920.(4)

The natural development of traffic control methods led from manually operated to automatic fixed-time signals, where predetermined stop and go periods were alternatively timed. These controls, introduced in 1923, helped to ease traffic conditions but were not efficient at intersections where the traffic volumes varied considerably. Consequently, in the late 1920's a first attempt at vehicular control of signals was made in Baltimore by placing microphones at the side of the street and requesting motorists to sound their horns. There were many objections to this scheme and a method using electrical contacts placed in the roadway in the paths of the vehicles was subsequently tried.(3) This method has survived in principle to the present day.

In 1975, there were an estimated 180,000 signal installations in the United States(5) and approximately 3,000 of those were in Virginia.(2)

INVENTORY OF EXISTING EQUIPMENT

A survey was conducted to determine the types of signal controls utilized at intersections by state and local governmental agencies. A questionnaire was sent to fifty-seven jurisdictions which operate and maintain traffic signals requesting information relative to manufacturer and type of equipment. Forty-five of the jurisdictions responded to the questionnaire as shown in Table 1. The majority of the existing equipment in Virginia was found to be supplied by three companies — Automatic Signal, Crouse-Hinds and Eagle. Other manufacturers, such as Econolite and Marbelite, have promoted their products in recent years and several jurisdictions have installed their equipment. Other equipment used in the state was manufactured by Darley and Singer. The basic types of control equipment are shown in Table 2. It should be pointed out that most of the models shown in Table 2 can be modified to perform various functions, therefore there are actually hundreds of different pieces of control equipment in use in the state.

Much of the equipment is quite old, and while it is relatively simple to operate, repairs are very difficult to make because of the unavailability of replacement parts. For example, the Darley equipment is no longer manufactured. The Crouse-Hinds GS and LS controllers were designed during the 1940's and were last manufactured in 1955. Other controllers from the same era are the Crouse-Hinds SVA and FVA, the Eagle ET 115 and ET 175, and the Automatic Signal 505 and 804 models.

On the other hand, the newer equipment is very sophisticated and trained technicians and electricians are required to operate and maintain it. Examples of this equipment are Automatic Signal's 90 series, Crouse-Hinds' DC series and Eagle's DP 900 models.

When considering the number of available signal controllers, one would surmise that each municipality would make an effort to standardize the equipment under its jurisdiction. Perhaps this is impossible because of a law which requires the state government to purchase all equipment on a competitive bid basis and many of the signal controllers in the cities and towns are installed under state construction contracts.

Over 70% of the agencies responding to the questionnaire used equipment from two or more manufacturers, and all but two of the agencies had various models of equipment.

Table 1

Manufacturers of Signal Control Equipment Used in Virginia

Governmental Jurisdiction	Manufacturer						
	Automatic Signal	Crouse-Hinds	Darley	Eagle	Econolite	Marbelite	Singer
State and Counties							
VDH&T	X	X		X		X	
Henrico County	X	X		X	X		
Arlington County	X	X		X	X		
Cities							
Alexandria	X	X		X	X		
Bedford		X					
Bristol	X	X		X			
Buena Vista	X			X			
Charlottesville	X	X					
Clifton Forge		X				X	
Colonial Heights	X	X		X			
Danville		X					
Fairfax		X		X			
Falls Church		X					
Fredericksburg		X					
Galax				X		X	
Hampton	X	X					
Harrisonburg		X					
Lexington		X					
Martinsville	X	X					
Newport News	X	X				X	
Norfolk	X	X		X			
Norton		X					
Petersburg	X	X					
Portsmouth	X						
Richmond	X	X		X			
Roanoke	X	X		X			
Salem	X	X					
South Boston	X	X					
Staunton	X	X					
Waynesboro	X	X				X	
Williamsburg	X						
Winchester	X	X	X				
Towns							
Abingdon	X			X			
Blacksburg		X					
Christiansburg	X	X					
Culpeper	X	X					
Front Royal	X	X					
Luray		X					
Manassas	X						
Pulaski		X					X
Rocky Mount		X					
Tazewell	X						
Vienna		X					
Warrenton	X						
Wytheville		X					

Table 2

Inventory of Existing Traffic Control Equipment

Manufacturer	Type	Models
Automatic Signal	Actuated — 2 phase	502, 505, 507, 517, 527, 804, 807, 812, 824, 826, 837, 855, 877, 1022, 90-2, series 102
	Actuated — 3 phase	1826, 1033, 1726
	Actuated — multiphase	922, MF Series, Series 90, Series 118
Crouse-Hinds	Pretimed	PCN, PCE, GF, KS, GS, LS
	Actuated — 2 phase	SST, SFT1, SFT2-10, SVA, FVA 210
	Actuated — 3 phase	SST2, SFT2-15, FVA 310
	Actuated — multiphase	LTD-510, SFT3, DC Series
Darley	Pretimed	194-A
Eagle	Pretimed	EF-15, EM-15
	Actuated — 2 phase	ET-115, ET-300, ET-415
	Actuated — 3 phase	ET-175
	Actuated — multiphase	DP-900
Econolite	Actuated — 2 phase	D-2000
	Actuated — multiphase	D-4000, D-8000
Marbelite	Pretimed	MN-20, M-30
	Actuated — 2 phase	MT2SRX
Singer	Pretimed	3S6L7

SIGNAL OPERATION

The basic function of a signal is to provide effective control in the allocation of the right-of-way through an intersection, first to one group of motorists and then to another. The time period for which a motorist or group of motorists receives the right-of-way is called a traffic phase. The number of phases required for the proper and efficient operation of a signalized intersection varies with the composition and direction of traffic flows as well as with the number of intersecting highways and the general intersectional layout.(6,7,8)

Before the characteristics of the control equipment are reviewed, the following discussion is presented in an attempt to familiarize the reader with the basic signal phasing schemes. The most commonly used schemes will be covered; however, many modifications of these may be found in the field.

Two-Phase Sequence

The usual traffic control will operate on a two-phase cycle in which the right-of-way (i.e., green time) is alternatively assigned to each of the two cross movements. This is illustrated in Figure 1. In phase A the green time is given to the traffic on the major street while the traffic on the minor street is stopped. After the allocated time period, the signal light indications are changed by the control unit to stop the major street traffic and yield the right-of-way to the traffic on the minor street.

The two-phase operation is generally used at all locations where all of the following criteria are not exceeded: (1) the intersection has no more than 4 approaches, (2) simultaneous movement in opposite direction presents no hazard, (3) the volume of left turn vehicles on an approach is less than 10% of the through volume in the opposing direction, and (4) there are few pedestrians crossing any approach.(5,9)

Three-Phase Sequence

Intersections having an unusually large left turn movement, heavy pedestrian movement, or more than 4 approaches for entering traffic may require more than two phases in the signal cycle to eliminate conflicts between vehicles or between vehicles and pedestrians. The division of the signal cycle should be avoided if at all possible since each additional phase introduces unavoidable delays before the green indication is given to other phases and increases the total cycle length. When the cycle length is increased, fewer cycles per hour are available; hence the intersection capacity may be reduced. Where more than two phases are required, a three-phase signal as illustrated in Figure 2 may be utilized. In this particular scheme the left turns on the major street move simultaneously from storage lanes while all other traffic is stopped.

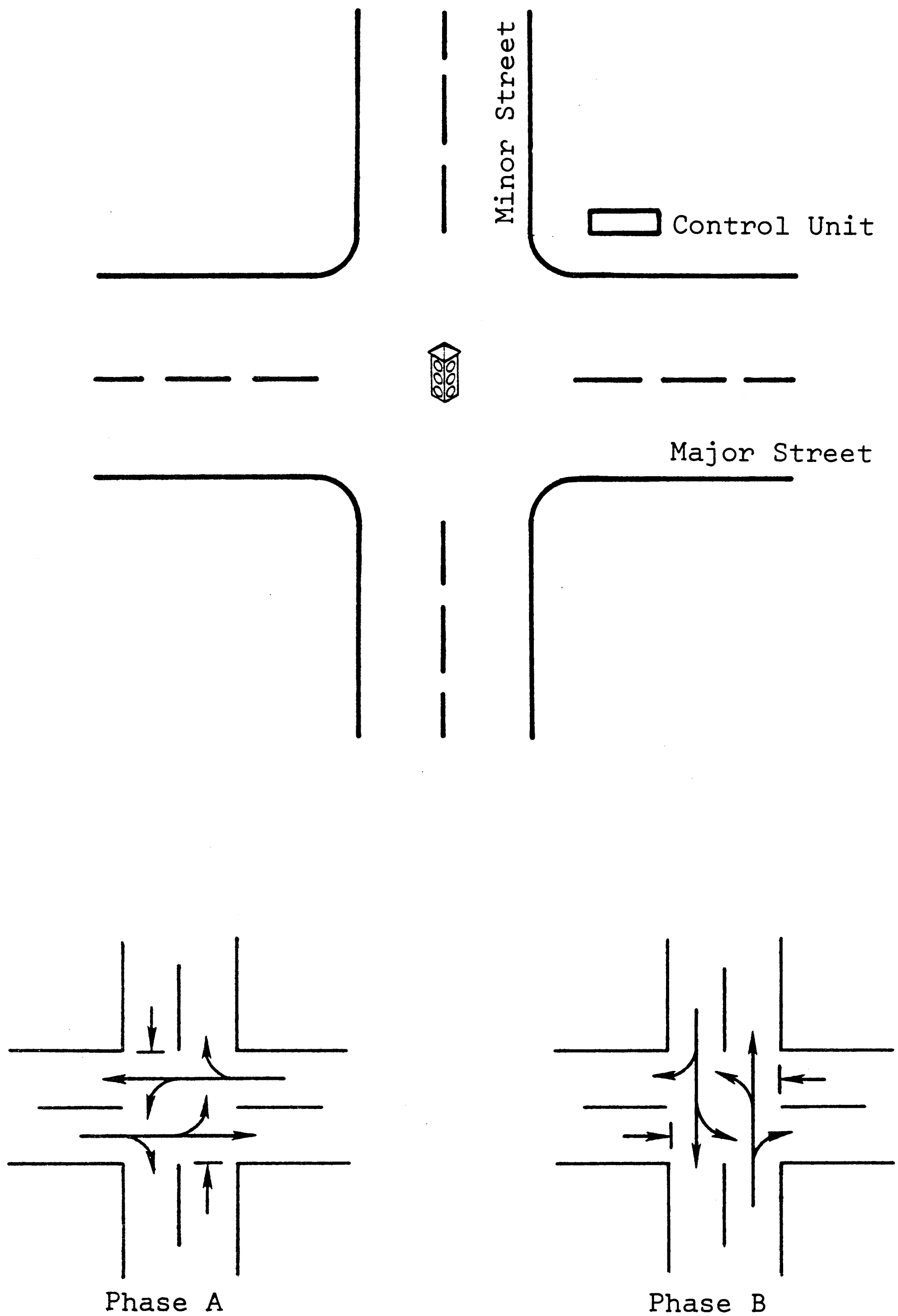


Figure 1. Typical two-phase signal sequence.

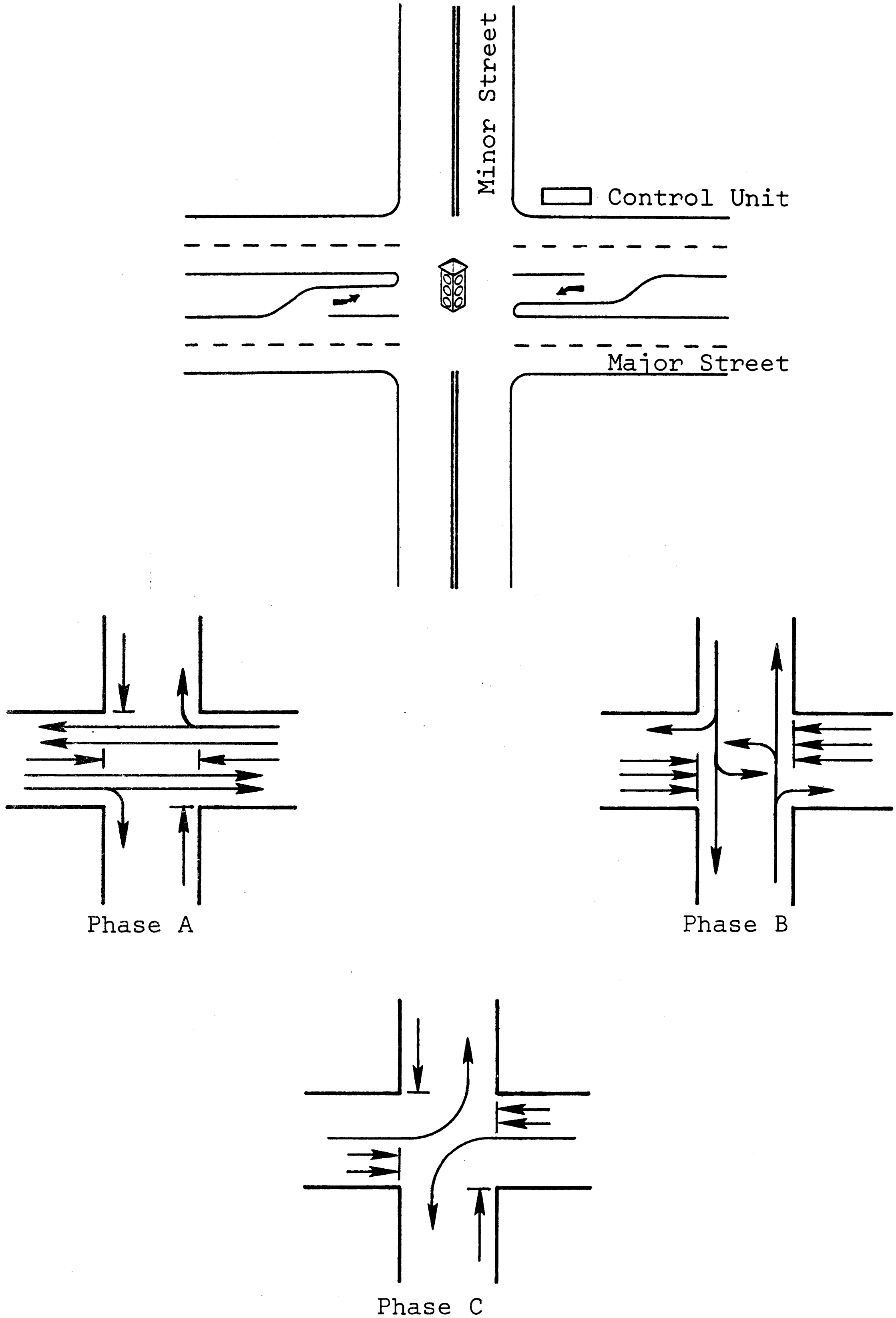


Figure 2. Typical three-phase signal sequence.

The split face or leading green illustrated in Figure 3 demonstrates a method of handling a heavy left turn movement in one direction. This is most effective when there is no left turn storage lane available. The leading green at the beginning of the phase is preferred over the lagging green at the end of the phase, because left turn traffic will still have the opportunity to turn during the regular through phase. In some cases the traffic characteristics may be such as to warrant a lagging left turn movement such as the one shown in Figure 4.

Multiphase Sequence

At the intersection of two major streets the traffic volumes may be of such a magnitude as to require more than three signal phases. For the purpose of this report a signal sequence consisting of four or more phases will be called a multiphase signal. A four-phase signal sequence is shown in Figure 5. In recent years highly sophisticated full-actuated control equipment has been developed which allows up to an eight-phase signal operation. The phasing diagram for an eight-phase sequence is shown in Figure 6 and it will be more fully discussed in another section of the report.

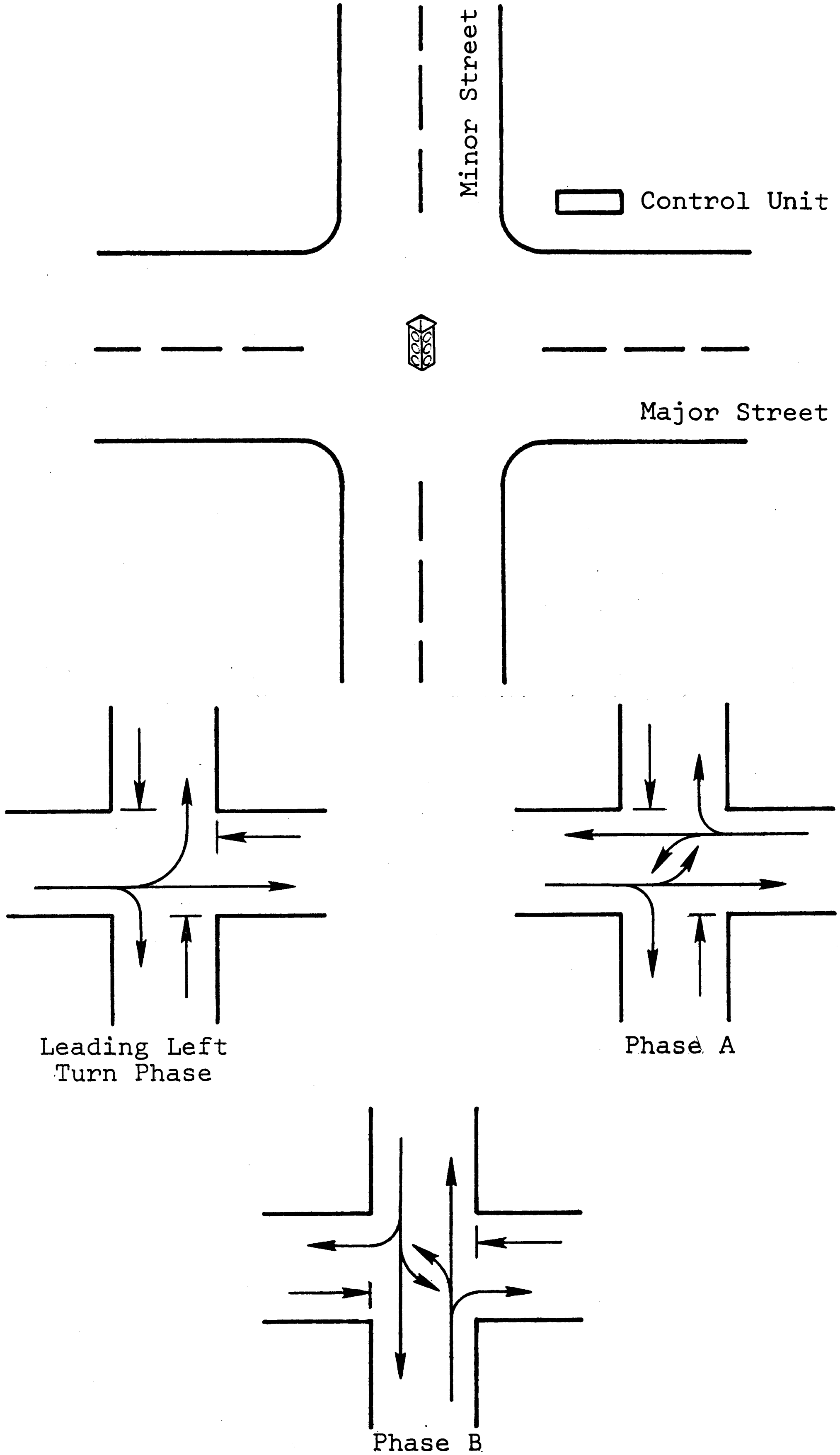


Figure 3. Typical leading green phase.

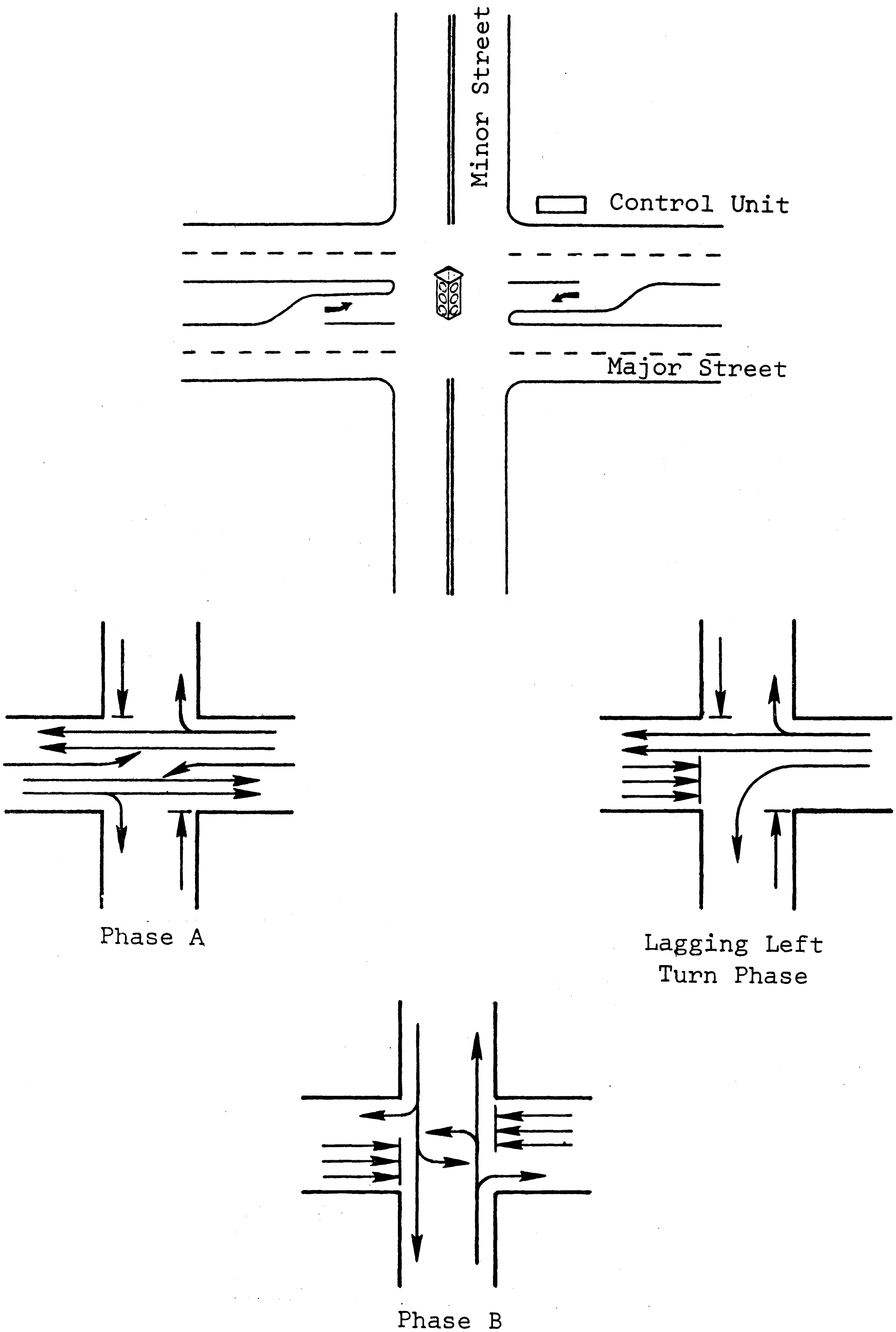


Figure 4. Typical lagging green phase.

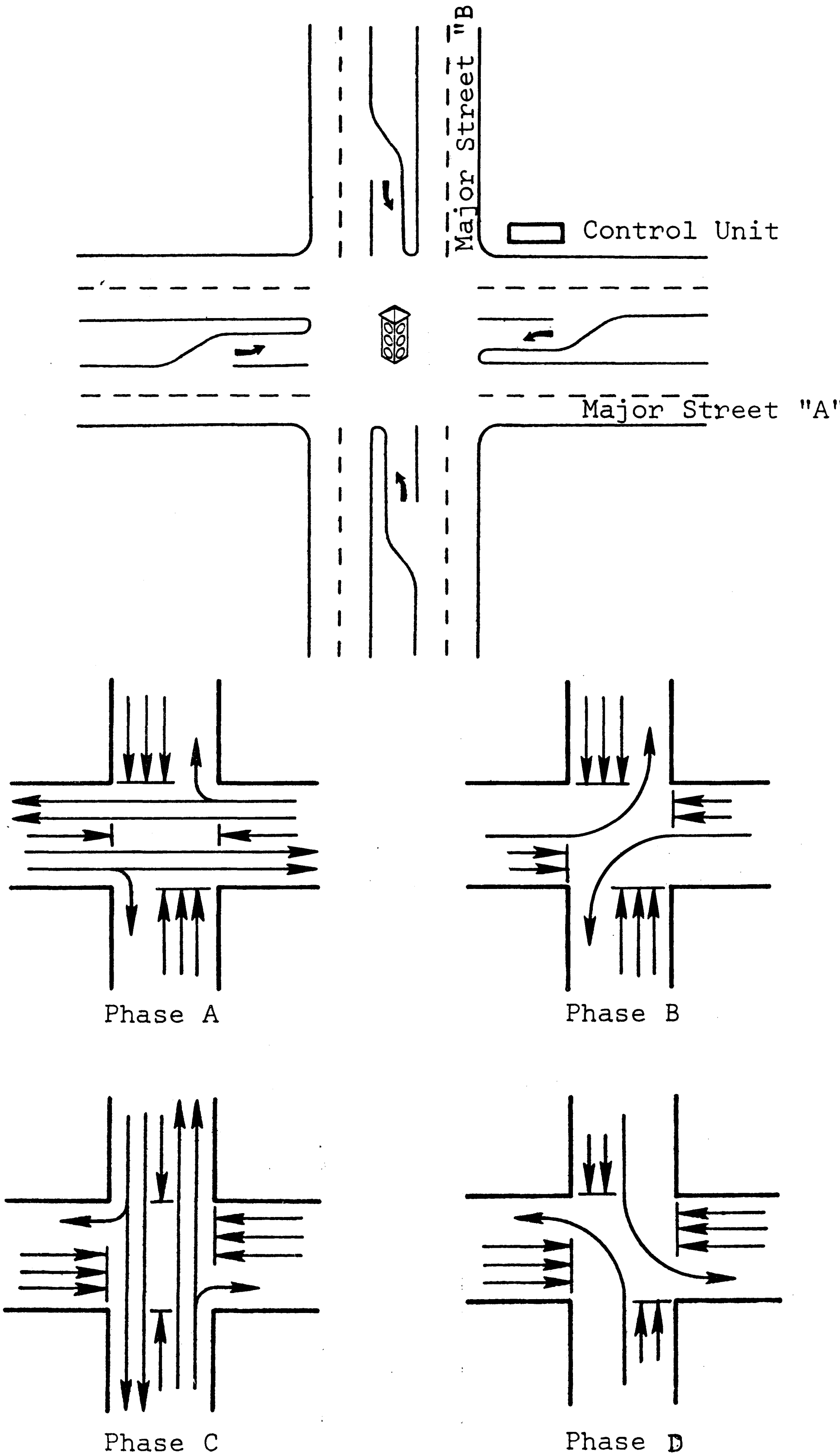


Figure 5. Four-phase signal sequence.

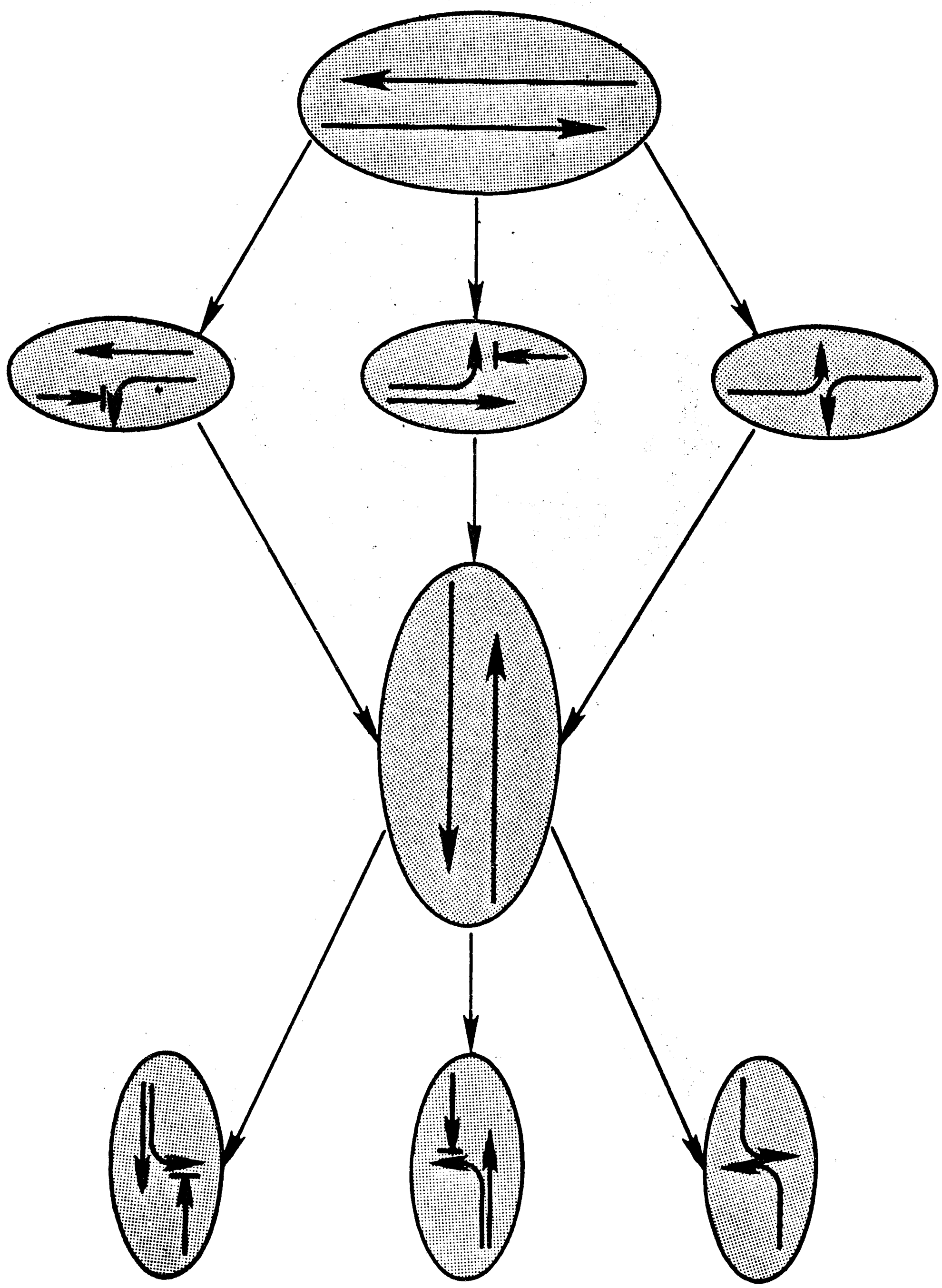


Figure 6. Primary phasing options for full-actuated control.

TYPES OF CONTROL EQUIPMENT

The function of the control equipment, commonly called controllers, is to switch the signal indications on and off according to a fixed or alterable plan to correctly and safely assign the right-of-way at a given location. Two basic kinds of controllers are used: pretimed and traffic actuated.[7,8,10,11,12] The characteristics of each type of controllers are discussed in the following sections.

Pretimed Controllers

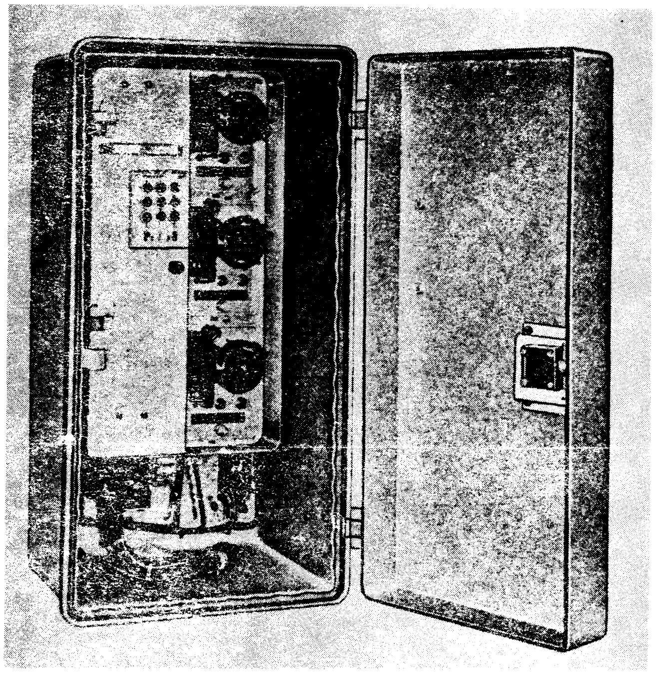
Many pretimed, or fixed timed, controllers are used in Virginia and the various manufacturers and models are shown in Table 2. Pretimed controlsare usually installed in urban areas where relatively stable volumes of traffic and fairly consistent volumes of pedestrians are found. Usually pretimed controllers are used for a two-phase operation similar to the one shown in Figure 1. A cycle length of 30 to 120 seconds is selected based on traffic demand, intersection delay, and vehicle arrival rate. It is divided into integrals necessary for handling the traffic, and signal indications appear in accordance with the predetermined sequence.

The pretimed controllers shown in Figure 7 generally come equipped with one to three dial units. Three dial units give the capability of using three different cycle lengths during a day. Oftentimes these are a morning peak-hour cycle, an evening peak-hour cycle, and an off-peak cycle.

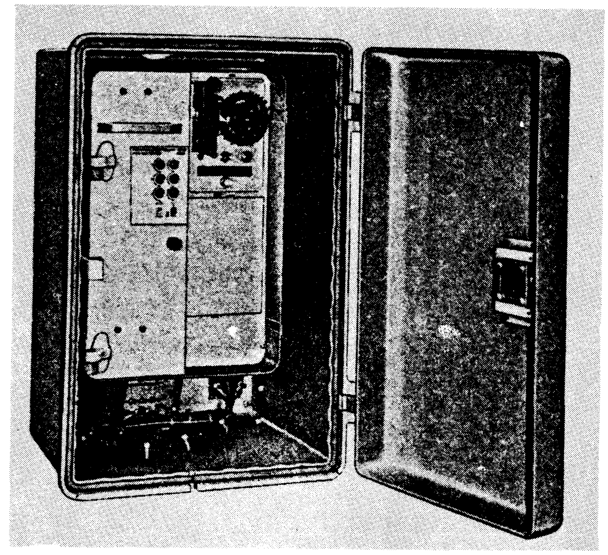
The dial unit provides the timing for the various phases selected for use at the intersection. A typical dial unit is illustrated in Figure 8.

The basic components of the dial unit are the motor, the cycle gear, the dial drum, and the timing keys.[8] The principle of operation of the dial unit is that the dial motor rotates the cycle gear, which in turn rotates the dial drum. The timing keys are placed in the slotted drum which is graduated in one percentage point increments from 0 to 100 percent. Timing keys serve to mark the beginning of the red, yellow, green etc. intervals for each phase. Cycled gears, which determine the total cycle length, are normally available in 5- to 10-second increments from 30 to 120 seconds.

In the typical dial unit illustrated in Figure 8 the camshaft impulse key serves to rotate the cam to the next timing interval (i.e., Phase A green, Phase A yellow, Phase A red, etc.). The camshaft release key operates a switch that provides for the synchronization of the cam and the dial to establish the offset relationship between intersections.



Multi-Dial Model



Single-Dial Model

Figure 7. Typical pretimed controllers.

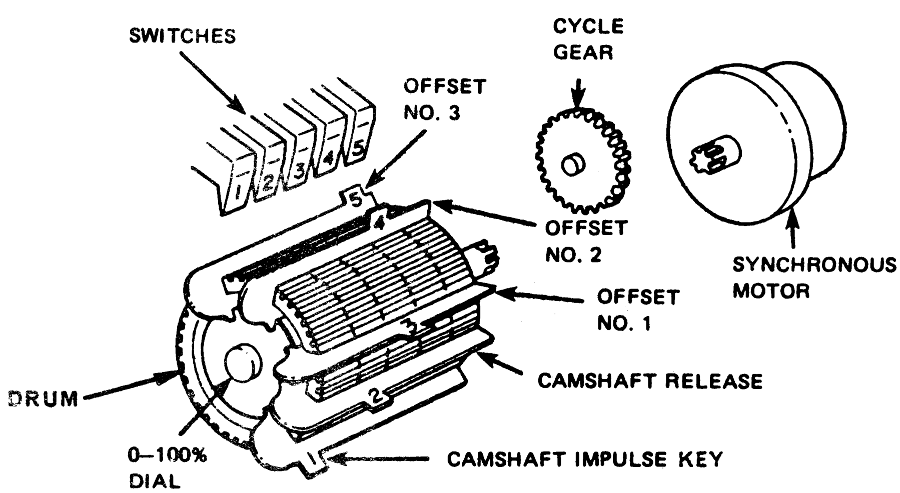


Figure 8. Typical dial unit.

The other basic part of the signal timing unit is the camshaft, or drum. This unit, as illustrated in Figure 9, is activated by the timing keys and rotates to cause the signal indications to change. As the timing key reaches the 12 o'clock position on the dial, it activates the camshaft impulse switch and causes the camshaft to rotate one position. The cams, which are "broken out" to allow a contact arm to drop into a slot in the cam, either actuate relays which change the signal indication or change the indication directly. Some controllers of older design may use cam inserts instead of breakouts.

The regularity of timing as provided by the pretimed controller is both an advantage and a handicap. It permits an established time relationship between other signals in the area so that vehicles can move through the signalized intersections with a minimum of delay; however, it does not recognize the short time variation in traffic flow. In most cases this means unnecessary delay when cars on one street are required to wait for a signal change while no traffic is using the cross street. These time losses are small but when they occur frequently they cause considerable delay and inconvenience and consequently reduce the intersection capacity.

A summary of the applications, advantages, disadvantages, and control features of pretimed controllers is presented in Figure 10.

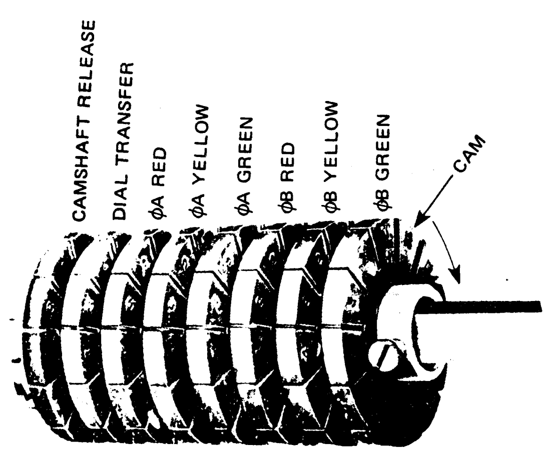


Figure 9. Typical camshaft.

TYPE	METHOD OF OPERATION	POSSIBLE TIMING CAPABILITIES	TYPE OF INTERSECTION WHERE APPLICABLE	ADVANTAGES	DISADVANTAGES
Pretimed	Fixed total cycle length and fixed phase time intervals for each dial.	1. Total cycle length generally from 30 to 120 seconds. 2. Generally capable of operating 3-dials with three different cycle lengths. 3. Phase timing in 1% increments. 4. Generally 3 offsets per dial.	Two or possible three way intersection where traffic volumes and vehicle arrivals remain constant throughout the day.	1. Easy to maintain. 2. Easy to time. 3. Easy to coordinate. 4. Relatively inexpensive.	1. Tend to waste green time. 2. Cannot adjust to fluctuations in traffic. 3. Have limited effective phasing capability.
Semiactuated	Minor street is actuated to provide adjustable timing on demand. Major street has fixed minimum green and is returned to each cycle.	1. Minimum green on one phase. 2. Initial green and vehicle extension on other phase. 3. Possible pedestrian walk and clearance intervals on actuated phase. 4. Maximum green on one phase. 5. All-red.	Two or three way intersection with medium to high traffic volumes on one or two approaches and low volumes on the actuated phase.	1. Provides more efficient timing of minor actuated phase. 3. Allows green to rest on major phase when there is no traffic on the minor street.	1. Minor street traffic will more than likely have to stop. 2. Coordination may cause major disruptions to minor street traffic flow. 3. Generally more difficult to maintain than pretimed.
Full-actuated	All approaches are actuated and phases may follow a definite sequence or may be fully independent. Nonconflicting phase may be timed concurrently (dual ring).	1. Initial green. 2. Variable initial green. 3. Vehicle extension. 4. Pedestrian walk and clearance. 5. Maximum green. 6. Dual maximum green. 7. Passage time. 8. Time waiting. 9. Density.	1. Same as for pretimed and semiactuated. 2. Multiple lane approach intersections with separate turn channelization. 3. High speed approaches when variable initial used.	1. Provides more efficient intersection control due to actuation of all approaches and flexibility in timing. 2. Capable of controlling complex intersections.	1. Considerably more expensive than pretimed or semiactuated, but cost may be offset by efficiency of control. 2. Generally more difficult to maintain than pretimed or semiactuated. 3. Coordination reduces flexibility of control.
Volume-Density	Same as full-actuated with added capability of gap reduction by vehicles waiting against a red.	1. Same as 1.,2.,3., 4.,5.,7.,8.,9. for full-actuated. 2. Car waiting gap reduction. 3. Platoon carryover.	1. Same as 1.,2.,for full-actuated. 2. High speed approaches.	1. Same as 1.,2.,for full-actuated controller. 2. Provides added benefit of gap reduction. 3. Can be used for high speed approaches.	1. Same as 1.,2.,3., for full-actuated controller.

Figure 10. Types of signal controllers.

Traffic Actuated Controllers

Traffic actuated signal control is an operation in which the right-of-way is assigned in accordance with the demand of traffic.[5,7,8,13] Unlike the pretimed equipment this signal relies on vehicle detectors to advise the controller of the traffic demand for a green light on a certain approach. The cycle is not fixed at any definite value and the integrals are self-adjusting within certain limits so that they closely fit the needs of traffic. This type of control has a large measure of flexibility. Capacity losses inherent in pretimed signals are automatically reduced. Figure 11 shows the equipment required for traffic actuated signalization.

The various types of vehicle detection devices are presented in another section of this report. The detectors are installed in such a way as to ensure that each approaching vehicle registers an impulse. The controller receives the impulse and assigns the right-of-way between the conflicting traffic flows. The type of controller used depends upon a number of factors such as volume and speed of the traffic, the physical characteristics of the intersection, and the relation of the intersection to other intersections. The classifications of traffic actuated signal controllers are semi-actuated, full-actuated and volume-density.[7,8] The characteristics of each are presented in the following sections.

Semiactuated Controllers

When used at an isolated intersection a semiactuated controller has a definite advantage over a pretimed controller in that it provides vehicle detection on the minor street. Its best use is perhaps at intersections where the major street volumes are relatively high as compared to the minor street volumes. The major phase is not actuated, therefore the right-of-way always returns to the major street when there are no vehicles present on the minor street or when the minor street's maximum green time has been reached.

A typical semiactuated controller is Automatic Signals' model 507 shown in Figure 12. Other semiactuated controllers are Crouse-Hind's SVA series and Marbelite's model MT 2SRX. Most of the major signal companies manufacture these types of controls, and, while there are variations in the physical appearance of the controllers, they all have the same basic timing adjustments. The time settings (or adjustments) include the following: (1) minimum green interval on major phase, (2) minimum initial green interval on minor phase, and (3) maximum green interval on minor phase.[8]

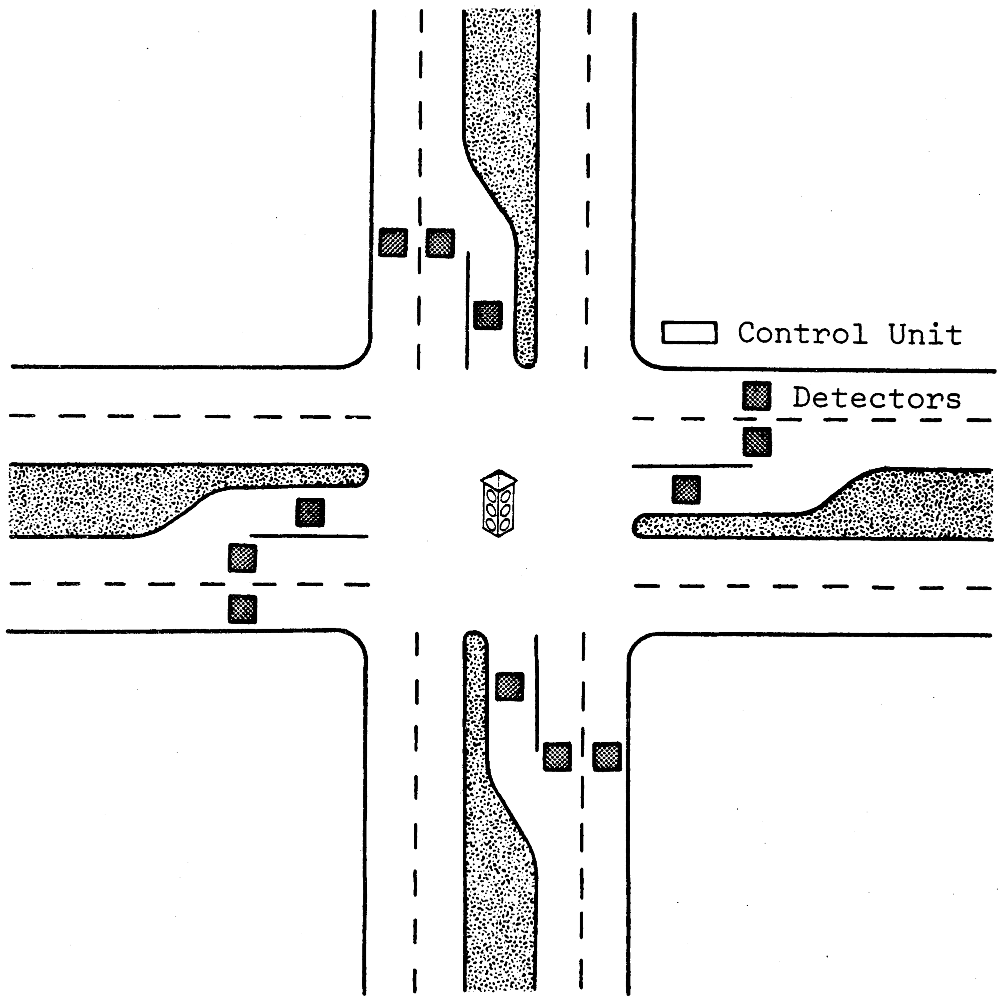


Figure 11. Actuated signal operation.

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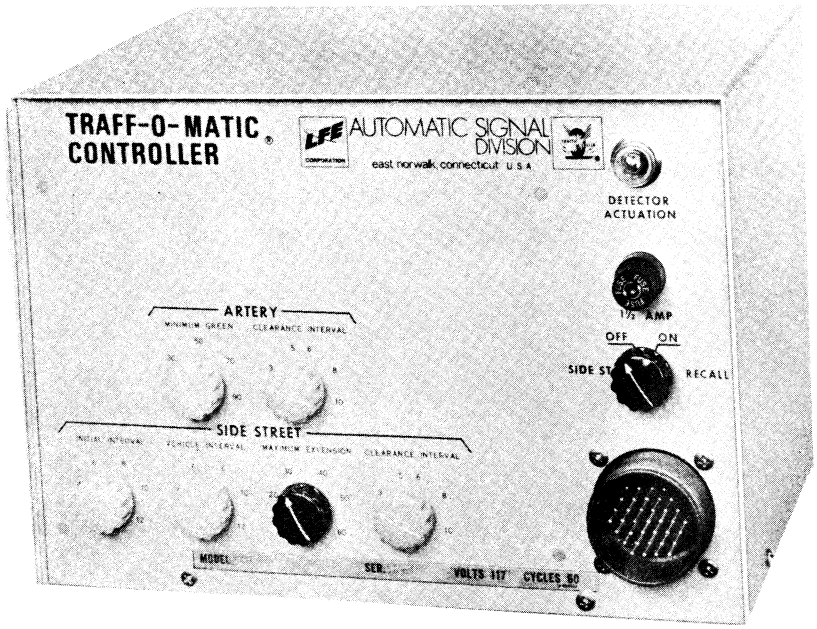


Figure 12. Typical semiactuated controller.

The timing adjustments on the controller shown in Figure 12 consist of a Phase A minimum green, Phase A yellow, Phase B initial interval, Phase B vehicle interval extension, Phase B maximum green, and Phase B yellow. Additional time settings such as pedestrian clearances may be incorporated into semi-actuated controllers.

The operation of the controller is such that the minimum green time set on it will always be allocated to the major street. It will continue to remain in the main street green phase until an actuation is received on the minor street. When the minor phase is actuated by a vehicle or pedestrian the controller will terminate the major street green and will time a yellow clearance interval. Then the minor street (Phase B) traffic will receive a green signal indication. The minimum green time on the minor street will always consist of the initial interval plus one vehicle interval extension. The initial green interval setting for the minor street phase is based on the amount of time required to allow one or two vehicles passage through the intersection from a stopped position. The length of the vehicle interval is in accordance with the amount of time required to pass from the detector into the intersection. A new vehicle interval will be added each time a vehicle crosses the detector during the time the interval is being timed out. The extension of vehicle intervals will continue until the maximum green time is reached as long as vehicles are crossing the detectors at time gaps equal to or less than the vehicle interval set on the controller. Before returning the right-of-way to the major street the controller will time out the Phase B green after one of three possible settings have been satisfied.

1. Initial plus one vehicle interval has been satisfied and there is no additional traffic on the minor street.

2. Vehicle time gaps are greater than the amount of time set on the vehicle interval and the controller has already timed the initial plus one vehicle interval.

3. The controller has timed out the maximum green setting.

A summary of the application, advantages, disadvantages, and controlled features of the semiactuated controls is presented in Figure 10.

Full-Actuated Controllers

Full-actuated control is characterized by traffic actuations on all phases. Full-actuated controllers may contain timing adjustments for 2 to 8 phases. Because of their flexibility of design full-actuated controls are capable of providing control for a simple two street intersection or a complex intersection with several approach legs. Full-actuated controllers can properly accommodate the signal operations shown in Figures 1, 2, 5 and 6. Examples of full-actuated controllers utilized in Virginia are Automatic Signal's models 807 and 1826, Crouse-Hinds' FVA series, Eagle's DP-900 series, and Econolite's model D-2000. A typical full-actuated controller is shown in Figure 13.

Although full-actuated controllers, like the semiactuated types, have several physical variations, they all perform the same basic function. This function is to measure traffic on all approaches to an intersection and make assignments of the right-of-way in accordance with the traffic demand.

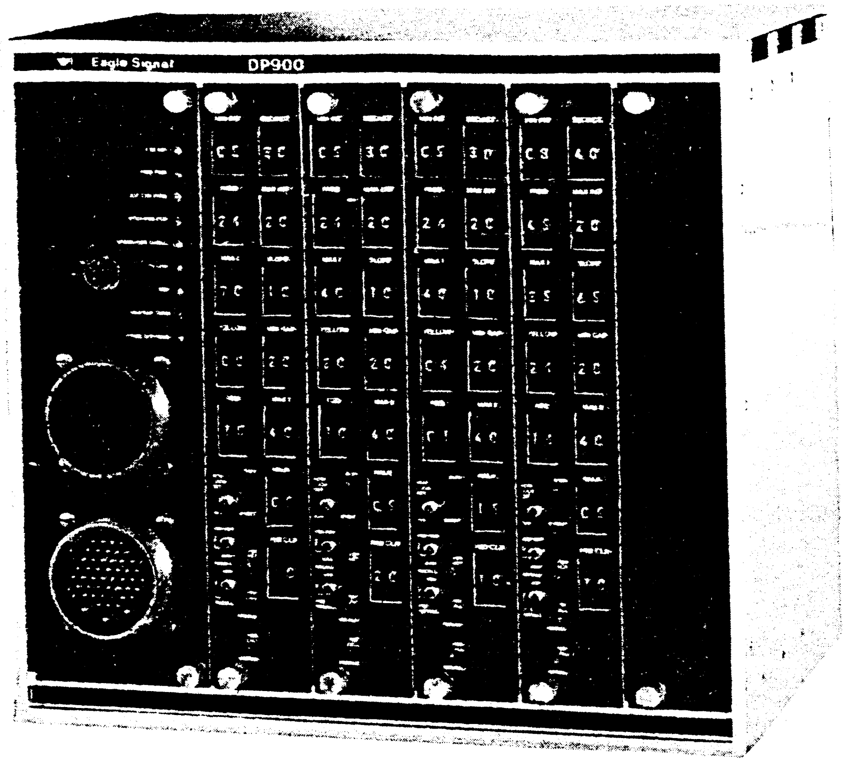


Figure 13. Typical full-actuated controller.

An illustration of the basic timing adjustments on a full-actuated controller is presented in Figure 14. This example shows the basic timing adjustments for a two-phase controller. Additional phases will have the same basic timing adjustments.

The full-actuated controller operates in a manner similar to the actuated phase of a semiactuated controller, except that it has several possible methods of transferring control to another phase after it has timed out a phase. After timing out a phase the full-actuated controller can take one of the following steps.

1. Remain in the phase that was timed out, if there are not actuations on another phase. The controller will remain in this phase until it receives a call from another phase, at which time it will clear the phase it is in and transfer control to the phase called.

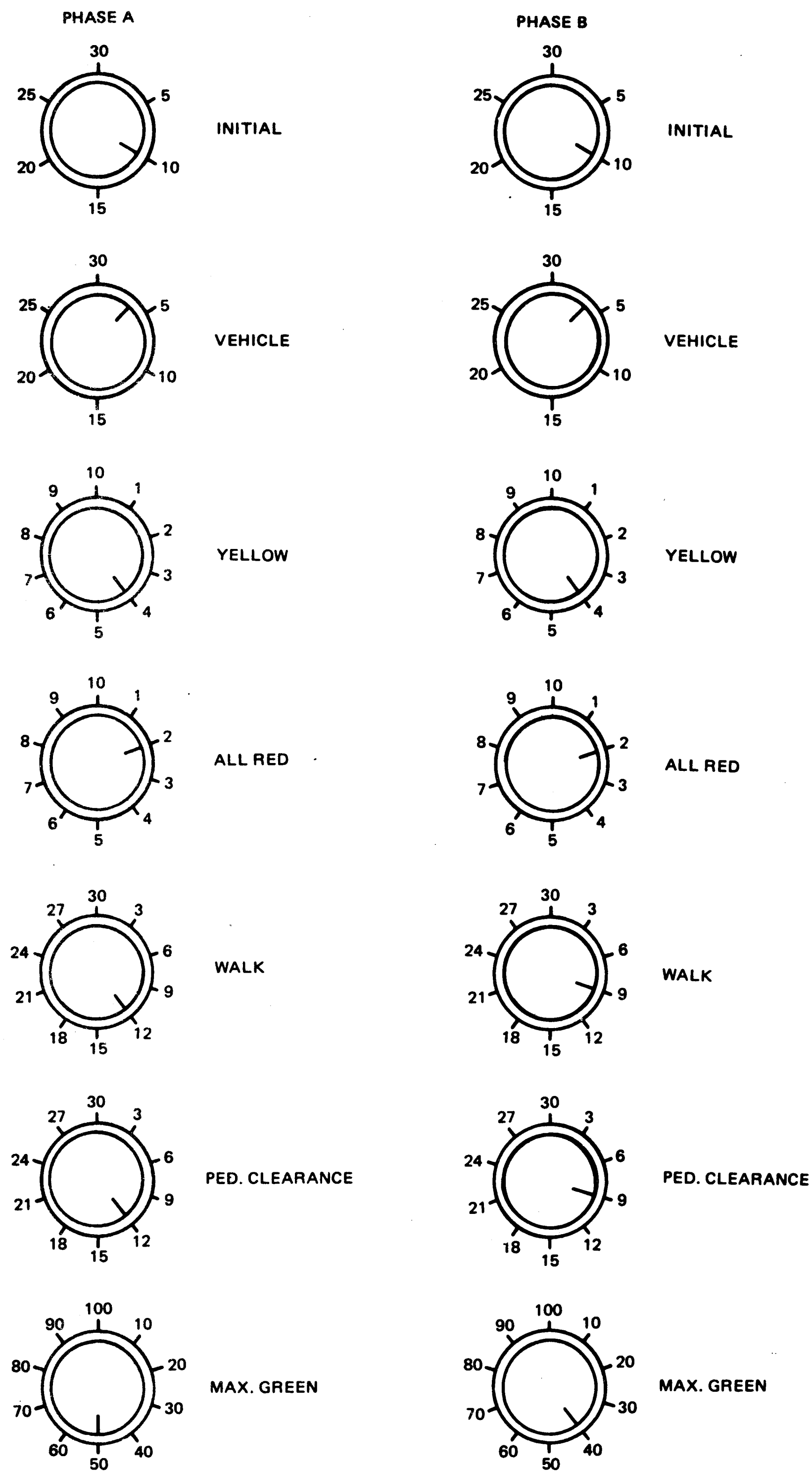


Figure 14. Typical timing adjustments for full-actuated controller.

2. Transfer control to another phase which has received a vehicle call. If the controller has three or more phases, control will be transferred to the next phase called for by a predetermined sequence, provided two or more phases have been called. If the controller does not have a predetermined sequence of phases, it will transfer control to the first phase called.

3. Transfer control to any phase which has been placed on recall. In the case of a multiphase, full-actuated controller transfer to the phase on recall will be accomplished only after all phases having calls on them have been served and the intersection is free of additional calls.

4. Go to an all-red condition on all approaches and await an actuation on any phase.

The timing of a full-actuated controller operates in the same basic manner as that discussed for semiactuated controllers. The minimum green time for any one phase consists of the initial interval plus one vehicle interval extension.

Vehicle actuations will increase the green time only when they are recorded during the time the phase is in the vehicle extension timing. Vehicle detections received at any other time will establish the need for another green interval.

The applications, advantages, disadvantages, and control features of the full-actuated controllers are summarized in Figure 10.

Volume-Density Controllers

Only a few volume-density controllers, such as Automatic Signal's 1022, 1033, and Series 90, are used in the state. Volume-density signal control is similar to the full-actuated control in that a detector is required on each approach. These detectors are usually spaced well in advance of the intersection. The controller depends on the gap between vehicles to assign the proper right-of-way. It compares the volume and density of traffic, vehicle gap, number of vehicles waiting for the light, and length of time waiting. These factors are weighed and the right-of-way assigned accordingly. It is an extremely flexible type of control, capable of taking advantage of every flucuation in traffic to assign the right-of-way where needed. It is suitable for use with heavy volumes of traffic on each approach. Because of the sophistication of the volume-density equipment, traffic engineers and technicians are encouraged to carefully review the manufacturer's literature supplied with the controllers before making timing adjustments and repairs. In Figure 10 the advantages, disadvantages, and applications of the volume-density signal controllers are presented.

Vehicle Detectors

Traffic actuated signals require vehicle detectors located on an approach to the intersection. Various types of detectors are available in both directional (detects only vehicles approaching the intersection) and nondirectional (detects all vehicles) models.[7,8,13] Illustrated examples of several types of detectors are presented in Figure 15.

The following detectors are commonly used in Virginia.

1. Pressure Sensitive Detector — This detector is installed in the roadway and is actually an electric switch operated by the pressure of vehicle wheels rolling over it. It can generally be used for speeds up to 60 mph and is available in both directional and nondirectional models. This detector is well adapted for use in left turn storage lanes where vehicles using only a certain lane are to be detected; however, it does not have presence measuring capabilities.

2. Magnetic Detector — This detector is actuated by the disturbance of an electric field, caused by the passage of a vehicle. It is installed under the pavement and its actuation is amplified and relayed to the controller. The detectors respond to moving vehicles and are not rendered inoperative by stationary metal objects within their zone of influence. Normally a magnetic detector can be used to detect from 1 to 3 lanes of traffic, depending on the sensitivity setting of the amplifier.

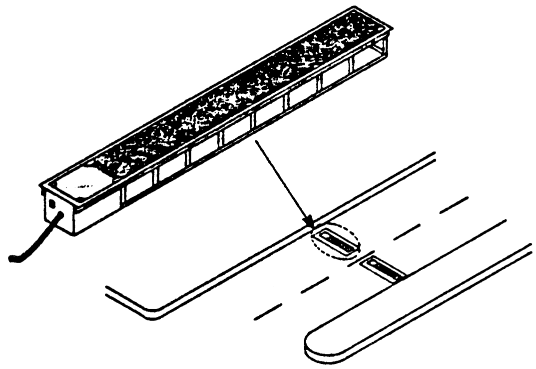
3. Induction Detector — This detector is composed of a wire loop embedded in the roadway, with a direct current supplied to the loop. When a vehicle passes over the loop, a change in circuit characteristics occurs. This change creates an actuation which is relayed to the controller. It is capable of detecting up to four lanes of traffic and has excellent presence measuring capabilities.

4. Radar Detector — The radar detector is mounted over the roadway and is capable of detecting from one to three lanes. The radar unit transmits a microwave beam into the lanes being covered. The microwaves are reflected back to the receiver when a vehicle passes through the beam. This detector can be used in conjunction with other types of detectors.

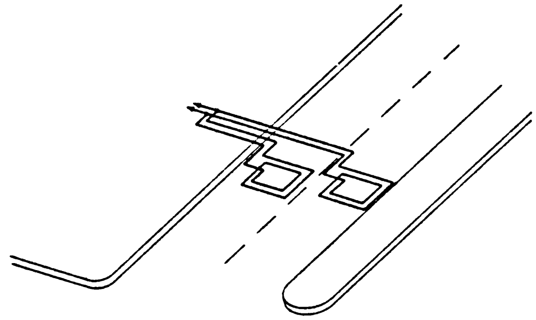
5. Ultrasonic Detector — This detector consists of an overhead mounted sensing unit and a nearby pole-mounted transceiver. This unit detects all motion within its zone of influence. It is capable of detecting up to two lanes of traffic. It is similar in operation to the radar detector in that an ultrasonic pulse is transmitted from the transmitter in the detector so that a vehicle entering the zone of influence will reflect the sound back to the detector, thereby indicating the presence of a vehicle.

6. Pedestrian Push-Button — This detector is a switch which, when pushed by a pedestrian, relays an actuation to the controller. The detector can be wired to either a special pedestrian interval which stops traffic or to the regular traffic phase in conjunction with the vehicle detectors. It is normally wired to the minor traffic phase for cross street operation.

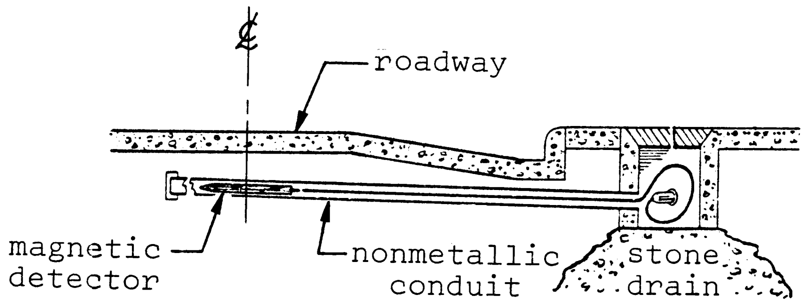
A summary of the capabilities, methods of operation, advantages, and disadvantages of the various types of detectors is presented in Figure 16.



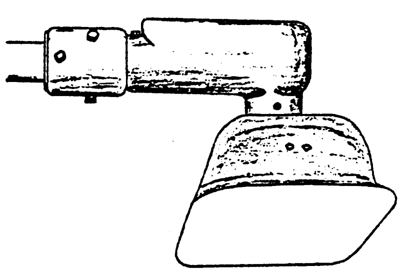
pressure detector



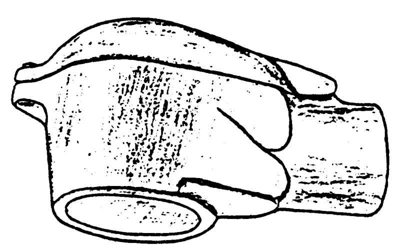
loop detector



magnetic detector



radar detector



sonic detector

Figure 15. Typical vehicle detectors.

Detector	Measuring Capability					Method of operation	Advantages	Disadvantages
	Count	Presence	Speed	Occu-pancy	Queue length			
Pressure	Yes	No	No	No	No	Weight of vehicle causes closure of metallic contacts to complete a circuit.	1. Well-defined detection zone. 2. Rugged construction. 3. Reliable. 4. Relatively inexpensive. 5. Capable of detecting all moving vehicles, regardless of speed. 6. Low maintenance and easy to repair.	1. Counts axles which yields poor count accuracy. 2. Does not measure presence. 3. Installation may disrupt traffic for excessive period of time. 4. Major resurfacing will render it inoperative. 5. Susceptible to damage by snowplow. 6. Cannot be easily relocated.
Magnetic Non-directional	Yes	No	No	No	No	Vehicle passage over coil of wire embedded in roadway disturbs earth's lines of flux that are passing through coil and induces a voltage in the coil. Voltage is amplified by high-gain amplifier to operate detector relay.	1. Under roadway location and not subject to damage. 2. Relatively easy to install. 3. Do not necessitate closing of traffic lanes . 4. Relative ease of relocation. 5. Low maintenance.	1. Nondirectional. 2. Difficult to set detection zone. 3. Subject to false calls where located near large dc lines. 4. Cannot detect presence.
Magnetic Directional	Yes	No	No	No	No	Same method of operation as nondirectional magnetic detector.	1. Directional. 2. Not affected by dc lines in vicinity. 3. Well-defined detection zone. 4. Low maintenance. 5. Under roadway location and not subject to damage.	1. Requires closing of traffic lane for installation. 2. More expensive than nondirectional magnetic detector. 3. Cannot detect presence. 4. Cannot be easily relocated.
Loop	Yes	Yes	Yes	Yes	Yes	Vehicle passage cuts magnetic lines of flux that are generated around the loop thereby increasing or decreasing the inductance so that a change is detected and transmitted to an amplifying circuit.	1. Size and shape of detection zone can be easily set by size of loop. 2. Excellent presence detector. 3. Capable of measuring all traffic parameters. 4. Relatively easy to install. 5. Relatively inexpensive to abandon loop and re-use amplifier at new location. 6. Capable of detecting small vehicles. 7. Under roadway location and not subject to damage.	1. Cost of installation may be excessive. 2. Requires closing of traffic lane or lanes for short periods of time. 3. Difficult to tune in order to detect small and large vehicles.
Radar	Yes	No	Yes	No	No	Passage of vehicle reflects radar microwaves (Doppler principle) back to antenna to operate detector relay.	1. Immune to electromagnetic interference. 2. Does not necessitate closing of traffic lanes to install.	1. Relatively expensive to purchase and install, particularly if existing poles not available for use. 2. Requires FCC license to operate. 3. Requires experienced personnel for installation and maintenance. 4. Does not measure presence.
Sonic Pulsed	Yes	Yes	Yes	Yes	Yes	Emits bursts of energy at a rate of approximately 20 times per second. Vehicle reduces wavelength resulting in the return signal arriving when receiver is open.	1. Does not necessitate closing of traffic lanes to install. 2. Does not require FCC license to operate. 3. Can be used at locations with unstable pavement. 4. Can classify vehicle by height.	1. Relatively expensive to purchase and install, particularly if existing poles not available for use. 2. Somewhat inaccurate due to conical detection zone and wide variations in vehicle configurations and heights. 3. Nondirectional. 4. Sensitive to environmental conditions. 5. Somewhat inaccurate under congested conditions.

Figure 16. Types of vehicle detectors.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the interest and cooperation of the members of the Planning Research Advisory Committee in the initiation of this research.

Appreciation is extended to T. R. Vest, traffic engineer; John D. Shelor, traffic supervisor; and Frank T. Jenkins, electrical superintendent; for their contributions of time, effort, and data. Without their cooperation, completion of the study would have been impossible.

Finally, acknowledgement is made of all the individuals who responded to the questionnaire, and to the Automatic Signal Division, the Crouse-Hinds Company, and the Eagle Signal Company for supplying equipment catalogs.

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